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INTERNATIONAL TELECOMMUNICATION UNION

CCIR

INTERNATIONAL
RADIO CONSULTATIVE
COMMITTEE

RECOMMENDATIONS AND REPORTS OF THE CCIR, 1982

(ALSO QUESTIONS, STUDY PROGRAMMES,
RESOLUTIONS, OPINIONS AND DECISIONS)

XVth PLENARY ASSEMBLY
GENEVA, 1982

VOLUME VIII

MOBILE SERVICES



Geneva, 1982

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PLAN OF VOLUMES I TO XIV
XVTH PLENARY ASSEMBLY OF THE CCIR

(Geneva, 1982)

VOLUME I	Spectrum utilization and monitoring.
VOLUME II	Space research and radioastronomy.
VOLUME III	Fixed service at frequencies below about 30 MHz.
VOLUME IV-1	Fixed-satellite service.
VOLUME IV/IX-2	Frequency sharing and coordination between systems in the fixed-satellite service and radio-relay systems.
VOLUME V	Propagation in non-ionized media.
VOLUME VI	Propagation in ionized media.
VOLUME VII	Standard frequencies and time signals.
VOLUME VIII	Mobile services.
VOLUME IX-1	Fixed service using radio-relay systems.
VOLUME X-1	Broadcasting service (sound).
VOLUME X/XI-2	Broadcasting-satellite service (sound and television).
VOLUME XI-1	Broadcasting service (television).
VOLUME XII	Transmission of sound broadcasting and television signals over long distances (CMTT).
VOLUME XIII	Vocabulary (CMV).
VOLUME XIV-1	Information concerning the XVth Plenary Assembly: Minutes of the Plenary Sessions. Administrative texts. Structure of the CCIR. Lists of CCIR texts.
VOLUME XIV-2	Alphabetical index of technical terms appearing in Volumes I to XIII.

All references within the texts to CCIR Recommendations, Reports, Resolutions, Opinions, Decisions, Questions and Study Programmes refer to the 1982 edition, unless otherwise noted; i.e., only the basic number is shown.

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DISTRIBUTION OF TEXTS OF THE XVTH PLENARY ASSEMBLY OF THE CCIR IN VOLUMES I TO XIV

Volumes I to XIV, XVth Plenary Assembly, contain all the valid texts of the CCIR and succeed those of the XIVth Plenary Assembly, Kyoto, 1978.

1. Recommendations, Reports, Resolutions, Opinions, Decisions

1.1 *Numbering of these texts*

Recommendations, Reports, Resolutions and Opinions are numbered according to the system in force since the Xth Plenary Assembly.

In conformity with the decisions of the XIth Plenary Assembly, when one of these texts is modified, it retains its number to which is added a dash and a figure indicating how many revisions have been made. For example: Recommendation 253 indicates the original text is still current; Recommendation 253-1 indicates that the current text has been once modified from the original. Recommendation 253-2 indicates that there have been two successive modifications of the original text, and so on. Within the text of Recommendations, Reports, Resolutions, Opinions and Decisions, however, reference is made only to the basic number (for example Recommendation 253). Such a reference should be interpreted as a reference to the latest version of the text, unless otherwise indicated.

The tables which follow show only the original numbering of the current texts, without any indication of successive modifications that may have occurred. For further information about this numbering scheme, please refer to Volume XIV-1.

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1.3 *Reports*

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(1) Published separately.

1.3.1 *Note concerning Reports*

The individual footnote "Adopted unanimously" has been dropped from each Report. Reports in this volume have been adopted unanimously except in cases where reservations have been made which will appear as individual footnotes.

1.4 *Resolutions*

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1.6 *Decisions*

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27	I	45	III		

1.6.1 *Note concerning Decisions*

Since Decisions were adopted by Study Groups, use was made of the expression "Study Group..., Considering" and the expression "Unanimously decides", replaced by "Decides".

2. Questions and Study Programmes

2.1 *Text numbering*

2.1.1 *Questions*

Questions are numbered in a different series for each Study Group: where applicable a dash and a figure added after the number of the Question indicate successive modifications. The number of a Question is completed by an *Arabic figure indicating the relevant Study Group.* For example:

— Question 1/10 would indicate a Question of Study Group 10 with its text in the original state;

— Question 1-1/10 would indicate a Question of Study Group 10, whose text has been once modified from the original: Question 1-2/10 would be a Question of Study Group 10, whose text has had two successive modifications.

2.1.2 *Study Programmes*

Study Programmes are numbered to indicate the Question from which they are derived if any, the number being completed by a capital letter which is used to distinguish several Study Programmes which derive from the same Question. The part of the Study Programme number which indicates the Question from which it is derived makes no mention of any possible revision of that Question, but refers to the current text of the Question as printed in this Volume.

Examples:

— Study Programme 1A/10, which would indicate that the current text is the original version of the text of the first Study Programme deriving from Question 1/10;

— Study Programme 1C/10, which would indicate that the current text is the original version of the text of the third Study Programme deriving from Question 1/10;

— Study Programme 1A-1/10, would indicate that the current text has been once modified from the original, and that it is the first Study Programme of those deriving from Question 1/10.

It should be noted that a Study Programme may be adopted without it having been derived from a Question; in such a case it is simply given a sequential number analogous to those of other Study Programmes of the Study Group, except that on reference to the list of relevant Questions it will be found that no Question exists corresponding to that number.

References to Questions and Study Programmes within the text are made to the basic number as well as for other CCIR texts.

2.2 *Arrangement of Questions and Study Programmes*

The plan shown on page II indicates the Volume in which the texts of each Study Group are to be found, and so reference to this information will enable the text of any desired Question or Study Programme to be located.

VOLUME VIII

MOBILES SERVICES

(Study Group 8)

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MOBILE SERVICES

STUDY GROUP 8

Terms of reference:

To study the technical and operating aspects of systems in:

1. all mobile services and all mobile-satellite services;

2. the radiodetermination services and the radiodetermination-satellite services, and;

3. the amateur service and amateur-satellite service.

1978-1982	*Chairman:*	W. H. BELLCHAMBERS (United Kingdom)
	Vice-Chairmen:	E. GEORGE (Germany (Federal Republic of))
		G. HEMPTON (United States of America)
1982-1986	*Chairman:*	G. HEMPTON (United States of America)
	Vice-Chairmen:	E. GEORGE (Germany (Federal Republic of))
		K. P. R. MENON (Malaysia)

INTRODUCTION BY THE CHAIRMAN OF STUDY GROUP 8, 1978-1982

1. Introduction

The period between the XIVth and XVth Plenary Assemblies has been an extremely active time for Study Group 8. Many participants in the work of the Study Group contributed to the success of the CCIR Special Preparatory Meeting 1978 and the World Administrative Radio Conference 1979; the Conference adopted many Resolutions and Recommendations which concern Study Group 8 and most of the urgent studies have been completed. Work has progressed rapidly on maritime and land mobile services and notable progress has been made on some aspects of the aeronautical services; studies on the amateur service have made a modest but sound start.

Cooperation with the Inter-Governmental Maritime Consultative Organization (IMCO) * has increased on all radio aspects of distress and safety and Study Group 8 studies have made a significant contribution to the proposed future global maritime distress and safety system. With the establishment of the International Maritime Satellite Organization (INMARSAT), Study Group 8 has reoriented its studies on maritime mobile satellite systems to assist this organization in its priority tasks.

The work of the Study Group is mainly devoted to future systems and techniques and, during the last period, many texts have been revised and a considerable number of outdated Reports have been deleted.

2. Special Meetings and Interim Working Parties

2.1 At the interim meeting (November/December 1980) the Study Group prepared a collection of Recommendations and Reports relevant to the agenda items of the World Administrative Radio Conference for Mobile Telecommunications (1983) to provide provisional guidance to administrations in formulating their proposals to the Conference. A special meeting of Study Group 8 was held in Geneva (7 to 18 September 1981) to prepare the technical bases for WARC-M-83 and the Report of that meeting was transmitted to the Secretary General through the Director of the CCIR for use as a conference document.

2.2 Interim Working Party 8/5 on automated VHF/UHF maritime mobile radiotelephone systems held four meetings under the Chairmanship of Mr. J. A. Aarsen (Netherlands) and completed its work resulting in a comprehensive Recommendation.

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* This Organisation has changed its name to «International Maritime Organisation (IMO)» with effect from 22 May 1982.

2.3 IWP 8/6 completed its work on the numerical identification of ship stations at a meeting in August 1978 under the Chairmanship of Mr. O. Lundberg (Sweden). The draft Recommendation was submitted to the CCIR Special Preparatory Meeting (SPM) 1978 and subsequently incorporated in the CCIR SPM Report to WARC-79. On the basis of this work the Conference adopted provisions for the introduction of this new identification system. Recommendation 585 was approved at the XVth Plenary Assembly. At the interim meeting, Study Group 8 gave further consideration to the introduction of the new system particularly in relation to the ad-hoc Group established by the Secretary-General. The Study Group designated three experts as rapporteurs to the ad-hoc Group: Mr. R. McIntyre (USA), Mr. P. Bliksrud (Norway) and Mr. A. Zudov (U.S.S.R.).

2.4 Three meetings of IWP 8/7, under the Chairmanship of Mr. R. O. Phillips (United Kingdom), were held prior to the interim meeting of Study Group 8 and a further meeting was held under the new Chairman, Mr. J. T. Gilsenan (USA), in April 1981. One of the tasks of IWP 8/7 at the latter meeting was to prepare the Study Group 8 input to IWP 4/1 in preparation for the WARC on the efficient use of the geostationary satellite orbit. The main tasks were to implement the Study Group 8 proposals regarding the establishment of a sub-group of the IWP and to prepare a coordinated trials programme for low power distress transmitters using the INMARSAT space segment. INMARSAT has offered the free use of the space segment for these CCIR coordinated trials. The actual trials are being financed and carried out by individual administrations under the CCIR trials programme.

2.5 IWP 8/8 was established in May 1979, in accordance with Resolution 24, to study the operational procedures for the digital selective calling system. It held three meetings under the Chairmanship of Mr. J. L. Hyatt (United Kingdom) and completed its work which is reflected in a substantive amendment to Recommendation 541. The IWP foresaw the need for practical trials using the digital selective calling system and IWP 8/10 was established by the Study Group under the Chairmanship of Mr. K. Oborne (United Kingdom) to coordinate these trials.

2.6 At the interim meeting, Study Group 8 established a new IWP 8/9, under the Chairmanship of Mr. B. Løken (Norway), to study the location registration in public land mobile systems. This IWP aims to complete its work for the interim meeting in 1983.

2.7 At the final meeting, it was appreciated that there was a need to study urgently the ambiguities regarding the re-phasing procedures before the introduction of direct-printing telegraph equipment. The Study Group established IWP 8/11 under the Chairmanship of Mr. T. de Haas (USA) to resolve the difficulties as a matter of urgency.

3. Future programme of work

Study Group 8 drafted 13 new Questions and modified or deleted most of the Questions under study at the time of the XIVth Plenary Assembly. Consequently, the programme of work has undergone considerable change since 1978. During the coming period, the many studies on maritime radiocommunications will involve cooperation with IMCO and INMARSAT particularly in studies concerned with safety and distress functions. In some areas CCIR advanced theoretical studies require practical trials to finalize the practicability of this work and suitable arrangements have been made with the cooperation of IMCO and INMARSAT to undertake such trials.

Land mobile and land mobile satellite services involving both private and public services form a major part of the Study Group 8 work programme. The effect of low cost, small microprocessors has been recognized and the land mobile services are urgently seeking to adapt this new technology as a matter of urgency in developing new technical standards and new techniques.

The low profitability of scheduled airlines has limited work on aeronautical mobile services and renewed attempts will need to be made in the coming period to stimulate new studies relevant to the late 1980/early 1990 years. New work on interference effects on aeronautical safety services has been started but further work is needed.

Work relevant to many of the Recommendations and Resolutions of WARC-79 has been completed but some studies will not be finalized until the end of the current period.

4. General matters

4.1 Study Group 8 has established good cooperative links with a number of CCIR and CCITT Study Groups by means of nominated rapporteurs and additional links will be established as mutual studies with other Study Groups dictate.

4.2 Study Group 8 considered that the XVth Plenary Assembly should note the long period existing between the special meeting of Study Group 8 (September 1981) and the World Administrative Radio Conference for Mobile Telecommunications and consequently may wish to consider making arrangements for any additional information to be made available to the Conference.

5. Recommendations and Reports of particular interest to developing countries

5.1 *Land mobile and amateur services*

Reports

- Characteristics of equipment and principles governing the allocation of frequency channels between 25 and 1000 MHz for land mobile services – Report 319.
- Signal-to-interference protection ratios and minimum field strengths required in the mobile services – Report 358.
- Interference due to intermodulation products in the land mobile service between 25 and 1000 MHz – Report 739.
- Technical investigations in the amateur service – Report 905.
- Frequency usage in the amateur service – Report 906.

Recommendations

- Technical characteristics of equipment and principles governing the allocation of frequency channels between 25 and 1000 MHz for the land mobile service – Recommendation 478.
- Technical characteristics of single sideband equipment in the MF and HF land mobile radiotelephone service – Recommendation 494.

5.2 *Maritime mobile service*

Recommendations

- Prevention of interference to radio reception on board ships – Recommendation 218.
- Use of radio beacon stations for communications – Recommendation 487.
- Emergency position-indicating radio beacons operating at the frequency 2182 kHz – Recommendation 439.
- Technical characteristics of VHF radiotelephone equipment operating in the maritime mobile service in channels spaced by 25 kHz – Recommendation 489.
- Internal communications on board ships by means of portable radiotelephone equipment – Recommendation 542.
- The use of R3E and J3E emissions for distress and safety purposes – Recommendation 543.
- The use of class J3E emissions for distress and safety purposes on the carrier frequencies 4125 kHz and 6215.5 kHz – Recommendation 544.
- The choice of frequencies in the maritime mobile bands above 4000 kHz to be reserved for distress and safety – Recommendation 545.
- Technical characteristics of fixed frequency radar beacons (racons) – Recommendation 554.

Reports

- The use of radio beacon stations for communications – Report 581.
- Internal communications on board ships by means of portable radiotelephone equipment – Report 589.
- Use of class J3E emissions for distress and safety purposes – Report 744.
- The choice of frequencies in the maritime mobile bands above 4000 kHz to be reserved for distress and safety purposes – Report 746.
- Technical and operating considerations for a future global distress and safety system at sea – Report 747.
- Future use and characteristics of emergency position indicating radio beacons – Report 749.
- Technical parameters of fixed frequency radar beacons (racons) – Report 774.
- Interference between fixed and maritime mobile and radionavigation services in the bands between 70 kHz and 130 kHz – Report 915.
- Technical characteristics of maritime radio beacons – Report 913.

5.3 *Mobile satellite services*

Reports

- Technical and operating characteristics of distress systems in the maritime mobile satellite service – Report 761.
- System aspects of low G/T ship earth stations – Report 921.
- Factors affecting the choice of antennas for mobile stations of the land mobile satellite service – Report 925.

5.4 *Aeronautical mobile service*

Reports

- General considerations relative to harmful interference from the viewpoint of the aeronautical mobile services – Report 927.
- Compatibility between the broadcasting service in the band 100 to 108 MHz and the aeronautical radionavigation service in the band 108 to 118 MHz – Report 929.

SECTION 8A: LAND MOBILE SERVICE AND RELATED SUBJECTS

Recommendations and Reports

RECOMMENDATION 494 *

TECHNICAL CHARACTERISTICS OF SINGLE-SIDEBAND EQUIPMENT IN THE MF AND HF LAND MOBILE RADIOTELEPHONE SERVICE

(1974)

The CCIR,

CONSIDERING

(a) that the growing use of single-sideband equipment in the land mobile service makes standardization increasingly important if mutual interference with other services is to be minimized;

(b) that some administrations have developed technical standards for single-sideband equipment operating in the MF and HF land mobile radiotelephone service;

(c) that the preferred technical characteristics for land mobile services should, as far as practicable, be compatible with those established for the aeronautical mobile (R) service and the maritime mobile services,

UNANIMOUSLY RECOMMENDS

1. that the preferred technical characteristics for MF and HF single-sideband land mobile equipment should be as follows:

1.1 *General*

1.1.1 class of emission J3E should be used; other classes of emission, e.g. H3E and R3E may be permitted, when necessary;

1.1.2 base and mobile stations should use the upper sideband;

1.1.3 the assigned frequency should be 1400 Hz higher than the carrier (reference) frequency;

1.1.4 for private mobile systems, the audio-frequency band should be 350-2700 Hz. For systems that can be connected to the public telephone network, the audio-frequency band may be increased to 300-3400 Hz.

1.2 *Transmitters*

1.2.1 the frequency tolerance should be ± 100 Hz. For short periods, of the order of 15 min, the maximum deviation of ± 40 Hz should not be exceeded. The unwanted frequency modulation of the carrier should be sufficiently low to prevent harmful distortion;

1.2.2 the permitted amplitude variation without pre-emphasis should not exceed 6 dB over the audio-frequency band specified in § 1.1.4, in either case;

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* This Recommendation terminates the Study of Question 8/8, which has been deleted.

1.2.3 the power levels of unwanted emissions supplied to the antenna transmission line on any discrete frequency should, when the transmitter is driven at the rated output power *, be in accordance with the following table:

TABLE I

Separation, Δ, in kHz between the frequency of the unwanted emission and the assigned frequency (kHz)	Minimum attenuation below the level of either fundamental sideband component when modulated by two tones (dB)
$1{\cdot}6 < \Delta \leqslant 4{\cdot}8$	25
$4{\cdot}8 < \Delta \leqslant 8{\cdot}0$	32
$8{\cdot}0 < \Delta$	37 (without exceeding the power of 50 mW)

Transmitters, using suppressed carrier emission may, as far as spurious emissions are concerned, be tested for compliance with this table by means of an input signal consisting of two audio tones that produce fundamental components of equal amplitude sufficient to produce the rated output of the transmitter, with a frequency separation between the tones such that all intermodulation products occur at frequencies at least 1.6 kHz removed from the assigned frequency;

1.2.4 for J3E emission, the power of the carrier should be at least 40 dB below the rated output power. In the case of hand portable equipment the power of the carrier need not be less than 1 mW;

1.2.5 the in-band intermodulation products should be in accordance with Recommendation 326. The test frequencies should be:

$$f_1 = 1900 \text{ Hz}, f_2 = 2600 \text{ Hz}$$

1.3 *Technical Characteristics of Receivers*

1.3.1 the sensitivity should be such that for a 12 dB signal plus noise plus distortion to noise plus distortion (SINAD) ratio, the input signal should not be more than −131 dBW **;

1.3.2 the two-signal selectivity should be such that the ratio of the level of the unwanted signal to the level of the wanted signal should be at least +60 dB when the level of the wanted signal is set at the sensitivity level given in § 1.3.1 and the level of the unwanted signal is adjusted until the 12 dB SINAD ratio is degraded by 6 dB *. The standard signal spacing for measuring receiver adjacent-signal selectivity should be 5 kHz;

1.3.3 the permitted amplitude variations without post-detector de-emphasis should not exceed 6 dB over the audio-frequency band specified in § 1.1.4, in either case;

1.3.4 the frequency stability should be within ± 100 Hz (with a maximum deviation of ± 60 Hz for short periods of the order of 15 minutes);

1.3.5 unwanted emissions on any discrete frequency should not exceed 2 nanowatts, measured either as a power level at the antenna terminals or as an effective radiated power from the equipment itself;

1.3.6 the spurious response rejection ratio should not be less than 60 dB in relation to the sensitivity of the receiver measured in accordance with § 1.3.1. In certain cases, the image frequency attenuation can be reduced to 50 dB for technical and economic reasons;

2. that a special requirement, necessary for single-sideband equipment used in the MF and HF land mobile service, is that, when an internal audio-frequency generator is used to modulate a transmitter to facilitate receiver tuning, the audio frequency should be 1000 Hz ± 1 Hz.

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* The rated output power may differ from that which would be established by Recommendation 326 and may be limited, on the other hand, by reasons of thermal dissipation, supply current limitations, or factors other than intermodulation products.

** The methods of measuring these characteristics should follow, as far as practicable, the practices as defined by the IEC.

REPORT 358-4

PROTECTION RATIOS AND MINIMUM FIELD STRENGTHS REQUIRED IN THE MOBILE SERVICES

(Question 1/8)

(1966-1970-1974-1978-1982)

1. VHF and UHF land and maritime mobile services

1.1 *Protection ratios based on internal noise and distortion in the receiver*

The World Administrative Radio Conference, Geneva, 1979, defined the protection ratio as the minimum value of the wanted-to-unwanted signal ratio, usually expressed in decibels, at the receiver input determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output (*RR No. 164*). For further information on the definition see Report 525. This ratio may have different values, according to the type of service desired.

However, in the absence of information submitted to Study Group 8 on subjective measurements made in the VHF and UHF land and maritime mobile services, several admininistrations have submitted the results of measurements using an alternative concept of protection ratio. This is based on electrical measurements, using appropriate test signals, of the degradation of the signal-to-noise ratio of the wanted test signal, when a co-channel interfering signal is superimposed on the latter. A degradation of the initial signal-to-noise ratio of 20 dB to a signal-to-noise + interference ratio of 14 dB is taken as the criterion. This criterion is considered to correspond with the minimum acceptable grade of service.

In the tests described by the various administrations, the frequency deviations are 70% or 60% of the maximum specified frequency deviations, and for amplitude modulation the modulation percentages are 70% or 60%, for both wanted and unwanted signals. From a study of the documents submitted, it may be deduced that the slight differences in measurement conditions and in the characteristics of the receivers used in the different tests, may result in differences in the measured protection ratios, of up to about ± 3 dB.

One administration performed tests to determine the protection ratio for the case where the wanted narrowband G3E signal is interfered by a direct-printing F2B signal (see Recommendation 476) [CCIR, 1978-82]. The e.m.f. of the wanted signal at the receiver input was 2 μV. In these tests the level of the interfering co-channel F2B signal was so adjusted that the subjective effect on the wanted signal was the same as that of an interfering co-channel narrowband G3E signal attenuated by the protection ratio of 8 dB laid down in Table I for this case. The peak frequency deviations used for the F2B signal were ± 1, ± 3 and ± 5 kHz respectively. The sub-carrier was 1500 Hz and the frequency shift 170 Hz. 12 dB was found to be a suitable representative value for the protection ratio and is therefore included in Table I.

Although the protection ratios may be dependent on the passband characteristics of receivers, the frequency difference between the co-channel wanted and unwanted signals, the frequency deviation, etc., the protection ratios in Table I are proposed as approximate standards for the design of mobile systems for a minimum grade of service if appropriate added consideration is given to multipath propagation effects and man-made noise.

When using frequency modulation, "capture effect" is enhanced as the frequency deviation of the wanted signal is increased; therefore, a wideband F3E, G3E system requires less protection than a narrowband F3E, G3E system for the same type of interfering source.

If a higher grade of service is required, a higher protection ratio should be adopted, particularly in the case of amplitude-modulated wanted emissions.

1.2 *Man-made noise*

Man-made noise degrades the performance of a mobile system. To maintain a desired grade of service in the presence of man-made noise, it is necessary to increase the level of the field strength of the wanted signal. Motor vehicles have been shown, by measurements [US Advisory Committee, 1967], to be the primary source of man-made noise for frequencies above 30 MHz. Other noise sources are fewer in number and usually radiate from fixed locations.

TABLE I

Wanted emission (Note 1)	Unwanted emission (Note 1)	RF protection ratio (dB)
Wideband F3E, G3E	Wideband F3E, G3E	8
Narrowband F3E, G3E	Narrowband F3E, G3E	8
Wideband F3E, G3E	A3E	8
Narrowband F3E, G3E	A3E	10
Narrowband F3E, G3E	Direct printing F2B	12
A3E	Wideband F3E, G3E	8-17 (Note 2)
A3E	Narrowband F3E, G3E	8-17 (Note 2)
A3E	A3E	17

Note 1. – Wideband F3E, G3E systems normally employ frequency deviations with a maximum value in the range ±12 to ±15 kHz. The narrowband F3E, G3E systems considered here normally employ frequency deviations with maximum values of either ±4 or ±5 kHz. The value of the F2B case is with a peak frequency deviation of ±5 kHz. Frequency deviations of ±3 and ±1 kHz do not significantly decrease this value.

Note 2. – The protection ratio may vary within the range shown dependent upon the difference in frequency between the carriers of the wanted and unwanted emissions and the frequency deviation of the unwanted emission. In general, it will tend towards the higher figure as the frequency deviation of the unwanted emission decreases.

For convenience in evaluating the degradation of performance of a base receiver, the following classifications of noise sources are provided:

- high noise locations – traffic density of 100 vehicles/km^2 at any given instant of time;
- moderate noise locations – traffic density of 10 vehicles/km^2 at any given instant of time;
- low noise locations – traffic density of 1 vehicle/km^2 at any given instant of time;
- concentrated noise sources (hot spots): noise radiated from individual sources or closely spaced multiple sources which are usually located within 500 m of the receiving antenna, such as a high concentration of vehicles, manufacturing plants and defective power transmission lines.

Noise data for base stations at high, moderate and low noise locations are presented by a noise amplitude distribution (NAD) (the number of pulses per second equal to or greater than the value shown as ordinate) and are illustrated in Fig. 1. The amplitude (A) (in dB(μV/MHz)) of noise pulses at a rate of 10 pps (pulse-per-second) is expressed as follows:

$$A = C + 10 \log V - 28 \log f$$

where,

C: constant (tentative value: 106 dB(μV/MHz)

V: traffic density vehicles/km^2

f: channel frequency, MHz.

Noise data for hot spots can also be presented in the form of a noise amplitude distribution. However, due to a wide variety of noise sources, it is not yet practical to provide a classified list.

The constant C is a function of the electrical noise suppression applied to vehicles and may also vary according to the relative proportion of goods and passenger vehicles if the level of suppression is not the same for both categories. A tentative value of 106 dB(μV/MHz) is shown and this may be revised as more information becomes available.

1.3 *Noise Amplitude Distribution (NAD) determination of degradation*

1.3.1 *Definitions*

1.3.1.1 *Noise amplitude distribution*

A presentation of impulsive noise data in terms of its basic parameters of spectrum amplitude and impulse rate.

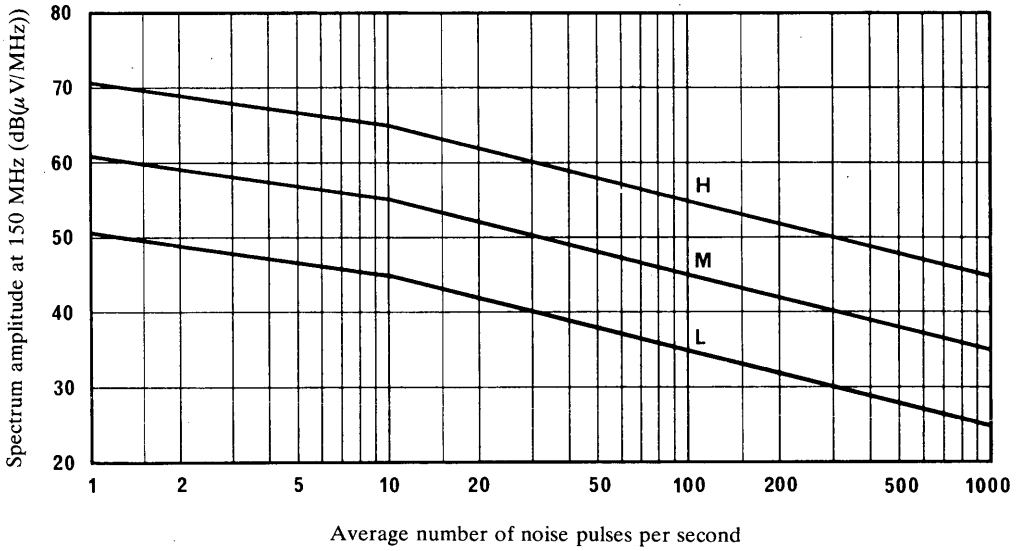


FIGURE 1 – *Noise amplitude distribution at base station (150 MHz)*

For frequencies other than 150 MHz, raise or lower curves H, M and L in accordance with the formula below.

$A = C + 10 \log V - 28 \log f$
where A = dB (μV/MHz) at 10 pps

Curve H: high noise location ($V = 100$)
Curve M: Moderate noise location ($V = 10$)
Curve L: low noise location ($V = 1$)

1.3.1.2 *Spectrum amplitude*

The vector sum of the voltages produced by an impulse in a given bandwidth, divided by the bandwidth.

1.3.1.3 *Impulse rate*

The number of impulses that exceed a given spectrum amplitude in a given period of time.

1.3.1.4 *Impulsive-noise tolerance*

The spectrum amplitude of impulses at a given pulse-repetition frequency at which the receiver, with an input signal applied at specific levels, produces standard signal-to-noise ratios at the output terminals.

1.3.2 *Determination of degradation*

Degradation of receivers can be determined as follows:

1.3.2.1 measure the impulsive noise tolerance of the receiving equipment in accordance with applicable IEC standards;

1.3.2.2 measure NAD in accordance with applicable IEC standards;

1.3.2.3 Superimpose the graphs for the receiver impulse noise tolerance and the NAD. An example is shown in Fig. 7.

1.4 *Minimum values of field strength to be protected*

The minimum values of field strength to be protected in the land mobile service at frequencies above 30 MHz are determined by internal noise generated in the receiver, man-made noise usually in the form of radiation from ignition systems of motor vehicles and the effects of multipath propagation to and from moving vehicles. Some information on the effects of traffic density is now available. In the maritime mobile service, the level of man-made noise depends on the number and nature of high level sources of noise on the ship.

A convenient measure of the threshold of performance for narrowband receivers is a specified value of

$$\frac{S + N + D}{N + D}$$

ratio; the conventionally accepted value being 12 dB (see Recommendation 331).

This defines the minimum usable field strength for any particular installation, in the absence of man-made noise.

The sensitivity of typical receivers is such that an input signal of 0.7 μV e.m.f. (assuming a receiver input impedance of 50 Ω) would result in a 12 dB

$$\frac{S + N + D}{N + D}$$

ratio at the output. A mobile service is characterized by large variations of field strength as a function of location and time. These variations may be represented by a log-normal distribution for which standard deviations of 8 dB at VHF and 10 dB at UHF are appropriate for terrain irregularities of 50 m (see Recommendation 370). To determine the minimum value of median field strength to be protected, it is necessary to specify the percentage of time for which the minimum usable field strength should be exceeded for different grades of service. For land mobile radiotelephony, a high grade of service would require that the value be exceeded for 99% of the time, but, for a lower (or normal) grade of service, for 90% of the time.

The minimum values of field strength to be protected can be determined subjectively, taking into account man-made noise and multipath propagation. Ignition systems of motor vehicles are usually the most prevalent source of man-made noise. Field strength cancellations due to multipath propagation produce an annoyance somewhat similar to that created by ignition systems. When a mobile unit is in motion, both of these annoyances occur at the same time. Only the effects of receiver noise and man-made noise remain when the mobile unit is stationary. The separation of motor vehicles is generally less with slow-moving or stationary traffic, and under these circumstances, particularly at the lower frequencies, the degradation experienced in a stationary mobile unit is greater than when it is in motion.

Figures 3 and 4 can be used to determine the combined degradation effects of man-made noise and multipath propagation for the case of vehicles in motion. These figures are based on subjective testing under traffic conditions commonly experienced by most mobile vehicles [FCC, 1973]. Specifically, these traffic conditions are the following: in motion while in a low noise area, in motion in traffic surrounded by other vehicles, and stationary surrounded by other stationary or moving vehicles.

The tendency for the curves of Figs. 3 and 4 to merge at the higher frequencies is due to the almost constant multipath degradation effect with frequency and the fact that the degradation effect of man-made noise decreases with frequency.

Degradation is defined as the increase of level necessary in the desired input signal to maintain the receiving signal at the degree of quality obtainable when affected by receiver noise only.

Definitions of signal quality are as follows:

Grade	*Interfering effect:*	
5	Almost nil	Speech understandable, but with increasing effort as the grade decreases
4	Noticeable	
3	Annoying	
2	Very annoying	
1	So bad that the presence of speech is barely discernible	

Some information on field strengths can be derived from Recommendation 370. Additional information can be found in the document of the CCIR, [1966-69], and in the article of Okumura *et al.* [1968].

Information on protection ratios and minimum field strengths may also be found in the "Special Agreement between the Administrations of Belgium, the Netherlands, and the Federal Republic of Germany relating to the use of metric and decimetric waves for fixed and mobile services in border areas, Brussels, 1963", and in the Final Acts of the Special Regional Conference, Geneva, 1960. Similar information may be found in the Agreement between the Telecommunications Administrations of Austria, the Federal Republic of Germany, Italy and Switzerland, Vienna, 1969.

The document of the CCIR [1963-66], deals with the above questions for signal-to-noise ratios of 30 dB and 40 dB at the receiver output.

Until values based on man-made noise and multipath effects are available, the calculated values of minimum and median values of field strength shown in Fig. 2 may be used for hand-portable stations.

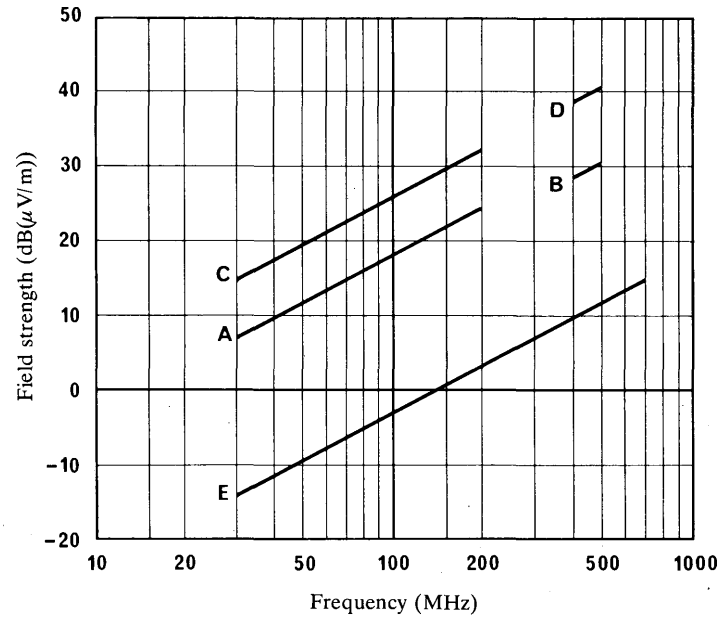


FIGURE 2 – *Minimum usable and median field strengths for typical hand-portable stations (based on minimum usable input of 0.7 μV e.m.f., in the absence of man-made noise)*

Characteristics assumed: antenna gain { A and C: – 9 dB; B and D: – 6 dB

A, B: median, normal grade
C, D: median, high grade
E: minimum usable field strength (dipole antenna)

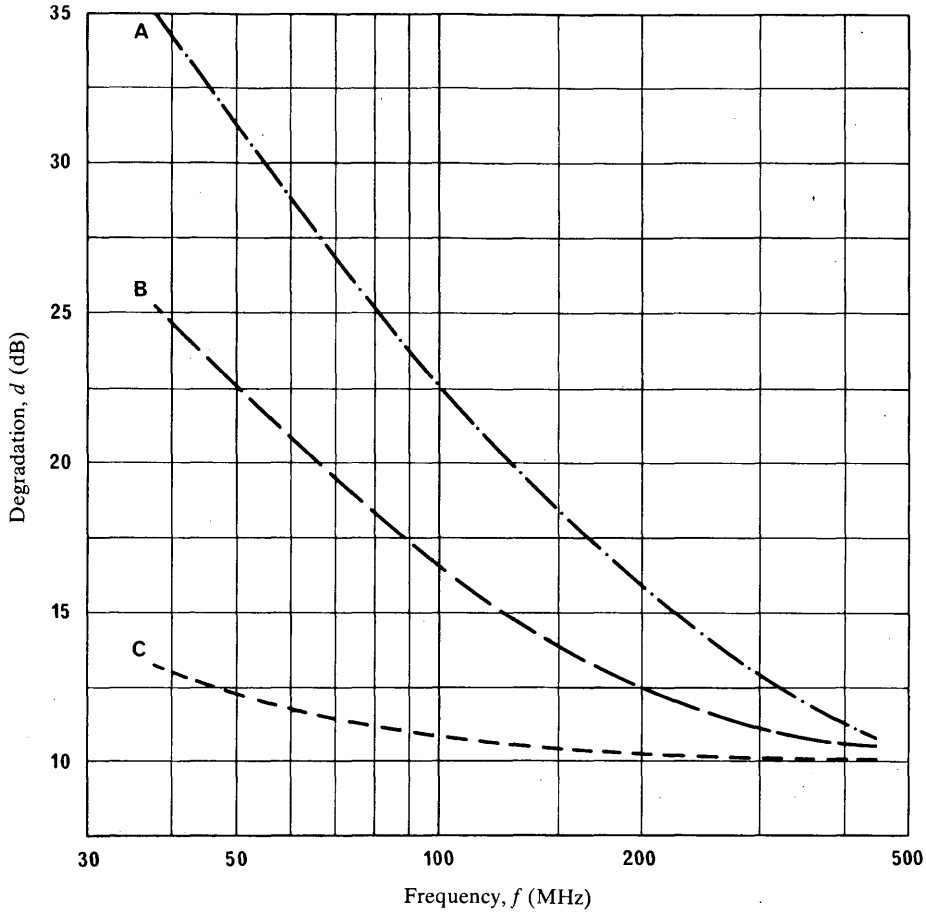


FIGURE 3 – *Variation of degradation of mobile reception and minimum values of field strength to be protected for* signal quality grade 4 *and receiver sensitivity of 0.7 μV e.m.f.*

$$\text{Field strength} = -41 + d + 20 \log f \qquad \text{dB}(\mu\text{V/m})$$

A: mobile vehicle stationary within a high noise area
B: mobile vehicle in motion within a high noise area
C: mobile vehicle in motion within a low noise area

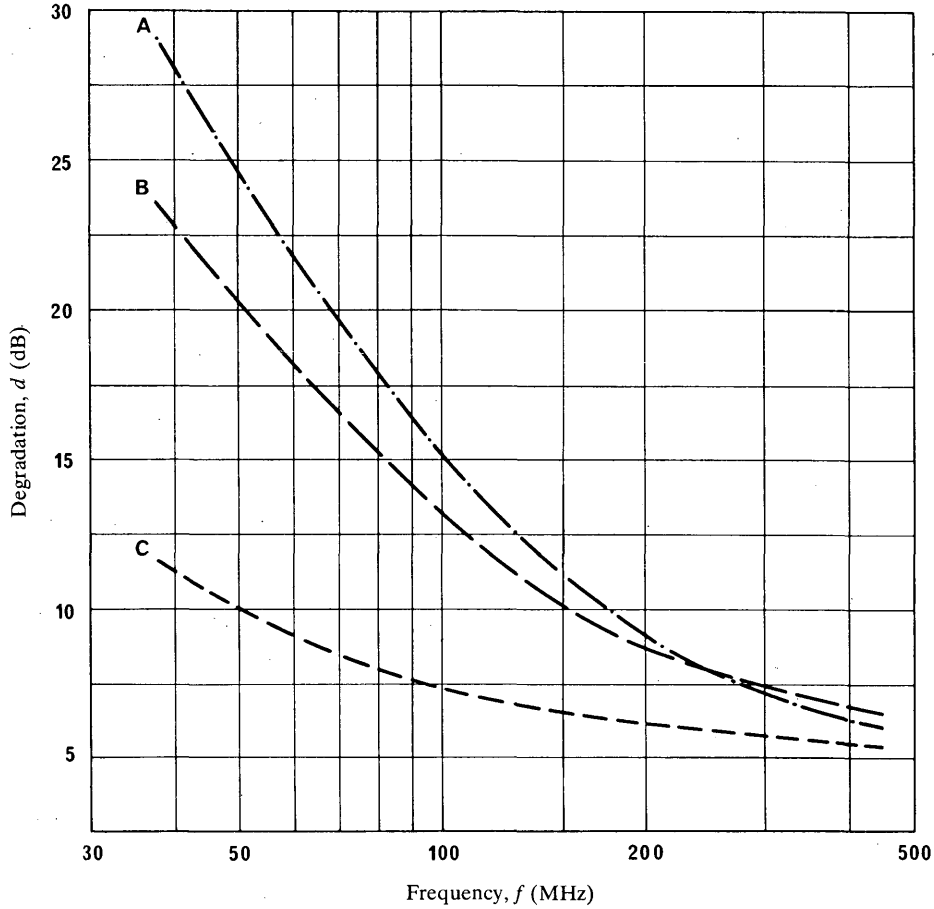


FIGURE 4 – *Variation of degradation of mobile reception and minimum values of field strength to be protected for* signal quality grade 3 *and receiver sensitivity of 0.7 μV e.m.f.*

$$\text{Field strength} = -41 + d + 20 \log f \qquad \text{dB}(\mu\text{V/m})$$

A: mobile vehicle stationary within a high noise area
B: mobile vehicle in motion within a high noise area
C: mobile vehicle in motion within a low noise area

Figures 5 and 6 can be used for determining the degradation of base station reception due to ignition noise and multipath propagation.

Curves A and B of Figs. 5 and 6 show the combined degrading effects of multipath propagation and ignition noise for heavy and moderate traffic rates. The speed of the traffic was approximately 80 km per hour. Curves D and E show the degrading effect of ignition noise only. Curve C shows the degrading effects of multipath propagation only.

The data presented here were obtained at a distance of 23.5 m from a heavily travelled thoroughfare. Except for the ignition noise created by the thoroughfare, the base station test site itself was quiet. Curves A and B were obtained by radiating the desired signal from a mobile unit in motion. In this case, degradation is based on median values of voltage at the input terminals of the receiver. The effects of ignition noise, only when the mobile unit is standing still, are shown by curves D and E. In this case the desired signal was obtained from a signal generator. Curve C was obtained by inserting sufficient attenuation at the receiver input terminals in order to eliminate ignition noise pulses. The increased attenuation was compensated for by radiating a stronger signal from the mobile unit.

At approximately 450 MHz the degradation of base station reception due to multipath is greater than that for mobile reception. This is primarily due to the higher level of the ambient aural noise in the mobile unit as compared to that of the base station. The road and vehicle aural noise mask the multipath degradation effect, thereby reducing the value of receiver input signal needed to obtain a given grade.

2. HF maritime mobile service

The question of the protection ratio and the minimum field strength to be protected in the HF maritime mobile service for various classes of emission used by that service needs further study. In so far as HF radiotelephony is concerned the Study Group gave provisional advice to the IFRB in respect of these parameters (see Report 748).

3. Conclusions

Considerable additional work concerning §§ 1 and 2 is necessary to determine more fully the appropriate protection ratios and the values of the field strengths to be protected, and also to determine and record the measurement methods which should be adopted.

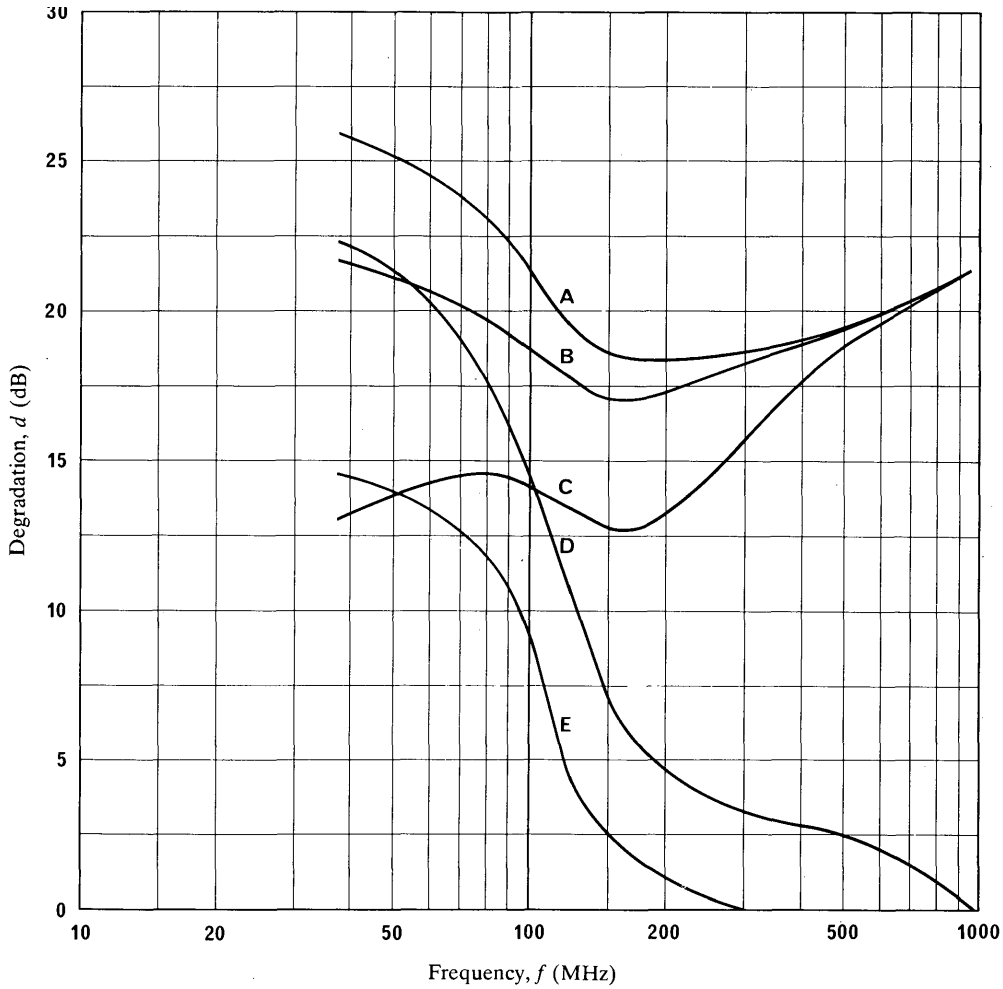


FIGURE 5 – *Variation of degradation of base station reception and minimum values of field strength to be protected* for signal quality grade 4 *and receiver sensitivity of 0.7 μV e.m.f.*

$$\text{Field strength} = -41 + d + 20 \log f \qquad \text{dB}(\mu\text{V/m})$$

A: mobile vehicle moving, traffic rate is 2 vehicles/s
B: mobile vehicle moving, traffic rate is 1 vehicle/s
C: mobile vehicle moving, no ignition or ambient noise
D: mobile vehicle standing still, traffic rate is 2 vehicles/s
E: mobile vehicle standing still, traffic rate is 1 vehicle/s

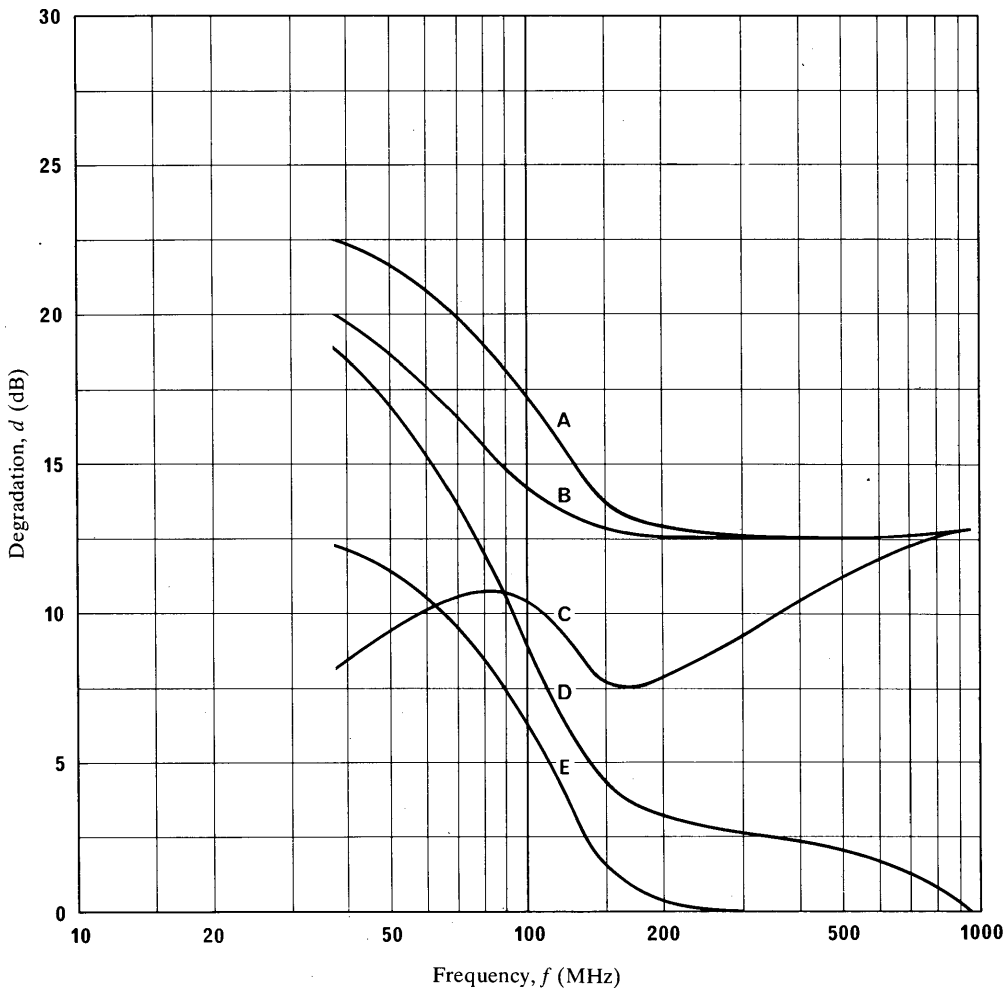


FIGURE 6 – *Variation of degradation of base station reception and minimum values of field strength to be protected for* signal quality grade 3 *and receiver sensitivity of 0.7 μV e.m.f.*

$$\text{Field strength} = -41 + d + 20 \log f \qquad \text{dB}(\mu\text{V/m})$$

A: mobile vehicle moving, traffic rate is 2 vehicles/s
B: mobile vehicle moving, traffic rate is 1 vehicle/s
C: mobile vehicle moving, no ignition or ambient noise present
D: mobile vehicle standing still, traffic rate is 2 vehicles/s
E: mobile vehicle standing still, traffic rate is 1 vehicle/s

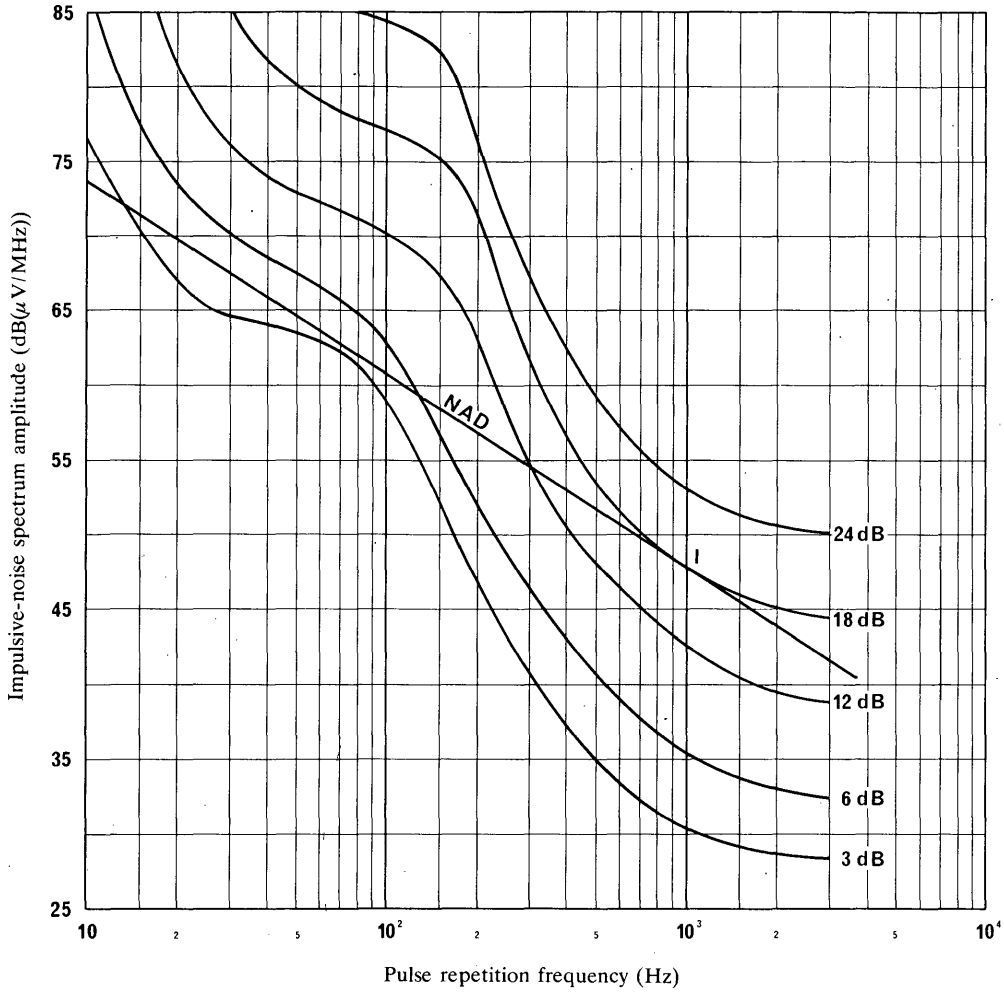


FIGURE 7 – *Example showing 18 dB degradation*
NAD tangent at 1 to 18 dB curve of the graph for receiver impulse noise tolerance

REFERENCES

FCC [August, 1973] Degradation of mobile radio reception at UHF and VHF. Research Division, Rep. No. R-7302.

OKUMURA, Y., OHMORI, E., KAWANO, T. and FUKUDA, K. [September-October, 1968] Field strength and its variability in VHF and UHF land-mobile radio service. *Rev. Elec. Comm. Labs., NTT*, Vol. 16, **9-10**, 825-873.

US ADVISORY COMMITTEE [1967] Man-made noise; Report from Working Group 3 of the Advisory Committee for the Land Mobile Radio Services, Vol. 2, Part 2, US Govt. Printing Office: 0-281-851, Washington, DC 20402.

CCIR Documents

[1963-66]: XIII/88 (Japan).

[1966-69]: XIII/146 (Japan).

[1978-82]: 8/3 (Germany (Federal Republic of)).

RECOMMENDATION 478-3

TECHNICAL CHARACTERISTICS OF EQUIPMENT AND PRINCIPLES GOVERNING THE ALLOCATION OF FREQUENCY CHANNELS BETWEEN 25 AND 1000 MHz FOR THE LAND MOBILE SERVICE

(Question 7/8)

(1970-1974-1978-1982)

The CCIR,

CONSIDERING

(a) that certain technical characteristics of equipment and stations in the land mobile service are of importance in connection with radio interference between the stations of different countries;

(b) that agreement is desirable on certain technical characteristics of land mobile equipment, to minimize mutual interference and to facilitate the use of the same types of equipment in different countries in a geographical region;

(c) that agreement is desirable on the practices governing the choice of station antenna height and effective radiated power taking into account geographical features, required communications range and system parameters;

(d) that agreement is desirable on the practices governing the allocation of channels in the land mobile service, in order to minimize mutual interference and to obtain economy of use of the frequency spectrum;

(e) that in some areas, different values for the technical characteristics of equipment are required, in order to minimize mutual interference;

(f) that the values agreed upon should be based on circumstances that typify high density radio usage areas and should be a compromise between optimum spectrum utilization and cost;

(g) that under some circumstances, e.g. where channel assignments and/or types of system operation permit, not all recommended technical characteristics are required to minimize mutual interference;

(h) that in the land mobile service, ultimate spectrum utilization is determined by assignment techniques, suppression and rejection of unwanted radiation, and other means additional to the actual characteristics of the equipment;

(j) that the characteristics of non-vehicular mounted portable equipment require further study;

(k) that in Opinion 42, the IEC has been invited to advise the CCIR of any methods of measurement applicable to radio equipment used in land mobile services,

UNANIMOUSLY RECOMMENDS

1. that the preferred technical characteristics for VHF and UHF land mobile equipment should be as follows:

1.1 *Transmitter characteristics*

1.1.1 *Necessary bandwidth and class of emission*

1.1.1.1 For class A3E: 6 kHz

1.1.1.2 For class F3E:

30 and 25 kHz channel separations: 16 kHz

20 kHz channel separation:

in frequency bands up to 160 MHz: $\leqslant$ 16 kHz, dependent on deviation

in frequency bands above 160 MHz: 14 kHz

12.5 kHz channel separation: 8.5 kHz

1.1.2 *Frequency tolerance*

Within the temperature ranges specified by each administration according to the environment, and for specified ranges of primary supply voltages, the frequency error of any carrier emission should not exceed the values given in Table I.

TABLE I – *Tolerances for each frequency band*

Channel spacing (kHz)	Frequency band											
	35 MHz		80 MHz		160 MHz		300 MHz		450 MHz		900 MHz	
	kHz(1)	10^{-6}	kHz(1)	10^{-6}	kHz(1)	10^{-6}	kHz(1)	10^{-6}	kHz(1)	10^{-6}	kHz(1)	10^{-6}
20, 25 and 30	0.7	20	1.6	20	1.6	10	2.1	7	2.25	5	2.7	3
12.5	–	–	1.0	12	1.3	8	–	–	1.35	3	–	–

(1) Approximate values.

1.1.3 *Adjacent channel power*

1.1.3.1 25 and 30 kHz channel spacing:

25-500 MHz: at least 70 dB below carrier power in a bandwidth of 16 kHz

500-1000 MHz: at least 65 dB below carrier power in a bandwidth of 16 kHz

1.1.3.2 20 kHz channel spacing:

At least 70 dB below carrier power in a bandwidth of 14 kHz, Δf: 4 kHz (Δf: the maximum permissible frequency deviation)

At least 60 dB below carrier power in a bandwidth of 14 kHz, Δf: 5 kHz (Δf: the maximum permissible frequency deviation)

1.1.3.3 12.5 kHz channel spacing:

At least 60 dB below carrier power in a bandwidth of 8.5 kHz.

In each case, it is not necessary to reduce the adjacent channel power below 0.25 μW.

1.1.4 *Conducted spurious emissions*

Spurious emissions on discrete frequencies, when measured in a non-reactive load equal to the nominal output impedance of the transmitter, should not exceed 2.5 μW for transmitter carrier powers up to 25 W. For carrier powers in excess of 25 W, the level of any spurious emission should be at least 70 dB below the carrier power.

In some radio environments lower values may be required.

1.1.5 *Cabinet radiation*

The cabinet radiated power should not exceed 25 μW. In some radio environments, a lower value may be required.

1.2 *Receiver characteristics*

1.2.1 *Reference sensitivity*

The reference sensitivity should be less than 2.0 μV, e.m.f., for a given reference signal-to-noise ratio at the output of the receiver.

1.2.2 *Adjacent channel selectivity*

1.2.2.1 20, 25 and 30 kHz channel spacing:

The adjacent channel selectivity should not be less than 70 dB.

1.2.2.2 12.5 kHz channel spacing:

The adjacent channel selectivity should not be less than 60 dB.

1.2.3 *Radio-frequency intermodulation*

The intermodulation response rejection ratio should not be less than 70 dB.

1.2.4 *Spurious responses*

At any frequency separated from the nominal frequency of the receiver by more than one channel spacing, the spurious response rejection ratio should not be less than 70 dB.

1.2.5 *Conducted spurious emissions*

The power of any spurious emission measured at the antenna terminals with matched termination, on any discrete frequency, should not exceed 2.0 nW.

In some radio environments, lower values may be required.

1.2.6 *Cabinet radiation*

The effective radiated power of any spurious emission on any discrete frequency up to 70 MHz should not exceed 10.0 nW. Above 70 MHz, the spurious emissions should not exceed 10 nW by more than 6 dB/octave relative to the value at 70 MHz in frequency up to 1000 MHz.

In some radio environments, lower values may be required.

1.3 *Station characteristics*

1.3.1 *Frequency characteristics*

1.3.1.1 Radio-frequency band of operation:

According to the Table of Frequency Allocations contained in Article 8 of the Radio Regulations; in particular the bands of 35, 80, 160, 300, 450 and 900 MHz.

1.3.1.2 Separation of the transmit and receive frequencies for full duplex operation:

35 MHz band: 4 MHz
80 MHz band: 3 MHz
160 MHz band: 3 MHz
300 MHz band: 4 MHz
450 MHz band: 5 MHz

The above are practical minimum values determined by cost and isolation required; smaller separations are possible using higher quality and more costly duplexers.

900 MHz band: 45 MHz

This preferred value is determined by the desirability to provide for high capacity systems with a great number of channels. However, in some systems, greater transmit/receive frequency separation might be required.

In practice, the actual separations used may be other than the values given and may be determined by other factors than were used in this Recommendation. Frequencies should preferably be assigned with a constant separation between the transmit and receive frequencies over the whole of a band or the sub-bands within a band.

1.3.2 *Effective radiated power and antenna height*

It is recognized that the responsibility for limiting the effective radiated power and antenna height over the average level of the ground rests with administrations, taking into account:

- the general requirement not to radiate more power than is necessary and not to use larger antenna heights than necessary;
- the required range and communication quality;
- the frequency band of operation;
- the terrain over which service is required;
- special conditions, e.g. diversity reception at remote receiving stations;
- the potential intra-service or inter-service effects between the mobile service and other radio services.

1.3.3 *Antenna system*

Vertically polarized.

2. that reference should be made to Part A of Report 319 for information on some of the existing practices adopted by administrations in the allocation of channels in the land mobile service between 25 and 1000 MHz;

3. that international agreement should be reached on as many aspects as possible of the practices for the allocation of channels in the land mobile service between 25 and 1000 MHz, and that reference should be made to Part A of Report 319;

4. that reference should also be made to the relevant IEC publications on methods of measurement.

REPORT 319-5 *

CHARACTERISTICS OF EQUIPMENT AND PRINCIPLES GOVERNING THE ASSIGNMENT OF FREQUENCY CHANNELS BETWEEN 25 AND 1000 MHz FOR LAND MOBILE SERVICES

(Resolution 20)

(1970-1974-1978-1982)

PART A

ASSIGNMENT METHODS

1. Suggested principles

1.1 The following broad principles are suggested for use in the assignment of frequencies in the land mobile service:

- the choice of the most advantageous mode of operation, i.e., single-frequency or two-frequency operation, according to the type of service, bearing in mind the need for coordination between administrations in border areas;
- the gradual adoption, as opportunity occurs, of the same blocks of frequencies for base stations by all administrations, and similarly the same blocks of frequencies for mobile stations, in order to minimize interference between services of different administrations;
- the gradual adoption by all administrations, as opportunity occurs, of the same blocks of frequencies for the same types of service or at least for those services required to provide similar coverage;
- the adoption of compatible frequency plans, with the same channel separation and the same centre frequencies of the channels and, when suitable, with centre frequencies off-set, e.g. by one half channel, especially in areas where mutual interference might occur between the services of different administrations;
- the use of common channel separation, preferably 25 kHz (see Note) and the use of equipments which are readily adaptable for a reduction in channel separation without replacement of the whole equipment;
- the allocation of channels in such a way as to minimize the production of interference due to intermodulation products;
- the adoption of optimum sizes and shapes for service areas in relation to frequency economy (Question 37/8 and Report 740 refer to this subject);
- the use of the minimum effective radiated power compatible with the required service range;
- the use of the minimum height of base station antennas compatible with the required service range;
- the siting of co-channel stations with the minimum geographical separation compatible with the protection ratios and minimum field strengths to be protected which are appropriate to the service. Information on this subject is given in Report 358;
- the use by all Administrations of common propagation data. References to CCIR documents on this subject are included in Report 358;
- the assignment of the same frequency channel to a number of users in the same area, in such a manner as to permit optimum use of the channel.

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* The Director, CCIR, is requested to draw the attention of IEC to Part B, § 3.4.

1.2 These principles can be applied to full advantage when planning land mobile services, only if all are applied, since they are highly interdependent.

Note. – It is recognized that some administrations use other channel separations. Every opportunity should be taken to achieve the use of common channel separations.

2. Single-frequency and two-frequency operation

It is not usually possible to use all the available frequencies in a given restricted area owing to intermodulation problems, adjacent channel disturbances, receiver desensitization, etc. The problems which arise may be somewhat different with single-frequency and two-frequency operation.

2.1 *Single frequency operation*

- Direct mobile-to-mobile communication independent of base stations is possible.
- Direct base-to-base communications when base stations are within range of each other is possible.
- Mobiles not within range of each other may transmit simultaneously causing interference at the base station.
- Base station can effectively control channel usage.
- Possibility for interference between base stations using the same channel.

2.2 *Two frequency operation-non-repeater mode (at base station)*

- Prevents direct mobile-to-mobile communication.
- Permits full control of channel usage by base station.
- Mobiles may transmit simultaneously causing interference at base station.
- Base-to-base communication not possible.
- Necessary for mobile telephone systems providing full duplex arrangements and interfacing with telephone networks.
- Prevents interference between base stations using the same channel.

2.3 *Two frequency operation-automatic repeater mode (at base station)*

- Mobile-to-mobile communications are automatically rebroadcast (repeated) by the base station thus mobile-to-mobile range is equal to that of base station coverage.
- Every user is aware of every transmission.
- Remote control of repeater easily accomplished from fixed control points by a radio equipment operating on mobile radio frequencies.
- Lends itself to shared use [Muilwijk, 1978].
- Permits use of mobile units in repeater mode to act as relay for portables.
- Permits totally unattended operation of base station.
- Failure of the automatic repeater results in total system failure, i.e. mobile-to-mobile communications is impossible without specially configured mobile units.
- Total channel occupancy may be determined by monitoring the base station frequency only.
- Prevents interference between base stations using the same channel.

2.4 Other factors to be considered when administrations develop two-frequency channelling plans for land mobile services are:

- practical values of transmit/receive frequency separation;
- practical values of maximum channel separation in multi-channel equipment;
- the use of a constant separation between the transmit and receive frequencies over the whole of a band or the sub-bands within a band.

3. Channel separation considerations

3.1 During the technical development of the land mobile service a progressive reduction of channel separation has occurred, thus making available an increased number of channels.

Some administrations, taking into account the need for new channels, especially in limited areas with high-density population, have decided to use frequency modulation with very narrow channel separation. Despite some disadvantages these administrations consider that they derive substantial benefits from the use of this technique (see Part C, § 1.4).

Nevertheless some conflicting factors have to be taken into account when considering whether it is effective to reduce the separation between channels by narrowing the bandwidth of the emissions and correspondingly narrowing the bandwidth of the receivers. Therefore, rather than concentrating only on finding ways to increase the number of channels to be derived from a given block of spectrum, the search should be directed to finding the combination of channel separation and technical characteristics that will result in accommodating the maximum amount of information and/or the maximum number of radio users per MHz in a given geographic area.

Reducing channel bandwidths (and consequently the modulation indices) in FM systems causes some degradation in transmission quality and in protection from interference. In a cellular system, reduction of channel bandwidth will not necessarily increase the traffic capacity per MHz per km^2 [Colavito, 1974].

Further study is necessary to determine the conditions under which channel bandwidth reduction increases spectrum efficiency.

Muilwijk [1978] has shown the relationship between transmission quality (signal-to-interference ratio in the audio-frequency baseband) and the carrier-to-interference ratio at the input to the receiver. Fig. 1 shows that, for a 20 dB ratio of signal to interference in the audio band, a receiver of 8K50F3E emissions, for which B/B_0 (ratio of radio-frequency bandwidth to audio-frequency bandwidth) = 3, requires a carrier-to-interference (C/I) ratio of 19 dB whereas a receiver for 16K0F3E emissions (B/B_0 = 5) requires only 9 dB.

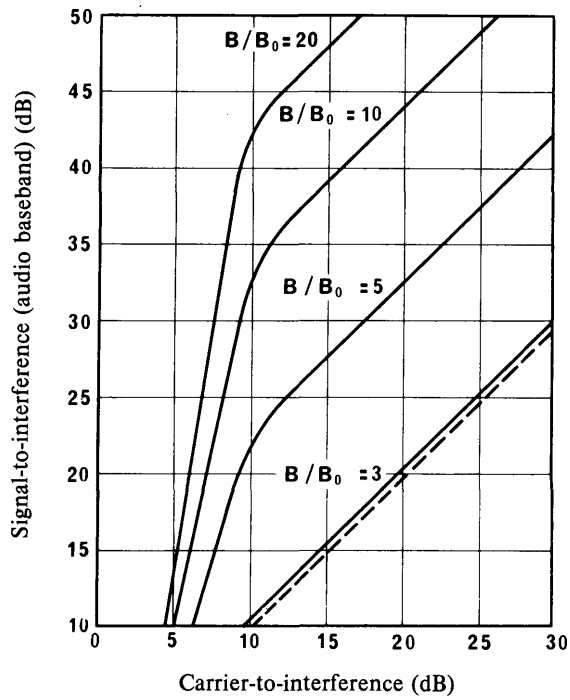


FIGURE 1

— — — SSB

Muilwijk [1978] also showed that the required radio-frequency system bandwith for optimum traffic handling capability in co-channel interference situations is proportional to $B\sqrt{C/I}$. Fig. 2 shows the relationships, derived from Muilwijk [1978], between B/B_0 and $B\sqrt{C/I}$. For a baseband signal-to-interference (S/I) ratio of 20 dB (considered minimum acceptable quality for a land mobile channel), the required radio-frequency bandwidth factor ($B\sqrt{C/I}$) is a minimum where B/B_0 is between 5 and 6, i.e. emissions in the range 15K0 to 18K0.

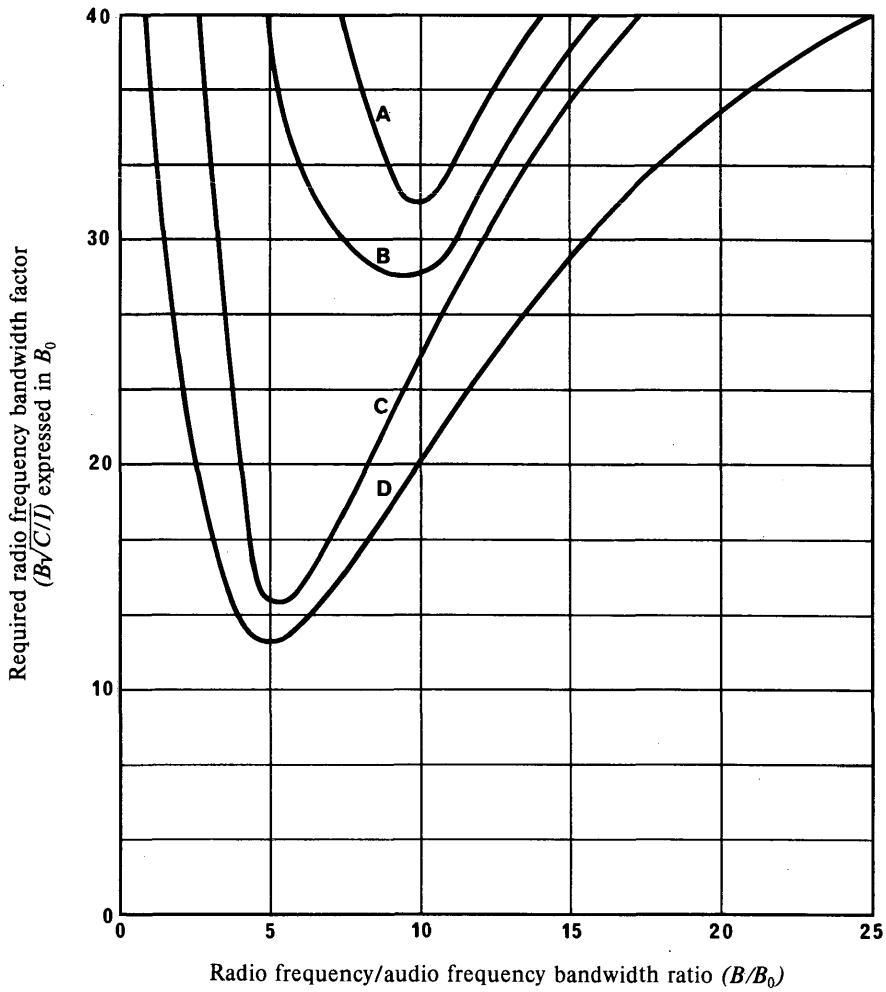


FIGURE 2

A: 36 dB
B: 30 dB
C: 20 dB
D: 16 dB *S/I*

3.1.1 In a moving vehicle, the concept of a constant ratio between desired signal and undesired (interfering) signal is not applicable, because both signal and interference vary widely and continuously. These variations may be separated into:

- macroscopic shadow variations, occurring over a few metres to about a hundred metres, which are due to large terrain features such as buildings and hills, and

- microscopic Rayleigh fading variations.

The simultaneous occurrence of a null in the desired signal and a peak in the interfering signal results in a "click" as shown in Fig. 3 [AT&T, 1971]. The "clicks" cumulatively degrade the circuit, but appear too rapidly to be individually distinguishable.

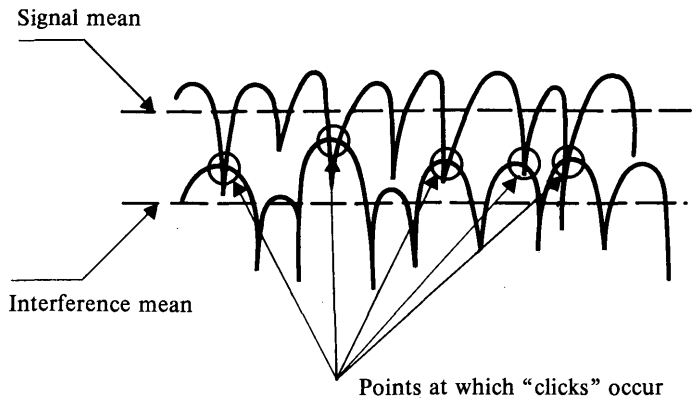


FIGURE 3 – *Effect of Rayleigh fading on subjective interference*

While it is obvious that the concept of an acceptable constant wanted-to-unwanted signal ratio (W/UNW) is not applicable in such a case, each signal in a region perhaps hundreds of metres wide may be characterized by a local mean, about which the distribution of the fading values is quite predictable. One may qualitatively determine the ratio of local-mean-signal to local-mean-interference which yields acceptable performance where both signal and interference exhibit independent Rayleigh fading about their local mean values. The minimum acceptable ratio E_i, is a function of the radio equipment as well as of the baseband quality desired. The interference criterion may now be written as the percentage of local areas in which the ratio of local-mean-signal to local-mean-interference exceeds E_i. This value E_i may now be considered as a new type of capture ratio, to be used with propagation data from which the variation due to Rayleigh fading has been removed.

3.1.2 An experimental program has been used [AT&T, 1971] to determine listeners' subjective evaluation of a FM voice channel in the presence of rapid fading, for a variety of (W/UNW) and radio-frequency S/N ratios. The result of this experiment were used to set E_i (local mean (W/UNW)) and E_n (local mean radio-frequency S/N). The peak frequency deviation of the transmitter was varied, and the effect on listener reaction and thus on E_i and E_n was noted. Listeners evaluated quality in terms of Circuit Merit ratings 5, 4, 3, 2 or 1 (excellent, good, fair, poor or unusuable).

Tests were made using peak frequency deviation of ± 12 kHz and ± 6 kHz respectively, the parameters of E_i and E_n being those values which must be exceeded with 90% probability, and a criterion being that at least 75% of the listeners should rate the quality good or better, and at least 90% should rate it fair or better.

The tests showed that:

- For thresholds based on Merit 4 (good) with 75% rating the circuit good or better, the use of ± 12 kHz peak deviation improved the co-channel protection ratio requirement by 8 dB for E_i and by 5 dB for E_n.

- For thresholds based on Merit 3 (fair) with 90% rating the circuit fair or better, the use of ± 12 kHz peak deviation improved the co-channel protection ratio requirement by 6 dB for E_i and by 4 dB for E_n.

These tests were made at 800 MHz in preparation for a cellular system. Further study is necessary to establish the relationship between modulation index and optimum channel spacing, and to determine what values apply for other frequency bands and other service requirements.

3.2 *Carrier frequency offset*

Additional co-channel protection between cells can be obtained by offsetting the carriers of the channels used in those cells. One example is the use of 16K0F3E emissions on channels offset by 12.5 kHz, using equipment designed for 20 or 25 kHz channel separation [Brusaferri *et al.*, 1979]. This retains the basic characteristics of the 16K0F3E system while increasing (but not doubling) the number of available channels and the traffic capacity.

In Toronto, Canada, a 150 MHz public mobile telephone system using 15 kHz offset channels to provide automated service has been interleaved with an existing manual service system on the prime channels, spaced 30 kHz. In order to achieve this all base transmitters are co-located and adjusted to give equal effective radiated powers. The following characteristics apply:

- base transmitters have ±3 ppm frequency tolerance;
- peak frequency deviation is reduced to ±4 kHz from ±5 kHz;
- average speech modulation on each transmitter is reduced by 3 dB;
- mobile telephone specifications are unchanged from those required for normal 30 kHz spaced operation;
- all channels use multiple-receive voting techniques to provide good quality audio from almost all locations, even in the presence of adjacent channel mobile transmissions.

4. Transmit/receive frequency separation for high capacity systems

Transmit and receive filters are necessary for full duplex operation of mobile radio telephone systems. In the design of such radio frequency filters, it is necessary to determine types and number of resonators considering such system parameters as transmit/receive frequency separation and allocated transmit and receive bandwidths, and such mobile unit parameters as size, cost, transmitter power, transmitter noise, spurious emission, spurious response, and so on.

However, further study of the transmit/receive frequency separation is required.

REFERENCES

AT&T [20 December, 1971] Technical Report in support of filing to FCC on high-capacity mobile radiocommunication systems.

BRUSAFERRI P., ONGARO D. and FAILLI R. [1979] Use of 12.5 kHz interleaved channel plan as a means of increasing traffic capabilities of nationwide public mobile systems. INTELCOM 79, Dallas. Horizon House International.

COLAVITO [September, 1974] On the efficiency of the radio spectrum utilization in fixed and mobile communication systems. Also "Interference control and radio channel utilization in the Italian public mobile radio telephone system". *Alta Frequenza.*

MUILWIJK, D. [April, 1978] Spectrum efficiency in mobile radio communication. *Philips Telecomm. Rev.* Vol. 36, **1**.

PART B

COMPONENTS AND ENGINEERING TECHNIQUES

1. Integrated engineering at base stations

The generation of spurious emissions and intermodulation products at base stations in the land mobile service can be considerably reduced by using suitably designed filters at the outputs of transmitters and the inputs to receivers, in conjunction with combining networks, so that numbers of transmitters and/or receivers can be coupled to a common antenna. Similar techniques can be used in the UHF band and for larger numbers of circuits.

The use of a single mast and antenna in this way minimizes spurious emissions arising in the external system. Another advantage is that it is possible to optimize the radiation pattern so as to obtain the best coverage of the desired area. Moreover, such a unified antenna and mast can be designed to be much more acceptable aesthetically than separate masts and antennas for each user. This is a consideration which is becoming increasingly important in view of the proliferation of base station antennas on prominent sites and buildings. Another important advantage is that the reduction in spurious emissions and intermodulation products enables better use to be made of the available frequency channels in a given area, as well as improving the quality of individual channels.

The transmit output filters attenuate any spurious emissions and harmonics. The filters may consist of bandpass filters (cavity resonators) and the insertion loss of each filter, for example, can be kept between 1 and 2 dB. The passband of the filter for each transmitter is centred on the transmit frequency and its impedance at that frequency is matched to the transmitter output and to the common cable ("throughline") connecting the transmitters to the combiner. At the frequencies of the other transmitters, the filter presents a high impedance to the "throughline". Whenever possible, the use of dissimilar metals at junctions should be avoided in order to avoid non-linear effects. Care should also be taken to ensure that the physical size and mechanical construction prevents the formation of corona, or brush discharges, which would otherwise cause electrical noise and interference.

On the receive side, two bandpass filters are used to attenuate the transmit frequencies and protect the receivers. This is followed by a low-noise preamplifier, followed by a cascade arrangement of passive hybrid couplers, depending upon the number of outlets required. The insertion loss of the cascade system between the antenna and any receiver can be compensated for by the preamplifier so that the performance of the system is not degraded. In practice, an improvement in signal/noise ratio is obtained compared with coupling the receiver directly to the antenna. For example, an improvement between 1 and 2 dB can be obtained with a VHF preamplifier of 3 dB noise figure and a gain of 18 dB.

If transmitters and receivers share a common antenna, then the combining network should have transmit and receive bandpass filters to provide sufficient additional isolation between the transmitters and receivers. The number of filter sections required depends upon the frequency spacing between transmitters and receivers. The filters in the transmitter arm attenuate any spurious emissions, especially those in the receiver band, and the filters also attenuate harmonics of the transmit frequencies. Care should be taken to avoid the formation of corona.

2. Tone squelch system

One method of providing more efficient use of the spectrum can frequently be achieved by placing more than one user on a single frequency or frequency pair and incorporating a continuous tone controlled squelch system (CTCSS) in the design of the base station and mobile station equipment. Each transmitter when keyed, transmits a tone unique to the particular system. Each receiver in the system must detect not only the presence of the radio frequency signal but also the unique tone before the squelch opens. Thus the user normally hears only those transmissions of his own system and is relieved of listening to the transmissions of others sharing the channel. The tone frequencies may be below 300 Hz or between 300 and 3000 Hz. In both cases they are filtered out of the audio heard by the user.

The selection and coordination of tone frequencies between separate users is necessary to avoid interference. For frequencies used in CTCSS reference should be made to IEC Publication 487-6A.

3. Crystals and oscillators

3.1 *Frequency variations with temperature*

3.1.1 Some commonly used crystals are listed below:

Designations			*Description*
(a)	(b)	(c)	
Style D	HC-6/U		Miniature metal can with short pins.
Style J	HC-18/U		Sub-miniature metal can with wires.
Style K	HC-25/U		Sub-miniature metal can with short pins.
Style L	HC-27/U	13	Miniature glass encapsulated with short pins.
Style M	HC-26/U	14	Sub-miniature glass encapsulated with wires.
Style N	HC-29/U	20	Sub-miniature glass encapsulated with short pins.

They exhibit a maximum frequency variation within 20 parts in 10^6 over the range $-20\,^{\circ}C$ to $+60\,^{\circ}C$, when the power dissipated in the crystal does not exceed about 0.5 mW.

3.1.2 Crystals normally in use exhibit frequency/temperature curves with inversion points usually above the lowest temperature limits required ($-20\,^{\circ}C$) and around the upper temperature limit required ($+60\,^{\circ}C$). It is quite difficult to supply crystals to a given tight tolerance for temperature limits much in excess of the inversion points because of the high slope of frequency/temperature curves beyond these points.

3.1.3 With selected crystals fitted in soft-soldered cans, maximum frequency variations of 10 to 12 parts in 10^6 over the range $-20\,^{\circ}C$ to $+60\,^{\circ}C$ and 5 parts in 10^6 over the range $-10\,^{\circ}C$ to $+40\,^{\circ}C$ can be achieved.

3.1.4 Glass encapsulated crystals in cold-welded cans may be supplied to similar limits and can be supplied to close tolerances, for example 5 parts in 10^6.

3.1.5 Smaller frequency variations can be achieved by using crystal ovens. The penalty is higher cost, greater power demand and a degraded mean-time-between-failure (MTBF).

3.1.6 *T*emperature *C*ompensated *C*rystal *O*scillators (TCXO), which include the maintaining oscillator, can be supplied with maximum frequency variations from a lower limit of about 2 parts in 10^6 to about 6 parts in 10^6 over a range $-20\,^{\circ}C$ to $+60\,^{\circ}C$. Adjustment accuracy is better than for a crystal in isolation from its maintaining oscillator and the TCXO may be set to a nominal frequency at a designed temperature.

3.2 *Ageing*

All crystals and their maintaining oscillators age to some degree. The ageing rate in service is reduced if the crystals are pre-aged during manufacture.

The best commercial performance limits for total variation for the various types of crystal in common use in the land mobile service are as follows:

Soft-soldered can crystals	5 to 20 parts in 10^6 per year
Glass encapsulated crystals	1 to 3 parts in 10^6 per year, after 30 days ageing
Cold-welded can crystals	as for glass encapsulated units.

These figures can be met for ageing of crystals at any temperature in the range $-20\,^{\circ}C$ to about $+60\,^{\circ}C$, but ageing rates increase as the temperature increases.

3.3 *Effect of maintaining oscillators on frequency variations*

Except for TCXO's, all the figures given above are for crystals alone. Most maintaining oscillators contribute appreciably to the frequency variations in practice and these contributions vary widely within a given design as well as between designs. It is estimated that the average contributions of the maintaining oscillator to total frequency variation could be as much as 4 parts in 10^6 over the range $-20\,^{\circ}C$ to $+60\,^{\circ}C$, for a change of $\pm$ 15% in the voltage supplied to the oscillator.

3.4 *Frequency synthesizers*

In synthesized equipment there is a danger, particularly during synthesizer settling time, of unwanted emissions, which should be avoided by proper design of the equipment.

To prevent the emission of unwanted frequencies (including harmonic and other spurious products) some of the following techniques could be considered:

- in phase locked synthesizers a circuit can be included in the loop to detect the out of lock condition;
- inverse translation of the division ratio to check that the correct channel frequency has been generated;
- correct choice of loop filter and other phase locked loop design parameters;
- generation of the carrier frequency directly by a voltage controlled oscillator in a single phase locked loop;
- adaptive phase locked loop which has a narrow bandwidth when locked, and then reduces spurious responses and noise, but a wider bandwidth (with shorter pull-in-time) when unlocked;
- direct synthesis with high stability oscillators.

The attention of the IEC should be drawn to this problem and they should be invited to prepare suitable methods of measurement.

PART C

NATIONAL PRACTICES

1. Summary of contributions

1.1 The information on separations between adjacent channels furnished by administrations, is reproduced in § 2 below. The names of countries are replaced by the appropriate symbols shown in Table I in the Preface to the International Frequency List.

1.2 The Federal Republic of Germany has described methods of the assignment and coordination of frequencies of public and private land mobile services. The planning methods described are, among others, based on the assumption that in an extended network the distance between stations using the same frequencies (co-channel spacing) should be as small as possible for the benefit of a good frequency economy. This can be reached on the one hand by reducing the transmitter range as far as possible and on the other hand by using so-called lattice plans. These lattice plans are set up in such a way that the co-channel spacing is the same for all frequencies and that the number of frequencies for one complete coverage of an extended area is as small as possible. A lattice plan for a public land mobile service using 7 duplex-frequencies for a complete coverage has been developed and a plan for a private land mobile service using 9 simplex-frequencies has been described. Furthermore, two different methods are described by which – when lattice plans are used – the frequency requirements of high traffic areas also can be fulfilled.

The described planning methods have been used in the Federal Republic of Germany with good results for the frequency assignment of about 140 000 land mobile stations.

1.3 Some special information concerning the coordination of frequencies on a multilateral basis is given in the Special Agreement between the Administrations of Belgium, the Netherlands and the Federal Republic of Germany, relating to the use of metric and decimetric waves for fixed and mobile services in border areas (Brussels, 1963).

Agreements also exist between the Administrations of Austria, Germany (Federal Republic of), Italy and Switzerland on the coordination of frequencies between 29.7 MHz and 470 MHz for fixed and land mobile services (Vienna, 1969) and between the Administration of Yugoslavia (Socialist Federal Republic of) and the Administrations of Italy (Vienna, 1969), Austria (Vienna, 1969: revised 1976), Romania (Socialist Republic of) (Belgrade, 1978), the Hungarian People's Republic (Budapest, 1976), Greece (Athens, 1979) and Bulgaria (People's Republic of) (Sofia, 1980). A document from Yugoslavia gives details of the procedures adopted [CCIR, 1978-82a].

1.4 The United Kingdom has drawn attention to the increased number of channels that become available when the separation is reduced. It suggests that, whenever possible, a separation of 12.5 kHz should be adopted and that equipment designed for wider channel separation should be readily adaptable for smaller separations without total replacement.

Since the introduction of 12.5 kHz channel spacing for the VHF band in the United Kingdom during 1968, there has been no evidence to suggest that the services have been significantly degraded by the change. Both amplitude and frequency modulation systems are used with 12.5 kHz channelling and the proportion of the latter is increasing.

Impulsive interference has not proved in practice to impose a limit on the use of frequencies in the 80 and 160 MHz bands.

Iraq reports [Al-Araji and Abdullah, 1982] that by selecting three bands in the audio, delaying them by 0, 4 and 8 ms respectively during transmission and subsequently restoring them at the receiver, the peak impulsive noise level in the audio can be reduced.

1.5 The USA has provided information concerning disadvantages of decreasing frequency modulation-system deviations from the widely used ± 5 kHz to ± 2.5 kHz; it concludes:

- that increases in impulsive noise interference will be noted;
- that about seven times increase in the number of intermodulation products can be expected.

Other important factors are also listed as follows:

- problems of required increased frequency stability;
- degradation of receiver performance due to adjacent channel transmitter modulation and noise;
- loss in protection ratio;
- loss in frequency-modulation improvement ratio.

1.6 The Federal Republic of Germany has developed a rule which can be used to determine the channels that may be chosen from a number of evenly spaced channels, in such a way that third-order intermodulation products are avoided. According to the rule, channels should be chosen so that the frequency differences between sequential channels, and also the various sums of differences between channels, occur only once. For example, if the evenly spaced channels are numbered 1, 2, 3 etc., then their frequency differences are proportional to the differences between the channel numbers themselves. Thus, assuming that adjacent channels are not to be used, then the chosen channels would be 1, 3, 6, 10, 16, etc., to avoid third-order intermodulation products according to the rule. A proof of the rule is given.

1.7 The USA has studied the interference which is caused by intermodulation products in the land mobile service between 25 and 500 MHz. In areas where there are large concentrations of such services, intermodulation interference is more serious than co-channel interference. Methods are available for predicting the expected level of intermodulation products; these procedures are applied to special transmitters and receivers, but they may be applied generally.

1.8 The People's Republic of Poland has supplied information on the intermodulation response in receivers equipped with crystal filters in the first intermediate-frequency stage. The intermodulation response of such receivers is, in principle, flat over a relatively wide frequency band, in contrast to receivers without crystal filters, in which the slope of this response increases as a function of the degree of detuning the interfering signals from the desired frequency.

In the case of the flat configuration of intermodulation response, there is a greater risk for mobile networks with regard to intermodulation interference caused by the signals widely spaced from the desired frequency. This fact indicates that intermodulation should be measured in a wide frequency band and the results obtained, which constitute the intermodulation response, should be used in planning the allocation of frequencies.

When using receivers with a flat intermodulation response, it is necessary to attempt to achieve the better values of the intermodulation parameter, e.g. by using field effect transistors (FET) or special circuits in the input stages of receivers.

1.9 France has submitted the following list of characteristics and values for possible subsequent insertion in Recommendation 478. Later it may be possible to modify the values quoted in the light of experience.

1.9.1 *Transmitter characteristics*

1.9.1.1 *Transmitter response for modulating frequencies above 3 kHz*

Between 3 kHz and 6 kHz the frequency deviation should not exceed that at 3 kHz. At 6 kHz it should be not more than half the deviation at 1 kHz. For frequencies above 6 kHz and up to the channel spacing, the deviation should decrease with an increase of the modulating frequency and, in addition, the ratio of the initial and final deviations for a doubling of frequency should have a value of 5.

1.9.1.2 *Attenuation of the intermodulation of base station transmitters*

The attenuation of intermodulation, due generally to the non-linearities of the output stage of the transmitter, should be at least 20 dB. Higher values of attenuation might be necessary and may be obtained by means of appropriate protection devices.

1.9.2 *Modulator characteristics*

1.9.2.1 *Limitation*

For a signal at a frequency of 1 kHz, with a level 20 dB greater than that which produces 20% of the maximum permissible deviation, the frequency deviation should be between 70% and 100% of the maximum.

1.9.2.2 *Sensitivity*

For a sound level at the microphone diaphragm of 93 dB relative to 2×10^{-5} Pascal, the deviation should be between 60% and 90% of the maximum permissible deviation.

1.9.2.3 *Audio-frequency response of the transmitter*

For a constant level of the modulating signal, the modulation index (phase modulation) or frequency deviation (frequency modulation) should remain constant, within limits of $+1$ to -3 dB, when the modulating frequency varies between 300 Hz and 3000 Hz.

1.9.2.4 *Residual modulation*

The residual modulation, in the absence of a modulating signal, should be lower at the output of a linear demodulator by 40 dB relative to the signal corresponding to a deviation of 60% of the maximum permissible deviation.

1.9.2.5 *Harmonic distortion*

The level of harmonic distortion should in no case exceed 10%.

1.9.3 *Receiver characteristics*

1.9.3.1 *Operation of the limiter*

When the radio-frequency varies between 6 dB(μV) and 100 dB(μV), the audio-frequency output signal should not vary by more than 3 dB.

1.9.3.2 *Co-channel rejection*

When a wanted signal is applied in the presence of an interfering signal on the same frequency, a reduction in the signal-to-noise ratio at the output from 20 dB to 14 dB should occur when the ratio of interference to signal is not less than −8 dB for 25 kHz channel spacing and not less than −12 dB for 12.5 kHz channel spacing.

1.9.3.3 *Duplex working*

Desensitization of the receiver with simultaneous transmission and reception should not exceed 3 dB.

1.9.3.4 *Output power at audio-frequencies*

The output power at audio-frequencies should not be less than 200 mW in the loudspeaker and 1 mW in the handset earphone.

1.9.3.5 *Audio-frequency response*

For a radio signal with a constant modulation index (phase modulation) or with a constant deviation (frequency modulation), the audio-frequency signal at the output should remain constant to within +1 dB to −3 dB when the modulating frequency varies between 300 Hz and 3000 Hz.

1.9.3.6 *Harmonic distortion*

The level of harmonic distortion should in no case exceed 10%.

1.9.3.7 *Noise and hum*

Noise and hum should not exceed −40 dB with respect to the output level produced by a strong radio signal modulated with a frequency of 1 kHz to a deviation equal to 60% of the maximum permissible deviation.

1.10 Japan has provided information [CCIR, 1978-82b] on tests performed on equipment designed for 12.5 kHz channelling FM systems in the 400 MHz band. The test confirmed that with special attention to protection against adjacent channel interference, a 12.5 kHz channelling FM system in the 400 MHz band, in accordance with characteristics and values of Recommendation 478 is possible. Other characteristics and values are as follows:

1.10.1 *Transmitter characteristics*

The maximum permissible frequency deviation should be 2.5 kHz. For modulating frequencies above 3 kHz, the level should decrease at a rate of 24 dB/octave.

1.10.2 *Receiver local frequency tolerance*

The receiver local frequency tolerance should be 3×10^{-6}.

1.10.3 *Co-channel interference*

The wanted-to-unwanted carrier power ratio (W/UNW ratio) giving a 12 dB SINAD ratio in the presence of co-channel interference (but with no adjacent channel interference) is shown in the Table. Measurements were made in the laboratory in accordance with IEC Publication 489. The tests showed that under these conditions the co-channel protection ratio required for 12.5 kHz-channelling equipment is only 2.4 dB higher than that required for 25 kHz channelling.

TABLE I

Channel spacing (kHz)	12.5	25
Maximum permissible frequency deviation (kHz)	2.5	5
Wanted-to-unwanted carrier power ratio (dB)	6.8	4.4

1.10.4 *Adjacent channel interference*

Subjective listener tests showed that adjacent channel interference in the 12.5 kHz channel spacing degraded the speech quality more severely, as compared to the case of 25 kHz channel spacing. Therefore, when introducing the 12.5 kHz channelling system, it is necessary to improve the wanted-to-unwanted power ratio by about 11 dB as shown in the Table II and Fig. 4 in order to keep speech quality in 12.5 kHz channel spacing as good as that in 25 kHz channel spacing.

TABLE II – *Opinion test conditions of adjacent channel interference*

Signal		Modulation level (dB)	Frequency drift (PPM)	
			12.5 kHz	25 kHz
Desired		0	0	0
Undesired (Adjacent channel)	Case 1	0	0	0
	Case 2	10	4	7

Note 1. – The 0 dB modulation level corresponds to the IEC Standard Test Modulation.

Note 2. – Case 2 represents the worst case, i.e. channel spacing reduced by the drift.

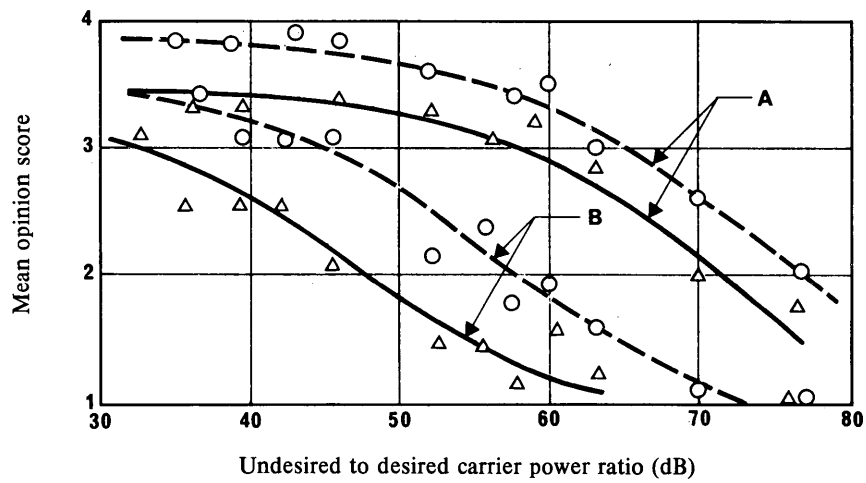


FIGURE 4

A: case 1

B: case 2

△——△ : 12.5 kHz

○— — —○ : 25 kHz

Desired carrier median power: 9 ~ 13 dBμV

1.10.5 *Receiver sensitivity*

Figure 5 below shows a comparison of the sensitivity of 12.5 kHz and 25 kHz channel spaced receivers. The reference sensitivities for a 12 dB $(S + N + D)/(N + D)$ (SINAD) ratio are -2.5 and -3 dB(μV), respectively.

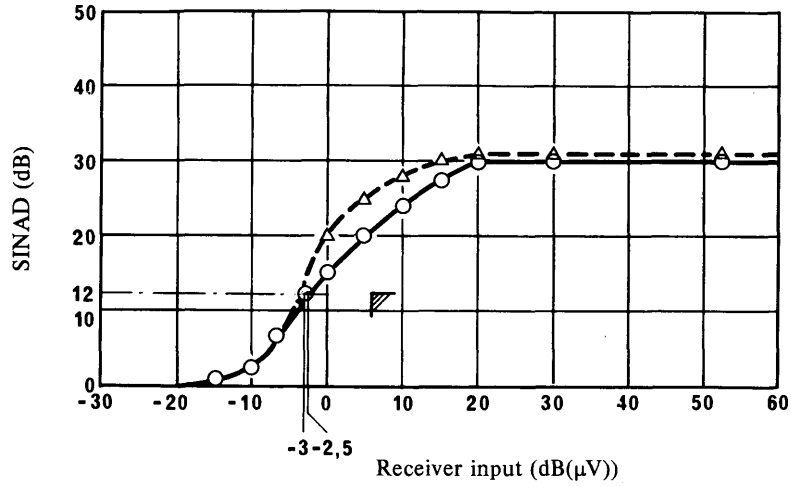


FIGURE 5

○——○——○: 12.5 kHz channel spacing (± 1.5 kHz deviation)
△— —△— —△: 25 kHz channel spacing (± 3 kHz deviation)

Figure 6 below shows a comparison of opinion tests on the speech quality of 12.5 kHz and 25 kHz channel spaced receivers.

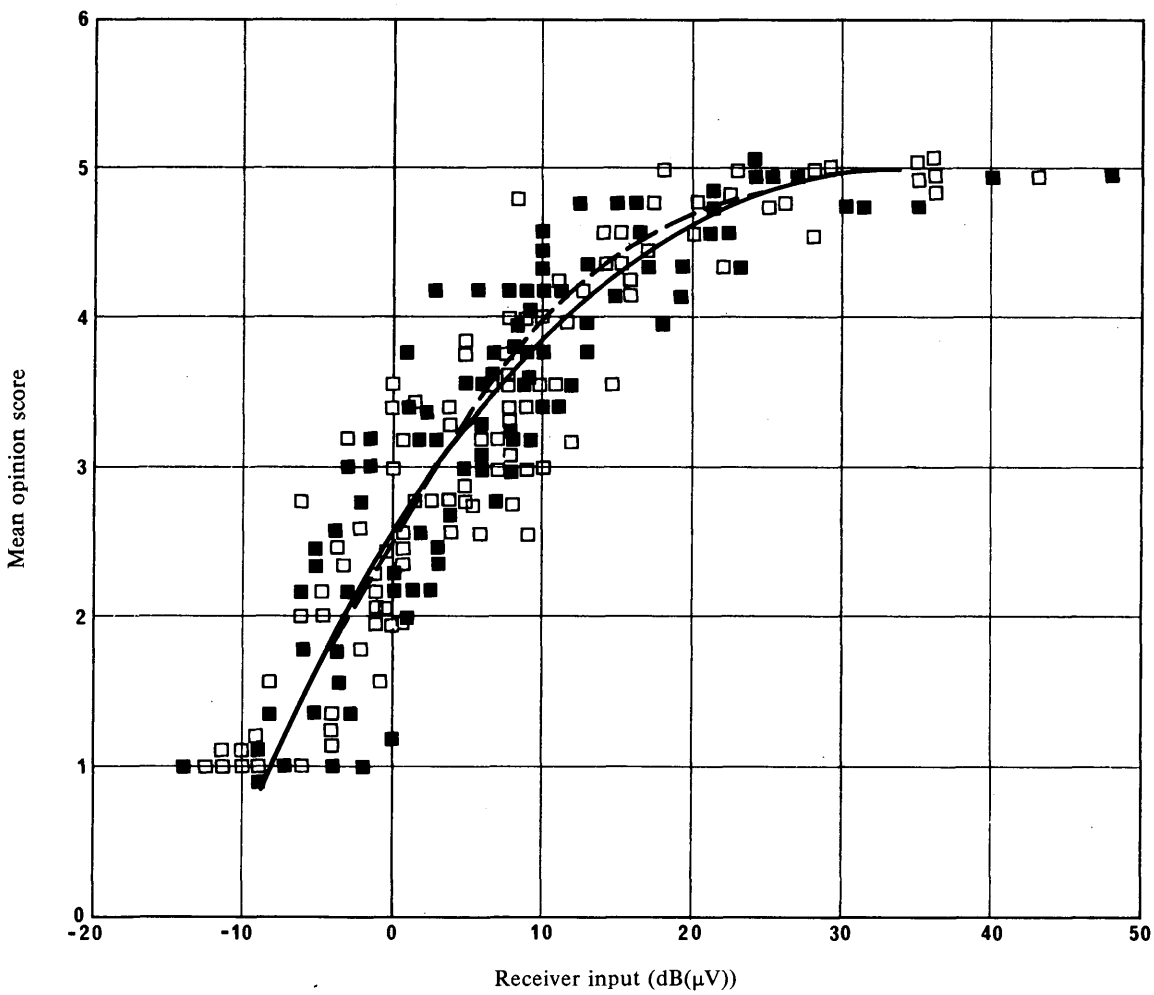


FIGURE 6

□——□ : 12.5 kHz
■— — —■ : 25 kHz

2. Adjacent channel separations in various frequency bands

2.1 *Separations for present and/or future use*

TABLE III

Channel separation (kHz)	Frequency ranges (MHz)				
	25 – 50	50 – 100	100 – 200	200 – 500	500 – 1000
10	D S* DNK SUI* DNK* USA NOR*				
12.5	NZL F(1)	F(1) IRL G NZL	F(1) IRL G NZL	F(1) J NZL	
15	TCH*	J	USA(2)		
20	CAN USA D	BEL(3) D CAN	BEL(3) F(1) D J	BEL D	
25	AUS ROU DNK TCH E(7) YOU F(1) FNL NOR POL DDR S SUI	BEL(4) S D(5) SUI DNK TCH E(7) YOU F(1) FNL G(8) IRL(8) NOR DDR ROU	BEL(4) ROU D(5) S DNK SUI E(7) TCH FNL YOU G(4, 8) IRL(8) NOR POL DDR	AUS POL CAN(6) DDR D(5) ROU DNK S E(7) SUI F(1) TCH FNL USA G YOU IRL J NOR	AUS J SUI USA
30		AUS	AUS USA CAN(6)		USA(9)
40	USA*				USA(9)

* When a country symbol is followed by an asterisk, the value given for the separation refers to low-power portable equipment.

(1) The transfer to 12.5 kHz separation is in progress, to be completed as follows:

25 – 100 MHz: 1 January 1983,
100 – 200 MHz: 1 January 1984,
200 – 500 MHz: 1 January 1986.

(2) An interleaved channel allocation plan is to be used and only alternate channels allocated in any one geographical area. Consequently, the equipment is designed for double the separation shown above.

(3) 20 kHz separation is being introduced gradually for new equipment.

(4) 25 kHz separation is still accepted in certain parts of the bands reserved for the fixed and mobile services.

(5) Only in exceptional cases upon multilateral agreement.

(6) An offset assignment plan is also used. The equipment is designed for the separation shown and advantage taken of geographic separation to assign offset channels at one half the separation shown.

(7) All assignments are being allowed with this separation since September 1975.

(8) Certain public services will continue to operate with 25 kHz channel separation.

(9) Acceptable for cellular mobile telephone systems only.

REFERENCES

AL-ARAJI, S. R. and ABDULLAH, A. H. [13-16 June, 1982] Impulsive noise reduction employing smear/desmear technique. IEEE International Conference on Communications (ICC '82), Philadelphia, Pa., USA.

CCIR Documents

[1978-82]: **a.** 8/467 (Yugoslavia (Socialist Federal Republic of)); **b.** 8/29 (Japan).

BIBLIOGRAPHY

DAVID, G. H. [November, 1975] Integrated site systems for mobile radio systems. IERE, Civil Land Mobile Radio Conference.

DAVID, G. H., HOWSON, D. P., BETTS, J. A. and GARDINER, J. G. [February, 1975] Integrated site system for VHF/UHF mobile communications. *Communications International*, 16-21.

GARDINER, J. G. [November, 1975] Computer modelling of non-linear interactions between co-sited transmitters. IERE, Civil Land Mobile Radio Conference.

JTAC [1968] *Spectrum engineering.* Joint Technical Advisory Committee. IEEE, New York, NY, USA.

ZIENKIEWICZ, R. [1971] Interference in the mobile radiocommunication networks caused by intermodulation (in Polish only). *Prace Instytutu Łączności*, Vol. XVIII, **1/62** and **2/62**, Warsaw.

ANNEX I

1. Test procedures

1.1 *Base station*

1.1.1 A 15 kHz offset test transmitter was established at the existing transmitter site. This transmitter was established on a frequency of 152.645 MHz (designated as XS). This transmitter was then tuned 1.6 kHz closer to the existing 152.660 MHz channel (designated as YK) in order to simulate worst case maintenance conditions.

1.1.2. The 15 kHz offset test transmitter was directly coupled to an antenna mounted below the existing Public Mobile antenna, with a vertical separation of approximately 8 ft. between antennas.

1.1.3. The power output of the 15 kHz offset test transmitter was adjusted for a difference in effective radiated power between it and the YK channel of less than 1.0 dB. The adjustment was made by measuring field strength from a point one mile from the site using a spectrum analyzer.

1.1.4. The YK channel transmitter, to be used as the desired channel (designated F_0), was modulated with a 1000 Hz tone at a deviation of ± 2.5 kHz.

1.1.5. The XS channel transmitter, to be used as the interfering 15 kHz offset channel (designated F_i), was modulated with a 1500 Hz tone at a deviation of ± 4.0 kHz.

1.1.6. The YK channel transmitter modulating oscillator was connected to a timer to provide alternating periods of modulation and no modulation at a rate of 5 s on and 5 s off.

1.2 *Test Mobile Unit*

1.2.1. The test equipment was connected as shown in Figure 8.

1.2.2. The distortion analyzer was used to measure SINAD performance, with the analyzer nulled for 1000 Hz. When the mobile received interference from the interfering transmitter with its 1500 Hz modulation, a large reduction in SINAD performance resulted.

1.2.3. The limiter output voltage was calibrated to give a measure of the RF signal level (in microvolts) received by the mobile receiver.

2. System measurements

2.1 The test mobile was driven along a vector from the transmitter site, out to 12 miles from the site.

Thirteen test measurements were made along the vector at 0.8 mile intervals after 1.0 miles from the site.

For each test measurement the strip chart recorder was run for a distance of 200 feet from a fixed point. The vehicle was moving at an approximate speed of 25 MPH and the strip chart recorder paper speed was 25 mm/sec.

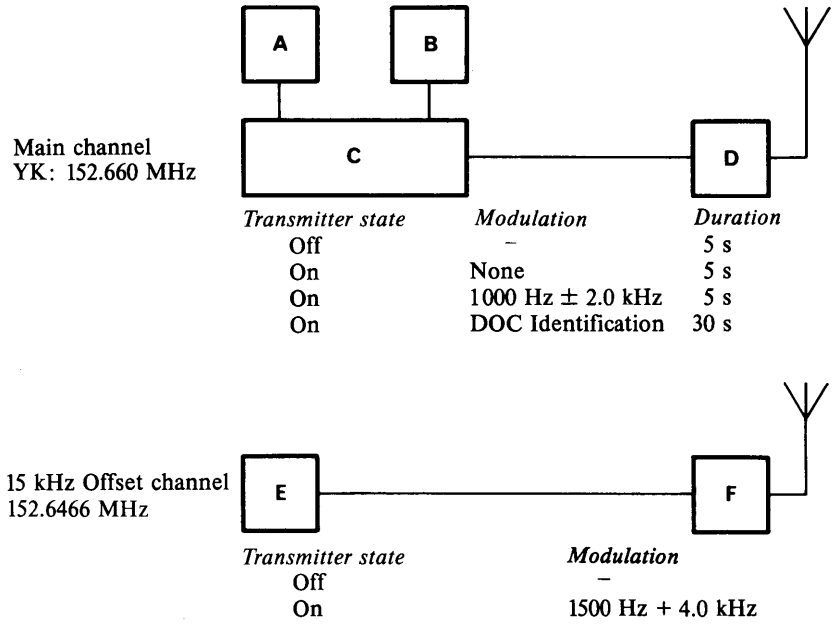


FIGURE 7 – *Base station transmitter formats*

A: station identifier
B: tone oscillator
C: 4 stage timer
D: transmitter
E: tone oscillator
F: transmitter

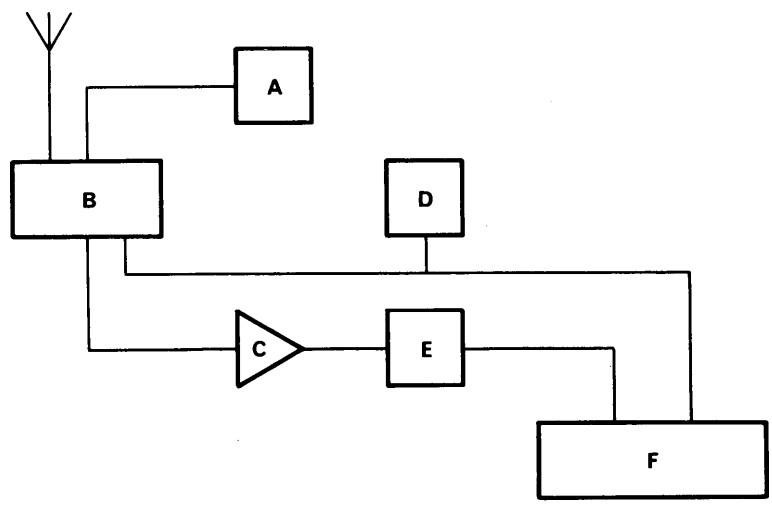


FIGURE 8 – *Test equipment configuration*

A: RF signal generator
(connected for calibration purposes only)
B: test mobile
C: low distortion linear amplifier
D: digital voltmeter
E: distortion analyser
F: strip chart recorder

2.2 Test measurements were taken for three mobiles, designated A, B & C.

2.2.1 Mobile A was selected since it represents the average Radio used in Toronto, for selectivity and nose bandwidth.

2.2.2 Mobile B was selected due to its relatively poor adjacent channel selectivity (65 dB), its wide nose bandwidth (±8 kHz) and the fact that it is one of the most commonly used Radios in Toronto.

2.2.3 Mobile C was selected since it is typical of the radios that will be used on the proposed VHF Automated Mobile Telephone System in Toronto.

3. Results

3.1 All test measurements for this report showed a noticeable amount of audible interference from the 15 kHz offset interfering channel as well as from intermodulation and overloading of the receiver due to the 30 kHz channels when the test mobile was within 1/2 mile of the transmitter site. For this reason, all measurements were made beginning at 1.0 mile from the transmitter site.

3.2 It was determined, by relating the subjective listening evaluation to the calculated standard deviation of SINAD performance, that only variations of greater than 2.0 dB (SINAD) with or without interference represented sufficient degradation to be audible to the listener at the radio audio output.

3.3 Since audible interference from the interfering channel manifested itself as short bursts of the interfering 1500 Hz tone and increased background noise, these two separate and distinct items can be evaluated separately. The short bursts of interfering tone normally caused a significant variation in the standard deviation of SINAD performance, but little variation in the median or mean SINAD performance.

3.4 Mobile A exhibited good SINAD performance within 5 miles of the transmitter site. From 5 to 8 miles from the transmitter site this mobile experienced substantial degradation in mean SINAD performance. Although the standard deviation did increase by 2.9 dB, it did not correspond to any audible interference at the radio receiver audio output. A review of the strip chart recordings confirmed that the degradation was due to many shallow dips in the SINAD performance. This type of degradation is not normally audible to the user but does affect the squelch operation of the radio.

3.5 Mobile B exhibited a general degradation in mean SINAD performance out to about 10 miles from the transmitter site. This degradation was much less than for Mobile A and did not correspond to a significant degradation in standard deviation except for an area 7-8 miles from the transmitter site. Within this range there were several very slight occurances of audible interfering tone.

3.6 Mobile C did not experience any significant increase in background noise until the desired signal (F_0) was reduced to 14.7 dB below the interfering signal. With the F_0 power output at 7 dB below the F_i power output, there was slight audible interference within two miles of the transmitter site and 6-7 miles from the transmitter site. At power outputs above this level, there was no apparent audible interference or increased background noise at any distance (beyond 1/2 mile) from the transmitter site.

4. Conclusions

4.1 With the radios tested, there was no indication of interference of an objectionable nature although there was some measureable degradation due to the 15 kHz offset interfering signal.

4.2 There may be a small number of marginal specification radios that will receive noticeable interference in small portions of the coverage area. However the possibility of objectionable interference is very slight, in view of the fact that there were no complaints from YK channel users during the test period. During 4 weeks of this period there were two 15 kHz offset channels in operation (one above and one below the YK channel) at full power with modulation of 1000 Hz at ±4 kHz deviation.

4.3 Interference in the mobile to base direction can be controlled through the use of high selectivity base receivers and receiver coverage diversity, through the use of coverage overlap between receiver sites.

This interference is not significantly dependent on the quality of the mobile radios and can be controlled through careful RF design and equipment selection.

REPORT 899

SYSTEMS OF MODULATION WITH HIGH SPECTRUM EFFICIENCY FOR THE LAND MOBILE SERVICE

(Question 7/8; Study Programme 7B/8)

(1982)

1. Lincompex system (linked compressor and expander system)

1.1 *Introduction*

The Lincompex system has been developed for improving the speech quality of HF radiotelephone service. The characteristics of Lincompex equipment for HF fixed telephone service and HF maritime mobile service, specified by Recommendations 455 and 475, are quite satisfactory for practical HF radiotelephone operations.

The congestion in the VHF band for land mobile services is a serious problem in many countries due to the rapid growth of the land mobile telephone service in limited geographical areas. Though the single-sideband technique is undoubtedly the best way for minimizing the occupied bandwidth, with ordinary single-sideband techniques, it is difficult to meet such inherent propagation conditions of the land mobile service as rapid fading and strong impulsive noise in urban areas.

The Lincompex system has high protection features against these conditions in itself.

It is generally understood that the Lincompex system is possibly applicable to the land mobile telephone service with some improvement of basic characteristics of HF Lincompex system.

1.2 *Improved characteristics of Lincompex system for land mobile service*

In order to overcome the inherent propagation conditions of the land mobile telephone service, the following improvements had been applied to the equipment used in trials effected in Japan:

- In order to reduce the Doppler effect and the influence of frequency error, the sensitivity of frequency modulation in the control channel is expanded to 6 Hz/dB (three times as large as 2 Hz/dB used in the HF band).
- In order to compensate for the deep and rapid fading, attack and recovery times of the compressor and expander are reduced to about one-third, and also the attack time of the fading regulator to about one-tenth compared with HF Lincompex; the lower limit of the fading regulator range is extended by about 15 dB; the level of the control channel is increased up to the same level of that of the speech channel.
- In order to improve the speech quality, a pre-emphasis circuit with 6 dB/octave characteristic is employed.

Table I shows the essential characteristics of the tested Lincompex system for the land mobile service.

1.3 *Test results*

Satisfactory test results were obtained in a field test conducted in Japan. Table II summarizes the results obtained of average field strength corresponding to each grade of evaluation in the field test.

It is indicated, in the grading range of 3 to 5, that the Lincompex system tested gave the same grade of speech quality even though the field strength is lower by about 5 dB than that of the FM system. When compared with the SSB system without Lincompex, the evaluators for speech quality felt that the Lincompex system was hardly affected by fading and the protection against city noise was almost the same as that of the FM system.

Table III shows the measured results of the adjacent-signal selectivity. It is noted that the ratio of the level of unwanted radio signal to the level of wanted radio signal is more than 70 dB at the frequency separation of 6 kHz.

1.4 *Future work*

In order to improve the technical characteristics and contribute to the reduction of channel separation, further studies should be undertaken.

Administrations are invited to expedite the study of the reduction of channel separation in the VHF land mobile service.

There are however further factors that directly influence the degree to which Lincompex might contribute to reduction of channel separation. In particular, extremely high frequency stability is necessary to achieve the indicated results. Implementation of such stabilities are presently costly and cause substantial increase in the size of portable equipment and some mobile equipment.

TABLE I – *Characteristics of an experimental VHF land mobile Lincompex system*

Transmit side	Speech channel	3 dB bandwidth Attack time Recovery time Compression range	0.3-2.1 kHz 2.0 ms 5.0 ms 45 dB
	Control channel	3 dB bandwidth Frequency change	2.5-2.9 kHz 6 Hz/dB
	SSB Transmitter	Frequency Frequency tolerance Occupied bandwidth Output power Spurious emission	151.97 MHz 30 Hz 3 kHz 5 W −80 dB in-band (1) −60 dB out-band (2)
Receive side	Fading regulator	Attack time Recovery time Compression range	1.2 ms 3.2 ms 40 dB
	Overall	Attack time Recovery time	10 ms 8 ms
	SSB Receiver	Frequency tolerance Sensitivity Selectivity (1 signal test) AGC time constant	30 Hz 0.6 μV for 12 dB, SINAD − 6 dB at ±1.5 kHz −70 dB at ±2.1 kHz 2 ms

(1) 146-162.0375 MHz.
(2) At all frequencies outside the band 146-162.0375 MHz.

TABLE II – *The measured results of average field strength necessary for each grade*

Grade	Overall rating	Field strength in dB(μV/m)		
		Lincompex	FM	SSB
5	excellent	41	47	(1)
4	good	25	30	37
3	fair	18	22	24
2	poor	18	16	19
1	unusable	(2)	(2)	(2)

(1) Not found.
(2) Not measured.

TABLE III – *Results of adjacent-signal selectivity (dB)*

Unwanted source		Frequency separation (kHz)										
		7.0	6.0	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
1 kHz	Lower side	71	75	61	60	42	25	14	1	−9	(1)	(1)
	Upper side	76	75	65	63	60	32	(1)	(1)	(1)	(1)	(1)
Weighted noise (CCITT Recommendation G.227)	Lower side	71	70	54	44	37	33	23	3	−6	−5	−5
	Upper side	78	74	60	51	45	40	25	15	6	4	2

(1) Difficult to discriminate between wanted signal and unwanted signal.

Note. – The tests measured by the 12 dB $(S + N + D)/(N + D)$ method.

2. SSB system (Yugoslavia)

2.1 *Introduction*

Several thousand VHF, SSB equipments have been used in land mobile applications in Yugoslavia [CCIR, 1974-78] for more than five years.

The performance of SSB was compared with FM by laboratory and also field tests using transceivers which could operate in both modes. The same receiver front-ends and transmitters linear power amplifier were used. The bias of the power amplifier was adjusted separately for the two modes.

2.2 *Equipment characteristics*

The transceiver characteristics are summarized in Table IV.

TABLE IV – *Transceiver characteristics*

Transmitter

	RF output power (W)	Bandwidth	Speech process
FM	2, 6, 20	±5 kHz deviation	pre-emphasis
SSB	2, 6, 20	2.4 kHz	20 dB-clipper

Receiver

	Sensitivity	IF-bandwidth	Speech process
FM	1 μV/20 dB SINAD	16 kHz/6 dB	de-emphasis
SSB	1 μV/20 dB SINAD	2.4 kHz/6 dB	

2.2.1 *Frequency stability*

A temperature compensated crystal oscillator (TCXO) was used, having the advantages of low power consumption, zero warm up time, and small size.

Frequency variation with temperature: $\pm 1 \times 10^{-6}$ (-30 to $+60$ °C). This stability is sufficient to provide reliable SSB communication up to 100 MHz.

2.3 *Test results*

2.3.1 *Power consumption*

In portable equipments, the weight, size and power consumption are most important. Comparisons are based on the same SSB and FM RF output power. In Table V, direct comparison of power consumption between FM and SSB in the same equipment is shown.

TABLE V – *Comparison of power consumption of FM and SSB transmitters*

Transmission	RF power output	Power consumption (W)		Intermodulation product level (dB)
		Final power amplifier(3)	Transmitter	
FM	20 W_{rms}	36	52	
SSB-I(1)	20 W_{pep}	22	36	−30
SSB-II(2)	20 W_{pep}	14	22	−30

f = 37 MHz
(1) SSB-I: Two-tone test conditions (CCIR).
(2) SSB-II: Average speech, clipping ratio of 20 dB.
(3) Final RF power amplifier is separately optimized for SSB and FM.

The comparison of power consumption at different RF output power levels can be seen on Fig. 1.

The diagram shows that the power consumption is more than two times greater in a FM system than in a SSB system of equivalent RF output power.

2.3.2 *Maximum range*

To compare the efficiency of FM and SSB modulation techniques with respect to intelligibility, a logatom articulation method was used. A complete test comprised 2000 logatoms.

The results of laboratory tests are given in Fig. 2, from which it can be seen that in conditions corresponding to maximum range, the FM transmitter must provide 6 to 10 dB more RF output power than the SSB transmitter.

The extensive field tests carried out show that at maximum range conditions the same acceptable quality of communication was obtained at the level of 2W PEP-SSB and 20W FM radio-frequency output power.

2.4 *Conclusions*

Considerable additional study should be done on:

- adjacent channel selectivity;
- co-channel interference, SSB/SSB and SSB/FM;
- speech processing methods;
- immunity to impulsive noise.

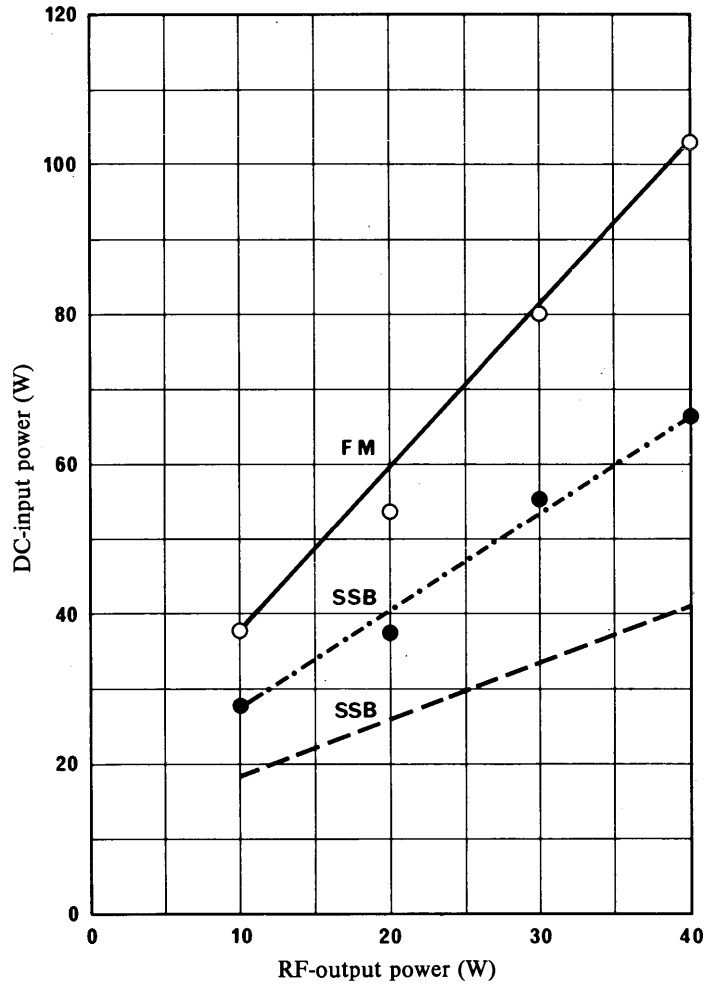


FIGURE 1 – *Comparison of power consumptions at different RF power levels*

——— FM
-·-·-·- SSB 2-tone
– – – – SSB average speech

Intermodulation product level: −30 dB

f = 37 MHz

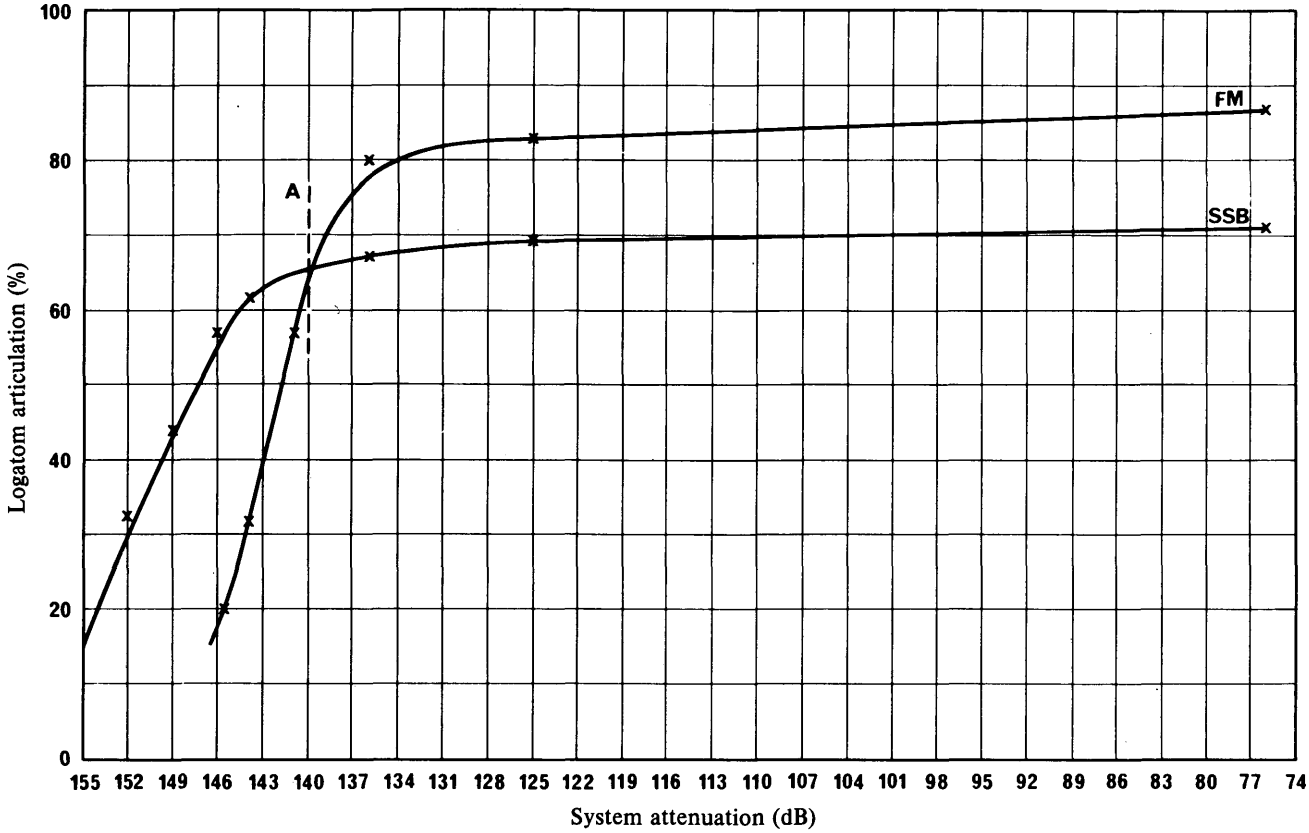


FIGURE 2 – *Logatom articulation versus system attenuation*

A: FM/SSB receiver sensitivity 1 μV/20 dB SINAD
FM: RF output power 2 W
SSB: RF output power 2 W (PEP) and 20 dB clipping

3. SSB system (United Kingdom)

3.1 *Introduction*

The possibility of using single sideband (SSB) systems to relieve spectrum congestion in the land mobile radio bands below 500 MHz has been investigated in the United Kingdom and a number of laboratory and field tests have been carried out to evaluate the performance of different SSB systems compared to existing AM and FM systems.

3.2 *SSB systems*

In order to meet the automatic gain control (AGC) requirements of SSB systems operating in a land mobile radio environment, where the received signal is subject to rapid fading, a continuous signal must be transmitted with the speech sideband, to maintain the AGC.

The continuous signal may be provided by one of the following systems:

- a pilot carrier;
- a tone in, or at the edge of, the audio passband;
- a Lincompex control subcarrier;
- a data subcarrier.

Studies in the United Kingdom have concentrated on the first of these systems with pilot signals in the range −10 to −20 dB relative to peak envelope power (PEP).

The necessary RF bandwidth is dependent on the audio bandwidth required and the type of pilot signal employed but in general is not greater than 3000 Hz for land mobile applications.

Feedback AGC, using the pilot signal as a reference may be employed at frequencies up to about 200 MHz. For UHF applications a combination of feedback and feed forward AGC may be employed.

3.3 *Channel spacing and frequency tolerance*

An overall system frequency tolerance of 500 Hz will permit the use of 5 kHz channel spacing.

Economic considerations make it advantageous to employ a high stability base station, with a narrow frequency tolerance, and therefore allow a greater frequency tolerance (approaching ± 500 Hz) for the more numerous mobiles.

3.4 *Impulsive interference*

Experiments have shown that an SSB receiver with an i.f. bandwidth of 3 kHz is not unduly sensitive to impulse noise [Gosling *et al.*, 1979]. Although impulses typical of ignition noise are stretched out to a greater extent by the narrow filter of the SSB receiver the total energy passed by the filter is correspondingly less. Side-by-side comparisons with 25 kHz spaced FM equipment in a high noise environment have shown that the subjective effect of ignition noise is approximately the same [Wells, 1978].

3.5 *Co-channel interference*

Subjective tests have demonstrated that under actual mobile-radio field conditions the effects of co-channel interference in an SSB system with 5 kHz channelling are very similar to those encountered by 25 kHz FM systems [Garner, 1980]. In both cases a signal-to-interference ratio of the order of 16 dB is necessary to achieve a quality of reception corresponding to grade 3 in Table II of § 1.4 of this Report.

The range of subjective gradings observed with various co-channel interference ratios is given in Figs. 3*a*, 3*b* and 3*c* for different wanted signal levels and carrier offsets. These curves are based on subjective tests carried out in the United Kingdom [Garner, 1980] in which the wanted and unwanted signals were of the same modulation type. The wanted signal was on tune and the unwanted signal was at a carrier frequency offset of 75 Hz for SSB and 500 Hz for FM, which was considered to give the worst result in each type of system.

Further subjective tests, carried out by the United Kingdom Home Office, have shown that in almost all conditions 25 kHz FM equipment was found to give better co-channel performance than SSB, 12.5 kHz or 12.5 kHz AM. However, in urban and suburban areas SSB was not shown to be markedly inferior to 25 kHz FM and in all conditions SSB performed at least as well as 12.5 kHz FM or AM.

3.6 *Compatibility with existing control signals*

When a pilot signal is used for automatic frequency control most standard signalling systems can be employed.

3.7 *User evaluation trials*

The results of a user evaluation trial carried out in the United Kingdom under typical private land mobile conditions and using speech [Barnes, 1981] have shown that from a users assessment 5 kHz SSB equipment could be used without any loss in quality or intelligibility when compared with 12.5 kHz equipment. Furthermore, in some high field strength situations the quality of the SSB systems would be better than that of existing 25 kHz FM systems.

However, it was judged that under almost all conditions 25 kHz FM equipment would provide a higher quality service.

4. SSB system (United States of America)

4.1 *Introduction*

Laboratory experiments have been conducted in the United States on the use of Amplitude Companded Single Sideband (ACSB) VHF radios for mobile communications. ACSB radios employ both Amplitude and ACSB Companding and audio pre-emphasis and de-emphasis voice processing. Some comparisons are made with FM, AM and ACSB receivers.

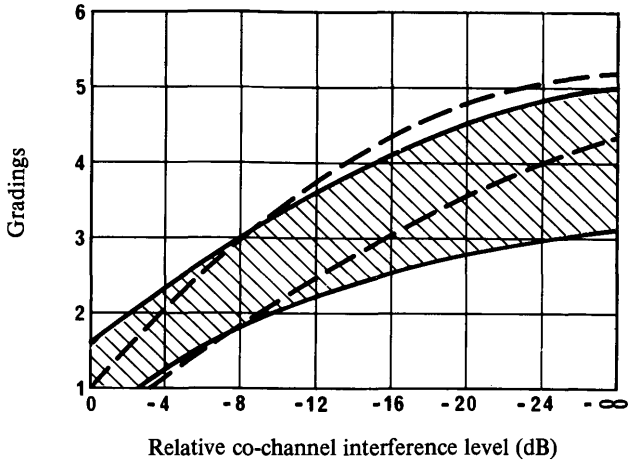


FIGURE 3a

——— : SSB

— — — — : FM

Wanted signal: 10 μV
Carrier offset: zero

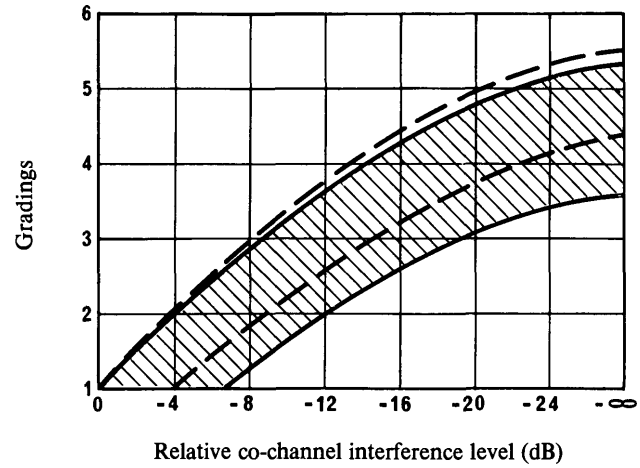


FIGURE 3b

——— : SSB

— — — — : FM

Wanted signal: 3 μV
Carrier offset: 75 Hz for SSB
500 Hz for FM

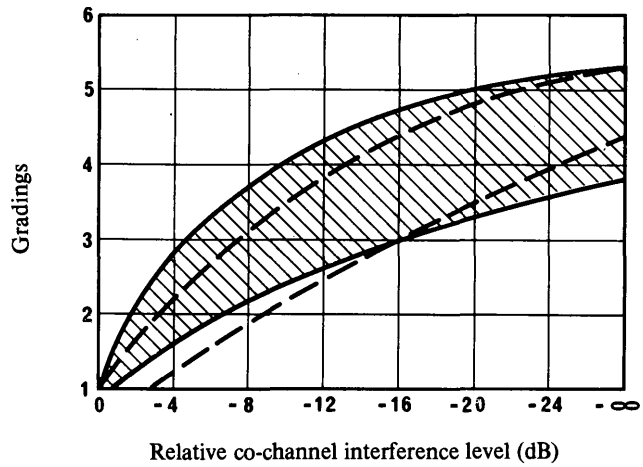


FIGURE 3c

——— : SSB

— — — — : FM

Wanted signal: 10 μV
Carrier offset: 75 Hz for SSB
500 Hz for FM

4.2 *Tone and voice co-channel tests*

The following type of receivers were tested:

- ACSB: For 3K00 R3E emission with 4:1 expander and 12 dB/octave de-emphasis
- 25 kHz FM: For 16K0 F3E emission 6 dB/octave de-emphasis
- 12.5 kHz FM: For 11K0 F3E emission 6 dB/octave de-emphasis
- AM: For 6K00 A3E emission

The reference sensitivity of each receiver was measured in accordance with IEC Publication 489 and adjusted for equal noise figure of 10 dB. The reference sensitivity of the four receivers are as follows:

	dB (μV) at receiver input
ACSB	− 6.0
25 kHz FM	−12.5
12.5 kHz FM	−15.0
AM	− 3.0

The range of the SINAD performance between −20 dB (μV) and 10 dB μV signal input to each receiver is given in Fig. 4. These results do not necessarily reflect system performance under other than constant tone modulation.

Co-channel interference tests using voice modulation were performed on three of the four receivers.

The protection is based on the ratio (dB) of the mean wanted signal to the mean interfering signal required to prevent an impairment of speech quality. The wanted signal was modulated with extracts from an English language news broadcast and the interfering signal was modulated by a female speaker reading Harvard sentences.

Each signal was passed through a separate multipath simulator and adjusted in level as described above. During the tests the wanted signal mean value was set at a fixed level, and the listener was instructed to set the interfering signal to the highest level and yet not impair speech quality. The results, shown in Fig. 5, were averaged for a team of 5 persons.

4.3 *Wanted signal voice tests (ACSB receiver)*

The attached Fig. 6 illustrates how pre-emphasis, de-emphasis and amplitude companding improves the signal-to-noise ratio of certain types of syllables as compared to an SSB transmitted and received signal without the use of audio processing.

Meaningful measurements of ACSB radio performance have been difficult to obtain using standard objective test procedures because these procedures may not account for the use of voice processing. Subjective tests (diagnostic rhyme test) have indicated that ACSB performance is better than implied by objective tests. Such conclusions must be interpreted with care.

The experiments seem promising. Development and field testing continue in the United States.

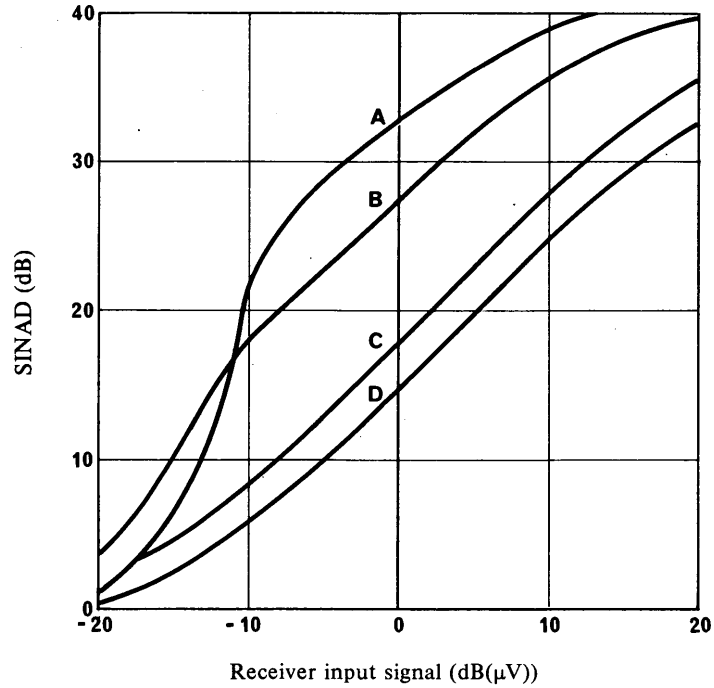


FIGURE 4 – *Receiver sensitivity*

A: FM – 25 kHz
B: FM – 12.5 kHz
C: ACSB
D: AM

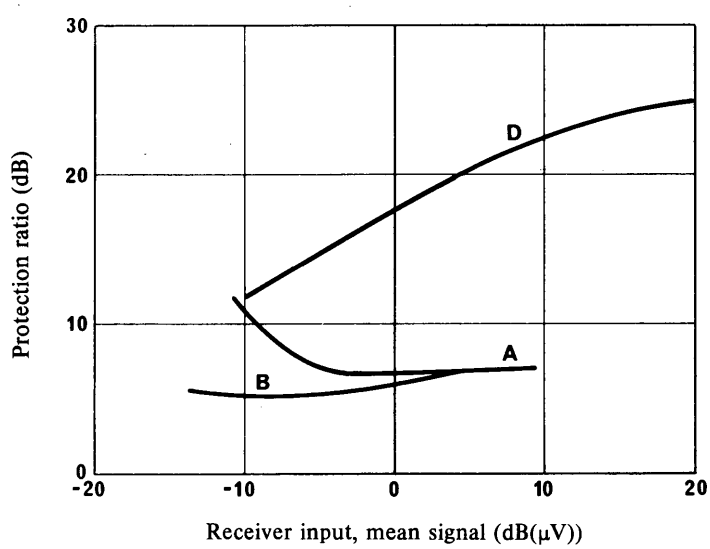


FIGURE 5 – *Co-channel protection ratio voice modulation, Rayleigh fading*

A: FM – 25 kHz
B: FM – 12.5 kHz
C*: ACSB
D: AM

*Complete test results for the ACSB receiver are not yet available, but will be added at a later date.

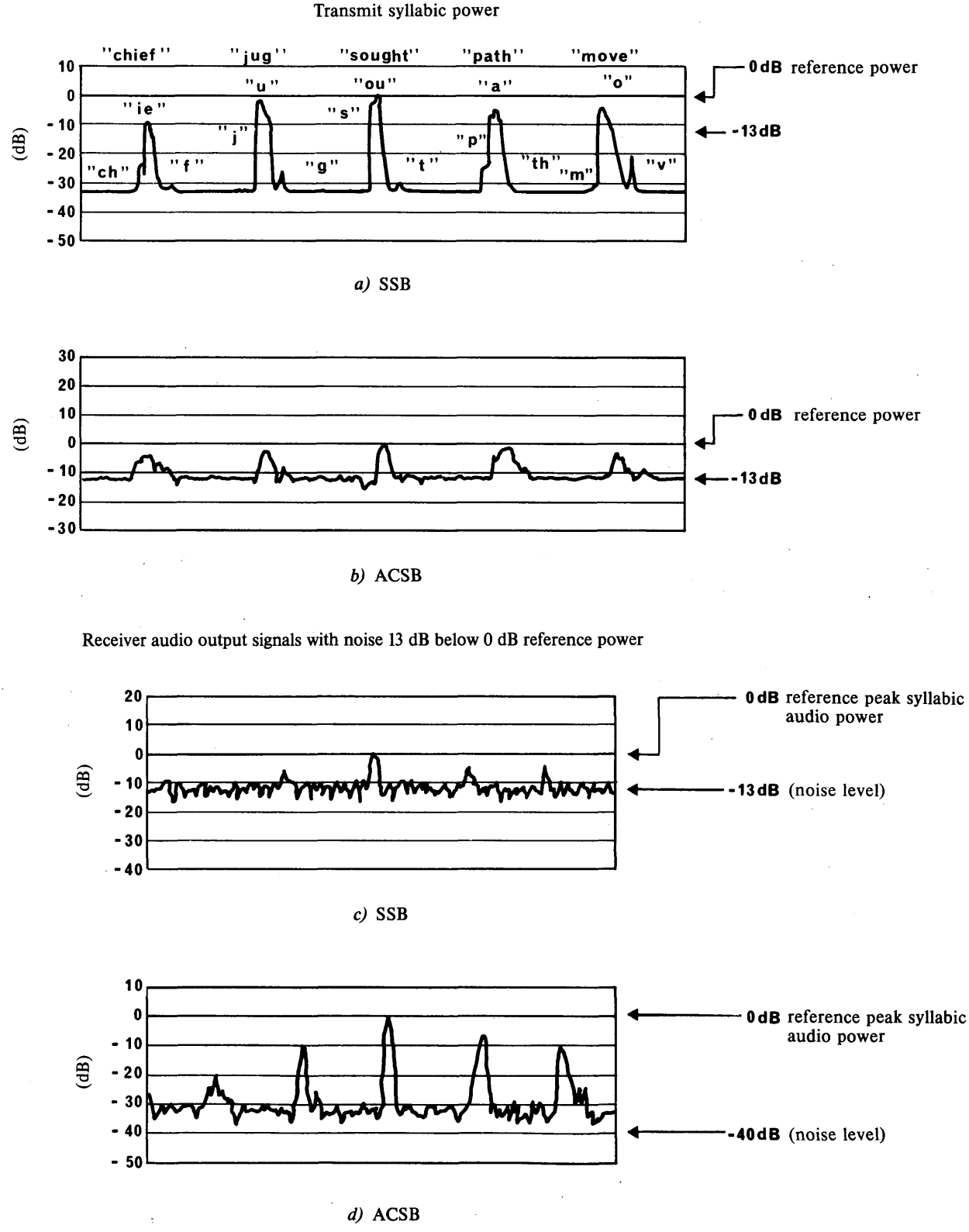


FIGURE 6 – *Performance of SSB and ACSB radios on English language test words in the absence of multipath fading*

REFERENCES

BARNES, D. M [July, 1981] A subjective evaluation of single-sideband radio for use in private land mobile radio services – initial trials. IERE Conf. Proc.

GARNER, P. J. [April, 1980] Co-channel and quasi-synchronous characteristics of SSB. IEE Conference Comms. 80. Communications equipment and systems. Conf. Publ. No. 184, 174-177. Birmingham, United Kingdom.

GOSLING, W., McGEEHAN, J. P. and RICHARDSON, J. H. [September, 1979] SSB as an optimum modulation for land mobile radio. IERE Conf. Proc. No. 44.

WELLS, R. [July, 1978] SSB for VHF mobile radio at 5 kHz channel spacing. IERE Conf. Proc. on Radio Receivers and Associated Systems, No. 40, Southampton, United Kingdom.

CCIR Documents

[1974-78]: 8/382 (Yugoslavia (Socialist Federal Republic of)).

BIBLIOGRAPHY

BELANGER, R. L. [1971] A double-sideband limiting radio frequency speech processor ... US Naval Postgraduate School, Monterey, USA.

CCIR [1978] Report 509-2. Signal quality and modulation techniques for radiocommunication and radiodetermination satellite services for aircraft and ships. Vol. VIII, 276-288.

FRENCH, R. C. [August, 1979] The effect of fading and shadowing on channel re-use in mobile radio. *IEEE Trans. Vehic. Tech.*, Vol. VT-28, **3**.

GIBSON, R. W. and WELLS, R. [March, 1979] The potential of SSB for land mobile radio. 29th Annual Conference of the IEEE Vehicular Technology Society, 27-30 March, Arlington Heights, Ill., USA, Conf. Record, Session 2A: New communication techniques and technologies – II, 90-94.

GOSLING, W. [February, 1979] Single-sideband as a contribution to spectrum efficient civil land mobile radio. Intelcom 79, Dallas, USA. Horizon House International.

ITO, S. and MATSUZAKA, Y. [November, 1978] 800 MHz band land mobile telephone system – overall view. *IEEE Trans. Vehic. Tech.*, Vol. VT-27, **4**, 205-211.

LUSIGNAN, B. B. [July, 1980] The use of amplitude compandored SSB in the mobile radio bands: Final Report. Communication Satellite Planning Centre, Report No. 31 (Stanford University), USA.

MIKULSKI, J. J. [1979] Technology and spectrum efficiency. Intelcom 79, Dallas, USA. Horizon House International.

PONTIUS, B. [April, 1981] Linear amplifier tests for SSB mobile radio. 31st Vehic. Tech. Conf. of the IEEE, IEEE Catalogue 81CH1638-6, Library of Congress Catalogue Card 75-643443.

WALA, P. [March, 1980] Rhyme test performance of ACSB, narrowband and FM radios. Communication Satellite Planning Centre, Report No. 28.

RECOMMENDATION 539-1 *

TECHNICAL AND OPERATIONAL CHARACTERISTICS OF FUTURE INTERNATIONAL RADIO-PAGING SYSTEMS **

(Question 12/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that agreed technical and operational characteristics for systems and equipment could facilitate the introduction of international paging;

(b) that certain technical characteristics of equipment and stations used in paging systems are of importance in connection with the grade of service offered and in respect of the radio interference between the stations of different countries;

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* The Director of the CCIR is requested to bring this Recommendation to the attention of the CCITT, particularly in reference to §§ 2.2 and 3.2.

** Radio paging: a one-way calling system without speech.

(c) that the use of agreed frequency bands and technical characteristics could reduce the risk of mutual interference between radio-paging systems and interference with other radio systems;

(d) that the public radio-paging systems making use of the national and international public switched telephone networks should be designed as extensions of those networks;

(e) that additional messages of different types are operationally required by subscribers to such paging services thus increasing the number of paging codes required or complicating the structure of a single message code;

(f) that the ultimate paging address capacity of a system is generally decided early in the planning process;

(g) that the most economical way of providing international radio-paging services may be as an extension of national systems;

(h) that the requirements for international radio paging can usually be anticipated in the planning of national systems,

UNANIMOUSLY RECOMMENDS

that the following technical and operational characteristics of the systems, stations and equipment for land mobile radio paging should be adopted for systems intended for future international use:

1. Operational and system characteristics

1.1 *Design principles*

The radio-paging system should be designed as an extension of the telephone network.

1.2 *Receiver operation when changing paging zones*

The procedure by which a user can obtain service when moving from one paging zone or system to another (even internationally), should be as simple as possible. Manual adjustment of the receiver should not be required.

1.3 *Additional messages*

The system should enable the transmission and reception of additional messages of different types, such as the telephone number of the caller or longer numeric or alpha-numeric messages. It should be possible to use different types of receivers for different types of messages. Further study is however needed to determine the types and lengths of such messages.

1.4 *Priority calls*

It should be possible to have groups of users that are given priority during times of high traffic load.

1.5 *Legitimation codes*

It should be possible for subscribers who wish so, to have legitimation codes that have to be used by the caller when calling such a subscriber.

1.6 *Group calls*

It should be possible to call several subscribers as a group.

1.7 *Receiver identification*

Each receiver should be identified uniquely in the system in which it is to operate. Where administrations combine national systems to give international service, they should ensure that no two receivers used for this purpose should have the same identity, except when required for group calling.

1.8 *Battery saving techniques*

As low power consumption is essential for the receiver, the system should include methods for battery saving.

2. Control centre characteristics

2.1 *Function*

The control centre should perform the store and forward functions for paging calls for national and international service.

2.2 *Telephone network signals*

The control centre forms part of the switched telephone network. It therefore has to accept and generate telephone network signals agreed for national and international networks. The format of such signals is a matter on which the appropriate CCITT Study Group should advise.

2.3 *Messages and signals to caller*

The control centre should generate call acceptance and call rejection messages or signals to the caller. These messages and signals should be immediately recognizable by the caller even when placing international calls. The messages and signals should not confuse persons who reach the paging system by error.

3. Telephone network requirements

3.1 *Dialling codes*

The dialling codes used to gain access to the paging system should conform to those agreed for national and international use.

3.2 *Dialling format*

The format should be such that the dialling codes used in international paging services may be transmitted over the international telephone network. Although it may be possible to find suitable transmitter codes with sufficient capacity for international paging, there are some problems in finding sufficient telephone dialling codes. Further study on this aspect is therefore needed.

3.3 *Group call codes*

The ability to page groups of subscribers according to § 1.6 should be included in the dialling codes.

4. Transmitters and distribution of paging signals

4.1 *Frequency of operation*

For international service, at least one common international frequency channel or band should be assigned. Further study is needed to enable the recommendation of suitable frequencies.

4.2 *Multiple transmitter zones*

In multiple transmitter zones, a single radio frequency channel, if possible, is preferred so as to avoid multi-channel receivers. The transmitters can operate either sequentially or simultaneously.

4.3 *Rate and type of data modulation*

For international service these parameters must be agreed between the corresponding administrations. For Radio Paging Code No. 1, the preferred parameters are currently:

- data transmission rate: 512 bit/s (with an accuracy of $\pm 1 \times 10^{-5}$;
- modulation type: direct FSK in non-return-to-zero manner, with positive frequency shift representing binary 0 and negative frequency shift for binary 1 and frequency deviation appropriate for the assigned channel, e.g. ± 4.5 kHz for a 25 kHz channel.

512 bit/s was selected as a compromise between the needs of various multitransmitter situations. Further study is needed to enable the recommendation of parameters for universal use.

4.4 *Phase equalization*

In systems where some or all transmitters operate simultaneously, the modulating signals should be equalized so as to be compatible with the data transmission rate and the modulation type. For the preferred values in § 4.3, the modulation time delay between adjacent transmitters should not exceed 488 μs.

4.5 *Frequency off-set*

The radio frequency off-set for transmitters operating simultaneously on a common radio frequency channel should be maintained within limits compatible with the data transmission rate and the modulation type. Further studies are needed to enable values to be recommended.

4.6 *Transmitter frequency tolerance*

The transmitter frequency tolerance should be, at least, in accordance with Recommendation 478. For the preferred values in § 4.3, the tolerance should be less than 5×10^{-6}. Where simultaneous transmitter operation with frequency off-set is used, tighter tolerances may be needed.

4.7 *Other transmitter characteristics*

For the other transmitter characteristics, the values should be in accordance with Recommendation 478.

5. Receivers

5.1 Size, weight and cost should be as small as possible.

5.2 *Power consumption*

Power consumption should be kept as low as possible. Battery saving methods as offered by the system should be implemented in the receiver.

5.3 *Sensitivity*

The calling sensitivity should be less than 10 μV/m, for reference calling probability (see IEC Publication 489 – Part 6).

5.4 *Selectivity*

The adjacent channel selectivity should not be less than 60 dB in the VHF band. A lower figure may be appropriate for the UHF band.

5.5 *Spurious emission*

The value of 10 nW should not be exceeded at any frequency up to 70 MHz. Above 70 MHz, the spurious emission should not exceed 10 nW by more than 6 dB/octave in frequency up to 1000 MHz. However, lower values are preferable (e.g. 2 nW or less) in view of the possible large number of receivers in certain areas.

6. Signalling code and format

Refer to Recommendation 584.

Further study is needed. In this study, the following factors, among others, should be studied and taken into account:

- address and message capacity requirements;
- expected calling rate;
- error detecting requirements;
- error correcting requirements;
- implementation possibilities.

REPORT 499-3

RADIO-PAGING SYSTEMS

(Question 12/8)

(1970-1974-1978-1982)

1. Introduction

1.1 The radio-paging systems referred to in this Report are described as one-way selective signalling systems without speech facilities and designed as extensions of the telephone network.

1.2 Some principle modes of operation are:

1.2.1 Dialled call to a common terminal, where a telephone number dialled into the telephone network is routed to a common terminal for processing into a radio-paging call;

1.2.2 Dialled call, with audio-frequency secondary end-to-end signalling, to a common terminal, where the common terminal accepts directly dialled digits and then accepts second stage audio-frequency digits to complete the information for processing into a radio-paging call;

1.2.3 Operator-handled calls.

1.3 False calls and messages should be eliminated so far as practicable, e.g. not more than one incident per user per year.

In the case of multiple-area paging systems, the user should be able to choose the area or areas within which he desires to be paged.

The radio signal strength should be as uniform as practicable within the service area but restricted outside it. Special system considerations may be necessary to operate an aircraft paging receiver.

Radio paging could also be used to enhance other mobile services, e.g. paging aircraft in the ground-to-air direction.

2. Control terminal design concepts

For a high-capacity system, the use of a stored programme device seems to be desirable to perform the storing and forwarding functions of the paging calls.

It would be desirable for the control terminal to make a validity check of all calls entering the system.

The control terminal should return the necessary supervisory signals to the telephone switching network.

The control terminal should generate directly or indirectly the transmitter modulating signals.

The number of control terminals needs to be limited to ease the telephone access and switching problems. For access to the control terminal, the dialling codes used over the public telephone network should conform to agreed national and international standards.

As the control terminal will be an integral part of the switched telephone network it should conform to the normal requirements for equipment in that network. The capacity of each control terminal should therefore be either 1000 or 10 000 or 100 000 paging addresses, i.e. discrete subscriber dialling codes. The last-mentioned capacity of 100 000 is considered to be optimum between all the requirements for the majority of applications and leads to an economic design. To obtain greater user capacity in any system, a number of such terminals could be used.

3. Radio-frequency considerations

3.1 The following factors need to be taken into account in the choice of a suitable radio frequency channel(s):

- economics of the system for a given area;
- availability of frequencies;
- propagation considerations and operational requirements;
- environmental noise levels;
- practical limits of receiver sensitivity;
- permitted limits of emitted power levels and antenna heights according to local regulations;
- levels of paging traffic.

3.2 *Possible frequency bands*

All three ITU Regions have some or all of the following frequency bands allocated to mobile services:

26.1 to 50 MHz
68 to 88 MHz
146 to 174 MHz
450 to 470 MHz
806 to 960 MHz

In the future, it is possible that higher frequencies may be allocated to the mobile service in all three Regions and consequently be available for radio paging, but the utility of such frequencies is not yet proved.

In addition, documents submitted by Sweden illustrate the possible use of the VHF-FM sound broadcasting transmitter network in the frequency band 87.5 to 104 MHz for a wide-area paging system over the coverage area of the broadcast transmission [CCIR, 1978-82].

3.3 *The cost of coverage*

The costs and ease of providing base station antenna gain at 150 MHz and 450 MHz, to overcome increased propagation losses at these frequencies, compared with the lower bands such as 26.1 to 50 MHz (in North America) and 68 to 88 MHz (in Europe), are of the same order as those for the basic unity gain antenna systems for the lower frequencies.

3.4 *Effect of man-made noise*

For receivers with identical gain, which is the current situation with paging receivers designed to operate in the various frequency bands, the receiver noise factor increases with frequency.

The level of man-made noise, which is particularly high in inner city areas and on busy highways, where paging systems find most of their subscribers, is inversely proportional to frequency.

In the category of man-made noise we can also include on-frequency interference. 150 and 450 MHz (the latter being the highest frequency for which any practical paging system has been designed) provide relative freedom from long-distance transmission and thus from interference, which is a major disadvantage of the bands around 50 MHz and below.

3.5 *Radio propagation into buildings*

Measurements results submitted by a number of administrations have indicated that frequencies in the range of 80 to 460 MHz are suitable for personal radio paging in urban areas with high building densities. It is possible that frequencies in the bands allocated around 900 MHz may also be suitable but that higher frequencies are less suitable.

From measurements made in Japan, the following median values of the propagation loss suffered by signals in penetrating buildings (building penetration loss) have been derived. These are shown the Table I below:

TABLE I

Frequency	150 MHz	250 MHz	400 MHz	800 MHz
Building penetration loss (see note)	22 dB	18 dB	18 dB	17 dB (1)

(1) Somewhat less accurate than the other results.

Note. – The loss is given as the ratio between the median value of the field strengths measured over the lower floors of buildings and the median value of the field strengths measured on the street outside.

Similar measurements made in other countries confirm the general trend but the values of building penetration loss vary about those shown. For instance, measurements made in the United Kingdom indicate that building penetration loss at 160 MHz is about 14 dB and about 12 dB at 460 MHz.

Frequencies of about 80 MHz suffer losses similar to those at 150 MHz, but still lower frequencies e.g., 35 MHz, 26 MHz have been shown [Mino *et al.*, 1965; Rice, 1959] to be less suitable for use in urban areas but have some slight advantage over higher frequencies in suburban fringe areas.

For radio-paging systems which are intended to cover large areas with little urban development, the frequency bands around 80 MHz and 160 MHz seem to be most suitable.

3.6 *Techniques applicable to multiple transmitter zones*

To cover a service area effectively, it will usually be necessary to use a number of transmitters. When the coverage from a single transmitter is small, a single radio-frequency channel should be used so as to avoid the need for multi-channel receivers. In these circumstances, the separate transmitters may operate sequentially or simultaneously. In the latter case, the technique of off-setting carrier frequencies, by an amount appropriate to the coding system employed, is often used. It is also necessary to compensate for the differences in delay to the modulating signals arising from the characteristics of the individual land-lines to the transmitters.

It is preferable that the frequency off-set of the transmitter carrier frequencies in a binary digital radio-paging system be at least twice the signal fundamental frequency.

It is also preferable that delay differences between the modulations of the transmitters in a binary digital paging system should be less than a quarter of the duration of a bit if direct FSK, non-return to zero modulation is used. For sub-carrier systems the corresponding limit should be less than 1/8 of a cycle of sub-carrier frequency.

Studies are required to determine optimum methods for the transmission of signals over land lines and for simultaneous operation of a number of transmitters.

3.7 *Receiver design*

Built-in antennas can be designed for 150 MHz with reasonable efficiency. A typical radio-paging receiver antenna using a small ferrite rod exhibits a loss factor of about 16 dB relative to a half-wave dipole.

The feasibility of large scale integration of circuits (LSI) seems now to be realized. Component costs for a receiver using these techniques are low.

The majority of wide-area systems which have been established have employed some form of angle modulation.

4. Signalling format

The signalling format should be standardized. The choice of the appropriate coding techniques should take into account the required capacity of code combinations, speed of transmission, call success rate, and lowest practicable false calling rate. The code should be designed to allow for transmission of various types of messages. Recommendation 584 provides details of a recommended code and format.

Cyclic block codes such as the Bose-Chaudhuri-Hoquenghem (BCH) codes, permit the reliability of signalling to be improved and the probability of false calling to be much reduced, because of their distance and their inherent error detection and correction capability.

It is desirable that the standardized code can easily share a channel with other codes.

Message repetition is one possible way of increasing the successful call probability.

For the measurement of the signalling reliability of equipment, it is understood that the IEC is working on this subject. Results from field tests are also desirable.

5. System capacity

The number of users to be catered for still has to be determined.

In a document submitted by France, it was estimated that the available overall capacity at a national level should be at least 20 per 1000 inhabitants.

The capacity of any system is affected by at least the following:

- the number and the characteristics of the radio channels used;
- the number of times each channel is re-used within the system;
- the actual paging location requirements of the individual users;
- the peak information (address and message) requirement in any location(s);
- tolerable paging delay;
- data transmission rate;
- code efficiency;
- method of using the total code capacity throughout the system (this may also affect the system's capabilities for "roaming");
- any inefficiency introduced by battery saving provisions.

In addition to the above, there may also be telephone system input restrictions.

6. Compatibility between international and national radio-paging systems

It was recognized that a high degree of compatibility would be necessary between the national and international radio-paging systems. However, this does not preclude the establishment of radio-paging systems in factories, buildings, etc., using different standards.

On an international basis, between systems that are technically compatible, the international user should be able to move to another country, and the service provided in his home service area be extended to him in remote service areas of another nation.

One method of providing service between systems which are technically incompatible, would be to exchange the subscriber's paging receiver, and to use an agreed method to transfer the access data between national telephone systems.

7. Objective

The various existing domestic and international systems may soon be followed by new systems. Some administrations have an urgent need for a standard for their future systems in order to permit easy implementation of cross-border systems, sharing of users between various system providers, and to give good guidance to providers of paging services. In respect of code(s) and format(s) this need has been largely satisfied by Recommendation 584. The studies necessary to define the requirements for international radio-paging systems are not complete and should be continued.

REFERENCES

MINO, N., KIMURA, M. and YAMADA, Y. [1965] "Pocket Bell" personal radio signalling service. Nippon Telegraph and Telephone Corp. (Report No. 38).

RICE, L. P. [January, 1959] Radio transmission into buildings at 35 and 150 MHz. *BSTJ*, Vol. 38, **1**, 197-210.

CCIR Documents

[1978-82]: 8/63 (Sweden)

BIBLIOGRAPHY

BRITISH TELECOM [June, 1978 and November, 1980] A standard code for radio paging. Report of the Post Office Code Standardization Advisory Group (POCSAG).

CEPT Recommendation T/R6, Système Eurosignal.

KOMURA, M., HAGIHIRA, T. and OGASAWARA, M. [November, 1977] New radio-paging system and its propagation characteristics. *IEEE Trans. Vehic. Tech.*, Vol. VT-26, **4**, 362-366.

KOMURA, M., YOKOKURA, A., HAGIHIRA, T. and OGASAWARA, M. [July, 1977] New radio-paging system. *Japan Telecomm. Rev.*, Vol. 19, **3**. 217-225.

MAAG, H. [1972] Un réseau public d'appel de personnes par radio. *Bull. tech. PTT* (Suisse), **4**.

MYRBY, S. [January, 1978] The mobile paging service starts up in Sweden. TELE No. 1/1978. Available from the Swedish Telecommunications Administration.

NELSON, L. E. [March, 1978] Selective signalling for portable applications. Conf. record 28th Vehic. Tech. Conf.

WEY, E. [1967] Das nationale Autorufnetz der Schweiz (The Swiss national network for calling motor vehicles). *PTT Techn. Mitt.*, **5**.

WEY, E. [1967] Planungsgrundlagen für den einseitigen selektiven Funkruf (Planning bases for one-way selective calling by radio). *PTT Techn. Mitt.*, **8**.

WILLARD, D. F. and SHARP, R. E. [January, 1974] Systems consideration in the expansion of a low capacity tone paging system through time sharing with high capacity signalling. Conf. record 24th IEEE Vehic. Tech. Conf.

RECOMMENDATION 584 *

STANDARD CODES AND FORMATS FOR INTERNATIONAL RADIO PAGING **

(Question 12/8, Study Programme 12A/8)

(1982)

The CCIR,

CONSIDERING

(a) Recommendation 539, and Reports 499 and 900;

(b) that the studies necessary to define the requirements for international radio-paging systems are not complete;

(c) that the results of such studies may make it desirable to amend any standard selection on the basis of the present limited information;

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* The Director of the CCIR is requested to bring this Recommendation to the attention of the CCITT in relation to Recommendation 539.

** Radio paging : a one-way calling system without speech.

(d) that some administrations have an urgent need to implement national radio-paging systems which might be developed to provide for international radio paging;

(e) that, among other things, standard code(s) and format(s) are necessary to permit international radio paging;

(f) that, for paging systems unlikely to be extended to provide for international paging, some other codes might be more suitable,

RECOMMENDS *

1. that the codes and formats described in Annex I are generally suitable for national use and should be considered for systems which an administration might intend to extend to international paging;

2. that system design should allow for possible future changes in the recommended codes and formats;

3. that studies should continue in order to define the requirements for international paging systems.

ANNEX I

RADIO-PAGING CODE No. 1

1. Code and format

A transmission consists of a preamble followed by batches of complete codewords, each batch commencing with a synchronization codeword (SC). The format of the signals is illustrated in Fig. 1. Transmission may cease at the end of a batch when there are no further calls.

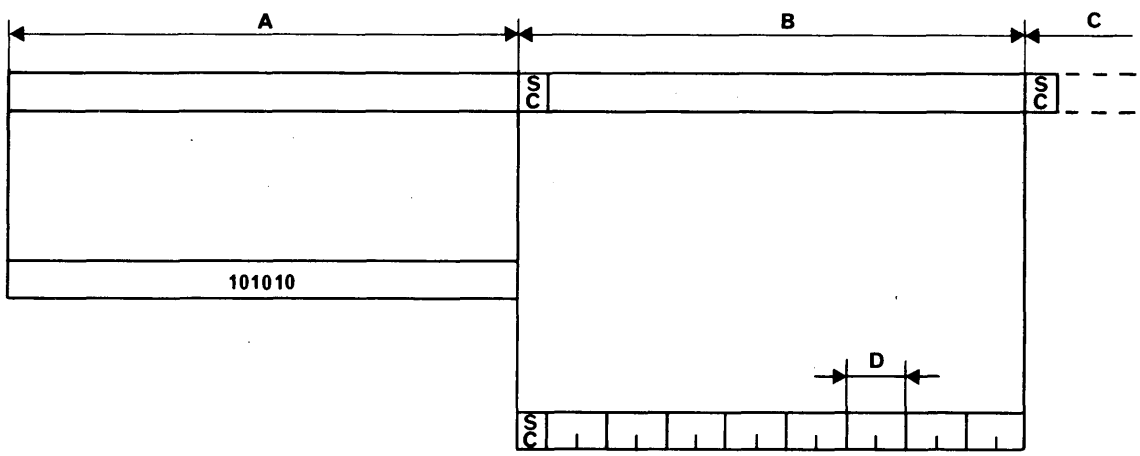


FIGURE 1 – *Signal format*

A: preamble. Duration at least 576 bits = the duration 1 batch + 1 codeword
B: first batch
C: second and subsequent batches
D: one frame = 2 codewords
SC: synchronization codeword

Note. – 1 batch = synchronization codeword + 8 frames = 17 codewords.

* The Administrations of Brazil and Japan reserve their position with respect to this Recommendation.

1.1 *Preamble*

Each transmission starts with a preamble to aid the pagers to attain bit synchronization and thus help in acquiring word and batch synchronization. The preamble is a pattern of reversals, 101010... repeated for a period of at least 576 bits, i.e. the duration of a batch plus a codeword.

1.2 *Batch structure*

Codewords are structured in batches which comprise a synchronization codeword followed by 8 frames, each containing 2 codewords. The frames are numbered 0 to 7 and the pager population is divided into 8 groups. Thus each pager is allocated to one of the 8 frames according to the 3 least significant bits (1sb) of its 21 bit identity (see § 1.3.2), i.e. 000 = frame 0, 111 = frame 7, and only examines address codewords in that frame. Therefore each pager's address codewords must be transmitted only in the allocated frame.

Message codewords for any receiver may be transmitted in any frame but follow, directly, the associated address codeword. A message may consist of any number of codewords transmitted consecutively and may embrace one or more batches but the synchronization codeword must not be displaced by message codewords. Message termination is indicated by the next address codeword or idle codeword. There is at least one address or idle codeword between the end of one message and the address codeword belonging to the next message.

In any batch, wherever there is no meaningful codeword to be transmitted, an idle codeword is transmitted.

1.3 *Types of codewords*

Codewords contain 32 bits which are transmitted with the most significant bit first. The structure of a codeword is illustrated in Fig. 2.

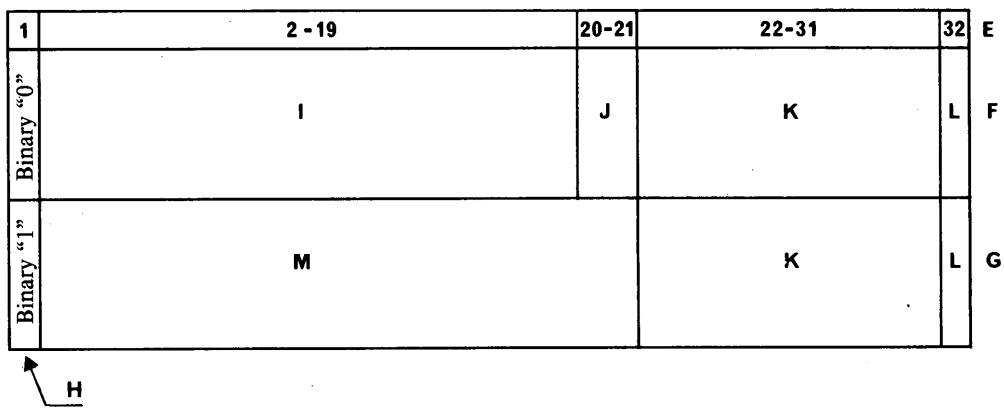


FIGURE 2 – *Form of address and message codewords*

E: bit number
F: address codeword
G: message codeword
H: flag bit
I: address bits (2-19)
J: function bits
K: check bits
L: even parity bit
M: message bits (2-21)

1.3.1 *Synchronization Codeword*

The synchronization codeword is shown in Table I:

TABLE I

Bit No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bit	0	1	1	1	1	1	0	0	1	1	0	1	0	0	1	0
Bit No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bit	0	0	0	1	0	1	0	1	1	1	0	1	1	0	0	0

1.3.2 *Address Codewords*

The structure of an address codeword is illustrated in Fig. 2.

Bit 1 (the flag bit) of an address codeword is always a zero. This distinguishes it from a message codeword.

Bits 2-19 are address bits corresponding to the 18 most significant bits of a 21 bit identity assigned to the pager.

For information regarding the least significant bits see § 1.2.

Bits 20 and 21 are the two function bits which are used to select the required address from the four assigned to the pager. Hence the total number of addresses is 2^{23} (over 8 million).

Bits 22 to 31 are the parity check bits (see § 1.4) and the final bit (bit 32) is chosen to give even parity.

1.3.3 *Message Codewords*

The structure of a message codeword is shown in Fig. 2. A message codeword always starts with a 1 (the flag bit) and the whole message always follows directly after the address codeword. The framing rules of the code format do not apply to a message and message codewords continue until terminated by the transmission of the next address codeword or idle codeword. Each message displaces at least one address codeword or idle codeword and the displaced address codewords are delayed and transmitted in the next available appropriate frame. Although message codewords may continue into the next batch, the normal batch structure is maintained, i.e., the batch will consist of 16 codewords, preceded by a synchronization codeword. At the conclusion of a message any waiting address codewords are transmitted, starting with the first appropriate to the first free frame or half frame.

Message codewords have 20 message bits, viz bit 2 to bit 21 inclusive and these are followed by the parity check bits obtained according to the procedure outlined in § 1.4 below.

1.3.4 *Idle Codeword*

In the absence of an address codeword or message codeword, an idle codeword is transmitted. The idle codeword is a valid address codeword, which must not be allocated to pagers and has the following structure as shown in Table II:

TABLE II

Bit No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bit	0	1	1	1	1	0	1	0	1	0	0	0	1	0	0	1
Bit No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bit	1	1	0	0	0	0	0	1	1	0	0	1	0	1	1	1

1.4 *Codeword Generation (31: 21 BCH + Parity)*

Each codeword has 21 information bits, which correspond to the coefficients of a polynomial having terms from x^{30} down to x^{10}. This polynomial is divided, modulo-2, by the generating polynomial $x^{10} + x^9 + x^8 + x^6 + x^5 + x^3 + 1$. The check bits correspond to the coefficients of the terms from x^9 to x^0 in the remainder polynominal found at the completion of this division. The complete block, consisting of the information bits followed by the check bits, corresponds to the coefficients of a polynomial which is integrally divisible in modulo-2 fashion by the generating polynomial.

To the 31 bits of the block is added one additional bit to provide an even bit parity check of the whole codeword.

2. Message formats

Although in principle, any message format can be inserted into message codewords, the following formats are regarded as standard. Adherence to these standards will enable a greater measure of interworking to be possible. The formats are not mixed within any one message.

2.1 *"Numeric-only" message format*

The "numeric-only" format is provided for the transmission of messages which may be represented solely in decimal numerals together with spaces, hyphens, opening and closing brackets, an urgency symbol "U" and one other symbol. There are 4 bits per character in this format and its use will save air-time compared to the other format.

The address which introduces a message (or segment of a message) using this format has its function bits set to 00. The character-set used for the message is as shown in Table III which is based on Binary Coded Decimal (BCD). The bits of each character are transmitted in numerical order starting with bit No. 1. Characters are transmitted in the same order as they are to be read and are packed 5 per message codeword. Any unwanted part of the last codeword of the message is filled with space characters.

2.2 *Alpha-numeric or general data format*

This format can be used for the transmission of messages requiring a greater range of characters than that provided within the "numeric-only" format but it may also be used to replace the latter when circumstances make this essential or desirable. There are 7 bits per character in this format.

The pager address which introduces a message (or segment of a message) using this format has its function bits set to 11.

The CCITT Alphabet No. 5 (7 bits per character) is used in this format. As in the case of the "numeric-only" format, bit order starting with bit No. 1 of each character, and character reading order are preserved in transmission. The complete message is partitioned into contiguous 20 bit blocks for the purpose of filling consecutive message codewords. Thus a character may be split between one message codeword and the next. Any unwanted part of the last codeword of the message is filled with appropriate non-printing characters such as "End of Message", "end of Text", Null, etc. All characters, except Null, are complete.

TABLE III – *"Numeric-only" character set*

4-bit Combination	Displayed character
Bit No.: 4 3 2 1	
0 0 0 0	0
0 0 0 1	1
0 0 1 0	2
0 0 1 1	3
0 1 0 0	4
0 1 0 1	5
0 1 1 0	6
0 1 1 1	7
1 0 0 0	8
1 0 0 1	9
1 0 1 0	Spare
1 0 1 1	U (urgency indicator)
1 1 0 0	Space
1 1 0 1	Hyphen
1 1 1 0	⊐
1 1 1 1	⊏

REPORT 900

RADIO-PAGING SYSTEMS

Standardization of Code and Format

(Question 12/8, Study Programme 12A/8)

(1982)

1. Introduction

An urgent need was expressed by some administrations for a standard code and format which could be used for systems due to enter service in the immediate future. Recommendation 584 is intended to provide advice and help to such administrations but this Report supplements the information.

2. Information on existing codes

2.1 A document submitted by Sweden described a code and format used in the Swedish radio-paging system. Each paging address consists of two codewords; the first contains two hexadecimal digits for the synchronization and system identification, as well as the first two digits of the address. The second codeword contains the four following digits of the address. An additional message may follow an address and may consist of any number of codewords, each containing four binary coded decimal (BCD) digits [CCIR, 1978-82a].

2.2 A document submitted by the United States describes a binary digital code and format with a single address capacity up to 400 000. The code used is a GOLAY (23:12) cyclic code with a Hamming distance of 7, and two codewords represent an address. The code and format are stated to provide queueing and message flexibility and ability to operate in a mixed mode of transmission with other formats [CCIR, 1978-82b].

2.3 Japan uses a BCH (31:16) codeword with Hamming distance 7. The format gives approximately 65 000 addresses, 15 groups for battery economy and a total cycle length of 4185 bits. Each group includes 8 address codewords headed by a 31-bit synchronizing and group indicating signal [CCIR, 1978-82c].

2.4 The United Kingdom employs a BCH 32:21 plus even parity codeword with a Hamming distance of 6. The code format caters for over 8 million addresses and can be expanded. It also caters for any type of data message (hexadecimal and CCITT Alphabet No. 5 are already standardized). It is designed to share a channel with other codes and to permit mixed simultaneous and sequential multi-transmitter operation at the normal (512 bit/s) data transmission rate [CCIR, 1978-82d].

2.5 The United Kingdom's code and format has also been planned for National paging services in Australia and New Zealand. It is also planned for use in the United States where numerous other codes and formats are currently in use.

3. Factors affecting standardization

Report 499 in § 4 identifies the need to standardize the signalling format and points out that the choice of the appropriate coding technique should take into account the required capacity of code combinations, the speed of transmission, call success rate and lowest practicable false calling rate. In addition the code should be designed to allow for transmission of various types of messages (for example, single address, multiple address, address plus numeric message, address plus alphanumeric message) and should easily share a channel with other codes.

Other factors which will need to be considered are interrelated. For example the number of subscribers to be served, the number of addresses which they require, the traffic generated, including that due to the transmission of messages and the signalling rate that is technically feasible. In some cases this last may be determined by the linking land line network characteristics, particularly when simultaneous radio transmission is employed, as well as by the radio system characteristics.

The choice of a code and format cannot be made without considering the system in which they are to be used. Certain codes and formats are capable of operating in a variety of systems but this does not apply to all.

4. Considerations of different codes and formats

4.1 In the choice of a standard code and format the following system requirements are considered important and should be taken into account:

- the number of subscribers to be served;
- the number of addresses assigned to each subscriber;
- the calling rate expected including that from any included message facility;

- the zoning arrangements;
- the data transmission rates possible over the linking network and radio channel(s), taking account of the propagation factors of the radio frequencies to be used;
- the type of service, e.g. vehicular or personal, urban or rural;
- the acceptable queueing delay.

4.2 From considerations of the above, codes may be compared by their characteristics in respect of:

- Code address capacity;
- Number of bits per address;
- Code efficiency, e.g. number of information bits/total number of bits per codeword;
- Codeword Hamming distance;
- Error detecting capability;
- Error correcting capability;
- Message capability and length;
- Battery saving capability;
- The ability to share a channel with other codes;
- The capability of meeting the needs of participating administrations with systems varying in respect of size, transmission mode, e.g. simultaneous and/or sequential, etc.

4.3 The various characteristics of coding systems described in the documents summarized in § 2 appear in Table I below.

5. Address capacity

Report 499 includes an estimate made by France that the available overall capacity on a national scale for radio-paging receivers should be at least 20 per 1000 inhabitants.

Assuming that particular national systems and international paging use the same code and format on a common frequency then the address capacity required may be large. On the other hand, if different formats and/or frequencies are chosen then the address capacity requirements could be smaller.

Further studies on the capacity required are needed urgently.

6. Additional information concerning Radio-Paging Code No. 1 (Recommendation 584)

Recommendation 584 provides details of Radio-Paging Code No. 1 but the following additional information may be useful in connection with the requirements for receivers to operate in systems using this code. [CCIR, 1978-82e].

6.1 *Loss of synchronization*

If a receiver loses synchronization, or if it commences receiving after the preamble has been completed, it is desirable that it can achieve synchronization on receipt of a number of valid batches.

6.2 *Decimal representation of pager identities*

A decimal representation of the pager identity might be useful. If so, it is suggested that it should be the decimal equivalent of the 21 bit identity.

6.3 *Message reception, display and alerting*

6.3.1 *End of message*

It is desirable that the pager ceases decoding a message when either an idle or address codeword is received or when two successive information codewords are indecipherable, even if they immediately follow a message indicating pager address.

6.3.2 *Minimum message storage capacity*

Some form of storage will be necessary for pagers which do not provide a printed output. It is suggested that the minimum storage capacity in pagers designed for the "numeric-only" format should be 20 characters and for the "alpha-numeric" format, 40 characters.

TABLE I – *Characteristics of different codes and formats*

Characteristics	Sweden	United States	United Kingdom and United States	Japan
Codeword related characteristics: Codeword type	Kasami 26 : 16 Truncated cyclic code	Golay 23 : 12	BCH 32 : 21 plus 1 bit even parity	BCH 31 : 16
Hamming distance	3 (Note 1)	7	6	7
Codeword error detection capability per word (Note 5)	Burst: 10 errors Random: 2 errors	Burst: 11 errors Random: 6 errors	Burst: 11 errors Random: 5 errors	Burst: 15 errors Random: 6 errors
Codeword error correction capability per word (Note 5)	Burst: 5 errors Random: 1 error	Burst: 5 errors Random: 3 errors	Burst: 5 errors Random: 2 errors	Burst: 7 errors Random: 3 errors
Codeword efficiency (No. of information/total codeword bits) (Note 9)	16/26 = 0.62	12/23 = 0.52	21/32 = 0.66	16/31 = 0.52
System related characteristics: Code address capacity	1×10^6	409 600	over 8×10^6 (Note 4)	65 000
Number of bits per address	52	60.5	32 (+ 3 implied) + 2 overhead + preamble	34.9 (Note 7)
System bit rate (bit/s)	1 187.5	300/600 (Note 2)	512	200
System message capability and length	Decimal, unlimited	Dual address, 4 functions, numeric and alphanumeric: length indefinite when asynchronous (Note 3)	4 addresses per identity: unlimited message length, hexadecimal or alphanumeric	Dual address
Battery saving feature and type	Time blanking (32 s)	Yes (Note 3)	No transmission Other codes in transmission (Note 6)	Call grouping into 15 groups
Ability to share a channel with other codes	Yes	Yes	Yes	No
Suitability of format to simultaneous and/or sequential transmission	Simultaneous: yes Séquential: not relevant to system as implemented in Sweden	Yes	Yes	Yes
Radio channel in use	FM Broadcasting 87.5 – 104 MHz	VHF and UHF mobile 150 MHz and 450 MHz	VHF mobile 150 MHz (Note 10)	VHF mobile 250 MHz
In service since	1978	1973	(Notes 8 and 10)	1978

Notes relative to Table I

Note 1. – Out of the 2600 possible 3-bit error patterns, 7 will convert any valid codeword to another valid codeword. There are know to be also some 4- and 5-bit error patterns which have the same effect.

Note 2. – The transmission system must be able to transmit the 1/2 bit duration signals at double rate, i.e. 600 bit/s.

Note 3. – Details have not yet been provided.

Note 4. – Although as implemented the code and format provide for more than 8×10^6 addresses, compatible methods of expansion are known.

Note 5. – The higher the error detection the greater is the protection against false calls and false messages. Conversely greater error correction will tend to increase the call success rate at the expense of protection against false calls.

The actual values of error correction and detection depend not only upon the codeword structure but also upon each particular design of receiver and upon the code and format.

Note 6. –

Transmission condition	Battery saving method
No transmission	Sampling to establish the presence of preamble
Other codes	Discrimination by chosen bit rate
Code and format	Grouping calls

Note 7. – This takes account of the 31 overhead bits shared between 8 calls in a group.

Note 8. – Experimental service in the United Kingdom since 1980, and planned for service in the United Kingdom, Australia and New Zealand.

Note 9. – Not equal to overall efficiency, which is affected by format.

Note 10. – Planned for service in the USA on 150 MHz in 1981 and later in the 450 and 900 MHz bands.

6.3.3 *Alerting tones*

6.3.3.1 The following repeated alerting tone patterns as shown in Table II are suggested:

TABLE II

Function Bit Combination	Alerting Tone
00	1 beep
01	2 beeps
10	3 beeps
11	4 beeps

6.3.3.2 When digital message pagers are used the following repeated alerting tone patterns as shown in Table III are suggested:

TABLE III

Function Bit Combination	Following Message Type	Alerting Tones
00	Numeric-only	1 beep
01	No message	2 beeps
10	No message	3 beeps
11	Alpha-numeric	1 beep

Thus the recipient will expect only a single beep irrespective of the type of message.

7. Conclusions

In order to reach agreement on a universal standard signalling format it is highly important to carefully identify the common bases for comparing codes and formats, taking into account the system requirements given in § 4.

However, agreement on a standard code and format will only be truly effective in international paging when agreement is also reached on radio channel assignments and modulation techniques, and on the method(s) for transferring calls between the systems in the participating countries.

REFERENCES

CCIR Documents

[1978-82]: **a.** 8/63 (Sweden); **b.** 8/82 (USA); **c.** 8/210 (Japan); **d.** 8/112 (United Kingdom); **e.** 8/397 (United Kingdom).

Note. – Statement by the United Kingdom concerning the POCSAG Radio-Paging Code: The members of the Post Office Code Standardisation Advisory Group (POCSAG) have stated that they would refrain from making any patent claims for the code itself (as distinct from any means of transmitting or receiving it). So far as they are concerned, the code is free of charge for use by any administration or other service provider, manufacturer or user.

For information, solely for its own purposes British Telecom has had a reasonably thorough patent search carried out without discovering any patent which the code might infringe.

REPORT 739

INTERFERENCE DUE TO INTERMODULATION PRODUCTS IN THE LAND MOBILE SERVICE BETWEEN 25 AND 1000 MHz

(Study Programme 7C/8)

(1978)

1. Introduction

Intermodulation causes a degradation to radio services when:

- unwanted emissions are generated in transmitters;
- unwanted emissions are generated in non-linear elements external to the transmitters;

or

- in-band intermodulation products are generated in the radio-frequency stages of receivers.

These cases occur with varying probability and varying severity. They may be reduced by equipment design or careful choice of channels, but solutions of the latter type to one case of intermodulation may increase another.

2. Transmitters

The last active stage of a transmitter is usually an amplifier. The current in this stage will be repeatedly swept from zero amplitude to a maximum and the impedance of the output active device is liable to contain a small amount of non-linearity.

If any other signal from another emission is also present at the output of this stage, the non-linearity will give rise to a number of products having frequencies with specific frequency relationships to the frequency of both the wanted and unwanted signals. These products are called intermodulation products, and their frequencies may be expressed as

$$f_i = C_1 \cdot f_1 + C_2 \cdot f_2 + \ldots + C_n \cdot f_n \quad (1)$$

where the sum $| C_1 | + | C_2 | + \ldots + | C_n |$ is the order of the product.

The odd-order intermodulation products may be relatively close in frequency to the wanted signal frequency and thus coupled via the output circuit to the antenna with minimal attenuation.

In order to be able to calculate the effects of these products, it is necessary to establish certain terms.

2.1 *Coupling loss, A_c*

The coupling loss, A_c, in dB, is the ratio of the power emitted from one transmitter to the power level of that emission at the output of another transmitter which may produce the unwanted intermodulation product.

Typical values for the coupling loss on a common site are of the order of 30 dB.

2.2 *Intermodulation conversion loss, A_I*

The intermodulation conversion loss A_I, in dB, is the ratio of power levels of the interfering signal from an external source and the intermodulation product, both measured at the output of the transmitter.

Without any special precautions, typical values for semi-conductor transmitters are to be found in the range of 5 to 20 dB and for valve transmitters, in the range of 10 to 30 dB, in respect of the 3rd order product $(2f_1 - f_2)$.

The overall loss between a transmitter providing the unwanted emission giving rise to the intermodulation product and a receiver operating at the frequency of the product is:

$$A = A_c + A_I + A_p \quad (2)$$

where A_p, in dB, is the propagation loss of the intermodulation product between the relevant transmitter output and the receiver input.

Note that the power level of the transmitter in which the intermodulation is produced is not included in the formula but this level may have an effect on the value of the intermodulation conversion loss A_I.

Example

Signal frequency of transmitter producing intermodulation product:	f_1
Signal frequency of transmitter whose emission is coupled into transmitter (f_1):	f_2
Power level of transmitter (f_2):	+ 10 dBW
Assumed coupling loss A_c:	30 dB
Assumed conversion loss A_I:	15 dB
Assumed receiver threshold signal level:	−150 dBW

Overall path loss is equal to 10 dBW − (−150 dBW) = 160 dB.

If $A_c + A_I = 45$ dB, then the required value of A_p is 115 dB.

Fig. 1 gives an example of propagation path losses at 100 MHz and, under free space conditions, a very large distance is required between the "product producing" transmitter and the receiver. If the receiver is a mobile station, this distance is considerably reduced. It may be concluded therefore that 2-frequency operation provides better conditions for the reduction of the effects of inter-transmitter intermodulation if the base receive frequency band is remote from the transmit frequency band.

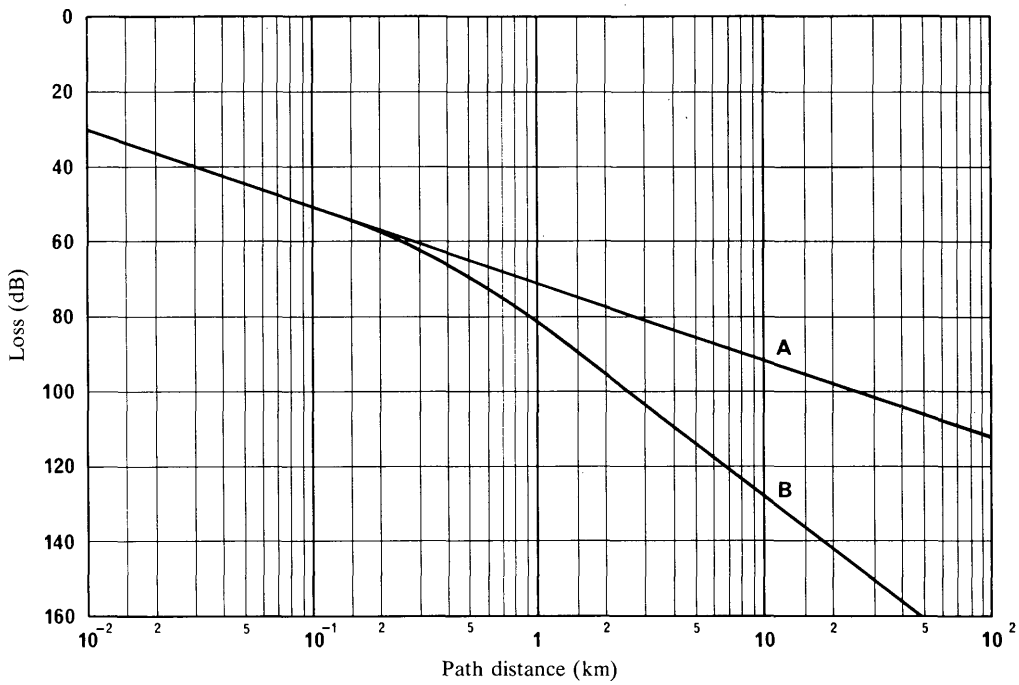


FIGURE 1 – *Short range path loss at 100 MHz ($\frac{\lambda}{2}$ dipoles assumed)*

Curves A: free space
B: Recommendation 370-3; $h_1 = 37.5$ m, $h_2 = 2$ m

The intermodulation caused by two or more mobile transmitters will be worse when the mobiles are closest together and when the desired signal originates at a mobile at the edge of the service area, an event which is associated with some (perhaps small) probability. The mobile being interfered with will be received at its base as a signal of widely varying level (due to fades and shadows) which will be independent of the IM interference. These wide and independent variations can allow the IM to reach harmful values for periods of time, even when its average value is much less than that of the signal.

3. External non-linear elements

On most sites, external non-linear elements will be at junctions in masts, feeders, and other antennas which are closely coupled to the radiating elements of nearby transmitters.

It would be useful to determine conversion losses for masts etc., of various qualities in terms of the isotropic loss between transmitters and the masts, etc. It would then be possible to establish specific values as good engineering practice.

4. Receivers

An intermodulation response is a response at the output of a receiver from an in-band signal generated in the RF stages of the receiver. This in-band signal is generated by the presence of two (or more) high-level signals in a non-linear section of the RF stages. As with transmitters, the two (or more) unwanted signals must have specific frequencies such that the intermodulation product lies within the frequency band accepted by the receiver.

This receiver characteristic is normally recorded as a single measurement with the level of the unwanted signals equal and is given as a single ratio which is:

the ratio of the level of these two equal signals

to

the apparent level of the intermodulation product at the input to the receiver.

It is possible, however, to cause a similar product level when the unwanted signals are not equal.

Fig. 2 gives examples (3 theoretical and 1 measured) of the overall third order intermodulation characteristic of receivers. It shows that intermodulation may easily be a problem when one of the unwanted signals is not excessively high. Such curves can be used to calculate other intermodulation product levels when the unwanted signals do not have values equal to those plotted.

For a product with a frequency relationship of the form $(2f_1 - f_2)$, the level will be proportional to the level of the signal at frequency f_2, but will vary as the square of the level of the signal f_1; i.e. the product will have an amplitude of the form $k \cdot V_1^2 \cdot V_2$, where V_1, V_2 are the amplitudes of the signals at frequencies f_1 and f_2 respectively.

5. Reduction of intermodulation product levels in transmitters

5.1 *Intermodulation conversion loss*

It is obvious that a reduction of the non-linearity, particularly of the odd-numbered orders, will improve the overall performance and increase the value of the intermodulation conversion loss A_I.

From the example in § 2, it is evident that a considerable improvement is necessary before the relevant path loss reduces to manageable values.

5.2 *Coupling loss*

The coupling loss can obviously be increased by increasing the distance between the relevant transmitters but it may not always be possible to do so effectively at a particular site.

Ferrite isolators could be used in the output circuits of the transmitter in which the product is generated but present production units do not provide much more than 25 dB additional loss and the use of multiple units is inhibited by the inherent non-linearity of the isolators themselves. To suppress undesirable products, filters may be required after such isolators. These isolators are equally effective irrespective of the frequency spacing between f_1 and f_2.

Cavity filters can also be used and examples of their theoretical responses are given in Fig. 3. They may be used in cascade or in more complex series-parallel combinations but in all cases, their performance is dependent on the frequency spacing between f_1 and f_2. They have the advantage that they will also attenuate the product level at the input to the antenna or transmission line and thus increase A_I.

An economic and efficient filter is the coaxial cavity resonator, either in its pure quarter-wavelength form or with varying degrees of modification to reduce the overall length and improve the value of the loaded Q. The resonator should be robust, simple to tune, highly efficient in terms of transmission loss, and provide a high degree of isolation at the required frequencies. Resonators for use with transmitters should have a low temperature coefficient and good thermal conductivity, so that their performance is not affected by changes in ambient temperature or through being heated by transmission losses. Temperature compensation can be employed to maintain the length of the centre conductors. Physical robustness is necessary to avoid changes in technical parameters from being caused by mechanical shock or deformation. The physical and mechanical design should also prevent the formation of electrical discharges or corona. Adjustable telescopic centre conductor assemblies permit a variation of resonant frequency of, typically, ± 15% of the centre frequency.

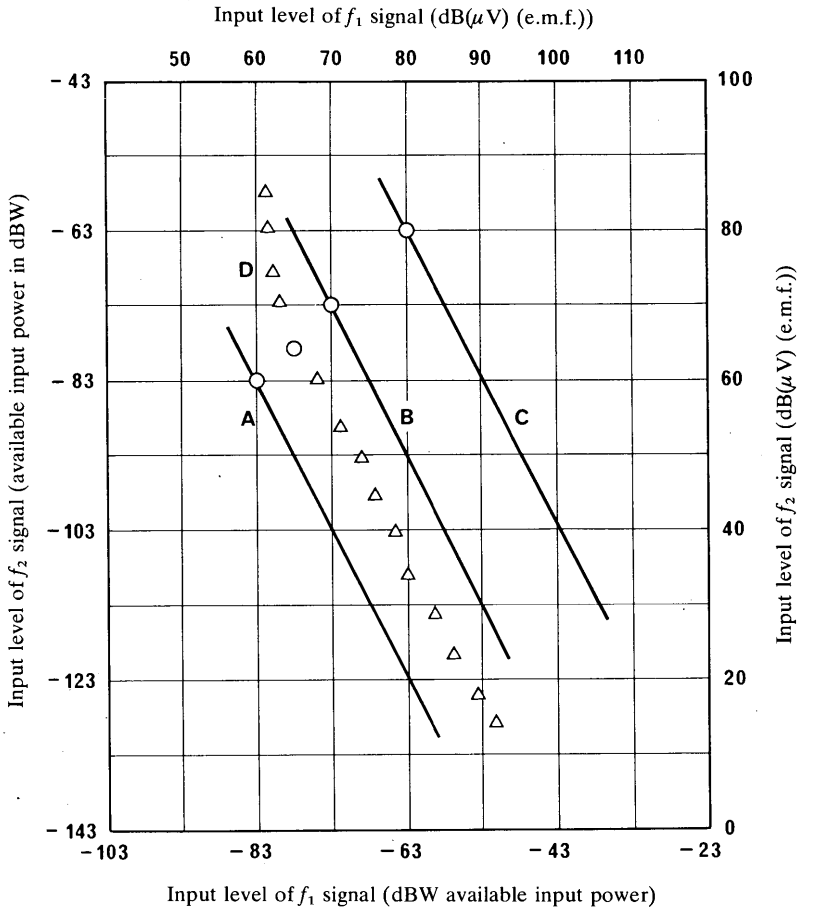


FIGURE 2 – *Receiver intermodulation characteristic*

Levels of unwanted input signals which together produce a constant product level.

Curves A, B and C: derived characteristics based on a single recorded value of the receiver's third order intermodulation characteristic, i.e. for $(2f_1-f_2)$.

Curves A: based on a single value, with both input levels at a level of 60 dB(μV) (e.m.f. to 50 ohms).

B: based on a single value, with both input levels at a level of 70 dB(μV) (e.m.f. to 50 ohms).

C: based on a single value, with both input levels at a level of 80 dB(μV) (e.m.f. to 50 ohms).

D: measured values for a receiver for which the specified criterion is achieved with equal input signal levels of 65.5 dB(μV) (e.m.f. to 50 ohms).

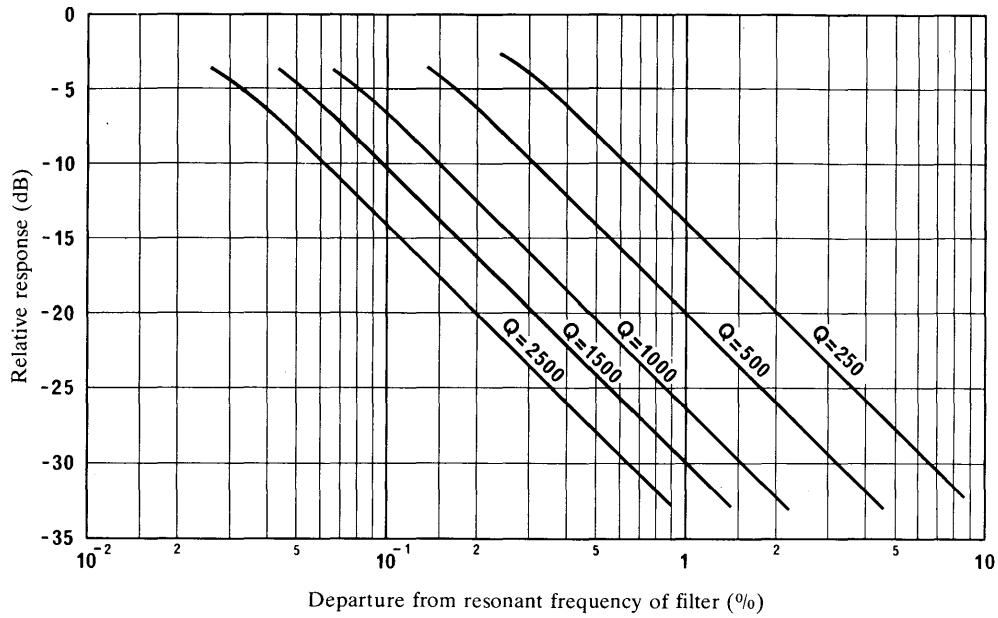


FIGURE 3 – *Theoretical response of cavity band-pass filters*

For values of loaded Q of 250-2500.

Note. — The unloaded Q should be at least 5 times the loaded Q and preferably 10 times.

Reliable and economical resonators can be manufactured from high-conductivity aluminium for the larger units, and silver-plated copper or brass for smaller units. Practical limitations of mechanical engineering govern the upper limits of Q obtainable with a cavity resonator. As the diameter is increased, the value of the unloaded Q is increased, but the sensitivity of tuning and the temperature coefficient become more critical. Practical and satisfactory resonators with a power handling capacity of up to 250 W can, however, be made for the band 150-170 MHz, for example, having an unloaded Q as large as 18 000, with a diameter of 0.58 m, and length 0.63 m, giving 35 dB discrimination at a frequency 1% removed from the resonant frequency.

It is not usual to employ cavity resonators for values of Q_0 below about 1000, since there are more satisfactory techniques, e.g. helical resonators, which can be coupled together to form smaller but relatively efficient filter units. Tables I and II give the choice of types of filter and their relative costs.

TABLE I – *Relative sizes and costs of resonators (150-174 MHz)*

1	2	3	4	5	6
Reference	Q_0	Q_L	Attenuation at 1% F_0 (dB)	Diameter (m)	Relative cost of practical resonators
A	920	100	7	0.03	1.0
B	2 300	250	14	0.07	1.7
C	4 600	500	20	0.14	2.8
D	6 900	750	24	0.21	3.3
E	9 200	1000	26	0.29	3.9
F	11 700	1250	28	0.37	4.6
G	13 800	1500	30	0.46	5.3
H	16 100	1750	32	0.53	6.8
I	18 400	2000	35	0.58	7.1

TABLE II – *Relative costs of practical resonators for other frequencies*

Resonant frequency (MHz)	Cavity height (m)	Unloaded Q					
		920	2300	4600	6900	9200	13 800
50- 60	1.55	*	*	8.7	12.0	14.7	+
60- 80	1.15	*	*	5.5	7.3	10.6	14.9
95-110	0.85	*	3.3	4.1	5.2	6.4	10.7
120-150	0.68	*	2.6	3.3	4.2	5.0	8.9
150-174	0.63	1.0	1.7	2.8	3.3	3.9	5.3
160-180	0.52	0.9	1.5	2.4	2.9	3.4	4.6
400-500	0.24	0.8	1.0	1.5	2.0	2.2	3.0

Note. – Items not tabulated are identified as follows:
*. Helical resonator superior
+ Single cavity large and somewhat uneconomic.

Compared with the total cost of the radio equipment at a base station, cavity resonator filters are an economical and efficient means of reducing spurious emissions and preventing or minimizing interference.

5.3 *Identification of the source of an intermodulation product*

The frequency of the third order intermodulation resulting from the interaction of two transmitters may be expressed as either $2f_1 - f_2$ or $2f_2 - f_1$.

If the product is $2f_1 - f_2$, the mixing is occurring within or close to the transmitter operating on f_1.

Conversely, if the product is $2f_2 - f_1$, the mixing is occurring within or close to the transmitter operating on f_2.

In the case of FM or PM emissions, the deviation caused by modulation is doubled when a second harmonic is generated. So if the modulation on one of the intermodulation products appears to be excessive, this modulation is probably transferred from the f_1 signal of a $2f_1 - f_2$ mixing.

6. Reduction of intermodulation products in receivers

As with transmitters, a reduction in the non-linearity of a receiver will improve the performance.

Attenuation at the input of the receiver may be used to reduce the level of an intermodulation product. The levels of these products are related to the levels of the signals that produce them, in such a way that the attenuation (in dB) of each "n^{th}" order product will, in most cases, be n times the attenuation (in dB) of the wanted signal.

For example, a 3 dB attenuator will reduce a third order product by 9 dB while reducing the wanted signal by 3 dB. This may also be used as a test device to prove that the intermodulation product is being generated in the receiver.

Cavity filters can be used, either as rejection filters to f_1 and/or f_2, or as band-pass filters to the wanted signal. Again the effectiveness of these filters depends on the frequency spacings involved.

7. Reduction of intermodulation interference by frequency arrangements

The frequencies to be used can be arranged so that no receiver on the product frequency is required to operate in an area where the unwanted signals may produce an intermodulation product of sufficient level to disturb the service. If this level is at the maximum sensitivity level of the receiver; it will mean receivers cannot be used for distances up to 2 km from the sites of the base station operating at f_1 and f_2. This applies even when the f_1 and f_2 stations are separated by several kilometres and thus implies that the base station on the product channel must be sited outside the service area of stations operating on f_1 and f_2. This leads to very poor use of the frequency spectrum.

In systems that operate a number of frequency channels, most cases of harmful base transmitter and mobile receiver intermodulation within the system can be alleviated by the choice of even channel sets at the base stations. This means that the channels of each base station are evenly distributed at a constant frequency separation. In a service area the intermodulation products within the band used will in that case coincide with channels of the set, and the ratio of the desired signal to the intermodulation product in a mobile receiver is independent of the distance and propagation characteristics.

8. Reduction of intermodulation interference by other arrangements

If continuous tone signalling is used, the receiver will operate only in the presence of this signalling tone and it is then necessary only to ensure that the wanted signal on the product channel exceeds the level of an unwanted product of f_1 and f_2 by an amount in excess of the required protection ratio. This can be best assured by siting the product channel base transmitter at the same, or near to, the site of stations operating on f_1 and f_2. Under these conditions, the need for filters or other devices in the transmitter or receiver is reduced.

REPORT 740-1

SYSTEMS WITH IMPROVED SPECTRUM EFFICIENCY FOR THE LAND MOBILE SERVICE

(Question 37/8)

(1978-1982)

Introduction

This Report is divided into Parts A and B. Part A deals with the general aspects of cellular systems. In Part B some examples are given of systems being installed or planned by some administrations.

PART A

GENERAL CONSIDERATIONS

1. Systems of cells

1.1 *Introduction*

Systems are in use for the land mobile service which utilize the frequency spectrum much more efficiently than conventional system approaches [Frenkiel, 1970; Staras and Schiff, 1970]. The technique which such systems have in common is the division of the desired service area into a number of sub-areas (cells), with one or more base stations providing radio coverage to each cell. In some of the systems, the cellular technique is applied to both directions of transmission. In others, it is applied to the mobile-to-base direction only [FCC, 1970], when for economic reasons transmission from the base station to the mobile station is provided by a centrally located transmitter.

1.2 *General system characteristics*

When a mobile unit either originates or receives a call, the cell in which it is located is determined (e.g. through a vehicle location sub-system) and it communicates through a base station covering that cell. With the proper spacing of co-channel cells, each frequency may be used simultaneously in several cells in the service area, thereby multiplying the capacity obtainable in conventional systems. Since the rejection of co-channel interference depends on signal-to-interference ratio and not on absolute amplitude, the required co-channel cell spacing is specified as some multiple of the cell radius.

Reducing the spacing between co-channel cells would allow each frequency to be re-used simultaneously in more cells in the service area. However, it could also increase the mutual interference between co-channel stations, unless other techniques, such as carrier frequency offset (see Note), diversity [Lundquist and Peritsky, 1971] and power control [US Advisory Committee, 1967] are used.

Note. – Carrier frequency offset is a technique to provide additional co-channel protection between cells by offsetting the carriers of the channels used in these cells. The amount of frequency offset should be determined by system design.

1.3 *Factors influencing cell size*

As described above, for any given spectrum allocation and service area, the system capacity may be increased by decreasing the size of each cell. It is therefore possible to adapt system capacity to increasing traffic demand by reducing cell size as necessary. This is accomplished by installing new base stations in regions of greatest traffic, thereby forming cells of a smaller radius. In this manner cell size can be tailored to the amount and distribution of radiotelephone traffic to be carried. To the extent that the mobile users are not uniformly distributed over the service area, the cells of a system at any particular stage of growth will be of different sizes. While total system cost increases as cell size decreases, the greater cost is shared by more users since small cells are provided only when the traffic demand requires it. This results in a nearly constant cost per user over a wide range of system capacities.

Cells as small as 1.5 km in radius appear to be practical. With smaller cells the transfer (hand-off) rate becomes very high. The upper limits on cell size are determined by such interrelated factors as propagation characteristics, base station antenna height, radiated power levels, receiver characteristics and desired grade of service.

1.4 *Operational techniques in small cell systems*

The small cell principle which has been described above in a general manner was proposed for both public and private use [Frenkiel, 1970; Staras and Schiff, 1970; FCC, 1970; Porter, 1971]. Although the specific system proposals may differ in detail, the following features are common:

- the division of the service area into cells and the provision of radio coverage from a multitude of base stations;
- in the service area, multiplying the frequency utilization;
- the overall control of the system by a centralized processor;
- the need to determine, for each mobile unit engaged in a call, the cell in which it is located.

Although such systems have been proposed for both public and private use, it should be noted that a system with a multitude of base stations, land transmission facilities to interconnect them and a processor with the capacity to control them, requires utilization by many mobile users to be economically justifiable. It should be noted that in situations where it is intended to transmit a message to a number of vehicles, distributed over several cells, the efficiency of frequency utilization is reduced. Further studies are needed to determine the effect on spectrum efficiency of combining private and public systems. Within the general description presented above, certain variations and "trade-offs" between cost and capacity are possible. Among these are the following:

1.4.1 *Frequency access capability and control*

The frequencies in a small cell system may be utilized in a variety of ways. Among these are the following:

- any single mobile unit may be capable of being switched to only one (or a limited number) of the frequencies, while each base station may serve all frequencies;
- each mobile unit may be capable of being switched to each frequency in the entire allocated set, while each base station may serve only a sub-set of the frequencies;
- each mobile unit may be capable of being switched to each frequency in the entire allocated set, and each base station may serve all frequencies.

Traffic studies indicate that the above techniques are in the order of increasing efficiency of frequency utilization.

Channel control means the control necessary to set up and maintain a traffic channel. Among the methods used to exchange channel control signals are:

- the exchange of control signals using traffic channels,
- the provision of dedicated control channels.

The choice between the above methods depends primarily on the amount of signalling traffic. In high capacity systems, the channels may be more efficiently utilized if the control channels are divided into paging channels and access channels.

1.4.2 *Diversity*

One or more diversity techniques to combat the effects of shadowing and multipath fading may be used, but are not absolutely necessary. The effect of such diversity is to increase significantly the efficiency of spectrum utilization [Lundquist and Peritsky, 1971]. The effects on system cost remain to be determined.

1.4.3 *Vehicle movement*

When a mobile unit engaged in a call crosses a cell boundary, the system may be equipped to become aware of this fact and to effect a transfer (hand-off) from the original base station to a more appropriate one; conversely, the system may only locate the mobile unit and assign a base station at the beginning of a call, maintaining that assignment for the duration of the call. If a mobile unit is allowed to continue to use a base station when it moves out of that station's cell, the signal it encounters will have greater variability and lower average value. Similarly, since it can now move closer to the co-channel base stations serving other mobile units on the same frequency, the interference it encounters, and the interference it causes, will increase. Therefore, for any given quality of transmission, co-channel base stations must, in general, be spaced further apart if "hand-off" is not employed. The extra spacing required (in absolute distance rather than multiples of cell radius) is proportional to the expected duration of the call. Therefore, the degradation in efficiency becomes less serious as expected holding time is decreased and as cell radius is increased. An important point to note is that small cell systems do not necessarily impose a limitation on the motion of the vehicle. With respect to the question of boundary crossings, there are two possibilities. For some systems (those with very short call duration) "hand-off" is not necessarily required since, typically, a call is ended while the vehicle is in or very near the cell it was in when the call started. For other systems (with much longer call durations), "hand-off" will be required. Fig. 1 shows the probability (S) with which a message of three minutes' duration can be completed as a function of the cell radius (r) for car speeds (v) between 10 and 100 km/h. Fig. 2 shows the probability for messages of one minute. Additional information can be found in [CCIR, 1970-74]. The technical problems associated with the implementation of "hand-off", while considerable, are not insoluble.

In a cell system, mobile location, detection and registration as well as inter-cell switching is necessary when a mobile station moves across a cell boundary. Requirements for these functions can be summarized as follows:

- to limit channel switching traffic;
- to maintain adequate transmission quality;
- to prevent the increase of co-channel interference;
- to minimize transmission line switching time.

In a system where common control channels are assigned to a group of neighbouring zones, one appropriate method to identify the radio zone, in which a moving vehicle exists, is the field strength level of the access burst signal transmitted from the mobile unit.

Mobile location registration may preferably be done in the home exchange memory. Each base station broadcasts its unique identification code via the control channel. The mobile stations in the area keep this code in memory. When a new identification code is received by the mobile station it automatically transmits its new location information, which is communicated to the home exchange.

1.4.4 *Channel assignment*

In a high capacity mobile telephone system using cells, it is necessary that intermodulation interference be minimized in the cells. However, the same channels need to be assigned for use in other cells beyond a critical cell spacing.

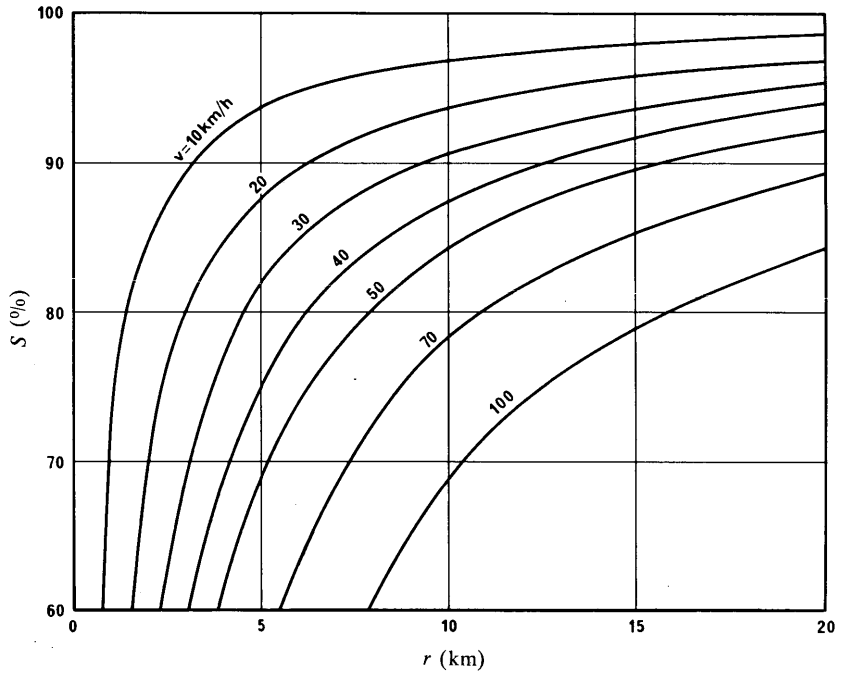


FIGURE 1

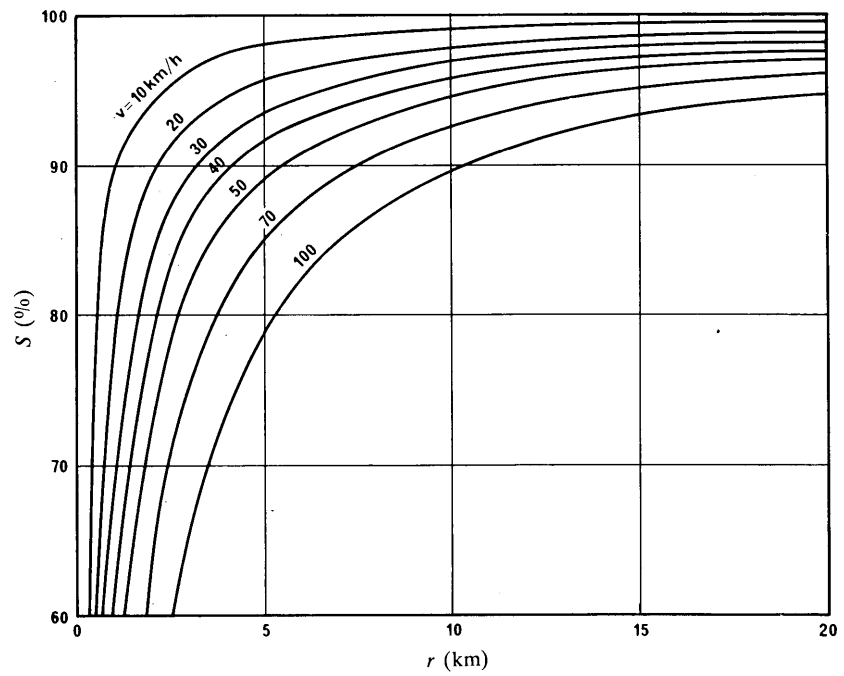


FIGURE 2 – *Probability (or probabilities) (S) of the completion of messages of 3 minutes (Fig. 1) and 1 minute (Fig. 2) as a function of the cell radius (r) for different car speeds (v) as parameters*

Various methods of assigning channels to avoid intermodulation have been proposed but most of these fail if the number of channels involved is more than about ten.

Effective and economical channel assignment methods are described in Report 901.

1.4.5 *Minimum allowable co-channel re-use distance*

Re-use in cellular systems will result in some co-channel interference which could reduce the quality of the wanted speech and even prevent access to the system. For this reason the re-use distance must be large enough to give an acceptable probability of co-channel intereference in the propagation conditions [Okumura, 1968] of multipath fading (which has a Rayleigh density function) and log-normal shadowing (slow fading), experienced in the land mobile radio service.

1.4.6 *Channel control in small cell systems*

Signal errors in the radio channel may result in loss of control and the inability to establish a traffic channel between mobile and base stations. The reliability with which a traffic channel may be obtained should be adequately high, since:

- radio channels correspond to lines in the public-switched telephone network and the reliability should be as good as in that network;
- to fail to establish a traffic channel means that the base station loses control of the mobile station. The probability of failure should therefore be as small as possible.

Methods which could improve the reliability of control and/or traffic channels are as follows:

- diversity;
- error correcting codes;
- repeated control signal transmission;
- message exchange protocol.

The choice between these methods depends upon the conditions of each system. The results of some field trials and simulator tests are given in Table I, Fig. 3 and Fig. 4.

In a high capacity system, a large number of mobile units request service by random transmission of burst signals via the reverse control channel. When two or more mobile units transmit request signals simultaneously, those signals interfere with each other and cannot be received correctly at a base station. Such an event is named a double or multiple seizure.

Various multiple seizure reduction techniques such as polling methods have been proposed, but in a high capacity system an efficient method of marking the busy/idle status of reverse channels on the corresponding forward channel is required.

1.4.7 *Control channel frequency assignment*

If the method which provides control channels for control use only is chosen, as shown in § 1.4.1, control channel frequency assignment may be independent of traffic channel cell size.

Two control channel frequency assignment methods are:

- assignment of a separate control channel for each traffic cell,
- assignment of a single control channel to cover a group of adjacent traffic cells.

The choice between the above methods is made in accordance with call processing reliability and control traffic in each system.

2. Reduction of ineffective air-time

In public radiotelephone systems, a significant delay resulting from switching and ringing time occurs between the initiation of a call and the start of the conversation.

The traffic capacity of a radiotelephone network can be increased by assigning radio channels only when both parties are ready to speak. Such a system may be described as an off-air call set up (OACSU) system [Tridgell, 1977].

TABLE I – *Experimental results of control and/or traffic channel reliability improvement*

Improvement Method	Measured equivalent carrier-to-noise ratio improvement value at the specified probability 1×10^{-2}
Diversity (simulation)	more than 10 dB (measured value shown in Fig. 3)
Error correcting coding (simulation)	more than 10 dB (measured value shown in Fig. 4)
Repeated transmission (field tests)	more than 7 dB (2 times instantaneous repetition) more than 14 dB (3 times instantaneous repetition)
Recycle (field tests)	more than 7 dB (maximum recycle: 2 times) more than 14 dB (maximum recycle: 3 times)
Conditions: Specified probability that message is not received Carrier frequency Control signal speed Type of code Message length Peak deviation of FSK modulation Fading rate Diversity specification Error correcting coding specification	 less than 1×10^{-2} 800 – 900 MHz 300 bit/s. Manchester code **30 bits** ± 5 kHz 40 Hz (mean) 2-branch antenna switched diversity whose threshold is 6 dB carrier-to-noise ratio BCH (36.30) coding

The capacity might be further increased if call requests are fed into the public switched telephone network (PSTN) and queued on a first-come-first-served basis until they materialize and a free traffic channel becomes available.

In addition, it is worth considering whether the base-mobile and mobile-base channels could be used independently and assigned on demand during a conversation.

A common signalling channel using time division multiplex and a fast signalling system could be shared between a number of users to initiate suitable action, e.g. to switch to a given traffic channel.

Supervisory signals normally generated at public telephone exchanges, e.g. engaged tone, would be simulated in the mobile equipment under control of data messages transmitted over the control channel.

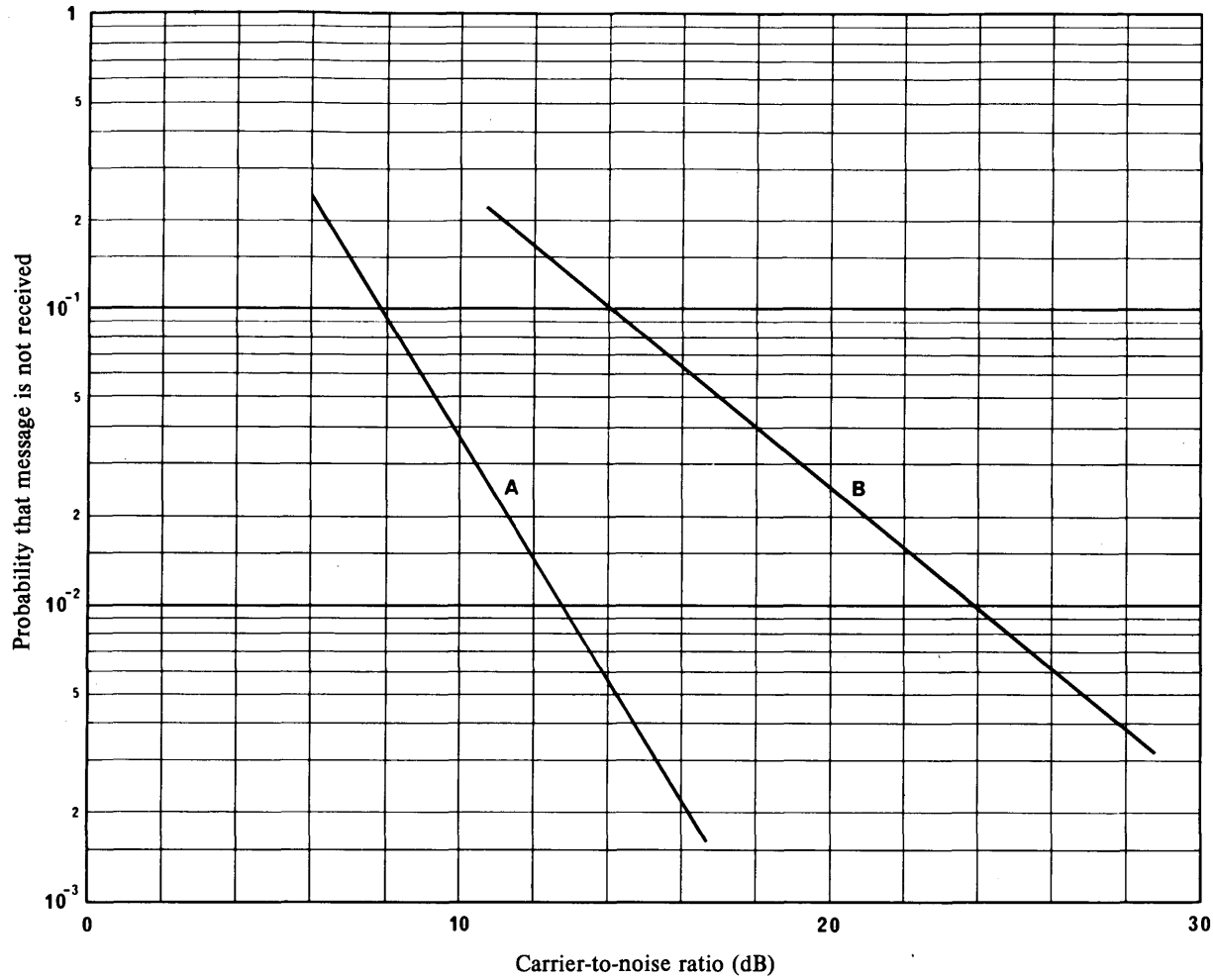


FIGURE 3 – *Diversity effect (measured value by fading simulator)*

Conditions:	signal speed	300 bit/s
	type of code	Manchester code
	message length	30 bits
	peak deviation of FSK modulation	± 5 kHz
	fading rate	40 Hz
	Noise is measured in 16 kHz band.	
	Carrier level is in median value.	

Curves A: 2-branch switched diversity (switching level *C/N*: 6 dB)
B: non diversity

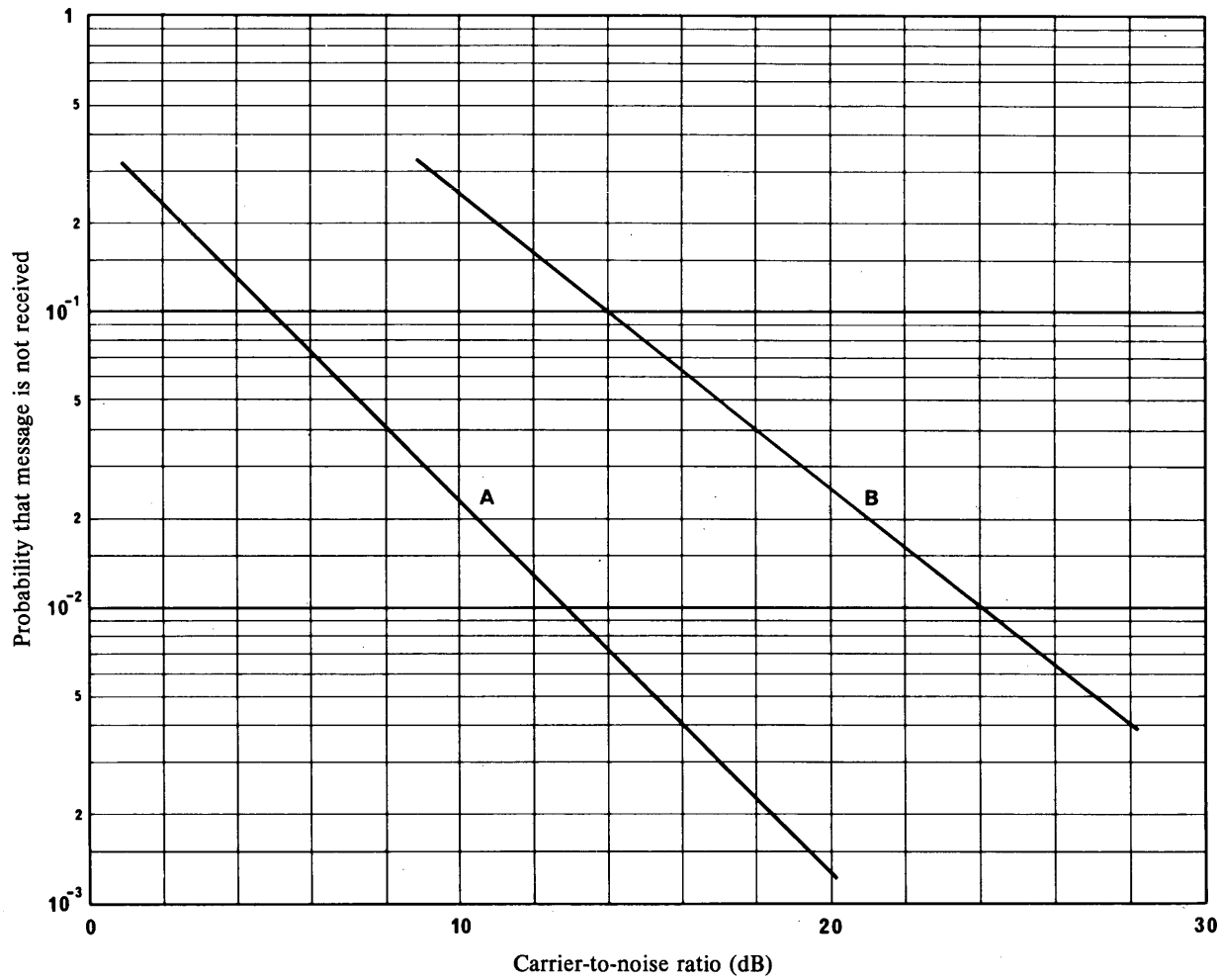


FIGURE 4 – *Error correcting coding effect (measured value by fading simulator)*

Conditions:	signal speed	300 bit/s
	type of code	Manchester code
	message length	30 bits
	peak deviation of FSK modulation	± 5 kHz
	fading rate	40 Hz
	Noise is measured in 16 kHz band.	
	Carrier level is in median value.	

Curves A: 1-bit error correcting
B: no correcting

REFERENCES

FCC [17 November, 1970] Motorola response. Docket 18262, Federal Communications Commission.

FRENKIEL, R. H. [May, 1970] A high capacity mobile radiotelephone system model using a coordinated small zone approach. *IEEE Trans. Vehic. Tech.*, Vol. VT-19, **2**.

LUNDQUIST, L. and PERITSKY, M. M. [August, 1971] Co-channel interference rejection in a mobile radio space diversity system. *IEEE Trans. Vehic. Tech.*, Vol. VT-20, **3**.

OKUMURA, Y. [September-October, 1968] Field strength and its variability in VHF and UHF land-mobile radio service. *Rev. Elec. Comm. Lab.*, NTT, Vol. 16, **9** and **10**.

PORTER, P. T. [August, 1971] Supervision and control features of a small-zone radiotelephone system. *IEEE Trans. Vehic. Tech.*, Vol. VT-20, **3**.

STARAS, H. and SCHIFF, L. [May, 1970] A dynamic space division multiplex mobile radio system. *IEEE Trans. Vehic. Tech.*, Vol. VT-19, **2**.

TRIDGELL, R. H. [March, 1977] Proposals for increasing the user capacity of the British Post Office public radiophone. IEEE 27th Vehic. Tech. Conf., Orlando, Florida, USA.

US ADVISORY COMMITTEE [1967] Report of the Advisory Committee for the land mobile radio services. United States Printing Office, Washington, DC, USA.

CCIR Documents

[1970-74]: 8/32 (Germany (Federal Republic of)).

BIBLIOGRAPHY

COX, D.C. and REUDINK, D. O. [July-August, 1971] Dynamic channel assignment in high-capacity mobile communications systems. *BSTJ*, Vol. 50, **6**.

FCC [20 December, 1971; 20 July, 1972; April, 1973] Motorola response. Docket 18262, Federal Communications Commission.

FCC [20 December, 1971; 20 July, 1972] AT&T response. Docket 18262, Federal Communications Commission.

SCHIFF, L. [February, 1970] Traffic capacity of three types of common user mobile radio communication systems. *IEEE Trans. Comm. Tech.*, Vol. COM-18, **1**.

PART B

SYSTEMS BEING INSTALLED OR PLANNED IN THE NEAR FUTURE *

1. High capacity cellular public mobile telephone services

1.1 *Introduction*

High capacity cellular systems have been developed in the United States, in the Nordic countries, and Japan to provide a high-quality, nationwide-compatible radiotelephone service [BSTJ, 1979; Ito and Matsuzaka, 1978].

One system in the United States is now in operation in the Chicago, Illinois, area.

It consists of ten cells which provide service to an area of about 5400 km^2. The system capacity can be expanded to meet the anticipated subscriber demands, which are expected to be more than 100 000 in the Chicago area. Another system using compatible technical parameters is in operation in the Washington DC/Baltimore, Maryland, area.

The system in Japan was put into commercial use in Tokyo in December 1979 and in Osaka in November 1980 and is being extended nationwide. The cellular system in Tokyo consists of 13 cells. Peripheral suburban areas (Yokohama, etc.) consist of more than 25 cells. The ultimate subscriber capacity is estimated to be 100 000 in the Tokyo metropolitan area (about 6000 km^2) with 1000 channels expected to be available. Traffic is estimated to be 0.01 erlang per subscriber in the busy hour.

The Nordic Mobile Telephone System (NMT) will be put into commercial use in Stockholm during October 1981 and will be extended to all participating countries during 1982 [NMT, 1980].

1.2 *Major system characteristics*

1.3 *System features*

The following system features are common to all three described systems unless otherwise stated:

- cellular structure in both base-to-mobile and mobile-to-base directions with frequency re-use and intercell handoff (switching call-in-progress);
- automatic, two-way, direct-dial operation;
- full duplex communications;

* See also Report 742-1.

TABLE II

	Chicago system	Japanese system	NMT system
Class of emission	40K0F9X	16K0F3E	16K0F3E
Transmit frequency bands (MHz)			
– base stations	870 – 890	870 – 885	463 – 467.5
– mobile stations	825 – 845	925 – 940	453 – 457.5
Duplex separation (MHz)	45	55	10
Channel spacing (kHz)	30	25	25
Total number of duplex channels	666	600 (expected to be increased to 1 000)	180
Power output (W)			
– base stations	45	25	50
– mobile stations	12 (with automatic remote power control)	5 (with automatic power control)	15 (with automatic remote power control)
Base station antenna gain (dB)	9	11	5
Typical cell radius (km)	2 (minimum) 20 (maximum) (cell splitting during system growth)	5 (urban area)(1) 10 (suburban area)(1)	5 (minimum) 40 (maximum) (cell splitting during system growth)
Voice signals			
– type of modulation	PM	PM	PM
– peak deviation (kHz)	±12	±5	±5
– processing	2 : 1 syllabic compandor	2 : 1 syllabic compandor	–
Control signals			
– type of modulation	FSK	FSK	FSK
– peak deviation (kHz)	±8	±4.5	±3.5
– type of code	Manchester	Manchester	NRZ
– transmission bit rate (kbit/s)	10	0.3	1.2
– effective information transmission rate (kbit/s) (depends on message type)	0.27 to 1.3	0.12 to 0.18	about 0.46
Error protection code	shortened (63 : 51) BCH-code	shortened (63 : 51) BCH-code shortened (15 : 11) BCH-code	
– base-to-mobile station	(40 : 28) BCH-code	(43 : 31) BCH-code	type B1 burst error correcting convolutional code (Hagelbarger)
– mobile-to-base station	(48 : 36) BCH-code	(43 : 31) BCH-code (access-channel) (11 : 7) BCH-code (paging channel)	
Error detection	minimum 3 errors	minimum 3 errors	–
Error correction	1 error	1 error	minimum 6 errors
Message protection	Recycled control signal transmissions repeated control signal/transmissions with bit-by-bit majority voting	Recycled control signal transmissions simultaneous transmissions from the base stations in a control zone	frame acceptance procedure depending on message category

(1) A control zone covers about 10 cells.

- voice channel supervision via continuous tone (Chicago system, NMT system);
- automatic roaming;
- dedicated control channels used for call setup (Chicago system, Japanese system);
- pre-seizure dialling.

1.4 *Conclusions*

Cellular radiotelephone systems using the parameters and features described above have been developed. There is a large demand for land-mobile radiotelephone service in many parts of the world and it is considered that systems with the above characteristics are capable of meeting that demand.

REFERENCES

BSTJ [January, 1979] Advanced mobile phone service. Vol. 58, **1**.

ITO, S. and MATSUZAKA, Y. [November, 1978] 800 MHz band land mobile telephone system – overall view. *IEEE Trans. Vehic. Tech.*, Vol. VT-27, **4**, 205-211.

NMT [1980] Nordic Mobile Telephone Group, Document 1: System description. Available at any of the Telecommunications Administrations of Denmark, Finland, Norway and Sweden.

REPORT 741-1

SHARED MULTI-CHANNEL PRIVATE MOBILE RADIO SYSTEMS EMPLOYING AUTOMATIC CHANNEL SELECTION

(Question 37/8)

(1978–1982)

Introduction

The portion of radio spectrum which is allocated to the land mobile radio service for private use is becoming increasingly congested and already many users (networks) have to share a channel with several other users. This practice employs the channel more effectively but gives the participants a reduced "grade of service" in the sense that they may often have to wait for some time for a channel to become free and they suffer from reduced privacy. The inconvenience involved may be unacceptable on even a moderately busy channel.

Improved channel utilization, better grade of service and good privacy conditions can be obtained if users are given access to several channels.

However, all kinds of shared systems (including the single-channel case) are characterized by the fact that the grade of service gets worse as more traffic is carried. Hence, it will be necessary to know what trade-offs can be made between the two and what improvements can be obtained by using more channels. Moreover, the question should be answered as to whether the performance of multi-channel systems using automatic channel selection provides enough improvement over a single-channel system to justify extra complexity, and, if so, how many channels will be needed.

This Report does not consider the interconnection of trunked dispatch systems with public or private switched telephone networks. Such interconnection requires further study. (For the purpose of this text "dispatch system" has the meaning: A radio system used to control the operation of a fleet of mobiles, such as aircraft, taxis, police, etc.).

This Report is divided into Parts A and B. Part A deals with the general aspects of multi-channel systems in which channel selection is made automatically, hereafter referred to as "trunked systems", with particular reference to dispatch systems. In Part B some examples are given of systems being installed or planned by some administrations.

PART A

GENERAL ASPECTS RELATING TO SPECTRUM
CONSERVATION AND SYSTEM DESIGN

1. System configuration

A typical arrangement of equipment, covering a single radio zone, is shown in Fig. 1 and consists of the following four principal items:

- a number of central control posts (CP), say a_c, each connected to a switching centre;
- a switching centre comprising a switching matrix controlled by a central processor;
- a number of channel equipments (CE), say n (where n is less than a_c, and equal to the number of radio channels), either located in the switching centre or not;
- a number of groups of mobile stations, each consisting of a_m Mobile Stations (MS) and each being served by its own CP.

To enable a CP to call one of its MSs, and vice versa, each CP and each MS considered have access to one of the radio channels by means of an access procedure which is still to be defined.

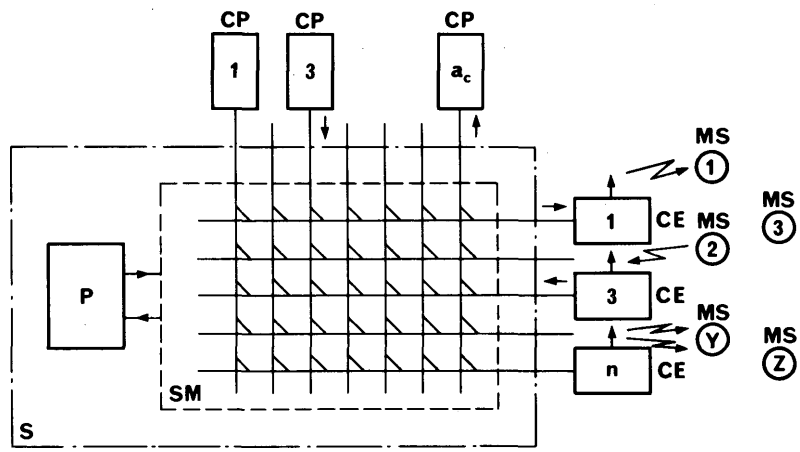


FIGURE 1 – *Arrangement of equipment in a trunked system*

CP: central control post
CE: channel equipment
MS: mobile station
P: processor
a_c: number of central control posts
n: number of radio channels
SM: switching matrix
S: switching centre comprising the central processor and the switching matrix. One or several CPs and one or several CEs may be located in the switching centre

2. Characteristics of dispatch traffic in private mobile radio systems

The increase in channel loading which can be achieved by trunking depends on the kind of traffic carried. Mobile radio dispatch traffic differs from public mobile telephony traffic in a number of ways:

- the mean holding time of calls is shorter (15 seconds may be typical);
- many users operate a vehicle fleet system where a single operator controls a number of mobiles;
- the size of fleets varies greatly.

2.1 *Fleet operation*

The number of users in the system is, in effect, equal to the number of CP operators not the number of mobiles, because if the operator is busy nobody in the fleet can place a new call. Thus all the traffic of the fleet passes through the operator and a mobile radio system therefore is characterized by a small number of users (operators), some of which may offer large loads and some small. Such a system is termed "unbalanced" (see also § 4).

Fleet operation means that there are actually two kinds of queue. The CP operator only ever has to wait because the channel is occupied by another fleet (the "sharing" delay) but a MS may have to wait not only for other fleets but also because his own operator is busy with a call to another MS (the "fleet" delay). It can be argued that the fleet delay can be ignored because:

- it is experienced only by the MSs, each of which uses the system rather sparingly compared with the CP;
- the delay can be reduced only if the fleet owner is prepared to employ extra operators, a factor which is outside the control of the systems designer;
- the psychological effect of waiting while one's colleagues talk to the CP is not the same as that of waiting while strangers block the channel.

2.2 *Random fluctuations*

The random nature of mobile radio dispatch traffic means that the busy hour traffic level will fluctuate. The fluctuations can be surprisingly large and last for significant periods. Upward fluctuations in the traffic level will result in a reduced grade of service which will be unacceptable to the users if they occur too often or last too long. It may be desirable to protect against this with an 'overload' criterion of the form:

- the ordinary busy hour grade of service should not degrade by more than, e.g., a factor of 2 for periods longer than half an hour occurring no more than once every 20 days.

2.3 *Day to day traffic variations*

Telephony experience [Hayward and Wilkinson, 1970] shows that there will be variations in the mean busy hour traffic from day to day in addition to the random fluctuations. With small numbers of users the variations can be expected to be large: the traffic will vary not only because of changes in the activity of the whole community, but also because of sudden changes in the demand of just a few of the users. The day to day variations add to the random fluctuations and so, in practice, the safety margin required for protection against overload is likely to be significantly larger than consideration of the random fluctuations alone would indicate. At present the extent of these variations has not been studied.

3. Grade of service and traffic handling capability

The increase in channel loading that can be achieved with a trunked system also depends on the grade of service required.

3.1 *Reference system*

The merits of the trunked system with respect to traffic handling capacity and radio channel efficiency can be compared with those of a single channel reference system employing automatic sharing, having the same amount of traffic per MS and the same number of MSs per CP and offering the same grade of service.

3.2 *Traffic assumptions*

In addition to the usual assumptions for dimensioning the traffic in ordinary telephone networks, the following assumptions may be made:

- communication is possible, in two directions in a simplex mode, between a CP and each of its MSs, but not more than one at a time;
- any other communication, for example between MSs of the same or different networks or between CPs of different networks, is excluded;
- all calls are queued and processed in the order of arrival;
- any degradation due to multipath fading, interference and other deficiencies inherent in radio transmission is disregarded.

3.3 *Delay criteria*

Because of the relatively short mean holding times encountered in mobile radio networks for private use, the character of the messages and the general pattern of conduct of the user of such networks, a waiting system, also known as delay or queueing system, is desirable.

For the purpose of traffic calculations a delay criterion, both under normal traffic and overload conditions, may then be used as a measure of the grade of service in accordance with current telephone practices.

The following criteria are appropriate:

- under *normal traffic conditions* the probability of excess delay (P), that is, the probability that a given waiting time is exceeded, shall be limited. If, for example, this waiting time is one mean holding time, then $P = P_r$. It may also be desirable to guard against occasional very long delays;
- under *overload conditions* the probability of excess delay shall not be more than, for example, twice the probability under normal traffic conditions (e.g. P_r), in the case that the traffic per MS increases by a given percentage, for example 10%. An alternative way of specifying the overload criteria is given in § 2.2.

3.4 *Probability of excess delay in the single-channel reference system*

The distribution of waiting time in the theoretical model of one telephone line serving a finite number of traffic offering sources is known and has been published. It can be shown that the model of a single mobile radio network consisting of one CP and a finite number of MSs is equivalent to the telephone model mentioned above, with the CP corresponding to the line and the MSs corresponding to the traffic sources.

However, the single-channel reference system consists of several such networks, each comprising one CP and several MSs. As the CPs are linked by the fact that they have access to only one radio channel, it was necessary to also consider the CPs as traffic sources. Consequently, a single radio channel serving simultaneously several CPs and their MSs will give rise to two rows of queueing calls which are linked to each other.

An exact solution of the distribution of waiting times has not been obtained but an approximate solution by means of computer calculations shows that for a single-channel reference system consisting of 10 CPs, each serving 10 MSs with a traffic load of 0.005 erlang per MS, the probability, P_r, of the waiting time exceeding the mean holding time (e.g. 15s) is equal to about 0.3.

3.5 *Channel efficiency and overload capability of a trunked system*

From the results of similar, preliminary calculations performed on a trunked system with the same probability of excess delay, $P_r \approx 0.3$, as the single-channel reference system, the following simple empirical relationship between the number of CPs (a_c) and the number of radio-channels n (where $n > 1$), is derived:

$$a_c = \frac{n - 0.6}{a_m \, \alpha_m}$$

where

a_m : the number of MSs per CP

α_m : the traffic per MS in the busy hour, expressed in erlang.

When the number of radio channels is increased, the admissible number of CPs increases in accordance with the above formula. The channel efficiency expressed in terms of traffic load per channel also increases. This last relationship is shown in Fig. 2 under normal traffic conditions, for a probability of excess delay of about 0.3.

However, with an increasing number of radio channels, the system becomes more sensitive to overload due to the increased traffic load per channel. Fig. 3 shows the permissible overload as a function of the probability of excess delay for different numbers of channels. From the overload criterion given in § 3.3, it may be concluded that the maximum number of radio channels in the case considered here amounts to 4 or 5, the overload criterion being slightly exceeded for $n = 5$.

3.6 *Discussion of the results*

Assuming five radio channels and 10 MSs per CP, each MS producing 0.005 E, it follows from the formula in § 3.5 that the system is capable of handling 88 CPs and 880 MSs with a radio channel efficiency (see Fig. 2) of 88%.

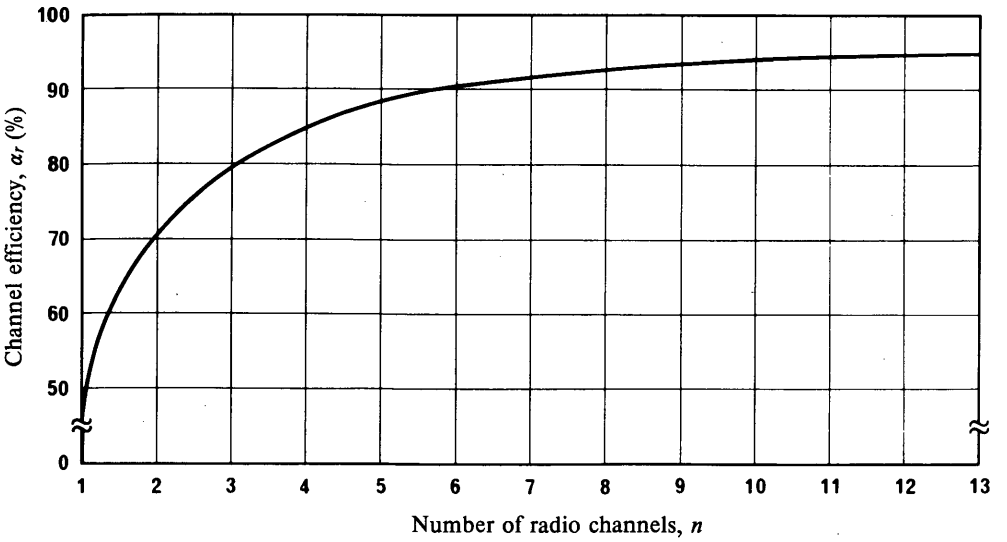


FIGURE 2 – *Radio channel efficiency in a trunked system*
(for a_m = 10, α_m = 0.005 E and P_r = 0.285)

α_m: traffic per MS
a_m: number of MSs per CP
P_r: probability of excess delay (delay equal to the mean holding time) under normal traffic conditions

One single-channel system with 10 CPs employing automatic sharing and serving the same number of MSs per CP with the same amount of traffic per MS, is capable of handling 100 MSs with the same grade of service, but with a channel efficiency of only 50%. The effective gain in spectrum utilization obtained by trunking thus amounts to $100(88 - 50)/50 = 76\%$.

When the system is compared with a manual system using a single radio channel and providing a similar grade of service, the effective gain only can be estimated; it will be of the order of 100%.

Figure 3 shows that if a smaller value of the permissible traffic overload and/or a larger value of the probability of excess delay under overload conditions is chosen, it is possible to increase the number of channels and, consequently, have a better spectrum utilization.

A further improvement is possible if, in contrast to what has been assumed in the present calculations, only those users are selected to participate in a particular trunked system, whose busy periods are not all coinciding.

It should be noted that the gain in spectrum utilization also depends on the inputs for the traffic data and further assumptions made, such as those mentioned in §§ 4 to 6.

4. Unbalanced systems

As discussed in § 2.1, fleet operation means that the number of users on a mobile radio system will often be small although the number of mobiles may be large. Also, the load offered by different users will often vary considerably [Davis and Mitchell, 1979]. A system in which large and small users are mixed is termed "unbalanced" and in such a system the large users can receive a much better grade of service than the small users [Davis and Mitchell, 1978], a large user offers a large amount of traffic in comparison to a small user. This leads to the problem of whose grade of service should be used to determined the permissible loading of the system.

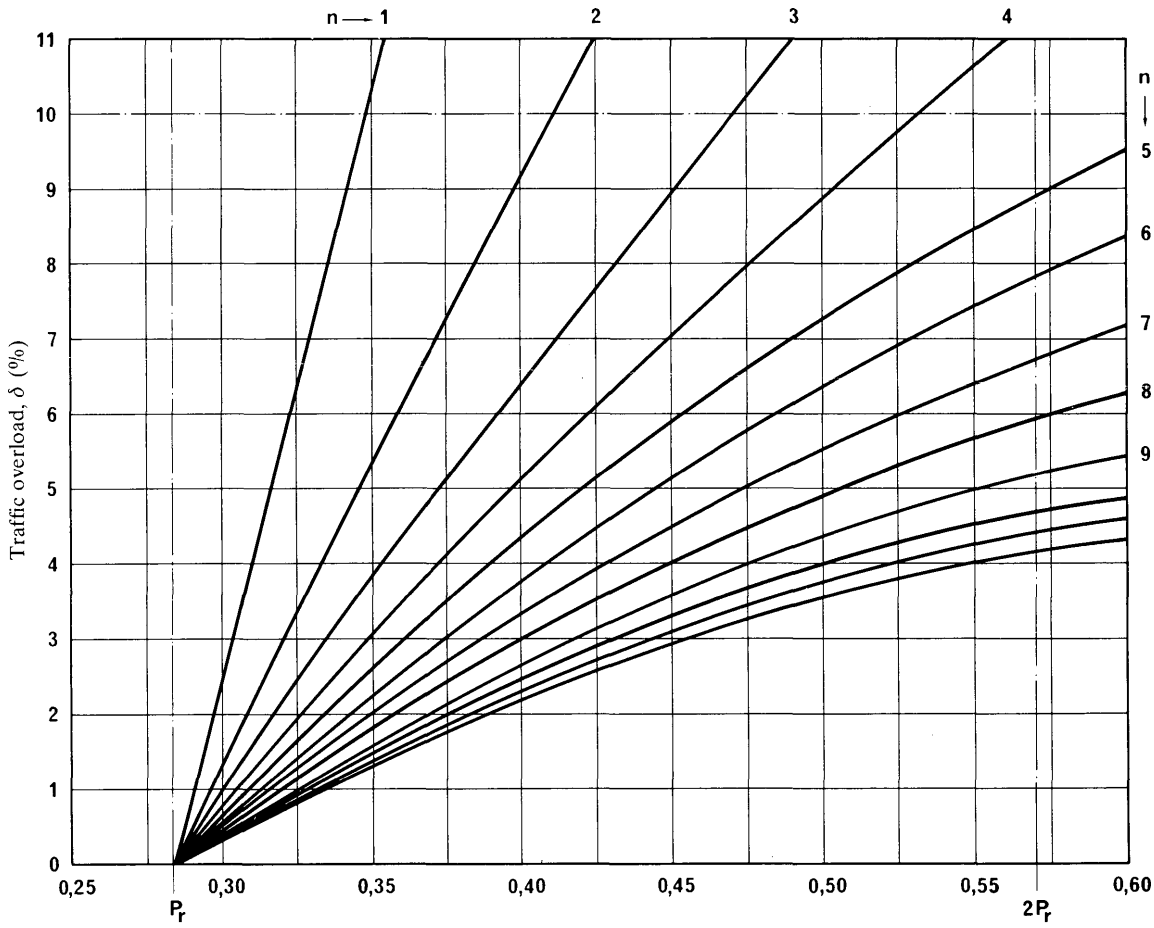


FIGURE 3 – *Traffic overload characteristics in a trunked system*
(for $a_m = 10$, $\alpha_m = 0.005$ E and $P_r = 0.285$)

n : number of radio channels
α_m: traffic per MS
a_m: number of MSs per CP
P_r : probability of excess delay (delay equal to the mean holding time) under normal traffic conditions

As an example, consideration is given to the channel efficiency which is possible in an unbalanced system, when a given grade of service criterion is applied to:

- the calls of the largest users only and,
- the calls of the smallest users only.

The grade of service criterion chosen for this example is that approximately 15% of calls may suffer a wait of more than one mean holding time. Only the time spent waiting for a channel is considered; the fleet delay is ignored.

The results for 1, 3 and 5 channel systems are shown in Fig. 4 [Davis and Mitchell, 1979]. When the grade of service criterion is applied only to the largest users then the channel efficiency can be significantly greater than it would be in a balanced but otherwise similar system. This is illustrated by curve A in Fig. 4. The probability of delay for the small users will then be worse than the specified grade of service criterion, but because they offer fewer calls the number of times they actually suffer a significant delay will still be small and perhaps acceptable. Curve A shows that unbalance reduces the amount there is to be gained from trunking in this situation because it allows the loading of a single channel to be increased.

If the grade of service criterion is applied to the small users in an unbalanced system the channel efficiency will in general be similar to the balanced situation as shown by curve B.

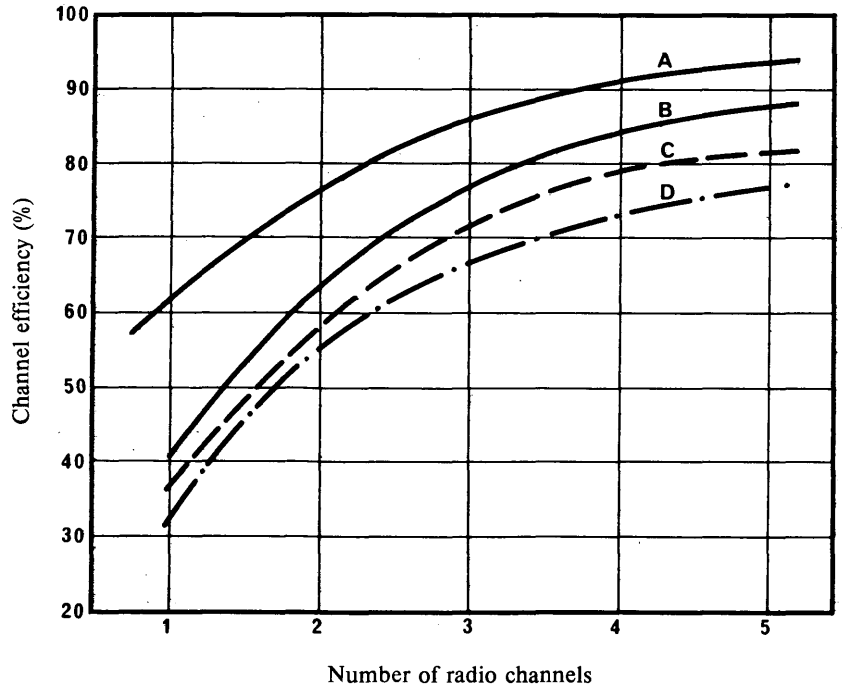


FIGURE 4 – *Radio channel efficiency in balanced and unbalanced systems as a function of the number of channels (such that the cumulative probability of delay greater than the mean holding time equals: 0.165)*

Curves A: results when the grade of service criterion is applied only to the large users (CPs) in an unbalanced system
B: results when the grade of service criterion is applied only to the small users in an unbalanced system
C: is for a balanced system in which all users offer the same amount of traffic
D: results from conventional telephone traffic theory

Note. – It is assumed that in the unbalanced case there are 1 large and 11 small equal users/channel (traffic ratio approximately: 11:1). In the balanced case there are 12 users/channel.

5. Signalling

In trunked systems with queuing of incoming call requests the signalling system used for handling these calls is crucial to the efficient operation of the system. The main design considerations are:

- the method for allocating the signalling channel;
- the method of access to the signalling channel;
- the method of contention control;
- the channel allocation time.

5.1 *Method for allocating the signalling channel*

The radio channel used for gaining access to the switching centre may be dedicated solely to signalling, but it is also possible to use any channel for that purpose. If, in this last case, one of the speech channels is temporarily idle, it may be marked as the signalling channel and be used as such during a limited period of time. In that case, the mobile attempting to place a call must detect this channel, for example by scanning the radio channels.

In both cases, dedicated signalling channel and non-dedicated signalling channel systems, the mobiles placing a call must all use the same channel and this may give rise to the problem of contention, that is, the problem of giving each contender a fair chance of gaining access to the channel in accordance with an established rule.

5.2 *Methods of access to the signalling channel*

There are two basic methods of accommodating in time the calls in the available signalling channel:

- an ordered method of access, for example a "polling" system in which each mobile is assigned a particular time slot which enables him to signal if he has a message to send,
- the random access method, for example some form of "ALOHA" [Kleinrock, 1976], in which the mobiles receive a standard starting signal inviting them to signal if they want to do so.

With polling, the signalling load depends on the number of users who have to be polled, rather than on the traffic offered. This is less efficient when there is a large number of users, each of whom offers traffic only occassionally. Moreover, any change in the number of mobiles requires some rearrangement of the polling routine.

The ALOHA type of systems may be much more efficient, provided the probability of "clashing", i.e. corruption of simultaneously transmitted calls, is sufficiently small.

5.3 *Contention control*

With the ALOHA type of systems every signalling message contains bits which are used for error detection allowing the control equipment to determine whether the message was corrupted by clashing with a simultaneous transmission from another MS. If the signal is successful an acknowledgement is sent; if it is not, the MSs concerned repeat their messages but with a randomly chosen delay between the first and second attempts. The process continues until the messages get through or a predetermined time elapses.

However, depending on the intensity of signalling messages and the availability of a signalling channel, there is a possibility of the system becoming unstable, i.e. the number of call requests pending (which are subsequently repeated and add to the new requests) becomes so large that the signalling channel's throughput is finally reduced to zero so that traffic handling ceases completely [Kleinrock and Lam, 1975].

Annex I to Part A reviews some alternative ALOHA systems and methods for contention control to improve stability.

5.4 *Channel allocation time*

For efficient operation the channel allocation time, i.e. the time that elapses between a channel becoming free and its being re-allocated, must be short compared with the average time between channels becoming free.

The channel allocation time depends on the signalling bit rate, the signalling format, the method of access and the system of contention control.

6. Other important design considerations

6.1 *Off-air call set up*

In order to minimize the amount of "air-time" wasted while a call is being set up all calls should be set up "off-air" as much as possible. This will be particularly important where the call is being made through the public telephone network where set-up times may be appreciable compared with typical holding times.

6.2 *End of conversation message*

A reliable end of conversation message should be used so that channels can be made available again as soon as the previous call is completed. Additionally, some form of time supervision of the channel may be required.

7. Conclusions

Although trunking cannot solve all problems relating to the frequency scarcity in the land mobile service, nevertheless it seems to be a valuable tool for frequency management. Trunking of moderately loaded single-channel systems (with a channel efficiency of about 50%) offers, as preliminary calculations have shown, for the same grade of service the possibility of accommodating up to twice the number of mobile stations on the same number of radio channels. Additionally, an improved service regarding privacy, operational convenience and overall system management is obtained.

As the improvement in channel utilization is very dependent upon the number of users, the way traffic is shared among them and the grade of service required, the improvement in channel utilization can be expected to vary considerably from one system to another. For example, preliminary results obtained by means of a traffic simulation with the system described in § 3 of Part B show that, for the same grade of service, a substantial spectrum efficiency can be achieved in the case of trunking of lightly loaded single-channel systems with a channel efficiency of the order of 15%. Trunking of heavily loaded single-channel systems with a channel efficiency of the order of 75% results in minor improvement of spectrum efficiency but will, however, lead to a substantial improvement in the grade of service.

From the above it should be noted that improved spectrum efficiency and/or grade of service is obtained by trunked systems, regardless of type of modulation, channel bandwidth and the like.

However, in order to convert to a trunked system the user has to incur additional cost due to a multi-channel radio set with more sophisticated signalling circuitry, and more complex base station operation. Further studies of the cost and benefits of achieving improvement in spectrum efficiency and/or grade of service, and also of the impact of signalling and the effect of unbalanced traffic, are needed.

REFERENCES

DAVIS, C.K. and MITCHELL, R.F. [April, 1978] Studies of small trunking systems for mobile radio. Communications '78 Conference Proceedings.

DAVIS, C.K. and MITCHELL, R.F. [June, 1979] Traffic handling capacity of trunked land mobile radio systems. IEEE International Conference on Communications, Boston.

HAYWARD, W.S. and WILKINSON, R.I. [1970] Human factors in telephone systems and their influence on traffic theory, especially with regard to future facilities. Proc. International Teletraffic Congress, Munich.

KLEINROCK, L. [1976] *Queueing Systems*, Vol. 2. John Wiley and Sons, New York, NY.

KLEINROCK, L. and LAM, S.S. [1975] Packet switching in a multi-access broadcast channel – Performance evaluation. *IEEE Trans. Comm.*, Vol. COM-23, 410-423.

ANNEX I TO PART A

METHODS OF CONTENTION CONTROL

1. Introduction

This Annex reviews some alternative ALOHA systems and methods of contention control to improve stability, distinguishing between systems with and without feed-back.

2. Systems without feed-back

Carrier sense systems [Kleinrock and Tobagi, 1975] seem to be less suitable as they cannot be used for two-frequency simplex operation and also labour under the so-called hidden terminal problem [Tobagi and Kleinrock, 1975].

By employing "slotted ALOHA", in which the signalling packets are transmitted in successive time slots, the clashing probability is reduced by a factor of about two compared with the conventional ALOHA-system without time slots [Abrahamson, 1977].

Introduction of an additional frame structure such that a mobile may signal in one of the slots of a frame, only if it had the signalling packet ready at the beginning of the frame ("framed slotted ALOHA" [Okada *et al.*, 1977]), leads to a better throughput of the signalling channel than "slotted ALOHA" [Capetanakis, 1979; Schoute, 1980].

In both cases, stability is improved if capturing occurs, for example with FM-transmissions where a strong call request signal may be received correctly even though it occupies the same time slot as the weaker signals.

Although under normal traffic conditions framed slotted ALOHA employing, for example, 3 frames of constant length with 4 slots each, is unlikely to become unstable when capturing occurs, some form of dynamic (or feed-back) control may be desirable for the reasons set out in § 3 below.

3. Systems with dynamic (feed-back) control

Among the reasons justifying dynamic control, the following may be mentioned:

3.1 It is generally assumed that the number of new call requests arriving is a random variable following a Poisson distribution. This would be correct if the arrival process is a Poisson process *and* the time between signalling periods is constant. If, as it is normally the case, the time between signalling periods is not constant, the assumption is no longer valid. The non-Poisson distribution results in an increased probability of the system becoming unstable, particularly under conditions of increased signalling intensity, such as those mentioned in 3.2 and 3.3 below.

3.2 An additional burden is placed on the signalling system if some event takes place (e.g. an accident, traffic queue and the like) near the boundary of the radio zone. In this case, an increased amount of weak call requests may be expected during a prolonged time, resulting in a reduced probability of capturing.

3.3 Initial bursts of call request may occur if for some reason (e.g. technical malfunctioning of the system or excessive holding times of a temporary nature) there is no possibility to signal during several minutes in systems with a non-dedicated signalling channel, and mobiles are eager to transmit a request packet.

Dynamic control procedures have been studied by various authors [Lam and Kleinrock, 1975; Fayolle *et al.*, 1977]; a quantitive analysis of instability when there is no feed-back in the case of "framed slotted ALOHA" may be found in [Schoute, 1980].

An example of dynamic control of random access, especially for use in the maritime mobile satellite service, is the binary search procedure, described in Annexes I and II of Report 596, which, when used in conjunction with "framed slotted ALOHA", can give relatively high throughput [Capetanakis, 1979].

Another example, specifically adapted to private land mobile radio, is slotted ALOHA with dynamic frame length control [Schoute, 1980].

With this system the number of slots in a frame is not constant, but is automatically adapted to the expected demand, thus eliminating the cause of instability. The algorithm used in the system is handled by the switching centre and controls the number of available time slots in a frame on account of observations made on the utilisation of the time slots in a previous frame. Each time an ALOHA start signal is transmitted, the mobiles are informed about the available number of slots. Each mobile with a request pending then selects at random one of those slots.

The process of updating the number of slots in the new frame is based on:

- the number of successful, garbled and empty slots in the previous frame;
- the expected number of new calls since the beginning of that frame;
- some data which are computed off-line from stored information concerning the properties of the modulation system, the regional radio propagation conditions and the geographical distribution of mobiles.

Updating of the stored information to cope with gradually changing conditions is possible by means of an automatic learning process based on long term observations, according to appropriate software to be incorporated in the switching centre.

Under certain practical assumptions the number of time slots in a frame is equal to one for low traffic intensities and may increase up to, for example, 15 during the busy hour.

The variable number of time slots also results in a signalling time and a waiting time, which, for low traffic intensities, are both equal to about half of that required for the slotted ALOHA system with fixed frame length mentioned in § 2 above.

REFERENCES

ABRAHAMSON, N. [1977] The throughput of packet broadcasting channels. *IEEE Trans. Comm.*, Vol. COM-25, 117-128.

CAPETANAKIS, J.I. [1979] Three algorithms for packet broadcast channels. *IEEE Trans. Inform. Theory*, Vol. IT-25, 505-515.

FAYOLLE, G., GELENBE, E. and LABETOULLE, J. [1977] Stability and optimal control of the packet switching broadcast channel. *J. ACM*, Vol. 24, 375-386.

KLEINROCK, L. and TOBAGI, F. [1975] Random access techniques for data transmission over packet switched radio channels. Nat. Computer Conference 1975.

LAM, S.S. and KLEINROCK, L. [1975] Packet switching in a multi-access broadcast channel – Dynamic control procedures. *IEEE Trans. Comm.*, Vol. COM-23, 891-904.

OKADA, H. *et al.* [1977] Analysis and application of framed ALOHA channel in satellite packet switching networks – FADRA method. *Electron. and Comm. in Japan*, Vol. 60-B, 72-80.

SCHOUTE, F.C. [July, 1980] Control of ALOHA signalling in a mobile radio trunking system. IEE radio spectrum conservation techniques. Conference Publication No. 188, 38-42.

TOBAGI, F. and KLEINROCK, L. [1975] Packet switching in radio channels – Part II. *IEEE Trans. Comm.*, Vol. COM-23, **12**, 1417-1433.

PART B

SYSTEMS BEING INSTALLED OR PLANNED IN THE NEAR FUTURE

The systems referred to in Part B do not necessarily meet all design indications mentioned in Part A.

1. Example of a trunked mobile radio dispatch system in the United States

In the United States, trunked mobile radio systems are being installed for dispatch traffic using between 5 and 20 channels in the 900 MHz band. One channel on each system is a dedicated signalling channel where all requests for service and instructions to mobile users are made. The other channels are for two-way voice communication. The base stations operate in a duplex mode and the mobiles on a push-to-talk basis.

The dedicated signalling channel is organized in a time slotted configuration for contention control and uses a 78 bit word format transmitted at a 3600 baud rate on a direct frequency modulated carrier at 3 kHz deviation requiring approximately 23 ms to be transmitted. A 21 bit word format at a 150 baud rate on the voice channel provides subaudible connect and disconnect signalling to mobiles. Error detecting and code correcting techniques are used to protect the integrity of information.

Requests for service are queued and mobiles are served on a first-come first-served basis. Generally users speak for periods of only 2 to 3 seconds, with pauses of a few seconds in between. The system signalling speed allows the processor to recognize these pauses in conversation and reclaim the idle talk channel for reassignment to other groups. When the original user group is ready to continue its message, it will be assigned a new voice channel (or its request will be placed in a priority recent system user queue if no talk channels are available).

The use of this trunked system for extended area coverage, portable units and/or satellite receivers and direct mobile to mobile/portable communications is still being evaluated.

2. Basic characteristics for a planned trunked dispatch system in Sweden, SARK

In Sweden [CCIR, 1978-82a] a trunked dispatch system with national coverage has been projected. The system will allow traffic between all users which will be of special importance during relief operations. The SARK system is based on the following assumptions:

Number of mobile stations	120 000
Number of base stations	250
Mean number of channel equipments per base station	approx. 9 (see § 1 of Part A)
Number of central control posts	8000
Number of switching centres	25
Traffic load/mobile station (during busy hour)	0.008 erlang
Mean holding time	30 s
Traffic mode	duplex/half duplex
Probability of delay exceeding 12 seconds (all calls included)	$< 1.5\%$

The requisite number of radio frequency pairs (channels) in the most congested area has been calculated to be 165. The neighbouring protection area occupies another 115 radio channels. In all 280 radio channels will thus be required.

To ensure a margin for increases in the traffic load the system will be allocated approximately 400 radio channels. The total number of radio channels occupied today (1980) by the same users is approximately 2000. In the comparison between these figures it should be taken into account that a lot of these users are organizations within the public security services which cannot accept conventional frequency sharing for reasons of their need for privacy and high service degree, and which therefore today occupy exclusive channels with a relatively low traffic load in some cases.

3. Experimental trunked mobile radio dispatch system developed in the Netherlands and the United Kingdom

The experimental trunked dispatch system developed in the Netherlands and the United Kingdom operates in accordance with the queueing principle and employs a switching centre of the Stored-Programme Control type. Communication is possible in a semi-duplex mode between a mobile and its control post and also, in a two-frequency simplex mode, between mobiles of the same fleet.

Binary signalling is employed with a message format containing the appropriate sync., data and error control bits. The method of contention control is that described in § 3 of the Annex to Part A and is known as slotted ALOHA with dynamic frame-length control.

The system is suitable from one radio channel upwards and can be expanded up to the limit of the switch matrix by adding new channel equipment and updating the ROM tables in the central processor and mobiles. Adding mobiles only requires the table of valid users in the central processor memory to be updated. The same is true for the control posts up to the limit of the switch matrix.

The system normally employs channel scanning but to further improve system efficiency when the number of channels increases, a transition can be made to a dedicated signalling channel mode of operation with only minor software modifications.

The system provides for ancillary functions, such as group calls, talk-through, call forwarding and emergency calls, and also permits the information handling required for multi-zone operation (e.g. roaming and hand-off) and network management.

To evaluate the effect of trunked operation for different system configurations under various conditions with respect to channel loading, propagation etc., traffic simulation tests have been made by employing a computerized Traffic Simulator and Analyser [CCIR, 1978-82b] which provides the signalling and simulates the traffic of an arbitrary number of virtual control posts and mobile stations, and analyses the resulting traffic.

The cumulative distribution of waiting times produced by the analyzer part of the simulation equipment has been used as a basis for the comparison of the performance of the various system configurations under varying conditions of use.

REFERENCES

CCIR Documents

[1978-82]: **a.** 8/60 (Sweden); **b.** 8/491 (Philips Telecommunicatie Industrie).

REPORT 901

FREQUENCY ASSIGNMENT METHODS FOR TRUNKED MOBILE RADIO SYSTEMS

(Question 37/8)

(1982)

1. Introduction

This Report deals with proposals from several administrations on the assignment of channels to trunked systems so as, among other reasons, to reduce intermodulation product interference between systems and within the trunked system itself.

2. Channel groupings with fixed channel separations

In this method, used in the 900 MHz band in the United States of America, channels are grouped into blocks and each channel is separated from the others in the block by a fixed number of channels of nominal channel spacing (usually 25 kHz). Consequently each successive channel block is offset by one channel. Sub-blocks can also be identified to provide flexibility in the number of channels assignable to any individual system.

Table I gives an example using a 200 channel allocation. This total allocation of 200 channels could be divided into 10 blocks of 20 channels with 10 channel spacing between frequencies within the block. This arrangement also subdivides each 20 channel block into 5 channel groups with 40 channel spaces between successive frequencies in each 5 channel group. In addition, these 5 channel groups are arranged into 4 blocks with two 20 channel spacings and one 10 channel spacing between 5 channel groups. This illustration also offsets successive 20 channel blocks by 1 channel to form ten 20 channel blocks.

With the method outlined above intrasystem interference is minimized, in particular since intermodulation products coincide with other frequencies in the same channel block and do not fall in between the channels. The signal from a multi-channel base station on a particular frequency will at any point in the coverage area exceed intermodulation products falling in the same channel, since they result from transmissions from the same base station (but also see Report 739).

TABLE I – *Channelization for trunked system*

Block	Channels	Block	Channels
1	1 – 41 – 81 – 121 – 161 21 – 61 – 101 – 141 – 181 11 – 51 – 91 – 131 – 171 31 – 71 – 111 – 151 – 191	6	6 – 46 – 86 – 126 – 166 26 – 66 – 106 – 146 – 186 16 – 56 – 96 – 136 – 176 36 – 76 – 116 – 156 – 196
2	2 – 42 – 82 – 122 – 162 22 – 62 – 102 – 142 – 182 12 – 52 – 92 – 132 – 172 32 – 72 – 112 – 152 – 192	7	7 – 47 – 87 – 127 – 167 27 – 67 – 107 – 147 – 187 17 – 57 – 97 – 137 – 177 37 – 77 – 117 – 157 – 197
3	3 – 43 – 83 – 123 – 163 23 – 63 – 103 – 143 – 183 13 – 53 – 93 – 133 – 173 33 – 73 – 113 – 153 – 193	8	8 – 48 – 88 – 128 – 168 28 – 68 – 108 – 148 – 188 18 – 58 – 98 – 138 – 178 38 – 78 – 118 – 158 – 198
4	4 – 44 – 84 – 124 – 164 24 – 64 – 104 – 144 – 184 14 – 54 – 94 – 134 – 174 34 – 74 – 114 – 154 – 194	9	9 – 49 – 89 – 129 – 169 29 – 69 – 109 – 149 – 189 19 – 59 – 99 – 139 – 179 39 – 79 – 119 – 159 – 199
5	5 – 45 – 85 – 125 – 165 25 – 65 – 105 – 145 – 185 15 – 55 – 95 – 135 – 175 35 – 75 – 115 – 155 – 195	10	10 – 50 – 90 – 130 – 170 30 – 70 – 110 – 150 – 190 20 – 60 – 100 – 140 – 180 40 – 80 – 120 – 160 – 200

3. Coherence bandwidth groupings

This method has been developed by Sweden.

Important effects in mobile radio propagation are amplitude fading and time dispersion limiting the coherence bandwidth (the bandwidth within which fading has 0.5 or greater correlation). Wanted signals and intermodulation products from the same antenna will fade in unison as long as they are contained within the coherence bandwidth, which is usually at least 100 kHz since the time delay spread in existing mobile bands is less than 3 μs r.m.s. over 99% of the urban area [Cox, 1977; Jakes, 1974]. This bandwidth may be lower in areas where a high excess path delay occurs, which has been observed in some areas. The optimum number of trunked channels is shown in Report 741 to be 4 or 5. Therefore, four consecutive 25 kHz channels fulfil the optimum and remain within an acceptable coherence bandwidth of 100 kHz.

When using four consecutive channels on a re-use interval of 4.6 times the coverage radius (a commonly used factor), up to 44% increase in spectrum efficiency is possible (using the methodology of Report 662) when compared with 4 randomly assigned channels. In the latter case many channels cannot be assigned within the coverage area due to the number of intermodulation products created.

Assignment of continuous frequency bands of 100 kHz may allow the future use of flexible time division systems for integrated signalling, data, telex and digitized (encrypted) speech.

REFERENCES

COX, D. C. [November, 1977] Multipath delay spread and path loss correlation for 910 MHz urban mobile radio propagation. *IEEE Trans. Vehic. Tech.*, Vol. VT-23, **4**, 340.

JAKES, W. C. [1974] *Microwave mobile communications.* John Wiley and Sons, New York, N.Y.

REPORT 742-1*

PUBLIC LAND MOBILE TELEPHONE SYSTEMS

(Question 39/8)

(1978-1982)

1. Introduction

This Report deals with the general principles of public land mobile telephone systems and, in particular, with system parameters and technical characteristics which are important for international operation.

Public land mobile telephone systems are defined as land mobile systems for public correspondence via radio stations connected to the switched public telephone network.

The major characteristics of some existing public land mobile telephone systems are given in Report 740.

2. Operational aspects of public land mobile telephone systems

The following general operational aspects should apply:

- automatic setting up and charging of calls to and from the mobile station;
- for international systems, the ability to set up calls between the mobile stations and any fixed telephone subscriber or any other mobile telephone subscriber within the system;
- costs should be charged in a manner consistent with charging principles in the public switched telephone network;
- the introduction of the system should not necessitate any significant changes in the fixed telephone networks.

3. Numbering plan and routing

A difficult problem in a fully automatic mobile telephone service is to select a numbering plan for the mobile subscribers which is compatible with the established fixed network. A numbering plan based on the conventions built up in the land network may impose severe limitations on mobile routing especially since the subscriber number in a mobile system no longer is referred to the location of the subscriber.

One solution is to allocate a special access number to the mobile service, in which case all dialling to the mobile network is handled free from the routing routines of the telephone service.

Since national numbering plans vary in their capability to manage long numbers and to allocate codes to special services, an international numbering plan needs to be established. This is a matter on which the appropriate CCITT Study Groups should advise.

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* The Director of the CCIR is requested to bring this Report to the attention of the CCITT.

4. Roaming

To be able to automatically set up calls between the mobile stations and any fixed telephone subscriber regardless of country, a fully automatic roaming facility is necessary. The mobile system has to be informed of the location of the mobile subscriber as he moves from one traffic area to another.

Further studies are required before adequate technical and operational roaming procedures can be defined. For this reason Interim Working Party 8/9 has been established.

5. Charging

The principle for charging in mobile networks varies in different national networks.

The question of charging therefore needs to be studied by the CCITT to achieve international agreement.

6. Radio frequency considerations

National and international public mobile radio systems under development and in service utilize the 450 MHz band and the 900 MHz band.

Further studies are necessary before the choice of a radio frequency band for an international public mobile telephone service can be made.

The following factors need to be taken into consideration:

- required system capacity;
- availability of frequencies;
- spectrum efficiency;
- propagation characteristics.

Other radio frequency parameters which need international agreement are the following:

- class of emission;
- modulation characteristics;
- channel spacing;
- standards relating to co-channel and adjacent channel requirements.

7. Signalling

The system functions which are required in an automatic public mobile telephone system require a fairly complicated signalling system. The mobility of the subscribers creates a need for information transfer of a kind that has no equivalence in the fixed telephone network. This applies both to the updating procedure, performed when the mobile station enters a new traffic area, and to the hand-off procedure when a call in progress is switched from one base station to another.

REPORT 902

RADIATING/LEAKY CABLE SYSTEMS IN THE LAND MOBILE SERVICES

(Question 36/8)

(1982)

1. Introduction

Radiating cables, also referred to as leaky cables or leaky feeders, will be referred to as leaky cables in this report, since this term is more generally used in the published literature.

A leaky cable is an "open" transmission line or waveguide in which the electromagnetic wave may travel longitudinally both "inside" and "outside" the guiding structure [Fernandes, 1981]. The transmission of radio frequency energy from a cable to an antenna and vice versa is possible, so that two way communication with a mobile radio can be achieved.

The mechanisms of electromagnetic energy exchange between a leaky cable and the environment largely depend on the modes of propagation in that environment and hence on the frequency, as well as the conditions in which the cable is used. These factors must therefore be considered in the study of leaky cables, which are mostly used in confined spaces, such as tunnels, mines or large buildings [Farmer and Shepherd, 1965, Martin, 1975, Martin and Haining, 1979]. Leaky cables may also be used to confine the coverage area of a radio system and thus improve the spectrum efficiency.

As an alternative to leaky cables, radio propagation from antennas may be used in tunnels. This is sometimes called "natural propagation" and can be economic at frequencies much higher than the cut off frequency of the tunnel considered as a waveguide. The Annex deals with natural propagation in tunnels and buildings.

2. Classification of leaky cables

It is common practice to use the following types of leaky cables:

(a) balanced cables;
(b) continuous leaky coaxial cables;
(c) coaxial cables with periodic apertures;
(d) cables with mode converters.

Balanced and continuous leaky coaxial cables are intrinsically non-radiating in the sense that a cable of infinite length extending in free space can only carry waves guided by the structure. However, any discontinuity along the cable causes mode conversion and radiation.

In type (c), the periodic apertures are radiating discontinuities and act like the elements of an antenna array. Maximum radiation is obtained in oblique directions determined basically by the ratio of the spatial interval to the wavelength.

In the last type, the mode converters or radiating elements are separate discontinuities acting in isolation.

2.1 *Basic cable performance parameters*

The performance of a leaky cable system may be characterized by two parameters:

- longitudinal attenuation,
- coupling loss.

The longitudinal attenuation is governed primarily by the factors which apply to normal transmission lines, such as construction and dielectric. Additionally there is a small loss component attributable to the leakage (or mode converters).

The coupling loss is, in general terms, the power loss between the cable and the mobile antenna in the vicinity of the cable. It is dependent on the degree of shielding, the configuration of the shield or conductors and the permittivity of the dielectric. For a given cable construction it should be noted that the coupling loss is also dependent upon:

- the environment in which the cable is mounted;
- cable mounting position;
- characteristics, position and orientation of the mobile antenna;
- the operating frequency.

The longitudinal attenuation of cables designed for a low coupling loss can increase substantially with close mounting of the cable to a wall, structure or other cables or with surface contamination, except for cables specifically designed to minimize this effect such as the triaxial (tri-coaxial) cables and cables with mode converters. In the same process the coupling loss is usually decreased (i.e. the received signal is increased).

For a given coupling loss, various types of cables are not subject to the same increase in attenuation. Balanced lines are by far the most sensitive, followed by longitudinally slotted cables and lastly by the various types of cable with numerous small holes.

2.2 *Balanced cables*

Balanced cables (bifilar lines) in general have a low coupling loss and a lower longitudinal attenuation for a given conductor size, when compared with coaxial cables. For these reasons they are generally the lowest cost of all leaky cables. However, they can be susceptible to mounting position and surface contamination at VHF and particularly at UHF.

If balanced cables are twisted at a ratio of 1 turn per wavelength the transversal radiation is increased (coupling loss decreased) by up to 15 dB [Farmer and Shepherd, 1965]. However, at frequencies when this twist ratio is not maintained the radiation may be decreased by up to 15 dB [Martin, 1975].

2.3 *Coaxial cables*

2.3.1 *Continuous leaky coaxial cables*

This type includes the loosely braided cable, cables with continuous slots, either with two or three coaxial conductors and cables with discrete apertures or slots separated at distances much smaller than the wavelength.

Since these coaxial cables have an imperfect outer conductor, part of the transmission line energy travels outside the cable as a leakage field.

The congestion radius in which most of the power of the coaxial mode leakage fields is situated is inversely proportional to the frequency. It is of the order of 60 cm at 100 MHz and varies in inverse ratio to the dielectric constant of the cable insulation.

The mechanism by which the mobile antenna is coupled to the coaxial mode is the diffraction of the coaxial mode leakage fields by the inhomogeneities within the congestion radius. These are the inhomogeneities and irregularities in the environment, cable construction and suspension brackets and obstacles of all kinds.

Since this diffraction is a random process, its intensity is usually defined by the coupling loss. It appears that, in tunnels, the coupling loss hardly depends on the distance of the antenna from the cable; this is due to the fact that the diffracted fields are carried by numerous waveguide modes.

An increase in the spacing in the braid or an increase in the size of the slot apertures or braid apertures can decrease the coupling loss with a resultant increase in cable attenuation, although this dependence is not linear [Fernandes, 1979 and 1980].

2.3.2 *Coaxial cables with periodic apertures*

Coaxial cables with discrete apertures with dimensions and/or periodicity comparable with the wavelength are a source of radiant energy.

A coaxial cable with zig-zag slot array can be treated as an antenna array [Nakahara et Kurquchi, 1968] and the transmission energy in the cable is little affected by the radiation from slots. The radiating field propagates as a cylindrical wave.

Properly located zig-zag slots in coaxial cables improve radiation in the transversal direction and it is possible to manufacture cables with different coupling losses suitable for grading (§ 3.2.2).

2.4 *Cables with mode converters*

These are ordinary balanced or coaxial lines fitted with devices to convert part of the energy carried by the line into guided modes propagating outside the line or into radiated spherical waves; the devices are installed with either regular or irregular spacing at points determined by the propagation conditions prevailing in the surrounding environment [Deryck, 1972; Delogne, 1973 and 1976].

As a radiating device for coaxial cables, a slot may be cut around the circumference, thus forming a complete interruption of the outer conductor, to which circuit elements are added so that only part of the power transported by the cable is radiated [Delogne and Liegeois, 1971].

The spacing of the mode converters may vary from 100 m to 1 km depending on the system input power, the position of the cable in the tunnel and the cable attenuation. The mode converter conversion rate may be adjusted by a suitable choice of circuit components. A common conversion rate is approximately 10% which gives rise to an insertion loss of about 0.5 dB per converter [Delogne, 1979].

Mode converter systems have been constructed using a short section of continuous leaky cable inserted in the conventional "non-leaky" cable. Such a section acts as a continuous network of circumferential slots.

3. Leaky cable systems

3.1 *Basic system*

A basic leaky cable system for two-way communications comprises a base station transmitter and receiver connected to a leaky cable which provides communications to conventional mobile stations as shown in Fig. 1. By placing the base station transmitter/receiver at the centre of a cable the longitudinal coverage of a leaky cable can be effectively doubled relative to the end fed cable.

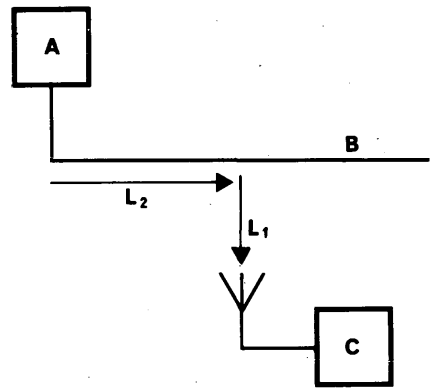


FIGURE 1 – *Basic system*

A: base station
B: leaky cable
C: mobile

L_1: coupling loss
L_2: cable insertion loss

3.1.1 *Communication range*

The linear (end-to-end) communication range of the basic leaky cable system can be calculated from the following:

$$S = P_{TX} - P_{RX} = L_1 + L_2$$

where:

S: System loss (dB)

P_{TX}: Transmitter power (dBW)

P_{RX}: Receiver input power at end of cable (dBW)

L_1: Coupling loss for the particular system (dB)

L_2: Cable insertion loss from the base station to the end of the cable (dB)

For end fed cables:

$$R = 2\,\frac{L_2}{A}$$

and for centre fed cables:

$$R = 2\left(\frac{L_2 - 3}{A}\right)$$

where:

R: the linear communications range (km)

A: cable longitudinal attenuation (dB/km).

Coupling loss is normally given in specification sheets at a given distance from the cable. For the purpose of this Report, coupling loss is the ratio, in dB, of the power transmitted within the cable to the available power received by a vertically polarized half-wave dipole located an arbitrary 10 m from the cable.

Typical values of coupling loss for balanced cables are from 30 dB (when twisted at 1 turn per wavelength) upwards; for continuous leaky coaxial cables, from 60 dB to 100 dB [Cree and Giles, 1975] and for coaxial cables with periodic apertures from 60 dB to 90 dB; cables with mode converters have been designed to give coupling losses from 50 dB upwards.

3.2 *More complex systems*

3.2.1 *Use of repeaters*

Line amplifiers or repeaters can be inserted at frequent intervals to compensate for losses in the leaky cable as shown in Fig. 2. Some system problems for two-way communication can be eliminated by separating the transmitter and receiver as shown in Fig. 3. Using these techniques the power radiated by the mobile or fed into the cable can usually be less than 100 mW per channel [Martin and Haining, 1979].

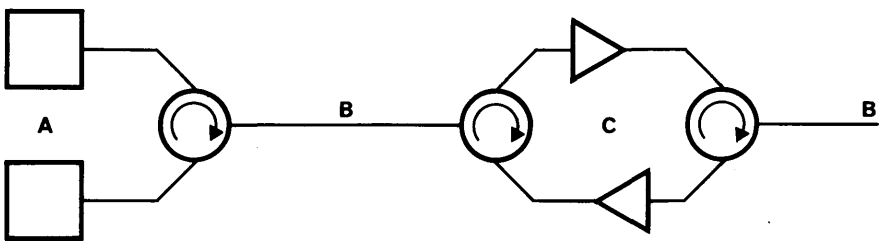


FIGURE 2 – *Extended system using two-way repeaters*

A: base station transmitter and receiver
B: leaky cable
C: two-way repeaters

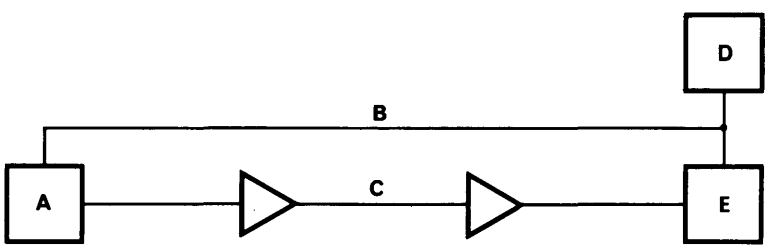


FIGURE 3 – *Daisy-chain system with one-way repeaters*

A: base station transmitter
B: audio line connection
C: leaky cable with one-way repeaters
D: control point
E: base station receiver

3.2.2 *Use of graded coupling cable*

In general, greater longitudinal attenuation is associated with lower coupling loss of coaxial cable. To design a system for minimum overall longitudinal attenuation, it is necessary to use two or more kinds of leaky cable with the cable having the largest coupling loss located near the base station and that with the lowest coupling loss located near the ends of the leaky cable.

3.2.3 *Multiple separate base stations*

Where very long cable runs are required the overall system can be sectionalized and each cable section linked to its own base station. Furthermore, below about 200 MHz in typical road and railway tunnels, there is a sharp decay in field strength measured beyond the cable end, typically 30 dB in the first 100 metres, and this enables separate closely spaced cable sections to be used. If the base stations transmit the same information the system can be used to provide extended range. The base stations can also transmit different information on the same frequency along their respective cables, thereby increasing the traffic handling capacity of the system. Care must be taken in the system design when considering the overlap area.

3.3 *Applications in mines and tunnels*

3.3.1 *Single wire conductor link*

The existence of an insulated longitudinal conductor in a tunnel substantially modifies propagation because it gives rise to a quasi-TEM mode of propagation. This has no cut-off frequency and may therefore be used at low frequencies.

The attenuation of the single-wire mode depends in a complex way on the form and dimensions of the tunnel, the electrical parameters of the wall, and especially on the distance of the cable from the wall and the frequency. Acceptable attenuation are obtained below about 30 MHz; such systems are used wholly underground.

3.3.2 *Balanced cable*

This type of leaky cable has been in use for a long time in underground systems.

Because of the high susceptibility of these cables, care must be taken with mounting position and surface contamination, particularly water.

3.3.3 *Coaxial cables*

All types of continuous leaky coaxial cables have been successfully used underground, but where severe moisture or difficult mounting conditions are encountered, loosely braided cables have given the best results.

Coaxial cables with periodic apertures have been successfully used in railways and motorway tunnels [Suzuki et al., 1980].

3.3.4 *Cables with mode converters*

Many installations have been made underground, which do not require any special care in cable laying, except for a few metres on either side of the radiating devices. In the intervals, any kind of laying will do, even unwinding in a duct. This has greatly reduced laying costs.

3.3.5 *Transversal variation of the field in a tunnel*

Since several modes are present in the tunnel, when leaky cables are used above the tunnel cut-off frequencies, a multipath situation occurs. The medium value of the field is approximately constant across the tunnel. The statistical distribution of the field strength obeys a Rayleigh law. With the twisted balanced cable or mode converter system this variation of the field strength is reduced.

3.4 *Applications in railways and motorways*

Train radio systems are in use at 400 MHz, using coaxial cables with periodic apertures installed alongside the railway track [Okada et al., 1975].

Lateral measurements of the radiated field strength in an open area along a railway showed that coupling loss is approximately 3 dB per distance doubling. Other types of leaky cables have been installed on motorways and railways and the coupling loss was measured to be about 6 dB per distance doubling [Cree and Giles, 1975].

3.5 *Application in buildings*

Many buildings have communication systems installed using leaky cables, sometimes in conjunction with external antennas connected to the base station.

The principles described for tunnels are applicable to confined spaces (corridors, stairways and lift shafts, parking spaces) in large buildings. But the large variety of shapes and dimensions of these spaces calls for some caution in system design.

4. Preferred frequency bands

Leaky cable systems have been used successfully over a wide range of frequencies, at least down to 500 kHz and as high as 900 MHz [Suzuki et al., 1980].

Generally, economic factors favour the use of the lower part of the VHF range but other factors that may influence the choice of operating frequency are:

- the availability of channels for a particular scheme;
- the size and configuration of a tunnel or building;
- if it is required to extend the coverage of a conventional mobile radio system;
- required linear (end-to-end) communications range.

Figure 4 compares the linear (end-to-end) communications range for three different typical centre-fed leaky cables with natural propagation in two different tunnel sizes, from half wave dipoles. For two way communication, a 50 W mobile transmitter is necessary.

It should be noted that although natural propagation appears attractive at UHF, blockage of the tunnel by vehicles between the base station antenna and the mobile antenna can give very large reductions in range depending on the vehicle and tunnel sizes.

It should also be noted that the leaky cable curves take no account of changes in longitudinal attenuation with contamination, particularly moisture. Balanced cables would be affected the most.

5. Sharing with other services

Leaky cable systems used completely underground may operate in frequency bands allocated to other services without interference, because the environment provides a high degree of shielding.

For surface applications, systems may be designed to have a reduced overall path loss, such as with in-line repeaters [Martin and Haining, 1979]. This enables the transmitter powers to be minimized and receivers to be desensitized thus reducing co-channel interference potential and susceptibility and facilitating sharing with other services.

In assessing an interference risk involving a leaky cable system, it should be noted that the interference sources (and susceptibilities) in such a system tend to be concentrated at or near the base station and repeaters. Also, the effective antenna height of such a source is usually very low compared with a conventional land mobile base station.

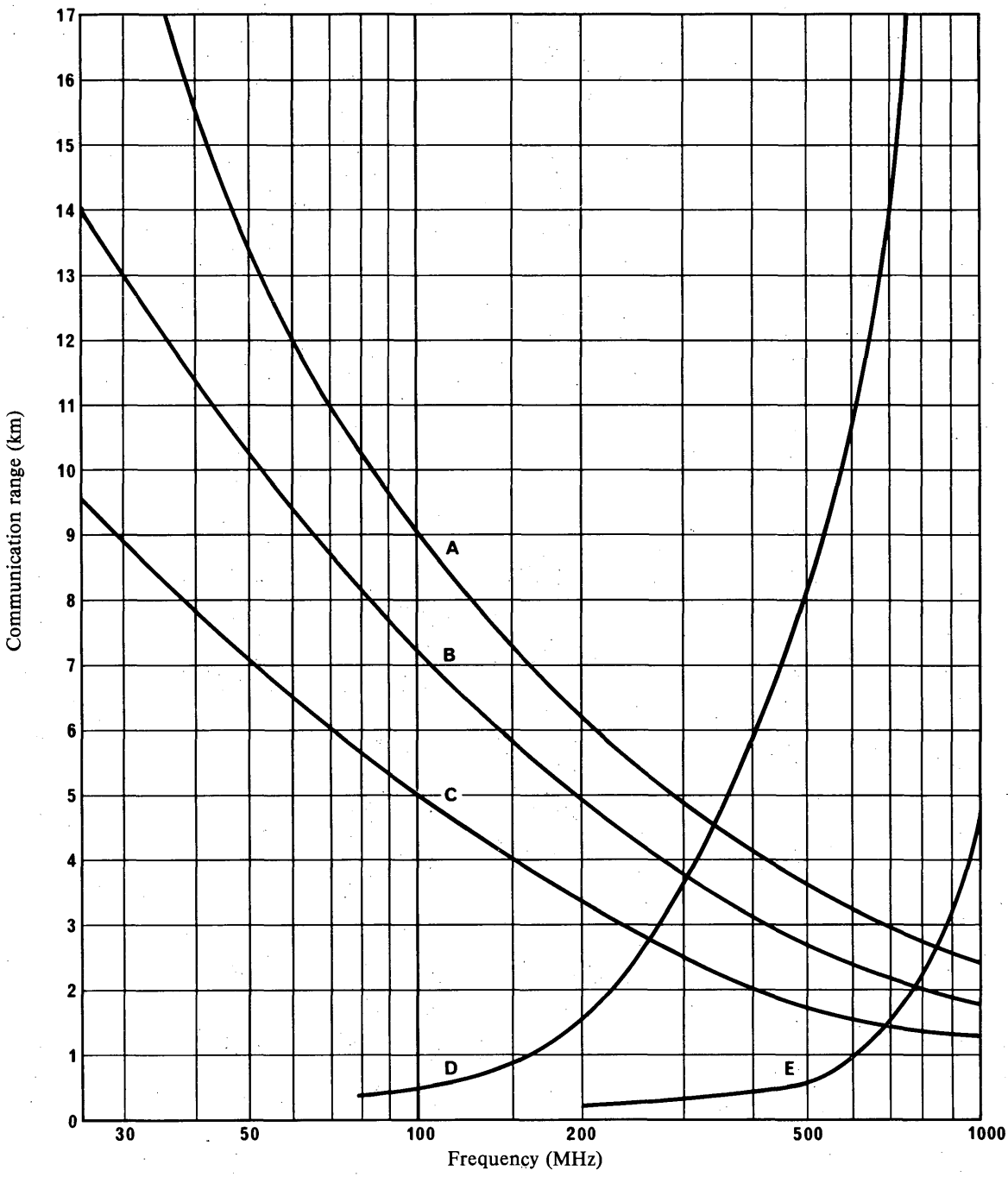


FIGURE 4 – *Linear (end to end) communications range in tunnels*

Transmitter output power: 50 W (centre feeding)
Minimum median received power: −137 dBW (1 μV in 50 Ω)
Mobile antenna gain: 0 dB

A: 200 Ω balanced cable 2.1 mm conductor diameter, coupling loss 35 dB
B: 50 Ω coaxial zigzag slotted cable 8 mm internal conductor diameter, coupling loss 70 dB
C: 50 Ω coaxial slotted cable 5 mm internal conductor diameter, coupling loss 80 dB
D: natural propagation in 6 × 9 m tunnel with halfwave dipole antennas
E: natural propagation in 3 × 4.5 m tunnel with halfwave dipole antennas
(tunnel wall dielectric constant 10)

REFERENCES

CREE, D. J. and GILES, L. J. [May, 1975] Practical performance of radiating cables. *Radio and Electron Engr.*, Vol. 45, **5**.

DELOGNE, P. [1973] Les liaisons par radio dans les tunnels. *Rev. HF*, Belgique, Vol. IX, **2**, 18-26.

DELOGNE, P. [April, 1976] Basic mechanisms of tunnel propagation. *Radio Sci.*, Vol. 11, **4**, 295-303.

DELOGNE, P. [1979] Mode converters for HF tunnels transmission. AGARD Conf. Proc. 263, paper **37**.

DELOGNE, P. and LIEGEOIS, R. [March-April, 1971] Le rayonnement d'une interruption du conducteur extérieur d'un câble coaxial. *Ann. des Télécomm.*, Vol. 26, **3-4**, 85-100.

DERYCK, L. [10 February, 1972] Radiocommunication in tunnels. *Electron. and Lett.*, Vol. 8, **3**, 71-72.

FARMER, R. A. and SHEPHERD, N. H. [February, 1965] Guided radiation – the key to tunnel talking. *IEEE Trans. Vehic. Tech.* Vol. VC-14, **93**.

FERNANDES, A. S. de C. [May, 1979] Propagation characteristics of a loose braid coaxial cable in free space. *Radio Electron. Engr.*, Vol. 49, **5**, 255-260.

FERNANDES, A. S. de C. [January, 1980] Propagation characteristics on a continuously slotted coaxial cable. *Tecnica*, Vol. XLI, **456**, 239-244.

FERNANDES, A. S. de C. [March, 1981] Slotted and loose braid cables; brief conclusions of a comparative study. *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-29, **3**, 273-275.

MARTIN, D. J. R. [May, 1975] A general study of the leaky-feeder principle. *Radio and Electron. Engr.*, Vol. 45, **5**.

MARTIN, D. J. R. and HAINING, R. W. [September, 1979] Leaky feeder radio techniques for mines and tunnels. IERE Conf. Proc. No. 44.

NAKAHARA, T. and KURQUCHI, N. [June, 1968] Various types of open wave-guides for future train control. *ICC of IEEE*, 185.

OKADA, S., KISHIMOTO, T., AKAGAWA, K., NAKAHARA, Y., MIKOSHIBA, K., HORIGUCHI, F., and OKAMOTO, K. [May, 1975] Leaky coaxial cable for communication in high speed railway transportation. *Radio and Electron. Engr.*, Vol. 45, **5**, 224-228.

SUZUKI, T., HANAZAWA, T. and KOZONO, S. [August, 1980] Design of tunnel relay system with leaky coaxial cable in an 800 MHz band land mobile telephone system. *IEEE Trans. Vehic. Tech.*, Vol. 29, **3**.

ANNEX I

RADIO WAVE PROPAGATION IN MINES AND TUNNELS – NATURAL PROPAGATION

1. In the land mobile frequency bands, radio waves are propagated in tunnels by waveguide modes. The attenuation of the dominant mode, in dB, is linear with distance [Emslie *et al.*, 1975].

1.1 *Antenna insertion loss*

A considerable loss of signal power occurs at both the transmitter and receiver end of a tunnel path when dipole antennas are used because of inefficient coupling to the waveguide mode. The insertion loss of each dipole antenna is given by the following:

$$A = -46.7 + 10 \log (d_1 d_2) + 20 \log f \quad \text{dB}$$

where

d_1 : tunnel width (m)

d_2 : tunnel height (m)

f : frequency (MHz).

1.2 *Loss in a straight tunnel*

The loss for vertical polarization in a straight tunnel varies with the dielectric constants of the roof/floor and its height. For a dielectric constant of 10, the loss is given by the following:

$$L_{10} = \frac{1.3\, z \times 10^6}{f^2 d_2^3} \quad \text{dB}$$

and for a dielectric constant of 5

$$L_5 = \frac{0.98\, z \times 10^6}{f^2 d_2^3} \qquad \text{dB}$$

where

z: tunnel length (m).

Most tunnel walls have a dielectric constant between 5 and 10 depending on the material and moisture content.

1.3 *Loss around a corner*

Generally, the loss around a corner is sufficient to prevent communications beyond a few metres. Corner loss is given by the following:

$$C = -57.3 + 30 \log f + 20 \log d_2 + 10 \log d_1 \qquad \text{dB}$$

1.4 *Radio wave propagation in buildings*

Radio wave propagation in buildings is similar to that in tunnels; however, the constantly changing structure of a building causes difficulties in calculating loss for specific locations. The following values of attenuation can be applied in general:

TABLE I

Type of construction	Frequency (MHz)	
	160	450 – 1 000
Open areas and large halls (dB/m)	0.4	0.3
20 cm concrete block wall (dB)	5-8	7-10
15 cm solid concrete wall or floor (dB)	10-15	12-18
Suspended metal ceiling (dB)	15-20	15-20
Solid metal walls (dB)	20-40	20-40

REFERENCES

EMSLIE, A. G., LAGACE, R. L. and STRONG, P. F. [March, 1975] Theory of the propagation of UHF radio waves in coal mine tunnels. *IEEE Trans. Ant. Prop.*, Vol. AP-23, **2**, 192 - 205.

REPORT 903

DIGITAL TRANSMISSION IN THE LAND MOBILE SERVICE

(Question 40/8)

(1982)

PART A

DIGITAL MODULATION METHODS

1. Introduction

This Part describes data modulation techniques in applications where analogue speech transmission is not required and the radio equipment can be optimized for data transmission alone.

2. Requirements

The following characteristics of digital modulation systems are important:

2.1 To achieve the required bit error rates, good carrier-to-noise ratio (C/N) and carrier-to-interference ratio (C/I) performance is needed.

2.2 The technique used must provide high transmission efficiency (in terms of bit/s/Hz) within the constraint of the narrowband assignment (usually 25 kHz channel).

2.3 Use of simplified and miniaturized circuitry is needed to ensure that weight and size are comparable with analogue equipment.

2.4 Class C amplifiers should be used in order to achieve power economy but out-of-band radiation must be reduced to a low level.

3. Comparison of different methods

Filter shaped binary phase shift keying (BPSK), quaternary phase shift keying (QPSK) and 16 quadrature amplitude modulation (QAM) are not suitable for non-linear mobile radio channels because the occupied bandwidth requirement is violated.

Tamed frequency modulation (TFM) and Gaussian filtered minimum shift keying (GMSK) are suitable since they produce a constant envelope and a sufficiently compact power spectrum as shown in Fig. 1.

Figure 1 shows the output power spectrum of the GMSK, where B_bT is the normalized 3 dB bandwidth of the filter. In the same Figure, the dashed line indicates that of the TFM.

The narrower the Gaussian low-pass filter bandwidth, the more compact the output power spectrum becomes. However, some bit error-rate (BER) performance degradation may be caused when the bandwidth is made excessively narrow.

Required E_b/N_0 for the specified BER of 10^{-3} versus B_bT is theoretically estimated as shown in Fig. 2, where the GMSK signal is demodulated by orthogonal coherent detection or maximum likelihood detection with differential decoding. The measured results with orthogonal coherent detection are shown in the same figure. The degradations of E_b/N_0 of GMSK ($B_bT = 0.25$) with othogonal coherent and maximum likelihood detections from the ideal binary or quaternary PSK modulation are 1.5 dB and 0.7 dB, respectively. For TFM, the theoretical degradation of a filter-and-sample detector is 1 dB with respect to the ideal binary and quaternary PSK modulation where differential decoding is not adopted [Murota and Hirade, 1981; Muilwijk, 1979].

The spectrum space factor F versus B_bT where α relates the received signal power and the distance between base and mobile stations [Murota and Hirade, 1981] is shown in Fig. 3. The minimum value of F is obtained at $B_bT = 0.25$ irrespective of the value of α and the application of diversity. It might be desirable to adopt the GMSK with $B_bT = 0.25$ from the viewpoint of maximizing the spectrum efficiency of digital land mobile radio [Murota *et al.*, 1981]. For TFM the spectrum space factor F is about equal to that for GMSK with $B_bT = 0.25$.

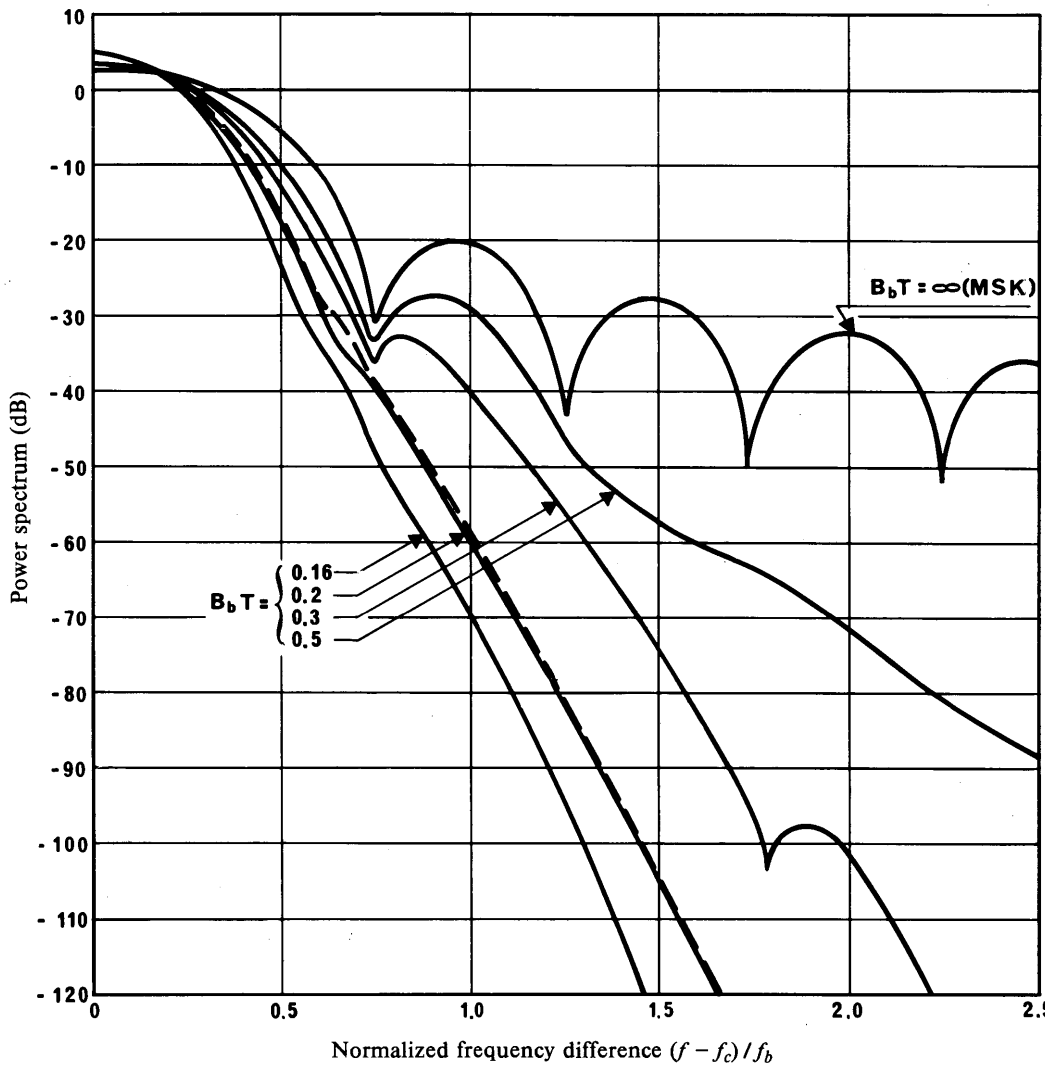


FIGURE 1 – *Power spectra of TFM and GMSK*

----: TFM
B_bT: normalized bandwidth of premodulation gaussian bandpass filter (GMSK)
f_c: carrier frequency (Hz)
f_b: bandwidth (Hz)

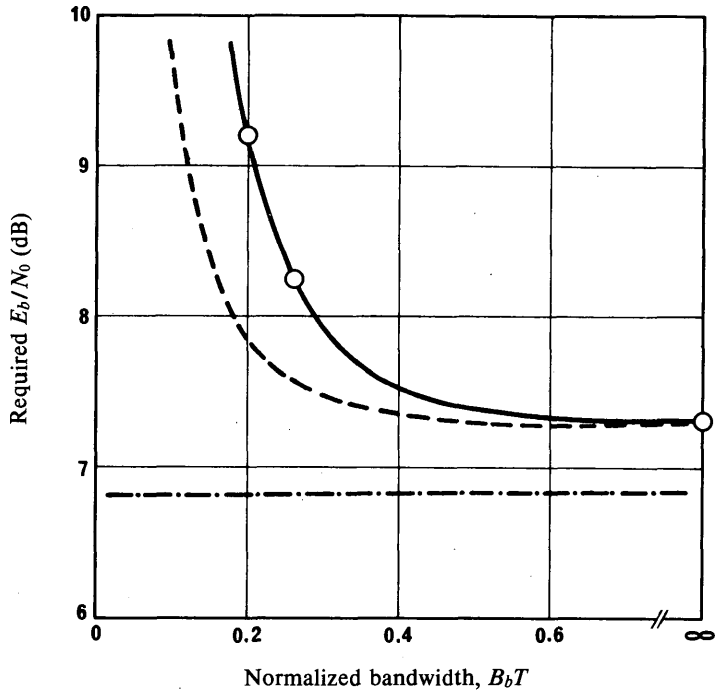


FIGURE 2 – *Required E_b/N_0 versus B_bT*

——————— : orthogonal coherent detection with differential decoding
– – – – – – – – – – : maximum-likelihood detection with differential decoding
——·——·—— : ideal orthogonal coherent detection
○: measured results for GMSK with orthogonal coherent detection

P_e: bit error ratio (BER) = 10^{-3} non fading
B_bT: normalized bandwidth of premodulation Gaussian low-pass filter
E_b/N_0: signal power per bit noise power density

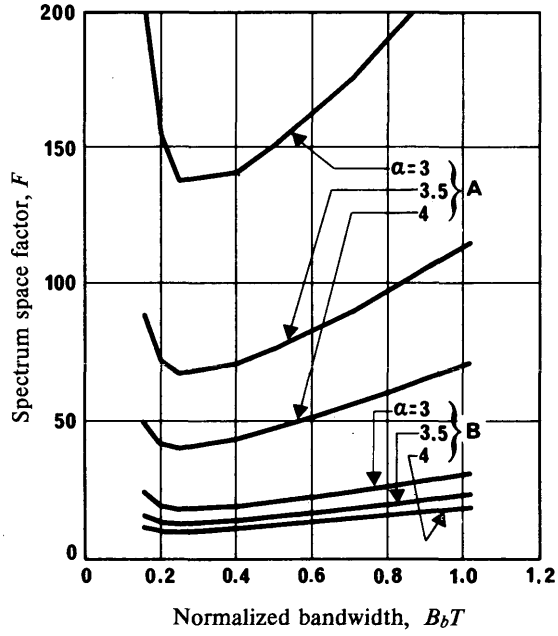


FIGURE 3 – *Spectrum space factor of GMSK*

A: no diversity
B: maximum ratio diversity

4. Maximum transmission bit rate imposed by analogue adjacent channel interference standards

Where digital mobile radio systems must co-exist with analogue mobile radio systems, the adjacent channel interference requirements of the analogue system may limit the maximum transmitted bit rate of the digital systems [Constantinou and Towaij, 1981].

5. Voice privacy

5.1 Various levels of privacy can be achieved using commercially available speech privacy techniques. A relative ranking of these different systems in terms of increasing difficulty to intercept is:

- clear speech with verbal code;
- noise masking of analogue speech;
- frequency inversion of analogue speech;
- frequency hopping;
- digitized speech;
- rolling code band splitting of analogue speech;
- linear digital voice scrambler;
- non-linear digital speech.

5.2 *Use of digitized speech systems*

In the United States there are digitized speech systems successfully operating within the limits of a 25 kHz channel assignment. These systems use a data rate of 12 kbit/s and a frequency deviation of ± 4 kHz.

From measurements made in the United States using rhyme tests these systems appear to have comparable intelligibility with standard FM systems.

It has been found that the sensitivity of receivers using this modulation is 6 to 8 dB less than an analogue receiver accepting normal 16K0F3E emissions.

6. Transmitter emission limitations

In the United States increasing use of digitized speech signals prompted the adoption of uniform emission standards for digital and analogue land mobile radio in the private mobile services. The principle used in deriving these standards was to restrict digital radio signals to the same emission bandwidths required for analogue speech since both types must occupy and share the same channel space.

Therefore it is necessary to review existing CCIR Recommendations and Reports to ensure that the emission limitations required for operation of digitized voice within the bandwidth occupied by an equivalent analogue signal are properly covered.

7. Efficiency of data compared with speech

Typical speech messages are transmitted at a rate of about 150 words/minute [Kelly and Ward, 1973]. In coded character form, this corresponds to a data rate of about 90 bit/s (based on 6 characters/word and 6 bits/character).

Bit rates of presently available data message systems significantly exceed the equivalent speech message rate of 90 bit/s. Such transmissions also normally include the transmitter identification (ID) with each message and this greatly improves the efficiency compared with speech.

Improvement factors (in air time utilization) are expected to vary between 5 and 15 depending upon the detailed system design, propagation effects, retransmission requirements and polling delays. [Parness, 1975].

REFERENCES

CONSTANTINOU, P. and TOWAIJ, S. J. [June, 1981] Digital transmission over conventional mobile channels: maximum bit rate. IEEE International Conference on Communications (ICC '81).

KELLY, T. C. and WARD, J. E. [October, 1973] Investigation of digital mobile radio communications. US Dept. of Justice, LEAA.

MUILWIJK, D. [March, 1979] Tamed frequency modulation – a bandwidth-saving digital modulation method, suited for mobile radio. *Philips Telecomm. Rev.*, Vol. 37, **1**.

MUROTA, K. and HIRADE, K. [1981] Transmission performance of GMSK modulation (in Japanese). *Trans. IECE Japan* (to be published).

MUROTA, K., KINOSHITA, K. and HIRADE, K. [16 June, 1981] Spectrum efficiency of GMSK land mobile radio. IEEE International Conference on Communications (ICC '81), 14-18 June, Denver, Col., USA, Conf. Record, Vol. 2, Session 23: Digital mobile radio, 23.8.1-23.8.5.

PARNESS, J. H. [March, 1975] Digital communications in police operations: The potential in the Los Angeles Police Department. Mitre Corporation Technical Report NTP-6586 Rev. 1, for NILECO/LEAA.

PART B

DATA TRANSMISSION OVER ANALOGUE SPEECH CHANNELS

1. Introduction

This part is concerned with data transmission over analogue speech mobile radio channels to provide new facilities in dispatch * systems like digital selective calling and status reporting or for end-to-end transmission in systems interconnected to the PSTN.

2. Accommodation of telematic services

It is desirable that mobile units which are interconnected with the PSTN should be able to send and receive services such as Videotex, telex and facsimile.

However, further study is needed:

- to reduce the error rates caused by fading, ignition noise and co-channel interference to acceptable levels;
- to establish that the protocols defined in the appropriate CCITT Recommendations can be used effectively in mobile radio systems for both stationary and moving vehicles;
- to ensure that the transmission of data messages should be completed in the minimum channel airtime possible.

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* For the purpose of this text "dispatch system" has the meaning: a radio system used to control the operation of a fleet of mobiles, such as aircraft, taxis, police, etc.

3. Interfacing data terminals to mobile radio equipment

The principal problem is the proper specification of the interface between the data device and conventional mobile radio equipment primarily designed for speech communications but which with appropriate modifications can become suitable for data transmission.

3.1 *Constraints of voice circuits on data speeds*

For bit rates up to 1200 bit/s the sub-carrier data signal can pass through the speech processing pre-emphasis and de-emphasis, usually with amplitudes below speech clipping levels; however if the de-emphasis/pre-emphasis circuits are not by-passed, some inter-symbol interference might result [Constantinou and Towaij, 1981].

One method of transmitting data over voice channels at 1200 bit/s uses a sub-carrier modulation scheme called FFSK, with a logical '1' transmitted by one cycle of a 1200 Hz sinwave and a logical '0' by one and a half cycles of an 1800 Hz sinwave. The scheme is in use in FMS (status message transmission system of the police in the Federal Republic of Germany), in ZVEI (digital selectocall system of the Federal Republic of Germany) and in other systems.

Error performance with this modulation scheme is given in part E. The generation and demodulation of the data signal is possible with a single microprocessor [Stein and Gibson, 1981].

To realize higher bit rates (e.g. 2400 bit/s or 4800 bit/s) it is usually necessary to modify the speech circuits or bypass them and apply the sub-carrier data signal directly to the modulator and take it directly from the demodulator.

3.2 *Standardization of modulation method and coding*

The mobile radio equipment interface should be transparent to the sub-modulation method and coding. There may be benefits from using standards such as CCITT Recommendations that have been developed for wireline applications but further study is needed to ensure that these standards can be applied practically to the mobile radio channel. The sub-modulation method selected should be applicable to all expected radio modulation schemes (FM, PM, AM and possibly SSB).

3.3 *Control signals*

Since many users share a radio channel, data transmissions must be inhibited when the channel is occupied. Therefore, a carrier sense (COR) signal is needed from the radio receiver to inhibit the data modem.

There can be widely varying time delays (10-200 ms) from application of the transmitter turn-on signal until receipt of the COR signal at the receiver. Data modems must presently have selectable delays which introduce inefficiencies. This would be overcome if the maximum time delay were set at a reasonably achievable level (e.g. 10 ms).

3.4 *Characteristics of the data modem/radio interface*

The following characteristics are important:

- transmitted signal spectrum at peak deviation;
- data de-emphasis characteristics;
- data rate and bandwidth;
- impedances and signals levels;
- undetected error rate;
- range of transmitter turn-on times;
- period to acquire modem synchronization;
- control signals (transmitter on, squelch, mute).

4. Integration of analogue speech and data

Canada has made analytic and simulation studies of the integration of analogue speech and data, by transmitting data packets in the gaps between consecutive voice calls, or alternatively in all the gaps in a voice conversation. In public mobile telephone channels in Montreal, the measured fraction of time during which the mobile talker is silent, can reach about 70% [Cohen and Haccoun, 1980].

Traffic simulation studies [DaSilva *et al.*, 1980; Callendar, 1981] have shown that most of this idle time may be utilized for data packet transmission.

Further studies are needed to investigate voice intelligibility, packet throughput and mean delay, the design of equipment such as speech detectors and fast acquisition circuits, and the problems caused by channel impairments such as fading and co-channel interference.

REFERENCES

CALLENDAR, M. H. [April, 1981] An integrated voice and data mobile service. Conference record of the IEEE VTG Conference.

COHEN, P. and HACCOUN, D. [October, 1980] Structure des conversations sur les voies radiotéléphoniques mobiles. *Revue Canadienne de Génie Electrique*, Vol. 5, **4**.

CONSTANTINOU, P. and TOWAIJ, S. J. [June, 1981] Digital transmission over conventional mobile channels: maximum bit rate. IEEE International Conference on Communications (ICC '81).

DASILVA, J. S., de MERCADO, J. B., MAHMOUD, S. A. [October, 1980] An approach to the integration of voice and data on land mobile channels. Proceedings of the International Computer Communications Conference, Atlanta, Georgia, USA.

STEIN, P. J. Y., GIBSON, R. W. [April, 1981] A 1200 bit/s single chip microcomputer data modem. Proc. of the Conf. on digital processing of signals in communications. IERE, Loughborough, United Kingdom.

PART C

DATA TRANSMISSIONS FOR SIGNALLING AND SUPERVISION IN PUBLIC MOBILE TELEPHONE SYSTEMS

1. Introduction

This Part is concerned with various aspects of data transmissions to establish and supervise telephone calls and channels assignments in public mobile telephone systems.

2. Characteristics of the transmission channel and modulation techniques

It is important to consider the following parameters, if applicable, in making a choice of modulation technique and data speed:

- available baseband bandwidth;
- occupied bandwidth of the data modulated radio signal;
- tolerance of group delay distortion;
- tolerance to frequency offset;
- tolerance to interference (e.g. impulsive noise, fading).

The telephone channels that link the telephone exchange with the radio base stations affect the data signalling mainly by introducing attenuation distortion, group delay distortion and frequency offset resulting from the use of voice frequency carrier systems.

2.1 In the nordic mobile telephone system (NMT) it was found that the available bandwidth of the transmission channel, using a 25 kHz FM radio channel (16K0F3E), was approximately 2200 Hz (500-2700 Hz). A subcarrier modulation method was selected using a data transmission rate of 1200 bit/s and fast frequency shift keying (FFSK).

For the nordic mobile telephone system (NMT) measurements were made with results of less than ± 5 Hz for the overall frequency offset.

2.2 In the advanced mobile phone service (AMPS) of the USA a 30 kHz radio channel (30K0F3E) is used. A data transmission rate of 10 kbit/s on dedicated channels was chosen with a peak frequency deviation of ± 8 kHz. The system uses direct binary frequency shift keying (FSK) of the carrier with discriminator detection (40K0F9X).

The AMPS transmits data on a fully dedicated digital channel called the "set-up" channel used for paging and access functions and also transmits data on the talking (voice) channel once a call has been established. In this instance the voice channel is interrupted or "blanked" and the data transmission is sent in a "burst" lasting not more than 100 ms. This "blank-and-burst" message is used to effect a channel frequency change in the mobile unit in order to accomplish "hand-off" as the mobile moves from one cell site's coverage to another.

2.3 In the Public Land Mobile Radio Telephone System in Japan a 25 kHz FM radio channel (16K0F3E) is used. A 300 b/s data transmission rate with peak deviation of ± 4.5 kHz was selected to give priority to signalling reliability. The system uses equivalent FM with discriminator detection because modem circuits are used for both voice and data.

3. Coding

The choice of coding in public mobile systems must take account of the need to establish telephone calls reliably in the shortest possible time. The power spectrum should also be considered. This usually results in different coding requirements for data transmissions for signalling and supervision of mobile telephone than those used in dispatch radio systems or for telematic services.

3.1 For the NMT a convolutional code was selected because it allows arbitrary message lengths, continuous decoding of the messages and is fairly straightforward to implement. Convolution codes are characterized by the maximum length of burst that can be corrected and the error-free zone that is required between two bursts (guard-space).

In the NMT a burst correcting capability of 6 bits was chosen and the guard-space is 19 bits using the Hagelbarger code. This code was felt to be optimal for the NMT regarding the relationship between the burst error correcting capability and the guard-space [Hagelbarger, 1959].

3.2 In the AMPS system a biphase (Manchester) bit encoding format was adopted. The peak of the power spectrum produced by this data transmission is well above the voice band. This separation is an advantage in a system transmitting both voice and signalling data on the same channel.

To combat burst errors caused by multipath fading, all ditigal data messages are encoded and repeated several times at the source. The coding used on all radio channels is a shortened (63 : 51) Bose-Chauduri-Hocquenghem code.

In the forward (base-to-mobile) set-up channels, all data messages are interlaced, encoded and repeated five times and a bit-by-bit 3 out of 5 majority vote is taken at the data receiver to determine the best-guess detected message to send to the decoder. In the blank-burst mode over the voice channel, the data messages are repeated 11 times in the forward direction but only 5 times in the reverse direction using bit-by-bit majority vote for both cases. The primary reason for the difference between the 11 and 5 message repeats is that the message from base site to mobile is usually received under poor S/I conditions and is considered a critical function since false interpretation results in a mishandled call [BSTJ, 1979].

3.3 In consideration of the changing rate of mobile speed and passage length, the system in Japan uses block codes as error correcting codes for random errors and repeated control signal transmissions for burst errors to combat errors caused by multipath fading. Moreover, diversity effect using a simultaneous multitransmitting technique for set-up channels increases signalling reliability.

Error correcting codes are a shortened (63 : 51) BCH and a shortened (15 : 11) BCH which correct 1 bit error in a frame. Control signal transmissions are repeated twice for paging channels and 4 times for access and voice channels. A Manchester code, which has non-direct current and code redundancy, was selected in consideration of radio channel transmissions and for prevention of erroneous signalling performance due to voice signals.

4. Signalling reliability

In the NMT it was found possible to express the requirements for signalling reliability in terms of the RF input signal level. The requirement was established at $\geqslant 0.9$ for input levels $\geqslant 0$ dB(μV) e.m.f. without fading and $\geqslant 10$ dB(μV) e.m.f. with fading.

5. Major system characteristics

Major system characteristics are contained in Report 740.

REFERENCES

BSTJ [January, 1979] Advanced mobile phone service, Vol. 58, **1**.

HAGELBARGER, D. W. [July, 1959] Recurrent codes: Easily mechanized, burst correcting, binary codes. *BSTJ*, **38**, 969-984.

BIBLIOGRAPHY

DE JAGER, F. and DEKKER, C. B. [May, 1978] Tamed FM, a novel method to achieve spectrum economy in digital transmission. *IEEE Trans. Comm.*, Vol. COM 26, **5**, 534-542.

FRENCH, R. C. [June, 1976] Mobile radio data transmission in the urban environment. IEEE International Conference on Communications (ICC '76), Philadelphia, USA.

FRENCH, R. C. [March, 1978] Error performance in mobile radio data transmission in the urban environment. *NTZ*, Vol. 31, **3**, 200-203.

FRENCH, R. C. [August, 1978] Error rate predictions and measurements in the mobile radio channel. *IEEE Trans. Vehic. Tech.*, Vol. VT-27, **3**, 110-116.

HATTORI, T. and HIRADE, K. [November, 1978] Multitransmitter digital signal transmission by using offset frequency strategy in a land-mobile telephone system. *IEEE Trans. Vehic. Tech.*, Vol. VT-27, **4**, 231-238.

HIRADE, K. and MUROTA, K. [March, 1979] A study of modulation for digital mobile telephony. IEEE 29th VTS Conf.

MABEY, P. J. [August, 1978] Mobile radio data transmission – Coding for error control. *IEEE Trans. Vehic. Tech.*, Vol. VT-27, **3**, 99-109.

YOSHIKAWA, N., OKASAKA, S. and KOMAGATA, H. [November-December, 1977] 800 MHz band land mobile telephone control system. *Rev. Elec. Comm. Labs.*, Vol. 25, **11-12**, 1172-1190.

PART D

ERROR PERFORMANCE OF DIGITAL TRANSMISSION

1. Introduction

This part is concerned with the error performance of digital transmission and with error reduction and error control techniques.

2. Errors caused by fading and shadowing

The measured bit error ratio (BER) at VHF for a moving vehicle has been shown to agree with the theoretical prediction [French 1980] for a fading signal (see Fig. 4). The theoretical effect of fading and shadowing together is shown (see Fig. 5). (Shadowing is also known as location variability.) Results at UHF from Japan are shown in Fig. 6 [Daikoku et al., 1981].

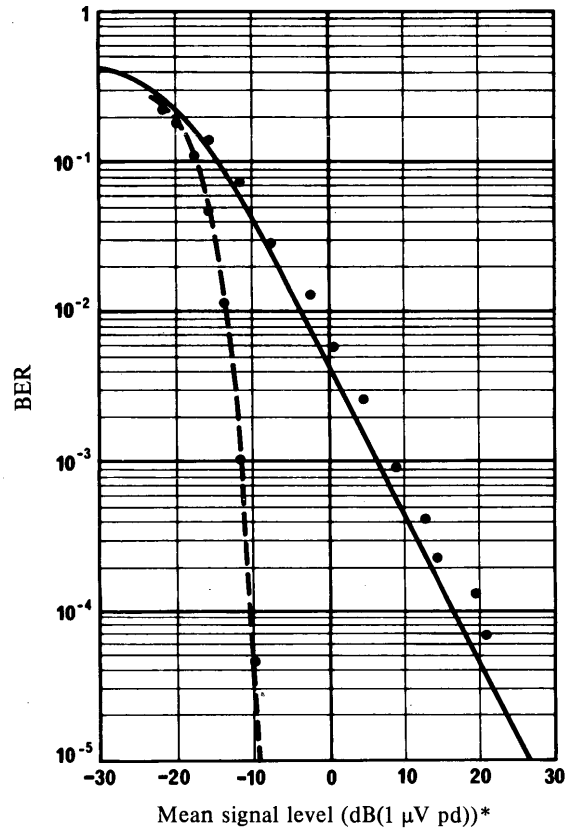


FIGURE 4 – *Measured BER with steady and fading signals*

——— : bench measurements
——————— : fading predictions
● : field measurements

Carrier frequency	: 165 MHz
Bit rate	: 1200 bit/s
Vehicle speed	: ≈ 30 km/h
Type of modulation	: direct FM
Deviation	: 2.4 kHz

*μV pd is μV potential difference, measured with the circuit closed.

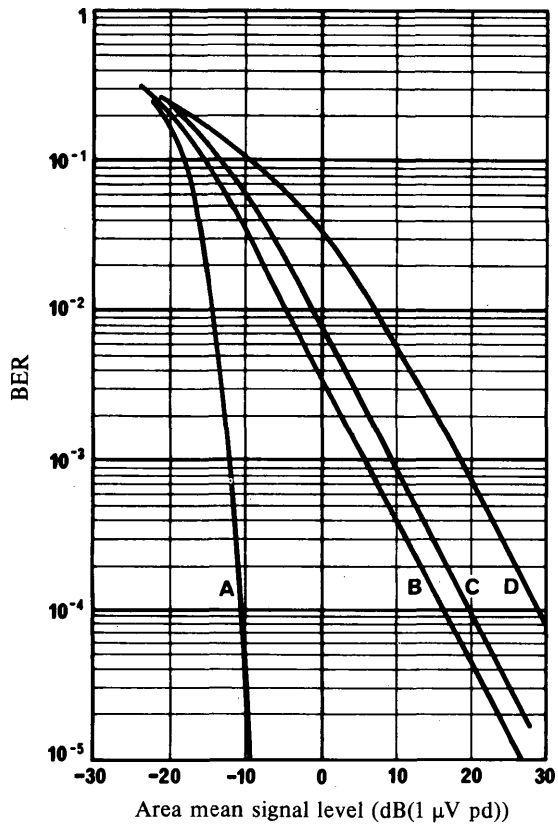


FIGURE 5 – *Impact of fading and shadowing on BER*

A: bench measurements
B: fading
C: fading and shadowing, σ = 6 dB
D: fading and shadowing, σ = 12 dB

Carrier frequency	: 165 MHz
Bit rate	: 1200 bit/s
Vehicle speed	: ≈ 30 km/h
Type of modulation	: direct FM
Deviation	: 2.4 kHz

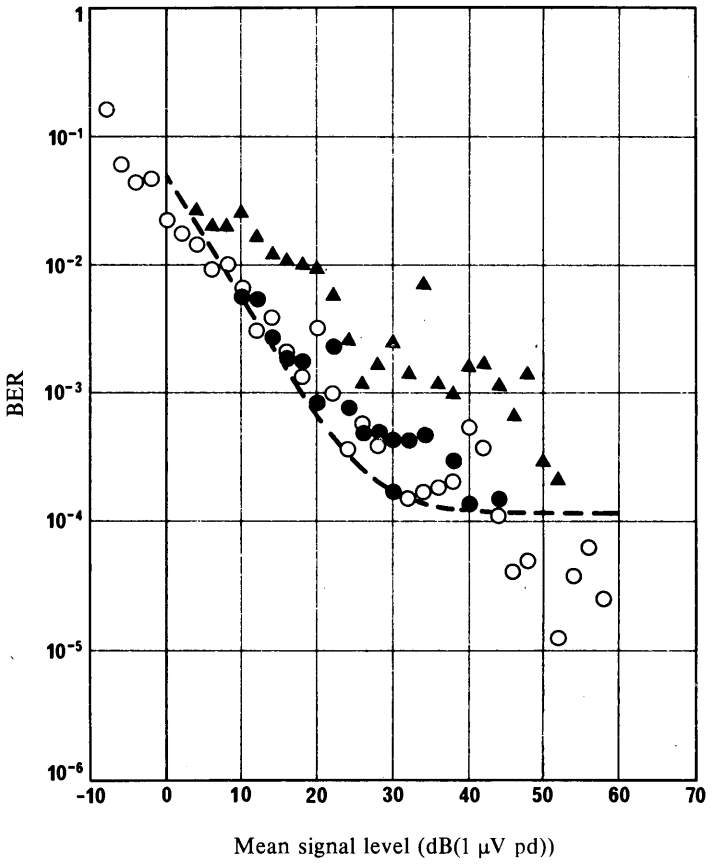


FIGURE 6 – *BER performance under fading conditions*

--- : simulation (Rayleigh fading and phase noise)
○ : suburban
● : urban, location 1
▲ : urban, location 2

Carrier frequency	: 920 MHz
Bit rate	: 16 kbit/s
Vehicle speed	: ≈ 40 km/h
Type of modulation	: GMSK (B_bT = 0.25)
Deviation	: 4.0 kHz

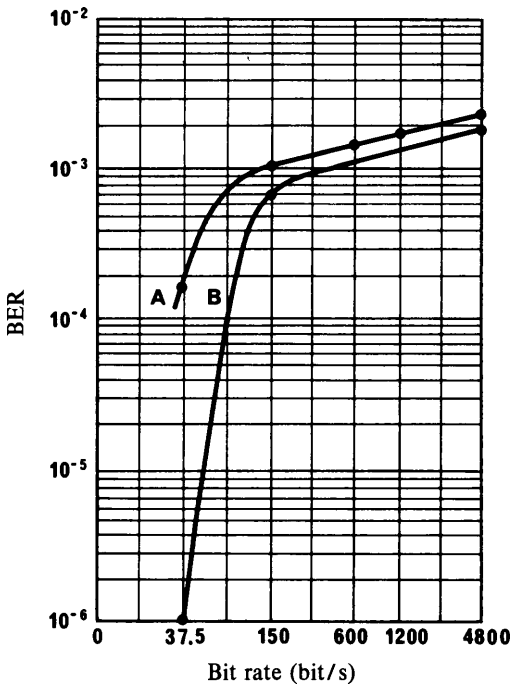


FIGURE 7 – *Measured BER as a function of bit rate, with fading only*

Carrier frequency	: 465 MHz
Vehicle speed	: ≈ 30 km/h
Type of modulation	: direct FM
Deviation	: A = 2.4 kHz
	: B = 4.8 kHz
Mean signal level	: 10 dB(μV pd)

2.1 *Dependence on bit rate*

Figure 7 [French, 1980] shows a critical bit rate below which errors are rare and above which the BER is high and nearly constant. Above the critical rate, the bit rate should be high enough to permit error control coding, but not so high that distortion or adjacent channel interference results.

2.2 *Error distribution*

Typical error distributions at VHF and UHF (see Figs. 8 and 9) show that errors caused by fading occur in bursts [French, 1980], where $P(\geqslant m, 64)$ is the probability of m or more errors in a code word of 64 bits.

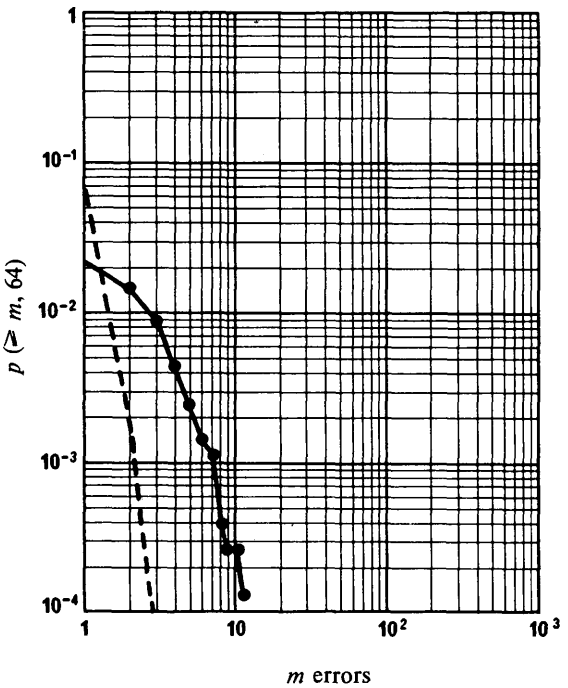


FIGURE 8 – *Distribution of errors caused by fading at 165 MHz with 2.4 kHz deviation*

——— : random
——— : fading

Bit rate	: 1200 bit/s
Vehicle speed	: ≈ 30 km/h
Type of modulation	: direct FM
Error rate	: BER = 0.9×10^{-3}

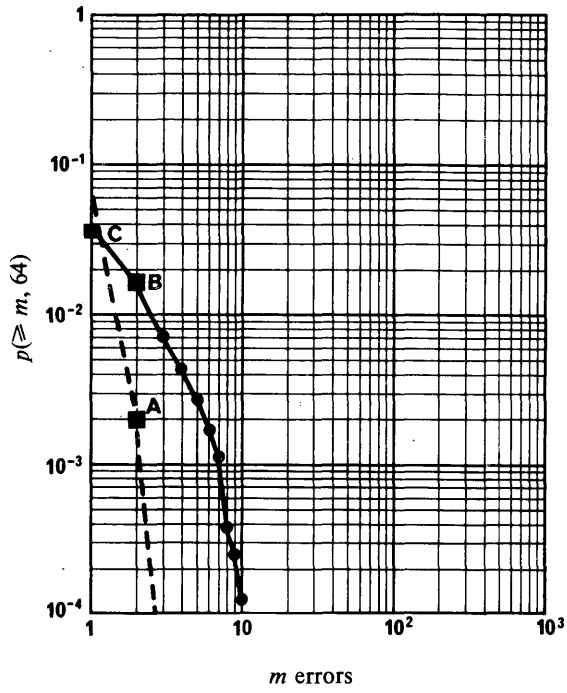


FIGURE 9 – *Distribution of errors caused by fading at 465 MHz with 4.8 kHz deviation*

——— : random
——— : fading
■A : $p(\geqslant 2.64) = 2.0 \times 10^{-3}$
■B : $p(\geqslant 2.64) = 1.6 \times 10^{-2}$
■C : $p(\geqslant 2.64) = 3.7 \times 10^{-2}$

Bit rate : 1200 bit/s
Vehicle speed : ≈ 30 km/h
Type of modulation: direct FM
Error rate : BER = 1.0×10^{-3}

3. Errors caused by ignition noise

Typical BERs in dense vehicle traffic in the UK are shown in Figs. 10 and 11 [French, 1980].

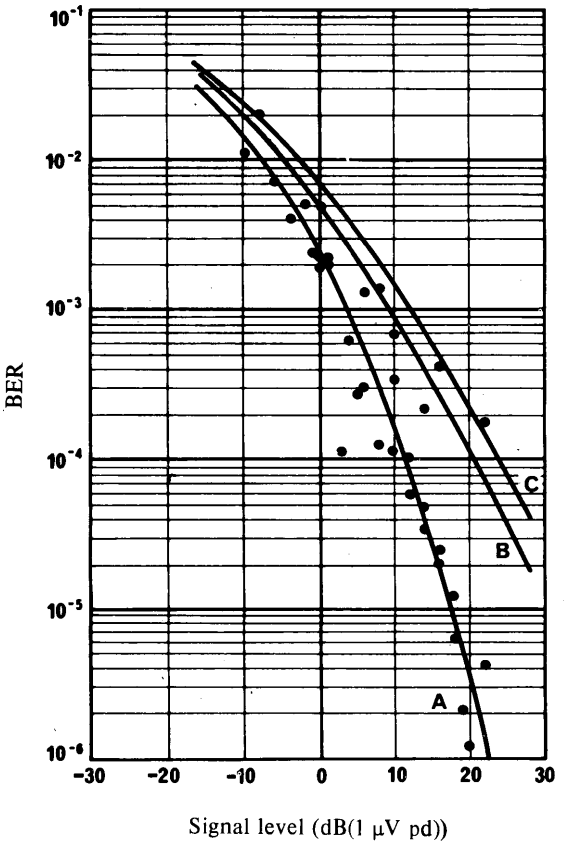


FIGURE 10 –*Errors due to ignition noise at 1200 bit/s and 165 MHz*

A: steady signal
B: fading
C: fading and shadowing,
σ = 6 dB, ignition noise only

Bit rate : 1200 bit/s
Vehicle speed : ≈ 30 km/h
Type of modulation: direct FM
Deviation : 2.4 kHz

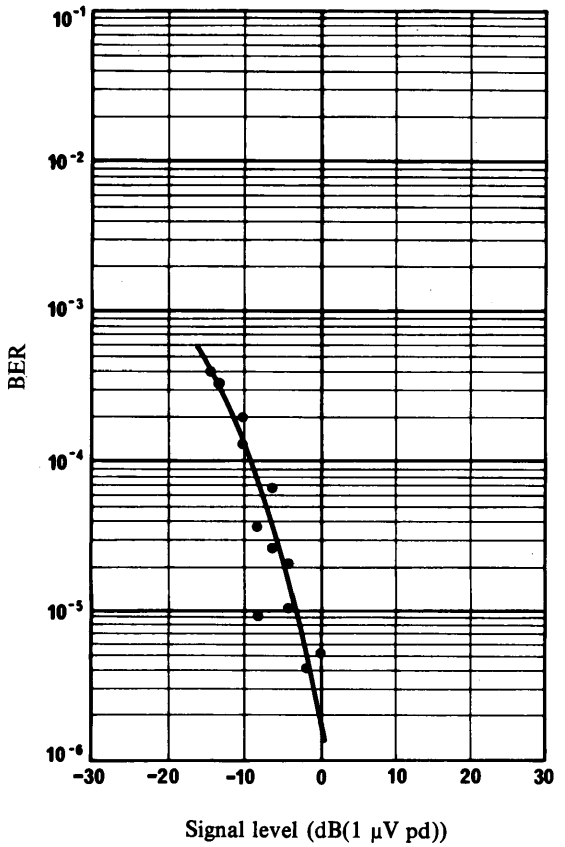


FIGURE 11 – *Errors due to ignition noise at 1200 bit/s and 465 MHz*

——— : steady signal

Bit rate	: 1200 bit/s
Vehicle speed	: ≈ 30 km/h
Type of modulation	: direct FM
Deviation	: 4.8 kHz

3.1 *Dependence on bit rate*

Similar error rates (see Figs. 12 and 13) occur at VHF and UHF at 4800 bit/s, but fewer errors at UHF at 1200 bit/s than at VHF [French, 1980].

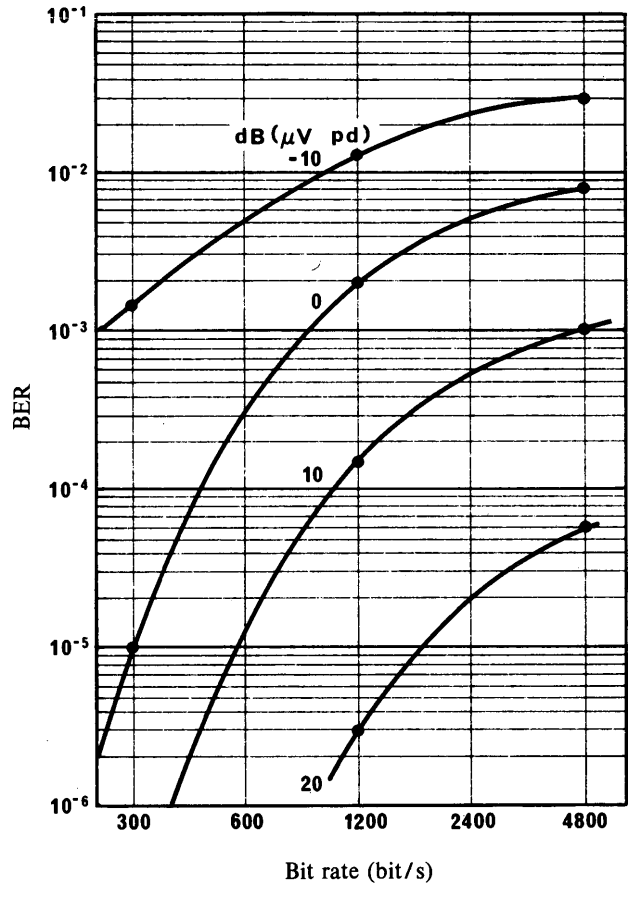


FIGURE 12 – *Dependence of ignition noise errors on bit rate at 165 MHz with signal level as parameter.*

Vehicle speed : ≈ 30 km/h
Type of modulation: direct FM
Deviation : 2.4 kHz

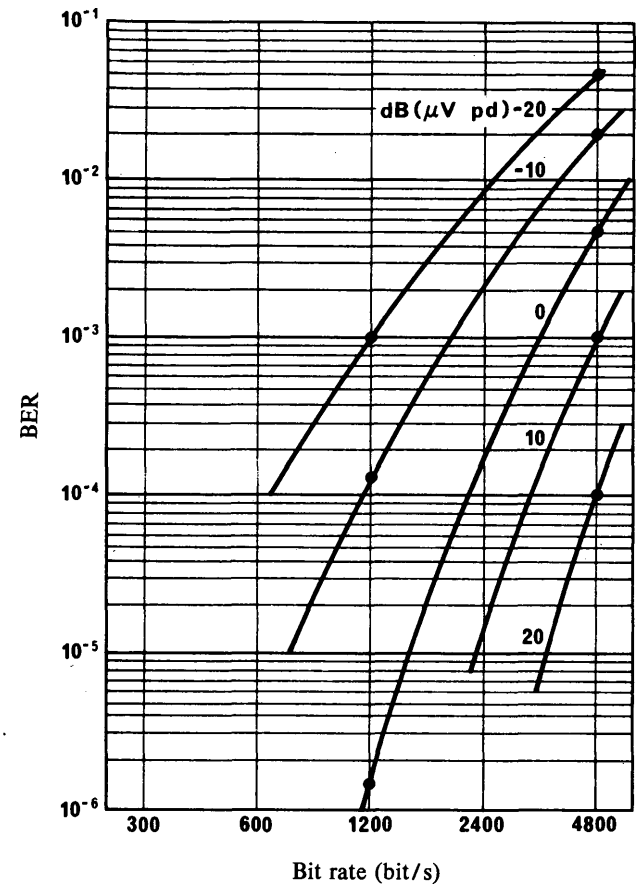


FIGURE 13 – *Dependence of ignition noise errors on bit rate at 465 MHz with signal level as parameter*

Vehicle speed : ≈ 30 km/h
Type of modulation: direct FM
Deviation : 4.8 kHz

3.2 *Error distribution*

At bit rates of 1200 bit/s and less, errors caused by ignition noise alone are normally isolated errors (see Figs. 14 and 15) [French, 1980].

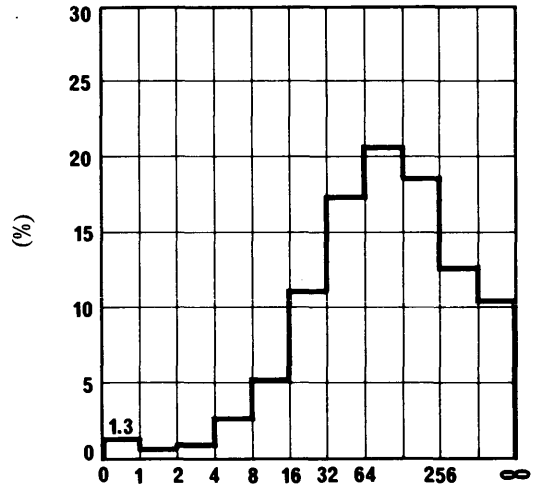


FIGURE 14 – *Error spacing at 165 MHz due to ignition noise*

Bit rate : 1200 bit/s
Type of modulation: direct FM
Deviation : 2.4 kHz
Error rate : BER = 1.3×10^{-3}

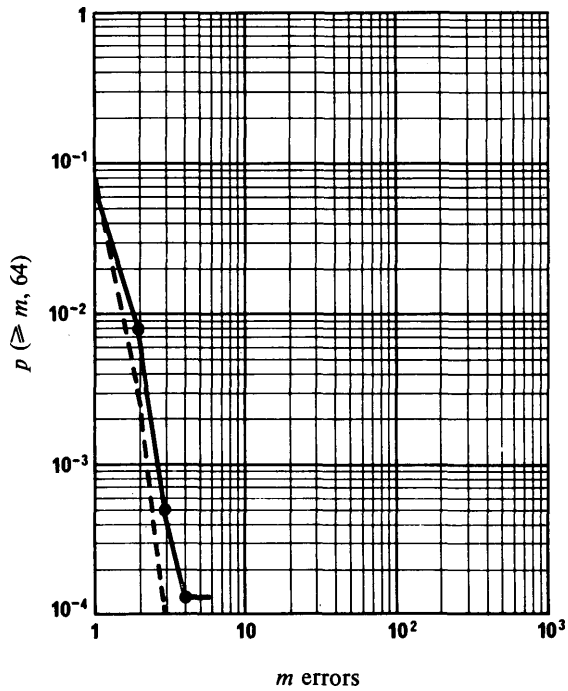


FIGURE 15 – *Distribution of errors due to ignition noise at 165 MHz*

——— : random
——— : ignition

Bit rate : 1200 bit/s
Type of modulation: direct FM
Deviation : 2.4 kHz
Error rate : BER = 1.3×10^{-3}

4. Errors caused by co-channel interference

For UHF the predicated BER is shown in Fig. 16 [Murota and Hirade, 1981].

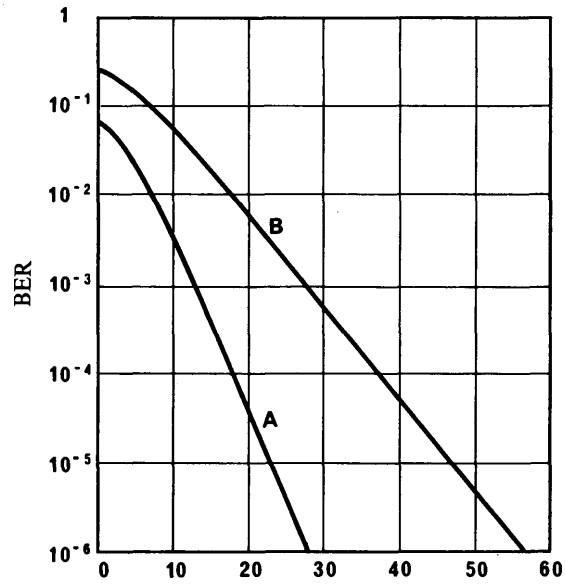


FIGURE 16 – *BER performance under fading conditions with co-channel interference*

A : 2-branch maximal ratio diversity
B : without diversity

Carrier frequency : 920 MHz
Bit rate : 16 kbit/s
Type of modulation: GMSK ($B_bT = 0.25$)
Deviation : 4.0 kHz

5. Error reduction technique

The predicted effect of diversity in the case of co-channel interference under fading conditions at 920 MHz is shown in Fig. 16.

6. Error control techniques

Mabey [1978] has shown that cyclic block codes can be used to detect errors in transmission to achieve an arbitrarily low false rate, and the repetition of message can realize an acceptable message success rate.

REFERENCES

DAIKOKU, K. et al. [April, 1981] High-speed digital transmission experiments in 920 MHz urban and suburban mobile radio channels. IEEE 31st VTS Conf.

FRENCH, R. C. [4-6 March, 1980] The mobile radio data channel Zurich International Seminar on Digital Communications, Zurich, Switzerland. IEEE Cat. No. 80CH1521-4 COM.

MABEY, P. J. [August, 1978] Mobile radio data transmission – Coding for error control. *IEEE Trans. Vehic. Tech.*, Vol. VT-27, 3, 99-109.

MUROTA, K., KINOSHITA, K. and HIRADE, K. [16 June, 1981] Spectrum efficiency of GMSK land mobile radio. IEEE International Conference on Communications (ICC '81), 14-18 June, Denver, Colo., USA, Conf. Record, Vol. 2, Session 23: Digital mobile radio, 23.8.1-23.8.5.

PART E

FORMATS FOR DATA TRANMISSION

1. Introduction

This part gives details of some of the data formats that are being used in the land mobile service.

2. The preferred binary format in the United Kingdom

The format is preferred for selective calling, status reporting, precoded messages, vehicle location, monitoring and supervisory systems, direct dialling, control in trunked systems and for mobile terminals (printers and displays).

2.1 *Format definition*

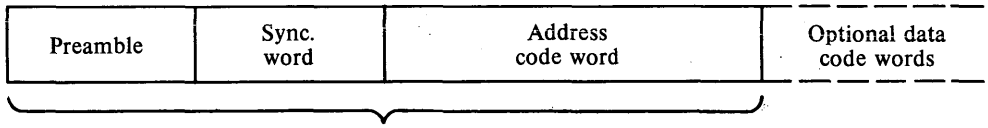


FIGURE 17 – *The format*

2.1.1 *Preamble*

16 or more bits "1010 . . . 10" ending with 0.

2.1.2 *Synchronization word*

Every message begins with:

Bit No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bit Value	1	1	0	0	0	1	0	0	1	1	0	1	0	1	1	1

(Bit number 1 is transmitted first.)

FIGURE 18 – *Synchronization word*

2.1.3 *Code words*

All code words are of 64 bits (including 16 check bits). Short messages consist of a single address code word (which includes some data); longer messages have an address code word followed by data code words.

2.1.4 *Address code word*

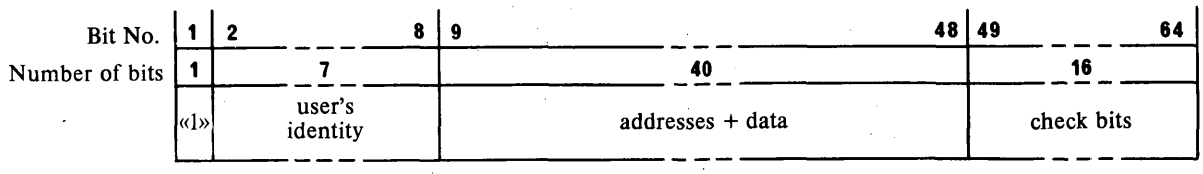


FIGURE 19 – *Address code word structure*

Bits:

1: always "1" to indicate an address word
2-8: user's identity
9-20: addressor identity (i.e. to) } optional
21-32: addressor identity (i.e. from) } optional
33-48: data
49-64: check bits (see § 2.1.7)

2.1.5 *Data code word*

As many as are needed for the message.

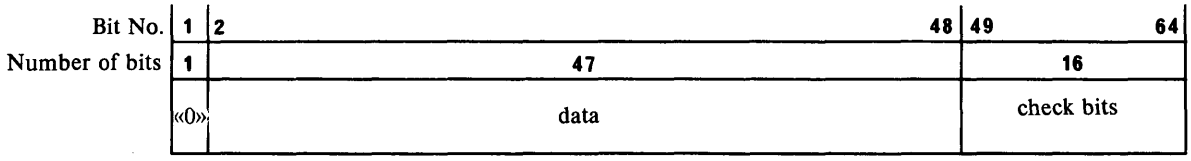


FIGURE 20 – *Data code word structure*

Bits:
1: always "0" to indicate data
2-48: data
49-64: check bits (see § 2.1.7)

2.1.6 *Character sets*

Binary coded decimal (BCD) coding can be used for the addressee and addressor identities. The character sets for messages are BCD for numeric-only messages, and the ISO 7-bit data code for alphanumeric messages. Characters are transmitted in reading order and least significant bit (b_1 in ISO code) first.

2.1.7 *Encoding and error checking*

The information bits 1-48 are the coefficients of a polynomial having terms from x^{62} down to x^{15}. This polynomial is divided modulo 2 by the generating polynomial $x^{15} + x^{14} + x^{13} + x^{11} + x4 + x^2 + 1$. The fifteen check bits, code word bits 49-63, correspond to the coefficients of the terms from x^{14} to x^0 in the remainder polynomial.

The final check bit of the code word (bit 63) is inverted to protect against misframing in the decoder.

One bit is appended to provide an even parity check of the whole 64 bit code word.

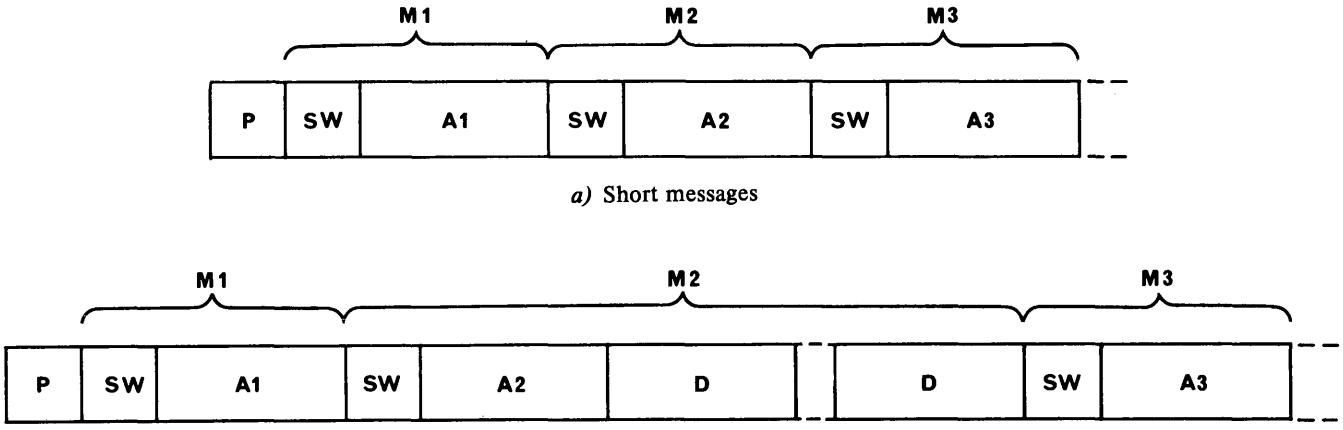
2.1.8 *Concatenated messages*

Figure 21 illustrates how several messages may be sent in one transmission.

2.2 *Format design*

An error detecting code (which has a distance of 5 bits) was chosen rather than an error correcting code because it has an adequate performance and a simple, fast decoder.

The format does not rely on a data operated squelch circuit to prevent false messages by inhibiting decoding at low signal levels. A low false rate is obtained by coding alone.



a) Short messages

b) Mix of short and arbitrary length messages

FIGURE 21 – *Concatenated messages*

P: preamble
SW: synchronization word
A: address code word
D: data code word
M: message

2.2.1 *Synchronization word*

The use of a synchronization word is the most efficient method of identifying the start of each message, establishing code word framing and ensuring a low false call rate by inhibiting code word decoding at high bit error ratios, without the need for a signal squelch circuit.

The synchronization word must satisfy the following criteria:

- it must have a good success rate so that the messages which follow are not missed;
- the success rate should be about equal to the success rate in decoding address code words. A suitable synchronization word is then 16 bits;
- the synchronization word should have good correlation properties when it is preceded by preamble so that it is not decoded spuriously during the preamble, and so a preamble of 15 bit with an additional bit is used;
- finally, the synchronization word must provide a high security against false messages.

2.2.2 *Error detecting code*

To avoid false messages caused by misframing, the format uses a coset code [Peterson and Weldon, 1972]. Inverting the final bit in the code word is sufficient to ensure that valid code words do not appear for misframing by up to 14 bit positions.

Because a synchronization word may be found falsely at the end of a preceding codeword it is necessary to label data code words with a flag bit to distinguish them from address code words.

2.2.3 *Performance with a steady signal level*

The successful message probability P_s and the false message probability P_f have been calculated for a steady signal level in terms of the bit error ratio p, assuming independent errors.

The successful message probability is $P_s = (1 - p)^{80}$ which is 80% at a bit error ratio of $p = 2.8 \times 10^{-3}$.

The false message probability has been calculated as the probability that errors cause a transmitted address code word to be decoded as a different address code word.

$$P_f \simeq P(0,s) \cdot P(\geqslant d,n) \cdot 2^{-r} \tag{1}$$

$P(0,s)$ is the probability that the s bit synchronization word ($s = 16$) is received error free. For independent errors $P(0,s) = (1-p)^{16}$.

$P(\geqslant d,n) \cdot 2^{-r}$ is the conventional expression for the false rate of a cyclic code [Lucky, Salz and Weldon, 1968] where d = minimum distance of the code ($d = 5$), n = code word length ($n = 63$), and r = number of check bits in a code word ($r = 15$). $P(\geqslant d,n)$ is the probability that an n bit word contains d errors or more.

For independent errors

$$P(\geqslant d,n) = \sum_{i=d}^{n} \binom{n}{i} p^i (1-p)^{n-i}$$

Because the code guarantees detection of all odd numbers of errors, $P(\geqslant d,n)$ was evaluated for even numbers of errors only (i = even integer).

P_f is plotted in Fig. 22 which shows that the false message probability is less than 2×10^{-6} per transmitted message.

The values of P_f calculated apply to mobile to base transmissions where the base decoder accepts any valid code word. The false message rate will be lower when some code words remain unused. For base to mobile transmissions the false message probability will be lower because a mobile decoder will only accept messages bearing its own address.

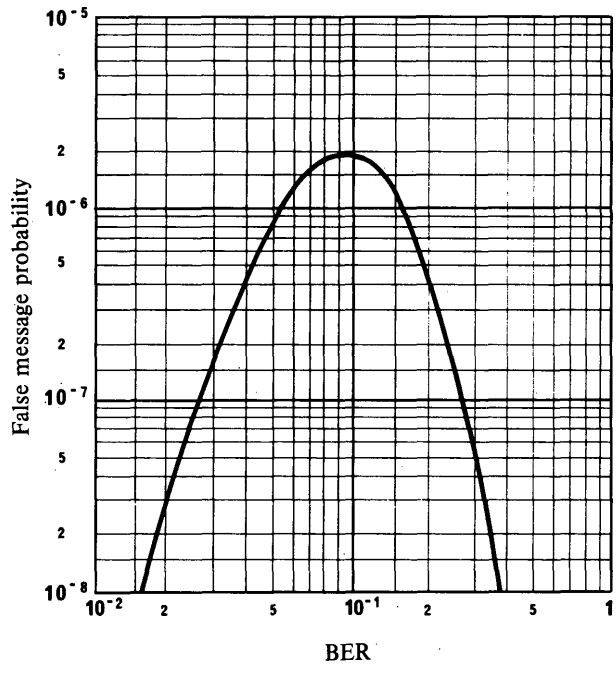


FIGURE 22 – *False message probability with a steady signal*

2.2.4 *Field measured performance*

Measurements made on a route which had Rayleigh fading and some shadowing (σ = 4 dB) with a vehicle speed of about 50 km/h, without ignition noise present, are given in Fig. 23.

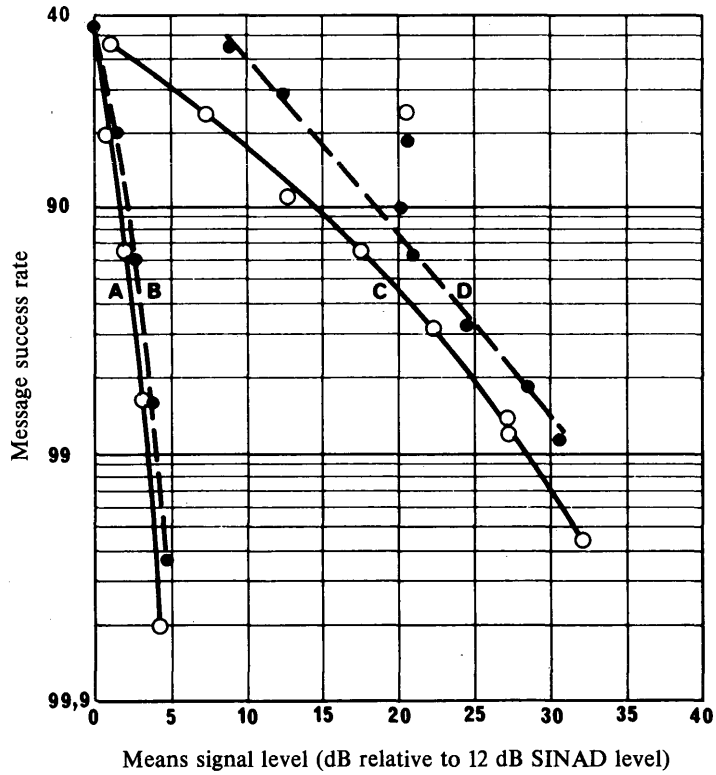


FIGURE 23 – *Field measured performance*

All curves: 1200 bit/s FFSK

A: stationary at 165 MHz FM
B: stationary at 465 MHz FM
C: moving at 50 km/h at 165 MHz FM
D: moving at 50 km/h at 465 MHz FM

REFERENCES

LUCKY, R. W., SALZ, J. and WELDON, E. J. Jr. [1968], *Principles of Data Communication*, McGraw-Hill, New York.

PETERSON, W. W. and WELDON, E. J. Jr. [1972], *Error Correcting Codes*, 2nd edition. MIT Press.

REPORT 904

AUTOMATIC DETERMINATION OF LOCATION IN THE LAND MOBILE SERVICE

(Question 51/8)

(1982)

1. Summary

In an automatic vehicle location (AVL) system the location of a mobile in a fleet is determined automatically as it moves around, within a given geographic area.

An AVL system comprises the location subsystem, data transmission subsystem and control and data manipulation subsystem. In dispatch operations including police, fire, public transportation, taxi, etc., a large percentage of the voice communications transmitted on land mobile radio channels is composed of routine information, the greater part of which is related to vehicle location status.

AVL techniques that can meet operational requirements of land mobile users can be classified into three major categories: proximity, dead reckoning and radio frequency positioning, each of which has its advantages and disadvantages. The selection of the most effective technique is dependent on the type of user and operations involved [Hansen, 1977].

Investigation has been conducted within the United Kingdom of the suitability of already established Area Navigation Systems as sources of positional information for the automatic location of vehicles. Information was derived about various forms and sources of interference, about the performance of systems in both urban and rural areas and about the effects of vehicle speed upon the accuracy and reliability of reporting.

Methods of relaying the position data and identity of vehicles were explored and a system developed for computer processing and presentation in various ways of the relayed data.

A special low cost experimental system was developed and extensively tested for AVL systems applications and test results from this system are reported in Annex I to this report.

2. Introduction

Increasingly over the past few years, police and public transportation operators around the world have realized the potential benefits associated with the knowledge of vehicle locations. Some operators in Europe, Japan and North America have already installed AVL systems.

With the continuing increase in the costs of land mobile dispatch services resulting from an overall increase in operating and maintenance costs and the rising demand by the public for improved services, it is becoming more important to find a means of reducing costs.

One of the most critical elements in dispatch services is the knowledge of current precise location of every vehicle in fleet of operation.

An AVL system with its data reduction facility can provide the information necessary to control and adjust the operation of a dispatch fleet on a real time basis, thus resulting in a more efficient and productive utilization of personnel and equipment.

3. Operational considerations

There is no authoritative body which can define the operational requirement for the many different kinds of AVL use. The following broad requirements have been stated by potential users.

3.1 *Positional accuracy*

From 100 to 200 metres for many services. Some require accuracies of 10 m; others (e.g. large area trucking dispatch systems) would be satisfied by accuracies of about 1 km.

3.2 *Frequency of up-date*

Once per minute or so for vehicles required to be quickly deployed in limited areas (e.g. police, fire tenders, ambulances) but less frequently for dispatch operations over larger areas. Attainable up-date period may sometimes be more related to the resolution of ambiguities in the positioning system and to the speed of the vehicle concerned than to the operational needs of the service.

3.3 *Coverage area*

For many systems (e.g. police, fire, ambulance, passenger omnibus, taxi services) operational areas up to 100 km × 100 km are common. Some operations are confined to much smaller areas up to 10 km^2. Others may require continental coverage.

4. Cost/benefit considerations

Potential benefits [Wilson, 1977] that can be achieved for the two different types of operation namely: fixed route, as in public transportation, and random route, such as in police and taxi operations, are summarized in the following sections.

4.1 *Potential benefits in fixed route operations*

- Reduction in checking and control personnel.
- More even distribution of passengers between vehicles.
- Reduction in (lay-over) time resulting in reduction in number of buses and personnel.
- Increased on-time service.

The AVL requirements of many fixed route systems can be satisfied by non-radio means.

4.2 *Potential benefits in random route operations*

- Reduction in response time to emergency and service calls.
- Reduction in the number of vehicles while maintaining the same coverage area.
- Reduction of unnecessary travel.

4.3 *AVL benefits-to-cost ratio*

Results based on a computer model for AVL benefit-to-cost [Symes, 1979] have indicated benefit-to-cost ratios of up to 7 to 1 are possible for the public transportation operation and as much as 13 to 1 are possible for police operations.

Although all the benefits stated above can potentially reduce the cost of running dispatch services, to date AVL systems that have been installed in Europe and North America have the objective of improving service reliability in general and reducing response time to emergency and service calls in police services in particular.

In some public transportation systems in Europe as a result of the installation of AVL systems, a reduction in the required number of buses was experienced; however these were retained to accommodate service expansion [Herrman and Zimmerman, 1974].

5. Spectrum efficiency considerations

With the installation of an AVL system, location information, which constitutes a large percentage of the voice communications [Fujaros, 1976], is automatically transmitted from vehicles to control centres in data form. This on-board capability facilitates transmission of other routine status messages as well, resulting potentially in an increase in spectrum utilization efficiency in the land mobile services.

6. Applicable radiodetermination systems

6.1 *Decca navigator (D-N) main chains*

Within the coverage of existing chains, valuable position data can be provided for many kinds of AVL systems. They are probably too costly to install specifically to provide AVL systems except in very special circumstances. Some of the test results in Annex I were obtained using standard D-N transmission in the London area.

6.2 *Loran-C and derivatives (Mini-Loran, Pulse/8)*

Within the coverage of established chains, these systems can provide valuable position data for many kinds of AVL service. Standard Loran-C is too costly to set up specifically for AVL systems but "Mini-Loran" or Pulse/8 are viable for some applications with moderately long baselines and large coverage areas. Protection from interference in the necessary wide bandwidth tends to make vehicle receivers expensive.

6.3 *Decca Hi-Fix/6 and LF derivative*

Hi-Fix/6 is a medium-frequency (2 - 4 MHz) positioning system originally developed specifically to meet the requirement of coastal and estuarial hydrographic surveying. Its suitability for AVL systems applications is limited by the rapid attenuation of the transmitted signals overland and by the short distance between "lanes", which gives rise to a high incidence of ambiguities and problems of initial lane setting. These problems are worsened by high vehicle speed. The system seemed sufficiently attractive for AVL systems to justify development and investigation of a low-frequency version to overcome some of the problems of MF operation. An experimental system was therefore built and has been extensively tested using vehicles in motion in metropolitan, urban, suburban and rural areas. The system synthesizes a hyperbolic pattern from the phase differences between successive transmissions of up to 6 time-multiplexed transmitters. Each transmitter emits two 20 ms bursts of signal. Since no contribution to system performance is made by the edges of the bursts, these can have a slow (1 to 2 ms) rise and fall, limiting the occupied bandwidth to about ± 125 Hz on each of two operating frequencies. The experimental system operates on frequencies about 133 kHz and 146 kHz. Some results of the work are shown in Annex I.

6.4 *Radio-determination satellite*

A reference to the use of radio-determination satellites for AVL appears in Report 770.

7. Conclusions

AVL should be viewed as a technology that could have significant influence on the effectiveness and productivity of dispatch operations as well as on spectrum utilization efficiency.

REFERENCES

FUJAROS, R. [September 1976] State-of-the-art of mobile radio data systems for police users. Proc. of "Telimove" Automated Vehicle Monitoring Conference, Toronto, Ontario.

HANSEN, G. R. [1977]. AVM – Is there a system for your city. Carnaham Crime Counter Measures.

HERRMAN, F. and ZIMMERMAN, W. [June 1974], The radio control system of the City of Zurich Transportation Authority. *Rev. Brown Boveri*, Vol. 61, 270-274.

SYMES, D. J. [March 1979] Advanced area-coverage automatic vehicle monitoring program. Proc. of the 29th IEEE Vehic. Tech. Conf., Illinois.

WILSON, G. D. [June 1977] The benefits of automatic vehicle location in the urban community. IEEE International Conference on Communications (ICC '77), Chicago, Illinois.

ANNEX I

TRIALS CONDUCTED WITH AVL SYSTEMS IN THE UNITED KINGDOM

1. Extensive trials have been conducted over a period of three years in London and in the urban, suburban and rural areas to the south and west of London.

The work reported is an extension of that leading to a system of remote monitoring of navigational marks now in use by UK Lighthouse Authorities [Clingen, 1980; Last, 1980].

2. These trials derived the vehicle position from two systems, as in §§ 2.1 and 2.2 below.

2.1 The English Chain of the standard Decca Navigator system was used to evaluate performance in regions where such a chain already provides coverage.

2.2 A low-frequency version of the Hi-Fix/6 system (Lo-fix) was developed to investigate the performance to be expected from a low-power and low-cost positioning aid installed specifically for AVL systems operation in areas where no coverage is provided by an established radionavigation system.

2.2.1 The "Lo-fix" system employed three unattended transmitting stations located approximately 65 km (40 miles) south-west, south, and north-east of London respectively, to provide coverage over the area of Greater London and a large part of the surrounding region.

2.2.2 Each station comprises a 21 m radiating mast antenna with radial earth mat and a small equipment cabin containing station control equipment, transmitter and antenna coupling circuits. The e.r.p. of each station is approximately 10 Watts. Operating frequencies are 133.39 (f_1) and 146.7 kHz (f_2). The occupied bandwidth of the transmission is minimised commensurate with the 20 ms burst length. Each station is remotely controlled by telephone using Post Office modems.

2.2.3 From each station a 20 ms burst of signal is radiated at f_1 immediately followed by 20 ms at f_2. The 2-burst cycle is repeated at intervals of 260 ms, allowing for a total of six stations in a chain when needed. One station is designated "prime" and transmits an additional 20 ms synchronising signal at f_1.

3. Vehicle positioning receivers of two types were used as in §§ 3.1 and 3.2 below.

3.1 The Decca Navigator (D-N) receiver is fully automatic, micro-processor controlled and acquires signals within 40 s of switch-on. Selection of the appropriate D-N chain is effected by micro-processor control of a synthesiser; entry of the required chain code may be performed locally or by radio-link from the control centre. The noise bandwidth is limited by hardware IF filters to 30 Hz (−3 dB) and within this limit is determined by software implemented adaptive tracking filters. All signals from the selected D-N chain (5f, 6f, 8f, 8.2f and 9f) are processed within the receiver to produce a digital output in the form of an FSK signal.

3.2 The "Lo-fix" receiver synchronises to the "Lo-fix" transmissions, switching between the two transmitted frequencies at the correct times. The IF bandwidth is 250 Hz (−3 dB), noise bandwidth being set within this limit by software tracking filters having time constants adjustable from a few seconds to several minutes. For the trials a typical value of 9 s was employed, thus avoiding excessive acceleration-induced errors when the vehicle was started, stopped or manoeuvred.

4. Each vehicle requires a radio transmitter/receiver installation to provide for automatic communication between the control centre and the vehicle. This may have the characteristics normal for radio telephone equipment in the land mobile service and may, in some circumstances, be shared between the AVL function and normal base-vehicle voice communications.

5. The control centre is equipped with data processing equipment to provide the following functions:

5.1 Selectively and automatically to call each vehicle in turn and then to receive position and other data sent in reply – the base to vehicle call may also include control data to the vehicle equipment.

5.2 To process and store the incoming data.

5.3 To display the vehicles' positions and other data to the control centre operator, either on a printer or Video Display Unit (VDU).

6. Equipment at the control centre is described in §§ 6.1 to 6.7.

6.1 The equipment comprises a mini computer, VDU and keyboard and a microprocessor controlled modem to couple the mini computer to the VHF base station terminal controller, itself linked to the transmitter site by a dedicated telephone circuit.

6.2 The control system keys the VHF transmitter and sends the vehicle calling code as modulated FSK. The mobile then replies immediately with its position and any other data to be processed and stored by the computer.

6.3 Also stored within the computer is a "street map" of the area of operations, digitised as a series of points to be joined by straight lines on the VDU. At present approximately one third of the roads for one quarter of the Greater London Area have been digitised, taking a total of approximately 9000 points.

6.4 The current positions of vehicles are displayed as alpha-numeric characters against the map background. As noted below, the absence of a road from the map does not prevent the vehicle being displayed at the correct point on the screen. No "force fitting" of vehicles to roads takes place and is not required.

6.5 Interrogation rates up to at least 8 vehicles/second are attainable using a singalling speed of 1200 bauds with standard radiotelephone equipment.

6.6 The display map may be set to a desired scale and to one of the following conditions:

- map centred on vehicle;
- map centred on entered grid co-ordinates;
- map centred on screen cursor points.

6.7 Scale and origin may be changed at any time. Map background may be deleted when not required, leaving vehicle markers only.

6.8 A "panic button" may be fitted in the vehicle and used to cause the vehicle symbol on the display to flash at a frequency of 1 or 2 Hz thus drawing the attention of the Controller to an emergency.

6.9 A block diagram of the system is shown in Fig. 1

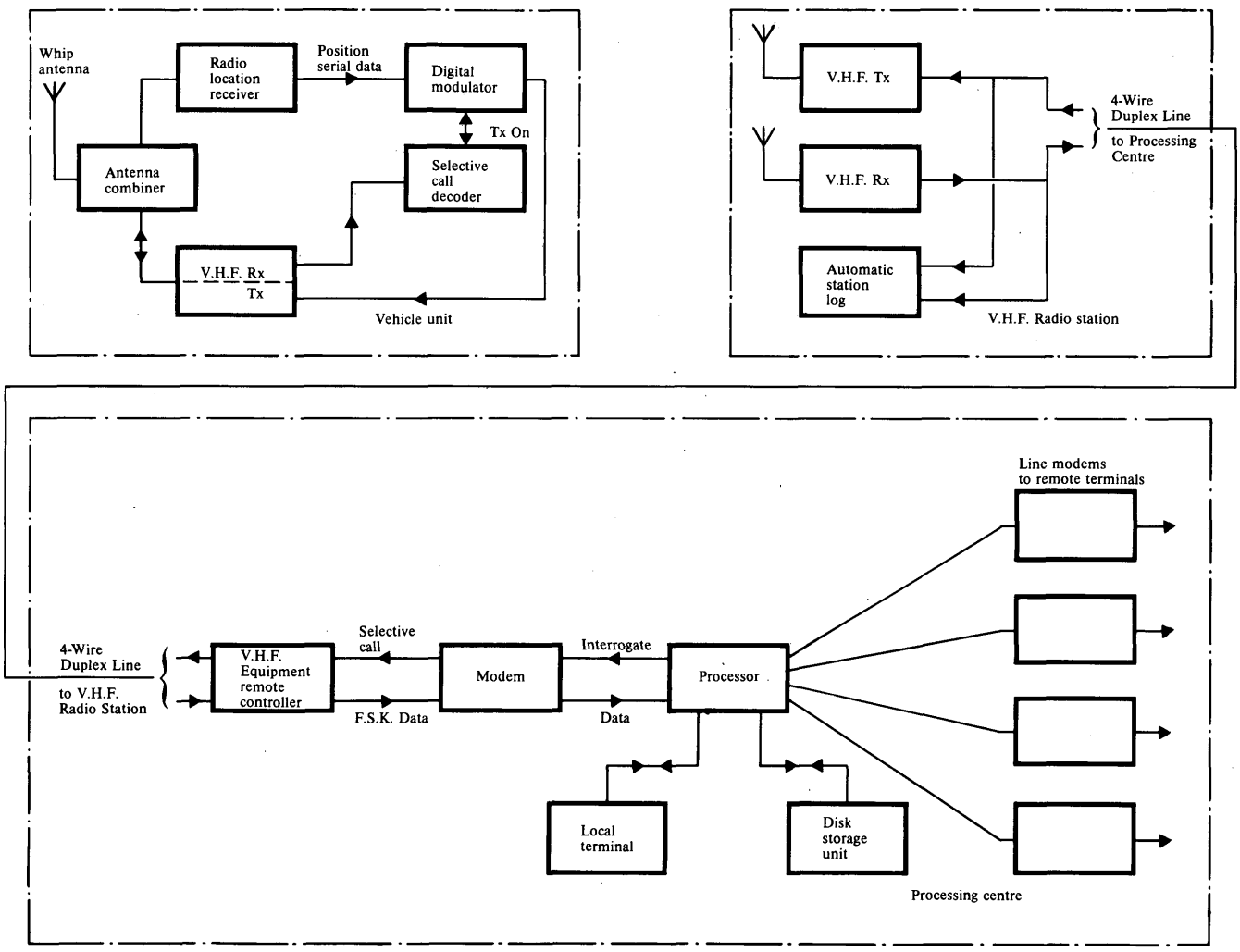


FIGURE 1 – *Vehicle location system*

7. Communication between the control centre and the test vehicle is conducted by the means described in §§ 7.1 to 7.4.

7.1 A base radio transmitter/receiver is installed on a television station at Norwood in south London, some 20 km (12 miles) from the control centre. A standard land-mobile base station feeds 10 W to a folded dipole installed 30 m up the mast. Base transmits on 138.00625 MHz, mobiles on 105.00625 MHz.

7.2 No quantitive assessment of the coverage has been made; this is satisfactory over most of the London basin with the exception of some parts of Central London in narrow streets with tall buildings on both sides.

7.3 The test vehicle uses a standard land-mobile transmitter/receiver; audio input and output are connected to the positioning receiver together with a keying line to control the transmitter.

7.4 Experiments have included the use of separate and combined antennas for both communication and positioning. Using a single antenna, cut for the VHF transmit frequency and coupled via a diplexer circuit to both the VHF Tx/Rx and LF positioning receivers, satisfactory performance of the systems has been obtained. Were UHF to be used, the length of a 1/4 wave antenna would be too short for satisfactory reception at LF although a longer ungrounded antenna would almost certainly be satisfactory.

8. Tests

8.1 Both static and dynamic tests were conducted. For the static tests the vehicle was parked at a known location identified on a 1: 2,500 scale Ordnance Survey map. The dynamic testing was conducted by driving the vehicle in a normal manner along public roads and observing its progress against a digitized map background at the control centre. Subjective evaluation of the data is necessarily limited to observation of the reported position relative to the "digital road" presented on the map.

8.2 Some results from static tests are presented in § 8.3, 8.4 and 8.5 and some computer printouts of recorded data from the dynamic tests are shown in Figs. 2 and 3.

8.3 Static tests were made by recording data from a stationary vehicle, using signals of the D-N English Chain (5B). The "observed position" was that estimated by the observer in the vehicle using Ordnance Survey maps with a scale of 1: 2500.

The "computed position" was derived from the recorded D-N hyperbolic coordinates converted to National Grid Reference using estimated propagation velocity. The "position error" is the distance between "observed position" and "computed position" in Eastings and Northings, resolved to give the radial error.

8.4 Static tests from 16 different locations in the area of Banstead, in open country with no significant industrial sites but with some overhead power lines yielded the following results:

- range of errors in Eastings: −61 to +9 m
- range of errors in Northings: −22 to +29 m, with one excursion to 219 m
- range of resolved errors: 16 to 63 m, with one excursion to 227 m.

8.5 In the area of the West End of London, in dense city conditions with narrow streets and high-rise buildings, and with high levels of electrical noise from vehicles and other sources, static tests from 11 different locations yielded the following results:

- Data rejected for gross error: 3 locations.

In remaining 8 locations:

- range of errors in Eastings: −59 to +26 m
- range of errors in Northings: −31 to +123 m
- range of resolved errors: 17 to 124 m.

8.6 In the urban area of Horley, where there are many light industrial sites and some overhead power lines, static tests were made from 14 different locations with the following results:

- range of errors in Eastings: −105 to +13 m
- range of errors in Northings: −18 to +63 m
- range of resolved errors: 8 to 125 m.

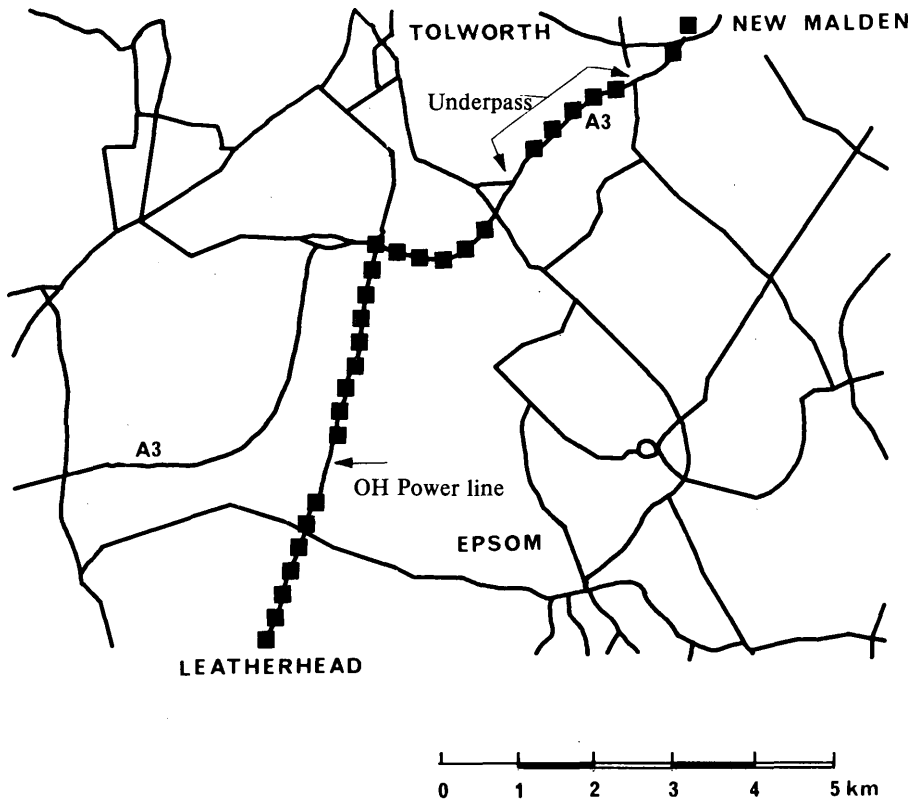


FIGURE 2 – *Decca Navigator receiver*

(Vehicle track from New Maldon to Leatherhead showing gaps in track due to disturbances from overhead power lines and bridges. Data recovers within 30 s of emerging from disturbed region.)

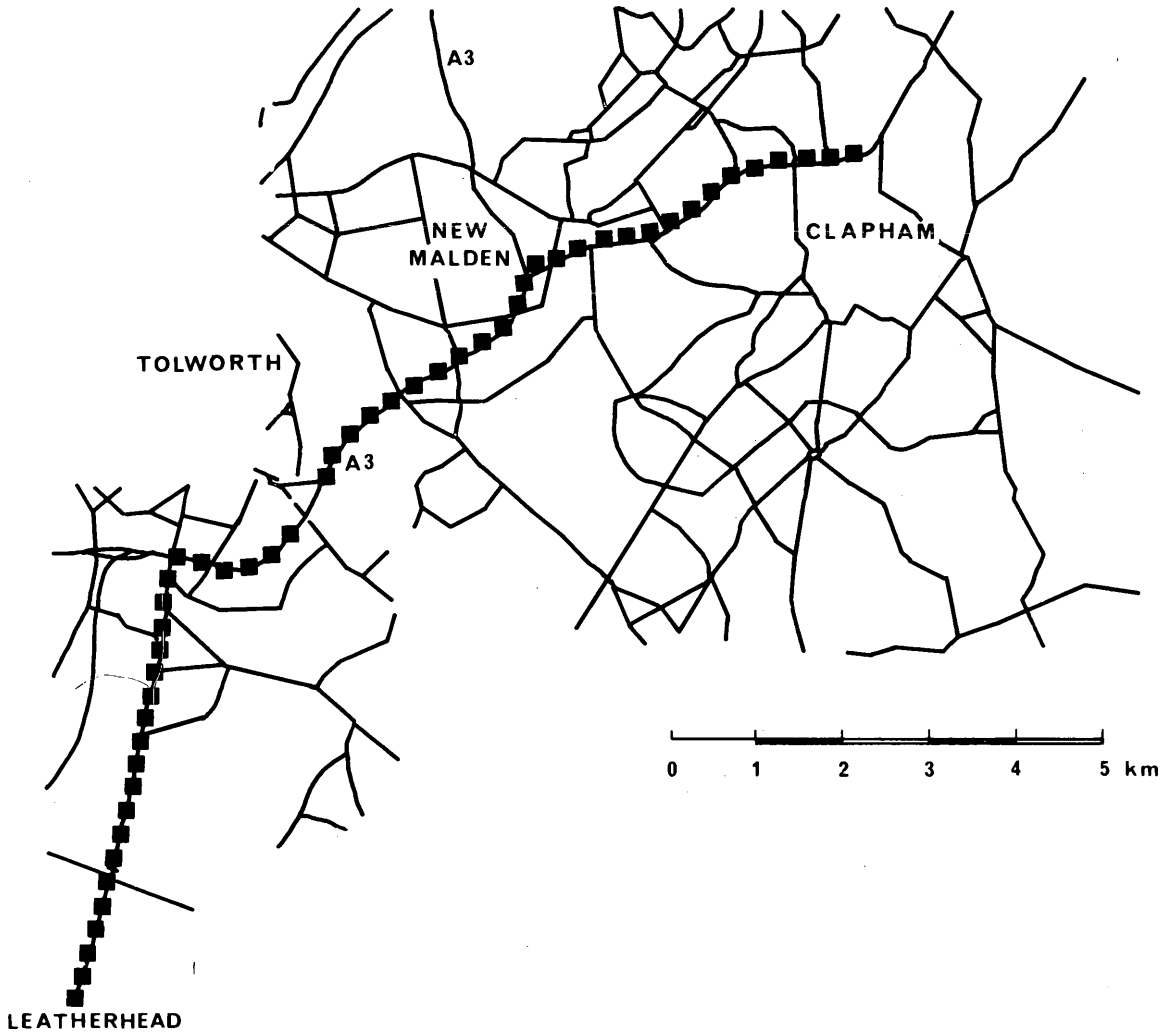


FIGURE 3 – *Low frequency Hi-Fix/6 receiver*

(Vehicle tracks from Clapham to Tolworth and from Tolworth to Leatherhead)

REFERENCES

CLINGEN [1980] An automated position-monitoring system for unmanned floating aids. Xth Conference IALA, Tokyo.

LAST, J. D. [June 1980] Use of single frequency Decca navigator signals for remote position monitoring. *Radio and Electron. Engr.*, IERE.

REPORT 778-1

WIRELESS COMMUNICATION SYSTEMS FOR PERSONS WITH IMPAIRED HEARING

(Question 49/8)

(1978-1982)

1. Introduction

Many forms of hearing impairment cannot be satisfactorily improved by the provision of amplification only. Difficulties such as distortion in the residual hearing, loss of binaural directivity, emphasis of environmental noise and room reverberation lead to the use of systems incorporating the placement of the microphone near to the speaker rather than to the listener.

2. Transmission systems

A number of means have been used to transfer the speech signals from the microphone to the listener's hearing device. The means include infra-red radiation, the magnetic induction field internal to current loops, VHF radio and the external induction field of a radiating antenna.

The use of infra-red radiation is of particular interest as it does not occupy allocated radio spectrum.

The radio induction field system is of particular interest as its realization leads to the following advantages:

- efficient use of the radio spectrum;
- ease of incorporation, with an acoustic hearing aid, into a single device;
- simulation of normal conditions of hearing;
- satisfactory use within the school, home, industrial or external environment.

On the other hand, VHF systems are employed to take advantage of the following:

- large coverage areas;
- relative immunity to natural and man-made noise.

3. System concepts

3.1 *Radio induction field system*

The mobile-to-mobile induction-field hearing assistance system exploits the FM capture effect to permit co-channel operation with selection by proximity. This pattern of selection closely parallels that used in ordinary conversation.

When an induction-field wireless hearing aid receiver is operated in the vicinity of two co-channel transmitters using a medium deviation FM transmission, the rapid change in field strength together with the FM capture effect ensures that there is a rapid changeover in reception from the more distant transmitter to the nearer transmitter with little subsequent breakthrough of consequence. For example, for a frequency deviation of 12 kHz and 75 μs receiver de-emphasis, as reported for the Australian system in Annex I, it can be shown that, at a field strength ratio of 8 : 1, the maximum breakthrough from the more distant transmitter is 34 dB (unweighted). Within the region of inverse cubic decay of the induction field, the unwanted transmitter need only be at twice the distance of the wanted one to achieve this result. The field decay rate is illustrated in Fig. 1.

A magnetic induction field is preferred as it is less perturbed by conducting objects such as the human body, and is compatible with the use of compact ferrite rod antennas. The measured decay of a magnetic induction field is shown in Fig. 2.

The design of the induction-field wireless hearing aid proceeds from the following four principles:

- The upper limit for the carrier frequency is about 4 MHz; at higher frequencies the extent of the rapidly decaying induction field is less than 12 m, which is insufficient.
- The lower limit to the maximum frequency deviation is taken as 12 kHz as with lesser deviations, excessive breakthrough from nearby co-channel transmission occurs.

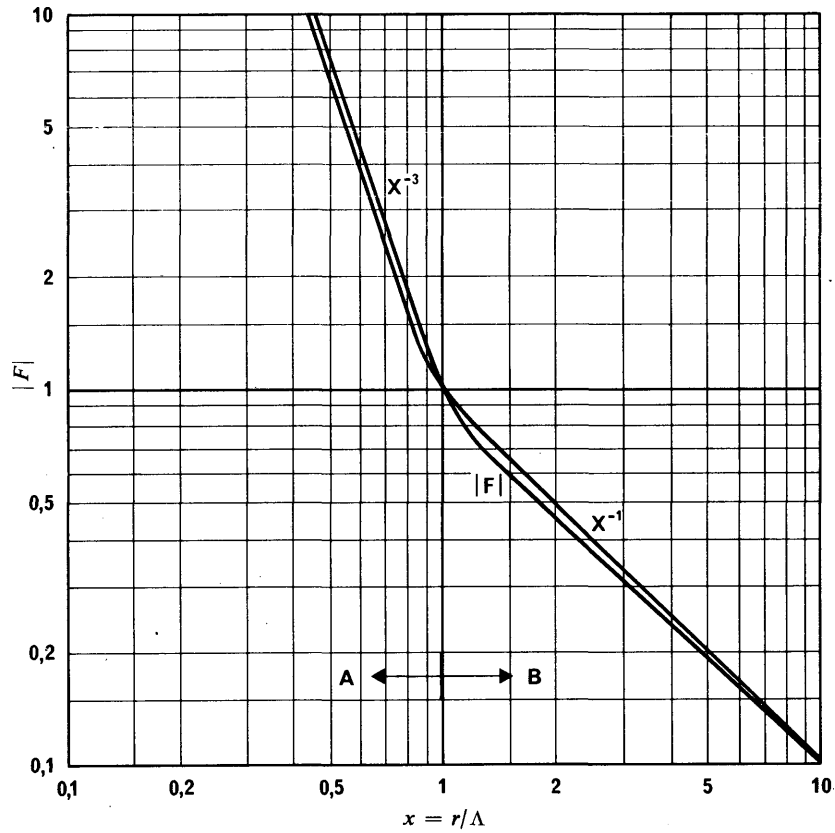


FIGURE 1 — *The field in free-space near a small dipole*

The field intensity $|F|$ in the equatorial plane is proportional to

$$|1/r^3 + j/\Lambda r^2 - 1/\Lambda^2 r|.$$

Λ is the radian wavelength $= \lambda/2\pi \approx 48$ metres divided by frequency in MHz

A: Induction
B: Radiation

– The lower limit of the carrier frequency is taken as 3 MHz. The quality factor (Q) of tuned windings on ferrite rod antennas is of the order of 200. At lower carrier frequencies the bandwidth of the tuned antenna circuits cannot accommodate the required frequency deviation.

– The mean carrier frequency of all transmitters should be stabilized to within 20 Hz of their nominal channel frequency to avoid the production of sustained audible beat notes in receivers operated near more than one co-channel transmitter. Since the carrier frequency has been set below 4 MHz, the required degree of stabilization can be obtained by reference against quartz crystal oscillators operating at ambient temperature.

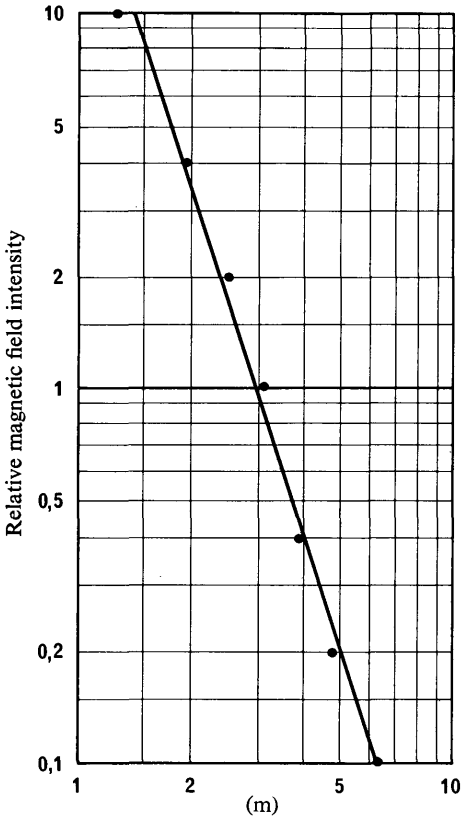


FIGURE 2 — *The measured decay of a magnetic induction field*

The points represent the measured values of the field; the straight line is an exact inverse cubic decay. The measurement were made in the laboratory in proximity to large metal objects. A frequency of 3.6 MHz was used.

3.2 *VHF system*

Systems employing VHF radio transmission are capable of providing communication over distances greater than those using the radio-induction field system, as they employ transmission via a radiation field which decays less rapidly with distance than does an induction field. As a consequence, VHF radio transmission systems require that each transmission in any locale, such as a school and its environs, be assigned a separate frequency channel. This requirement is met with available frequency assignment methods, and is not a significant factor in the operation of the system.

VHF reception is generally less susceptible to interference from natural and man-made noise than is reception at lower frequencies, and systems employing VHF radio transmission may be useful in certain circumstances to avoid local problems of interference which may affect the operation of the radio-induction field system.

Radiocommunication systems intended only for short-range communication are capable of producing high field strengths at their required working distances, without radiating significant levels of power. Exploitation of the resulting possibilities of shared spectrum usage results in improved spectrum utilization, and may allow large numbers of channels to be made available to satisfy the requirements of large schools for children with impaired hearing.

The requirements of VHF auditory training systems used in the United States of America [CCIR, 1978-82] are also shown in Annex I.

ANNEX I

SYSTEM CHARACTERISTICS

1. Radio induction field system used in Australia

Using the system design principles enumerated in the body of this Report, an experimental induction-field wireless hearing aid system had been built for purposes of evaluation and demonstration. It has neither been miniaturized nor optimized in terms of circuit design. However, the basic parameters have been chosen as being suitable for a transmitter miniaturized to the size of a spectacle case, and a receiver to the size of a body worn hearing aid.

The parameters are as follows:

Transmission medium:	Magnetic dipole induction field
Modulation:	FM
Frequency deviation:	± 12 kHz
Experimental carrier frequency:	3.6 MHz
Transmitting antenna:	Ferrite rod, 150 mm × 10 mm, disposed vertically
Transmitter final stage power:	60 mW
Field strength produced at 3 metres:	14 mV/m (measured)
Transmitter radiated power:	120 nW (calculated from above)
Transmitter spurious emission:	Undetectable, but calculated as 0.1 pW
Receiving antenna:	Ferrite rod, 60 mm × 10 mm disposed vertically
Receiver type:	Single conversion superheterodyne
Intermediate frequency:	455 kHz
System range:	12 m

The low carrier frequency, which is specified to ensure that transmission takes place via an induction field, confers other benefits. It assists the receivers' battery consumption to be kept low and allows good image rejection to be obtained without recourse to double conversion superheterodyne techniques. It therefore contributes to the economical miniaturization of the receivers.

The use of a self-contained ferrite rod antenna is particularly convenient in a transmitter designed to be handed informally to another person.

2. VHF radio systems used in the United States of America

Systems have successfully shared the 72-76 MHz and the 88-108 MHz frequency bands for many years, with the type of radio services to which these frequency bands are allocated by the Radio Regulations.

2.1 *72 to 76 MHz*

Channel bandwidth:	50 kHz for a narrowband device 200 kHz for a wideband device
Frequency tolerance:	± 0.005% (Transmitter)
Frequency stability:	± 0.005% (Receiver)
Field strength produced at 30 m:	Not to exceed 8000 μV/m
Transmitter radiated power:	1170 μW (calculated from above)
Modulation requirements for FM:	± 20 kHz maximum (narrowband) ± 75 kHz maximum (wideband)
Out of band emissions:	25 kHz or more from carrier, no more than 150 μV/m at 30 m for narrowband. 150 kHz or more from carrier, no more than 150 μV/m at 30 m for wideband.
Receiver selectivity:	40 dB minimum, adjacent channel
Receiver image rejection:	40 dB minimum.

2.2 *88 to 108 MHz*

Channel bandwidth:	200 kHz
Field strength produced at 15 m:	Not to exceed 50 μV/m
Transmitter radiated power:	0.011 μW (calculated from above)
Out of band emissions:	100 kHz or more from the carrier, no more than 40 μV/m at 3 m
Receiver standards:	Comply with normal receiver standards for this band.

REFERENCE

CCIR Documents

[1978-82]: 8/88 (USA).

BIBLIOGRAPHY

BURGESS, V., CHRISTEN, R., DONALD, G. and LOWE, A. [February-March, 1979] Radio frequency hearing aids. The need for complementary and compatible channel allocation. *The Volta Rev.*, Vol. 81, **2**, 91-99.

SECTION 8B: MARITIME MOBILE SERVICE: TELEGRAPHY AND RELATED SUBJECTS

Recommendations and Reports

RECOMMENDATION 585

ASSIGNMENT AND USE OF MARITIME MOBILE SERVICE IDENTITIES

(1982)

The CCIR,

CONSIDERING

a) the need for a unique ship identity for safety and telecommunication purposes;

b) the need for this identity to be usable in automatic systems;

c) that, in the interest of having a common address format for automatic systems, identities assigned to ship stations, coast stations and used for establishing group calls should be of a similar nature when transmitted over the radio path;

d) Article 25 and Appendix 43 of the Radio Regulations;

e) that it is highly desirable that the code which forms the ship identity or part thereof can be used by subscribers to the public switched networks for calling ships automatically;

f) that the public switched networks in some countries have restrictions, with respect to the maximum number of digits that may be dialled or keyed to indicate ship station identity;

g) that CCITT Recommendation E.210/F.120 describes a ship station identification method which provides for this contingency;

h) that whatever restrictions may be required should, in the interests of the development of automatic shore-to-ship operations, be as few as possible;

UNANIMOUSLY RECOMMENDS

1. that ships equipped with automated radiocommunication systems, including Digital Selective Calling and/or carrying alerting devices of the Future Global Maritime Distress and Safety System should be assigned ship station identities in accordance with Annex I to this Recommendation (see Note);

Note. – The World Administrative Radio Conference for the Mobile Services, scheduled for 1983, should consider this subject (see RR No. 2083).

2. that ship and coast stations using Morse telegraphy may continue to use existing alphanumeric call signs;

3. that ship and coast stations using digital selective-calling equipment in accordance with Recommendation 493 should use their 9-digit numerical identities transmitted as a 10-digit address/self-identity with a digit 0 added at the end of the identity;

4. that administrations issuing 5-digit numbers according to Radio Regulation No. 2134 should, if possible, assign 9-digit numerical identities and 5-digit numbers in such a way that there is a clear relation between them;

5. that the present octal numbering system in use in an existing maritime mobile-satellite system should be converted as early as feasible to a decimal system with 9-digit ship station identities;

6. that any future international automatic maritime telecommunication system should be designed to use the 9-digit ship station identities on the radio path.

ANNEX I

ASSIGNMENT OF SHIP STATION IDENTIFICATION

1. Introduction

1.1 Ships participating in the maritime radio services mentioned in RECOMMENDS 1 shall be assigned a nine digit unique ship station identity in the format $N_1I_2D_3X_4X_5X_6X_7X_8X_9$ wherein the first three digits represent the Nationality Identification Digits (NID).

1.2 Restrictions may apply with respect to the maximum number of digits which can be transmitted on some national telex and/or telephone networks for the purpose of ship station identification.

1.3 At present, the maximum number of digits that are able to be transmitted over the national networks of many countries for the purpose of determining ship station identity is six. The digits carried on the network to represent the ship station identity is referred to as the "ship station number" in this text and in the relevant CCITT Recommendation. The use of the techniques described below should make it possible for the coast stations of such countries to engage in the automatic connection of calls to ship stations.

1.4 To obtain the required nine digit ship station identity a series of trailing zeros is added to the ship station number by the coast station for shore-originated automatic services, e.g.:

Ship station number	*Ship station identity*
$N_1I_2D_3X_4X_5X_6$	$N_1I_2D_3X_4X_5X_60_70_80_9$

2. As long as the restrictions in § 1 apply in one's own network limiting ship station numbers to 6 digits, ships that intend to receive automatic network traffic from national coast stations only, should be assigned identities wherein X_9, but not X_8, = 0. This assumes that "9" is used to abbreviate the national NID for such ships for network purposes.

Ship station number	*ship station identity*
$9\ X_4X_5X_6X_7X_8$	$N_NI_ND_NX_4X_5X_6X_7X_80_9$

$N_NI_ND_N$ are the Nationality Identification Digits of one's own country. (See also § 3.2 of CCITT Recommendation E.210/F.120). If a country has more than one NID, only one may be used for this purpose.

3. As long as the restrictions in § 1 apply it may be useful for some administrations to expand the capacity for numerical ship station identification by using as many as ten "8 Y" abbreviations for NIDs.

Such a technique may allow the assignment of ship station identities wherein trailing zeros are applied only to X_8 and X_9.

Ship station number	*Ship station identity*
$8\ Y\ X_4X_5X_6X_7$	$N_1I_2D_3\ X_4X_5X_6X_70_80_9$

The usefulness of this technique to a given administration may depend on whether its abbreviation (e.g. 83) of its own NID is duplicated in other administrations in which some of its ships have a community of interest. When such is the case the ship in question can be called using the same ship station number in all the automatic networks of interest to that ship. As an example, a group of up to ten countries, with community of interest, might agree to assign the same abbreviation for their respective NIDs. The abbreviation should always relate to the numerically lowest NID, when more than one is assigned to a given country.

Country	*"8 Y" Assignment*	
A	80	
B	81	
C	82	
D	83	
E	84	(All countries recognize a particular 8 Y abbreviation
F	85	as associated with a particular country)
G	86	
H	87	
I	88	
J	89	

For example a coast station in any of the countries A to J receiving "83" as the first two digits of a ship station number would transmit the NID of country D.

4. As long as the restrictions in § 1 apply, ships that require regular automatic communications from foreign coast stations additional to those that may conform to the abbreviation arrangement noted in § 3 shall only be assigned ship station identities with $X_7X_8X_9 = 000$ to support 6 digit ship station numbers.

5. When it becomes necessary to progress to stage 2, (seven digit ship station numbers for automatic shore-originated traffic) in the ship station identity scheme the format of ship station identities in § 4 would change from $N_1I_2D_3X_4X_5X_6 0_7 0_8 0_9$ to $N_1I_2D_3X_4X_5X_6X_7 0_8 0_9$. If "8 Y" abbreviations are used in stage 1 (six digit ship station numbers for automatic shore-originated traffic) some ship station identity assignments will already have taken the $N_1I_2D_3X_4X_5X_6X_7 0_8 0_9$ format. It would therefore be useful to reserve at least one value in the X_7 digit position if ship station identity assignments are made on the basis of "8 Y" network abbreviations:

Ship station number	*Ship station identity*
8 Y $X_4X_5X_6X_7$	$N_1I_2D_3X_4X_5X_6X_7 0_8 0_9$

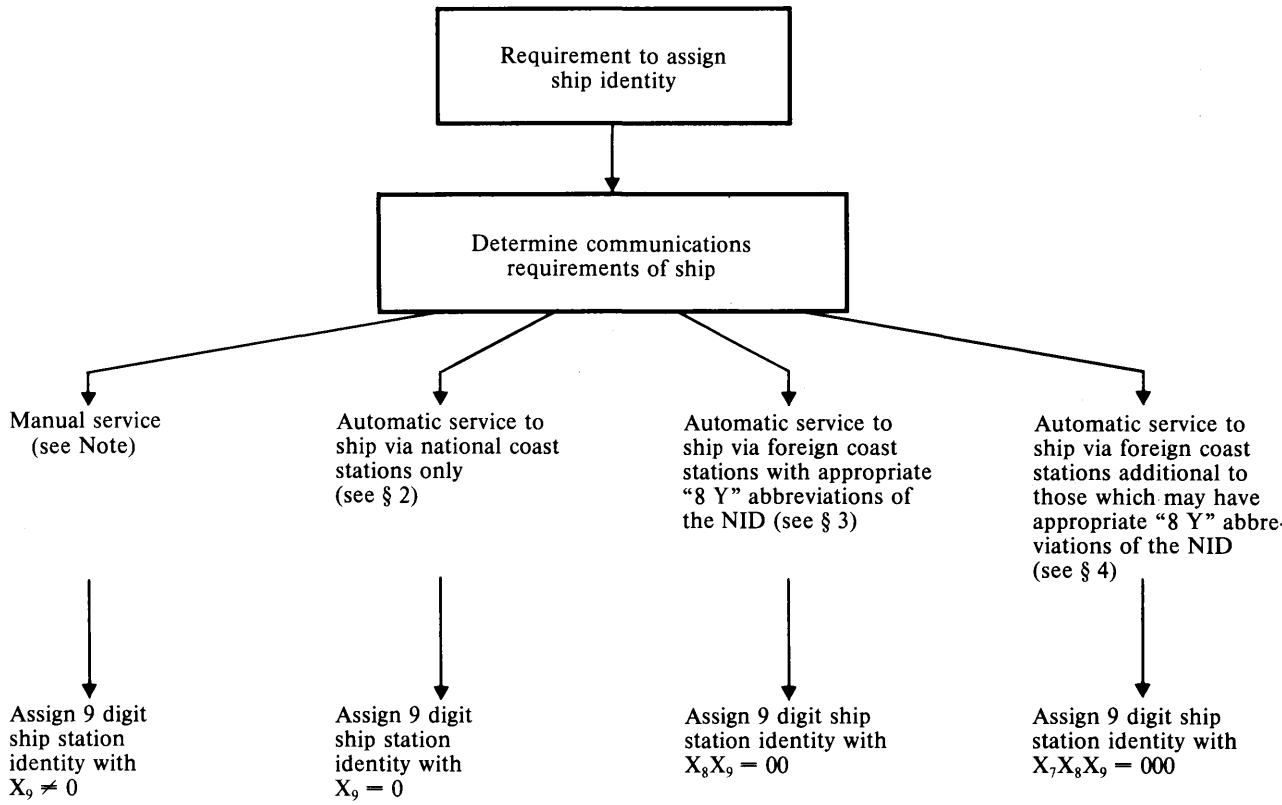


FIGURE 1 – *Procedure for selecting numerical ship station identities as long as network restrictions apply*

Note. – "Manual" refers to manual operation in the terrestrial telecommunication networks.

RECOMMENDATION 218-1

PREVENTION OF INTERFERENCE TO RADIO RECEPTION ON BOARD SHIPS

(1951-1956-1974)

The CCIR,

CONSIDERING

(a) that the Maritime Regional Radio Conference, Copenhagen, 1948, recommended that the CCIR study the question of interference to radio reception caused by electrical installations on board ship;

(b) that the International Conference on Safety of Life at Sea, London, 1974 (Chapter IV, Regulation 10), requested that all steps be taken to eliminate, as far as possible, the causes of radio interference from electrical and other apparatus on board ship;

(c) that electrical interference is generally caused by the unwanted excitation of the radio receiving equipment, including the antenna, by fluctuating electromagnetic fields set up by other electrical installations;

(d) that the fluctuation of electromagnetic fields, which gives rise to interference, is caused by abrupt changes in current in the source of interference, and by abrupt changes in the resistance of conductors situated in electromagnetic fields;

(e) that electrical interference may be transmitted by direct radiation and induction from the source of interference itself, and also by radiation, re-radiation and induction from conductors which carry interfering currents,

UNANIMOUSLY RECOMMENDS

1. that the design, construction and installation of electrical equipment on ships should be such that interference is minimized at its source (see No. 3600, 4100, 5131 of the Radio Regulations);

2. that electrical equipment installed in ships should be properly maintained to prevent any increase in the level of interference which it causes;

3. that antennas used for transmission or reception should be erected as far above and as far away as possible from electrical machinery and from parts of the ship's structure such as funnels, stays and shrouds;

4. that the feeders of antennas which are used exclusively for reception should be screened; that the screen should extend continuously from the receiver to a point which is as high as practicable above the ship's structure, and that the screen should be effectively earthed;

5. that the frame or loop antennas used for direction-finding, should be effectively screened against electrostatic interference;

6. that radio receiving equipment should be sited in a room specifically provided for the purpose. This room should be effectively screened and situated as high as practicable in the ship;

7. that where a room cannot be provided specifically for radio equipment then the space provided should be as far away as possible from all sources of interference and situated as high as practicable in the ship;

8. that the radio receiving equipment should be designed so that it is effectively screened and protected against conducted interference;

9. that suppressor filters, intended to reduce to an acceptable level the interference which is propagated, should be fitted at the sources of interference, preferably being built into equipment producing the interference, and that in particular:

9.1 the electrical ignition systems of internal combustion engines, including those which may be installed in life-boats, should be fitted with suppressors;

9.2 the navigational instruments and other electronic equipment, should, if necessary, be fitted with suppressors, be screened, and the screen effectively earthed;

9.3 the necessary degree of suppression should be determined taking into account:

- the susceptibility to interference of the receiver, and
- the coupling between the ship's electrical installation and the receiving antennas;

10. that cables in the vicinity of the receiving antennas or the radio receiving room, and cables within the radio room, should be screened by enclosing them in metal conduits, unless the cables themselves are effectively screened;

11. that "lead" and "return" conductors should be in the same cable to avoid the formation of current loops. The metal structure of the ship should not be used for carrying current;

12. that suppressors should be fitted to cables at their point of entry into the radio receiving room;

13. that cables, ducts and pipes which do not terminate in the radio receiving room, should preferably not be routed through the radio receiving room; if it is essential for them to pass through the radio receiving room, the ducts and pipes and the screening of the cables should be effectively earthed;

14. that all radio, electrical and electronic apparatus in the radio receiving room should be effectively connected to the metal structure of the ship in the shortest possible way, and that the screens of all cables in the ship should be properly earthed;

15. that rigging should be either deliberately insulated from or bonded to the ship's structure (stays that are subject to considerable tension can more conveniently be bonded);

16. that for smaller vessels, vessels without specific radio receiving rooms, and those constructed of non-conducting materials, the principles recommended should be applied as far as is practicable;

17. that particular care should be taken to minimize interference on the frequency bands used for distress, safety and radionavigation in the maritime service;

18. that administrations should bring the above recommendations to the attention of naval architects, shipbuilders, those responsible for the construction, installation and maintenance of electrical, electronic and radio equipment and those organizations responsible for the formulation of standards.

RECOMMENDATION 476-3 *

DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question 5/8)

(1970-1974-1978-1982)

The CCIR,

CONSIDERING

a) that there is a requirement to interconnect mobile stations, or mobile stations and coast stations, equipped with start-stop apparatus employing the International Telegraph Alphabet No. 2, by means of radiotelegraph circuits;

b) that direct-printing telegraphy communications in the maritime mobile service can be listed in the following categories:

b.a telegraph service between a ship and a coast station;

b.b telegraph service between a ship and an extended station (ship's owner) via a coast station;

b.c telex service between a ship and a subscriber of the (international) telex network;

b.d broadcast telegraph service from a coast station to one or more ships;

b.e telegraph service between two ships or between one ship and a number of other ships;

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* The Director, CCIR is requested to bring this Recommendation to the attention of the CCITT.

c) that those categories are different in nature and that consequently different degrees of transmission quality may be required;

d) that the categories given in *b.a*, *b.b* and *b.c* above may require a higher transmission quality than categories *b.d* and *b.e* for the reason that data could be handled through the services in the categories *b.a*, *b.b* and *b.c*, while the messages passed through the service of category *b.d*, and via the broadcast service of category *b.e* are normally plain language, allowing a lower transmission quality than that required for coded information;

e) that the service in category *b.d* and the broadcast service in category *b.e* cannot take advantage of an ARQ method, as there is in principle no return path;

f) that for these categories of service which by their nature do not allow the use of ARQ, another mode, i.e. the forward error-correcting (FEC) mode should be used;

g) that the period for synchronization and phasing should be as short as possible and should not exceed 5 seconds;

h) that most of the ship stations do not readily permit simultaneous use of the radio transmitter and radio receiver;

j) that the equipment on board ships should be neither unduly complex nor expensive;

k) that provision is made in Appendix 38 of the Radio Regulations for direct-printing telegraph operation,

UNANIMOUSLY RECOMMENDS

1. that when an error-detecting and correcting system is used for direct-printing telegraphy in the maritime mobile service, a 7-unit ARQ system or a 7-unit forward acting, error-correcting and indicating time-diversity system, using the same code, should be employed;

2. that equipment designed in accordance with § 1 should meet the characteristics laid down in Annex I.

ANNEX I

1. **General** (Mode A, ARQ and Mode B, FEC)

1.1 The system is a single-channel synchronous system using the 7-unit error-detecting code as listed in § 2 of this Annex.

1.2 The modulation rate on the radio link is 100 bauds. The equipment clocks controlling the modulation rate should have an accuracy of better than 30 parts in 10^6.

Note. – Some existing equipments may not conform to this requirement.

1.3 The terminal input must be able to accept the 5-unit start-stop CCITT International Telegraph Alphabet No. 2 at a modulation rate of 50 bauds.

1.4 The frequency shift on the radio link is 170 Hz. When frequency shift is effected by applying audio signals to the input of a transmitter, the centre frequency of the audio spectrum offered to the transmitter should be 1700 Hz.

Note. – A number of equipments are presently in service, using a centre frequency of 1500 Hz. These may require special measures to achieve compatibility.

1.5 The radio frequency tolerance of the transmitter and the receiver should be in accordance with Appendix 38 of the Radio Regulations. It is desirable that the receiver employs the minimum practicable bandwidth (see also Report 585).

Note. – The receiver bandwidth should preferably be between 270 and 340 Hz.

2. Table of conversion

2.1 *Traffic information signals*

TABLE I

Combination No.	Letter-case	Figure-case	International Telegraph Alphabet No. 2 Code	Emitted 7-unit signal(1)
1	A	—	ZZAAA	BBBYYYB
2	B	?	ZAAZZ	YBYYBBB
3	C	:	AZZZA	BYBBBYY
4	D	☒(3)	ZAAZA	BBYYBYB
5	E	3	ZAAAA	YBBYBYB
6	F	(2)	ZAZZA	BBYBBYY
7	G	(2)	AZAZZ	BYBYBBY
8	H	(2)	AAZAZ	BYYBYBB
9	I	8	AZZAA	BYBBYYB
10	J	Audible signal	ZZAZA	BBBYBYY
11	K	(	ZZZZA	YBBBBYY
12	L	)	AZAAZ	BYBYYBB
13	M	.	AAZZZ	BYYBBBY
14	N	,	AAZZA	BYYBBYB
15	O	9	AAAZZ	BYYYBBB
16	P	0	AZZAZ	BYBBYBY
17	Q	1	ZZZAZ	YBBBYBY
18	R	4	AZAZA	BYBYBYB
19	S	'	ZAZAA	BBYBYYB
20	T	5	AAAAZ	YYYBYBBB
21	U	7	ZZZAA	YBBBYYB
22	V	=	AZZZZ	YYYBBBBY
23	W	2	ZZAAZ	BBBYYBY
24	X	/	ZAZZZ	YBYBBBY
25	Y	6	ZAZAZ	BBYBYBY
26	Z	+	ZAAAZ	BBYYYBB
27	← (Carriage return)		AAAZA	YYYBBBB
28	= (Line feed)		AZAAA	YYBBYBB
29	↓ (Letter shift)		ZZZZZ	YBYBBYB
30	↑ (Figure shift)		ZZAZZ	YBBYBBY
31	Space		AAZAA	YYBBBYB
32	Unperforated tape		AAAAA	YBYBYBB

(1) B represents the higher emitted frequency and Y the lower.

(2) At present unassigned (see CCITT Rec. F.1 C8). Reception of these signals, however, should not initiate a request for repetition.

(3) The pictorial representation shown is a schematic of ✠ which may also be used when equipment allows (CCITT Rec. F.1).

2.2 *Service information signals*

TABLE II

Mode A (ARQ)	Emitted signal	Mode B (FEC)
Control signal 1 (CS1)	BYBYYBB	
Control signal 2 (CS2)	YBYBYBB	
Control signal 3 (CS3)	BYYBBYB	
Idle signal β	BBYYBBY	
Idle signal α	BBBBYYY	Phasing signal 1
Signal repetition	YBBYYBB	Phasing signal 2

3. Characteristics

3.1 *Mode A (ARQ)* (see Figs. 1 and 2)

A synchronous system, transmitting blocks of three characters from an information sending station (ISS) towards an information receiving station (IRS), which stations can, controlled by the control signal 3 (see § 2.2), interchange their functions.

3.1.1 *Master and slave arrangements*

3.1.1.1 The station that initiates the establishment of the circuit (the calling station) becomes the "master" station, and the station that has been called will be the "slave" station;

this situation remains unchanged during the entire time in which the established circuit is maintained, regardless of which station, at any given time, is the Information Sending Station (ISS) or Information Receiving Station (IRS);

3.1.1.2 the clock in the master station controls the entire circuit (see circuit timing diagram, Fig. 1);

3.1.1.3 the basic timing cycle is 450 ms, and for each station consists of a transmission period followed by a transmission pause during which reception is effected;

3.1.1.4 the master station transmitting time distributor is controlled by the clock in the master station;

3.1.1.5 the slave station receiving time distributor is controlled by the received signal;

3.1.1.6 the slave station transmitting time distributor is phase-locked to the slave station receiving time distributor; i.e. the time interval between the end of the received signal and the start of the transmitted signal (t_E in Fig. 1) is constant;

3.1.1.7 the master station receiving time distributor is controlled by the received signal.

3.1.2 *The Information Sending Station (ISS)*

3.1.2.1 Groups the information to be transmitted into blocks of three characters (3 × 7 signal elements), including, if necessary, "idle signals β" to complete or to fill blocks when no traffic information is available;

3.1.2.2 emits a "block" in 210 ms after which a transmission pause of 240 ms becomes effective, retaining the emitted block in memory until the appropriate control signal confirming correct reception by the Information Receiving Station (IRS) has been received;

3.1.2.3 numbers successive blocks alternately "Block 1" and "Block 2" by means of a local numbering device. The first block should be numbered "Block 1" or "Block 2" dependent on whether the received control signal (see § 3.1.4.5) is a control signal 1 or a control signal 2. The numbering of successive blocks is interrupted at the reception of:

- a request for repetition; or
- a mutilated signal; or
- a control signal 3 (see § 2.2);

3.1.2.4 emits the information of Block 1 on receipt of control signal 1 (see § 2.2);

3.1.2.5 emits the information of Block 2 on receipt of control signal 2 (see § 2.2);

3.1.2.6 emits a block of three "signal repetitions" on receipt of a mutilated signal (see § 2.2).

3.1.3 *The Information Receiving Station (IRS)*

3.1.3.1 Numbers the received blocks of three characters alternately "Block 1" and "Block 2" by a local numbering device, the numbering being interrupted at the reception of:

- a block in which one or more characters are mutilated; or
- a block containing at least one "signal repetition"; (3.1.2.6)

3.1.3.2 after the reception of each block, emits one of the control signals of 70 ms duration after which a transmission pause of 380 ms becomes effective;

3.1.3.3 emits the control signal 1 at the reception of:

- an unmutilated "Block 2", or
- a mutilated "Block 1", or
- Block 1" containing at least one "signal repetition";

3.1.3.4 emits the control signal 2 at reception of:

- an unmutilated "Block 1", or
- a mutilated "Block 2", or
- a "Block 2" containing at least one "signal repetition".

3.1.4 *Phasing*

3.1.4.1 When no circuit is established, both stations are in the "stand-by" position. In this stand-by position no ISS or IRS and no master or slave position is assigned to either of the stations;

3.1.4.2 the station desiring to establish the circuit emits the "call" signal. This "call" signal is formed by two blocks of three signals;

3.1.4.3 the call signal contains:

- in the first block: "signal repetition" in the second character place and any combination of information signals * in the first and third character place,
- in the second block: "signal repetition" in the third character place preceded by any combination of the 32 information signals * in the first and second character place;

3.1.4.4 on receipt of the appropriate call signal the called station changes from stand-by to the IRS position and emits the control signal 1 or the control signal 2;

3.1.4.5 on receipt of two consecutive identical control signals, the calling station changes into ISS and operates in accordance with § 3.1.2.4 and 3.1.2.5.

3.1.5 *Rephasing* **

3.1.5.1 When reception of information blocks or of control signals is continuously mutilated, the system reverts to the "stand-by" position after a predetermined time (a preferable predetermined time would be the duration of 32 cycles of 450 ms), to be decided by the user, of continuous repetition; the station that is master station at the time of interruption immediately initiates rephasing along the same lines as laid down in § 3.1.4;

3.1.5.2 if, at the time of interruption, the slave station was in the IRS position, the control signal to be returned after phasing should be the same as that last sent before the interruption to avoid the loss of an information block upon resumption of the communication. (Some existing equipments may not conform to this requirement);

3.1.5.3 however, if, at the time of interruption, the slave station was in the ISS position, it emits, after having received the appropriate call blocks, either:

- the control signal 3; or
- the control signal 1 or 2 in conformity with § 3.1.4.4, after which control signal 3 is emitted to initiate changeover to the ISS position;

3.1.5.4 if rephasing has not been accomplished within the time-out interval of § 3.1.9.1, the system reverts to the stand-by position and no further rephasing attempts are made.

3.1.6 *Change-over*

3.1.6.1 *The Information Sending Station (ISS)*

- Emits, to initiate a change in the direction of the traffic flow, the information signal sequence "Figure shift" – "Plus" ("figure case of *Z*") – "Question Mark" ("figure case of *B*") *** followed, if necessary, by one or more "Idle Signals β" to complete a block;
- emits, on receipt of a control signal 3, a block containing the signals "Idle Signal β" – "Idle Signal α" – "Idle Signal β";
- changes subsequently to IRS after the reception of a "signal repetition".

3.1.6.2 *The Information Receiving Station (IRS)*

- Emits the control signal 3:
  (a) when the station wishes to change over to ISS,
  (b) on receipt of a block in which the signal information sequence "Figure shift" – "Plus" – (figure-case of Z) – "Question Mark" (figure-case of B) terminates *** or upon receipt of the following block. In the latter case, the IRS shall ignore whether or not one or more characters in the last block are mutilated:
- changes subsequently to ISS after reception of a block containing the signal sequence "Idle signal β" – "Idle signal α" "Idle signal β";
- emits one "signal repetition" as a master station, or a block of three "signal repetitions" as a slave station, after being changed into ISS;

3.1.7 *Output to line*

3.1.7.1 the signal offered to the line output terminal is a 5-unit start-stop signal at a modulation rate of 50 bauds.

3.1.8 *Answerback*

3.1.8.1 The WRU (Who are you?) sequence, which consists of combination Nos. 30 and 4 in the International Telegraph Alphabet No. 2, is used to request terminal identification.

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* The composition of these signals and their assignment to individual ships require international agreement (see Recommendation 491).

** Some coast stations do not provide rephasing (see also Recommendation 492).

*** In the Telex network, the signal sequence combination No. 26 - combination No. 2, sent whilst the teleprinters are in the figure case condition, is used to initiate a reversal of the flow of information. The IRS is, therefore, required to keep track of whether the traffic information flow is in the letter-case or figure-case mode to ensure proper end-to-end operation of the system.

3.1.8.2 The Information Receiver Station (IRS), on receipt of a block containing the WRU sequence, which will actuate the the teleprinter answerback code generator:

- changes the direction of traffic flow in accordance with § 3.1.6.2;
- transmits the signal information characters derived from the teleprinter answerback code generator;
- after transmission of 2 blocks of "Idle signals β" (after completion of the answerback code, or in the absence of an answerback code), changes the direction of traffic flow in accordance with § 3.1.6.1.

Note. – Some existing equipments may not conform to this requirement.

3.1.9 *End of communication*

3.1.9.1 When reception of information blocks or of control signals is continuously mutilated, the system reverts to the "stand-by" position after a predetermined time of continuous repetition, which causes the termination of the established circuit, (a preferable predetermined time would be the duration of 64 cycles of 450 ms);

3.1.9.2 the station that wishes to terminate the established circuit transmits an "end of communication signal";

3.1.9.3 the "end of communication signal" consists of a block containing three "Idle Signal α":

3.1.9.4 the "end of communication signal" is transmitted by the ISS;

3.1.9.5 if an IRS wishes to terminate the established circuit it has to change over to ISS in accordance with § 3.1.6.2;

3.1.9.6 the IRS that receives an "end of communication signal" emits the appropriate control signal and reverts to the "stand-by" position;

3.1.9.7 on receipt of a control signal that confirms the unmutilated reception of the "end of communication signal", the ISS reverts to the "stand-by" position;

3.1.9.8 when after a predetermined number of transmissions * of the "end of communication signal" no control signal has been received confirming the unmutilated reception of the "end of communication signal", the ISS reverts to the stand-by position and the IRS times out in accordance with § 3.1.9.1.

3.2 *Mode B, forward error correction (FEC)* (see Figs. 3 and 4)

A synchronous system, transmitting an uninterrupted stream of characters from a station sending in the collective B-mode (CBSS) to a number of stations receiving in the collective B-mode (CBRS), or from a station sending in the selective B-mode (SBSS) to one selected station receiving in the selective B-mode (SBRS).

3.2.1 *The station sending in the collective or in the selective B-mode (CBSS or SBSS)*

3.2.1.1 Emits each character twice: the first transmission (DX) of a specific character is followed by the transmission of four other characters, after which the retransmission (RX) of the first character takes place, allowing for time-diversity reception at 280 ms time space;

3.2.1.2 emits as a preamble to messages or to the call sign, alternately the phasing signal 1 (see § 2.2) and the phasing signal 2 (see § 2.2) whereby phasing signal 1 is transmitted in the RX, and phasing signal 2 in the DX position. At least four of these signal pairs (phasing signal 1 and phasing signal 2) should be transmitted.

3.2.2 *The station sending in the collective B-mode (CBSS)*

3.2.2.1 Emits during the breaks between two messages in the same transmission the phasing signals 1 and the phasing signals 2 in the RX and the DX position, respectively.

3.2.3 *The station sending in the selective B-mode (SBSS)*

3.2.3.1 Emits after the transmission of the required number of phasing signals (see § 3.2.1.2) the call sign of the station to be selected. This call sign is a sequence of four characters that represents the number code of the called station. This transmission takes place in the time diversity mode according to § 3.2.1.1;

3.2.3.2 emits the call sign and all further signals in a 3B/4Y ratio, i.e. inverted with respect to the signals in Table I of § 2 in the column "emitted 7-unit signal". Consequently, all signals, i.e. both traffic information signals and service information signals, following the phasing signals are transmitted in the 3B/4Y ratio;

3.2.3.3 emits the service information signal "Idle signal β" during the idle time between the messages consisting of traffic information signals.

* A preferable predetermined number would be four transmissions of the "end of communication signal".

3.2.4 *The station(s) receiving in the collective or in the selective B-mode (CBRS or SBRS)*

3.2.4.1 Checks both characters (DX and RX), printing an unmutilated DX or RX character, or printing an error symbol or space, if both are mutilated.

3.2.5 *Phasing*

3.2.5.1 When no reception takes place, the system is in the "stand-by" position as laid down in § 3.1.4.1;

3.2.5.2 on receipt of the sequence *"phasing signal 1" – "phasing signal 2"*, or of the sequence *"phasing signal 2" – "phasing signal 1"*, in which phasing signal 2 determines the DX and phasing signal 1 determines the RX position, and at least one further phasing signal in the appropriate position, the system changes from "stand-by" to the CBRS position;

3.2.5.3 when started as CBRS the system changes to the SBRS (selectively called receiving station) position on receipt of the inverted characters representing its selective call number;

3.2.5.4 having been changed into the CBRS or into the SBRS position the system offers continuous stop-polarity to the line output terminal until either the signal "carriage return" or "line feed" is received;

3.2.5.5 when started as SBRS, the decoder re-inverts all the following signals received to the 3Y/4B ratio, so that these signals are offered to the SBRS in the correct ratio, but they remain inverted for all other stations;

3.2.5.6 both the CBRS and the SBRS revert to the stand-by position if, during a predetermined time, the percentage of mutilated signals received has reached a predetermined value.

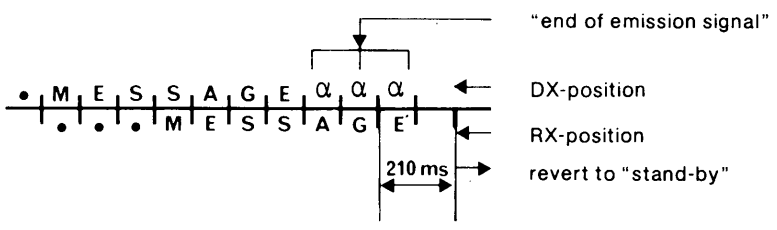
3.2.6 *Output to line*

3.2.6.1 The signal offered to the line output terminal is a 5-unit start-stop CCITT International Telegraph Alphabet No. 2 signal at a modulation rate of 50 bauds.

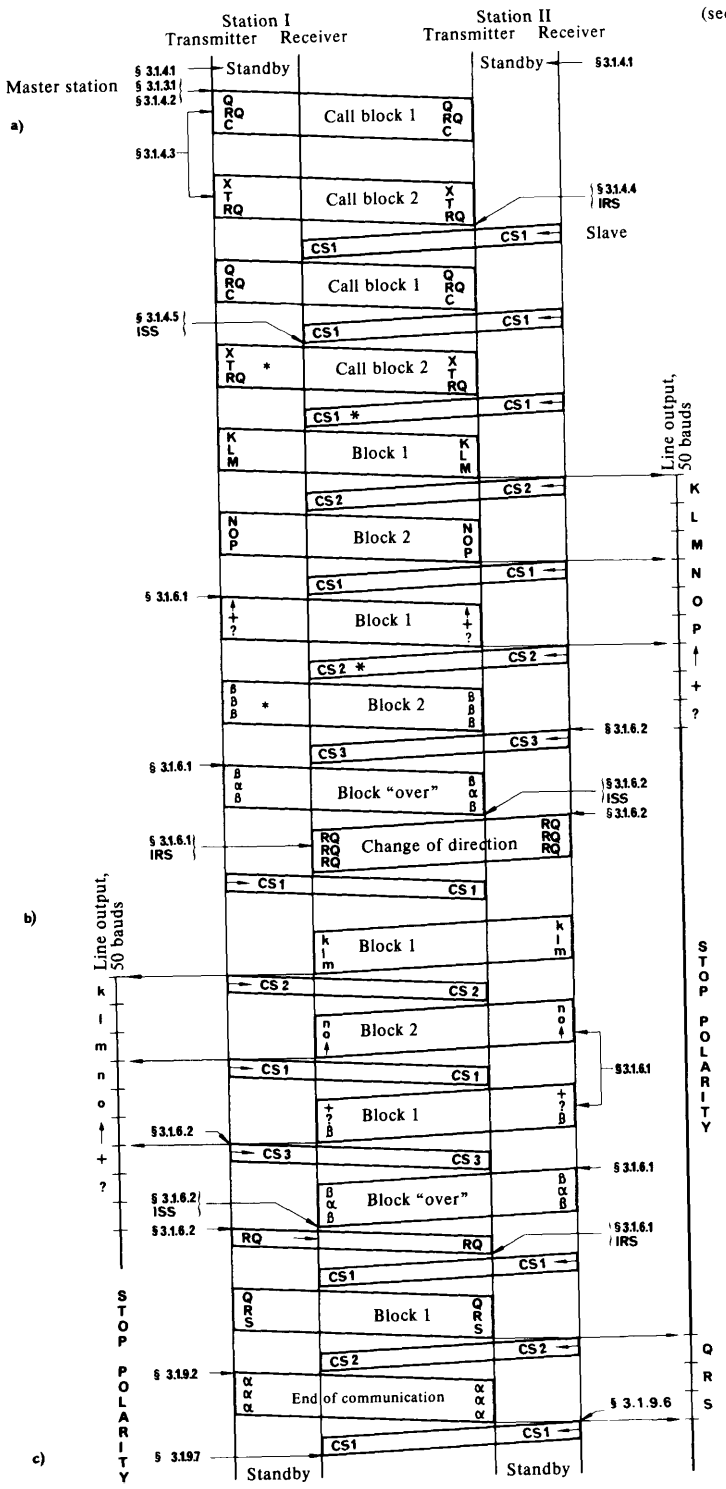
3.2.7 *End of emission*

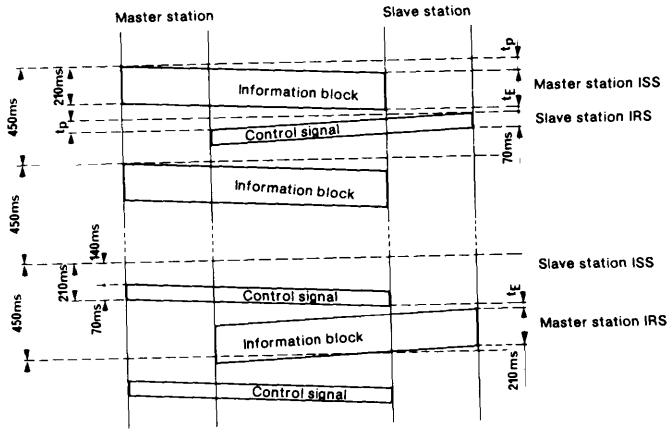
3.2.7.1 The station sending in the B-mode (CBSS or SBSS) that wishes to terminate the emission transmits the "end of emission signal";

3.2.7.2 the "end of emission signal" consists of three consecutive "idle signals α" (see § 2.2) transmitted in the DX position only, immediately after the last transmitted traffic information signal in the DX position, after which the station terminates its emission and reverts to the "stand-by" position;



3.2.7.3 the CBRS or the SBRS reverts to the "stand-by" position not less than 210 ms after receipt of at least two consecutive "idle signals α" in the DX position.





Basic timing cycle

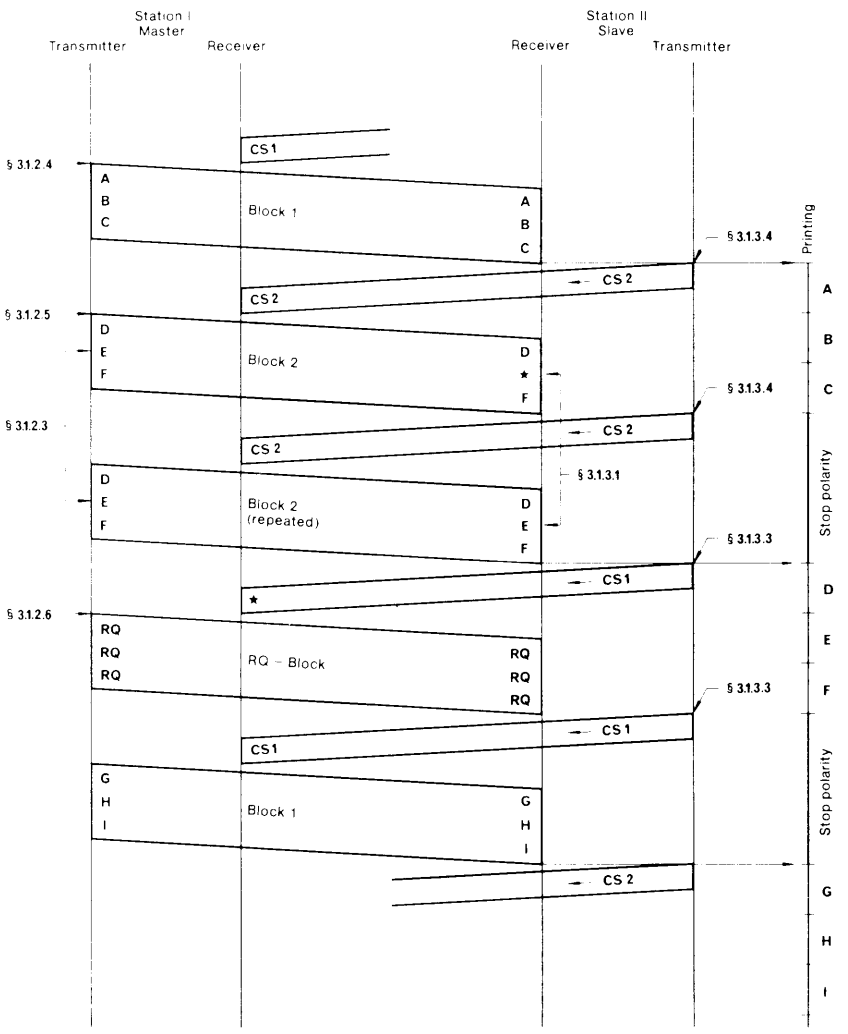
FIGURE 1 – *A-Mode operation*

a) Start of communication
b) Change of the direction of the traffic flow
c) End of communication
CS: Control signal

ISS: Information sending station
IRS: Information receiving station
RQ: Signal repetition information signal

t: Figure shift
t_p: (One way) propagation time
t_E: (Fixed) equipment delay

*The transmission of these signals may be omitted.



* Detected error Symbol.

FIGURE 2 – *Mode A under error receiving conditions*

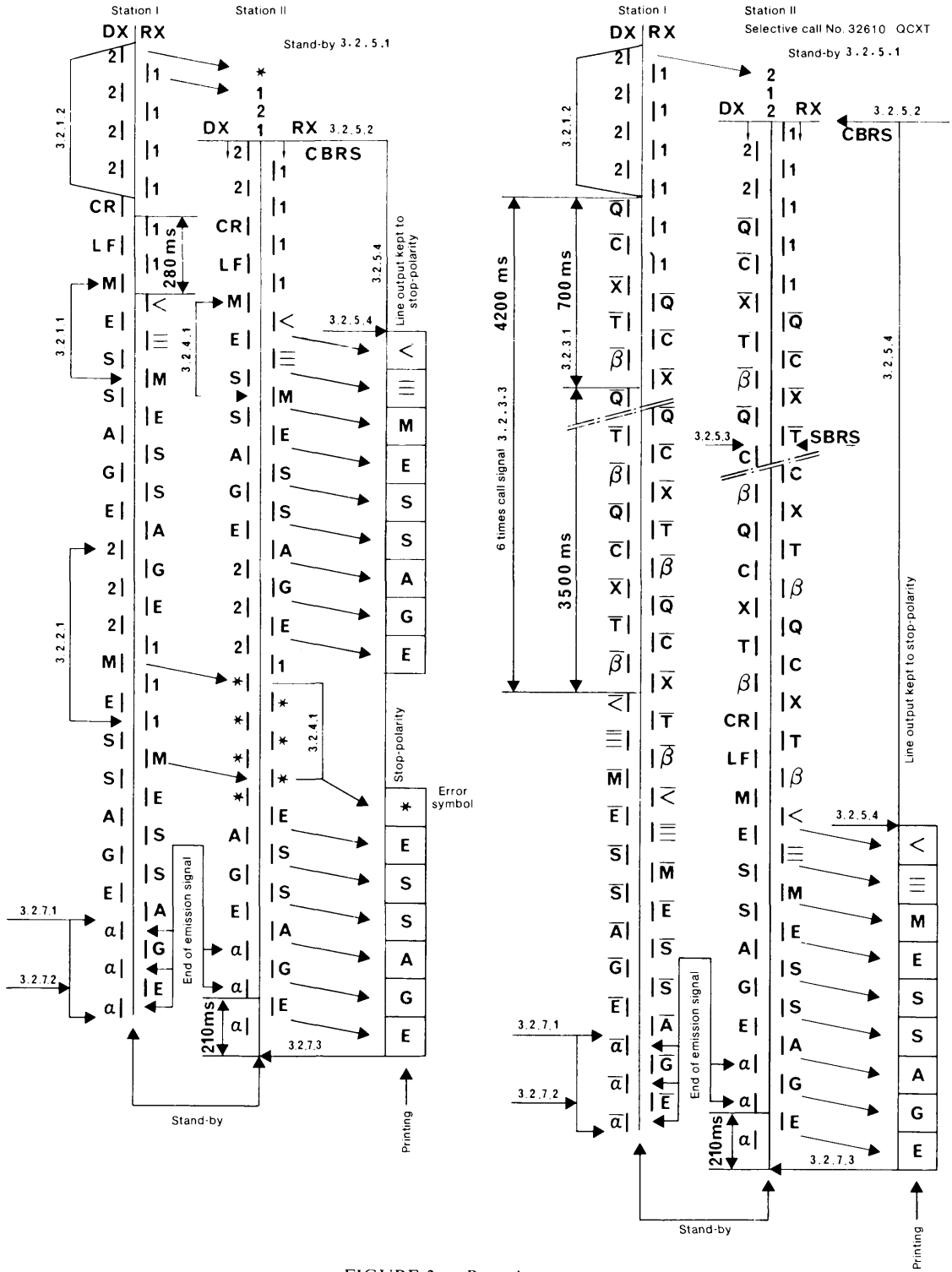


FIGURE 3 – *B-mode operation*

Collectively
1: Phasing signal 1
2: Phasing signal 2
<: Carriage return (CR)
≡: Line feed (LF)
*: Detected error symbol

Selectively
CBSS: B-mode – Sending collectively
CBRS: B-mode – Receiving collectively
SBSS: B-mode – Sending selectively
SBRS: B-mode – Receiving selectively

Overlined symbols (e.g. $\overline{M}$) are transmitted in the 3B/4Y ratio

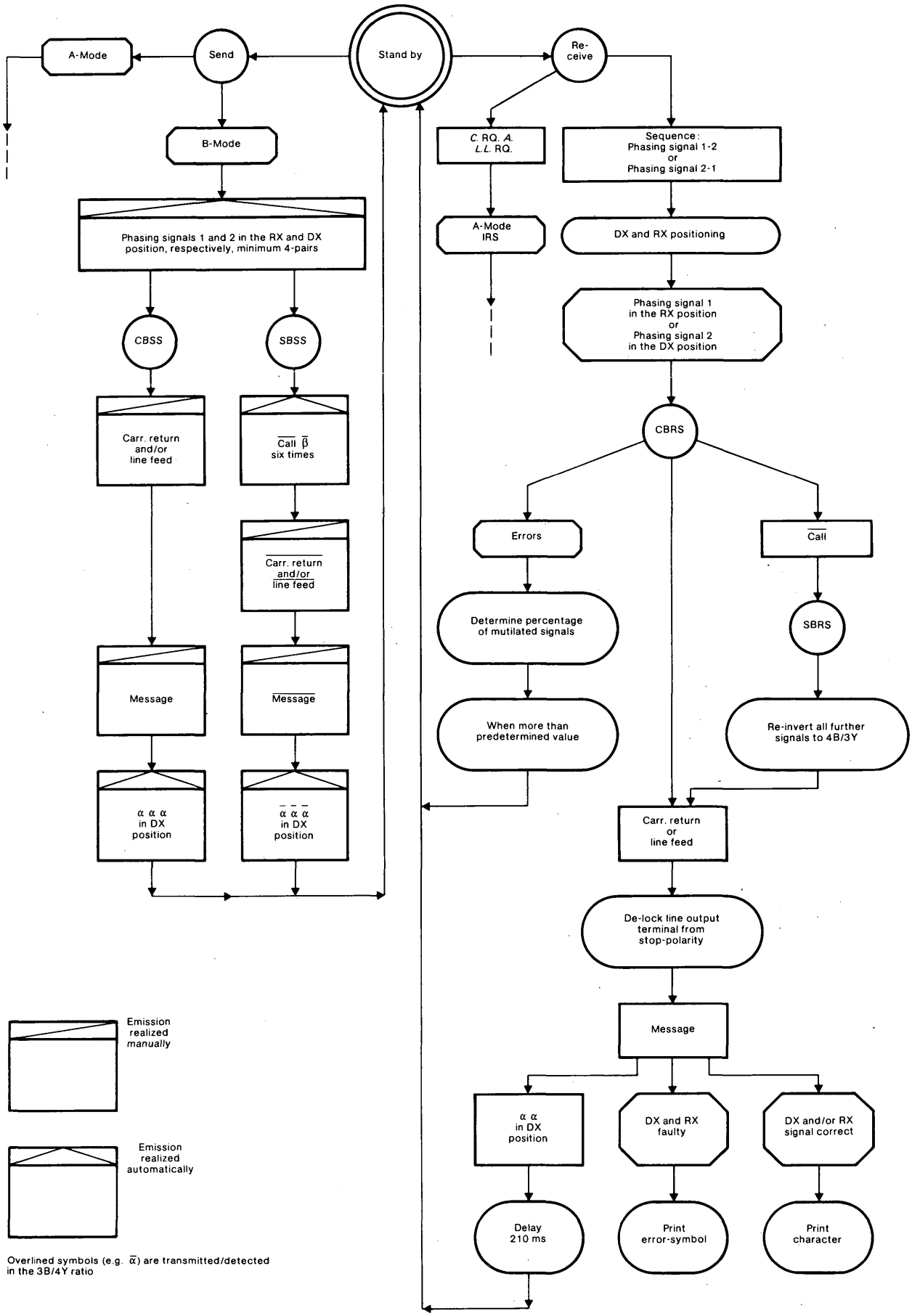


FIGURE 4 – *Flow chart showing processes in B-Mode operation*

REPORT 585-2 *

INTRODUCTION OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question 5/8)

(1974-1978-1982)

1. This Report discusses some operational and procedural considerations in the introduction of direct-printing equipment in the maritime mobile service. As a goal, it is considered that provision should be made for fully automatic and unattended operation. Provision should also be made for attended operation, particularly during the period of time leading up to the implementation of fully-automated systems [CCIR, 1970-74a, b, c, d, e, f, g and h].

2. Automatic operation gives the possibility of messages being exchanged irrespective of the hours of duty of the radio operator on board the ship. The ultimate objective would be for ships to be treated in the same way as a subscriber using the international telex network. Where non-automatic operation is employed, it should still be possible for calls to be established by direct-printing equipment. Selective-calling is an important element of the operation of both the attended and fully-automatic systems.

3. A number of administrations have installed direct-printing equipment with varying degrees of automation.

The Netherlands report that they have introduced a system that gives rapid access to the coast station without prior contact by other means. By means of a scanning system the direct printing equipment is connected to pre-tuned receivers and, if activated by an incoming call, to a transmitter tuned to the transmit frequency paired with the receive frequency. Tunable receivers and transmitters are also available to handle narrow-band direct-printing on other frequencies by prior arrangement.

In the near future the system will be expanded and modified to offer ship stations direct access to the (international) telex network. Unattended operation at the coast station is foreseen, but operator assistance will be available on demand. Plans are under consideration to incorporate an automated store-and-forward service for message transmission in both ship-to-shore and shore-to-ship directions.

The Swedish Administration has operated a system called MARITEX since 1972, which, technically, is based on relevant parts of Recommendation 476 and Appendix 38 to the Radio Regulations. This system is designed for unattended operation in the coast station as well as on board ships, for message transmission in either direction. Operational features include automatic choice of the optimum frequency band based on propagation forecasts fed into the system. The system has proved efficient and reliable. In the ship-to-shore direction delay is negligible and traffic is generally handled within 30 min in the other direction. At the end of 1980 the number of ship stations participating in the system was of the order of 200.

[CCIR, 1970-74e] describes a direct-printing and selective-calling system based on International Telegraph Alphabet No. 5 and the results of tests of this system.

[CCIR, 1970-74f] contains proposals concerning the use of direct-printing equipment in the maritime mobile service according to Recommendation 476.

Distinction is made between manual and automatic operation, while attention is paid to the following operational aspects:

- the determination of the duration of call signals, and the intervals between them, with a view to activating the called station transmitter, in order to reduce internal system interference;
- clearing the ARQ-circuit, in the case of poor propagation conditions, by reverting to the stand-by position after reception of a predetermined number of RQ signals or identical control signals;
- using a fixed procedure for clearance of the circuit in the course of which the sequences "Fig + ?" and "HHH" are exchanged between the stations concerned.

* This Report and particularly note 5 of Appendix 3, should be brought to the attention of the CCITT.

In a further contribution, [CCIR, 1970-74g] information is given on the unattended operation of direct-printing circuits. The need for close frequency tolerance is stressed and the results of laboratory tests to determine the effects of receiver off-tune on bit error-rates are given (see Figs. 1 and 2). These results relate to tests upon a specific type of receiver demodulator. In the document it is considered that automatic frequency control is one solution to the problem of detuning. During the discussion it was noted that other solutions to the problem could include the use of other demodulator techniques or closer frequency tolerances.

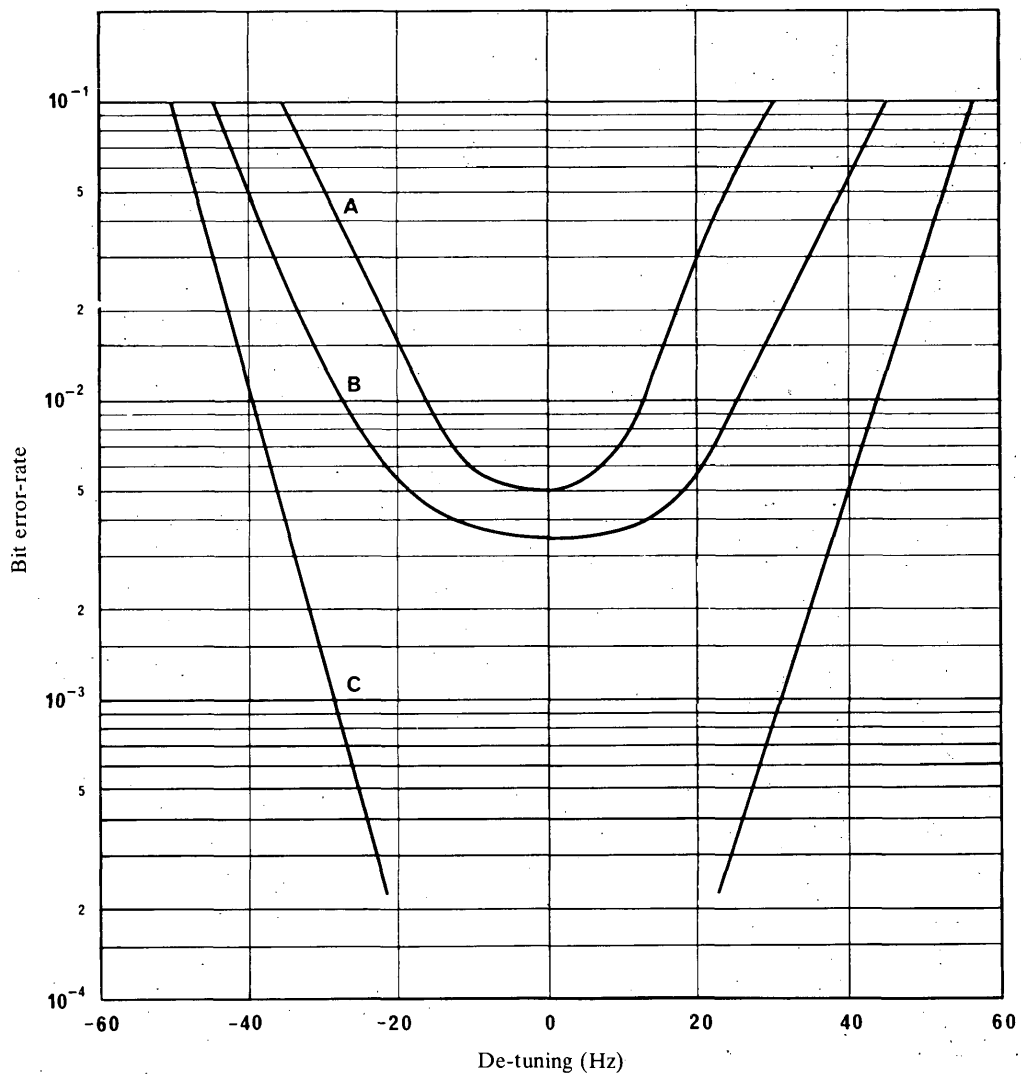


FIGURE 1 – *Bit error-rate as a function of de-tuning*
(No fading)

Receiver input voltage:
Curves A: −22 dB(1μV)
B: −20 dB(1μV)
C: −18 dB(1μV)

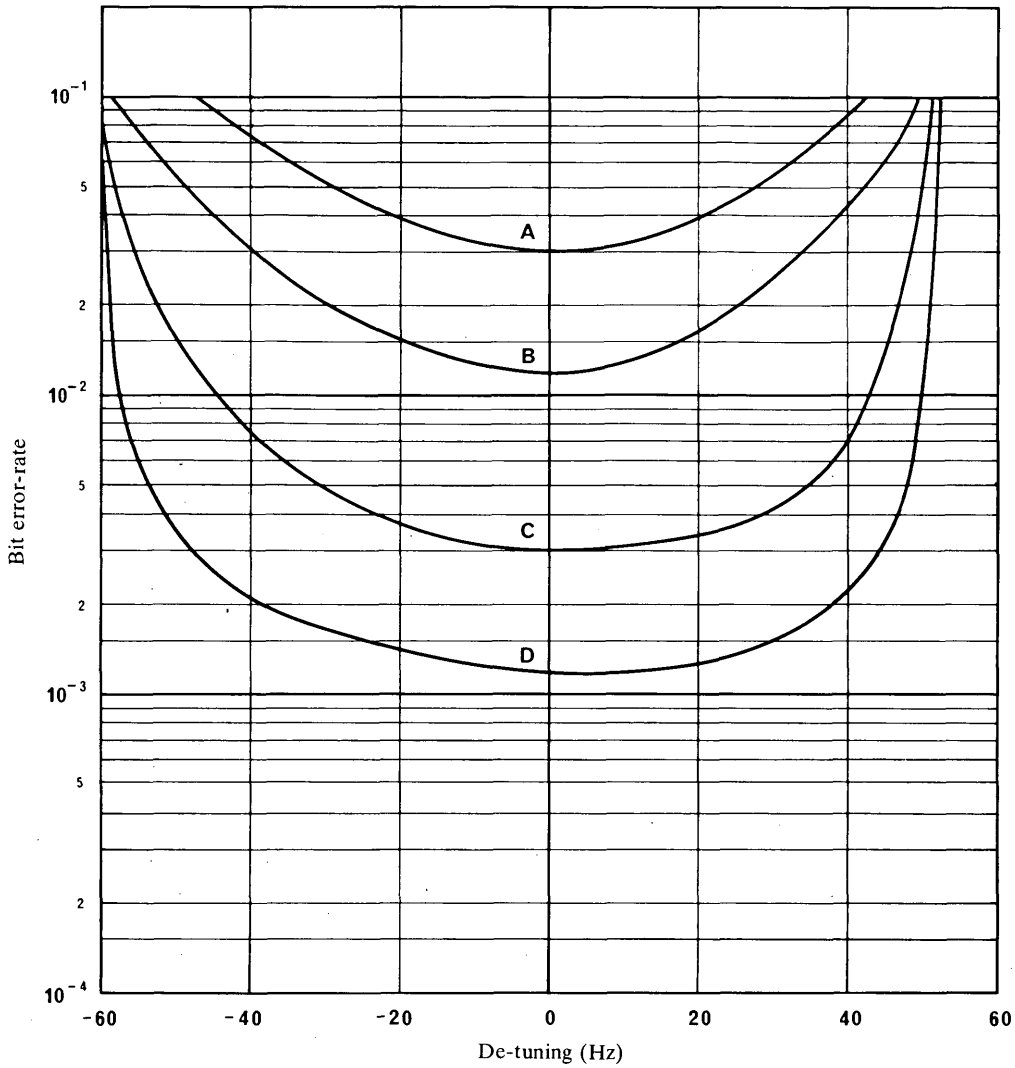


FIGURE 2 – *Bit error-rate as a function of de-tuning*
(Under random fading close to Rayleigh distribution, with fading rate of 15 fades/min)

Receiver input voltage (median value):
Curves A: −8 dB(1μV)
B: −3 dB(1μV)
C: 2 dB(1μV)
D: 7 dB(1μV)

The effect of receiver selectivity upon error-rate is also considered in the document and curves are given (see Figs. 3 and 4) of the effect upon bit error-rate of different values of selectivity without and in the presence of adjacent channel interference. (Similar curves in the contribution mentioned above are in terms of character error-rate.) In discussion it was also noted that the selectivity problem was closely related to the phase-delay characteristics of the receiver filters. The document considers that further study of these aspects is required.

Report 747 reproduces the IMCO requirements for the Future Global Maritime Distress and Safety System. The IMCO requirements include the use of narrowband direct-printing in the 0.5, 2, 4, 6, 8, 12, 16 and 156 MHz frequency bands for distress and safety messages.

[CCIR, 1974-78a and b] propose some additions to the operational procedures for the narrowband direct printing service outlined in Article 64 of the Radio Regulations. These have been incorporated in Recommendation 492. Further study is required on the precise format of the answer-back signals to be used by coast-station and ship.

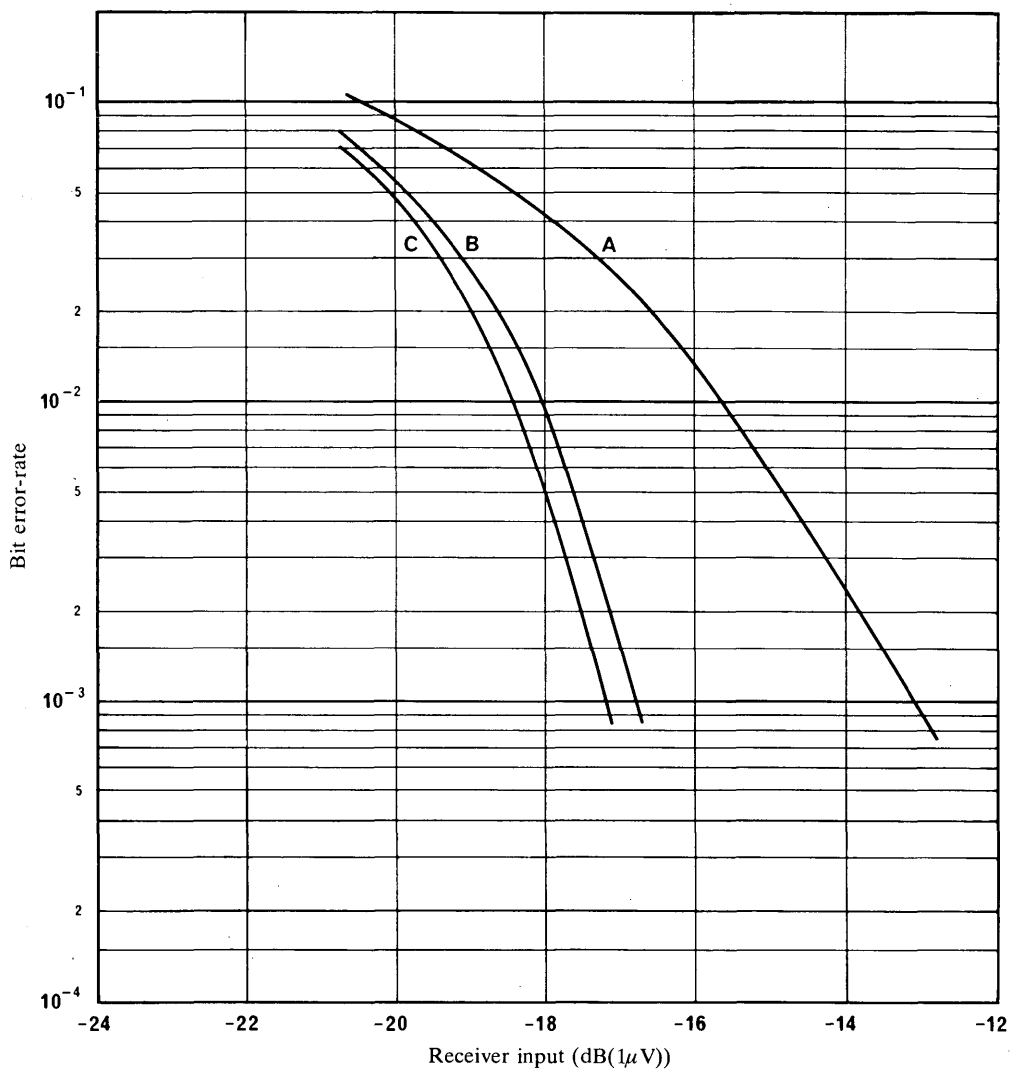


FIGURE 3 – *Bit error-rate as a function of receiver input for variation in receiver bandwidths under no interference conditions*

Receiver bandwidth:

	<6 dB	>66 dB
Curves A:	210 Hz	500 Hz
B:	240 Hz	560 Hz
C:	310 Hz	700 Hz

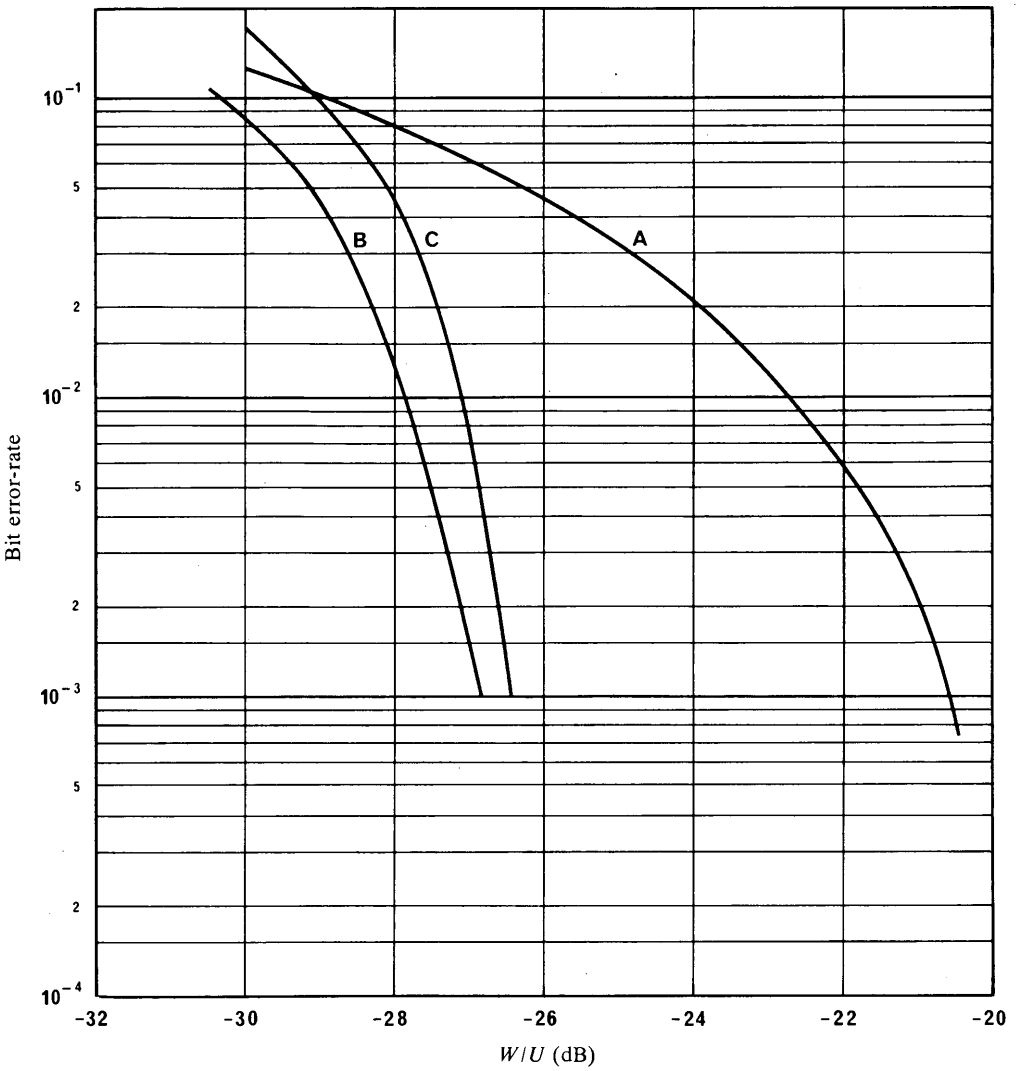


FIGURE 4 – *Bit error-rate as a function of W/U (ratio of wanted to unwanted signal) with different receiver bandwidths in the presence of adjacent channel interference*

Wanted signal: 1 μV at receiver input
Unwanted signal: 100 bit/s dot signal, separated from desired signal by 500 Hz

Receiver bandwidth:

	< 6 dB	> 66 dB
Curves A:	210 Hz	500 Hz
B:	240 Hz	560 Hz
C:	310 Hz	700 Hz

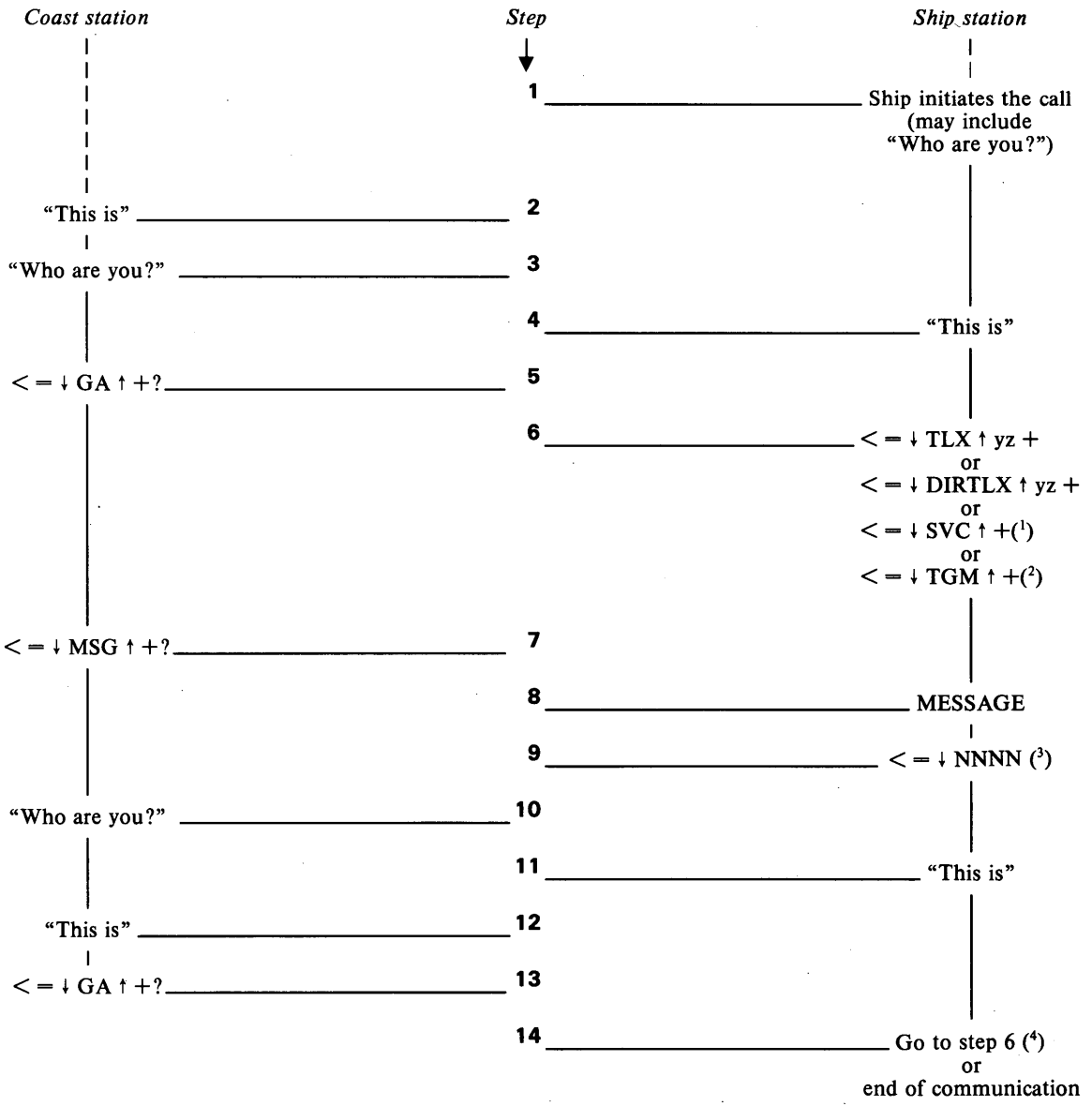
4. During the study period 1978-82, attention was drawn [CCIR, 1978-82a] to ambiguities in the wording of Recommendation 476-2 § 3.1.5. As a result of consideration given to this subject, contributions [CCIR, 1978-82b] were made to the Final Meeting 1981, reporting some technical and operational problems experienced with the use of re-phasing procedures on radio circuits which were extended into the public switched network or to automated store-and-forward or switching equipments. This has resulted in the inclusion of notes in Recommendations 476 and 492. During the Final Meeting 1981, it was brought out that some problems have occurred due to the lack of exchange of automatic identification signals [CCIR 1978-82c]. It was agreed that further study of the application of rephasing and the exchange of automatic identification signals is required.

5. During the Final Meeting of Study Group 8 (1981), Recommendation 492 was discussed. It was the opinion of the Meeting that this Recommendation should be extended. Administrations are therefore invited to study the operational procedures considering:

- the relevant CCITT Recommendations;
- the requirements of manual, semi-manual and fully-automatic operations;
- the type of service offered, and
- the attached Appendices illustrating alternative interpretations of procedural requirements:
  Appendix 1: Procedures previously included in §§ 1.9 to 1.10 of Recommendation 492 (Kyoto, 1978);
  Appendix 2: The proposal made by the USSR [CCIR 1978-82d] concerning §§ 1.9 and 1.10 of Recommendation 492 (Kyoto, 1978).
  Appendix 3: Generalized procedure proposed by some administrations during the Final Meeting of Study Group 8, 1981, indicating particular elements of procedure which require attention.

APPENDIX I

1. *Procedure for setting up a call in the ship-to-coast station direction*



(1) The characters SVC + are transmitted in sequence and preceded by at least one carriage return and a line feed; SVC denotes that the message that follows is a service message and "+" indicates end of sequence.

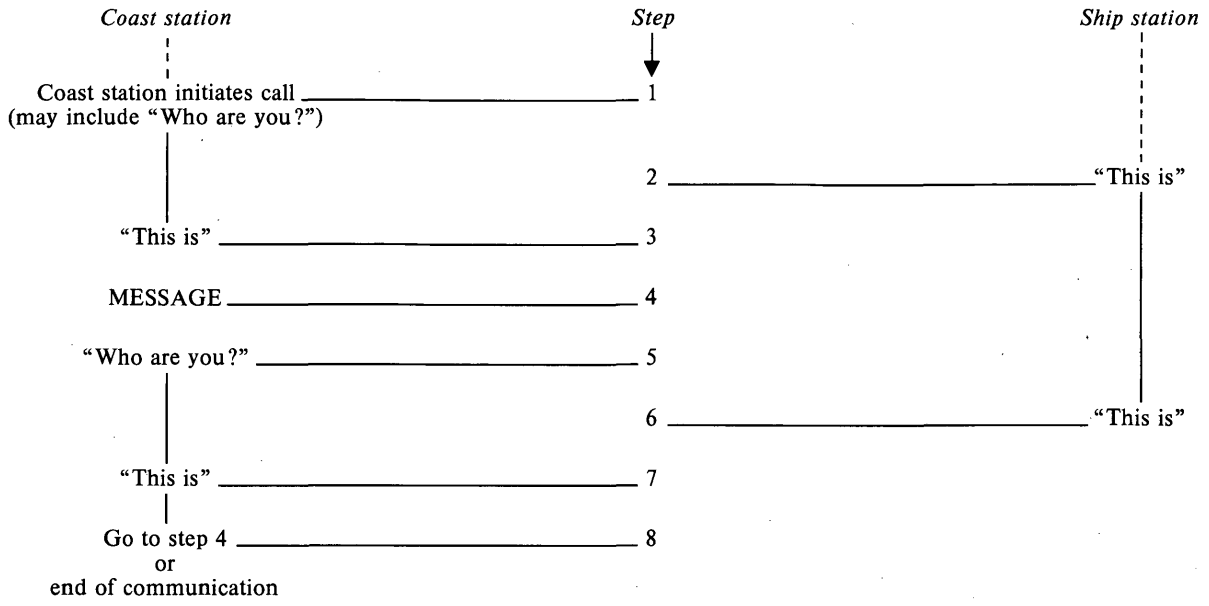
(2) The characters TGM + are transmitted in sequence and preceded by at least one carriage return and a line feed; TGM denotes that the message that follows is a radiotelegram and "+" indicates end of sequence.

(3) This sequence of combinations may need to be considered further by the CCITT.

(4) Each separate radiotelegram shall be both preceded and followed by an exchange of answerback signals, the latter indicating the acknowledgement of receipt of that particular radiotelegram.

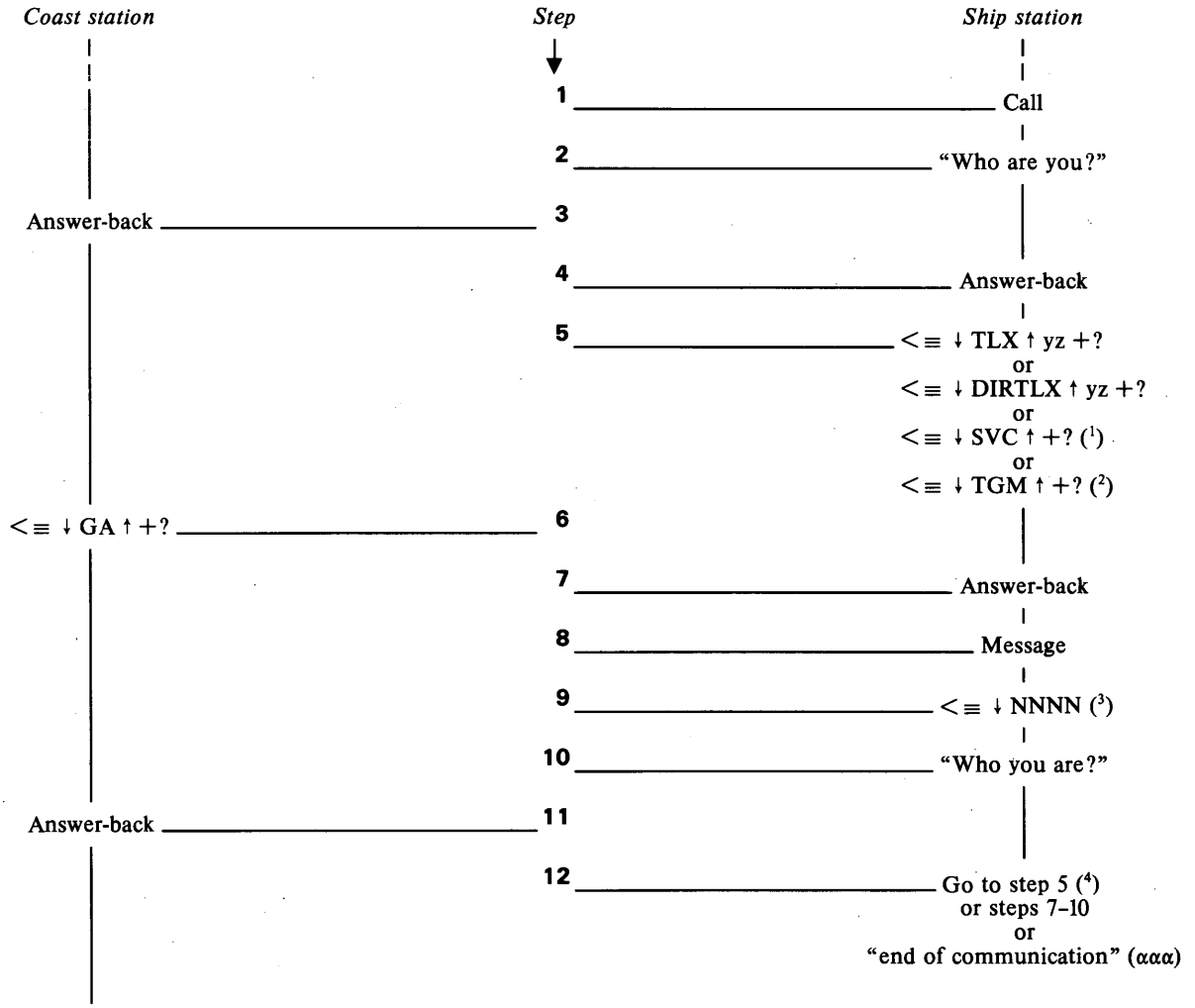
2. *Procedure for setting up a call in the coast-to-ship station direction*

Operation in the direction coast station to ship may need to be in the store-and-forward mode owing to the fact that radio propagation conditions may not allow the setting up of a call at the intended time.



APPENDIX II

1. *Procedure for setting up a call in the ship-to-coast station direction*



(1) The sequence SVC indicates that the message which follows is a service message.
(2) The sequence TGM indicates that the message which follows is a radiotelegramme.
(3) This sequence may need to be considered further by the CCITT.
(4) Each radiotelegramme shall be preceded and followed by an exchange of answer-back signals, the latter acknowledging receipt of the radiotelegramme.

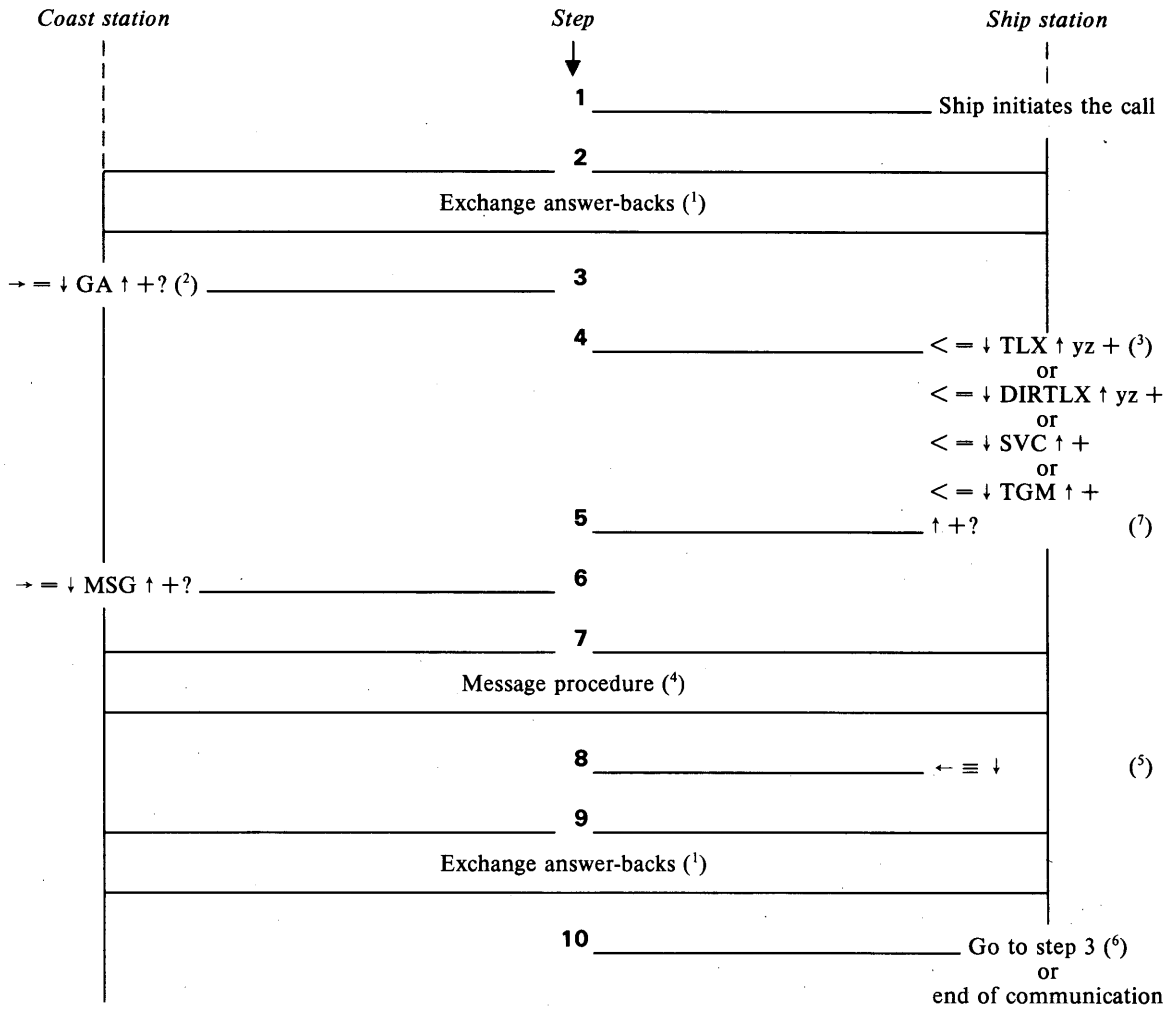
2. *Procedure for setting up a call in the coast-to-ship station direction*



(5) As defined by the CCITT in Recommendation F.130.
(6) For attended ship station.

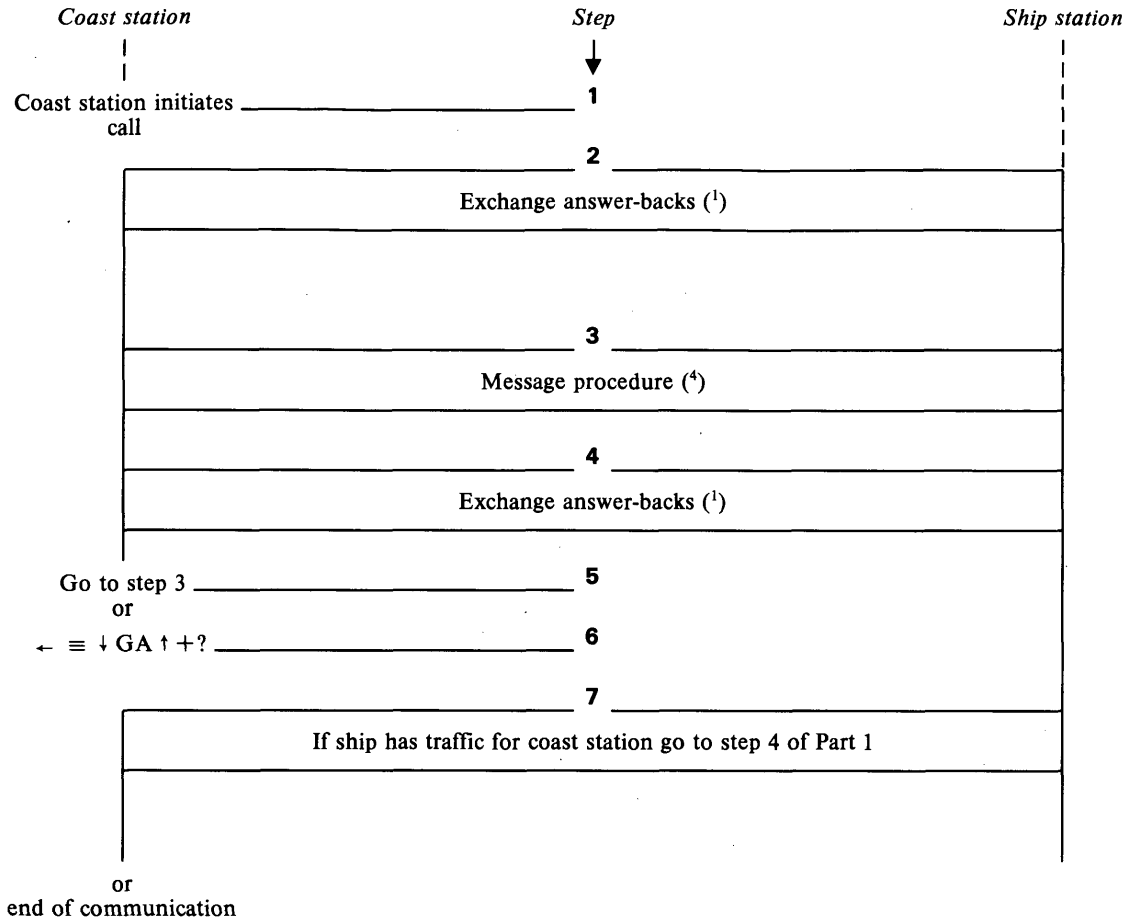
APPENDIX III

1. *Procedure for setting up a call in the ship-to-coast station direction*



2. *Procedure for setting up a call in the coast-to-ship station direction*

Operation in the direction coast station to ship may need to be in the store-and-forward mode owing to the fact that radio propagation conditions may not allow the setting up of a call at the intended time.



Notes relative to § 1 and 2

(1) a) Each separate message procedure shall be both preceded and followed by an exchange of answer-back signals, the latter indicating the acknowledgement of receipt.
b) For calls set up by the ship the answer-back exchange in manual operation is initiated by the ship. Some administrations expressed the opinion that in automatic operation the answer-back exchange should be initiated and controlled by the coast station.
c) For calls set up by the coast station the answer-back exchange is initiated by the coast station in manual and automatic operation.
d) Answer-back code as defined in CCITT Recommendation F.130.

(2) Required by some automatic services.

(3) a) The application of the sequences TLX and DIRTLX is defined in the Radio Regulations, Article 64.
b) The sequence SVC indicates that the message which follows is a service message.
The sequence TGM indicates that the message which follows is a radio telegram.
c) Other service requests and codes may be needed and agreement on these codes should be reached. Refer also to CCITT Recommendation F.60 for telex service codes.

(4) For message procedures refer to appropriate CCITT Recommendations (F.1 Telegram, F.60 Telex, F.132 Automatic store and forward and others).

(5) Following the sequence "carriage return", "line feed", "letter shift", a sequence of 4 International Telegraph Alphabet No. 2 combinations to be assigned to permit clear down of the network connection where required (e.g. on completing a telex message), while maintaining the radio circuit.

(6) Procedures are undefined for transmission of coast-to-ship station traffic when the call was initially set up by the ship station. A study is urgently required to define these procedures.

(7) Required for manual services; preferably should not be used in automatic services.

REFERENCES

CCIR Documents

[1970-74]: **a.** 8/3 (United Kingdom); **b.** 8/9 (USA); **c.** 8/74 (Netherlands); **d.** 8/80 (Sweden); **e.** 8/93 (Japan); **f.** 8/94 (U.S.S.R.); **g.** 8/192 (Japan); **h.** 8/261 (CCIR).

[1974-78]: **a.** 8/313 (Australia); **b.** 8/365 (Sweden).

[1978-82]: **a.** 8/23 (Japan); 8/292 (CCIR Secretariat); **b.** 8/365 (United Kingdom); 8/405 (Sweden); **c.** 8/427 (Netherlands); **d.** 8/143 (U.S.S.R.).

RECOMMENDATION 490

THE INTRODUCTION OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

Equivalence of terms

(Question 5/8)

(1974)

The CCIR,

CONSIDERING

(a) that the use of direct-printing telegraphy by ship and coast stations is rapidly expanding;

(b) that there is a need for standardizing the designation of the higher and lower F1B frequencies to ensure compatible world-wide operation when using the direct-printing telegraphy system;

UNANIMOUSLY RECOMMENDS

that the equivalence of terms as shown in the following table shall be adhered to (this Recommendation is in accordance with CCITT Recommendations U.1 and V.1.):

TABLE I

Frequency of emission	Circuits using teleprinter or punched tape equipment					
	International Telegraph Alphabet No. 2				Emitted 7-unit signal	Telex
Higher frequency	Space	Start	No perforation	A (1)	B (2)	Free line condition
Lower frequency	Mark	Stop	Perforation	Z (1)	Y (2)	Idle circuit condition

(1) on a wire circuit.

(2) on a radio channel.

RECOMMENDATION 491

DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question 5/8)

(1974)

The CCIR,

CONSIDERING

(a) that, according to Article 25 of the Radio Regulations, a station shall be identified either by a call sign or by other recognized means of identification, such as a ship station selective call number or signal, or coast station selective call number or signal;

(b) that the two-block call signal described in Recommendation 476 effectively provides a selective-calling system for use with the ARQ equipment;

(c) that this signal is unique for each station and may therefore be used as its identification;

(d) that the use of this signal makes unattended operation of direct-printing equipment possible;

(e) that the footnote, Recommendation 476, § 3.1.4, calls for international agreement on the composition of signals used in the phasing procedure;

(f) that it would be convenient if the numbers assigned in accordance with Radio Regulations No. 2088 and No. 2143 to 2146 were used for programming the 28-bit (4-character) pattern in the phasing procedure;

(g) that the capacity of this numbering system (see § *(f)*) will cover the immediate requirements for selective calling, including the direct-printing service;

(h) that there is a need for a conversion scheme from numerical identification to the 28-bit (4-character) pattern used in the phasing procedure;

(j) that such a conversion scheme as described in Annex I is already in use in existing direct-printing equipment,

UNANIMOUSLY RECOMMENDS

1. that, in direct-printing systems, the two-block call signal used in the phasing procedure described in Recommendation 476 may be used as identification of a radio station;

2. that for immediate requirements:

2.1 a station equipped with a selective-calling system, in accordance with Appendix 39 of the Radio Regulations, and with a direct-printing system in accordance with Recommendation 476 and using a two-block call signal should be given the same number for both systems;

2.2 a station, equipped with a direct-printing system in accordance with Recommendation 476 and using a two-block call signal, not already assigned a number in accordance with No. 2088 and No. 2143 to 2146 of Article 25 of the Radio Regulations, should be assigned such a number for the direct-printing service;

2.3 that the conversion from the numerical identification to the 28-bit (4-character) pattern should be performed according to the Tables in Annex I.

ANNEX I

To translate a number, proceed as follows:

For a 5-digit number let the first digit determine which vertical column in Table I to use. Translate the last four digits to four alphabetic characters as indicated for each digit in the column selected in accordance with the table of conversion as given in Table I.

For a 4-digit number Table II should be used.

Examples:

The 5-digit number 32610 is transmitted as:

Q (RQ) C	X T (RQ)

The 4-digit number 1234 is transmitted as:

X (RQ) Q	K M (RQ)

TABLE I

5-digit numbers										
1st digit		0	1	2	3	4	5	6	7	8	9
2nd digit	0	T	V	V	V	T	T	T	V	V	V
	1	B	X	X	X	B	B	B	X	X	X
	2	U	Q	Q	Q	U	U	U	Q	Q	Q
	3	E	K	K	K	E	E	E	K	K	K
	4	O	M	M	M	O	O	O	M	M	M
	5	I	P	P	P	I	I	I	P	P	P
	6	R	C	C	C	R	R	R	C	C	C
	7	Z	Y	Y	Y	Z	Z	Z	Y	Y	Y
	8	D	F	F	F	D	D	D	F	F	F
	9	A	S	S	S	A	A	A	S	S	S
3rd digit	0	V	T	V	V	T	V	V	T	T	V
	1	X	B	X	X	B	X	X	B	B	X
	2	Q	U	Q	Q	U	Q	Q	U	U	Q
	3	K	E	K	K	E	K	K	E	E	K
	4	M	O	M	M	O	M	M	O	O	M
	5	P	I	P	P	I	P	P	I	I	P
	6	C	R	C	C	R	C	C	R	R	C
	7	Y	Z	Y	Y	Z	Y	Y	Z	Z	Y
	8	F	D	F	F	D	F	F	D	D	F
	9	S	A	S	S	A	S	S	A	A	S
4th digit	0	V	V	T	V	V	T	V	T	V	T
	1	X	X	B	X	X	B	X	B	X	B
	2	Q	Q	U	Q	Q	U	Q	U	Q	U
	3	K	K	E	K	K	E	K	E	K	E
	4	M	M	O	M	M	O	M	O	M	O
	5	P	P	I	P	P	I	P	I	P	I
	6	C	C	R	C	C	R	C	R	C	R
	7	Y	Y	Z	Y	Y	Z	Y	Z	Y	Z
	8	F	F	D	F	F	D	F	D	F	D
	9	S	S	A	S	S	A	S	A	S	A
5th digit	0	V	V	V	T	V	V	T	V	T	T
	1	X	X	X	B	X	X	B	X	B	B
	2	Q	Q	Q	U	Q	Q	U	Q	U	U
	3	K	K	K	E	K	K	E	K	E	E
	4	M	M	M	O	M	M	O	M	O	O
	5	P	P	P	I	P	P	I	P	I	I
	6	C	C	C	R	C	C	R	C	R	R
	7	Y	Y	Y	Z	Y	Y	Z	Y	Z	Z
	8	F	F	F	D	F	F	D	F	D	D
	9	S	S	S	A	S	S	A	S	A	A

TABLE II

4-digit numbers		
1st digit	0	V
	1	X
	2	Q
	3	K
	4	M
	5	P
	6	C
	7	Y
	8	F
	9	S
2nd digit	0	V
	1	X
	2	Q
	3	K
	4	M
	5	P
	6	C
	7	Y
	8	F
	9	S
3rd digit	0	V
	1	X
	2	Q
	3	K
	4	M
	5	P
	6	C
	7	Y
	8	F
	9	S
4th digit	0	V
	1	X
	2	Q
	3	K
	4	M
	5	P
	6	C
	7	Y
	8	F
	9	S

RECOMMENDATION 492-2 *

OPERATIONAL PROCEDURES FOR THE USE OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question 5/8)

(1974-1978-1982)

The CCIR,

CONSIDERING

(a) that narrow-band direct-printing telegraph services are in operation using equipment as described in Recommendation 476;

(b) that the operational procedures necessary for such services should be agreed upon;

(c) that, as far as possible, these procedures should be similar for all services and for all frequency bands (different operational procedures may be required in the frequency bands other than the HF and MF bands),

UNANIMOUSLY RECOMMENDS

that the following operational procedures in the MF and HF bands for the use of narrow-band direct-printing telegraph equipment in accordance with Recommendation 476 in the maritime mobile service should be observed:

1. Mode A (ARQ)

1.1 Methods used for setting up narrow-band direct-printing telegraph communications between a ship station and a coast station in the ARQ-mode should be on a fully automatic or semi-automatic basis, insofar that a ship station should have direct access to a coast station on a coast station receiving frequency and a coast station should have direct access to a ship station on a coast station transmitting frequency;

1.2 however, where necessary, prior contact by Morse telegraphy, radiotelephony or other means is not precluded;

1.3 through connection to a remote teleprinter station over a dedicated circuit or to a subscriber of the international telex network may be achieved by manual, semi-automatic or automatic means;

Note 1. – Before an international automatic service can be introduced, agreement has to be reached on a numbering plan, traffic routing and charging. This should be considered by both the CCITT and the CCIR.

Note 2. – Recommendation 476 (see § 3.1.5) makes provision for automatic re-establishment of radio circuits by rephasing in the event of interruption. However, it has been reported that this procedure has, in some countries, resulted in technical and operational problems when radio circuits are extended into the public switched network or to certain types of automated switching or store-and-forward equipments. For this reason, some coast stations do not accept messages if the rephasing procedure is used.

1.4 when, by prior arrangement, unattended operation is required for communication from a coast station to a ship station, or between two ship stations, the receiving ship station should have a receiver tuned to the other station's transmitting frequency and a transmitter tuned or a transmitter capable of being tuned automatically to the appropriate frequency and ready to transmit on this frequency;

1.5 for unattended operation a ship station should be called selectively by the initiating coast or ship station as provided for by Recommendation 476. The ship station concerned could have available traffic stored ready for automatic transmission on demand of the calling station;

1.6 at the "over" signal, initiated by the calling station, any available traffic in the ship's traffic store could be transmitted;

* The Director, CCIR, is invited to bring this Recommendation to the attention of CCITT.

1.7 at the end of the communication, an "end of communication" signal should be transmitted, whereupon the ship's equipment should automatically revert to the "stand-by" condition;

1.8 where paired frequencies are used, as for the bands 4 MHz to 22 MHz, arrangements should be made, if required, for the coast station to indicate when the circuit is open for traffic. The format of the signal, transmitted by the coast station, i.e. the "free channel" signal should be composed of signals in the 7-unit error detecting code as listed in § 2 of Annex I to Recommendation 476. Three of these signals are grouped into a block, the middle signal being the "Signal Repetition" (RQ), the first and third signals of the block being any of the signals VXQKMPCYFS TBUEOIRZDA (see Recommendation 491). The signals in the block are transmitted at a modulation rate of 100 bauds and the blocks are separated by pauses of 240 ms. This "free channel" signal may be interrupted by a signal or signals, that would enable an operator to recognize the "free channel" condition by ear. The aurally recognizable signal, e.g. a Morse signal, may be used alone as the "free channel" signal in manual systems.

Note 3. – (General note to paragraph 1) detailed operating procedures previously included in §§ 1.9 and 1.10 of Recommendation 492-1, as adopted at the XIVth Plenary Assembly, Kyoto 1978, require further consideration and study and have, therefore, been placed in Report 585.

2. Mode B (FEC)

2.1 Messages could, by prior arrangement, be sent in the B mode from a coast station or ship to a number of ships or to a single ship, preceded if desired by the selective call code of the ship(s) concerned where:

2.1.1 a receiving ship station is not permitted or not able to use its transmitter, or

2.1.2 communications are intended for more than one ship, or

2.1.3 unattended reception of the B mode is required and automatic acknowledgement is not necessary;

in such cases, the ship station receivers should be tuned to the appropriate coast or ship station transmitting frequency;

2.2 all B mode messages should start with "carriage return" and "line feed" signals;

2.3 when the ship station receives phasing signals in the B mode, its teleprinter should start automatically and should stop automatically when reception of the emission ceases.

REPORT 907 *

IDENTIFICATION OF SIMPLEX ARQ DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question 5/8)

(1982)

1. Introduction

This Report addresses the subject of the need for unambiguous identification of ARQ equipment complying with Recommendation 476-2 when used on two-way narrowband direct-printing circuits.

2. Background

Since the introduction of direct-printing equipments in the maritime mobile service in 1965, operational experience gained has proved that the system provides a satisfactory means of communication. The existing Recommendation 476-2, however, does not include provisions for the exchange of identification signals. The increased use of direct-printing equipment and the advent of automation have focused attention on problems which arise from the lack of such an exchange.

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* This Report should be brought to the attention of the CCITT.

During the period 1978-1982 it was proposed that Question 5/8 be broadened to include the study of means of providing unambiguous identification. In response, some administrations submitted proposals to modify Recommendation 476-2.

3. Discussion

The basic short-coming of the present system is that on establishing (or re-establishing) a radio circuit, neither the calling station nor the responding station are completely assured of the identity of the station at the other end of the circuit. A number of problems arise from this deficiency and there are also a number of technical and operational improvements which could be made if the stations were informed of the identities of both stations involved.

3.1 *Problems arising from lack of mutual identification*

Among the problems which have been experienced are the following:

3.1.1 It is possible to enter into communication with a station other than the desired station. This can result in delivery of messages to the wrong station. As a consequence of this:

- messages (in whole or in part) may not be delivered to the correct station, although the sending station may believe that the messages have been delivered correctly;
- stations may receive messages not intended for them.

3.1.2 The responding station has no information concerning the identity of the calling station, which can prevent the called station from re-initiating communication if the circuit is interrupted or if, at some later time, there is a need to request information or repetition of messages.

3.1.3 Lack of a positive indication of the identity of a calling ship station, makes it difficult for coast stations to improve call-connection and accounting procedures. This problem is exaggerated by the lack of an international implementation of standard answer-back code identities for teleprinters aboard ships. (See CCITT Recommendation F.130.)

3.2 *Improvements which could be made if there were unambiguous mutual identification of stations*

3.2.1 The possibility of being connected on the radio circuit to a station other than the desired one would be reduced. This would reduce the possibility of delivery of messages to the wrong station.

3.2.2 Since both stations would be aware of each other's identities, re-establishment of the circuit and the making of enquiries would be simplified.

3.2.3 Coast stations would be able to provide automatic connection of ship calls to public switched networks and to automate associated accounting and billing procedures.

3.2.4 It would be possible to simplify procedures for logging/recording incoming calls.

3.2.5 It would be possible to determine the eligibility of calling stations at an early stage.

3.2.6 It would be possible to simplify the introduction of automated polling and/or reporting procedures.

3.2.7 It would be possible to provide, internationally, facilities enabling stations to call and collect stored messages, using self-identifying procedures to authorize release of stored information.

3.2.8 It would be possible to store relevant information about ship stations and, on receipt of a call from a ship, to use this information to improve the quality of communication, e.g., the ship's position information could be used to select appropriate frequencies and directional antennas.

4. Conclusions

Although the foregoing shows the need for exchange of identities, it is recognized that the most critical periods of the radiocommunication are during the phasing and, more especially, the re-phasing sequences. It is essential, therefore, that these periods are kept as brief as possible.

At the Final Meeting in 1981, some administrations responded to the Question 5/8 regarding identification. From these contributions it became clear that the amended Question did not fully address the identified problem areas. After discussion, it was agreed that these problems required further study. To assist administrations in such studies, the relevant contents of the received contributions are annexed to this Report.

ANNEX I

SWEDEN

1. Introduction

Recommendation 476-2 describes the technical characteristics for establishing communication. Station identification procedures are governed by Recommendation 492-1, since Recommendation 476 does not fully specify them.

Rephasing is used in cases where the equipments have timed out due to bad propagation conditions. Rec. 476-2 is ambiguous with regard to control signals in the case where the slave station was information sending at the time of interruption.

The rephasing function may cause confusion when used in star-shaped automatic or semi-automatic networks, especially when the circuit is extended into the telex network.

2. Master identification

From an operational point of view the slave station is identified by the "call" sequence given in § 3.1.4.3. Further measures to identify the slave station at system level are not required, since the risk that a station other than the called will respond is negligible.

The master station is not identified by the procedures in Rec. 476-2. However, if it is modified to let the master station emit it's call number prior to other information signals, the demand for master identification is met. (Reference is made to Question 5/8).

This modification implies that the identity of the master is printed immediately upon establishing the circuit. The design of the identification sequence is such that it will always be printed at the top left corner of the message, well separated from the text:

12345

klmnop + ?

Compatibility between existing and new equipments is maintained, since reception of the master identification sequence is treated by the slave station as normal information signals. New equipment, employed in automatic systems, would improve efficiency, since identification is performed at system level as early as possible. Printing out the identification sequence may be user-defined.

The earliest possible time after phasing that the called station may be aware of the identity of the caller is 12 cycles of 450 ms, or 5.4 s, the time required for transmission of an answer-back sequence and two change-over sequences. The operational procedures of Rec. 492 indicate around 11-12 s before the called station is aware of the caller's identity. Fully utilized, automatic master identification would save a considerable amount of time. However, the adoption of a master identification procedure will not make the exchange of answer-back signals obsolete, since this exchange is often used to verify that the printing equipment at the distant station is working.

The required modification to Rec. 476-2 to accommodate a master identification sequence is limited to adding a new paragraph:

> 3.1.4.6 Prior to emitting any other information the calling station emits four identification blocks, containing the signals "carriage return", "line feed", "figure shift", followed by four or five "digit" signals, forming the assigned call code as defined in Recommendation 491 and terminated by the signals "carriage return", "line feed", "line feed" and at least one signal "letter shift".

3. Rephasing

Rephasing, § 3.1.5 is a feature which may have some uses in point-to-point circuits. If the rephasing facility is used when the connection has been extended to a telex subscriber, continuous stop polarity during the time-out and rephasing periods will result in doubt and possibly disconection of the telex line.

The Swedish Administration has operated it's fully automatic MARITEX system since 1972. From the start it was necessary to delete the rephasing function, since the use of it would confuse land-telex and radio operators. The drawbacks of rephasing becomes obvious in the case where a ship station as master loses contact with the coast station. In the meantime, another ship is passing traffic to the coast station. When the channel is clear again, the first ship rephases and continues, without identification, where it left off earlier, thus creating confusion.

From this standpoint the Swedish Administration proposes to delete § 3.1.5 rephasing entirely. A remark to § 3.1.9.1 to the effect that in point-to-point applications the time-out period could be user-defined to 96 cycles would substitute the entire rephasing procedure and have the same or better effect. The time elapsed from the beginning of time-out to the end of rephasing can be 32 + 64 = 96 cycles, (§§ 3.1.5.1 and 3.1.9.1).

An advantageous consequence to deleting § 3.1.5 would be that the starting criterion, §§ 3.1.4.4 and 3.1.4.5, can be narrowed down to only control signal 1.

ANNEX II

THE NETHERLANDS

IDENTIFICATION OF SIMPLEX ARQ DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE, OPERATING IN ACCORDANCE WITH RECOMMENDATION 476-2

(Question 5/8)

Introduction

In Decides 2 of Question 5/8 is stated that provisions for unambiguous identification during establishing and re-establishing of direct-printing equipment in accordance with Recommendation 476-2 should be studied. The transmission of the identity of a called station is actually performed by a master station in the phasing and re-phasing period. Presently it is not possible for master nor slave station to transmit automatically its own identity (self-identification).

Stations for this type of operation are identified by a numerical identification, converted into a 28-bit (4-character) pattern in accordance with Recommendation 491.

For the immediate requirements the capacity of this numbering system is adequate. If more identities are required, the 4-character method can meet this requirement. In principle, 35 seven-unit characters are available. However, it is practical to exclude the signals listed in Table II "service information signals" of Recommendation 476-2 from the use for identification purposes. An ISS transmits blocks of three signals in each transmitting period. Together with the transmitting pause, the transmitting period forms a "cycle" of 450 ms. This is so for transmitting traffic and service information signals. Thus to transmit an identity, composed of four characters (X_1 X_2 X_3 X_4), two blocks are required. This takes two cycles or 900 ms.

Actually the transmission of an identity is that of the called station. With some minor modifications the ISS would be able to transmit the self-identification as well.

An IRS in the present situation can only emit three different control signals, one in each cycle. If the IRS has to transmit any other information, e.g. self-identification, it must follow the change-over procedure into ISS in accordance with § 3.1.6 of Annex I to Recommendation 476-2. This takes, under non-repeating conditions a time equal to 3 cycles or 1.35 s before the transmission of identification characters can start. Then, if the ISS has asked for the IRS-identification, the system has to change over again to the original situation. This means another 3 cycles, so that the whole process takes 3 + 2 + 3 = 8 cycles or 3.6 s.

If the IRS could transmit the identification in the IRS position it would transmit the four characters one per cycle, thus taking 4 cycles or 1.8 s. This is half the time used in the previous way.

Appendix I describes a method in which the automatic exchange of identities is performed while the existing and the new equipment are compatible excluding the exchange of the identification.

Appendix II is the draft amendment of Recommendation 476-2.

ANNEX II

APPENDIX I

METHOD OF AUTOMATIC EXCHANGE OF IDENTITIES BETWEEN DIRECT-PRINTING TELEGRAPH EQUIPMENTS IN THE MARITIME MOBILE SERVICE

1. General

In this document the system as specified in Recommendation 476-2 will be indicated as DE (Direct-printing Existing) and the proposed system will be referred to as DN (Direct-printing New).

It is essential that DE and DN systems can communicate together, however in that case the feature of exchange of identification cannot be used.

2. Description of the proposed procedure

2.1 *Characteristics of master and slave stations*

It is proposed that as a part of the phasing and re-phasing procedure the exchange of the identities takes place in the hand-shaking procedure. This means that the master station transmits the identity of the called station according to the DE procedures, and that it also transmits its own identity, the "self-identification". The slave station transmits its identity as an answer to the call received.

The master station sends the call and self-identity in blocks of two identification characters each, and the slave station transmits its identity in separate characters, one during each cycle.

In this stage where the exchange of identities takes place simultaneously, the system acts in a quasi duplex mode.

Apart from the "service blocks" used in the DE system:

1. X_1-RQ-X_2 : Character 1 and 2 of the called station identity
2. X_3-X_4-RQ : Character 3 and 4 of the called station identity
3. RQ-RQ-RQ : Request for repetition of the last transmitted control signal
4. β-α-β : Signal to change the direction of the traffic flow
5. α-α-α : Signal to initiate the end of communication.

The master station in the DN system should be able to transmit the following extra "service blocks":

6. X_1-α-X_2 : Self-identification character 1 and 2
7. X_3-X_4-α : Self-identification character 3 and 4
8. RQ-β-β : Request for self-identification to start with character 1
9. RQ-β-α : Request for self-identification to start with character 2
10. RQ-α-β : Request for self-identification to start with character 3
11. RQ-α-α : Request for self-identification character 4.

Apart from the control signals used in the DE system (CS1, CS2 and CS3), the slave station in the DN system should be able to transmit during the phasing or re-phasing periods the signals:

- β : Request for the identification characters 1 and 2 of the master station
- α : Request for the identification characters 3 and 4 of the master station
- RQ : Request for the re-transmission of the last information block
- All the characters of the Table "traffic information signals" in the paragraph 2.1 of Annex I to Recommendation 476-2. These signals with the exception of the signals 12 (character L), 14 (character N) and 32 (unperforated tape) are, or may be used for identification purpose.

Consequently, the master station in the DN system should be able to detect and interpret all 35 signals, and the slave station in the DN system should be able to detect and interpret all service blocks. On receipt of the appropriate call signal the slave station starts emitting alternating three control signals CS1 and three idle signals β. Starting with three control signals CS1, until reception of either a block containing RQ-β-β or a block containing traffic information.

2.2 *Unmutilated reception*

The phasing procedure of two DN stations is shown in Fig. 1 and will be elucidated briefly. The propagation conditions are supposed to be so that no repetition will take place.

Station I (identity QEMP) and station II (identity ZFST) are in the stand-by position. Station I wants to call station II. So it transmits the call signal to station II in the blocks Z-RQ-F (call block 1) and S-T-RQ (call block 2).

On recognition of its call sign, station II becomes IRS and transmits the control signal CS1. Station I on receipt of CS1, becomes ISS and transmits the block RQ-β-β, asking for the self-identification of station II, to start with character 1.

Station II does so, and on unmutilated reception of "Z", station I starts transmitting its own identification: Q-α-E.

The idle signal α in the second character position means that it is the first block of self-identification characters. Station II stores the received characters (Q) and (E) in the "identity caller register", and transmits the second character (F) of its identity. Station I now sends the second block of identification signals M-P-α, with α in the third characters position to indicate it is the second block.

The identification characters (M) and (P) are stored in the station II register and the latter station sends the third character (S) of its identification. On receipt of this character, station I, having completed its self-identification, transmits a block RQ-α-α, which means that station II still has to send its last identification character.

Station II transmits the last identification character (T) and station I compares the received identity on similarity with the transmitted call. If the similarity is not found, station I transmits a block α-α-α to initiate the end of communication. If the received identification is the same as the transmitted call, station I transmits a block RQ-RQ-RQ to indicate the end of the "phasing" and the start of the traffic information stage. Station II, having received the block RQ-RQ-RQ sends the control signal CS1, and operating goes on in accordance with Rec. 476-2.

2.3 *Re-phasing*

The re-phasing procedure takes place in a way similar to the phasing. The difference however, is that station II, when entering into the re-phasing situation, has available the identity of the station that initiated the circuit (QEMP). When accepting the identification characters of the station I during the re-phasing process, it compares the received call on similarity with the registered identity. If the identity is the same, the procedure from now on is identical to the phasing procedure.

If the identity is not the same, station II transmits the control signal CS3 after the last self-identification character (T) and inititates the "end of communication" procedure in accordance with paragraph 3.1.9 of Annex I to Rec. 476-2.

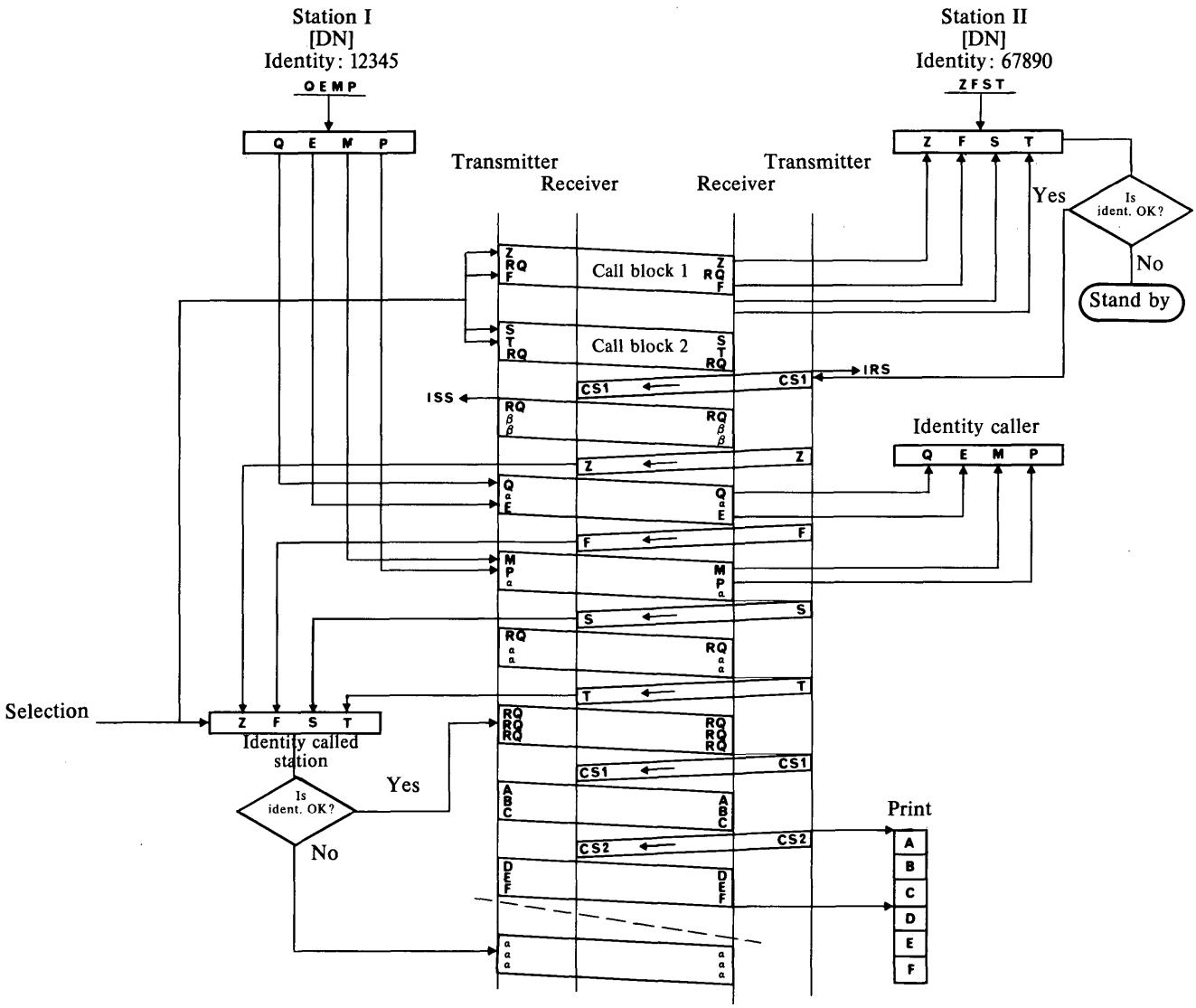


FIGURE 1 – *Phasing procedure of two NEW stations*

2.4 *Mutilated reception*

Figure 2 illustrates the phasing process in the condition of mutilated reception.

After the call blocks being received mutilated in station II a number of successive blocks RQ-β-β are supposed to be mutilated. In that case station II changes over to the transmission of idle signals β instead of CS1 after three successive control signals CS1.

Station I, now receiving an idle signal β, concludes that the called station is of the DN-type and therefore the transmission of blocks RQ-β-β should be continued.

If one or more of the blocks RQ-α-β, RQ-α-α or RQ-RQ-RQ are received mutilated by station II, this station emits the signal RQ.

The transmission of traffic blocks does not take place before the exchange of identification characters has been completed.

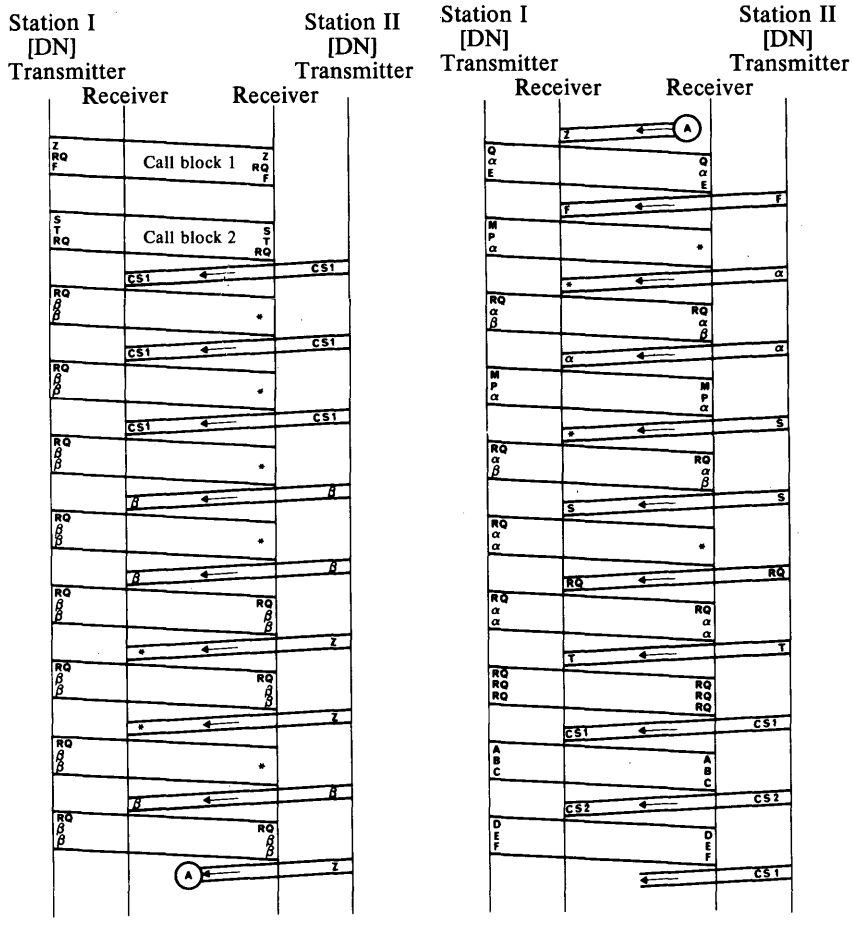


FIGURE 2 – *Phasing process of two NEW stations in the condition of mutilated reception*

3. Cooperation of "DE" and "DN" stations

3.1 *DN station calling a DE station (see Fig. 3)*

The procedure starts as described in Fig. 1 – case: Station I calls station II and transmits the call blocks 1 and 2.

Station II, the DE station, on detection of its identification characters sends back the control signal CS1.

In the rephasing case this also could be CS2 or CS3.

Station I, after having received two control signals CS1, at a distance of three time cycles, concludes that the called station is of the DE type because stations of the DN type would never respond by sending more than three successive control signals CS1.

Because station I has received at least two control signals CS1, it starts the transmission of traffic blocks in accordance with paragraph 3.1.4. and 3.1.5 of Annex I to Rec. 476-2.

In this case the transmission of traffic blocks starts without exchange of identification characters.

3.2 *DE station calling a DN station (see Fig. 4)*

Station I sends the two calling blocks and receives the control signal CS1 from station II.

Station I will transmit the call blocks once more and when station II receives the first call block after it has transmitted control signal CS1, it re-transmits the same control signal.

Station I concludes from the reception of two successive identical control signals that the call has been succesful and starts the transmission of traffic blocks.

3.3 *Examples with mutilated reception*

In Fig. 5 and 6 some more examples have been given for phasing procedures of DN and DE stations under poor propagation conditions.

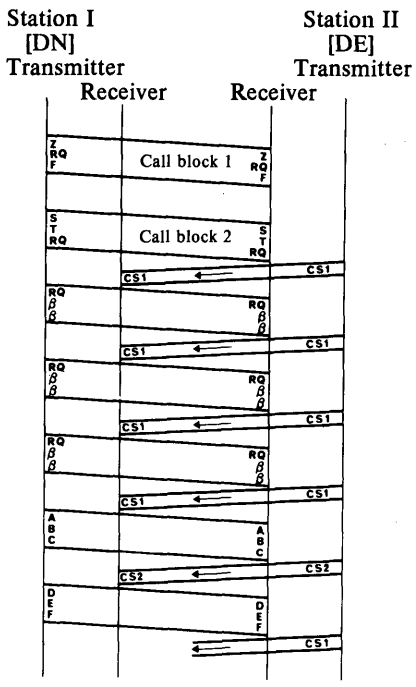


FIGURE 3 – *Phasing procedure of a NEW master and an existing slave*

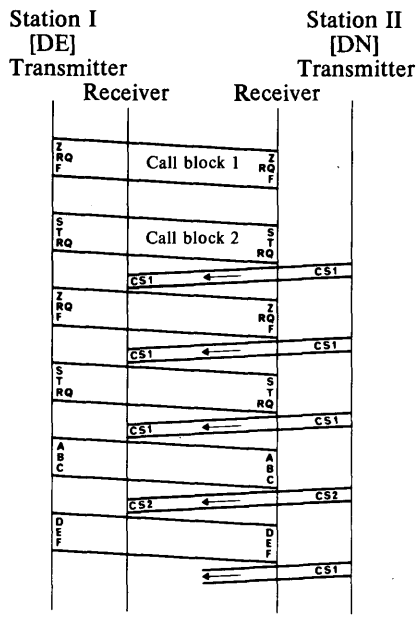


FIGURE 4 – *Phasing procedure of an existing master and a NEW slave*

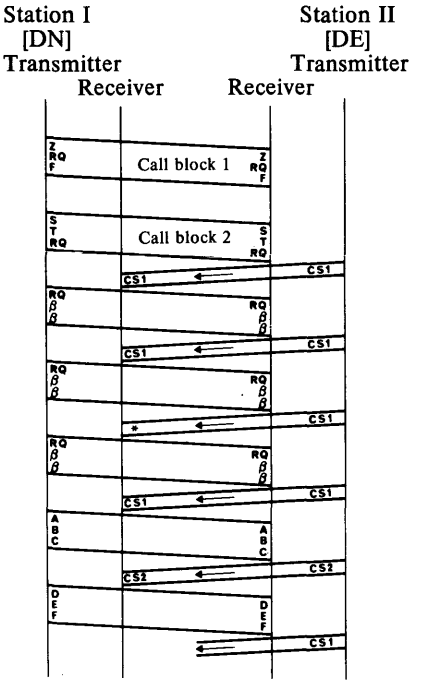


FIGURE 5 – *Phasing process of a NEW master and an existing slave in the condition of mutilated reception*

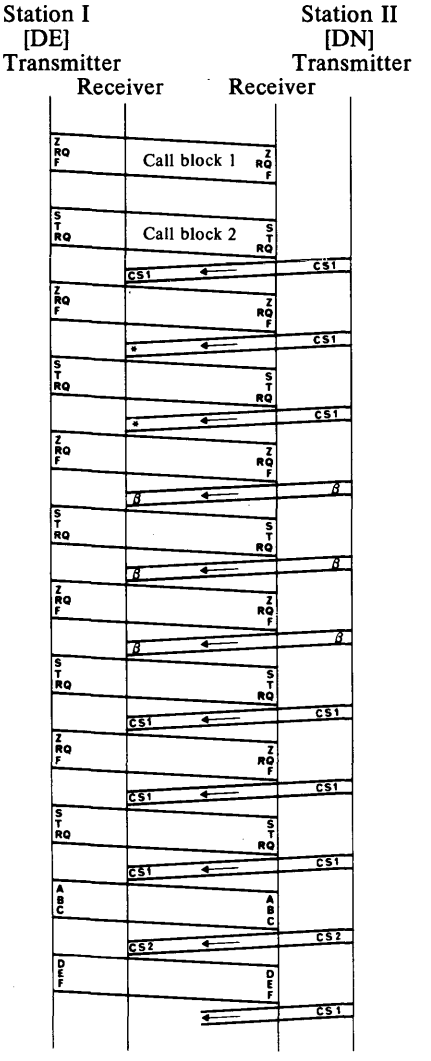


FIGURE 6 – *Phasing process of an existing master and a NEW slave in the condition of mutilated reception*

ANNEX II

APPENDIX II

PROPOSAL FOR MODIFICATION OF RECOMMENDATION 476-2

3.1.4 *Phasing*

3.1.4.1 when no circuit is established, both stations are in the "stand-by" position. In this stand-by position no ISS or IRS and no master or slave position is assigned to either of the stations;

3.1.4.2 the station desiring to establish the cirtuit emits the "call" signal. This "call" signal is formed by two blocks of three signals. (Some administrations also use a one-block "call" signal, which was an alternative in Recommendation 476 (1970).)

3.1.4.3 the call contains:

- in the first block: "signal repetition" in the second character place, and any combination of information signals, except the six service information signals as listed in the table of paragraph 2.2 of this Annex (The composition of these signals and their assignment to individual ships require international agreement (see Recommendation 491)), in the first and third character places;

- in the second block: "signal repetition" in the third character place and any combination of information signals, except the six service information signals listed in the table of paragraph 2.2 of this Annex (The composition of these signals and their assignment to individual ships require international agreement (see Recommendation 491)), in the first and second character places;

3.1.4.4 * on receipt of the appropriate call signal the called station changes from stand-by to the IRS position and emits alternating three times control signal 1 and three times signal β starting with control signal 1 until either a block containing "signal repetition" – signal β – signal β or a block containing traffic information has been received, taking into account the time limits meant in paragraph 3.1.9.1.

3.1.4.5 receipt of the control signal 1, the calling station changes into the ISS position and emits a block which contains "signal repetition" in the first place and signals β in the second and third character places;

3.1.4.6 on receipt of the block containing the signal sequence "signal repetition", signal β – signal β, the IRS transmits its first identification character;

3.1.4.7 the calling station, on receipt of the first identification character, transmits a block containing its own first identification character, signal α and its second identification character in the first, second and third character places respectively;

3.1.4.8 on receipt of the block containing the first two identification characters of the calling station, the IRS transmits its second identification character;

3.1.4.9 the calling station, on receipt of the second identification character of the IRS, transmits a block containing its third and fourth identification character and signal α in the first, second and third character places respectively;

3.1.4.10 on receipt of the block containing the third and fourth identification characters of the calling station, the IRS transmits its third identification character and the IRS registers the identification characters of the calling station;

3.1.4.11 on receipt of the third identification character from the IRS, the calling station transmits a block containing "signal repetition" in the first, and signals α in the second and third character places;

3.1.4.12 on receipt of the block containing "signal repetition", signal α – signal α, the IRS transmits its fourth identification character;

3.1.4.13 on receipt of this fourth IRS identification character the calling station compares the four identification characters received from the IRS with the identification characters, transmitted in the first and second call blocks.

- If these characters are not identical the calling station initiates the "end of communication" procedure in accordance with paragraph 3.1.9.

- If these characters are identical, the calling station emits a block of three "signal repetitions".

Moreover the calling station registers that the called station operates in accordance with this recommendation;

3.1.4.14 on receipt of a block containing three "signal repetitions", the IRS station transmits control signal 1 after which the traffic flow is started in accordance with paragraphs 3.1.2 and 3.1.3;

3.1.4.15 * if the calling station, after having transmitted the block containing "signal repetition", signal β, signal β as described in paragraph 3.1.4.5, receives, instead of the first identification character, control signal 1 or a signal β, it transmits the block containing "signal repetition", signal β, signal β, until the first identification signal of the called station is received, taking into account the time limits meant in paragraph 3.1.9.1.

However, if the calling station receives two control signals 1 in a distance of three time cycles, it immediately starts the transmission of traffic blocks in accordance with paragraphs 3.1.2 and 3.1.3;

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* The procedures as under 3.1.4.4 and 3.1.4.15 are introduced to allow equipment built in accordance with this recommendation to cooperate with equipment built in accordance with Recommendation 476-2.

3.1.4.16 if, due to mutilated reception, the calling station does not receive:

- control signal 1 or the first identification character, it retransmits the call sign;
- the first identification character after reception of control signal 1, it transmits a block containing "signal repetition" – signal β, signal β;
- the second identification character, it transmits a block containing "signal repetition" – signal β – signal α;
- the third identification character, it transmits a block containing "signal repetition" – signal α – signal β;
- the fourth identification character, it transmits a block containing "signal repetition" – signal α – signal α;

3.1.4.17 if the calling station receives:

- a signal β, after it has received the first identification character, it retransmits the block containing its first two identification characters;
- a signal α, it retransmits the block containing its last two identification characters;
- a "signal repetition", it retransmits the previous block;

3.1.4.18 if, due to mutilated reception, the called station does not receive:

- the block containing "signal repetition" – signal β – signal β, after it had emitted the control signal 1, it retransmits this signal in accordance with paragraph 3.1.4.4;
- the block containing the first two caller identification characters, after it had emitted its own first identification character, it transmits the signal β;
- the block containing the last two caller identification characters, it transmits the signal α;
- the block containing three "signal repetitions", it transmits the appropriate control signal;
- any block after correct reception of the block containing the last two identification characters of the calling station, it emits the "signal repetition" until a block containing three "signal repetitions" has been correctly received.

3.1.5 *Rephasing*

3.1.5.1 When reception of information blocks, control signals, identification signals, signals α or signals β is continuously mutilated, the system reverts to a position similar to the stand-by position after a predetermined time (to be decided by the user) of continuous repetition. A preferable predetermined time would be the duration of 32 cycles of 450 ms. Both the master and the slave station have registered the identity and the way of operating of the other station;

3.1.5.2 after being reverted to the position similar to stand-by the master station immediately initiates re-phasing. The re-phasing proceeds along the same line as laid down in paragraph 3.1.4 taking into account that the way of operating of the other station is known;

3.1.5.3 if the slave station receives the self-identification characters of the master station (in accordance with the paragraphs 3.1.4.7 and 3.1.4.9), it compares the received identification characters with the registered ones:

- if the received characters are identical to the registered ones, the phasing process continues to start with paragraph 3.1.4.10;
- if they are not identical, the IRS acts in accordance with paragraph 3.1.9.5;

3.1.5.4 the slave station after having received its complete call signal during rephasing, emits:

- the control signal 1 if it had correcly received information block 2 before the interruption occurred:
- the control signal 2 if it had correctly received information block 1 before the interruption occurred:
- the control signal 3 if it was in the ISS position at the moment of interruption;

and continues to do so until either a block containing "signal repetition" – signal β – signal β or a block containing traffic information or a block containing signal β – signal α – signal β is received, disregarding the procedure described in paragraph 3.1.4.4.

3.1.6 *Change over* (no modification).

ANNEX III

UNITED STATES OF AMERICA

AUTOMATIC IDENTIFICATION OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

1. Introduction

This Annex proposes a method for providing automatic identification of ARQ direct-printing equipment in the maritime mobile service. The proposal provides compatibility with existing equipment by introducing three new control signals. A call validation procedure confirms that the intended slave station has responded. Master identification is provided to the slave station.

2. Background

The proposal is based on the following principals:

2.1 The calling procedures defined in Recommendation 476-2 select the intended slave station. The slave station activates automatically upon receipt of its call signal, and responds with service information signals. This proposal adds an address validation procedure which requires the slave to positively confirm successful reception of two identical call signals before message transmission begins.

2.2 The calling station transmits its identity automatically to the called-station following completion of the slave station validation procedure. The identity of the calling station will not be printed at the called station unless special measures are taken.

2.3 Service information signals permit "new" station equipment to recognize whether other station equipment is "new" or "old" when phasing or re-phasing occurs, and before any message traffic is passed. "New" equipment has the ability to provide automatic identification of the calling station; "old" equipment operates in accordance with Recommendation 476-2 and does not have the ability to provide automatic identification of the calling station.

2.4 Compatibility between "new" and "old" equipment is obtained by introducing three new service information signals.

3. Service information signals

The list of service information signals given in § 2.2 of Recommendation 476-2 is increased by the addition of three new control signals CS1 *, CS2 * and CS3 *, obtained by inverting the elements of CS1, CS2 and CS3. These new signals have the same maximum distance properties as non-inverted control signals – that is, their 7-unit equivalents differ from each other in four unit positions. Furthermore, they appear to "old" equipment as mutilated signals and therefore evoke a characteristic response as defined in Recommendation 476-2, which informs "new" equipment whether the other station equipment is "new" or "old".

The three new control signals have the following functions:

- CS1* : confirms address verification or self-identification. Used where "old" equipment would return CS1;
- CS2* : similar in function to CS1 *, but used where "old" equipment would return CS2;
- CS3* : requests repetition of an address verification block or self-identification block which contains detected errors.

4. Self-identification signal

This signal, derived in accordance with Recommendation 491, is transmitted by the master in two three-character blocks, with RQ in the first position of block 1, and RQ in the third position of block 2. This procedure allows the use of the assigned call code for self-identification of the master, differentiates the identification portion of the signal from the call blocks, and inhibits printing of the identification signal at the slave station.

During the phasing process between new equipments, the slave station receives and stores the master identification code. If re-phasing occurs, the slave station determines whether the identification code received during re-phasing matches the code in his memory. If it does, information transfer continues as before re-phasing; if it does not, the slave initiates the end-of-communication sequence described in § 3.1.9.5 of Recommendation 476-2 and awaits a recall from the original master. However, the total writing time should not exceed the interval defined in § 3.1.9.1 of Recommendation 476-2.

5. Typical operation

Mode A operation under various conditions is shown in Figs. 7 to 15, and discussed briefly below. As noted above, the term "new" is associated with a station which is capable of providing call validation and automatic transmission of a self-identification code; the term "old" is associated with a station which is not capable of providing automatic identification.

In the case of re-phasing, the slave should always return the same control signals as at the time of circuit interruption. For the sake of simplification, it is assumed in the following figures that CS1 is returned as the appropriate control signal during re-phasing.

Figure 7 illustrates normal call procedure occurring between two stations fitted with "new" equipment. The slave confirms call validation by transmitting CS1 * to the master; the master returns his identification code (ID blocks 1 and 2), and the slave confirms reception of the master identification and enters the code in memory. Following these steps, message transfer begins with the master acting as ISS.

Figures 8 illustrates normal call procedure occurring between a "new" master and an "old" slave. The master recognizes that the slave is "old" by noting that the acknowledgement to the second call block 2 is not inverted. Message transfer then begins immediately with the master as ISS.

Figure 9 illustrates the effect of errors in the call validation blocks, as well as link termination by the slave when call validation fails.

Figure 10 illustrates the effect of errors in the master identification code, as well as link termination by the slave when the master identification received fails to match the master identification stored in his memory.

Figure 11 illustrates a normal call or re-phasing procedure between an "old" master and a "new" slave. It is noted that reception of a mutilated CS1 * signal by a "new" master would also result in an RQ response. Therefore the slave station, in response to an RQ block, should repeat the CS1 * signal [3] times before concluding that the master station is "old".

Figure 12 illustrates a normal re-phasing procedure between a "new" master and a "new" slave. In this case, the slave was acting in the ISS mode at the time of link interruption; therefore, the slave initiates the "over" procedure immediately upon recognizing that the master identification code received matches that in his memory, and then proceeds normally as the ISS.

Figure 13 illustrates a re-phasing procedure between a "new" master and an "old" slave. In this case, the slave was acting in the ISS mode when the link dropped. A type 2 slave is one which responds to a call immediately with a CS3 under the conditions shown. The master recognizes that the slave is "old" by virtue of repeated CS3 responses to call validation blocks.

Figure 14 illustrates re-phasing as in Fig. 13, but with a type 1 slave. The master recognizes an "old" type 1 slave by the failure to return CS1 * in response to call validation blocks.

Figure 15 illustrates re-phasing between an "old" master and a "new" slave. The slave recognizes the master is "old" by virtue of its RQ response to the CS1 * call validation signal, and initiates the over sequence as appropriate to resume the ISS mode. The discussions under Fig. 11 regarding the reception of mutilated CS1 * signals by a "new" master also apply in this case.

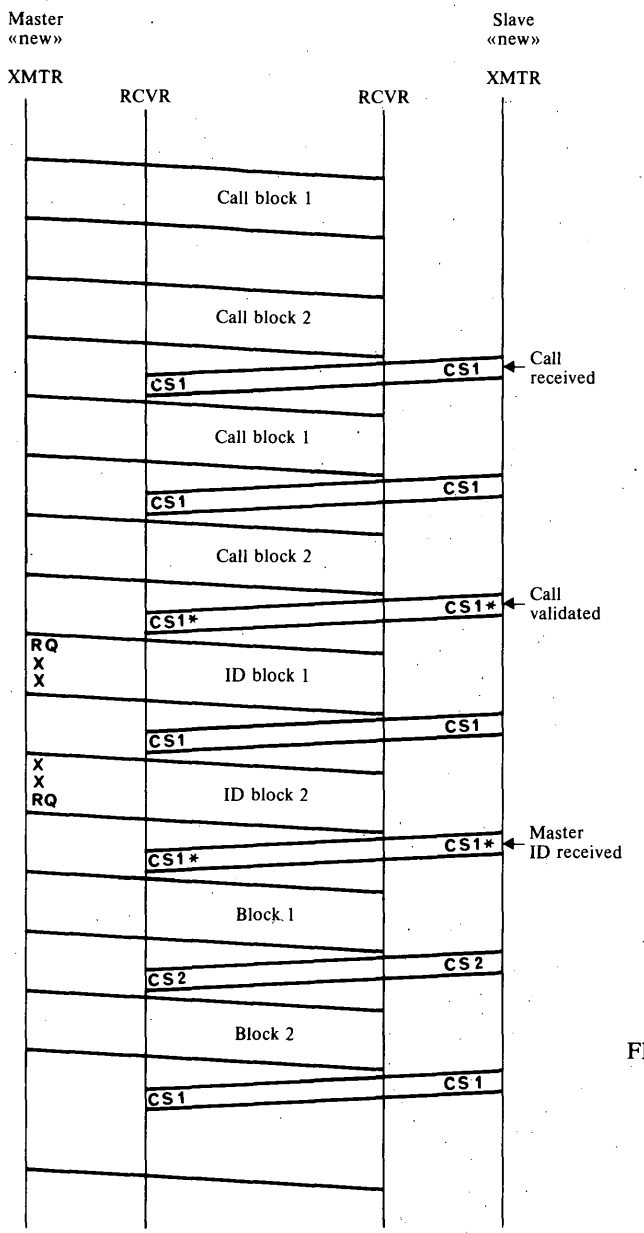


FIGURE 7 – *Normal call/re-phasing procedure between two "new" equipment*

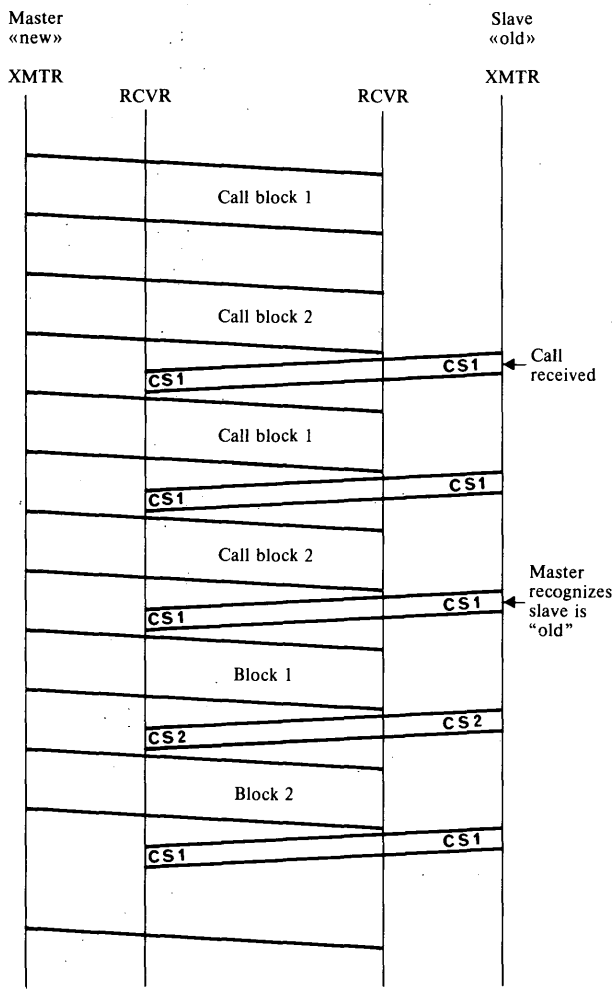


FIGURE 8 – *Normal call/re-phasing procedure between a "new" and a "old" equipment – master was ISS*

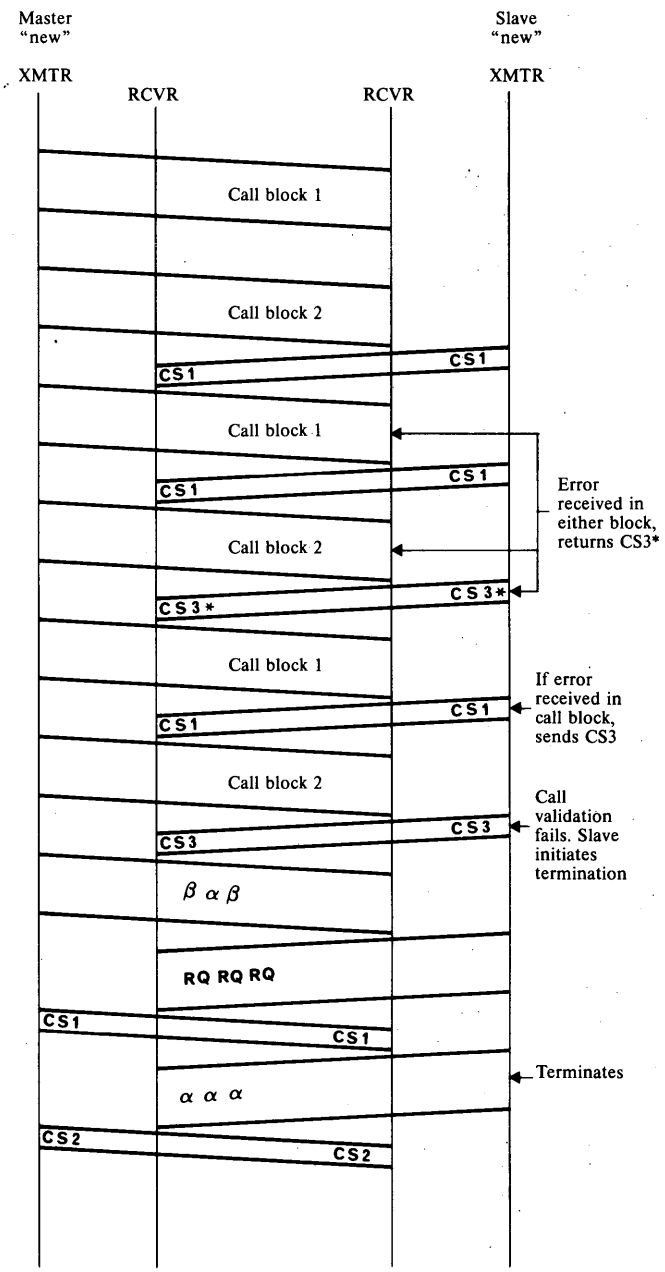


FIGURE 9

– error in call validation
– call validation fails to match

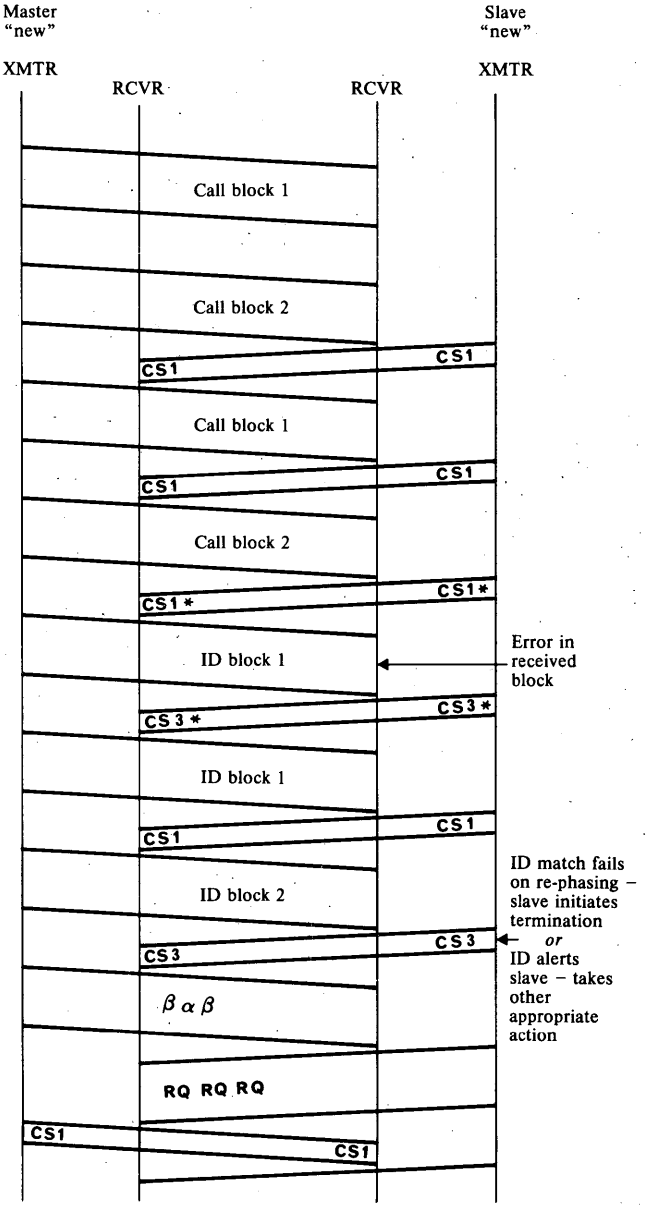


FIGURE 10

– error in ID block
– ID fails to match (re-phasing) or alerts slave

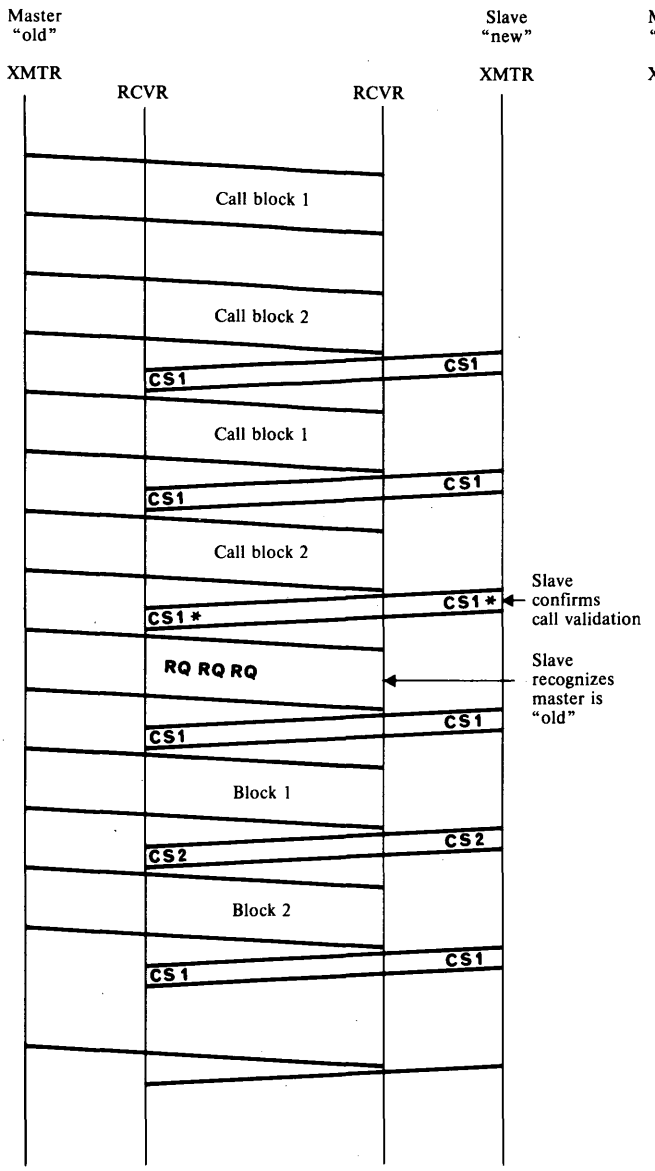


FIGURE 11

– normal call, or
– re-phasing, master was ISS

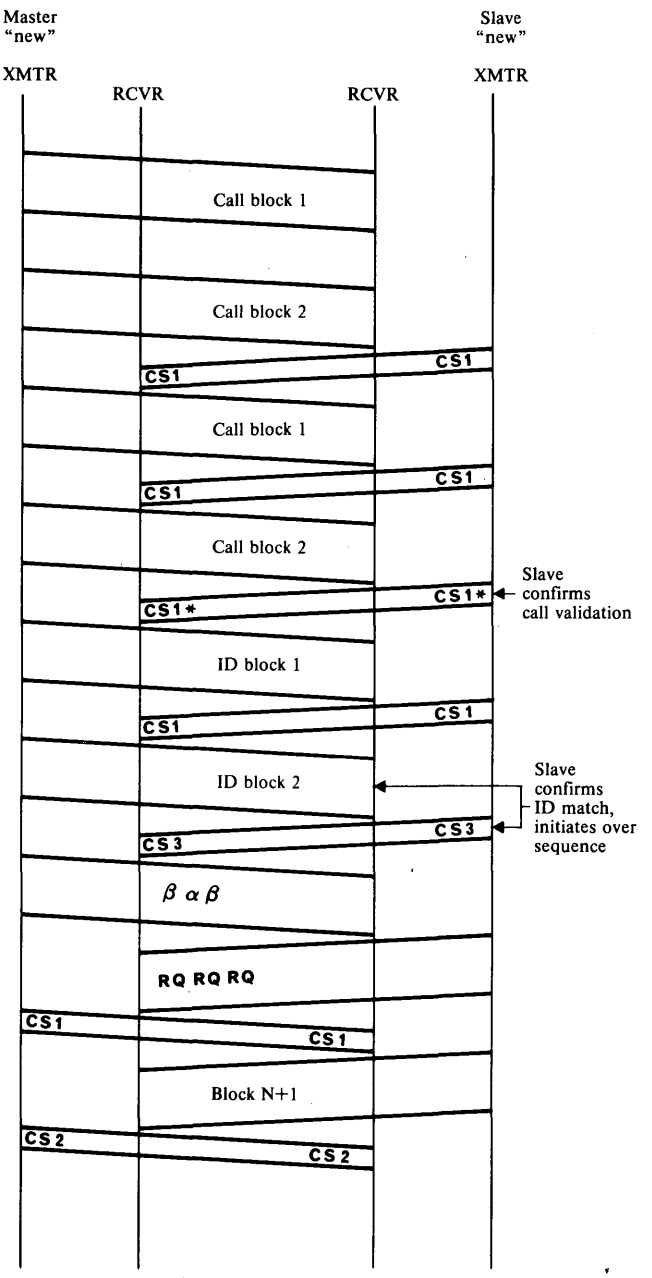


FIGURE 12

– re-phasing, slave was ISS

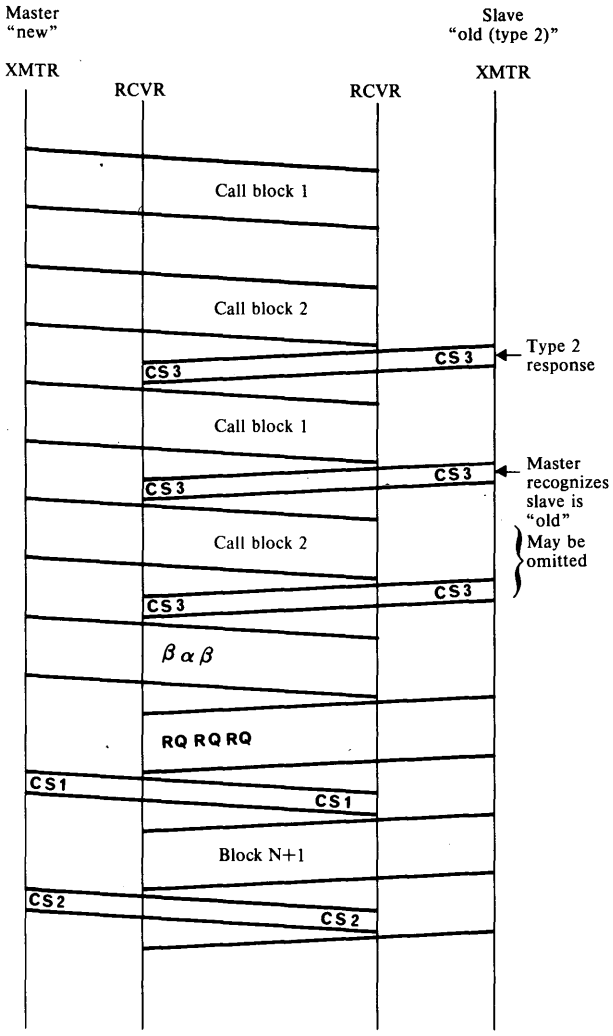


FIGURE 13

– re-phasing, slave was ISS

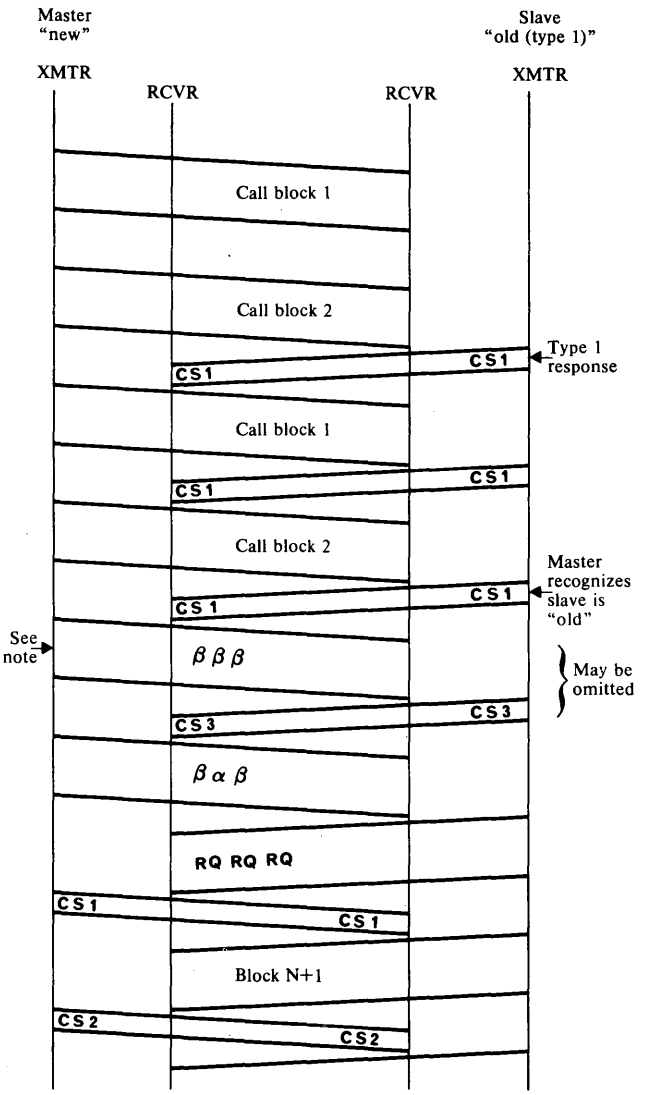


FIGURE 14

– re-phasing, slave was ISS

Note. – Content may differ should be non-printing; could be β α β if master.

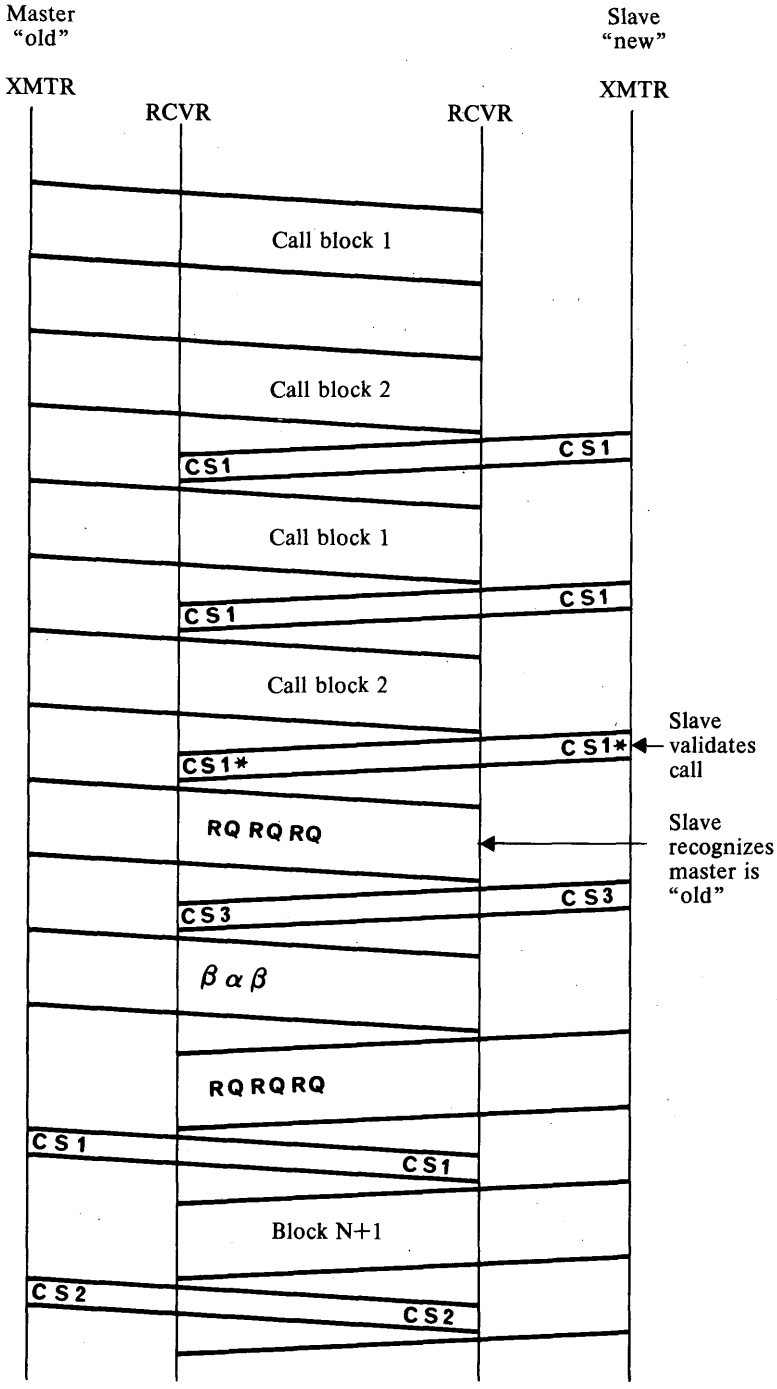


FIGURE 15

– re-phasing, slave was ISS

RECOMMENDATION 540-1 *

OPERATIONAL AND TECHNICAL CHARACTERISTICS FOR AN AUTOMATED DIRECT-PRINTING TELEGRAPH SYSTEM FOR TRANSMISSION OF NAVIGATIONAL AND METEOROLOGICAL WARNINGS AND URGENT INFORMATION TO SHIPS

(Question 5/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that the availability of navigational and meteorological warnings and urgent information on board ships is of great importance for safety;

(b) that the existing radiocommunication system for transmission of navigational and meteorological warnings and urgent information to ships can be improved by use of modern techniques;

(c) that IMCO in its requirements for a Future Global Maritime Distress and Safety System has included provisions for the transmission of navigational and meteorological warnings using narrow-band direct printing techniques;

(d) that several countries are operating a coordinated service, called NAVTEX, based on narrowband direct-printing;

(e) that the system should be applicable to the maritime mobile service (both international and national);

(f) that it is desirable that the service fulfils the requirements of all types of ships desiring to use it;

(g) that although each area may need specific guidance, the use of standard technical and operational characteristics would facilitate the extension of the service,

UNANIMOUSLY RECOMMENDS

1. that the operational characteristics for transmitting navigational and meteorological warnings and urgent information using NBDP should be in accordance with Annex I;

2. that the technical characteristics for transmitting navigational and meteorological warnings and urgent information using NBDP should be in accordance with Annex II.

ANNEX I

OPERATIONAL CHARACTERISTICS

1. The radiated power from the coast station transmitter should only be that sufficient to cover the intended service area of that coast station. The range extension occurring during night hours should also be considered.

2. The information transmitted should primarily be of the type used for coastal waters preferably using a single frequency (see also Recommendation No. 309, WARC-79).

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* The Director, CCIR, is requested to bring this Recommendation to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO), the International Hydrographical Office (IHO), the World Meteorological Organization (WMO) and to the International Association of Lighthouse Authorities (IALA).

3. The transmission time allocated to each transmitting station should be restricted to that which is adequate for the anticipated messages to be broadcast to the area concerned.

4. Scheduled broadcasts should take place at intervals not exceeding eight hours and be coordinated, as far as practicable, to avoid interference with broadcasts from other stations.

5. Periods should be scheduled between the regular transmission periods permitting immediate/early transmission of particularly important messages.

In certain cases message types A, B, D, G, H, I and J (see Annex II § 3) should be sent immediately upon issue subject to avoiding interference to on-going or scheduled transmissions.

Initial distress messages should be broadcast on the agreed frequency by coast stations in whose SAR area distress cases are handled.

6. Participating transmitting stations should be provided with monitoring facilities to enable them to:

- monitor their own transmissions as to signal quality and transmission format;
- confirm that the channel is not occupied.

7. In order to avoid overloading of the channel it is desirable to use a single language (see Note).

8. Dedicated on-board equipment is recommended.

8.1 Ship equipment should be capable of automatically rejecting unwanted information using character B_1 (see Annex II § 3).

8.2 Ship equipment should be capable of disabling print-out of selected categories of messages with the exception of message types A, B and D.

8.3 If any facility is rejected or disabled as described in § 8.1 and 8.2 above, the extent of any such limitation must be clearly indicated to the user.

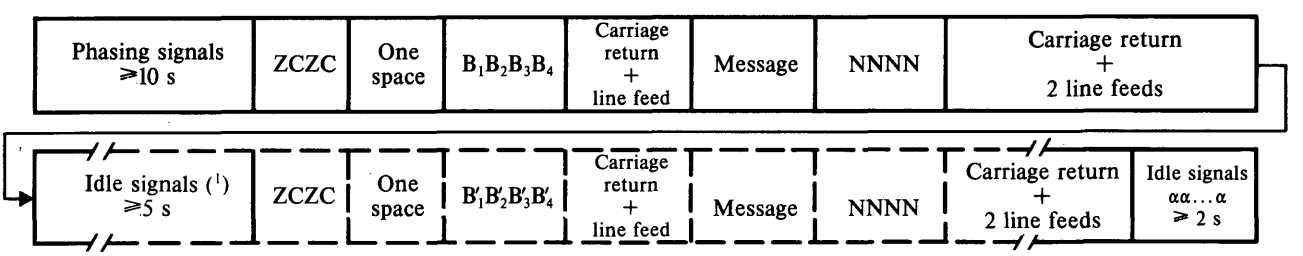
ANNEX II

TECHNICAL CHARACTERISTICS

1. Narrowband direct-printing techniques should be used for an automated telegraph system for transmissions of navigational and meteorological warnings and urgent information to ships. Common frequencies for such transmissions should be internationally agreed upon (in most European countries the frequency 518 kHz has been designated for this purpose).

2. The signals transmitted should be in conformity with the collective B-mode of the direct-printing system specified in Recommendation 476.

3. That the technical format of the transmission should be as follows:



(1) Idle signals are used to provide at least 5 s of phasing.

Note by the CCIR Secretariat. – IMCO has been requested by Study Group 8 to comment on this paragraph. At the 24th session of the Sub-Committee on Radiocommunications (London, March 1982) it was agreed that the following words should be added to paragraph 7: "and where a single language is used it shall be English".

in which

ZCZC defines the end of the phasing period

B_1 is a character identifying the transmitter coverage area

B_2 is a unique character for each type of message as follows:

A : navigational warning,
B : meteorological warning,
C : ice report,
D : search and rescue information,
E : meteorological forecast,
F : pilot message,
G : Decca message,
H : LORAN-C message,
I : Omega message,
J : differential Omega message,
(see Note)
Z : QRU (no message on hand),
K to Y : reserve indications to be defined later.

B_3B_4 is a two-character serial number for each B_2, starting with 01 except in special cases where the serial number 00 is used (see § 7 below).

The characters ZCZC $B_1B_2B_3B_4$ need not be printed.

4. The printer should only be activated if the preamble B_1-B_4 is received without errors.

5. Facilities should be provided to avoid printing of the same message several times on the same ship, when such a message has already been satisfactorily received.

6. The necessary information for the measures under § 5 above should be deduced from the sequence $B_1B_2B_3B_4$ and from the message.

7. A message should always be printed if $B_3B_4 = 00$.

8. Extra (redundant) letter and figure shifts should be used in the message to reduce garbling.

9. In case a message is repeated by another transmitting station (e.g. for better coverage) the original preamble B_1-B_4 should be used.

10. The equipment on board ships should be neither unduly complex nor expensive.

11. The transmitter frequency tolerance for the mark and the space signals should be better than ± 10 Hz.

Note by the CCIR Secretariat. – IMCO's Sub-Committee on Radiocommunications proposed to add a new type message "K" on "other electronic navigational aid system message".

RECOMMENDATION 493-2 *

DIGITAL SELECTIVE-CALLING SYSTEM FOR USE IN THE MARITIME MOBILE SERVICE

(Question 9/8)

(1974-1978-1982)

The CCIR,

CONSIDERING

(a) that selective calling in the shore-to-ship, ship-to-ship and ship-to-shore directions would expedite the handling of traffic in the maritime mobile service;

(b) that the Inter-Governmental Maritime Consultative Organization (IMCO) has listed a number of operational requirements that should be taken into account when designing a general purpose selective-calling system;

(c) that IMCO has recommended for the maritime mobile service that digital selective-calling be the only method of distress alerting and safety calling in the Future Global Maritime Distress and Safety System;

(d) that neither the selective-calling system described in Recommendation 257, nor that forming part of the system described in Recommendation 476, can fully meet the IMCO operational requirements;

(e) that several administrations have indicated an urgent need for a general purpose selective-calling system;

(f) that several administrations have been developing different systems;

(g) that the system should be applicable to the maritime mobile service, both for international and national needs;

(h) that it is desirable that the selective-calling system fulfil the requirements of all types of vessels desiring to use it,

UNANIMOUSLY RECOMMENDS

1. that, where there is a need for a general purpose digital selective-calling system, the system should have operational characteristics according to Annex I;

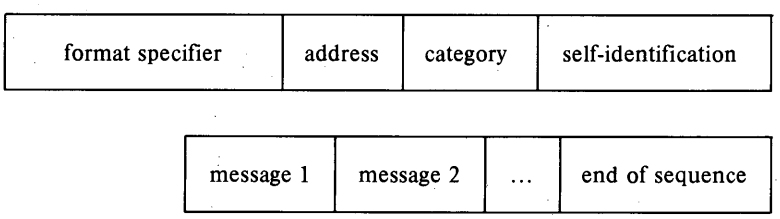
2. that equipment designed in accordance with § 1 above should meet the technical characteristics given in Annex II.

ANNEX I

OPERATIONAL CHARACTERISTICS

1. General

1.1 The format of a call sequence is:



1.2 The call sequence may be of variable length.

1.3 Provision should be made for call sequences of the following types:

1.3.1 distress calls;

1.3.2 calls other than distress calls;

1.3.3 "reply to received call" sequences.

1.4 The flow-charts illustrating the operation of the digital selective-calling system are shown in Fig. 1a and Fig. 1b.

* The Director, CCIR, is requested to bring this Recommendation to the attention of IMCO.

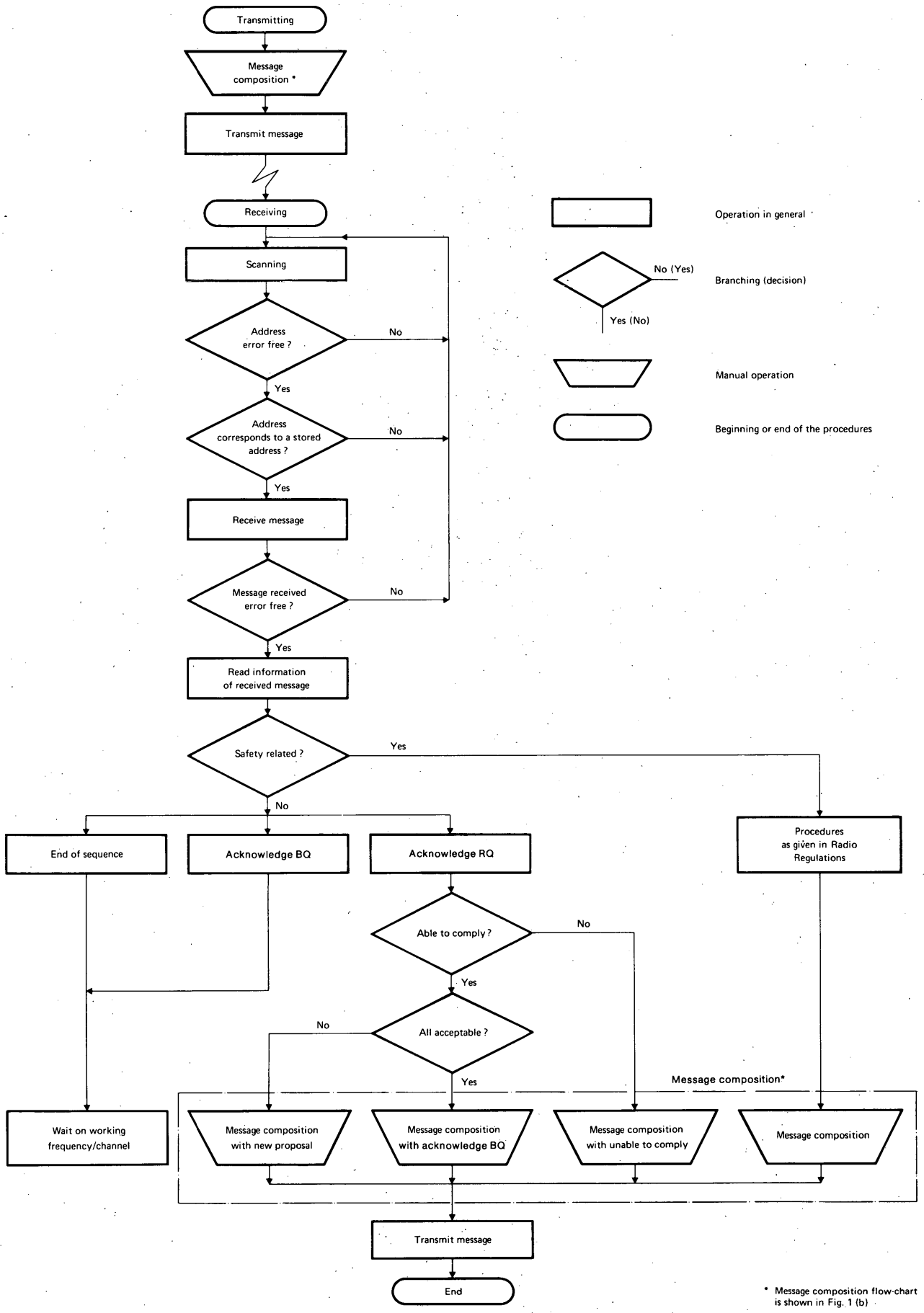


FIGURE 1-a – *Operational flow-chart*

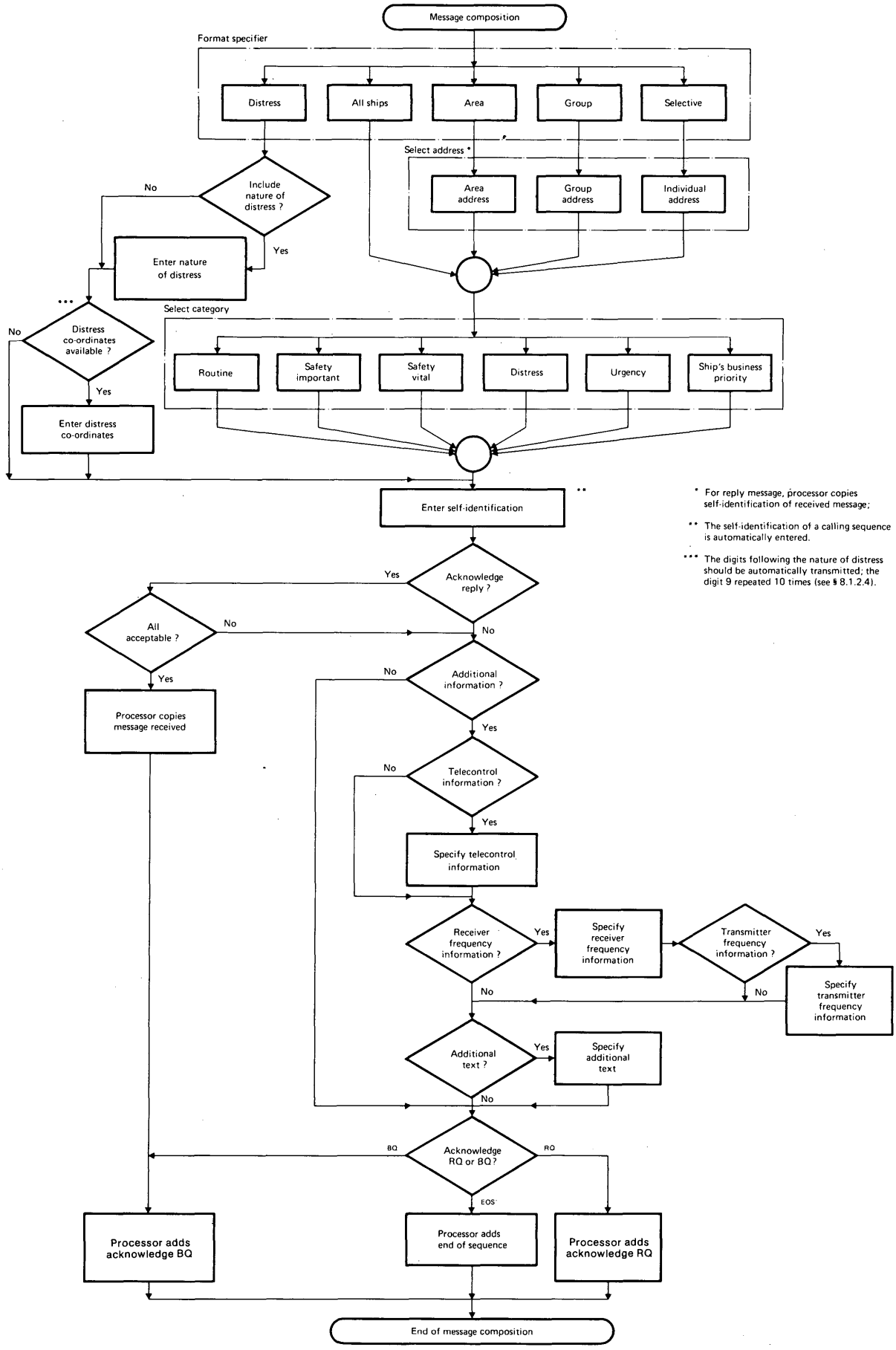


FIGURE 1-b – *Message composition flow-chart*

2. Format specifier

2.1 The format specifier indicates:

2.1.1 a "distress call" with an alphanumerical self-identification address; or

2.1.2 a "distress call" with a numerical self-identification address; or

2.1.3 an "all ships call"; or

2.1.4 a selective call with an alphanumerical address assigned:

2.1.4.1 either to an individual station; or

2.1.4.2 to a group of stations having a common interest; or

2.1.5 a selective call with a numerical address, assigned:

2.1.5.1 either to an individual station; or

2.1.5.2 to a group of stations having a common interest; or

2.1.6 a selective call directed to a group of ships in a particular geographical area; or

2.1.7 special sequences for automated VHF/UHF services (e.g. marking sequences, signalling sequences).

3. Address

3.1 For "distress calls" and "all ships calls" the address information is contained in the format specifier.

3.2 For other calls the address is:

3.2.1 the numerical, or alphanumerical identification or call sign of the called ship or coast station; or

3.2.2 the numerical, or alphanumerical identification assigned to a group of ships having a common interest; or

3.2.3 a numerical identification of a particular geographical area.

3.3 The "format specifier" indicates whether the address of the called station is numerical or alphanumerical (see § 2.1).

4. Category

4.1 For a "distress call" (Radio Regulations No. 3086) the category information is contained in the format specifier.

4.2 For other calls, the "category" information specifies:

4.2.1 the degree of priority of the call sequence:

4.2.1.1 distress (Radio Regulations 3134);

4.2.1.2 urgency;

4.2.1.3 vital safety;

4.2.1.4 important safety;

4.2.1.5 ship business priority;

Note. – Proposed definition for "ship business priority":

"Designating a call authorized by the ship owner or his agent requiring immediate handling on the ship."

This definition should be established by the next competent WARC.

4.2.1.6 routine;

4.2.1.7 ... (the possibility of adding up to five more categories later);

4.2.2 whether the self-identification of the calling station is numerical or alphanumerical.

5. Self-identification

5.1 The self-identification is the selective call (identification) of the calling station.

5.2 The self-identification is either numerical or alphanumerical as indicated by the "category" signal (see § 4.2.2).

6. Messages

The messages that may be included in a call sequence may contain the following message elements, which are listed in the order in which they would appear in each message:

6.1 *Distress information* is part of a "distress call" and includes, in the following sequence:

6.1.1 an indication of the nature of the distress as follows:

6.1.1.1 fire, explosion;

6.1.1.2 flooding;

6.1.1.3 collision;

6.1.1.4 grounding;

6.1.1.5 listing, in danger of capsizing;

6.1.1.6 sinking;

6.1.1.7 disabled and adrift;

6.1.1.8 undesignated distress;

6.1.1.9 EPIRB emission;

6.1.1.10 the possibility of adding up to 14 more indications of the nature of the distress.

6.1.2 an indication of one of the four quadrants: north-west, south-west, south-east, north-east;

6.1.3 the longitude in degrees and minutes;

6.1.4 the latitude in degrees and minutes;

6.1.5 the time in hours and minutes UTC;

6.1.6 ..., the possibility of additional information, to be decided later (e.g., frequency or channel information and indication of type of assistance requested).

6.2 *Telecommand information* which may include:

6.2.1 terminal control functions;

6.2.2 transmitter and receiver control functions;

6.2.3 special response functions;

6.2.4 ..., the possibility for expansion at a future time.

6.3 *Frequency or channel information* consisting of:

6.3.1 an actual frequency value, given in multiples of 100 Hz, or

6.3.2 a channel number.

Note. – If only one channel or frequency message element is used, this indicates the called station receive channel or frequency or a two-frequency (paired) channel. A second channel or frequency message element may be used to designate the called station transmit channel or frequency. If the calling station indicates only the called station receive frequency (for broadcast mode transmissions) then zeros should be transmitted instead of the called station transmit channel or frequency message element.

6.4 *Additional information* which may include:

6.4.1 the number assigned to the ARQ equipment of the calling station;

6.4.2 the possibility of additional information to be decided at a future time.

6.5 *Acknowledgement*

6.5.1 *Acknowledge RQ*

This message element is used if a confirmation of the call is required.

6.5.2 *Acknowledge BQ*

This message element designates the call as being the confirmation of a received call containing the "Acknowledge RQ" request.

7. End of sequence

The "end of sequence" signal terminates a particular call sequence and may be followed by a character that serves to check the entire sequence for the absence of undetected errors.

Note. – All coast stations which handle international traffic should include the error check character in the transmitted call sequences. It is recommended that ships engaged in international traffic also have this capability.

8. Protection against errors

8.1 For call sequences containing telecommand information intended to automatically control the communications equipment at the called station, the following requirements should apply:

8.1.1 the total transmission time of the call, including repetitions of the call sequence, should not exceed 30 s;

8.1.2 the probability of undetected errors in the call sequence should be less than 1 in 10^6, for any value of bit error probability at the receiving station;

8.1.3 in watch-keeping operation, including simultaneous multichannel monitoring in several frequency bands, the probability of receiving a false call resulting in the unintentional activation of radio transmitting equipment should be less than one such occurrence per year;

8.1.4 the probability of correct reception of the entire call sequence should be not less than 0.99 under receiving conditions characterized by a bit error probability of 1 in 10^2 or better.

ANNEX II

TECHNICAL CHARACTERISTICS

1. General

1.1 The system is a synchronous system using a ten-unit error-detecting code as listed in Table I of this Annex.

1.1.1 The first seven bits of the ten-unit code of Table I of this Annex are information bits. Bits 8, 9 and 10 indicate, in the form of a binary number, the number of B elements that occur in the seven information bits, a Y element being binary number 1 and a B element a binary number zero. For example, a BYY sequence for bits 8, 9 and 10 indicates 3 ($0 \times 4 + 1 \times 2 + 1 \times 1$) B elements in the associated seven information bit sequence; and a YYB sequence indicates 6 ($1 \times 4 + 1 \times 2 + 0 \times 1$) B elements in the associated seven information bit sequence.

1.2 Time diversity is provided in the call sequence as follows:

1.2.1 Apart from the phasing signals, each signal is transmitted twice in a time-spread mode; the first transmission (DX) of a specific signal is followed by the transmission of four other signals before the re-transmission (RX) of that specific signal takes place, allowing for a time-diversity reception interval of:

1.2.1.1 400 ms for HF and MF channels, and

1.2.1.2 33 1/3 ms for VHF radio-telephone channels.

1.2.2 For a call which includes repetition(s) of the call sequence (see § 8.1.1 of Annex I), Fig. 3c shows the transition between the end of one call sequence and the start of the following call sequence.

1.3 The classes of emission, frequency shifts and modulation rates are as follows:

1.3.1 F1B, 170 Hz and 100 bauds for use on HF and MF channels. When frequency-shift keying is effected by applying audio signals to the input of single-sideband transmitters, the centre of the audio-frequency spectrum offered to the transmitter is 1700 Hz.

1.3.2 Frequency-modulation with frequency-shift keying of the modulating sub-carrier: shift of 800 Hz and 1200 bauds on the VHF telephony channels; the sub-carrier is at 1700 Hz.

1.3.3 The radio-frequency tolerances of new designs of both transmitters and receivers in the MF and HF bands should be:

- Coast station ± 10 Hz
- Ship station ± 10 Hz
- Receiver bandwidth 200 to 270 Hz.

Initially the following tolerances could apply (to permit the use of existing equipment to improve reliability, special measures may need to be taken at coast stations (see Report 501)):

- Coast station ± 15 Hz
- Ship station ± 40 Hz
- Receiver bandwidth 270 to 340 Hz.

1.4 The higher frequency corresponds to the B-state and the lower frequency corresponds to the Y-state of the signal elements.

1.5 The information in the call is presented as a sequence of seven-unit binary combinations constituting a primary code.

1.5.1 The seven information bits of the primary code express a symbol number from 0 to 127, as shown in Table I, and where:

1.5.1.1 the symbols from 0 to 99 are used to code two decimal figures according to Table IVa;

1.5.1.2 for alphanumerical address and self-identification information, the symbols according to Table IVb are used;

1.5.1.3 the symbols from 100 to 127 are used to code service commands.

1.6 Where the reliability requirements described in § 8.1 of Annex I apply, the following conditions are considered necessary:

1.6.1 the transmitter encoder must include the error check character (see § 11 of this Annex) and provide repetitive transmission of the call sequence, but within the limitation of § 8.1.1 of Annex I; and

1.6.2 the receiver decoder must provide maximal utilization of the received signal, e.g. by proper utilization of the error check character and by using an iterative decoding process with adequate memory provision.

2. Technical format of a call sequence

2.1 The technical format of the call sequence is:

dot pattern	phasing sequence	format specifier	address	category	self-identification

message 1	separator*	message 2	separator*	...	end of sequence	error check character

* If required

2.2 Examples of typical call sequences and the construction of the transmission format are given in Figs. 3, 4, 5 and 6 and in Tables IX, X and XI.

3. Dot pattern and phasing

3.1 The phasing sequence provides information to the receiver to permit correct bit phasing and unambiguous determination of the positions of the signals within a call sequence.

3.2 The phasing sequence consists of specific signals in the DX and RX positions transmitted alternatively. A minimum of four and a maximum of six DX signals are transmitted.

3.2.1 The phasing signal in the DX position is symbol 125 of Table I.

3.2.2 The phasing signals in the RX position specify the start of the information sequence (i.e. the format specifier) and consist of the signals for the symbols 111 (if required), 110 (if required), 109, 108, 107, 106, 105 and 104 of the Table I, consecutively.

3.3 To allow for scanning methods to monitor several frequencies by ship stations, the phasing sequence of calls from coast stations should be preceded by a dot pattern (i.e. alternating B-Y sequence) with a duration of:

3.3.1 2 s for HF and MF channels;

3.3.2 1 s for VHF channels.

Note 1. – Dot patterns should not be included in acknowledgement sequences from either ship or coast stations.

Dot patterns should not be included in calls from ship stations.

Note 2. – If dot patterns to precede distress calls are needed or not is dependent on decisions yet to be taken by IMCO.

4. Format specifier

4.1 The format specifier signals are:

4.1.1 symbol No. 112 for a "distress call" followed by numerical self-identification, or

4.1.2 symbol No. 113 for a "distress call" followed by alphanumerical self-identification, or

4.1.3 symbol No. 116 for an "all ships call", or

4.1.4 symbol No. 114 for a selective call to a group of stations having a common interest (e.g. belonging to one particular country, or to a single shipowner, etc.) which has been assigned a numerical address, or

4.1.5 symbol No. 115 for a selective call to a group of stations having a common interest (see § 4.1.4) which has been assigned an alphanumerical address, or

4.1.6 symbol No. 120 for a selective call to a particular individual station which has been assigned a numerical address, or

4.1.7 symbol No. 121 for a selective call to a particular individual station which has been assigned an alphanumerical address, or

4.1.8 symbol No. 102 for a selective call to a group of ships in a particular geographic area,

4.1.9 symbol No. 110 for a special marking sequence (e.g. in the automated VHF/UHF service),

4.1.10 symbol No. 124, for special signalling sequences.

4.2 It is considered that receiver decoders must detect the format specifier signal in both the DX and RX positions for "distress calls" and "all ships calls" to effectively eliminate false alerting. For other calls, the address signals provide additional protection against false alerting and, therefore, single detection of the format specifier signal is considered satisfactory.

5. Address

5.1 "Distress calls" and "all ships calls" do not have addresses, since the address information is contained in the format specifier.

5.2 For a selective call directed to an individual ship or to a coast station, the address consists of the signals corresponding to the identification assigned to that station, as follows:

5.2.1 for a numerical identification, a sequence consisting of signals coded in accordance with Table IVa *, or

5.2.2 for an alphanumerical identification, a sequence consisting of signals with symbol numbers corresponding to those indicated in Table IVb.

5.3 For a selective call directed to a group of ships the address should be constructed as follows:

5.3.1 for calls to ships in a particular geographic area a numerical geographic coordinates address consisting of either 6 or 8 digits (i.e., 3 or 4 characters), and is constructed as follows (see Fig. 2):

5.3.1.1 the designated geographic area will be a rectangle in Mercator projection;

5.3.1.2 the upper left-hand (i.e., north-west) corner of the rectangle is the reference point for the area;

5.3.1.3 the horizontal (i.e., west-to-east) and vertical (i.e., north-to-south) sides of the rectangle, $\Delta\lambda$ and $\Delta\varphi$, are specified in degrees if the coordinates of the reference point are given in degrees, and in tens of degrees if the coordinates of the reference are given in tens of degrees;

---

* According to Appendix 43 to the Radio Regulations, maritime mobile service identities are formed of a series of nine digits, consisting of 3 digits of the Nationality Identification Digits (NID) and six more digits.

These identifications are included in the address and self-identification parts of the call sequence and are transmitted as five signals $S_1S_2S_3S_4S_5$, comprising the ten digits of

(X_1, X_2) (X_3, X_4) (X_5, X_6) (X_7, X_8) and (X_9, X_{10})

respectively, whereas digit X_{10} is always the figure 0 and reserved for future use.

Example:

NID $X_4 X_5 X_6 X_7 X_8 X_9$ being the ship station identity is transmitted by the digital selective calling equipment as:

(N, I) (D, X_4) (X_5, X_6) (X_7, X_8) (X_9, 0).

5.3.1.4 the first and second digits indicate $\Delta\varphi$ and $\Delta\lambda$, respectively;

5.3.1.5 the third digit indicates the azimuth sector in which the reference point is located, as follows:

5.3.1.5.1 quadrant NE is indicated by the digit "0",

5.3.1.5.2 quadrant NW is indicated by the digit "1",

5.3.1.5.3 quadrant SE is indicated by the digit "2",

5.3.1.5.4 quadrant SW is indicated by the digit "3",

5.3.1.6 the fourth, sixth and eighth digits indicate the longitude of the reference point in hundreds, tens, and units of degrees;

5.3.1.7 the fifth and seventh digits indicate the latitude of the reference point in tens and units of degrees;

5.3.1.8 the seventh and eighth digits, i.e., the fourth character, are not transmitted if the coordinates of the reference point (and consequently $\Delta\varphi$ and $\Delta\lambda$) are only specified in tens of degrees.

5.3.2 For calls to ships having a common interest, the signals with symbol numbers corresponding to the identification assigned to that group and in accordance with § 5.2.1 or § 5.2.2 above.

5.4 The "category" information following the address determines the end of the address part.

6. Category

6.1 The "category" information is coded as shown in Table III and defines:

6.1.1 the degree of priority of the call sequence, and

6.1.2 whether the following self-identification address is in numerical or alphanumerical form.

7. Self-identification

7.1 Self-identification may be:

7.1.1 a numerical identification assigned to the calling station, coded as indicated in § 5.2.1, or

7.1.2 an alphanumerical identification of the calling station, coded as indicated in § 5.2.2.

7.2 The indication of the end of the "self-identification" information is constituted by:

7.2.1 the beginning of the "nature of distress" message in the case of a "distress call";

7.2.2 the beginning of the "telecommand" message in the case of other types of calls.

8. Messages

8.1 For a "distress call", the distress information is contained in two or three messages in the following order:

8.1.1 a "nature of distress" message, coded as shown in Table VII;

8.1.2 a "distress coordinates" message, consisting of ten digits coded on the principle described in § 1.5.1.1, in pairs, starting from the first and the second digits.

8.1.2.1 The first digit indicates the quadrant in which the incident has occurred, as follows:

8.1.2.1.1 quadrant NE is indicated by the digit "0",

8.1.2.1.2 quadrant NW is indicated by the digit "1",

8.1.2.1.3 quadrant SE is indicated by the digit "2",

8.1.2.1.4 quadrant SW is indicated by the digit "3".

8.1.2.2 The next five figures indicate the longitude in degrees and minutes.

8.1.2.3 The next four figures indicate the latitude in degrees and minutes.

8.1.2.4 If "distress coordinates" cannot be included, the 10 digits following the "nature of distress" should be automatically transmitted as the digit 9 repeated 10 times.

8.1.3 The time indication consisting of four digits coded on the principles described in § 1.5.1.1 and Table IVa starting from the first and second digits in pairs.

8.1.3.1 The first two digits indicate the time in hours.

8.1.3.2 The third and fourth digits indicate the part of the hour in minutes.

8.1.3.3 If the time cannot be included the four time indicating digits should be transmitted automatically as "8 8 8 8".

8.1.4 An optional signal to indicate the type of communication which is preferred by the station in distress for subsequent exchange. This one-character signal is coded as shown in Table Va.

8.2 For other types of calls, message 1 is the "telecommand" information (if used) and consists of one or two signals * coded as follows:

8.2.1 a one-symbol signal to indicate one of the types of communication as shown in Table Va;

8.2.2 if a station is unable to comply it sends back the telecommand signal "104" which may be followed by a second telecommand signal in accordance with Table Vb;

8.2.3 should it be necessary to transmit information in addition to the type of communication or to transmit other telecommand information, a two-symbol signal as shown in Table VI may be used.

8.3 The "frequency or channel information" always consists of three signals, "signal 1", "signal 2" and "signal 3", coded in accordance with Table IVa, indicating the actual frequency (in multiples of 100 Hz) or the channel number (see Table VIII).

8.3.1 *Frequency information*

The actual frequency in multiples of 100 Hz may only be indicated as such when the frequency is below 30 MHz. The three signals provide for the required six decimal digits. Signal 1 represents the units (U) and tens (T) of 100 Hz, signal 2 the hundreds (H) and thousands (M) and signal 3 the tens of thousands (TM) and hundreds of thousands (HM) of 100 Hz.

8.3.2 *Channel information*

8.3.2.1 *HF and MF channels*

If the HM digit is 3, this indicates that the number represented by the digits TM, M, H, T and U is the HF/MF channel number (either single frequency or two frequency channels).

8.3.2.2 *VHF and UHF channels*

If the HM digit is 8, this indicates that the number represented by the values of the digits M, H, T and U is the channel number on which the transmission takes place (own channel number).

If the HM digit is 9, this indicates that the number represented by the values of the digits M, H, T and U is the assigned or proposed VHF/UHF working channel number.

If the HM digit is 8 or 9, the values of the TM digit may be used to indicate up to ten types of VHF/UHF operations in accordance with Table VIII of Annex II to this Recommendation.

Note. – When the frequency message consists of both "receive" and "transmit" frequency or channel information no separator signal shall be used between these two elements.

8.4 Information on the number assigned to the calling station's ARQ equipment should follow the frequency or channel information and should consist of three signals: Signal 1, Signal 2 and Signal 3, coded as shown in Table IVa. As an example, the number 55283 should be coded as 05 52 83.

9. Separator

The "separator" is the unique signal corresponding to symbol number 126 of Table I and is used to separate adjacent messages which are otherwise not distinguishable, i.e., when both adjoining messages are symbols 0 to 99 or both messages are symbols 100 to 124.

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* This may be expanded, if necessary, to a maximum of three signals. The digital selective calling system has the capacity to accommodate transports other than medical transport (symbol 108) requiring protection as the case may be in the future.

10. End of sequence

The "end of sequence" signal is one of the three unique signals corresponding to symbols 117, 122 and 127 as follows:

10.1 Symbol 117 if the call requires acknowledgement (Acknowledge RQ);

10.2 Symbol 122 if the sequence is an answer to a call that requires acknowledgement (Acknowledge BQ);

10.3 Symbol 127 for all other calls.

11. Error check character

The seven information bits of the error-check signal shall be equal to the least significant bit of the modulo-2 sums of the corresponding bits of all information characters (i.e., even vertical parity). The Format Specifier, the Separator and the End of Sequence characters are considered to be information characters. The phasing signals shall not be considered to be information characters. The error check character shall also be sent in the DX and RX positions.

TABLE I – *Ten-unit error-detecting code*

Symbol No.	Emitted signal
0	BBBBBBBYYY
1	YBBBBBBYYB
2	BYBBBBBYYB
3	YYBBBBBYBY
4	BBYBBBBYYB
5	YBYBBBBYBY
6	BYYBBBBYBY
7	YYYBBBBYBB
8	BBBYBBBYYB
9	YBBYBBBYBY
10	BYBYBBBYBY
11	YYBYBBBYBB
12	BBYYBBBYBY
13	YBYYBBBYBB
14	BYYYBBBYBB
15	YYYYBBBBYY
16	BBBBYBBYYB
17	YBBBYBBYBY
18	BYBBYBBYBY
19	YYBBYBBYBB
20	BBYBYBBYBY
21	YBYBYBBYBB
22	BYYBYBBYBB
23	YYYBYBBBYY
24	BBBYYBBYBY
25	YBBYYBBYBB
26	BYBYYBBYBB
27	YYBYYBBBYY
28	BBYYYBBYBB
29	YBYYYBBBYY
30	BYYYYBBBYY
31	YYYYYBBBYB
32	BBBBBYBYYB
33	YBBBBYBYBY
34	BYBBBYBYBY
35	YYBBBYBYBB
36	BBYBBYBYBY
37	YBYBBYBYBB
38	BYYBBYBYBB
39	YYYBBYBBYY
40	BBBYBYBYBY
41	YBBYBYBYBB
42	BYBYBYBYBB
43	YYBYBYBBYY
44	BBYYBYBYBB
45	YBYYBYBBYY
46	BYYYBYBBYY
47	YYYYBYBBYB
48	BBBBYYBYBY
49	YBBBYYBYBB
50	BYBBYYBYBB
51	YYBBYYBBYY
52	BBYBYYBYBB
53	YBYBYYBBYY
54	BYYBYYBBYY
55	YYYBYYBBYB
56	BBBYYYBYBB
57	YBBYYYBBYY
58	BYBYYYBBYY
59	YYBYYYBBYB
60	BBYYYYBBYY
61	YBYYYYBBYB
62	BYYYYYBBYB
63	YYYYYYBBBY
64	BBBBBBYYYB
65	YBBBBBYYBY
66	BYBBBBYYBY
67	YYBBBBYYBB
68	BBYBBBYYBY
69	YBYBBBYYBB
70	BYYBBBYYBB
71	YYYBBBYBYY
72	BBBYBBYYBY
73	YBBYBBYYBB
74	BYBYBBYYBB
75	YYBYBBYBYY
76	BBYYBBYYBB
77	YBYYBBYBYY
78	BYYYBBYBYY
79	YYYYBBYBYB
80	BBBBYBYYBY
81	YBBBYBYYBB
82	BYBBYBYYBB
83	YYBBYBYBYY
84	BBYBYBYYBB
85	YBYBYBYBYY
86	BYYBYBYBYY
87	YYYBYBYBYB
88	BBBYYBYYBB
89	YBBYYBYBYY
90	BYBYYBYBYY
91	YYBYYBYBYB
92	BBYYYBYBYY
93	YBYYYBYBYB
94	BYYYYBYBYB
95	YYYYYBYBBY
96	BBBBBYYYBY
97	YBBBBYYYBB
98	BYBBBYYYBB
99	YYBBBYYBYY
100	BBYBBYYYBB
101	YBYBBYYBYY
102	BYYBBYYBYY
103	YYYBBYYBYB
104	BBBYBYYYBB
105	YBBYBYYBYY
106	BYBYBYYBYY
107	YYBYBYYBYB
108	BBYYBYYBYY
109	YBYYBYYBYB
110	BYYYBYYBYB
111	YYYYBYYBBY
112	BBBBYYYYBB
113	YBBBYYYBYY
114	BYBBYYYBYY
115	YYBBYYYBYB
116	BBYBYYYBYY
117	YBYBYYYBYB
118	BYYBYYYBYB
119	YYYBYYYBBY
120	BBBYYYYBYY
121	YBBYYYYBYB
122	BYBYYYYBYB
123	YYBYYYYBBY
124	BBYYYYYBYB
125	YBYYYYYBBY
126	BYYYYYYBBY
127	YYYYYYYBBB

B = 0
Y = 1

TABLE II – *Format specifier*

Format	Symbol No.	Bit number 1	2	3	4	5	6	7	8	9	10
Distress call	112	0	0	0	0	1	1	1	1	0	0
	113	1	0	0	0	1	1	1	0	1	1
All ships call	116	0	0	1	0	1	1	1	0	1	1
Marking sequence	110	0	1	1	1	0	1	1	0	1	0
Selective calls to:											
Individual stations	120	0	0	0	1	1	1	1	0	1	1
	121	1	0	0	1	1	1	1	0	1	0
Ships in a particular geographic area	102	0	1	1	0	0	1	1	0	1	1
Ships having a common interest	114	0	1	0	0	1	1	1	0	1	1
	115	1	1	0	0	1	1	1	0	1	0
Signalling in automated VHF/UHF service	124	0	0	1	1	1	1	1	0	1	0

Numerical format = 0
Alphanumerical format = 1

Call sequence specifier

TABLE III – *Category*

Category	Symbol No.	Bit number 1	2	3	4	5	6	7	8	9	10
Safety related:											
Distress	112	0	0	0	0	1	1	1	1	0	0
	113	1	0	0	0	1	1	1	0	1	1
Urgency	110	0	1	1	1	0	1	1	0	1	0
	111	1	1	1	1	0	1	1	0	0	1
Vital safety	108	0	0	1	1	0	1	1	0	1	1
	109	1	0	1	1	0	1	1	0	1	0
Important safety	102	0	1	1	0	0	1	1	0	1	1
	103	1	1	1	0	0	1	1	0	1	0
Others:											
Ships business priority	106	0	1	0	1	0	1	1	0	1	1
	107	1	1	0	1	0	1	1	0	1	0
Routine	100	0	0	1	0	0	1	1	1	0	0
	101	1	0	1	0	0	1	1	0	1	1

Numerical format = 0
Alphanumerical format = 1

TABLE IVa – *Packing table for decimal numbers into ten-unit signals*

The digits for the									
Thousands of millions D2	Hundreds of millions D1	Tens of millions D2	Millions D1	Hundreds of thousands D2	Tens of thousands D1	Thousands D2	Hundreds D1	Tens D2	Units D1
Signal 5		Signal 4		Signal 3		Signal 2		Signal 1	

The digit sequence D2-D1 varies from 00 to 99 inclusive in each signal (signal 1 to 5 inclusive). The signal that represents a particular two-decimal figure is transmitted as the symbol number (see Table I) that is identical to that particular two-decimal figure. Signal 1 is the last signal transmitted.

When the number consists of an odd number of decimal digits, a zero shall be added in front of the most significant position to provide an integral number of ten-unit signals.

TABLE IVb – *Table of conversion for figures and letters in alphanumerical address and self-identification information*

Figures	Symbol No. (1)	Letters	Symbol No. (1)	Letters	Symbol No. (1)
0	48	A	65	N	78
1	49	B	66	O	79
2	50	C	67	P	80
3	51	D	68	Q	81
4	52	E	69	R	82
5	53	F	70	S	83
6	54	G	71	T	84
7	55	H	72	U	85
8	56	I	73	V	86
9	57	J	74	W	87
		K	75	X	88
		L	76	Y	89
		M	77	Z	90

(1) See Table I.

TABLE Va – *One-symbol telecommand signal*

Symbol No. (1)	Mode of operation	Class of emission	Additional equipment	Terminal equipment
100	Simplex	G3E		Telephone
101	Duplex	G3E		Telephone
105	Transceive	J3E	Lincompex	Telephone
106	Duplex			Data
107	Transceive	R3E	Lincompex	Telephone
109	Transceive	J3E		Telephone
111	Transceive	R3E		Telephone
113	Receive	F1B	(2)	Teleprinter ARQ
114	Transmit	F1B	(2)	Teleprinter ARQ
115	Transceive	F1B	(2)	Teleprinter ARQ
116	Receive	F1B		Teleprinter
118	Transmit	F1B		Teleprinter
119	Transceive	F1B		Teleprinter
120	Receive	A1A		Morse, tape recorder
123	Transceive	A1A		Morse
124	Receive	F1C, F2C, F3C		Phototelegraphy

(1) Symbol 102 is a reserve combination. Symbols 117, 122, 125, 126 and 127 should not be used.

(2) Equipment to increase transmission reliability, such as defined in draft Recommendation 476.

Symbol No.	Telecommand
103	Polling
104	Unable to comply
108	Medical transport
110	Distress acknowledgement
112	Distress relay
121	Ship's position or location register updating

TABLE Vb – *Second telecommand signal when the first telecommand signal is "Unable to comply"*

100	No reason given
101	Congestion at the Maritime Switching Centre
102	Busy
103	Queue indication, the queue number Q_1, Q_2 may follow
104	Station barred
105	No operator available
106	Operator temporarily unavailable
107	Equipment disabled
108	Unable to use proposed channel
109	Reserve

TABLE VI – *Two-symbol telecommand signal*

Symbol No. of first telecommand character \ Symbol No. of second telecommand character	100	101	102	103	.	.	.	.	120	121	123	124
100												
101												
102												
103												
.												
.												
120												
121												
123												
124												

Note 1. – The assignment of specific functions is to be determined at a later date.

Note 2. – Symbols 117, 122, 125, 126 and 127 should not be used.

TABLE VII – *Nature of distress*

Nature of distress	Symbol No.
Fire, explosion	100
Flooding	101
Collision	102
Grounding	103
Listing, in danger of capsizing	104
Sinking	105
Disabled and adrift	106
Undesignated distress	107
EPIRB emission	112

Note. – Symbols 117, 122, 125, 126 and 127 should not be used for future expansion of this table.

TABLE VIII – *Frequency or channel information*

Frequency	0 1 2	X X X	X X X	X X X	X X X	X X X	The frequency in multiples of 100 Hz as indicated by the figures for the digits HM, TM, M, H, T, U.
Channels	3	X	X	X	X	X	The HF/MF channel number indicated by the values of the digits TM, M, H, T and U.
	8	X(1)	X	X	X	X	The VHF/UHF own channel number indicated by the values of the digits M, H, T and U.
	9	X(2)	X	X	X	X	The VHF/UHF assigned channel number indicated by the values of the digits M, H, T and U.
	HM TM		M H		T U		
	Signal 3		Signal 2		Signal 1		

Note. – Signal I is the last signal transmitted.

(1) May be used for power level control.

(2) Used in automated VHF/UHF services.

TABLE IX – *Use of symbol 100 to 127*

Symbol No.	Phasing and unique functions	Format specifier	Category	Nature of distress	Telecommand	Remarks
100			N, AN: Routine	Fire, explosion	Simplex G3E (TP)	Request (from coast station): combination of 103 and Ack. RQ (117) Reply (from ship station): combination of 103 and Ack. BQ (122)
101				Flooding	Duplex G3E (TP)	
102		Geographical area	N, AN: Important safety	Collision	*	
103				Grounding	Polling	
104	Phasing RX-0 position			Listing, in danger of capsizing	Unable to comply	
105	Phasing RX-1 position			Sinking	Transceive J3E (LCPX, TP)	
106	Phasing RX-2 position		N, AN: Ship business priority	Disabled and adrift	Data transmission services	
107	Phasing RX-3 position			Undesignated distress	Transceive R3E (LCPX, TP)	
108	Phasing RX-4 position		N, AN: Vital safety		Medical transport	
109	Phasing RX-5 position				Transceive J3E (TP)	
110	Phasing** RX-6 position	Marking sequence in VHF/UHF service	N, AN: Urgency		Distress Acknowledgement	
111	Phasing** RX-7 position				Transceive R3E (TP)	
112		N, AN: Distress	N, AN: Distress	EPIRB emission	Distress relay	
113					Receive F1B (TTY-ARQ)	
114		N, AN: Ships having common interest			Transmit F1B (TTY-ARQ)	
115					Transceive F1B (TTY-ARQ)	
116		All ships			Receive F1B (TTY)	
117	Ack. RQ (EOS)					Request (from coast station): combination of 121 and Ack. RQ (117) Reply (from ship station): combination of 121 and Ack. BQ (122) Registration (from ship station): combination of 121 and EOS (127)
118					Transmit F1B (TTY)	
119					Transceive F1B (TTY)	
120		N, AN: Individual stations			Receive A1A (Morse TR)	
121					Ship's position or location register updating	
122	Ack. BQ (EOS)					
123					Transceive A1A (Morse TR)	
124		Signalling sequence in VHF/UHF service			Receive F1C, F2C, F3C (Photo)	
125	Phasing DX position					
126	Separator					
127	EOS					

AN: alphanumerical format
N: numerical format
*: reserve
**: if required
LCPX: Lincompex
TP: telephone
TR: tape recorder
TTY: direct printing
ARQ: Rec. 476 equipment
EPIRB: emergency position-indicating radiobeacons
Photo: phototelegraphy
EOS: end of sequence

TABLE X – *Call sequences of "distress call" and "all ships call"*

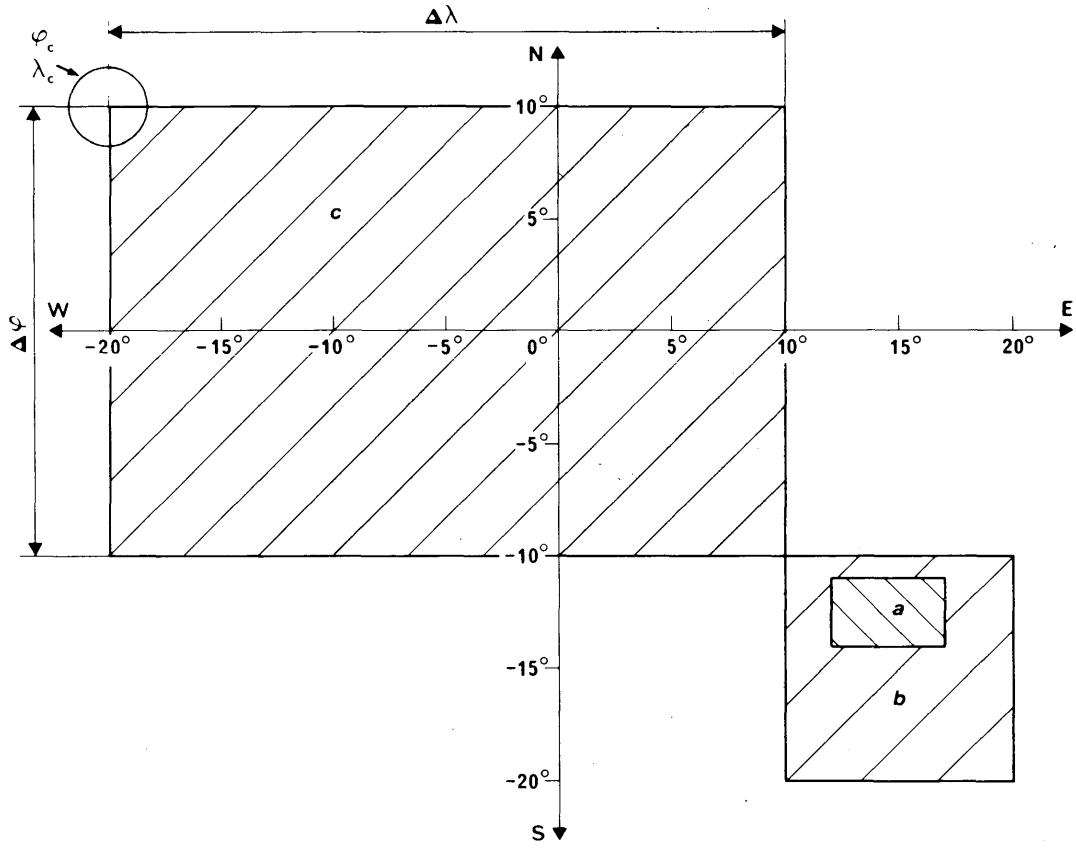
(1) Format specifier	(*n*) Address	(1) Category	(*n*) Self-identification	Message			(1) EOS	(1) ECC
				1	2	3--------*n**		
Distress call 112/113	———	———	N/AN 00--------99	(1) Nature of distress 100--------124	(5) Distress coordinates 00--------99	See § 6.1.5 of Annex I	127	ECC**
All ships call 116	———	Distress 112/113 Urgency 110/111 Vital Safety 108/109 Important Safety 102/103	N/AN 00--------99	(1-2) Telecommand 100--------124 except 117 and 122	(3-6) Frequency or channel 00--------99	See § 6.4 of Annex I	Ack. RQ 117 or Ack. BQ 122 or EOS 127	ECC

* See § 9 ("Separator") of Annex II.
** When the "Nature of distress" is "EPIRB emission", the call sequence does not have ECC.
(): Number of characters.
ECC: Error check character.
EOS: End of sequence.

TABLE XI – *Call sequences of selective calls*

(1) Format specifier	(*n*) Address	(1) Category	(*n*) Self-identification	Message			(1) EOS	(1) ECC
				1	2	3--------*n***		
Geographical area call 102	N*/AN 00--------99	Distress 112/113	N/AN 00--------99	(1-2)	(3-6)	see § 6.4 of Annex I	Ack. RQ 117 or Ack. BQ 122 or EOS 127	ECC
Ships having common interest call 114/115	see § 5.3 of Annex II	Urgency 110/111		Telecommand 100--------124 except 117 and 122	Frequency or channel 00--------99			
Individual call 120/121		Vital safety 108/109						
		Important safety 102/103						
		Ship business priority 106/107						
		Routine 100/101						

* When the format specifier is "Geographical area" (102), the address is numerical format only.
** See § 9 ("Separator") of Annex II.
(): Number of characters.
ECC: Error check character.
EOS: End of sequence.



(a) $\lambda_a = +12^\circ$ (East) $\varphi_a = -11^\circ$ (South) $\Delta\lambda_a = 5^\circ$ $\Delta\varphi_a = 3^\circ$

Format specifier	3	5	2	0	1	1	1	2	Category
	$\Delta\varphi_a$		$\Delta\lambda_a$	Sector					

λ_a
φ_a

(b) $\lambda_b = +10^\circ$ (East) $\varphi_b = -10^\circ$ (South) $\Delta\lambda_b = 10^\circ$ $\Delta\varphi_b = 10^\circ$

Format specifier	1	1	2	0	1	1	Category
	$\Delta\varphi_b$		$\Delta\lambda_b$	Sector			

λ_b
φ_b

(c) $\lambda_c = -20^\circ$ (West) $\varphi_c = +10^\circ$ (North) $\Delta\lambda_c = 30^\circ$ $\Delta\varphi_c = 20^\circ$

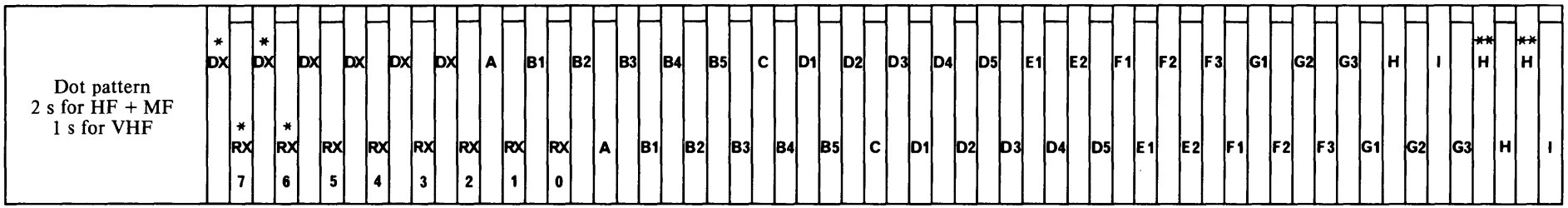
Format specifier	2	3	1	0	1	2	Category
	$\Delta\varphi_c$		$\Delta\lambda_c$	Sector			

λ_c
φ_c

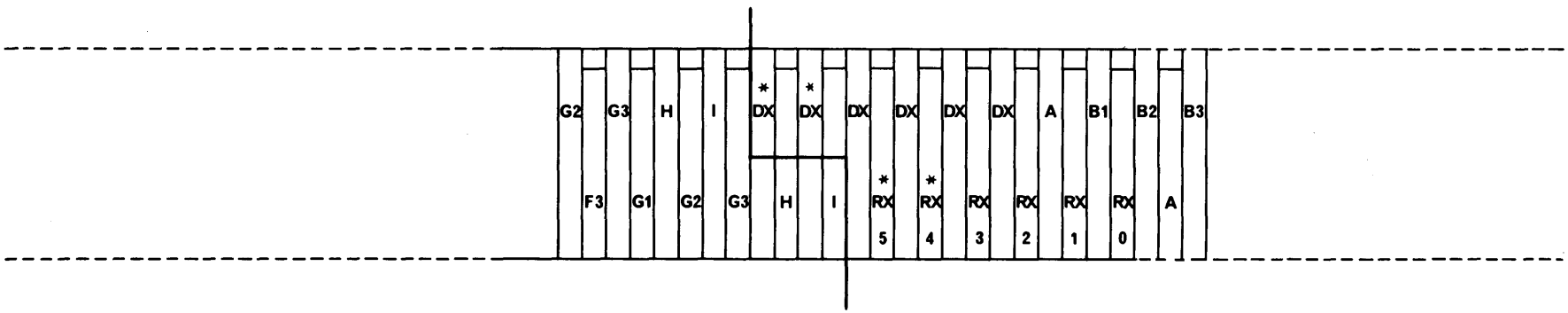
FIGURE 2 – *Geographic coordinates*

Dot pattern	DX/RX Phasing sequence	A Format specifier 1 symbol	B Called party address 5 symbols	C Category 1 symbol	D Self identification 5 symbols	E Telecommand message 2 symbols	F Frequency message Element 1	G Frequency message Element 2	H End of sequence 1 symbol	I Error check character 1 symbol

a) Technical format of a typical routine message



b) Transmission sequence corresponding to Fig. 3a



c) Transmission sequence for repetition of a call to the same address according to § 8.1.1 of Annex I

FIGURE 3 – *Construction of call sequence*

* The first two DX/RX pairs are deleted if a four-pair phasing-sequence is used.
** In these DX positions, any signals excluding symbol 125 may be transmitted.

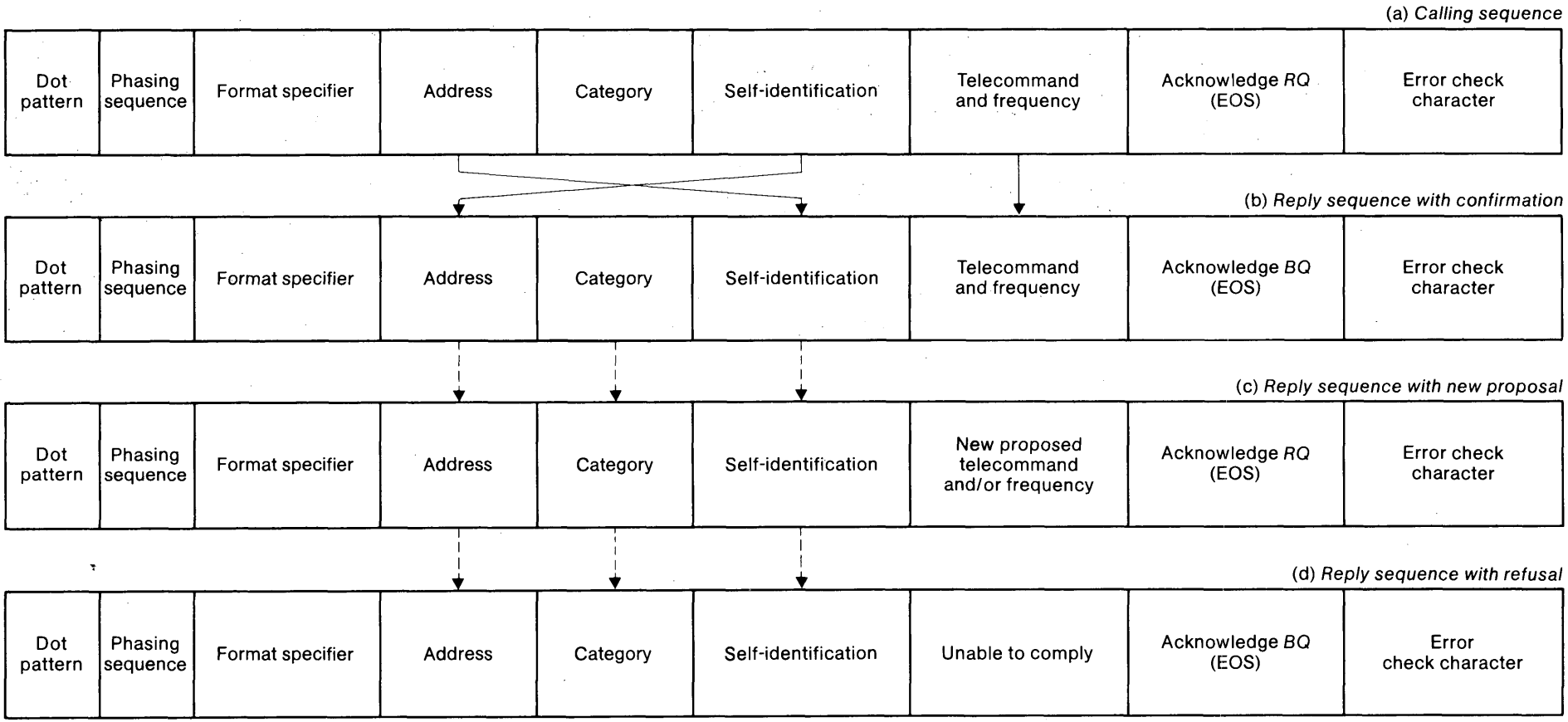


FIGURE 4 – *Examples of a calling sequence and reply sequences for typical individual calls*

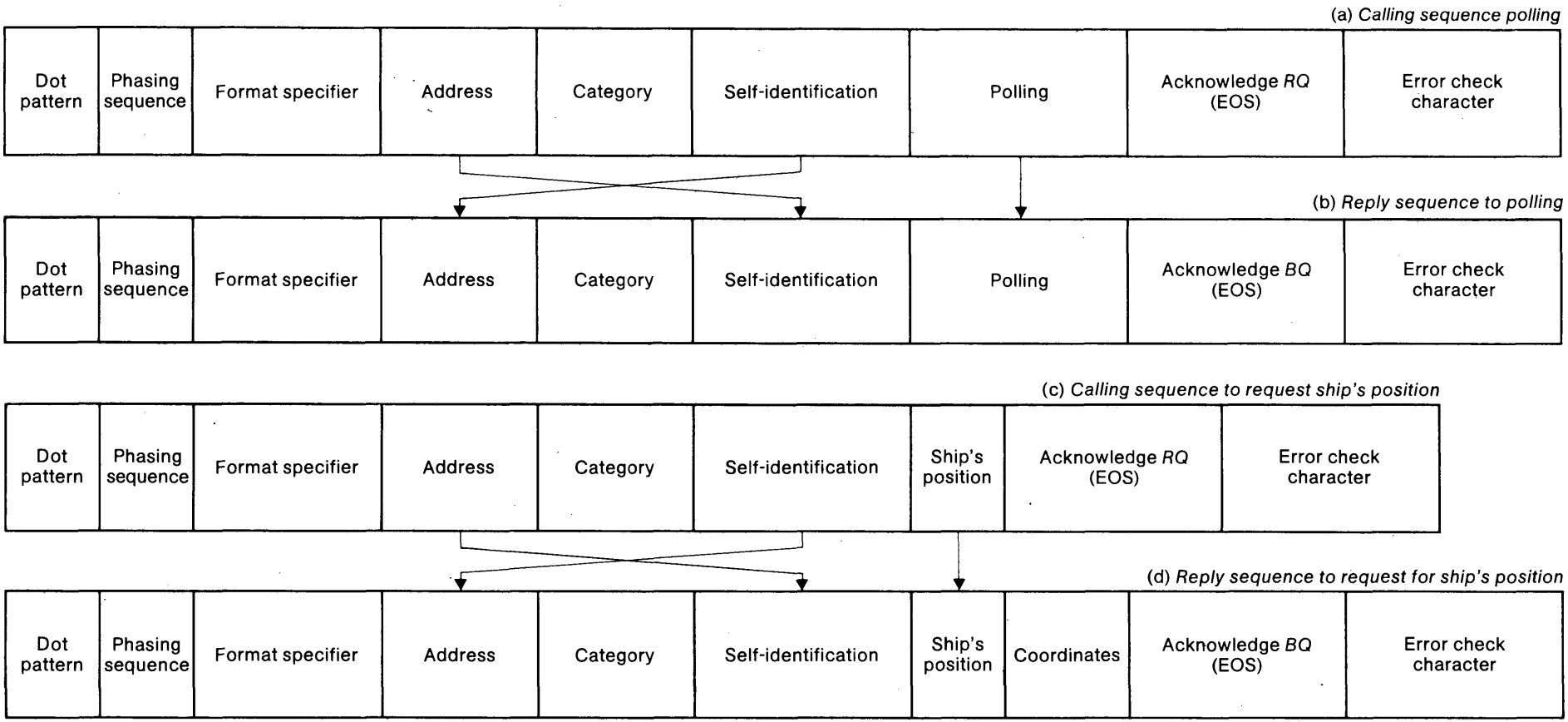


FIGURE 5 – *Calling sequences and reply sequences for polling and ship's position*

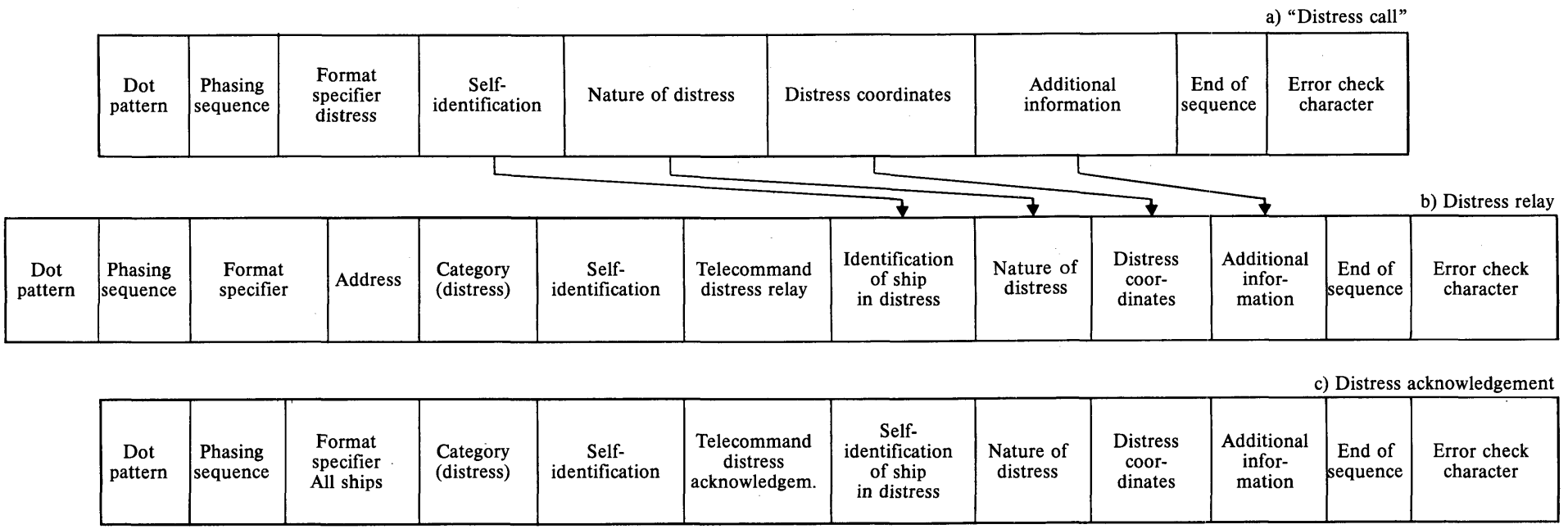


FIGURE 6 – *Sequences of "distress call", distress relay call and distress acknowledgement*

RECOMMENDATION 541-1 *

OPERATIONAL PROCEDURES FOR THE USE OF DIGITAL SELECTIVE-CALLING (DSC) EQUIPMENT IN THE MARITIME MOBILE SERVICE

(Question 9/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that provisions for digital selective-calling (DSC) have been set out in Articles 60 and 62 of the Radio Regulations;

(b) Resolution No. 311 and Recommendation No. 312 of the World Administrative Radio Conference, Geneva, 1979;

(c) that digital selective-calling will be used as described in Recommendation 493;

(d) that the requirements of the Future Global Maritime Distress and Safety System (IMCO, 1980) are based on the use of digital selective-calling for distress alerting on terrestrial frequencies and that operational procedures are necessary for transition to, and implementation of that system;

(e) that, as far as is practicable, operational procedures in all frequency bands and for all types of communications should be similar;

(f) that digital selective-calling may provide a useful supplementary means of transmitting a distress call in addition to the provisions of transmitting the distress call by existing methods and procedures in the Radio Regulations;

(g) that conditions when alarms have to be actuated should be specified,

UNANIMOUSLY RECOMMENDS

1. that the digital selective-calling system having technical and operational characteristics in accordance with Recommendation 493 should be used in the maritime mobile service;

2. that the operational procedures to be observed in the MF, HF and VHF bands for DSC calling should be in accordance with Annex I for distress and safety calls and Annex II for other calls;

3. that provisions should be made at stations equipped for DSC for:

3.1 the manual entry of address, type of call, category and various messages into a DSC sequence;

3.2 the verification and if necessary the correction of such manually formed sequences;

3.3 a specific aural alarm and visual indicator to indicate receipt of a distress call or a call with distress category. It should not be possible to disable this alarm. Provisions should be made for it to be reset manually;

3.4 an aural alarm and visual indicator to indicate the receipt of an "urgency" or "vital safety" call. The aural alarm may be capable of being disabled;

3.5 aural alarms and visual indicators for calls other than distress, urgency and vital safety. The aural alarm may be capable of being disabled;

3.6 such visual indicators to indicate:

3.6.1 type of received call address (to all stations, to a group of stations, geographical, individual);

3.6.2 category;

3.6.3 identity of calling station;

3.6.4 numerical or alphanumerical type of information, e.g. frequency information and telecommand;

3.6.5 type of "end of sequence" character;

3.6.6 detection of errors, if any;

---

* The Director, CCIR, is requested to bring this Recommendation to the attention of IMCO.

4. that the equipment should be simple to operate.

Note. – The following definitions are used throughout this Recommendation:

a) single frequency: the same frequency is used for transmission and reception;

b) paired frequencies: frequencies which are associated in pairs; each pair consisting of one transmitting and one receiving frequency;

c) international DSC frequencies: those frequencies designated in the Radio Regulations for exclusive use for DSC on an international basis;

d) national DSC frequencies: those frequencies assigned to individual coast stations or group of stations on which DSC calling is permitted (this may include working frequencies as well as calling frequencies). The use of these frequencies must be in accordance with the Radio Regulations.

e) automatic DSC operation at a ship station: a mode of operation employing automatic tunable transmitters, suitable for unattended operation which provide for automatic call acknowledgements upon reception of a DSC;

f) call attempt: one or a limited number of call sequences directed to the same station on one or more frequencies and within a relatively short time period (e.g. a few minutes). A call attempt is considered unsuccessful if no acknowledgement is received in this time interval.

ANNEX I

PROVISIONS AND PROCEDURES FOR DISTRESS AND SAFETY CALLS

1. Introduction

The Future Global Maritime Distress and Safety System proposed by IMCO is based on the use of digital selective-calling (DSC) for distress alerting in accordance with the requirements of Annex I to Report 747.

2. DSC distress call and message

The DSC "distress call" provides for alerting, self-identification, ship's position including time, nature of distress and contains both the distress call (No. 3091 and 3092) and the distress message (No. 3093 and 3094) as defined in the Radio Regulations.

3. Procedures for DSC distress calls

3.1 *Transmission by a mobile unit in distress*

3.1.1 The DSC equipment should be capable of being preset to transmit the distress call on at least one distress alerting frequency.

3.1.2 The distress call shall be composed in accordance with Recommendation 493; the ship's position information, the time at which it was taken and the nature of distress should be entered as appropriate. If the position of the ship cannot be entered, then the position information signals shall be transmitted automatically as the digit 9 repeated ten times. If the time cannot be included, then the time information signals shall be transmitted automatically as the digit 8 repeated four times.

3.1.3 A distress call attempt shall consist of five consecutive distress calls on the same frequency. Where no acknowledgement to a distress call attempt is received after an interval of 3 min, the attempt should be repeated on the same, or other, distress alerting frequencies. Once initiated, the transmission of a distress call attempt, its repetitions and any changes of frequency, should preferably be achieved by automatic means. However it should be possible to manually override the 3 min period. Transmissions of the distress call should terminate when an acknowledgement is received or when the equipment is reset manually.

3.1.4 In the case of distress the operator should:

3.1.4.1 if time permits, enter the ship's position and time * it was taken and the nature of distress *;

3.1.4.2 select the distress frequency(ies) to be used *;

3.1.4.3 activate the "distress call" attempt by a simple action.

* If these are not provided automatically.

3.2 *Reception*

The DSC equipment should be capable of:

3.2.1 maintaining a reliable watch on a 24 h basis on appropriate DSC distress alerting frequencies; and

3.2.2 activating an audible and visual alarm on receipt of a distress call.

3.3 *Acknowledgement of distress calls*

3.3.1 Acknowledgements of DSC distress calls should be initiated manually.

3.3.2 The acknowledgement of a distress call shall be transmitted on the distress alerting frequency on which the call was received and should be addressed to "all ships". The acknowledgement shall include the identification (see Recommendation 493) of the ship whose distress call is being acknowledged.

3.3.3 Distress calls should normally be acknowledged by DSC only by appropriate coast stations. Coast stations should, in addition, set watch on the appropriate radiotelephone distress and safety traffic frequency(ies).

3.3.4 Ship stations should, on receipt of a distress call, set watch on an appropriate radiotelephone distress and safety traffic frequency and acknowledge the call by radiotelephony. If a ship station continues to receive a DSC distress call on an MF or VHF channel, a DSC acknowledgement should be transmitted to terminate the call.

3.4 *Distress relays*

3.4.1 A distress relay call should use the telecommand signal "distress relay" in accordance with Recommendation 493 and the calling attempt should follow the procedure described in § 3.1.3 above for distress calls.

3.4.2 Any ship, receiving a distress call on an HF channel which is not acknowledged by a coast station within 5 min, should transmit a distress relay call to the appropriate coast station.

3.4.3 Acknowledgement of distress relay calls should be sent by radiotelephony on an appropriate distress and safety traffic frequency.

4. Procedures for DSC urgency and safety calls *

4.1 DSC, on the distress and safety calling frequencies, should be used to advise shipping on the impending transmission of urgency, vital navigational and safety messages, except when the transmissions take place at routine times. Where the subsequent transmission of an urgency, vital navigational or safety message takes place on a working frequency, the call should indicate the frequency which will be used.

4.2 The announcement and identification of medical transports should be carried out by digital selective calling techniques, using appropriate distress and safety calling frequencies. Such calls should use the category "urgency", and telecommand "medical transport" and be addressed to "all ships".

ANNEX II

PROVISIONS AND PROCEDURES FOR CALLS OTHER THAN DISTRESS AND SAFETY

1. Frequency/channels

1.1 Only paired frequencies should be used.

1.2 *International calling*

The paired frequencies listed in Appendix 31 and Article 62 should be used for international DSC calling.

1.2.1 International DSC frequencies should only be used for shore-to-ship calls and for the associated call acknowledgements from ships fitted for automatic DSC operation where it is known that the ships concerned are not listening to the coast station's national frequencies.

* Use of the DSC distress and safety calling frequencies for urgency and safety calls is acceptable, technically, provided that the total channel loading is maintained below 0.1 erlang.

1.2.2 All ship-to-shore DSC calling should be done on the coast station's national frequencies.

1.3 *National calling*

Coast stations should avoid using the international DSC frequencies for calls that may be placed using national frequencies. National DSC frequencies are foreseen to be assigned by the Mobile WARC in 1988.

1.3.1 Ship stations should keep watch on appropriate national and international channels. (Appropriate measures should be taken for an even loading of national and international channels.)

1.3.2 Administrations are urged to find methods and negotiate terms to improve the utilization of the DSC channels available, e.g.:

- coordinated and/or joint use of coast station transmitters;
- optimizing the probability of successful calls by providing information to ships on suitable frequencies (channels) to be watched and by information from ships to a selected number of coast stations on the channels watched on-board.

2. Operating procedures

A typical DSC calling and acknowledgement sequence contains the following signals (see Recommendation 493).

Composition of a typical DSC calling and acknowledgement sequence

Signal	*Method of composition*
– format specifier	selected
– address	entered
– category	selected
– self-identification	pre-programmed
– telecommand information	selected
– frequency information (if appropriate)	entered
– end of sequence signal	selected *

The method of composing a DSC sequence is illustrated in the flow diagram of Fig. 5.

2.1 *Coast station initiates call to ship*

Figures 1 and 2 illustrate the procedures below in flow chart and by time sequence diagram respectively.

2.1.1 There are two categories of calls for commercial communications:

(a) Routine call;

(b) Ship Business Priority call. (The category of the call does not affect the procedures at the coast station but only affects the method of operation on board the ship.)

2.1.2 If a direct connection exists between the calling subscriber and the coast station, the coast station asks the calling subscriber for the approximate position of ship.

2.1.3 If the ship's position cannot be indicated by the caller, the coast station operator tries to find the location in the information available at the coast station.

2.1.4 The coast station checks to see whether the call would be more appropriate through another coast station (see § 1.3.2).

2.1.5 The coast station checks to see whether transmission of a digital selective call is inappropriate or restricted (e.g. ship not fitted with DSC or barred).

2.1.6 Assuming a DSC is appropriate the coast station composes the calling sequence as follows:

- selects format specifier;
- enters address of the ship;
- selects category;
- selects telecommand information;
- inserts working frequency information in the message part of the sequence, if appropriate;

* If the calling sequence EOS signal incorporates a request for acknowledgement "RQ" (117) an acknowledgement is mandatory and shall incorporate the EOS signal "BQ" (122).

– usually selects "end of sequence" signal "RQ". However, if the coast station knows that the ship station cannot respond or the call is to a group of ships the frequency is omitted and the end of sequence signal should be 127, in which case the following procedures relating to an acknowledgement are not applicable.

2.1.7 The coast station verifies the calling sequence.

2.1.8 The coast station operator selects the calling frequencies which are most suitable for the ship's location. The number of frequencies should be limited to those which may be successful in order to minimize spectrum usage. (Ultimately simultaneous transmission on more than one frequency should only be used in exceptional circumstances.)

2.1.8.1 After checking as far as possible that there are no calls in progress the coast station operator initiates the transmission of the sequence on one of the frequencies selected. Transmission on any one frequency should be limited to no more than 2 call-sequences separated by intervals of at least 45 s in the case of MF and HF and 3 s in the case of VHF to allow for reception of an acknowledgement from the ship.

2.1.8.2 Transmission of the same call sequence on other frequencies if appropriate should be made in turn at suitable intervals and follow the same pattern as in 2.1.8.1.

2.1.9 If an acknowledgement is received further transmission of the call sequence should not take place.

2.1.10 The acknowledgement of the received call should only be transmitted upon receipt of a calling sequence which terminates with an acknowledgement request.

2.1.11 The acknowledgement should indicate whether or not the ship is able to comply immediately with the request.

2.1.12 When a station called does not reply, the call attempt should not normally be repeated until after an interval of at least 30 min. The same call attempt should not be repeated more than five times every 24 h. The aggregate of the times for which frequencies are occupied in one call attempt, should normally not exceed one minute.

The following procedures apply at the ship:

2.1.13 Upon receipt of a calling sequence at the ship station, the received message is recorded and an appropriate indication is activated as to whether the call category is "Routine" or "Ship's Business Priority". The category does not affect the DSC procedures at the ship.

2.1.14 An acknowledgement sequence should be composed in accordance with § 2 and transmitted.

The format specifier and category information should be identical to that in the received calling sequence.

2.1.14.1 If the ship station is not equipped for automatic DSC operation the ship's operator initiates a call to the coast station as soon as possible, using the ship-to-shore calling procedures detailed in 2.2. However the transmitted sequence should contain a "BQ" End of Sequence signal in place of the "RQ" signal.

2.1.14.2 If the ship is equipped for automatic DSC operation, the ship station automatically transmits an acknowledgement with an End of Sequence signal "BQ" on the paired frequency. This acknowledgement should be transmitted after a time interval of 20 ± 0.1 s for MF and HF and 3 ± 0.1 s for VHF following receipt of the complete sequence.

2.1.14.2.1 If the ship is able to comply immediately the acknowledgement sequence should include a telecommand signal which is identical to that received in the calling sequence indicating that it is able to comply.

2.1.14.2.2 If the ship is not able to comply immediately the acknowledgement sequence should include the telecommand signal 104 (unable to comply), with a second telecommand signal giving additional information (see Recommendation 493, Table Vb).

At some later time when the ship is able to accept the traffic being offered, the ship's operator initiates a call to the coast station using the ship-to-shore calling procedures detailed in 2.2.

2.1.15 On receipt of an acknowledgement which indicates ability to comply the DSC procedures are complete and both coast station and ship station should communicate on the working frequencies agreed, with no further exchange of DSC calls.

2.1.16 If the ship station transmits an acknowledgement which is not received at the coast station then there are two possibilities:

2.1.16.1 If the ship station transmits an acknowledgement in accordance with either 2.1.14.1 or 2.1.14.2.1 but is subsequently unsuccessful at establishing communication with the coast station on the working frequency then it should manually repeat the acknowledgement. The number of repetitions should be limited.

2.1.16.2 If the ship station transmits an acknowledgement in accordance with 2.1.14.2.2 which is not received by the coast station then this could result in the coast station repeating the call (in accordance with 2.1.12). In this event the ship station should transmit a new acknowledgement.

2.2 *Ship station initiates call to coast station*

Figures 3 and 4 illustrate the procedures below in flow chart and by time sequence diagram respectively.

This procedure should also be followed both as a delayed response to a call received earlier from the coast station and to initiate traffic from the ship station.

2.2.1 The ship composes the calling sequence as follows:

- selects the format specifier;
- enters address;
- selects the category;
- selects the telecommand information;
- inserts working frequency information in the message part of the sequence if appropriate;
- selects the appropriate "end of sequence" signal; for a ship initiated call this would normally be the acknowledgement request.

2.2.2 The ship verifies the calling sequence.

2.2.3 The ship selects the most appropriate calling frequency.

2.2.4 The ship initiates the transmission of the sequence on the frequency selected after checking as far as possible that there are no calls in progress on that frequency.

2.2.5 If a called coast station does not reply, the call sequence from the ship station should not normally be repeated until after an interval of at least 5 min. After 3 repetitions, further repetition should not be made before 1 h. These repetitions may be made on alternative frequencies.

2.2.6 The coast station should transmit an acknowledgement sequence within 4.5 minutes on the return frequency containing the format specifier, the address of the ship, the category, the coast station self-identification and:

- if able to comply immediately on the working frequency suggested the same telecommand and frequency information as in the call request;

- if not able to comply on the working frequency suggested but able to comply immediately on an alternative frequency, the same telecommand but an alternative working frequency;

- if unable to comply immediately the telecommand signal 104 with a second telecommand signal giving additional information. This second telecommand signal may include information regarding queue number (signal 103 followed by another digit). An alternative working frequency may also be included if necessary.

The appropriate End of Sequence signal should also be included ("BQ" if the ship's calling sequence "RQ" or "127" if the ship's calling sequence contained "BQ").

2.2.7 If an alternative working frequency is proposed in accordance with 2.2.6 but this is not acceptable to the ship station, then the ship station should immediately transmit a call to the coast station indicating (by the use of telecommand signals 104 and 108) that it cannot comply on that frequency.

2.2.8 The coast station should then transmit an acknowledgement in accordance with 2.2.6 either accepting the ship station's original suggested frequency or proposing a second alternative.

2.2.9 On receipt of an acknowledgement which indicates ability to comply the DSC procedures are complete and both coast station and ship station should communicate on the working frequencies agreed with no further exchange of DSC calls.

2.2.10 If the coast station transmits an acknowledgement which is not received at the ship station then the ship station should repeat the call in accordance with 2.2.5. If the establishment of communication on the working frequency is unsuccessful the coast station should repeat the original acknowledgement. The number of repetitions should be strictly limited.

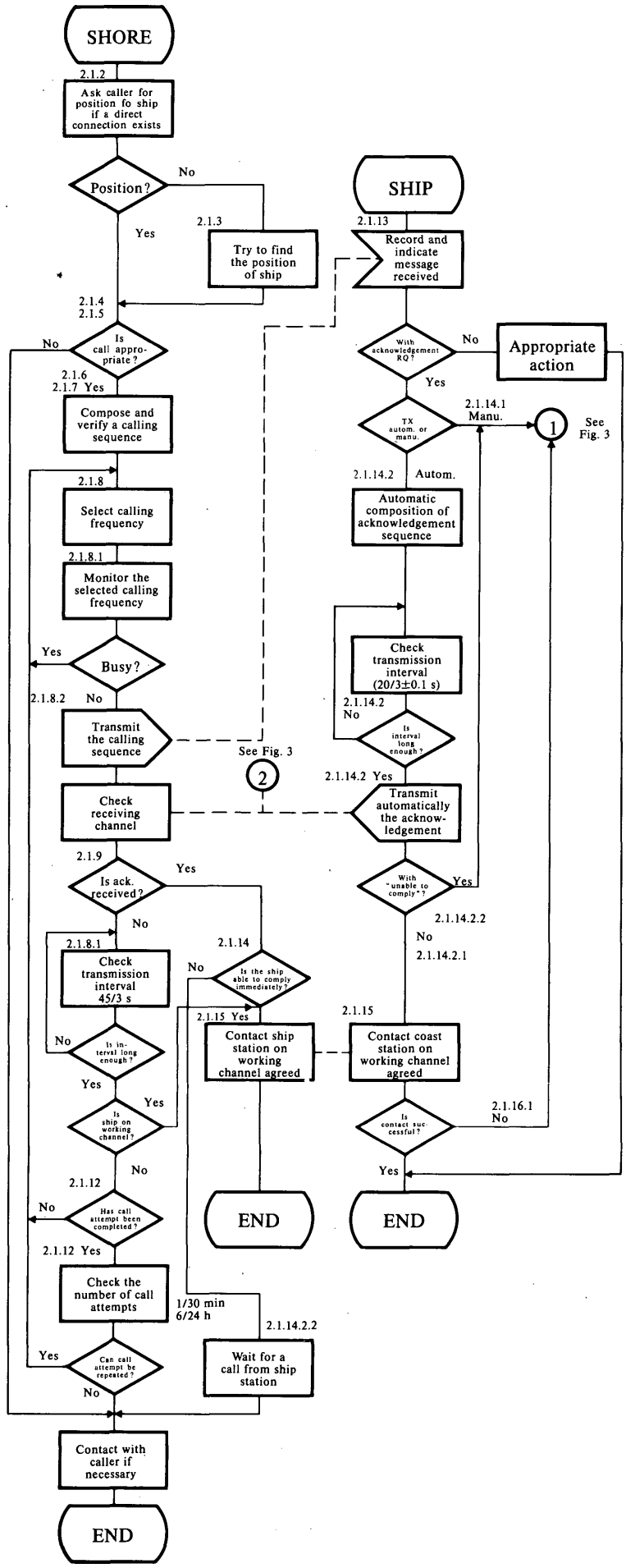


FIGURE 1 – *Flow chart of operational procedures for calling in the shore-to-ship direction*

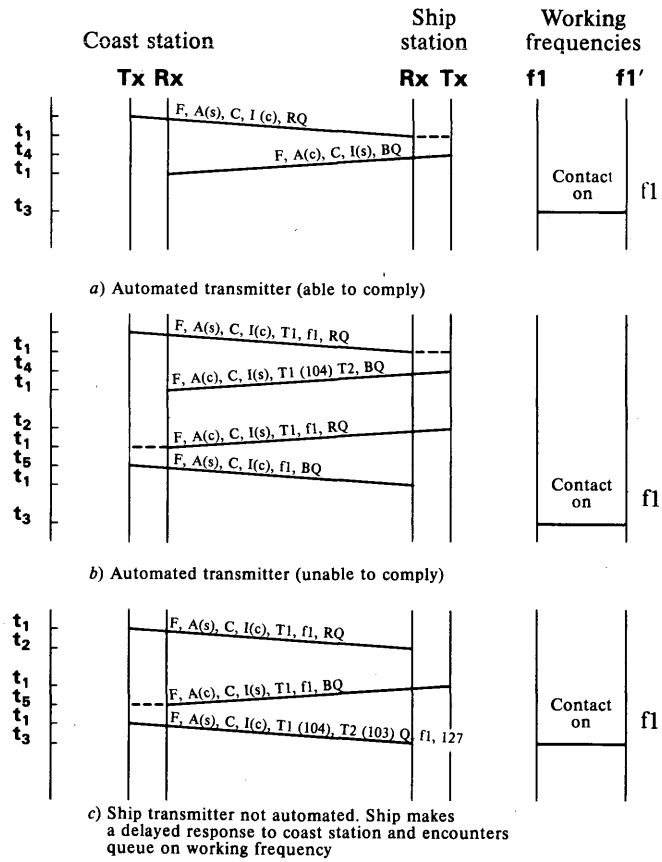


FIGURE 2 – *Examples of timing diagrams for calling in shore-to-ship direction*
(See legend on Figure 4)

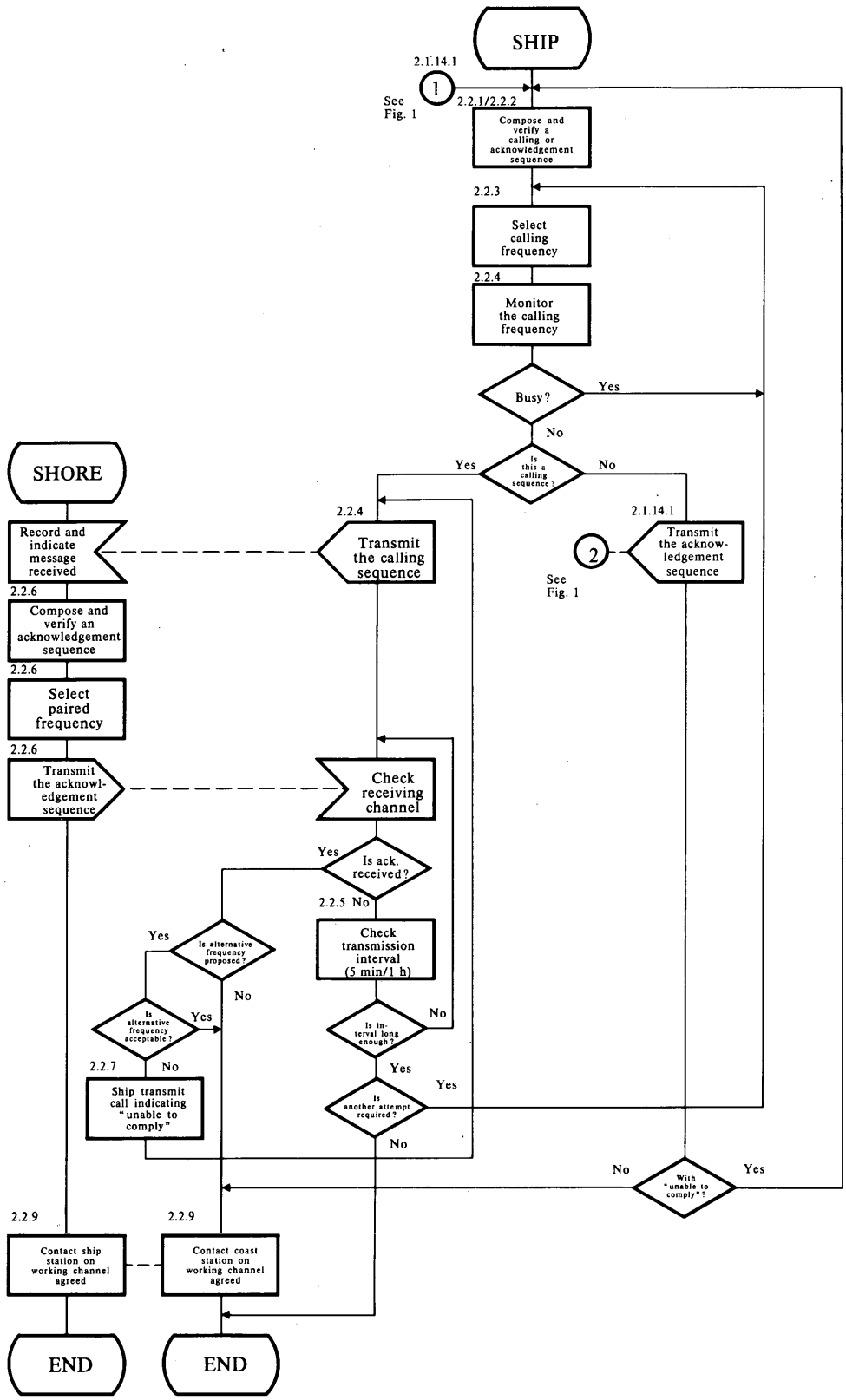
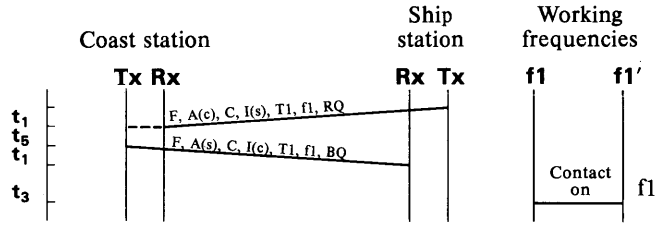
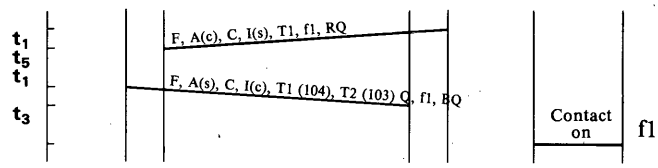


FIGURE 3 – *Flow chart of operational procedures for calling or acknowledgement in the ship-to-shore direction*



a) Able to comply immediately



b) Queue exists on working frequency

FIGURE 4 – *Examples of timing diagrams for calling in ship-to-shore direction*

The following symbols are used in figures 2 and 4:

t_1 : transmission time of a DSC sequence
t_2 : interval between the DSC reception at the ship and transmission from the ship after the operator's appearance in the radio room (from several minutes up to several hours)
t_3 : transition time from calling to working frequency including, if necessary, the time for working channel clearing (queue waiting time)
t_4 : the time needed for ship station radio transmitter tuning
t_5 : time for coast station to prepare acknowledgement
F : format specifier
A : called station address
I : calling station self-identification } suffix (c) or (s) indicate coast station or ship station respectively
C : category
T1 : first telecommand signal, (104) indicates unable to comply
T2 : second telecommand signal, (103) Q indicates queue number
f1, f1' : working frequencies
RQ, BQ, 127: end of sequence signals

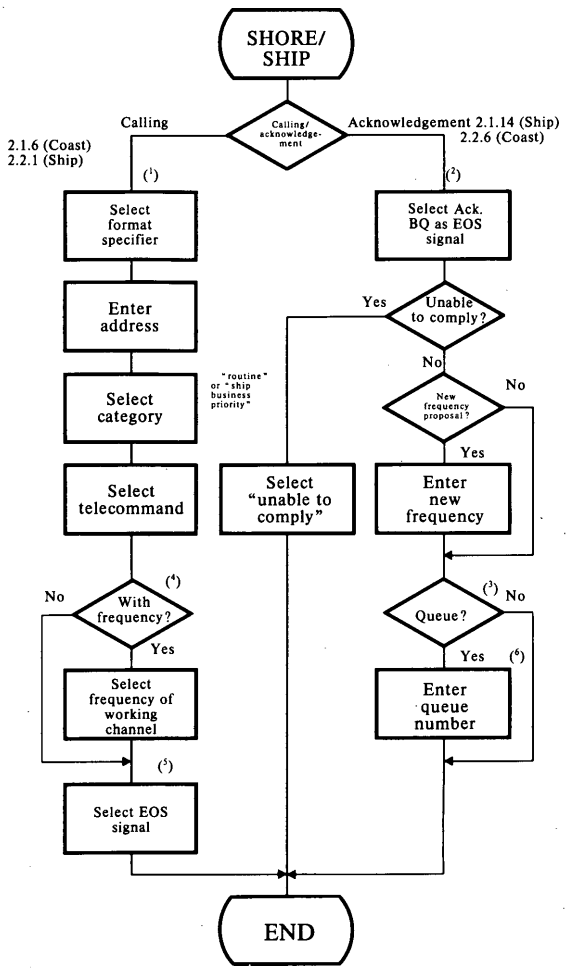


FIGURE 5 – *Composition procedures for calling and acknowledgement sequences*

(1) Normally Ack. RQ may automatically be selected as a EOS signal of individual call by selecting a format specifier.
(2) The format specifier, the category and the frequency information are automatically transferred from the received call. The Self-ID in the received sequence is automatically transferred into the address part of acknowledgement sequence by selecting Ack. BQ.
(3) This procedure is only for coast stations.
(4) If the coast station knows that the ship station cannot respond, the frequency information is omitted.
(5) In the case of note (4), the EOS signal should be symbol number 127. Calls to a group of ships shall not contain an acknowledgement request.
(6) Telecommand symbols T1 (104) and T2 (103) are automatically inserted.

REPORT 501-3 *

DIGITAL SELECTIVE-CALLING SYSTEM FOR FUTURE OPERATIONAL REQUIREMENTS OF THE MARITIME MOBILE SERVICE

(Question 9/8)

(1970-1974-1978-1982)

1. Summary of work

Studies on the subject of a digital selective-calling system to meet the future operational requirements of the maritime mobile service have been carried out since the 1966-69 study period.

The choice of the system is based on theoretical studies and on field tests carried out by the Administrations of the USA, U.S.S.R., Japan and the Netherlands [CCIR, 1974-78].

In order to expedite the study of the digital selective-calling system, Interim Working Party 8/3 was set up in 1975.

Recommendation 493-1 resulted mainly from the work carried out by Interim Working Party 8/3 during the study period 1974-78. It covered both the operational and technical characteristics in detail.

At the Final Meeting of Study Group 8, January 1978, Geneva, Recommendation 493-1 which was modified at the second meeting of Interim Working Party 8/3, held in Stockholm 1977, was considered in detail and adopted with minor amendments.

Initial guidance on operational procedures was considered in Recommendation 541 (Operational procedures) which was prepared at the second meeting of Interim Working Party 8/3 and considered at the Final Meeting of Study Group 8 (1978). It was recognized that these procedures were in general terms only and that the formulation of detailed procedures could not be carried out until practical experience had been gained in the actual operation of the digital selective-calling system.

In accordance with CCIR Resolution 24-4 Interim Working Party 8/8 was set up in 1979 to hasten the development of operational procedures especially in relation to the requirements of a future global distress and safety system which is scheduled for consideration at the World Mobile Administrative Radio Conference in 1983.

Interim Working Party 8/8 subsequently amended Recommendation 541 to include detailed operational procedures for both distress and safety and other services and also considered the number of channels required for the DSC system. The resulting Recommendation 541-1 was adopted at the Final Meeting of Study Group 8 (1981) and Report BY/8 gives a preliminary view on channel requirements. In developing Recommendation 541-1 further modifications to Recommendation 493-1 were required and these were adopted by the Final Meeting of Study Group 8 (1981) and incorporated in Recommendation 493-2.

Interim Working Party 8/8 also agreed that the radio frequency tolerance required for transmitters as well as receivers used in digital selective calling systems should be 10 Hz. (Existing equipment having a tolerance of 40 Hz for ship stations and 15 Hz for coast stations could be used in the initial implementation of the digital selective-calling system).

During an initial period of implementation, a large number of ship transmitters might have greater frequency tolerances (e.g. 100 Hz) in accordance with Appendices 7 and 17 to the Radio Regulations.

To enable ship-borne transmitters with the above frequency tolerances to use, Sweden in a contribution to Interim Working Party 8/8 proposed a receiver with three decoders connected in parallel with a suitable frequency offset and followed by a logical network to select the correct information. This could be one interim solution to facilitate the early introduction of digital selective calling. Laboratory tests in the Federal Republic of Germany confirmed the feasibility of the Swedish proposal. A frequency offset of ± 80 Hz would be required for a frequency tolerance of 100 Hz in the ship transmitter. This solution could be realized for acceptable extra complexity at the coast station.

France also presented a document concerning the 10 Hz tolerance which is recommended for DSC. This document discusses the additional cost to fulfil such a requirement and expresses concern on the maintenance and long-term tolerances of the equipment under these conditions.

2. Future work

2.1 *Radio Regulations*

It was noted that following the introduction of the digital selective-calling system, a number of provisions of the Radio Regulations will have to be reviewed and possibly modified by a competent World Administrative Radio Conference. These include Articles 1, 9, 25, 33, 35, 54 to 64, Appendices 7, 31, 36 and 41.

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* The Director, CCIR, is invited to bring this Report to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO).

2.2 *Trials*

Trials of DSC are urgently required to prove the system described in Recommendation 493-2 and test the procedures of Recommendation 541-1. Interim Working Party 8/10 has been set up to coordinate trials carried out by administrations.

2.3 *Calling channels*

An estimate for the required number of calling channels is needed for the future allocation of exclusive digital selective-calling frequencies. Report 908 makes a preliminary estimate but finds a need for more traffic statistics, more study of frequency sharing and more study on the probability of the success of a call. In particular in § 8 of that Report, means of reducing the number of calling channels are discussed but these also require further study. Interim Working Party 8/10 has additionally been charged with this work.

2.4 *EPIRB signal*

Further study is required to assure compatibility between EPIRB emissions and the digital selective-calling system.

This study should include the consideration of frequency tolerances.

Annex I to this Report shows a possible format of an EPIRB emission containing digital selective-calling signals.

REFERENCE

CCIR Document

[1974-78]: 8/205 (Conclusions of the Interim Meeting of Study Group 8, 1976).

ANNEX I

A POSSIBLE EPIRB EMISSION INCORPORATING DIGITAL SELECTIVE-CALLING SIGNALS

There should be a facility for the automatic detection of an EPIRB emission, incorporated in the receiving/detecting equipment of the proposed digital selective-calling system for use in the international maritime mobile service.

The detection of an EPIRB emission should activate a device giving an audible signal on board ships (or at coast stations) to attract attention. An indication should thereby be given that the received call has been sent by an EPIRB.

1. The EPIRB emission

As a "distress call" is a call that is transmitted by a ship in distress, it seems justified to consider an EPIRB transmission, later on referred to as an "ES" (EPIRB Sequence), as a distress call from a ship in distress, not being able to transmit itself.

Consequently an ES should be classified as a special form of a distress call, with an indication that this special distress call is in fact an ES.

Figure 1 shows an example of an ES for an EPIRB belonging to a ship with the identification number e.g. 123456789. If the ship had an alphanumerical call sign (e.g. PA 739), the indication: "distress call" in sequence Part I would be 113 instead of 112. The self-identification, as in sequence Part 2, would then be:

80	65	55	51	57	
P	A	7	3	9	(International Alphabet No. 5)

instead of 123456789

2. The emission cycle

If the above-mentioned ES is to be incorporated in the digital selective-calling system, the signal from the EPIRB as presently prescribed in Article 41, Section I of the Radio Regulations could, certainly for the period of introduction, be retained.

However, to be compatible with the proposed digital selective calling-system, the ES should follow the signal of No. 3258 of the Radio Regulations and produce tones of 1615 Hz and 1785 Hz by frequency shift-keying of a sub-carrier.

Note. – The duration of the cycle in Fig. 1, and the separate parts in it, are to be decided by IMCO.

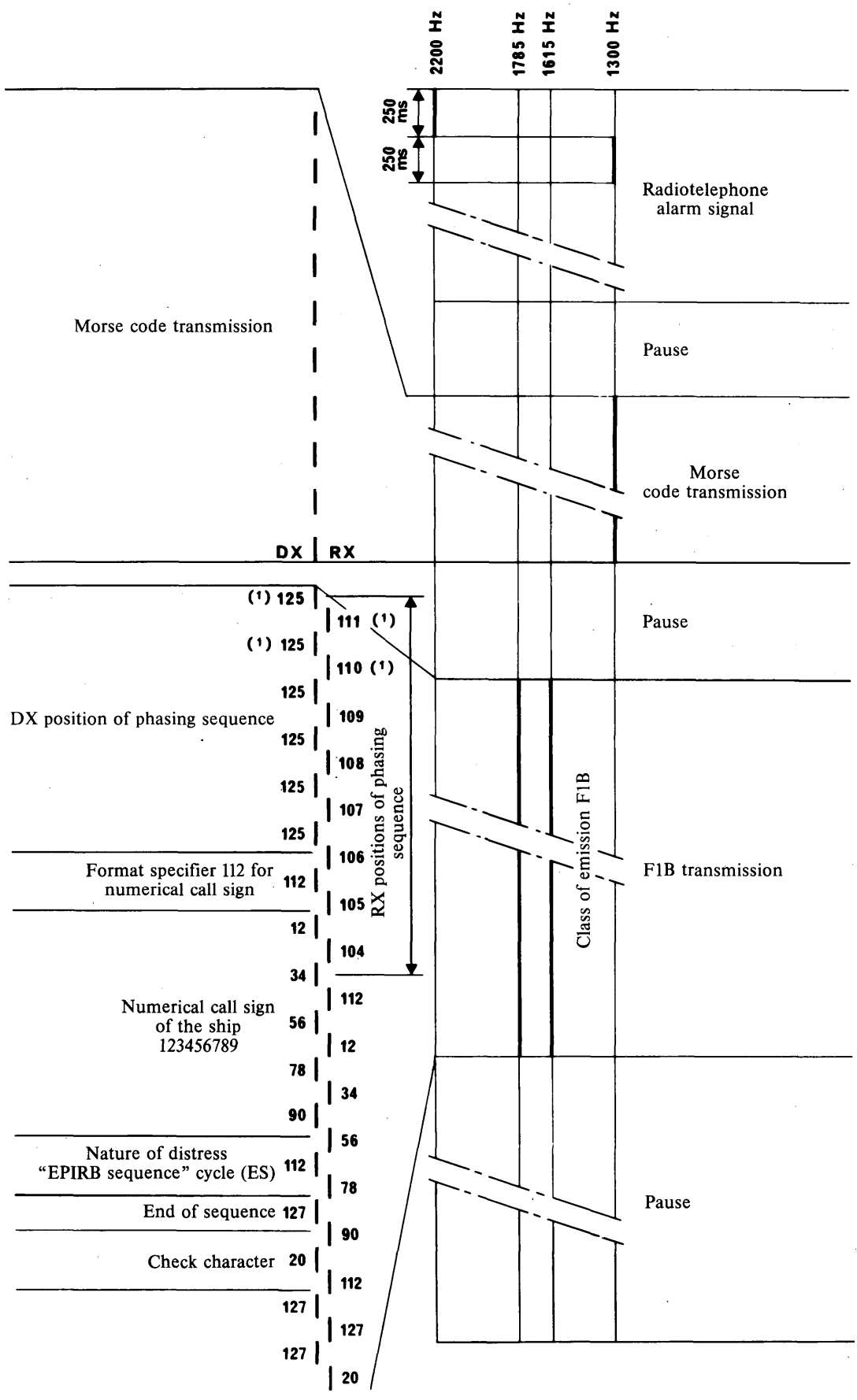


FIGURE 1

(1) See Recommendation 493, Annex II, Figure 3.

REPORT 908

CHANNEL REQUIREMENTS FOR A DIGITAL SELECTIVE-CALLING SYSTEM

(Question 9/8)

(1982)

1. Introduction

A digital selective-calling (DSC) system could ultimately replace manual watchkeeping on ships and give automatic alerting facilities for all the communications of interest to the ship such as morse telegraphy, radiotelex, radiotelephony etc. Two types of channel will be required: international and national.

- *International channels.* These are used in the direction shore to ship only when a coast station wishes to call a ship but does not know which frequencies are being monitored by the ship. It is considered that these calls will be relatively few, about 6% of the total calls. International channels are available to all coast stations.
- *National channels.* These are used when a ship wishes to contact any coast station or a coast station wishes to contact a ship of its own nationality or a ship which it contacts regularly. National channels are associated with particular coast stations. Although the calls can be in both directions current calling patterns suggest that mainly the direction is ship to shore but this could change with an improved service. Experience with the INMARSAT system may give some guidance here.

This Report considers the number of calling channels that may ultimately be required for calls other than distress and safety. This information is of value to assist in preparation for the World Administrative Radio Conference for the Mobile Services in 1988.

2. Development of the system

No national DSC channels are as yet allocated, and the presently, allocated numbers of international DSC channels may not be sufficient to support a fully developed DSC system, and, at least initially, new allocation of DSC channels will have to come out of the existing overall frequency allocation to the maritime mobile service. It is, therefore, important to endeavour to make a provisional forecast for the initial development of the DSC system.

In view of the role of DSC in distress and safety operations it may reasonably be expected that convention ships will constitute the major part of the DSC equipped vessels in the initiated phase. The ratio of convention ships to the total population of HF radio equipped ships (excluding recreational vessels) is less than 10%. If a factor of 1.5 is assumed to take into account other early participants in the DSC system, the expected channel loading will be less than 15% of the loading for the fully developed system.

The development beyond the initial phase is difficult to predict due to a number of unknown factors; e.g. the influence of further development of maritime mobile satellite communications on HF traffic loading; shifting of present morse telegraphy traffic to radiotelephone and/or direct printing, etc. It may be noted that a shift of morse telegraphy traffic to direct printing techniques would be likely to decrease the working channel time required and thus possibly make channels available for DSC calling. The ultimate channel requirement estimated in this Report is based on current (1981) traffic distributions and takes no account of future trends or predictions.

3. Use of scanning receivers

The use of a scanning receiver leads to a non-zero probability that a call intended for the receiving station is lost due to the decoder being engaged on another channel, usually referred to as the scanning loss. Scanning loss is a function of the number of channels scanned by a single receiver and the loading of the DSC channels, but, as follows from the definition, is independent of the number of calls intended for the receiving station. As a general rule the use of scanning receivers is not to be encouraged as the scanning loss increases channel loading and thus has a cumulative effect. Nevertheless, it must be recognized that the use of scanning receivers may be a necessity on many ships for economic reasons.

As a provisional value for a fully developed system, a single receiver should scan not more than six channels (see Annex I); thus the number of channels that a ship station should be expected to watch is of significant economic consequence. Two cases may be considered:

- minimum of about 6 frequencies, i.e. 1 national and 1 international channels in 3 bands. This would require cooperation of the ship's personnel to select the most appropriate bands at any given time and could increase the traffic load on the international channels due to the limited watch on national channels;

– minimum of about 15 frequencies, i.e. 2 national and 1 international channel in each of the bands 4, 6, 8, 12 and 16 MHz. This would give a more automatic service to the ship's personnel but would require more than one scanning receiver.

4. Assumptions for calculating channel requirements

Calculations were based on the following data/assumptions:

4.1 The traffic handled by the Netherlands and United Kingdom coast stations is composed as follows:

HF Morse	170 communications during the average peak hour
HF Telex (ARQ)	48 communications during the average peak hour
MF Telegraphy	140 communications during the average peak hour
HF Telephony	62 communications during the average peak hour
MF Telephony	153 communications during the average peak hour

It was assumed that this kind of traffic can completely be separated from VHF telephone traffic. It is further assumed that the total amount of traffic will remain constant during the time period considered here.

4.2 *a)* Long-distance traffic handled by the above mentioned coast stations constitutes 12% of world traffic.

b) MF traffic handled by these coast stations constitutes 30% of the European traffic.

4.3 The duration of a call is 7.5 s.

4.4 The called station transmits an acknowledgement which also lasts 7.5 s. Calls are repeated until acknowledgement has been received.

4.5 The maximum permitted loading of a random access calling channel is 0.1 erlang (according to traffic theory the probability that two or more calls coincide and therefore fail, is 18%). Even for this relatively low channel loading, a second effect, i.e. congestion of a calling channel as a result of repeated unsuccessful calls cannot be neglected. Congestion can only be prevented by requiring a time delay of the order of a few minutes before repeating the transmission of a call sequence. A higher channel loading would also adversely affect the use of scanning receivers (see Annex I).

4.6 As a result of imperfect propagation, interfering signals, coincidence with other calls, etc., the transmission of two call sequences are required for a successful call. This corresponds to a probability of receiving the acknowledgement by the called station of 0.5.

4.7 Calls in the higher HF bands can, in principle, be received all over the world, and, therefore, cause interference to other calls. Calls in the lower bands are received only regionally. In view of the aforegoing the assumption is made that 75% of the calls can cause interference to other calls in the HF bands.

4.8 A second reduction factor is required to take into account that peak hours are not the same for all coast stations. This factor is 0.5 if the resulting total traffic intensity would be constant over 24 h (this is due to the fact that the traffic intensity during peak hours equals approximately twice the average traffic intensity in 24 h). As some fluctuation with time may be anticipated, a factor 0.75 is used.

4.9 In the case of national calling, ship-to-shore and shore-to-ship calls are made via common paired frequency channels.

4.10 Determination of the required number of national calling channels is based on the assumption that all traffic is originating from ships. In reality only part of the traffic is generated by ships, but ship-to-shore frequencies are not only used for ship-to-shore calls, but also for acknowledging shore-to-ship calls.

4.11 *a)* 25% of the total traffic is shore-to-ship traffic.

b) 25% of the shore-to-ship calls are international calls.

4.12 The present distribution of traffic (sunspot maximum) over the various HF frequency bands is roughly as follows:

MHz:	4	6	8	12	16	22
% of traffic:	4	6	16	20	31	23

The same distribution is assumed for the worldwide traffic.

During minimum sunspot activity, the distribution could be roughly as follows:

MHz:	4	6	8	12	16	22
% of traffic:	4	11	37	32	16	0

The distribution of the number of calling channels should be sufficient for both situations. This yields the following distribution of channels:

MHz:	4	6	8	12	16	22
% of traffic:	4	11	37	32	31	23

5. Calculation of the required number of MF/HF calling channels

5.1 *Required number of national calling channels in the HF bands*

The calculation is based on 280 communications (assumption 4.1) during the average peak hour. Two attempts are required, on average, to achieve a successful call (assumption 4.6). Consequently the total number of calls is 560.

Worldwide, during the peak hour (assumptions 4.2 and 4.8) $\frac{100}{12} \times 0.75 \times 560 = 3500$ calls go out.

94% of these calls are made on national channels (assumption 4.11). Therefore the total number of calls on national channels is: 0.94 x 3500 = 3290.

75% of these calls can potentially interfere with other calls. Therefore, the total number of interfering calls is: $0.75 \times 3290 = 2470$ calls.

Every call lasts 7.5 s (assumption 4.3), so the total traffic intensity is

$$\frac{2470 \times 7.5}{3600} = 5.1 \text{ erlang.}$$

In accordance with assumption 4.12, the required traffic handling capacity in the HF frequency bands would be:

MHz:	4	6	8	12	16	22
% of the total traffic intensity of 5.1 erlang:	4	11	37	32	31	23

or,

MHz:	4	6	8	12	16	22
erlang:	0.21	0.56	1.89	1.63	1.58	1.17

The maximum permitted load per calling channel is about 0.1 erlang (assumption 4.5), so that worldwide a total of approximately 73 paired frequency calling channels would be required for national calling in the HF bands, divided as follows over the frequency bands:

MHz:	4	6	8	12	16	22
channels:	3	6	19	17	16	12

5.2 *National calling channels in the HF bands with other sharing factors*

In the calculation of channel requirements by the method of 5.1 it is assumed that 75% of worldwide calls have the potential of interfering, and this factor has been applied for all frequency bands. In practice, a considerably greater sharing of common radio frequency channels exists on a worldwide basis.

For the purpose of calculation, a number of sharing factors are now assumed in order to demonstrate the effect upon radio frequency spectrum requirements. This does not alter the required number of effective calling channels, and the achievable sharing factors would depend on frequency management and the availability of propagation data and worldwide time and geographical distribution of calls.

The previous figure of 3500 calls in the smoothed worldwide peak is used and the assumptions for requirements in each band to cover the sunspot cycle. The allowance of 75% for potential interference used in the previous calculations of band loading is omitted.

This calculation introduces two zones, nominally "Europe" and "Non Europe", between which calls are equally divided (based on ITU statistics).

94% national calls at 7.5 s duration

= 6.9 erlang

TABLE I

4	6	8	12	16	22	MHz
4	11	37	32	31	23	% of traffic
0.28	0.76	2.6	2.2	2.1	1.6	Erlang (total)
0.14	0.38	1.3	1.1	1.05	0.8	Erlang (Europe)
0.14	0.38	1.3	1.1	1.05	0.8	Erlang (Non-Europe)
Assumed sharing factors:						
2	2	2	1	1	1	Europe
3	3	3	2	2	2	Non-Europe
This gives shared channels:						
1	2	7	11	11	8	Europe
1	2	5	6	6	4	Non-Europe
If it is then further assumed that the "Non-Europe" requirements can be met by sharing the "Europe" assignments the total channels required are:						
1	2	7	11	11	8	
The result is 40 paired frequency channels.						

This assumes that the traffic characteristics are the same in all parts of the world and thus the traffic of the Netherlands and United Kingdom coast stations can be extrapolated as a simple function of a percentage of worldwide traffic.

Traffic statistics from Australia indicate that 20% of the total traffic is shore-to-ship traffic. The present distribution of traffic over the various HF frequency bands is roughly as follows:

MHz:	4	6	8	12	16	22
% of traffic:	37	10	19	16	13	5

No indication is given on the percentage of world traffic this refers to, but the number of communications during an average peak hour is 74.

As 47% of this traffic takes place in the 4 and 6 MHz bands sharing factors need careful consideration.

5.3 *Required number of international calling channels in the HF band*

The total world-wide traffic as calculated in 5.1 is 3500 calls/h;

25% of the total traffic is shore-to-ship traffic (assumption 4.11 a), i.e. 875 calls/h.

25% of shore-to-ship calls are international calls (assumption 4.11 b), i.e. 219 calls/h.

75% of the calls will have the potential of interfering with calls transmitted by other coast stations, i.e. 165 calls/h.

The duration of each call is 7.5 s (assumption 4.3); i.e. total call intensity is $165 \times \frac{7.5}{3600} = 0.35$ erlang.

Regarding the calling procedure by coast stations three possibilities may be considered:

a) Coast stations know the position of all ships. In this case calls need to be transmitted on only one frequency.

b) As above for 50% of the calls. 25% of the calls are transmitted via all 6 HF frequency bands. 25% of the calls are transmitted via the 8, 12 and 16 MHz bands.

c) In all cases, calls are transmitted via all 6 HF frequency bands. This simplifies the procedure for coast stations considerably.

It follows that the required capacity in the HF frequency bands will be:

TABLE IIa

MHz	4	6	8	12	16	22	
Possibility a	0.04	0.11	0.37	0.32	0.31	0.23	× 0.35 Erlang
b	0.50 × 0.04 + 0.25	0.50 × 0.11 + 0.25	0.50 × 0.37 + 0.25 + 0.25	0.50 × 0.32 + 0.25 + 0.25	0.50 × 0.31 + 0.25 + 0.25	0.50 × 0.23 + 0.25	× 0.35 Erlang
c	1	1	1	1	1	1	× 0.35 Erlang

which yields

TABLE IIb

MHz	4	6	8	12	16	22	
Possibility a	0.01	0.04	0.13	0.11	0.11	0.08	Erlang
b	0.09	0.11	0.24	0.23	0.23	0.13	Erlang
c	0.35	0.35	0.35	0.35	0.35	0.35	Erlang

Possibility *c)* results in an impractically large number of calling channels. Therefore, only possibility *b)* will be considered further.

The maximum permitted load per calling channel is about 0.1 erlang, so that worldwide a total of 14 international calling channels would be required divided as follows over the HF frequency bands:

MHz:	4	6	8	12	16	22
channels:	1	2	3	3	3	2

5.4 *Required number of MF calling channels*

During the peak hour about 293 communications are set up via the United Kingdom and Netherlands coast stations (assumption 4.1). Consequently, there are 2 × 293 = 586 calls (assumption 4.6). These coast stations handle about 30% of the European MF traffic (assumption 4.2 b). All these calls have the potential of interfering and the peak hours in Europe are more or less coincident.

Therefore the total number of potentially interfering calls during the peak hour is

$$\frac{100}{30} \times 586 = 1953 \text{ calls.}$$

The total calling traffic intensity amounts to:

$$\frac{1953 \times 7.5}{3600} = 4.0 \text{ erlang}$$

This would require a total of 40 calling channels.

6. Other factors influencing the required number of calling channels

In the calculation of the number of national calling channels, it is implicitly assumed that at the coast station it is known which particular calling channels are being watched at a particular time by the ship to be called. It is also implicitly assumed that the position of the ship is known so that an operator is able to select both the optimum frequency band, the correct channel in the selected frequency band and the optimum time for sending the call.

In the calculation of the number of international calling channels this is assumed for at least a relatively large percentage of the cases. Lack of knowledge of the required information would increase the required number of call attempts and consequently would result in a correspondingly higher number of calling channels.

The problem of obtaining the information on the channels watched by a ship, can be solved by grouping them, e.g. according to the alphabet or the ship's identification. Such an arrangement would, however, not guarantee an even distribution of calling traffic over the calling channels.

A similar problem may arise in the allocation of national calling channels to coast stations. Since the number of coast stations is too large to allow the use of exclusive calling channels, shared use must be made of a limited number of common calling channels.

The allocation of national calling channels should be such that calling traffic would be evenly distributed over these channels. Imperfect distribution of traffic from coast stations and ships over the calling channels would create relatively busy calling channels and relatively empty calling channels. Adverse effects due to such an imperfection could be prevented by lowering the average loading of calling channels, i.e. by increasing the total number of calling channels.

7. Comparison of calling and traffic channels

The total number of HF channels allocated to the maritime mobile service for morse, telex and telephony use is about 1200 and the total number of HF calling channels (national and international) calculated above is of the order of 100. The required number of calling channels is thus around 8% of the traffic channels.

In terms of bandwidth the comparison is shown in Table III:

TABLE III

	HF morse	HF telex	HF telephony
Communication bandwidth (kHz)	785	257	1054
DSC bandwidth (kHz)	63	13	24
Ratio of bandwidth (DSC/communication)	0.08	0.05	0.02

i.e. the calling requires about 8% of the bandwidth for morse, 5% for telex and 2% for telephony. Overall, the bandwidth ratio is 5%. To justify its introduction therefore, DSC needs to produce an improvement in bandwidth efficiency of the order of 5%.

8. Possible means of reducing the number of calling channels

8.1 *Introducing "slotting"*

"Slotted random access" is similar to the normal random access so far considered except that calls can only be transmitted in fixed time slots. This concept would reduce the loss due to call overlap from 18% to 9% and at the same time would have a positive effect on channel stability. However, the possible increase in channel loading would be less than the factor of two indicated from the call overlap. Further study is required on the implementation aspects, the reduction in channel requirements and the effect on the use of scanning receivers.

8.2 *Listening to a channel before transmitting*

This would reduce the probability of call overlap but more study is required to assess the possible reduction factor. Such a procedure would be most effective if coast stations transmitted busy signals. This would however, require additional coast station transmitters.

Note. – In a "slotted" system, lisening would not give such valuable information, because it is not permitted to start a transmission *during* the time slot, only at the beginning.

8.3 *Coordinating the transmissions of coast stations*

This would permit a higher loading of calling channels without causing congestion.

For instance, to give coverage of a region served by several countries, e.g. the North Sea, calls from the administrations having interests in the region could be sent through one station which was common for the countries. Alternatively, the calls could be sent through each country's coast stations and means taken to correlate its transmission times with those of other countries serving the area.

Where it is required to cover an area larger than the service area of one station, additional service areas would be required, either operating on the same frequency in a coordinated manner, or on a separate frequency.

This approach would have most impact on the number of international calling channels but the higher loading could limit the use of scanning receivers aboard the ship (see Annex I).

Coast stations could also control the shore-to-ship calls in such a manner that the peak to average traffic ratio approached unity. Such a procedure is more easily applied to radiotelegraph calls than radiotelephone but could be applied in varying degrees to each type of service.

8.4 *Coordinating the transmissions of ship stations*

In many stations it is presently common practice to establish schedules for certain vessels to contact coast stations when their operational requirements permit such a method of contacting. This scheduling procedure should particularly lend itself to the type of reliable contacting provided by DSC. It is expected that once vessels find that contacting a desired station can be accomplished in a very reliable manner the peaking will be reduced and a large number of calls will be placed in "off-hours".

Additionally, it may be possible to provide monetary incentives to ship stations to contact the station in other than peak hours. If the charge for calls placed during the peak hours is high, it can be assumed that some vessels will call during periods when the charge is reduced. This will reduce the ratio of peak/average calls/hour to be handled at the coast station.

8.5 *Use of 500 kHz band*

IMCO has proposed frequencies in the 500 kHz band to be used for DSC in the shore-ship direction and for the transmission of navigational warnings by direct printing (NAVTEX).

These proposals are based on the experience that the 500 kHz band is superior for reliable coverage by means of ground-wave propagation.

When it is considered that a large part of the world's fleet is at any moment sailing close to coasts, the use of 500 kHz for DSC purposes could reduce the load on other frequencies considerably, particularly for the international channels.

The probability of a successful call on 500 kHz will be high and therefore a reply from the ship in the same band need not be necessary. The ship by knowing its position could select the most appropriate band.

9. Summary

Estimates for the number of DSC channels ultimately required have been calculated as:

- 14 for international calling in the HF bands;
- 40 to 73 for national calling in the HF bands;
- 40 for calling in the MF bands.

The range in the estimates is caused by different assumptions on the amount of frequency sharing possible and more work is required on this topic. The estimates are based on current traffic loads in the European area and thus may not truly represent the world as a whole. More traffic information is required from administrations to check this. Also no account has been taken of possible changes in traffic loads in the future.

The estimated number of DSC channels is about 8% of the number of traffic channels and would occupy about 5% of the bandwidth of the traffic channels.

The estimates assume fully random calling and assume that a ship is monitoring a number of channels – around 6 to 15 as a minimum. Consideration is given to non-random calling to reduce the number of channels but more work is required before any conclusions can be drawn.

Since it is expected that DSC will reduce the ratio of peak to average calls per hour currently experienced by coast stations, and that this has not been taken into account, the attention of administrations is particularly directed to § 8 of this report. Contributions concerning the degree that these means will reduce the number of calling channels are requested.

ANNEX I

FAILURE OF CALLS DUE TO SCANNING

1. Assumptions

Calculations were based on the following assumptions:

- the scanner only halts at a calling channel if the "dot pattern" (see § 2) is recognized;
- in all other cases the scanner immediately moves on (so no time is required for recognizing another situation);
- a time $t_3/2$ (see § 2) is required, on an average, to recognize that a call is destined for a different station; after that the scanner immediately moves on.

2. Format of the call

Figure 1 contains the information relevant for the calculation:

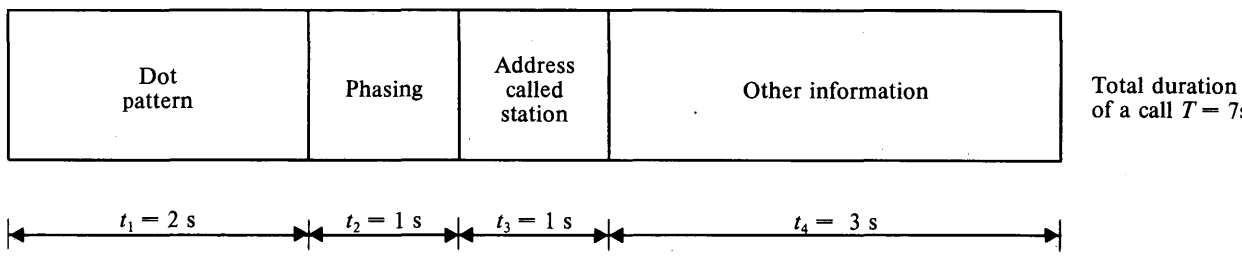


FIGURE 1

3. Result of the calculation

The probability that a call for station A fails, due to scanning is equal to the sum of 2 sub-probabilities:

- p_2 the probability that the scanner is busy decoding calls (on other channels) for other stations while the "dot pattern" is being transmitted;
- p_3 the probability that the scanner is busy decoding calls (on other channels) for station A while the "dot pattern" is being transmitted.

$$p_2 = 1 - e^{-(n-1)\lambda(t_2 + \frac{t_3}{2})}$$

$$\approx (n-1)\lambda(t_2 + \frac{t_3}{2}) \qquad \text{(neglecting second order effects)}$$

$$p_3 = 1 - e^{-(n-1)(T-t_1)\lambda a}$$

$$\approx (n-1)(T-t_1)\lambda a \qquad \text{(neglecting second order effects)}$$

in which

n: the number of channels which is scanned by the scanner,

λ: the average calling frequency; if the average load of a calling channel is 0.1 erlang, $\lambda T = 0.1$, so that $\lambda = 1/70$;

a: the percentage of calls for station A.

For ships, a can be considered to be 0; for Scheveningen Radio (for long-distance traffic) $a = 3.5\%$.

For t_1, t_2, t_3 and T: see § 2 of this Annex.

The result of the calculations is represented in Table IV below for three values of λ. The first value is in line with the assumptions. The third value applies if the load of the calling channels is halved (so the number of channels is doubled).

TABLE IV – *Percentage of calls lost as a result of scanning*

λ \ n	3	4	5	6	7	8	9	10	11	12	13	14	
1/70 (0.1 Erlang)	4.8	7.3	9.8	12.4	15.0	17.6	Impermissibly high						Coast station $a = 3.5\%$
	4.3	6.6	8.8	11.1	13.5	15.9							Ships
1/93.3 (0.075 Erlang)	3.7	5.4	7.3	9.0	10.8	12.6	14.4	16.2	Impermissibly high				Coast station $a = 3.5\%$
	3.3	4.8	6.5	8.1	9.7	11.3	12.9	14.5	16.1				Ships
1/140 (0.05 Erlang)	2.5	3.5	4.8	6.1	7.4	8.6	9.9	11.1	12.5	13.7	15.0	16.3	Coast station $a = 3.5\%$
	2.2	3.2	4.3	5.5	6.6	7.7	8.9	10	11.2	12.3	13.5	14.7	Ships

4. Conclusion

It follows from Table IV that in the case of ships receivers for acceptable loss:

- 6 channels could be scanned for 0.1 erlang channel loading,
- 8 channels could be scanned for 0.075 erlang channel loading,
- 11 channels could be scanned for 0.05 erlang channel loading.

REPORT 588-1

BLACK AND WHITE FACSIMILE TRANSMISSIONS OVER COMBINED METALLIC AND RADIO CIRCUITS IN THE MARITIME MOBILE SERVICE AND IN THE MARITIME MOBILE-SATELLITE SERVICE

(Question 20/8)

(1974-1978)

1. Introduction

Interest in maritime public correspondence facsimile continues to be small, although there are indications that it will develop in the future. It is therefore desirable that the preferred characteristics of a system are identified and specified. It is necessary to note that a maritime facsimile service might take place over MF/HF, VHF and satellite radio circuits and that in formulating any set of technical characteristics it is necessary to take into account the specific requirements of these different frequency bands.

2. Uses of facsimile and operational aspects

2.1 It is considered that facsimile transmissions can have special advantages for the safe and efficient operation of ships. In addition to the already existing WMO meteorological transmissions, facsimile could be used for broadcasting navigational warnings. The transmission of documents in both the shore-ship and ship-shore directions makes possible the rapid and accurate interchange of technical information and diagrams.

2.2 Several administrations have stressed the operational advantages of being able to carry on telephone conversations between ship and shore, changing over as required for the interchange of documents by facsimile without the need for intervention by the coast station operator. Ideally there is a need to permit the transmission of both emissions on the same radio channel. However, several administrations had strong reservations about this and, indeed, reservations about the general development of maritime public correspondence facsimile services, bearing in mind the further overloading of the already congested maritime frequency bands that would ensue. This limitation does not apply to the maritime mobile-satellite service.

2.3 In Norway, facsimile transmissions are performed both as broadcast of news to ship stations and as part of ordinary correspondence between ship stations and subscribers in the public network, with equipment operating in accordance with the CCITT system specifications. The United States transmits information on the state of ice to ships on the Great Lakes, using standards similar to those of the WMO, but has also identified a need for public correspondence ship-to-shore and ship-to-ship facsimile communication utilizing 8½ inches by 11 inches (21.6 cm by 28 cm) pages in association with radiotelephone calls. For this purpose, it is not practicable to employ WMO standards which accommodate continuous-roll paper of 19 inch (48.3 cm) width. Technical standards for this facsimile communication system would have some common parameters with both WMO and CCITT standards, but there are also some important differences which make it incompatible with either.

Some other administrations, including the United Kingdom, have carried out trials of facsimile, but do not operate a service at the present time.

3. System characteristics

3.1 *General*

There is general agreement that, as far as possible, all maritime public correspondence facsimile should adopt a single set of standards. However, there are two sets of characteristics in international maritime use at the present time: that specified by the World Meteorological Organization * for the transmission of weather maps and that specified by CCITT ** for transmission over metallic circuits.

3.2 *Centre frequency and "black" and "white" frequencies*

It was noted that the centre frequency in general use for the transmission of meteorological charts was 1900 Hz in accordance with CCIR Recommendation 343. However, this Recommendation is generally concerned with transmissions over fixed radio circuits and would not normally include extension into the public telephone networks. It was considered, therefore, that it was not strictly appropriate to a maritime public correspondence facsimile service. It was also noted that, in accordance with Opinion 24 (Kyoto, 1978), weather chart transmissions intended for reception by ships use, in principle, direct frequency modulation of the assigned radio frequency. This Recommendation would also be inappropriate to a public facsimile service. It was agreed that whilst the adoption of a single centre frequency for the weather chart and public correspondence facsimile services was operationally desirable, the use of two different values would not pose insuperable problems and could be allowed for by slight adjustment to the tuning of radio receivers.

It was noted that whilst the WMO uses the lower frequency for "black" and the higher for "white" which is in opposition to the CCITT Standard there is no pressing need to standardize on this particular characteristic because most facsimile recorders are fitted with a polarity reversal switch.

3.3 *Index of Cooperation (IOC)* ***

The Index of Cooperation recommended by CCITT is 264 whilst that used by the WMO is 288. There are very strong reasons why neither of these specifications can be aligned to the other in regard to this characteristic. The Study Group considered that the CCITT value should be adopted as the maritime standard although one administration (United Kingdom) suggested that the slight distortion of picture aspect ratio that would be caused by the adoption of the WMO value of 288 could be tolerated in the public correspondence service.

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* WMO Manual on the Global Telecommunications System 1974, Volume 1, Part III.

** CCITT, Volume VII, Recommendation T.10*bis* (revised 1976).

*** The index of cooperation is defined as $1/\pi$ times the ratio between the line length and line spacing.

3.4 *Scanning line frequency*

There was a consensus of opinion that the CCITT recommended scanning line frequency of 180 lines per minute * could be adopted since it would provide a reasonable compromise between rapid transmission of messages and protection against the effects of multi-path propagation over long-distance circuits.

It is understood that WMO weather transmissions over radio circuits do not normally use a scanning line frequency greater than 120 lines per minute although a speed of 240 lines per minute is also available on WMO equipments. However, some administrations favour the adoption of a value of 240 lines per minute, as permitted by the CCITT, since it would speed up transmission of messages and would permit reception on existing weather chart equipments operating on 120 lines per minute and is claimed to provide a satisfactory performance under multi-path propagation conditions. The Study Group considered therefore that a decision on this factor should be deferred pending further study of the problem. It is possible that a choice of scanning speed should be made operationally available to speed up transmissions when conditions are favourable.

3.5 *Start/stop control signal*

Some administrations considered that the CCITT type start/stop control signal used over metallic circuits might not be sufficiently reliable for general use over MF/HF radio circuits. It was therefore proposed that the WMO type start/stop signals ** that had been developed specially for radio circuits might be better for all maritime uses. Further study of this problem is required.

3.6 *Choice of characteristics*

It is considered that neither the CCITT nor WMO characteristics fully meet the requirements for HF/MF transmissions in all respects. The United Kingdom has suggested that WMO specifications be adopted as a whole for the maritime public correspondence facsimile service, save for the scanning speed which should be 180 lines per minute, because of the radio propagation problems to be encountered on the MF/HF frequencies and in the interest of compatibility with the weather map service.

However, although it was accepted that there was a need to have special control signals on the HF/MF service, it was felt to be premature to adopt the full WMO Standards at this stage for public correspondence services. It was also noted that transmission over VHF and satellite radio circuits would be sufficiently good to permit the use of the CCITT standards in full.

Nevertheless, there was general agreement on a number of characteristics as listed below:

Modulation of sub-carrier	frequency modulation
Centre frequency (f_0)	1700 Hz
"Black" frequency	f_0 + 400 Hz
"White" frequency	f_0 − 400 Hz
Frequency stability	± 32 Hz over a 15-minute period
Index of cooperation	264.

4. Conclusion

The Study Group considered that either CCITT or WMO type of signals could be used satisfactorily for VHF and satellite communications.

Special control signals are probably required for HF/MF transmissions. These are likely to be incompatible with existing CCITT Recommendations.

* The CCITT Recommendations do permit the use also of 240 lines per minute and other scanning speeds.

** The *start signal* consists of alternate black and white signals repeated at a frequency of 675 Hz for a period of 5 seconds.

The *stop signal* consists of alternate black and white signals repeated at a frequency of 450 Hz for a period of 5 seconds followed by 10 seconds of continuous black.

Further work is required to determine the precise nature of these control signals and also the preferred value(s) of the scanning speed(s) for maritime use. It is, however, highly desirable that a single standard be established for use in the maritime mobile-satellite service.

Note 1. – Attention is also drawn to CCITT Recommendation T.3, on a 3-minute facsimile apparatus for use over the general switched telephone network and on the CCITT studies of a digital facsimile apparatus requiring a transmission time below one minute. These two apparatus might be of special interest for application on maritime mobile satellite and VHF connections.

Note 2. – The Director, CCIR, is requested to bring this Report to the attention of IMCO, WMO and the CCITT.

REPORT 743-1

TRANSMISSION QUALITY ASSESSMENT OF DIGITAL CHANNELS IN MARITIME MOBILE SERVICES

(Question 42/8)

(1978-1982)

1. Introduction

Modern requirements with regard to the transmission quality of digital maritime HF channels raise a number of complex problems. The increasing requirements imposed on the maritime radiocommunication system can only be met by automation of message preparation, transmission and recording processes and of call set-up and error detection and correction procedures.

The CCIR has already made some progress in this direction:

- it has recommended a direct printing system with error detection and correction which has already been used by a number of countries for several years;
- valid solutions are being found to problems of establishing a digital selective-calling system designed to meet future requirements in the maritime mobile service.

Future studies sponsored by the CCIR call for the development of means of automating radiocommunications using discrete information transmission channels. The improvement of the equipment and methods used for information transmission in digital maritime channels requires that an objective means be found of evaluating the effectiveness of the technical solutions applied. One criterion which might conveniently be adopted is the variation in the probability that a given quantity of information will be transmitted with an acceptable standard of reliability within a given time. Given the critical relation between the various methods of improving digital information transmission media and the variation in the transmission conditions in the channels concerned, the first essential is to identify the character and range of the variation in qualitative channel characteristics and to develop a methodology which can be applied in CCIR studies in comparing the findings of equipment tests carried out by the administrations of various countries.

Digital channels to carry ship-to-shore direct printing telegraph services have low individual transmission rates, but in busy areas many channels would be required to carry the traffic in both the satellite services and the terrestrial HF and VHF services. There is a possible future need for higher rate data transmission of the computer type, and digital transmission of speech and facsimile could also be advantageous in some conditions, but these require consideration separately from the direct printing application.

Performance tests with digital equipment may be made for two purposes, the first to assess the performance of complete message transmission equipment, the second to establish the distribution of errors caused by the propagation path so that equipment design may be improved by changing modulation, coding or diversity methods.

In evaluating the quality of maritime mobile service channels it is very important to consider the effect on the test results of the duty period, the test parameter averaging intervals selected within the duty period and the total number of duty periods, i.e. the scale and algorithm of statistical processing.

2. Methods of performance assessment

2.1 Work by France on laboratory tests with coded radio signals has indicated a method to produce high-level white noise by frequency modulating a carrier with noise. This work is reported in relation to Reports 499 and 501, and would be applicable to tests of equipment in a white noise environment. They are minimum tests to be performed, and would not give complete information for HF tests in which noise must have a burst characteristic.

2.2 The ultimate assessment of the effectiveness of equipment must be based on measurement of its performance in service, so as to ensure that all relevant factors are taken into account. Such tests must be made over the whole distance range at which the equipment is intended to be used, and in all types of propagation conditions. The measured performance will depend especially on the path attenuation, noise and interference conditions prevailing at the time of the test, and because these conditions are variable it is only possible to compare the performance of different equipments by averaging results from tests made over many months. In addition to the propagation factors mentioned, changes in multipath propagation delays can introduce telegraph distortion and bursts of digital errors even when other conditions are favourable for reliable communication.

2.3 The difficulty in making repeatable performance measurements of equipment by sea trials, and the long time that these take, has led to the use of ionospheric path simulators, with which laboratory tests of equipment may be made under controlled conditions. The important advantage of making tests with a channel simulator instead of with a real ionospheric path is that comparisons may be made between equipments when working under exactly the same conditions and that any required conditions may be reproduced without waiting for them to arise fortuitously.

3. Work of Study Group 3

The performance assessment of fixed HF telegraphy circuits has been studied by Study Group 3 of CCIR. Reports 203, 345 and 435 are relevant, but are concerned mainly with the relative performance of telegraph modulation and coding methods. The following Reports are particularly concerned with performance measurement.

Report 200. – Telegraph distortion, error rate. This relates especially to the relevant CCITT Recommendations on distortion measurement.

Report 349. – Single-channel radiotelegraph systems employing forward error correction. Test methods and results are given for several candidate systems.

Report 345. – Performance of telegraphy systems on HF radio circuits. This summary of more recent tests indicates that a measurement of telegraph distortion is a more useful way to assess transmission quality than the measurement of channel efficiency.

Report 549. – HF ionospheric channel simulators. The model which represents the transmission path and the method of simulating it with delay lines, attenuators and adders are described.

4. Measurements with path simulators

4.1 Many path simulators have been experimentally used and at least one is available for purchase, but few administrations have access to such equipment. They differ in the detail with which they simulate the propagation mechanism.

4.2 When using a path simulator, its capabilities in representing real reception conditions must be considered. The model should accurately reproduce the fading conditions over the spectrum occupied by the signal and therefore produce the same signal distortion as multipath propagation. In addition, the path simulator must have a sufficient dynamic range to represent realistically the wide variations in signal level encountered in practice and have provisions for accurately simulating different noise characteristics (for example, atmospheric noise and man-made noise) over a wide range of signal-to-noise ratios. Insufficient data exist to determine accurately the parameters to be used in simulating specific propagation paths. Nevertheless, it has been found that tests over a range of representative propagation parameters carried out by several administrations on a comprehensive simulator, for example, as described in Report 549 can provide a reliable indication of how the equipment will perform under practical conditions, and that even a simple model of the multipath mechanism can be helpful for comparison of performance of different equipments, providing that the path parameters chosen are reasonably representative of the actual ionospheric paths.

4.3 Recommendation 520 suggests ranges of signal parameters which would be appropriate for HF communication. It notes that the simulator may produce not only the radio path properties but also those of parts of the radio equipment such as automatic gain control, frequency drifts and jumps in frequency and phase such as might be produced by some frequency synthesizers. These additional facilities are required to test modems independently of the receiving equipment. Report 549 also comments on the need for further information on parameter values, and in particular no specific values for signal strength and noise level are proposed for use in equipment tests.

4.4 It may be concluded that at the present time the channel simulator is the most satisfactory way to evaluate different communication equipments, but that for the final determination of whether the performance is adequate for the demands of the service, the equipment must be tested under operating conditions in the actual ship, shore station and propagation path environment.

5. Sea trials

Digital channels may also be represented on a statistical basis by their error rate and error pattern behaviour. This should include error probabilities and types of error patterns (for example, random patterns, burst patterns, systematic patterns) as a function of time-of-day, month (or season) and sunspot cycle, as well as path length and geographical location.

A large-scale measurement programme is in progress in the U.S.S.R. to provide a data basis from which mathematical models could be derived to evaluate the performance of digital transmission equipment under practical operating conditions. This work needs to be continued to provide a comprehensive data base which may represent a wide variety of actual communication channels.

5.1 Since 1967, experiments have been conducted in the U.S.S.R. to evaluate the qualitative characteristics of HF maritime channels using direct-printing equipment with and without error correction. Studies have also been conducted on the determination of the character of error grouping in HF maritime channels with synchronous working and for the evaluation of the size of sample required in deriving conclusions on channel quality.

The test procedures and some of the results obtained are described below.

5.2 *Purpose of tests*

One feature of the maritime mobile service is the need for brief exchanges of information between ships and shore stations. Communications are exchanged in the form of separate short duty periods preceded by the necessary call setup procedures. The relatively large selection of frequencies used for ship-shore communications, the constant changes in the ship's position during the voyage and the various times in the day and season at which calls have to be made all result in a wide variety of space, time and frequency characteristics. Before any duty period, the "working" HF channel must be selected but the quality of transmission varies within very wide limits from one duty period to another, largely owing to the different propagation conditions of the working frequencies used and the degree to which they are "contaminated" by interference. The variation in location, distance, time and frequency of the duty periods is one of the basic operational properties of the maritime mobile service and must be taken into account in defining the qualitive characteristics of digital HF maritime channels.

The main purpose of the studies was to identify the law governing the variation in transmission quality of digital maritime HF channels from one duty period to another. In the studies, channel working states were selected with various location, distance, time and frequency values.

The second objective was to collect the necessary statistical data on the character of error grouping in digital HF maritime channels in synchronous operation using different modulation rates.

The next aim was to explain the correlation between the test sample and the validity of results obtained from HF band trials.

5.3 *Parameters studied*

The method most widely used in recent years to assess the quality of digital channels consists in transmitting a test signal of a given structure on a channel and in determining the error distribution in time (in bits or alphabetical characters) or some of its numerical parameters at the channel output. As the quality of digital HF maritime channels can be fairly comprehensively described by the probability that a given volume of information will be transmitted to the correspondent within a given time with an acceptable standard of reliability,

it was laid down in the studies that error distribution in time must be obtained at the channel output adequate to define all the required parameters. In a study of channels using direct printing without error protection (see Figs. 3, 4, 6, 7, 8 and 9) in which the test signal was transmitted for fixed-time segments at constant speed, the channel quality can be conveniently defined by the distribution of character error rates determined in the individual duty periods.

The above remarks are also true for the synchronous transmission of test signals (see Figs. 1, 2 and 5) which were also transmitted in fixed time segments without a backward channel at a given speed. Digital channel quality in the Maritime Service is also defined by the bit error rates measured in the duty periods. Apart from yielding information on the error rates for the individual duty periods, the bit error distribution in time obtained can be used to define the error grouping rates for blocks of varying length, the distribution of lengths of adjacent error bursts and a number of other probability characteristics required for the purpose of selecting methods of enhancing digital transmission reliability.

5.4 *Test conditions*

The transmission quality of HF maritime channels using direct printing equipment was evaluated using typical radio equipment with F1B emission.

In devising the test programme and method, full account was taken of the operating features of a real communication system, since this factor is decisive for the accuracy of the results obtained.

About 60 foreign-going ships scattered throughout the world participated in the tests carried out to evaluate transmission quality in links using direct-printing equipment. The links with these vessels were maintained by five coast stations using more than 70 frequencies during the test period.

As a test text, we transmitted all characters of the Russian alphabet arranged in such a way that the structure of the sequence of information bits contained in them was nearly recurrent. The test programme included over 900 duty periods involving the transmission of about 4 million characters. The duty periods occurred at various times of day. The test results are given only for the shore-to-ship direction because of the limited sample size obtained in the ship-to-shore direction.

In view of the wide variation in communication conditions in the channels studied versus time and the inevitable dependence of the error rates from the length of the duty period, the mean duration of real duty periods, amounting to 10 min, was taken as the basis for the test periods.

The received test signal was recorded on punched tape. The received text was compared with the transmitted text to obtain the character error stream together with its numerical parameters.

The synchronous working tests were carried out with specially designed instrumentation for determining and recording the error distribution in time. The error stream was also recorded on punched tape by binary registration of the numbers of the test signal bits in which the mistakes occurred. This representation of the varying error rate was extremely compact and convenient for computer processing of the test results. To ensure stable synchronization of the transmitted and received test signal, the test signal adopted was a regular sequence of binary signals of the type 1 : 1. The experimental study of HF signals with this type of working was carried out on two ships – the "Novoaltaisk" on the Leningrad-Australian ports-Leningrad run, and the "Shota Rustaveli" plying between Odessa-England-Pacific islands-Australian and Indonesian ports. The test signal was transmitted in the direction shore-to-ship by four shore stations using 30 frequencies in all HF long-distance sub-bands.

The sample size for 700 duty periods amounted to more than 20 million bits.

Trials were carried out in the U.S.S.R., the goal of which was to obtain information on variations in the characteristics of digital channels depending on the scope of the experimental period. These trials took place during a 6-month period on board ships of the "Puskin" and "Magnitogorsk" type with direct-printing equipment according to Recommendation 476. A total of 572 615 blocks were transmitted and 286 recordings were made during the trials.

5.5 *Analysis of test results*

The sample mean of the character error rates $\overline{CER}$ for all test duty periods amounted to 3.9×10^{-2}. The sample mean was obtained from the formula

$$\overline{\mathrm{CER}} = \frac{1}{n} \sum_{i=1}^{n} \mathrm{CER}_i \qquad (1)$$

where n = total number of test duty periods, and CER_i = character error rate for the ith duty period.

Hence the sample mean of the coefficients of the bit error rates $\overline{BER}$ amounted to 9.2×10^{-3}. In order to establish a statistical law of variation in the error rates and to assess the effect produced on this variation by the frequency, space and time characteristics of the duty periods, all the data obtained were reduced to statistical series (samples) on the principle that one or another of the duty period characteristics remains constant. In view of the wide range of values obtained for the character error rates *CER*, and for the bit error rates *BER* ($ER_{max} = 5 \times 10^{-1}$; $ER_{min} = 2.3 \times 10^{-5}$) in plotting the histograms of the series formed and calculating the distribution curves approximating them, error rate logarithms were used (the symbols m' and m'' are used below to denote the logarithms of *CER* and *BER* respectively). Despite some differences in the individual statistics, all the samples, represented in interval form by variation series, are statistically stable and satisfactorily approximated by Gram-Charlier curves [Mitropolsky, 1971; Korn and Korn, 1970]. To illustrate this conclusion, some histograms and theoretical curves are given below for 10 variation series (see Figs. 1 to 9) derived from test results and covering a wide range of distinctive characteristics. The characteristics of the series reflecting the test conditions, together with the sample sizes and the sample means of the error rates for each series, are given in Table I. For purposes of comparison, Figs. 1 and 2 show the histograms and theoretical curves based on data obtained on reception by the "Novoaltaisk" of the test signal, in synchronous working, from two different coast stations, in Moscow (see Fig. 1) and Odessa (see Fig. 2). On all Figures, the y-axis shows the values of the relative frequency with which the error rates occur in the i th class interval i.

$$h_i = \frac{n_i}{n} \tag{2}$$

where n_i = number of duty periods with an error rate CER_i or BER_i occurring in the i th class interval, and n = the total sample size in the duty periods. For purposes of clarity, the x-axis shows the mean interval values CER_i or BER_i, although the curves were plotted for the logarithms of these values (m' and m'').

The plotted curves show results over a range of bit error-rates and character error-rates of about 2×10^{-5} to about 5×10^{-1}, but it is suggested that future tests should relate to a practical range of equipment performance and a range 10^{-1} to 10^{-4} should be used for tests.

Figures 1 and 2 show a clear and distinct difference in quality of communication between the Odessa and Moscow stations. Figures 3 and 4 are histograms and distribution curves for log *CER* for the Moscow station communicating in direct-printing working with the same ship crossing the Atlantic (see Fig. 3) and Indian (see Fig. 4) Oceans ("Novoaltaisk", Leningrad-Australian ports-Leningrad). As can be seen from the figures, there is also a difference in quality of communications, but the statistical law remains unchanged.

The histograms and distribution curves in Figs. 5, 6, 7 and 8 were plotted, as distinct from the previous curves, on the basis of a much greater sample size, which considerably improved the agreement between the empirical and the theoretical curves. These curves also provide clearer confirmation of the statistical stability of the variation series and of the constant character of the approximating curves, despite the fact that, in the formation of the series, a summation was made of the data obtained from operation with several shore stations communicating with different ships in the most widely scattered locations.

Distribution curves 1 and 2 in Fig. 9 (the histograms of the experimental data are not given, in order not to complicate the figure) relate to the experimental data obtained simultaneously with identical duty period frequency and space characteristics in a channel without (curve 1) and with (curve 2) a signal bit regenerator.

Figure 9 is a good illustration of the way in which distribution curves for log *CER* can be used to assess the effectiveness of various technical solutions in telecommunication channels. For example, Fig. 9 shows that, on average, a signal bit regenerator increased the reliability of information transmission from 2.2×10^{-2} to 8.1×10^{-3}. The type and size of the change in curve 2 in relation to curve 1 clearly shows the scale of the advantage to be derived from the use of this equipment.

Thus, in view of the stability of the law of variation of log *CER* or log *BER* with different combinations of frequency, space and time characteristic values of the duty periods (in selecting the working condition of an HF channel), there is a genuine possibility of objectively assessing the effectiveness of a new technical solution in the channel. Hence, when new equipment is tested, sufficient statistical data must be obtained on the condition of

the channel both before and after the equipment is used. Experience gained in statistical studies of the quality of maritime HF channels warrants the tentative conclusion that 100-150 ten-minute test duty periods provide a basis for statistical generalizations within a quite acceptable margin of error. When an equipment is tested by the administrations of a number of countries, differences in the assessment of the quality of the initial channel condition are perfectly understandable and acceptable. In assessing the effectiveness of new types of equipment in HF channels, these differences may be standardized on the basis of the data obtained by all Administrations. The standardized values can be applied for purposes of a comparative assessment of the effectiveness of various technical devices without any need for joint full-scale tests.

In the experimental work on board the "Puskin" and "Magnitogorsk" the relative transmission rate V_r was determined in addition to the above-mentioned characteristics using direct-printing equipment in the ARQ mode, thus providing information concerning the average values of the lengths of series of unbroken erroneous blocks and the nature of the distribution. V_r is defined as the ratio of the number of blocks N_c received correctly to the total number of blocks N transmitted. V_r was determined for separate intervals within each duty cycle in order to determine the dynamics of changes in channel quality during the duty period. The purpose of this investigation was to assess the necessary duration of the measuring periods when determining the performance of digital channels on a statistical basis.

Figure 10 shows a unified histogram and a curve of the distribution of the probability density h_i versus the relative transmission rate V_r during a duty period. The curve in Fig. 10 as well as those in Figs. 1 to 9 follow the Gram-Charlier law.

During the tests it was established that the interval over which V_r should be averaged in order to obtain a meaningful operational assessment of the channel quality during the duty period should not be less than 100 blocks. The lengths of the duty periods for the tests should not be less than 10 to 12 min, taking account of the off-on/on-off channel state transitions characteristic of the HF bands.

6. Preferred methods of performing tests

6.1 From the sea trials performed and the analysis of the results by the U.S.S.R., together with the methods reported by other workers for testing complete equipments, a known sequence of characters, including shift coding if used, should be transmitted, the performance being expressed as received character error-rate. For establishing optimum design methods, a long random sequence of digits is used, the complete sequence of correct and error digits being recorded on paper or magnetic tape for subsequent analysis by computer to give error burst statistics, or to be applied as error occurrences to digitally coded characters for comparing different coding and error control methods. Instead of the pseudo-random stream, some workers have used the sequence 010101 which simplifies the code synchronizing problem at the receiver but does not give an accurate simulation of message traffic.

6.2 When complete equipment tests are made under real conditions the tests must at least include all hours of the day, summer and winter. If equipments are to be compared, tests should be made alternately on the same frequency channel.

6.3 Tests of digital transmitting equipment on VHF and UHF maritime mobile links are much less difficult than HF tests because the main contributors to multipath propagation are terrestrial reflecting objects, which give similar wave interference patterns from one day to another. The multipath delays are also much shorter than at HF so that there should normally be no frequency differential fading over the bandwidths used for the VHF channels. So long as tests are made over routes with several representative environments, it should be possible to make reliable comparisons of the performance of equipments and to establish the probable service range.

6.4 Tests of digital equipment using satellite relay should take into account both reflection from the ship structure by transmitting in many directions at different angles of elevation, and also reflection from the sea surface by making tests with the range of sea states likely to be encountered.

TABLE I

No.	Sample size in duty periods	Sample mean of (bits or character) error rates	Number of frequencies used	Name of shore stations taking part in the test	Name of ships taking part in the test	Cruising area of ships	No. of figures illustrating empirical and theoretical sample distributions	Remarks
1	54	9.5×10^{-3} (bit)	7	Moscow	"Novoaltaisk"	Indian Ocean	Fig. 1	Significance level of the criterion of agreement between empirical and theoretical curves for each of the samples did not exceed 0.05
2	110	7.4×10^{-3} (bit)	5	Odessa	"Novoaltaisk"	Indian Ocean	Fig. 2	
3	71	2.9×10^{-2} (character)	8	Moscow	"Novoaltaisk"	Atlantic Ocean	Fig. 3	
4	62	4.5×10^{-2} (character)	10	Moscow	"Novoaltaisk"	Indian Ocean	Fig. 4	
5	263	9.2×10^{-3} (bit)	12	Moscow, Odessa	"Novoaltaisk"	Atlantic and Indian Oceans	Fig. 5	
6	572	3.9×10^{-2} (character)	23	Moscow, Odessa, Vladivostok, Leningrad	Different ships	Atlantic, Indian and Pacific Oceans	Fig. 6	
7	373	3.8×10^{-2} (character)	14	Moscow, Odessa	"Novoaltaisk"	Atlantic and Indian Oceans	Fig. 7	
8	199	4.0×10^{-2} (character)	19	Archangel, Murmansk, Leningrad, Moscow, Odessa	Different ships	Atlantic Ocean, Mediterranean and Black Seas	Fig. 8	
9	104	2.2×10^{-2} (character)	7	Vladivostok	"Shota Rustaveli"	Pacific Ocean	Fig. 9 Curve 1	Without signal regenerator
10	109	8.1×10^{-3} (character)	7	Vladivostok	"Shota Rustaveli"	Pacific Ocean	Fig. 9 Curve 2	With signal regenerator

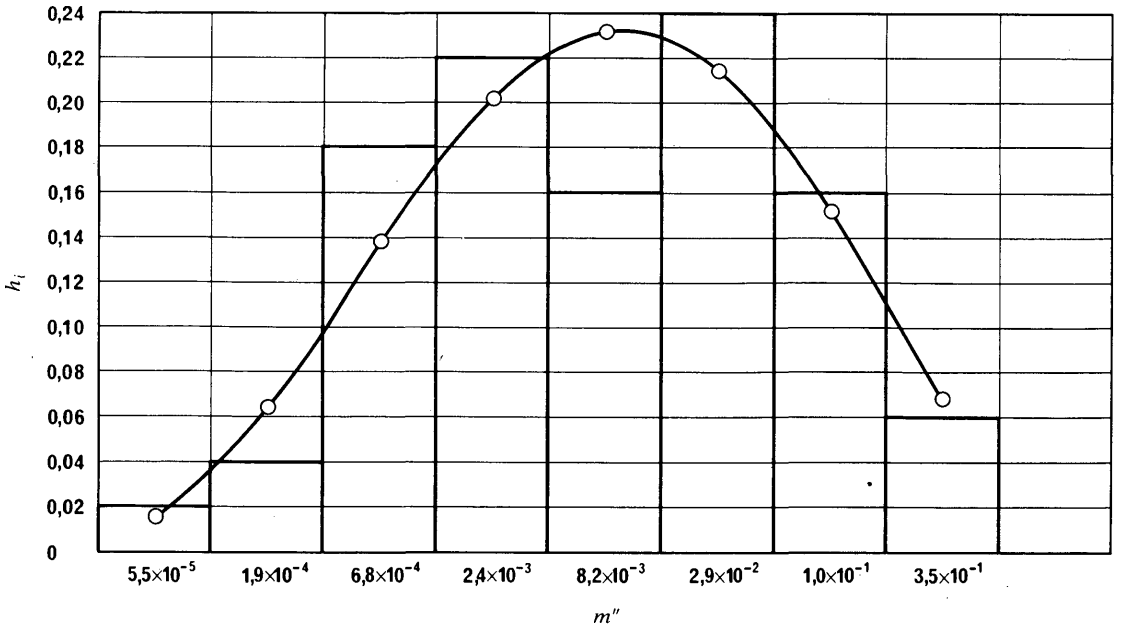


FIGURE 1

(See Table I, No. 1)

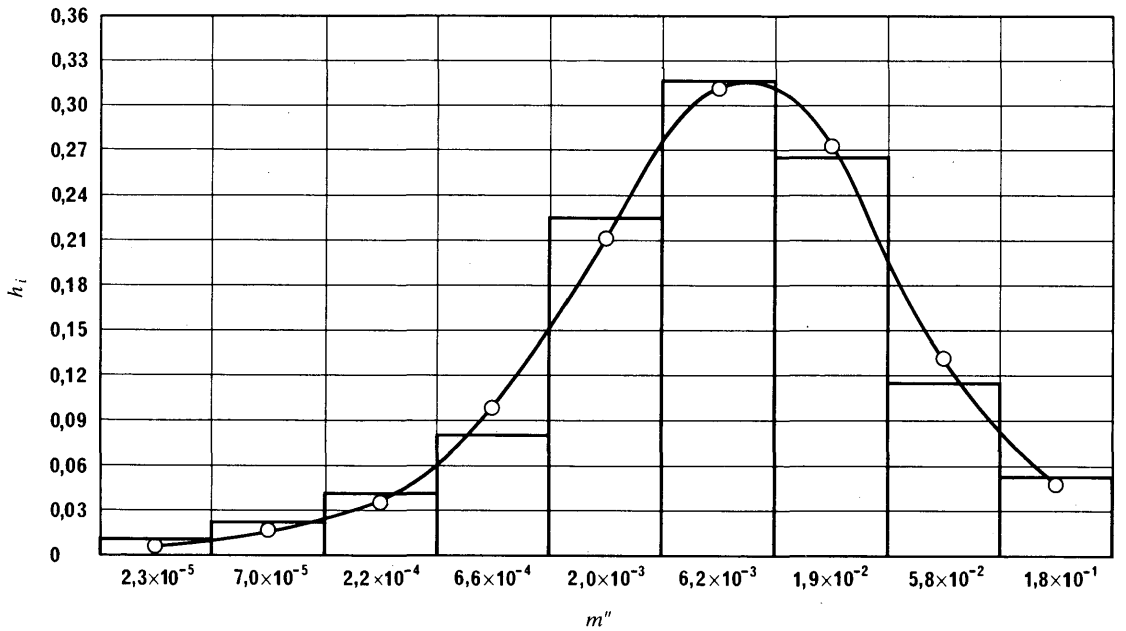


FIGURE 2

(See Table I, No. 2)

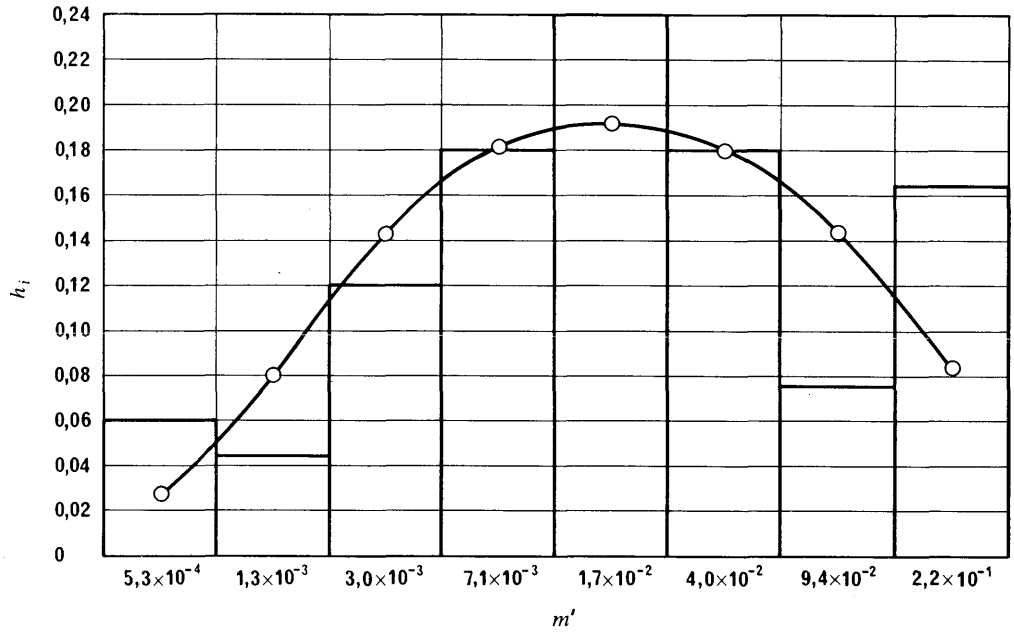


FIGURE 3

(See Table I, No. 3)

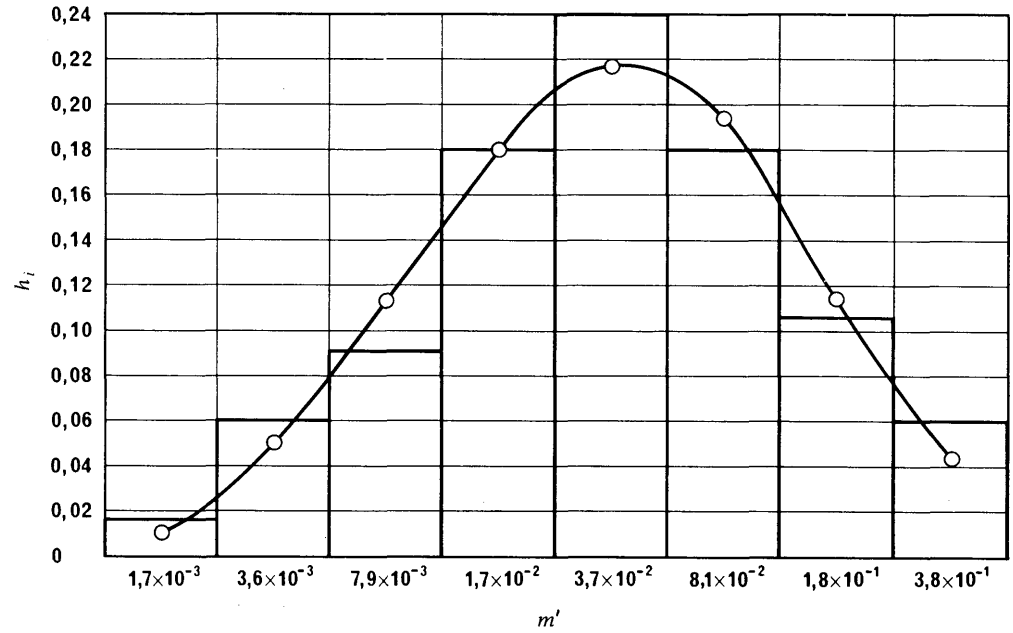


FIGURE 4

(See Table I, No. 4)

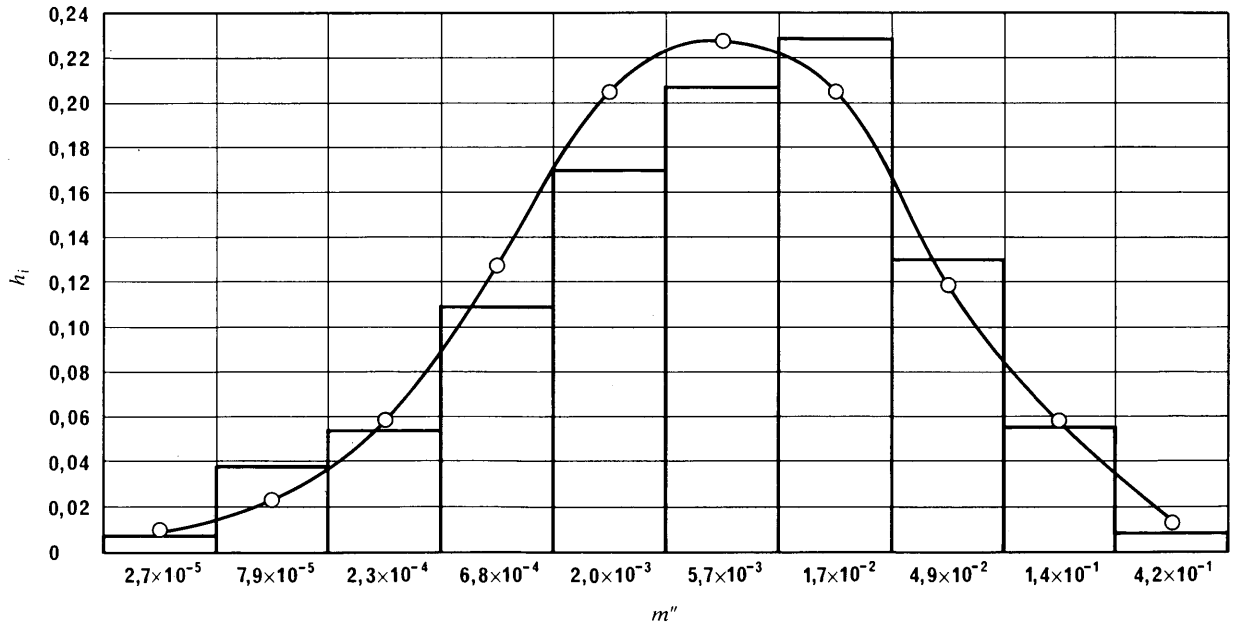


FIGURE 5

(See Table I, No. 5)

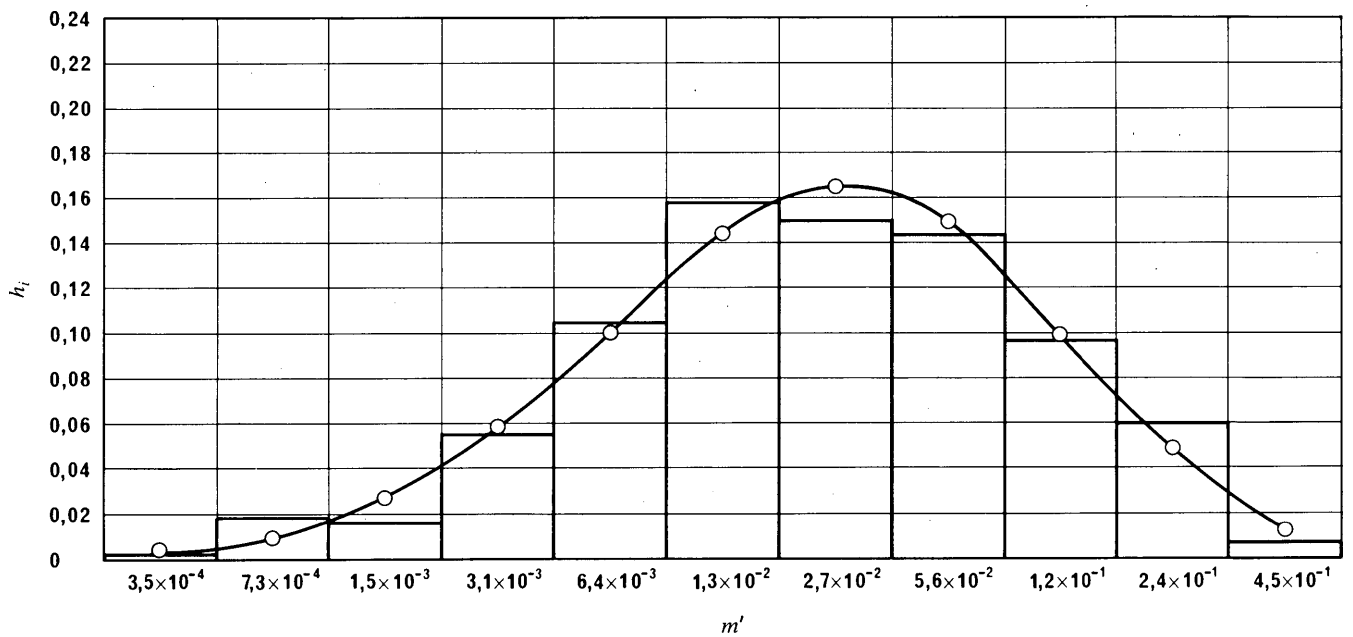


FIGURE 6

(See Table I, No. 6)

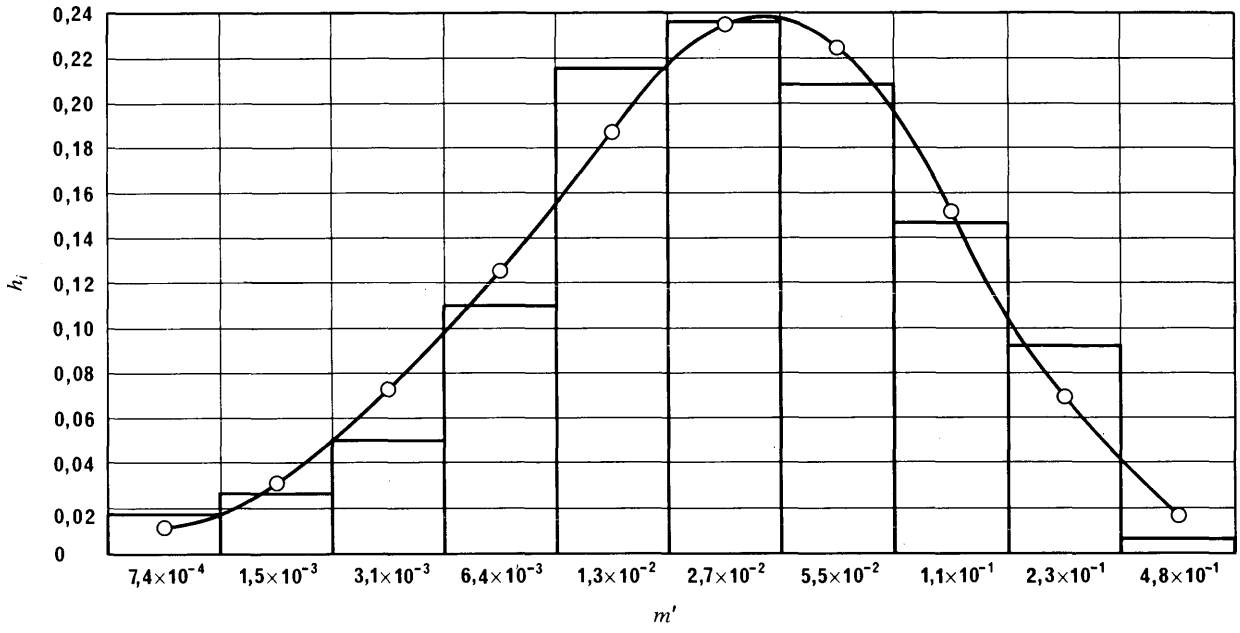


FIGURE 7

(See Table I, No. 7)

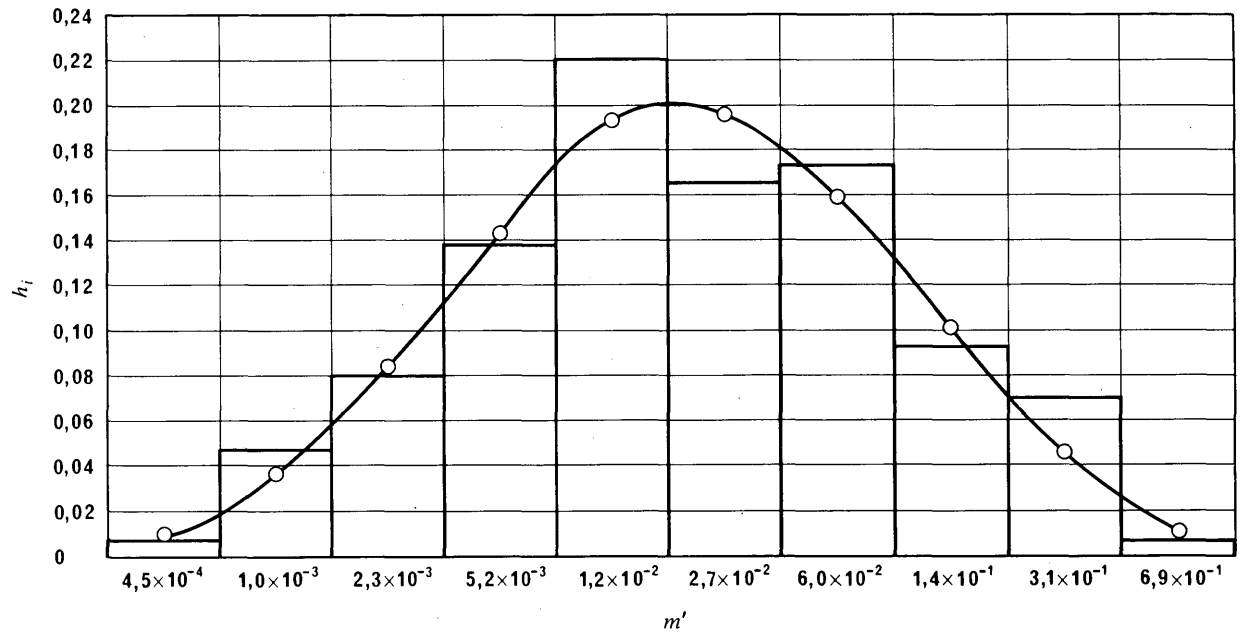


FIGURE 8

(See Table I, No. 8)

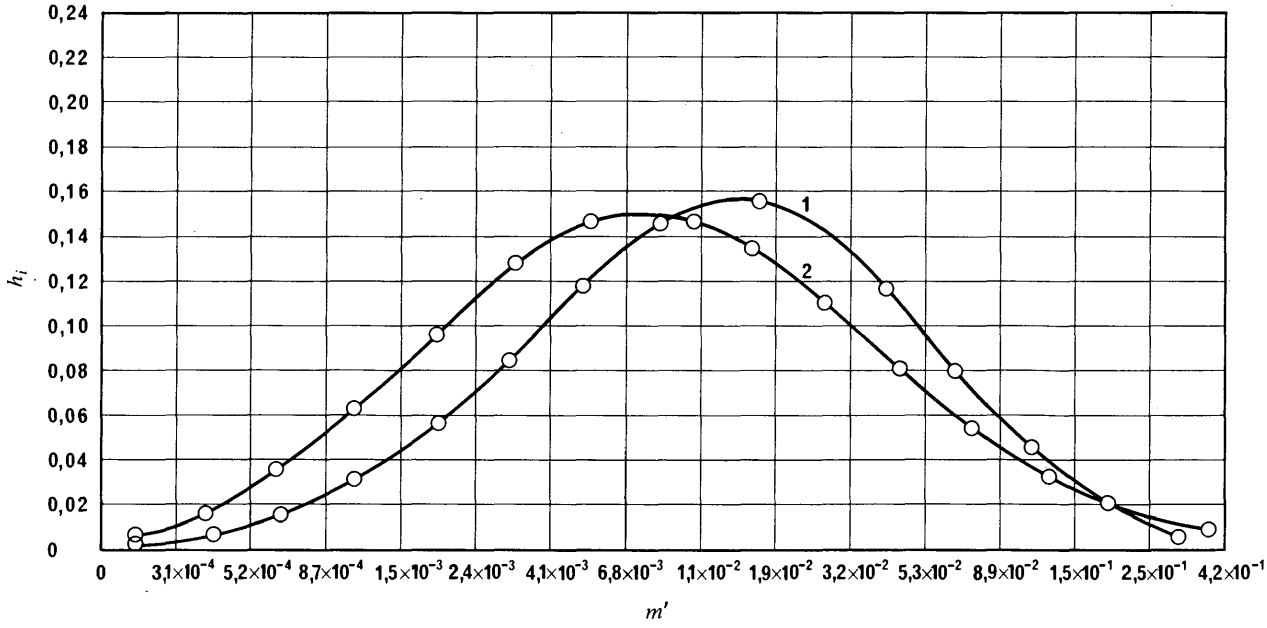


FIGURE 9

(See Table I, Nos. 9 and 10)

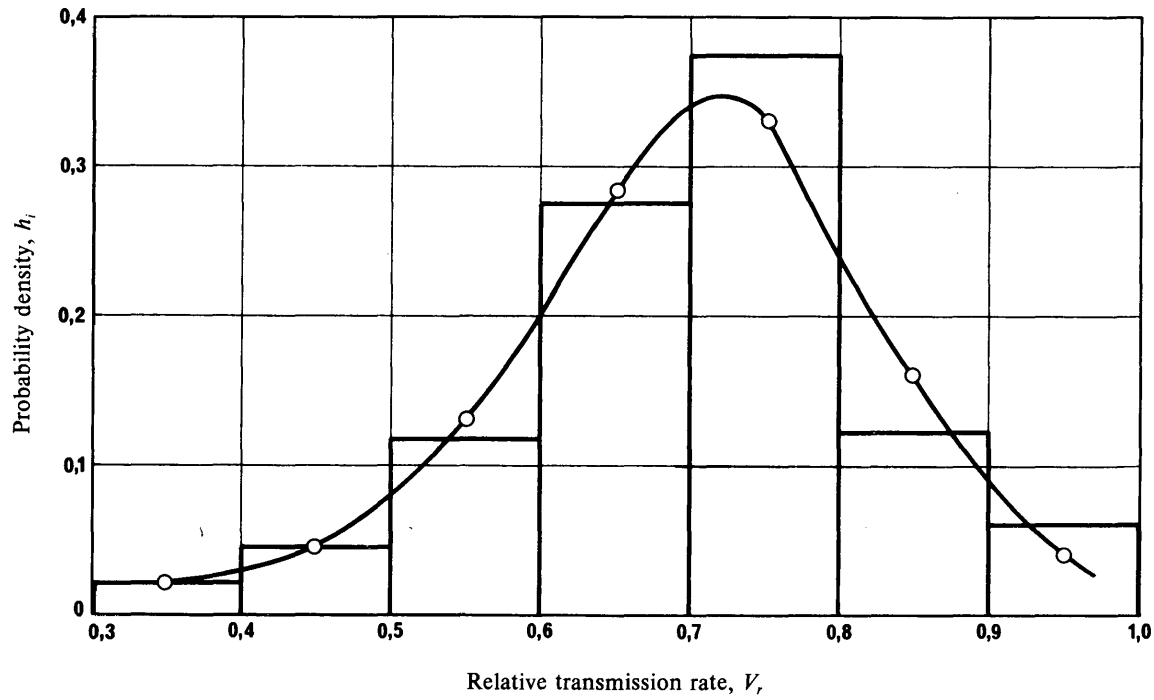


FIGURE 10 – *Distribution of the probability density*

7. Conclusions

7.1 The documentation in Study Group 3 is directly applicable to HF aspects of this question.

7.2 Statistics for the range of signal strengths and noise levels to be expected in HF ship-to-shore communications at all times and ranges are not available. Therefore a final assessment of equipment performance must at present be made on real transmission paths. Owing to the variability of propagation conditions with time, season and frequency, reliability can only be attained with tests over a long period. Direct comparison of different equipment should be made simultaneously, or not more than minutes apart.

7.3 HF path simulators have been made but cannot be considered generally available to administrations. Such simulators enable test conditions to be closely defined and repeated, if necessary, so that reliable comparisons of equipment can be made. There is however insufficient information about ship-to-shore signal strength and noise conditions to enable the path simulator to be set up with the confidence so it represents the communication conditions which occur in practice.

7.4 Until the transmission path parameters and noise statistics which are relevant to ship-to-shore communication conditions have been established, the range of values given in Annex I to Recommendation 520 should be used for path simulator tests.

7.5 Since the tests carried out do not cover all aspects of the problem of the objective evaluation of the quality of digital channels, and considering the importance of finding a solution, experimental and theoretical work should continue to provide answers to Question 42/8.

REFERENCES

KORN, G. and KORN, T. [1970] *Spravochnik po matematike dlya nauchnykh rabotnikov i inzhenerov* (Handbook of mathematics for scientists and engineers). Translated from English. Ed. Nauka, Moscow.

MITROPOLSKY, A. K. [1971] *Teknika statisticheskikh vychisleny* (Statistical calculation technique). Ed. Nauka, Moscow.

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SECTION 8C: MARITIME MOBILE SERVICE; TELEPHONY AND RELATED SUBJECTS

Recommendations and Reports

RECOMMENDATION 219-1

ALARM SIGNAL FOR USE ON THE MARITIME RADIOTELEPHONY DISTRESS FREQUENCY OF 2182 kHz

(1951-1953-1956-1966)

The CCIR,

CONSIDERING

(a) that it is desirable and practicable to establish an internationally agreed alarm signal for use on the calling and distress frequency of 2182 kHz (see Art. 39 of the Radio Regulations);

(b) that the alarm signal should be such as to:

- provide reliable operation of automatic alarm equipment;
- provide a distinctive signal, which is readily recognized aurally, when received on a loudspeaker or headphones;
- be capable of being received through interference from speech transmissions, through other kinds of interference, and through noise;
- avoid false responses when received either aurally or by automatic means;
- be capable of being produced by a simple manual device, as well as by automatic means;

(c) that the alarm signal should be such as to permit the construction of alarm equipment which is rugged, dependable, stable in performance, of low cost, of easy production, of long life with a minimum of maintenance, and which can be used with existing maritime radiotelephone equipment;

(d) that to help in clearing the calling and distress frequency channel of emissions from other stations the alarm signal and detecting device should be effective beyond the range at which speech transmission is satisfactory;

(e) that the automatic alarm equipment should be capable of operating, in as short a time as possible, consistent with the avoidance of false responses;

(f) that the results of the further examination of this problem by the administrations which participated in Study Programme 29, Geneva, 1951, are sufficiently conclusive to determine the essential characteristics of the signal, including tolerances that should be recommended for international adoption;

(g) that it is possible to specify the minimum performance standards for automatic alarm equipment, for both transmission and reception, to such an extent that future progress and development are not hampered;

(h) that it is undesirable that the specification of performance standards for automatic alarm equipment should exceed in scope the requirements already established by international agreement for automatic alarm devices, intended for the reception of the international alarm signal or the international distress signal in radiotelegraphy, normally transmitted on the frequency 500 kHz (see Nos. 3281 and 3282, and Appendix 36, § 1 of the Radio Regulations; and Chapter IV, Regulation 11 of the International Convention for the Safety of Life at Sea, London, 1974),

UNANIMOUSLY RECOMMENDS

1. that the alarm signal described below should be adopted internationally, for use on the maritime radiotelephony calling and distress frequency of 2182 kHz;

1.1 the alarm signal shall consist of two substantially sinusoidal audio-frequency tones, transmitted alternately. One tone shall have a frequency of 2200 Hz and the other a frequency of 1300 Hz. The duration of each tone shall be 250 ms;

1.2 the tolerance of the frequency of each tone shall be ± 1.5%; the tolerance on the duration of each tone shall be ± 50 ms; the interval between successive tones shall not exceed 50 ms; the ratio of the amplitude of the stronger tone to that of the weaker shall be within the range 1 to 1.2;

1.3 when generated by automatic means, the alarm signal shall be sent continuously for a period of at least 30 s but not exceeding one minute; when generated by other means, the signal shall be sent as continuously as is practicable over a period of approximately one minute;

2. that the automatic devices, intended for the reception of the alarm signal in question, should fulfil the following conditions:

2.1 the frequencies of maximum response of the tuned circuits, and other tone selecting devices, shall be subject to a tolerance of ± 1.5% in each instance; and the response shall not fall below 50% of the maximum response for frequencies within 3% of the frequency of maximum response;

2.2 in the absence of noise and interference, the automatic receiving equipment shall be capable of operating from the alarm signal in a period of not less than four and not more than six seconds;

2.3 the automatic receiving equipment shall respond to the alarm signal, under conditions of intermittent interference caused by atmospheric and powerful signals other than the alarm signal, preferably without any manual adjustment being required during any period of watch maintained by the equipment;

2.4 the equipment shall not be actuated by atmospheric or by strong signals other than the alarm signal;

3. that the automatic alarm equipment for both transmission and reception, on the calling and distress frequency of 2182 kHz, shall fulfil the following conditions:

3.1 the equipment shall be effective beyond the range at which speech transmission is satisfactory;

3.2 the equipment shall be capable of withstanding vibration, humidity, changes of temperature and variations in power supply voltage equivalent to the severe conditions experienced on board ships at sea, and shall continue to operate under such conditions;

3.3 the equipment should, as far as practicable, give warning of faults that would prevent the apparatus from performing its normal functions during watch hours;

4. that, before any type of automatic alarm equipment for transmission and reception on the calling and distress frequency of 2182 kHz is approved for use on ships, the administrations having jurisdiction over those ships should be satisfied by practical tests, made under operating conditions equivalent to those obtained in practice, that the equipment complies with the provisions of §§ 1, 2 and 3 of this Recommendation.

RECOMMENDATION 257-2

SELECTIVE-CALLING SYSTEM FOR USE IN THE MARITIME MOBILE SERVICE

(1959-1970-1978)

The CCIR,

CONSIDERING

(a) that selective calling of ships by coast stations would expedite the handling of traffic in the maritime mobile service;

(b) that a selective-calling system has the following advantages:

- it is rapid and positive;
- it overcomes the disadvantages of ships having to listen to all calls;
- it reduces the difficulties caused by differences of language;
- it reduces the time taken by coast stations to establish contact with ships and thus reduces congestion on the channels used for calling;
- it increases operating efficiency generally;

(c) that a number of administrations have an immediate requirement for selective-calling facilities;

(d) that ideally, a selective-calling system should be suitable for use in all maritime mobile bands;

(e) that a selective-calling system should have sufficient capacity of code numbers to accommodate all ships that desire to use it;

(f) that the Inter-Governmental Maritime Consultative Organization (IMCO) has expressed in its letter of 2 November, 1966, the opinion that it would be desirable from the viewpoint of maritime safety, if selective-calling devices could include a facility for calling all ships;

(g) that there may be a need for a facility to call predetermined groups of ships;

(h) that it may be operationally desirable for a ship's operator to be able to ascertain either the identity of the coast station which has called him, or the VHF channel on which he should reply;

(j) that a selective-calling system should be suitable for use with normal types of radio equipment on ships,

UNANIMOUSLY RECOMMENDS

1. that, where there is a need to fulfil immediate requirements for selective calling, the system to be used should have the following characteristics;

1.1 the selective call signal should consist of five figures representing the code number assigned to a ship for selective calling;

1.2 the audio-frequency signal applied to the input of the coast station transmitter should consist of consecutive audio-frequency pulses conforming to the following:

1.2.1 the audio frequencies used to identify the figures of the code number assigned to a ship should conform to the following series:

TABLE I

Figure	1	2	3	4	5	6	7	8	9	0	Figure repetition
Audio frequency (Hz)	1124	1197	1275	1358	1446	1540	1640	1747	1860	1981	2110

For example, the series of audio-frequency pulses corresponding to the selective call 12133 would be 1124-1197-1124-1275-2110 Hz, and the series corresponding to the code number 22222 would be 1197-2110-1197-2110-1197 Hz:

1.2.2 if the series of numbers represented by the use of only two frequencies, chosen from those in § 1.2.1, are reserved for calling predetermined groups of ships, then 100 different groups of numbers are available for allocation, according to the needs of administrations;

1.2.3 the waveforms of the audio-frequency generators should be substantially sinusoidal, not exceeding 2% total harmonic distortion;

1.2.4 the audio-frequency pulses should be transmitted sequentially;

1.2.5 the difference between the maximum amplitude of any audio-frequency pulses should not exceed 1 dB;

1.2.6 the duration of each audio-frequency pulse, measured between the half-amplitude points, should be 100 ms ± 10 ms;

1.2.7 the time interval between consecutive pulses, measured between the half-amplitude points, should be 3 ms ± 2 ms;

1.2.8 the rise and the decay time of each audio-frequency pulse, measured between the 10% and 90% amplitude points, should be 1.5 ms ± 1 ms;

1.2.9 the frequency tolerance of the audio frequencies given in § 1.2.1 should be ± 4 Hz;

1.2.10 the selective call signal (ship's code number) should be transmitted twice with an interval of 900 ms ± 100 ms between the end of the first signal and the beginning of the second signal (Fig. 1);

1.2.11 the interval between calls from a coast station to different ships should be at least 1 s (Fig. 1); but the interval between calls to the same ship, or the same group of ships, should be at least 5 s;

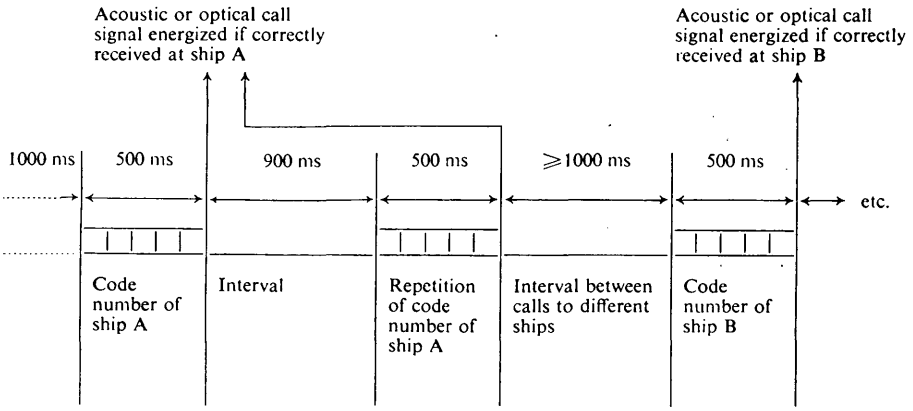


FIGURE 1 – *Composition of selective call signals without additional information*

2. that if additional information is added to the selective call signal it should be as follows:

2.1 to identify the calling coast station four figures should be transmitted;

2.2 to identify the VHF channel on which a reply is required two "zeros" followed by two "figures" should be transmitted;

2.3 the characteristics of the signals should conform to §§ 1.2.1 and 1.2.3 to 1.2.9 inclusive;

2.4 the composition of the signal should be as shown in the diagram (Fig. 2), the tolerance on the 350 ms interval being ± 30 ms;

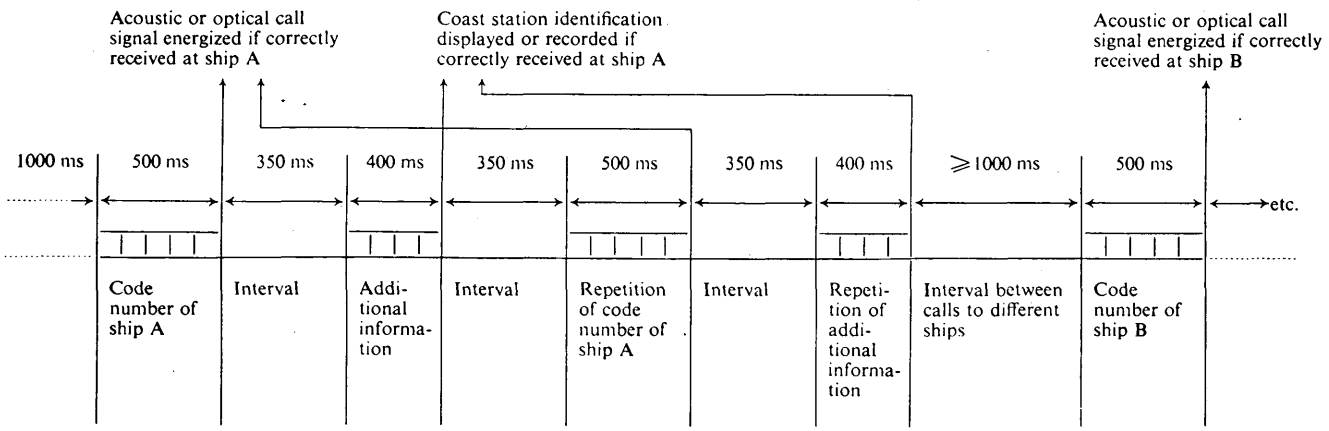


FIGURE 2 – *Composition of selective call signals with additional information*

3. that an "all ships call" to actuate the receiving selectors on all ships, regardless of their individual code numbers, should consist of a continuous sequential transmission of the eleven audio frequencies given in § 1.2.1. The parameters of the audio-frequency pulses should be in accordance with §§ 1.2.3, 1.2.4, 1.2.5 and 1.2.9. The duration of each audio-frequency pulse, measured between the half-amplitude points, should be 17 ms ± 1 ms and the interval between consecutive pulses, measured between half-amplitude points, should not exceed 1 ms (Fig. 3). The total duration of this "all ships call" signal should be at least 5 s;

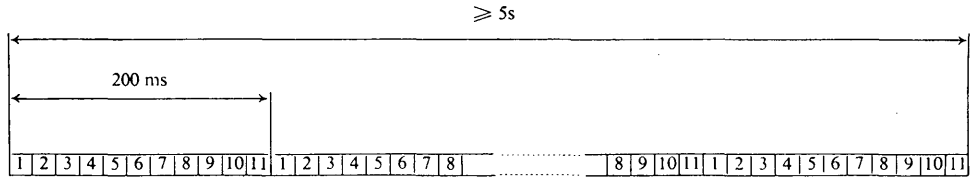


FIGURE 3 – *Composition of the "all ships call" signal*

4. that receiving selectors on ships should operate reliably in any radio conditions acceptable for satisfactory communication;

5. that the receiving selector should be designed to accept the signals as defined in §§ 1 and 3. However, bearing in mind that coast stations may transmit additional signals (e.g. coast station identification), it is important to ensure that during reception of a selective call the decoder should be re-set after 250 ± 40 ms if an incorrect digit or no digit is received;

6. that the receiving selector should be so designed, constructed and maintained that it is resistant to atmospherics and other unwanted signals including selective-calling signals other than that for which the decoder has been set up;

7. that the receiving selector should include an audible or visual means of indicating the receipt of a call and, if required, an additional facility allowing the determination of the identity of the calling station or the VHF channel on which to reply according to the needs of administrations;

8. in order to distinguish whether an incoming call is a normal selective call or an "all ships call", the multiple actuation of the ship's decoder by the "all ships call" signal (see § 3) can be used;

9. that the indicating means mentioned in § 7 should be actuated on correct reception of the calling signal, no matter whether the correct registration has occurred on the first, or the second, or both parts of the calling signal transmitted by the coast stations;

10. that the indicating means should remain actuated until re-set manually;

11. that the receiving selector equipment should be as simple as is practicable, be capable of reliable operation over long periods with a minimum of maintenance, and could, with advantage, include facilities for self-testing.

Note. – The Director, CCIR, is requested to bring the contents of this Recommendation to the attention of IMCO.

REPORT 93

HF (DECAMETRIC) AND VHF (METRIC) DIRECTION-FINDING *

(1956)

1. Introduction

Two documents [CCIR, 1956a and b] were submitted to the VIIIth Plenary Assembly in response to Question 106. A summary of these two documents, and of the discussion on them, is given below.

It was generally agreed that, whenever possible, the accuracy of bearings and positions and their classification should be based on the probability concept.

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* See also Appendix 41 to the Radio Regulations.

[CCIR, 1956b] expresses bearing accuracies in the form of errors that are exceeded on only 1 occasion in 20 and [CCIR, 1956a] gives the standard deviation error. For ease of comparison of results, all accuracies have been expressed in a common form in this Report.

2. Accuracy of HF (decametric) bearings

The accuracy of HF (decametric) bearings depends principally upon the following factors:

- type of direction-finding (DF) equipment, for example, Adcock type,
- type of site,
- frequency,
- range and signal strength,
- ionospheric conditions, particularly diurnal variations,
- amount of interference,
- number of bearings taken,
- skill of the operator.

By day, the error which is exceeded on only 1 occasion in 20 (referred to subsequently as the 95% error) lies between about 3° and 10° for ranges of the order of 500 to 4000 km, depending on the site, frequency, and whether a group of bearings is taken or only one snap bearing. More detailed data are given in Annex I. At night, errors are somewhat greater, by amounts of up to about 1°. At distances less than 500 to 1600 km (depending on ionospheric conditions), the error progressively increases, and may rise to as large as 10° to 20° until the ground wave or the E-layer mode of propagation predominates. In general, errors are less at the higher frequencies.

3. Accuracy of VHF (metric) bearings

In the United Kingdom, the 95% error of VHF aeronautical direction-finding stations is generally about 5°, but in the United States it has been found that the 95% error is usually about 12° on transmissions from aircraft. The difference is probably due mainly to the effects of differences of siting, since with refinements in siting, the 95% error is reduced to about 4° in the United States. At long ranges, beyond the normal service area, VHF direction-finding bearings in the United States have been found to be sporadic, but the accuracy is sometimes as good as 6°.

4. Accuracy of HF (decametric) position fixing

The accuracy of position fixing depends principally on the "geometry" of the direction-finding network, its size and its disposition with respect to the transmitting station concerned, the degree to which the various stations can take simultaneous bearings and act in unison, and the number of stations in the network. The greatest accuracy is obtained when the most probable position of the transmitting station can be evaluated statistically, although in certain applications it is recognized that statistical evaluation may not be practicable or of operational importance. The accuracy of a direction-finding fix can be expressed in terms of the size, position and orientation of the ellipse in which the transmitting station lies with a given probability. Various methods for deriving and plotting probability ellipses are given in the references [CCIR, 1956b].

5. Accuracy of VHF (metric) position fixing

The accuracy of VHF position fixing can be determined in a manner similar to that for HF. But in the aeronautical mobile service, which is one of the main users of VHF direction-finding, there is not usually sufficient time to evaluate the accuracy of a fix because of the high speed of the aircraft. At VHF, the problem may be simpler than at HF because the direction-finding networks, in general, will be smaller and can more easily be controlled automatically and have a central automatic display.

6. Classification of bearings in general

It was considered that it would be very advantageous to have a common classification system of bearings for all frequency bands (MF, HF and VHF) and for all types of service, for example, the maritime mobile and aeronautical mobile.

7. Classification of HF (decametric) bearings

The United States proposed a subjective method of classification by the operator for describing to the plotting centre the conditions under which a bearing has been taken. The factors that the operator should take into account are strength of signal, sharpness of the null, amount of fading and interference, the amount of goniometer swing required in taking the bearing and the number of bearings that have been taken in the time available. The proposed system of classification is as follows:

Class A – Bearing appears GOOD, meeting the following requirements:

(1) strong signal,

(2) definite indication (sharp null, etc.),

(3) negligible fading,

(4) negligible interference,

(5) less than 3° of arc of bearing swing,

(6) observed repeatedly for an adequate period of time.

Class B – Bearing appears FAIR, being degraded by one or more of the following factors:

(1) marginal signal strength,

(2) blurr (blunting) of indication,

(3) fading and/or audio distortion,

(4) light interference,

(5) more than 3°, but less than 5° of arc of bearing swing,

(6) short observation time.

Class C – Bearing appears POOR, being degraded by one or more of the following factors:

(1) inadequate signal strength,

(2) severe blurr (blunting) of indication,

(3) severe fading and/or audio distortion,

(4) strong interference,

(5) more than 5° of arc of bearing swing,

(6) insufficient observation time.

The United Kingdom proposed that the accuracy of a bearing should be evaluated statistically from a knowledge of the five component variances which make up the total variance of the bearing, namely, instrumental, site, propagation, random-sampling and observational components. The bearing would then be classified as follows:

Class A: probability of less than 1 in 20 that the error exceeds 2°,

Class B: probability of less than 1 in 20 that the error exceeds 5°,

Class C: probability of less than 1 in 20 that the error exceeds 10°,

Class D: bearings whose accuracy is less than that of Class C.

8. Classification of VHF (metric) bearings

It was considered that time alone prevents the classification of VHF bearings taken on transmission from aircraft and it is not possible for the operator to classify bearings. But the United Kingdom suggested that it would be helpful if VHF aeronautical *stations* were classified, based upon flight-checking procedures. All bearings would then be given the classification of the station, unless they were taken under conditions inferior to those under which the station was calibrated.

9. Classification of HF (decametric) position-fixes

It was generally agreed that the accuracy of a fix-position should, whenever time permits, be given in terms of probability ellipses. The United Kingdom proposed that no formal classification be adopted since the size and shape of the ellipse for a given probability depends upon the "geometry" of the network and the transmitting

station, the ionospheric conditions, etc. Where time is important, the USA proposed that the most probable fix-position would be given in degrees and minutes of latitude and longitude and should be classified as the equivalent circle in which the transmitting station probably lies:

Classification	Limit of areas
Good	40 km radius, or less
Fair	80 km radius, or less
Poor	120 km radius, or less
Estimated	more than 120 km radius

10. Classification of VHF (metric) position-fixes

For the aeronautical mobile service, it was considered that classification in terms of probability ellipses was not likely to be practicable or useful. The United Kingdom made no proposals on this point; the USA proposed the following classification:

Classification	Limit of areas
Good	4 km radius, or less
Fair	8 km radius, or less
Poor	12 km radius, or less
Estimated	more than 12 km radius

11. Aeronautical aspects

It was considered that since VHF direction-finding stations are widely used in civil aviation, administrations should be invited to seek the advice of the International Civil Aviation Organization (ICAO) on all the aeronautical aspects of VHF direction-finding and position-finding.

12. Type of signal for VHF (metric) direction-finding

In general, the signal for VHF direction-finding purposes should include long dashes of at least 5 s duration, but the direction-finding station should also be permitted to specify the duration of the signal in certain circumstances. In the aeronautical mobile service, the procedure laid down by the ICAO has been found satisfactory. This specifies two dashes of plain carrier, each of approximately 10 s duration, followed by the call sign of the aircraft, unless another signal has been requested or is known to be required by the direction-finding station.

REFERENCES

CCIR Documents

[1956]: **a.** 67 (USA); **b.** 232 (United Kingdom).

ANNEX I

APPROXIMATE ERROR (IN DEGREES) WHICH MAY BE EXPECTED TO BE EXCEEDED ON ONLY 1 OCCASION IN 20

Conditions:
- HF Adcock direction-finder
- Daylight
- Ranges between about 500 and 4000 km.

TABLE I

Type of site	3 MHz		6 MHz		9 MHz	
	Single snap bearing	Mean of 10 bearings taken in 5 min	Single snap bearing	Mean of 10 bearings taken in 5 min	Single snap bearing	Mean of 10 bearings taken in 5 min
Very good	7	6	6	5	6	4
Good, average	10	9	8	7	7	6

RECOMMENDATION 422

PULSE TRANSMISSION FOR RADIO DIRECTION-FINDING

(1953-1963)

The CCIR,

CONSIDERING

(a) that certain studies, extending over many years, of the errors of direction finders show that, under ideal conditions of site, equipment and operation, the use of pulse transmissions offers only a slight improvement in accuracy over the use of continuous-wave transmissions;

(b) that, in practice, unavoidable departures from the ideal conditions referred to in § *(a)* would tend to reduce this improvement in accuracy;

(c) that pulse transmissions occupy wide bandwidths,

UNANIMOUSLY RECOMMENDS

that the use of pulse transmissions for radio direction-finding at frequencies below 20 000 kHz is generally undesirable.

ANNEX I

The following errors in high-frequency direction-finding can occur:

1. observational errors introduced by the operator;

2. instrumental errors, including polarization errors and those due to deficiencies of the direction-finder site;

3. errors due to radiation scattered from topographical features many wavelengths distant from the direction finder;

4. errors due to lateral deviation in the ionosphere;

5. errors due to wave interference caused by convergence of rays and by different modes of propagation.

The advantage of a pulse emission over a continuous-wave emission lies in its ability to allow signals arriving over different paths to be separated, and so to reduce errors arising from sources 4 and 5 above.

The degree of accuracy to be expected from the use of pulse emissions for radio direction-finding has been studied, and it is estimated that in most favourable circumstances, for a frequency of about 8000 kHz, the standard deviation of a single rapidly observed bearing might be about 3° for a continuous-wave emission and about 2° for a pulse emission. The corresponding figures for the mean of ten such bearings taken in a period of five minutes are: continuous-wave 2.5°, pulse 1.7°.

RECOMMENDATION 423-2

USE OF 8364 kHz FOR RADIO DIRECTION-FINDING

(1951-1956-1959-1963-1966-1970)

The CCIR,

CONSIDERING

(a) that Nos. 2988, 3002 and 3005 of the Radio Regulations concern the use of the frequency 8364 kHz;

(b) that land stations keep watch during their hours of service in the band 8356 to 8374 kHz of which 8364 kHz is approximately the centre;

(c) that Regulations 13 and 14 of Chapter IV of the International Convention for the Safety of Life at Sea, London, 1974, indicate minimum specifications for automatic distress transmitters;

(d) that tests and operational experience have shown that radio direction-finding at 8364 kHz may be a valuable aid (in conjunction with direction-finding at 500 kHz) in finding the position of both aircraft and ships in distress and survival craft;

(e) that complete coverage cannot be obtained with direction-finding on only one frequency in the HF (decametric) band because of the limitations caused by radio-propagation conditions;

(f) that HF (decametric) radio direction-finding requires apparatus as free as possible from local site error and polarization error;

(g) that the accuracy of the bearing will depend upon the field strength of the signal and the signal/noise ratio;

(h) that in view of the rapid variation of the apparent azimuth of the bearing which is frequently observed in HF (decametric) radio direction-finding, measurements should be made over several minutes to obtain a more accurate mean bearing; and that the bearing and fix may be improved subsequently by a further series of measurements;

(j) that standardized distress transmissions are desirable;

(k) that it is essential to have a means of rapid communication between the watch-keeping station and the direction-finding stations,

UNANIMOUSLY RECOMMENDS

1. that the site of the HF (decametric) radio direction-finding station should be, as far as possible:

1.1 flat and horizontal for a radius preferably of at least 200 m, with the surrounding neighbourhood flat and free from obstruction;

1.2 of high and uniform ground conductivity;

1.3 free from large metallic masses and objects likely to resonate at frequencies near to 8364 kHz;

2. that the antenna system should be as free as possible from wave polarization error (e.g. Adcock systems and spaced-loop systems);

3. that the bandwidth of the direction-finding receiver, used when bearings are taken, should be as narrow as possible, compatible with the modulation and frequency stability of the signal on 8364 kHz and that a broader bandwidth position should also be incorporated in the receiver for watch-keeping purposes;

4. that the sensitivity of the direction-finding equipment should be such that it operates satisfactorily with a field strength as low as 5 μV/m;

5. that the bearing should be determined by an aural null-method or by any other method of comparable or better accuracy;

6. that the direction-finding equipment should be adjusted, balanced and calibrated at frequent intervals at the frequency of 8364 kHz;

7. that the signal radiated by survival craft should be as strong as possible and stable in frequency to ensure the greatest accuracy in determining the bearings;

8. that the signals transmitted by survival craft should preferably include long dashes sent over a period of not less than five minutes for direction-finding purposes;

9. that, to give as great an accuracy of fix as possible, several widely spaced and interconnected direction-finding stations should be employed (see Annex I);

10. that the attention of administrations concerned should be drawn to the advantage of their studying further:

10.1 the most suitable type of network for providing rapid communication between direction-finding stations and plotting centres;

10.2 the most suitable way in which information should be exchanged between different stations or networks (e.g. use of "Q" code);

10.3 the best way to evaluate the most probable fix (position) from bearings supplied by the diection-finding stations;

11. that the attention of administrations should also be drawn to the fact that world-wide direction-finding coverage cannot be obtained with only one frequency in the HF (decametric) band.

ANNEX I

ACCURACY OF BEARINGS AT 8364 kHz

At distances greater than about 1200 km the root-mean-square (r.m.s.) bearing error to be expected with a modern HF (decametric) direction-finding system is of the order of 3° to 5°.

At distances less than 1200 km the error progressively increases with decrease of distance to values of the order of 5° to 10°; at small distances, less than about 100 km, the error may be even greater than 10°.

The above figures refer to the arithmetic mean of bearings spread over an interval of not more than about 10 min.

RECOMMENDATION 428-2

DIRECTION-FINDING AND/OR HOMING * IN THE 2 MHz BAND ON BOARD SHIPS

(1963-1966-1970)

The CCIR,

CONSIDERING

(a) that, according to the International Convention for the Safety of Life at Sea, London, 1974, the medium frequency radiotelephony calling and distress frequency of 2182 kHz will become of increasing importance to the safety of life at sea;

(b) that, in most distress cases, merchant ships and fishing vessels and other surface craft participate in search and rescue;

(c) that in addition to ships between 500 and 1600 tons gross tonnage, which are already required to be fitted with medium frequency radiotelephone equipment if they do not carry medium frequency radiotelegraph equipment, ships between 300 and 500 tons gross tonnage will also be required to fit such equipment, in accordance with Chapter IV, Regulation 4 of the International Convention for the Safety of Life at Sea, London, 1974;

(d) that a large number of ships of more than 1600 tons gross tonnage (which are compulsorily fitted with medium frequency radiotelegraph equipment) are voluntarily fitted with medium frequency radiotelephone equipment and that the number of such ships is increasing;

(e) that the majority of deep-sea fishing vessels are fitted voluntarily with medium frequency radiotelephone equipment;

(f) that an increasing number of ships are being fitted with direction-finding equipment capable of taking bearings in the 2 MHz band;

(g) that direction-finding and especially homing by ships is important in cases of distress;

(h) that Recommendation No. 31 of the International Conference on Safety of Life at Sea, London, 1960, drew the attention of contracting governments to the studies being undertaken under Question 2/XIII of former Study Group XIII by the CCIR;

(j) that technical studies in several countries have shown:

j.a. that direction-finding, or at least homing, is usually possible in the 2 MHz band on many ships;

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* For the purpose of this Recommendation "homing" means the taking of direction-finding bearings without ambiguity of sense within an arc of 30° on either side of the bow.

j.b. that compared with the problems of direction-finding by ships in the lower parts of the medium frequency band, the main cause of error in direction-finding in the 2 MHz band is re-radiation from various parts of the ship's superstructures, masts, downleads, halyards, stays, derricks, etc., and from other antennas;

j.c. that errors caused by re-radiation effects, however, should be constant if the disposition and electrical conditions of the re-radiators are constant and that such errors can be taken into account by calibrating the direction-finder;

j.d. that direction-finding and homing is easier on board small ships than on larger ones, because an increase in the size of ships and their superstructures, masts, etc., as given in § *j.b.* leads to an increase of disturbing resonance effects;

j.e. that a reliable direction-finder calibration can be more readily obtained if it is restricted to a specific frequency such as 2182 kHz, instead of a wide frequency band;

j.f. that even where omnidirectional direction-finding, even on a specific frequency, is difficult or impossible (such as on board large vessels with strong re-radiation effects), homing will nearly always be possible,

UNANIMOUSLY RECOMMENDS

1. that the following technical measures and precautions should be observed when installing direction-finders for taking bearings in the 2 MHz band, and in particular for homing on the frequency 2182 kHz;

1.1 the antenna system, including the sense antenna, of the direction-finder should be erected as far as possible away from any re-radiators;

1.2 the direction-finder antenna system should, preferably, be installed on the fore-and-aft line of the ship;

1.3 if the direction-finding antenna system is to be fitted on a mast it should preferably be installed symmetrically on top of the mast and not to one side of it; where a mast-head installation may require the use of longer cables, their possible influence on the bearing should be taken into consideration;

1.4 the mounting of the direction-finding antenna system may be considered satisfactory for homing purposes if the calibration in the sector ahead as in § 2.5 has proved to be possible;

1.5 if the resonance frequency of a mast and its rigging is within approximately ± 20% of the frequency used for direction-finding, then the antenna system of the direction-finder should not in general be mounted on or near the top of the mast, unless the antenna system is one which is not influenced by the mast resonance. The calculation or assessment of the resonance frequency should take into account the effect of the antenna system of the direction-finder;

1.6 that the sense antenna should be mounted on or as near as is practicable to the central axis of the antenna system of the direction-finder;

1.7 the effects caused by re-radiating antenna wires can be minimized by providing properly located isolating switches for the antennas;

1.8 re-radiation from the rigging (e.g. stays, wire ropes, etc.) should be reduced by the insertion of insulators such that the resonance frequency of the longest portion is considerably above the highest frequency used for direction-finding or considerably above 2182 kHz where the installation is used for homing only;

1.9 the formation of "closed loops", e.g. by the rigging, should be avoided by inserting insulators at appropriate points;

1.10 to avoid electrically doubtful connections, the connecting points of movable parts of the rigging and connections between masts and derricks, wire ropes, etc., should be short-circuited as far as possible;

2. that the following measures and precautions should be observed in the calibration of direction-finders for the 2 MHz band and in particular for homing on the frequency 2182 kHz;

2.1 the rigging, downleads, derricks, halyards, etc. should be in their sea-going positions;

2.2 any antennas that affect the direction-finder should preferably be isolated and other antennas which cannot be isolated (for example, because of operational requirements), should be in the same condition as they will be when bearings are being taken or when homing is being done at sea; the condition and electrical arrangement of all antennas should be noted on the direction-finder calibration charts;

2.3 calibration in the forward direction for the purpose of homing (or a more complete calibration if so desired) should be carried out in an area well clear of the shore and of other ships. If a shore-based transmitter is used, calibration should be carried out on a line passing through that station and crossing the coast-line approximately at right angles. The transmitting antenna should radiate vertically polarized waves from a single element, and care should be taken to avoid re-radiation from any object in the vicinity. The distance between the transmitting antenna and the direction-finder should be great enough to avoid the calibration being affected by the induction field of the transmitting antenna;

2.4 care should be taken to ensure that the direction-finder gives the correct sense on all bearings and frequencies concerned and in particular for homing purposes on the frequency 2182 kHz, within a sector of 30° on both sides of the bow;

2.5 the calibration, if not complete, should at least cover a sector of 30° on both sides of the bow, and as far as possible should be made at sufficiently small bearing intervals (say, in steps of a few degrees) to detect any sudden changes (for example, re-entrant portions where two or more different corrections exist for the same indicated bearing);

2.6 calibration at 2182 kHz should be carried out at a frequency as near as possible to 2182 kHz, special attention being paid to No. 3023 of the Radio Regulations, and to the avoidance of interference to established operations in adjacent channels;

3. that the calibration should be checked periodically, especially if the condition of the rigging, etc. has been altered since the last calibration;

4. that on board ships equipped with a direction-finder, the frequency range of which includes the 2 MHz band, a calibration should be made to determine if the direction-finder could be used without modification for omnidirectional direction-finding, or at least for homing on the frequency 2182 kHz;

5. that when administrations encourage the use of direction-finders on board ship, capable of operating in the 2 MHz band, or at least on the international radiotelephony distress and calling frequency 2182 kHz, they should also encourage the provision of suitable facilities for the calibration of such direction-finder equipment;

6. that the Director, CCIR, should be invited to bring this Recommendation to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) (reference is made to Recommendation No. 31 of the International Convention for the Safety of Life at Sea, London, 1960);

7. that administrations should bring the above Recommendation to the attention of those responsible for the provision, installation and maintenance of direction-finders on ships.

ANNEX I

Under good conditions, when the above precautions and technical measures have been taken, an accuracy of about ± 2° can be attained in taking bearings in the 2 MHz band by reception of "ground" waves on board ships of less than about 800 tons gross tonnage. In unfavourable conditions, for example, when the ship is pitching and rolling, an accuracy of about ± 5° can be obtained. On larger ships, the accuracy may be worse, but in most cases it should usually be possible to use the direction-finder for homing purposes on 2182 kHz. Bearings taken by reception of sky-waves, although variable in azimuth and sharpness, are useful for homing into the ground-wave range by utilizing their average value.

RECOMMENDATION 488 *

EQUIVALENT POWERS OF DOUBLE-SIDEBAND AND SINGLE-SIDEBAND RADIOTELEPHONE EMISSIONS IN THE MARITIME MOBILE SERVICE

(1974)

The CCIR,

CONSIDERING

(a) that according to the International Convention for the Safety of Life at Sea, London, 1974, in the 2 MHz band using A3E emissions, it may be assumed that clearly perceptible signals will be obtained by day and under normal conditions and circumstances at 150 nautical miles by a power in the antenna of 15 W (unmodulated carrier) with an antenna efficiency of 27%;

(b) that clearly perceptible signals are assumed to be received when the r.m.s. value of the field strength produced at the receiver by the unmodulated carrier is at least 25 μV/m;

(c) that in normal operation the transmitter shall have a depth of modulation of at least 70% at peak intensity;

(d) that in the interest of more efficient spectrum utilization Resolution No. 306, Geneva, 1979, of the Radio Regulations requires the conversion by 1 January 1982, of all maritime emissions in the 2 MHz band to SSB except those on 2182 kHz, which may be A3E or H3E;

(e) that the Safety Convention requires that transmitters use the classes of emission assigned by the Radio Regulations;

(f) that to further improve efficient spectrum utilization all stations are constrained by the Radio Regulations to radiate no more than such power as is necessary to ensure a satisfactory service;

(g) that the Inter-Governmental Maritime Consultative Organization (IMCO) is considering an amendment to the Safety Convention to include minimum power requirements for SSB transmitters on board ships;

(h) that SSB transmitters utilize R3E, H3E and J3E emissions;

(j) that there is consequently a need to specify for each of the types of SSB emission, the powers and field strengths equivalent to those in the DSB system at present employed;

(k) that cross-system operation between SSB and DSB equipments will at times be utilized;

UNANIMOUSLY RECOMMENDS

1. that the bases for the calculation of the field strengths of H3E, R3E and J3E emissions equivalent to a reference signal, which is an A3E emission for which the unmodulated carrier produces a field strength of 25 μV/m at the receiver, are as follows:

1.1 the signal-to-noise ratios at the output of the demodulator of all cases considered, including the reference case, are equal;

1.2 for single-tone modulation, the signal-to-noise ratio to be considered is only that of the fundamental component of the modulating tone at the output of the demodulator;

1.3 for class of emission A3E, the carrier is modulated by a single modulating tone to depths of 70% or 100%;

1.4 for class of emission H3E, the sideband amplitude for a single modulating tone is 70% or 100% of the carrier amplitude for equivalent 70% or 100% respectively, depths of modulation;

1.5 for class of emission R3E, the amplitude of the sideband signal corresponding to 70% and 100% modulations is the same as that for H3E in § 1.4 but the carrier level is reduced to 16 dB below peak envelope power corresponding to 100% modulation;

1.6 for class of emission J3E, the amplitude of the sideband signal corresponding to 70% and 100% modulations is the same as that for H3E in § 1.4, but the carrier level is reduced by at least 40 dB below peak power corresponding to 100% modulation;

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* This Recommendation terminates the study of Question 19/8, which has been deleted.

2. that under the above conditions the calculated equivalent r.m.s. field strengths for the various classes of emission and for different types of receiving systems, with the types of test signals indicated, are shown in Table I:

TABLE I

Class of emission	Type of receiver	Test signal	r.m.s. field strength (μV/m) equivalent to the reference signal (see § 1) with a modulation depth of:	
			70%	100% (2)
A3E	DSB	carrier only	25.0	25.0
A3E	SSB	carrier only	35.4	35.4
H3E	DSB	carrier only (1)	26.8	29.4
H3E	SSB	carrier only	17.7	17.7
R3E	SSB	carrier and sideband	12.8	18.0
J3E	SSB	sideband only	12.4	17.7

(1) Envelope detection of the H3E emission is assumed and this requires the reference field strength of 25 μV/m to be increased by 7% and 18% at 70% and 100% modulation, respectively, to compensate for the reduction in the amplitude of the fundamental component due to harmonic distortion in the detection process.

(2) The calculations for 100% modulation are based upon the reference carrier (unmodulated) field strength of 25 μV/m.

3. that the calculated equivalent peak envelope powers into the antenna to achieve the field strengths given in § 2 are as listed in Table II; these powers are in all cases based upon a modulated signal:

TABLE II

Class of emission	Type of receiver	Peak envelope power (W) equivalent to the reference signal (see § 1) with a modulation depth of:	
		70%	100%
A3E	DSB	43.4	60
A3E	SSB	86.7	120
H3E	DSB	49.7	83.2
H3E	SSB	21.7	30.0
R3E	SSB	5.9	10.6
J3E	SSB	3.7	7.5

Note. – The values given in this Table are valid irrespective of the type of modulating signal (i.e. single-tone, two-tone, smoothly-read text, etc.), provided the same modulation is used for all classes of emission.

Note. – The Director, CCIR, is requested to bring this Recommendation to the attention of IMCO.

RECOMMENDATION 489-1

TECHNICAL CHARACTERISTICS OF VHF RADIOTELEPHONE EQUIPMENT OPERATING IN THE MARITIME MOBILE SERVICE IN CHANNELS SPACED BY 25 kHz

(1974-1978)

The CCIR,

CONSIDERING

(a) that Resolution No. 308 of the World Administrative Radio Conference, Geneva, 1979, stipulates that:

- the channel spacing for maritime mobile VHF radiotelephone services is being reduced from 50 kHz to 25 kHz;
- the technical characteristics of equipment for 25 kHz channel spacing in these services shall be in accordance with Appendix 19 to the Radio Regulations, and that all equipment shall conform to 25 kHz standards by 1 January 1983;

(b) that it is desirable to supplement the list of technical characteristics given in Appendix 19 to the Radio Regulations in the interests of reduction of interference and of compatibility between equipments;

(c) that Appendix 18 to the Radio Regulations gives a table of transmitting frequencies which is based upon the principle of 25 kHz channel separations for the maritime mobile service;

(d) that many administrations have already prepared their national specifications for this type of equipment and consequently it is not possible at the present time to reach international agreement on the detailed specification and measurement of some equipment characteristics;

(e) that in Opinion 42, the IEC has been invited to advise the CCIR of any methods of measurement applicable to radio equipment used in land mobile services; and that such methods of measurement may also be suitable for radio equipment used in maritime mobile services,

UNANIMOUSLY RECOMMENDS

1. that the following characteristics should be met by VHF (metric) FM radiotelephone equipment used for the maritime mobile services operating on the frequencies specified in Appendix 18 to the Radio Regulations;

1.1 *General characteristics*

1.1.1 The class of emission should be F3E/G3E. *

1.1.2 The necessary bandwidth should be 16 kHz.

1.1.3 Only phase modulation (frequency modulation with a pre-emphasis characteristic of 6 dB/octave) should be used. *

1.1.4 Where duplex or semi-duplex systems are in use, the performance of the radio equipment should continue to comply with all the requirements of this Recommendation.

1.1.5 The equipment should be designed so that frequency changes between assigned channels can be carried out within 5 s.

1.1.6 Emissions should be vertically polarized at the source. *

* See also Radio Regulations, Appendix 19.

1.2 *Transmitters*

1.2.1 The frequency tolerance for coast station transmitters should not exceed 5 parts in 10^6, and that for ship station transmitters should not exceed 10 parts in 10^6. *

1.2.2 Spurious emissions on discrete frequencies, when measured in a non-reactive load equal to the nominal output impedance of the transmitter, should be in accordance with the provisions of Appendix 8 of the Radio Regulations.

1.2.3 The carrier power for coast stations should not normally exceed 50 W. *

1.2.4 The carrier power for ship station transmitters should not exceed 25 W and means should be provided to readily reduce this to 1 W or less for use at short ranges.

1.2.5 The frequency deviation should not exceed ± 5 kHz. * Deviation limiting circuits should be employed such that the maximum frequency deviation attainable should be independent of the input audio frequency.

1.2.6 The upper limit of the audio-frequency band should not exceed 3 kHz. *

1.2.7 The cabinet radiated power should not exceed 25 μW. In some radio environments, lower values may be required.

1.3 *Receivers*

1.3.1 The reference sensitivity should be equal to or less than 2.0 μV, e.m.f., for a given reference signal-to-noise ratio at the output of the receiver.

1.3.2 The adjacent channel selectivity should be at least 70 dB.

1.3.3 The spurious response rejection ratio should be at least 70 dB.

1.3.4 The radio frequency intermodulation rejection ratio should be at least 65 dB.

1.3.5 The power of any conducted spurious emission, measured at the antenna terminals, should not exceed 2.0 nW at any discrete frequency. In some radio environments lower values may be required.

1.3.6 The effective radiated power of any cabinet radiated spurious emission on any frequency up to 70 MHz should not exceed 10 nW. Above 70 MHz, the spurious emissions should not exceed 10 nW by more than 6 dB/octave in frequency up to 1000 MHz. In some radio environments, lower values may be required.

2. that reference should also be made to Recommendations 331 and 332 and to the relevant IEC publications on methods of measurement.

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* See also Radio Regulations, Appendix 19.

RECOMMENDATION 475-1

IMPROVEMENTS IN THE PERFORMANCE OF RADIOTELEPHONE CIRCUITS IN THE MF AND HF MARITIME MOBILE BANDS

(Question 11/8)

(1970-1974)

The CCIR,

CONSIDERING

(a) that there is a need to improve the quality of transmission of MF and HF maritime mobile radiotelephone circuits;

(b) that methods presently used usually employ voice-operated devices to eliminate instability or unwanted retransmission;

(c) that such voice-operated devices frequently degrade the performance of the circuit;

(d) that the use of conventional compressors and expanders on MF and HF circuits is inhibited by the variability of the transmission path loss;

(e) that compressors and expanders may be linked to overcome this variability;

(f) that such a system is already used by several administrations;

(g) that further tests of this system may be necessary, and further systems may be proposed;

(h) that when linked compressor and expander systems are used, it is necessary to ensure the compatibility of the equipment used by coast and ship stations,

UNANIMOUSLY RECOMMENDS

1. that systems used in the international maritime mobile radiotelephone service should as far as possible maintain optimum modulation of the transmitter despite variations in subscribers' speech volume and line losses;

2. that the speech and any control signals should both be contained within a 2700 Hz channel;

3. that administrations should be encouraged to continue their studies, and in the meantime, when it is desired to use a linked compressor and expander system, then in order to ensure compatibility between the sending and receiving stations, the characteristics of the equipment should be in accordance with Annexes I and II; for optimum performance, it is desirable that the characteristics of SSB radio equipment be in accordance with the minimum standards contained in Annex III.

Annex I : Characteristics for ship stations.

Annex II : Characteristics for coast stations.

Annex III: Characteristics of SSB radio equipment.

ANNEX I

CHARACTERISTICS OF EQUIPMENT FOR SHIP STATIONS

1. Transmit side (Fig. 1*a*)

1.1 *Speech channel*

1.1.1 *Steady-state conditions*

For input levels between +5 dBm0 and −25 dBm0 the output levels should lie within the limits shown in Fig. 2.

The overall amplitude/frequency response for the speech path, under both fixed-gain and controlled conditions, at any level within the range +5 dBm0 to −25 dBm0 should be:

Frequencies	Attenuation relative to response at 800 Hz
Above 300 Hz	
For frequencies in the band 350 Hz to 2300 Hz	−1 to +3 dB
For frequencies in the band 2300 Hz to 2380 Hz	−1 to +6 dB
For frequencies in the band 2510 Hz and above	> 50 dB
Below 300 Hz	
Increase in overall gain for frequencies below 300 Hz	⩽ 1 dB

1.1.2 *Transmit response (Overall)*

Attack time (Fig. 3*a*) (Note 1)	5 to 10 ms
Recovery time (Fig. 3*b*) (Note 1)	15 to 30 ms

1.2 *Control channel*

Frequency-modulated oscillator

Nominal centre frequency	2580 ± 1 Hz
Maximum frequency deviation	+40 to −60 Hz
Change of frequency for each 1 dB change of input levels (Fig. 4)	2 Hz
Input level to transmit side to produce nominal centre frequency	−25 dBm0
Oscillator frequency resulting from an input level of +5 dBm0	2520 Hz
Oscillator frequency resulting from an input level of −45 dBm0	2620 Hz
Oscillator frequency when there is no input to transmit side	⩽ 2680 Hz
For sudden increases in input that exceed 3 dB the time taken for the oscillator to complete 80% (10% to 90%) of the corresponding change in frequency should be	5 to 10 ms
For sudden decreases in the input that exceed 10 dB the rate of change of the oscillator frequency should lie between	1.5 and 3.5 Hz/ms
Upper limit of output spectrum	2700 Hz
Output level relative to test tone level in the speech channel *	−5 dB

2. Receive side (Fig. 1*b*)

2.1 *Speech channel*

2.1.1 *Fading regulator*

2.1.1.1 *Steady-state conditions*

For input levels between +7 dBm0 and −35 dBm0 the output should be within the limits shown in Fig. 5.

2.1.1.2 *Transmit response*

Attack time (Fig. 3*a*) (Note 1)	7 to 13 ms
Recovery time (Fig. 3*b*) (Note 1)	24 to 40 ms

2.1.2 *Expander* (controlled by the discriminator output)

Effective dynamic range	60 dB

* When the combined line signal is adjusted in accordance with § 1.2 (control channel) the average power of the combined speech and control channel signals can be considered to be +4 dB relative to the level of the control channel signal by itself. Further, the speech peaks can be considered to be +12 dB relative to the control channel signal.

Frequencies	Attenuation relative to response at 800 Hz

2.2 *Control channel*

2.2.1 *Amplitude/frequency and differential-delay characteristics of filter*

Attenuation within the band 2520 Hz to 2640 Hz (relative to that at 2580 Hz)	−1 to +3 dB
Attenuation below 2400 Hz and above 2770 Hz (relative to that at 2580 Hz)	> 50 dB
Differential delay within the band 2520 Hz to 2640 Hz	⩽ 3.5 ms

2.2.2 *Discriminator* (Frequency/amplitude translator)

Characteristics at nominal control-tone level

Changes in the expander output with changes in the frequency of the control tone between 2520 Hz and 2640 Hz should be within the limits shown in Fig. 6	
Nominal change in expander loss resulting from each 2 Hz in control-tone frequency	1 dB
Control-tone frequency range over which 2 Hz per dB is maintained	2520 to 2640 Hz
Receive-side output level for control-tone frequencies of:	
2520 Hz	+5 dBm0
2640 Hz	−55 dBm0

2.2.3 *Amplitude range of discriminator*

A tolerance of ± 1 dB may be added to the performance requirements of § 2.2.2 for control-tone input level variations of	30 dB
A tolerance of ± 2 dB may be added to the performance requirements of § 2.2.2 for control-tone input level variations of	50 dB

2.3 *Overall attack and recovery time*

(A sudden change of 24 Hz in the frequency of the control tone is used to simulate a 12 dB step)

Attack time (Fig. 3*c*)	15 to 30 ms
Recovery time (Fig. 3*d*)	15 to 30 ms

3. Equalization of overall transmission time delay

To avoid the necessity for the coast radio station to vary the amount of time delay equalization to cater for different designs of equipment, the control signal should lag behind the corresponding speech signal:

3.1	at the output of the transmit side by	⩽ 4 ms
3.2	at the expander (when the speech and associated control signal are simultaneously applied to the receive-side input) by	16 to 24 ms (Note 2)

Note 1. – The definitions of attack and recovery time which are similar to those defined by the CCITT for compandors (Recommendation G.162) are as follows:

- the *attack time* of a compressor is defined as the time between the instant when a sudden increase of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 1.5 times its steady-state value;
- the *recovery time* of a compressor is defined as the time between the instant when a sudden decrease of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 0.75 times its steady-state value.

Note 2. – This delay includes an allowance for the time-constants of the circuits preceding the expander, in addition to that for the band-pass filter itself.

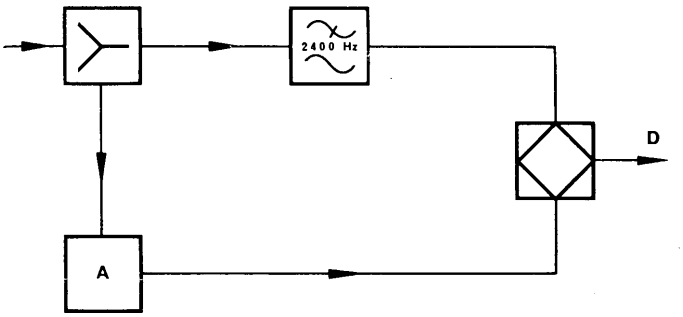


FIGURE 1*a*

Transmit side

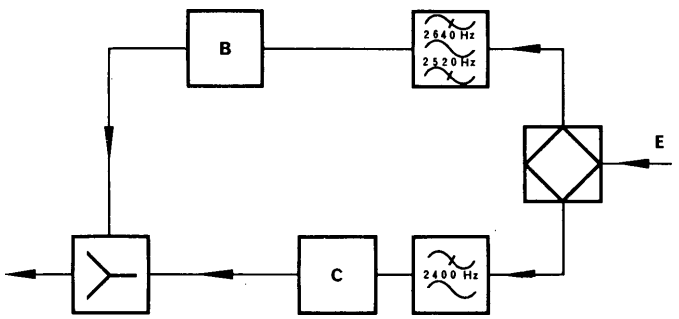
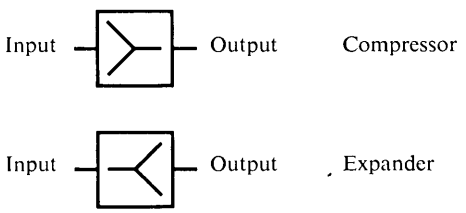


FIGURE 1*b*

Receive side

A: frequency-modulated oscillator
B: frequency discriminator
C: fading regulator (constant volume amplifier)
D: to radio transmitter
E: from radio receiver



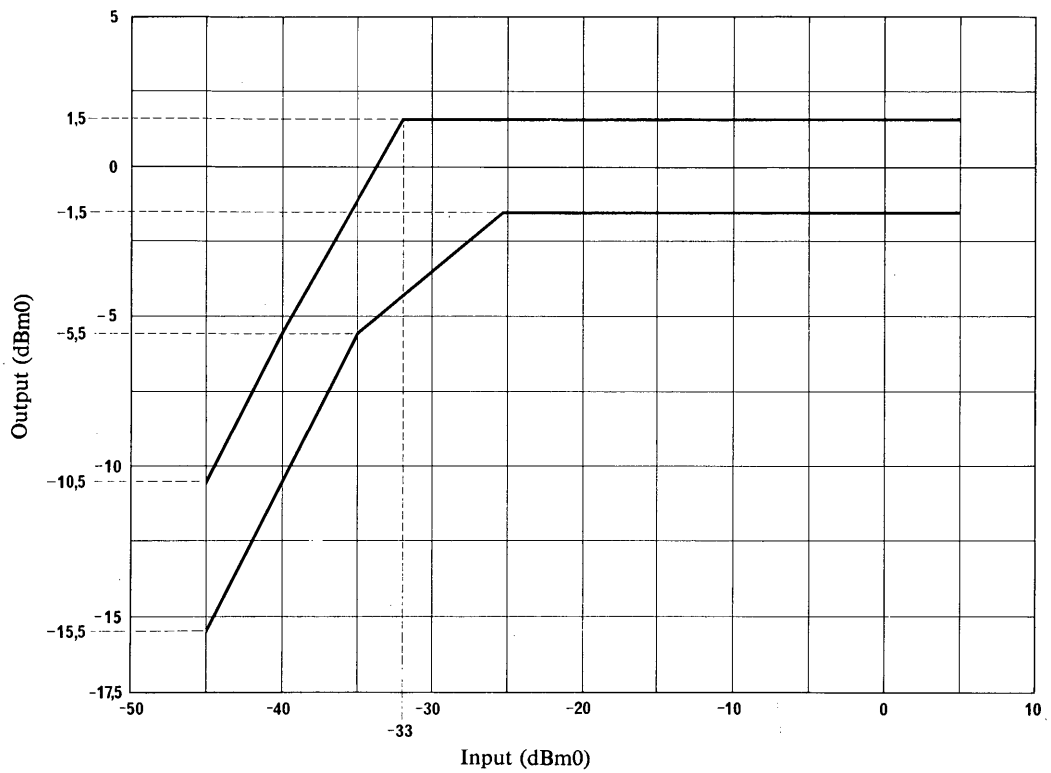


FIGURE 2

Input/output characteristic of transmit side

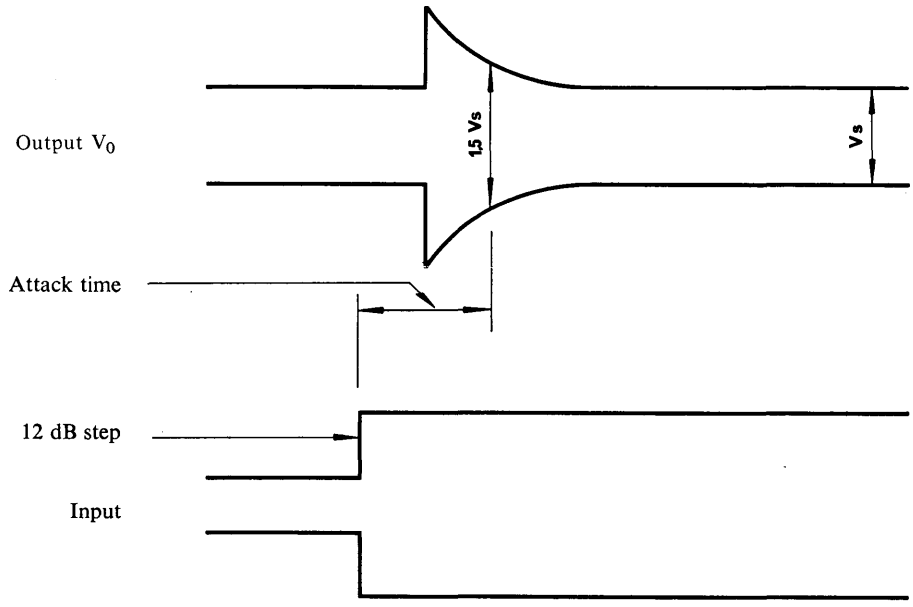


FIGURE 3*a*

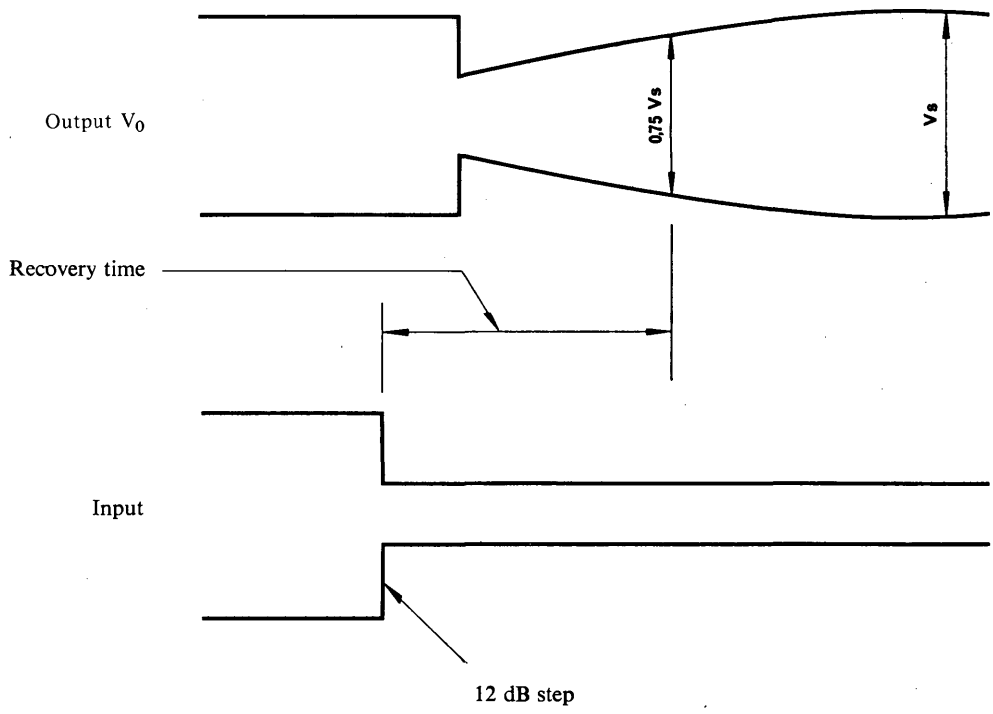


FIGURE 3*b*

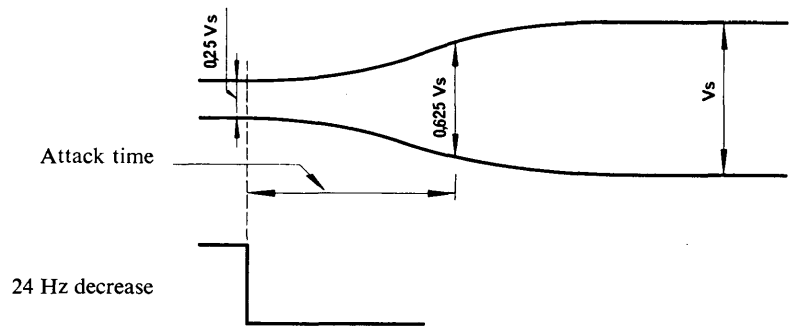


FIGURE 3*c*

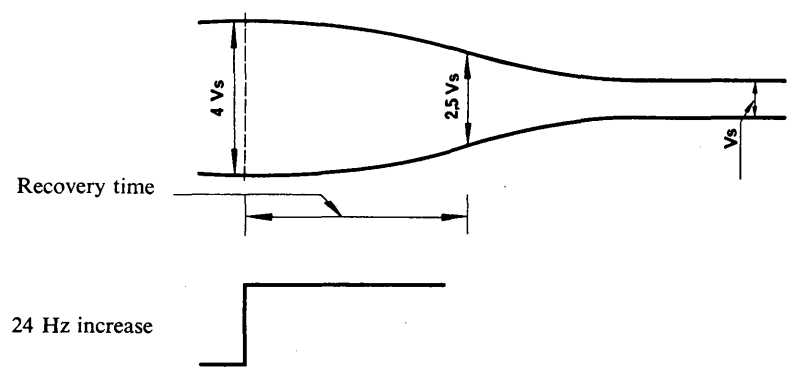


FIGURE 3*d*

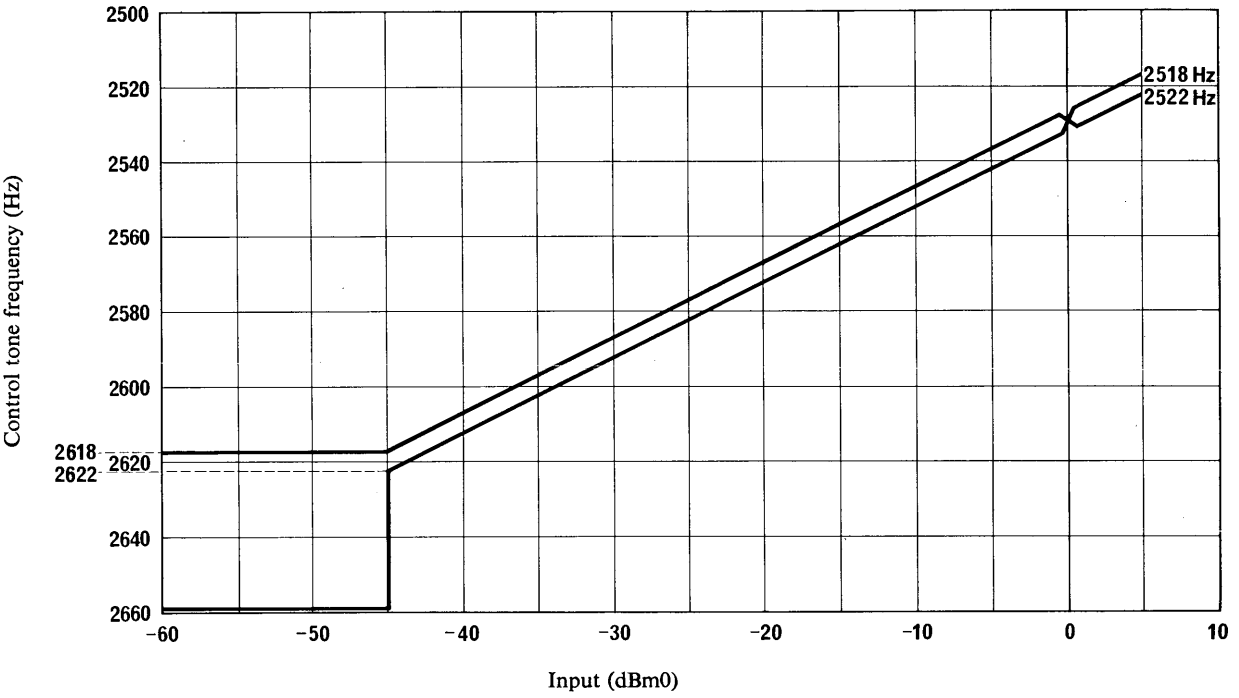


FIGURE 4

Variation of control tone frequency with changes of input level to the transmit side

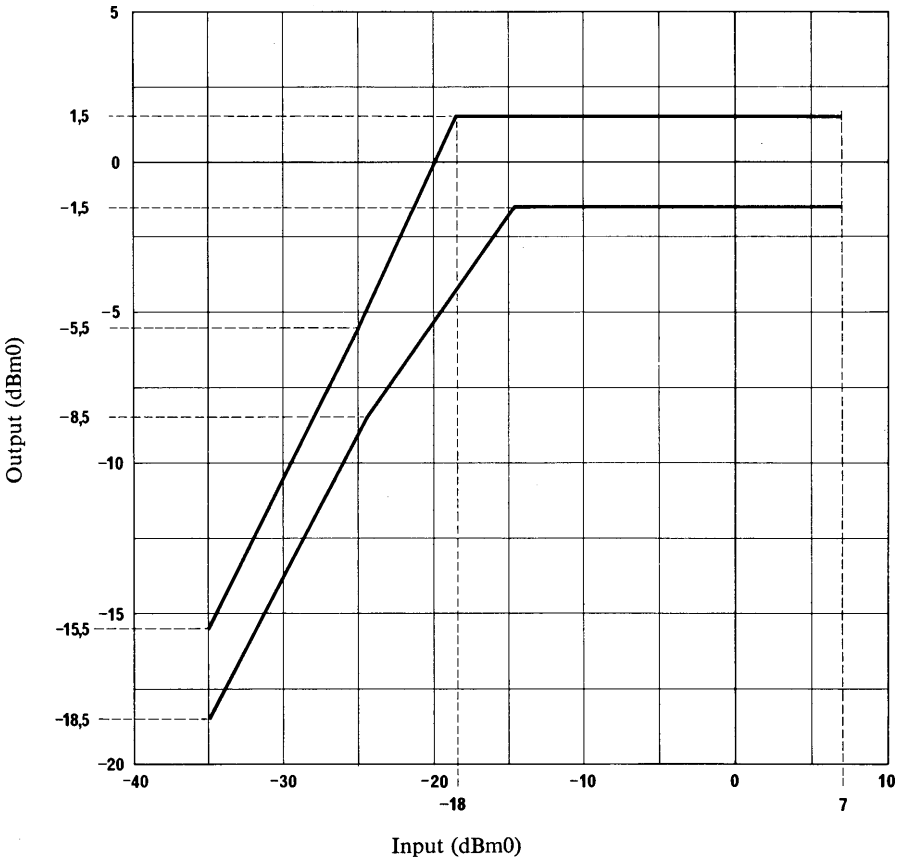


FIGURE 5

Input/output characteristic of fading regulator

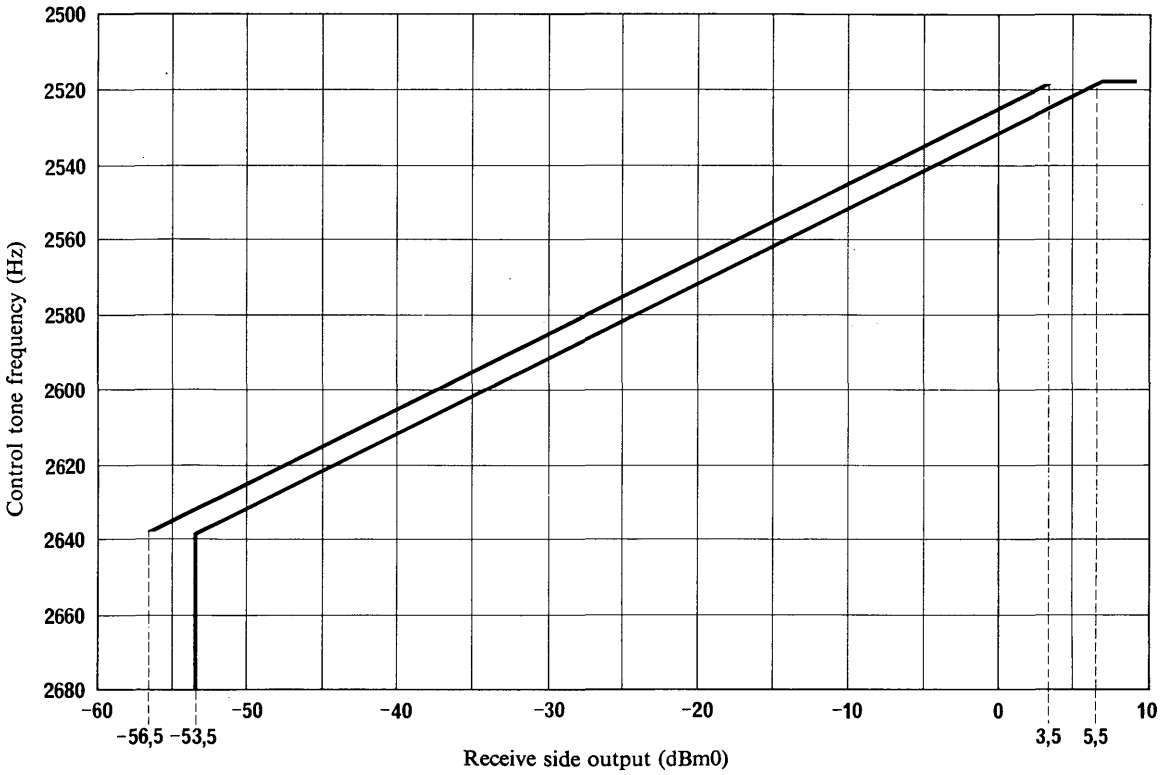


FIGURE 6

Variation of receive side output with changes of control tone frequency

ANNEX II

CHARACTERISTICS OF EQUIPMENT FOR COAST STATIONS

1. Transmit side (Fig. 7*a*)

1.1 *Speech channel*

1.1.1 *Steady-state conditions*

For input levels between +5 dBm0 and −35 dBm0 the output should lie between the limits shown in Fig. 8.

The overall amplitude/frequency response for the speech path, under both fixed-gain and controlled conditions, at any level within the range +5 dBm0 to −35 dBm0 should be:

Frequencies	Attenuation relative to response at 800 Hz
Above 300 Hz	
For frequencies in the band 350 to 2300 Hz	−1 to +3 dB
For frequencies in the band 2300 to 2380 Hz	−1 to +6 dB
For frequencies in the band 2510 and above	> 50 dB
Below 300 Hz	
Increase in overall gain for frequencies below 300 Hz	⩽ 1 dB

Frequencies	Attenuation relative to response at 800 Hz
1.1.2 *Transmit response (Overall)*	
Attack time (Fig. 9*a*) (Note 1)	5 to 10 ms
Recovery time (Fig. 9*b*) (Note 1)	15 to 30 ms

1.2 *Control channel*

Frequency-modulated oscillator

Nominal centre frequency	2580 Hz
Maximum frequency deviation	± 60 Hz
Change of frequency for each 1 dB change of input level (Fig. 10)	2 Hz
Input level to transmit side to produce nominal centre frequency	−25 dBm0
Oscillator frequency resulting from an input level of +5 dBm0	2520 Hz
Oscillator frequency resulting from an input level of −55 dBm0	2640 Hz
Oscillator frequency when there is no input to the transmit side	⩽ 2680 Hz
For sudden increases in input that exceed 3 dB the time taken for the oscillator to complete 80% (10% to 90%) of the corresponding change in frequency should be	5 to 10 ms
For sudden decreases in the input that exceed 10 dB the rate of change of oscillator frequency should lie between	1.5 and 3.5 Hz/ms
Upper limit of spectrum	2700 Hz
Output level relative to test tone level in the speech channel *	−5 dB

2. Receive side (Fig. 7*b*)

2.1 *Speech channel*

2.1.1 *Fading regulator*

2.1.1.1 *Steady-state conditions*

For input levels between +7 dBm0 and −35 dBm0 the outputs should be within the limits shown in Fig. 11.

2.1.1.2 *Transmit response*

Attack time (Fig. 9*a*) (Note 1)	7 to 13 ms
Recovery time (Fig. 9*b*) (Note 1)	24 to 40 ms

2.1.2 *Expander* (controlled by the discriminator output)

Effective dynamic range	50 dB

* When the combined line signal is adjusted in accordance with § 1.2 (control channel) the average power of the combined speech and control channel signals can be considered to be +4 dB relative to the level of the control channel signal by itself. Further, the speech peaks can be considered to be +12 dB relative to the control channel signal.

Frequencies	Attenuation relative to response at 800 Hz

2.2 *Control channel*

2.2.1 *Amplitude/frequency and differential-delay characteristics of filter*

Attenuation within the band 2520 Hz to 2640 Hz (relative to that at 2580 Hz)	−1 to +3 dB
Attenuation below 2400 Hz and above 2770 Hz (relative to that at 2580 Hz)	> 50 dB
Differential delay within the band 2520 Hz to 2640 Hz	< 3.5 ms

2.2.2 *Discriminator* (Frequency/amplitude translator)

Characteristics at nominal control-tone level

Changes in the expander output with changes in the frequency of the control tone between 2520 Hz and 2620 Hz should be within the limits shown in Fig. 12	
Nominal change in expander loss resulting from each 2 Hz change in control-tone frequency	1 dB
Control-tone frequency range over which 2 Hz per dB is maintained	2520 to 2620 Hz
Receive-side output level for control-tone frequencies of:	
2520 Hz	+5 dBm0
2620 Hz	−45 dBm0

2.2.3 *Amplitude range of discriminator*

A tolerance of ± 1 dB may be added to the performance requirements of § 2.2.2 for control-tone input level variations of	30 dB
A tolerance of ± 2 dB may be added to the performance requirements of § 2.2.2 for control-tone input level variations of	50 dB

2.3 *Overall attack and recovery time*

(A sudden change of 24 Hz in the frequency of the control tone is used to simulate a 12 dB step)

Attack time (Fig. 9*c*)	15 to 30 ms
Recovery time (Fig. 9*d*)	15 to 30 ms

3. Equalization (overall) of transmission time

Taking into account § 3 of Annex I for ship-station equipment, sufficient time delay shall be incorporated in the coast-station equipment to ensure that in both directions of transmission, the overall transmission times of the speech and control signals, as measured at the expanders, shall be equalized to within	± 8 ms

Note. – The definitions of attack and recovery time which are similar to those defined by the CCITT for compandors (Recommendation G.162) are as follows:

- the *attack time* of a compressor is defined as the time between the instant when a sudden increase of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 1.5 times its steady-state value;
- the *recovery time* of a compressor is defined as the time between the instant when a sudden decrease of 12 dB in input is applied and the instant when the output voltage envelope reaches a value equal to 0.75 times its steady-state value.

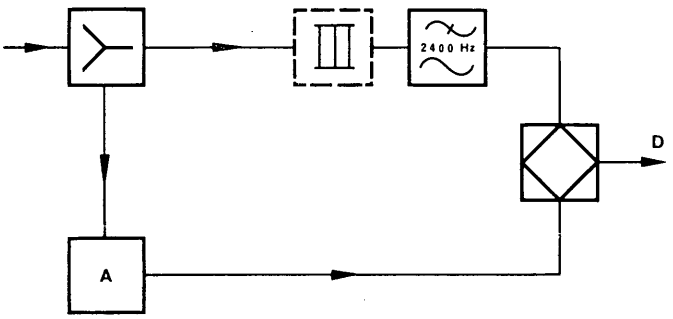


FIGURE 7*a*

Transmit side

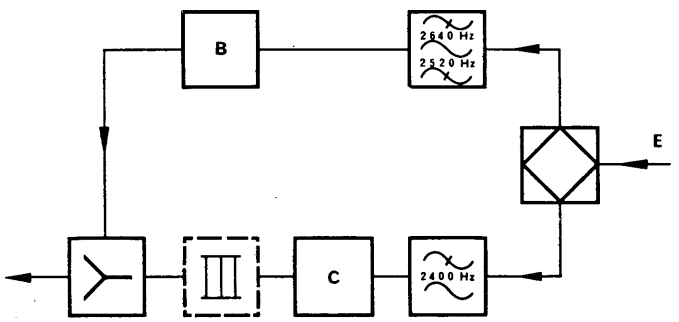
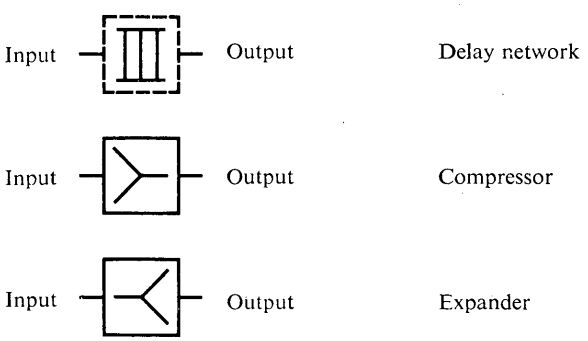


FIGURE 7*b*

Receive side

A: frequency-modulated oscillator
B: frequency discriminator
C: fading regulator (constant volume amplifier)
D: to radio transmitter
E: from radio receiver



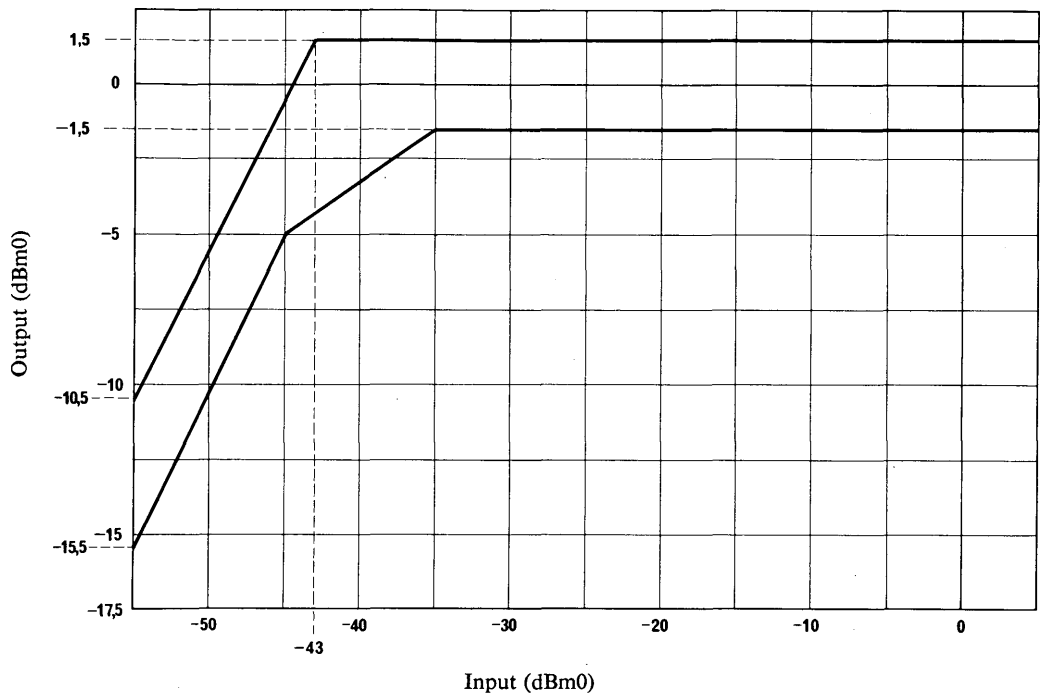


FIGURE 8

Input/output characteristic of transmit side

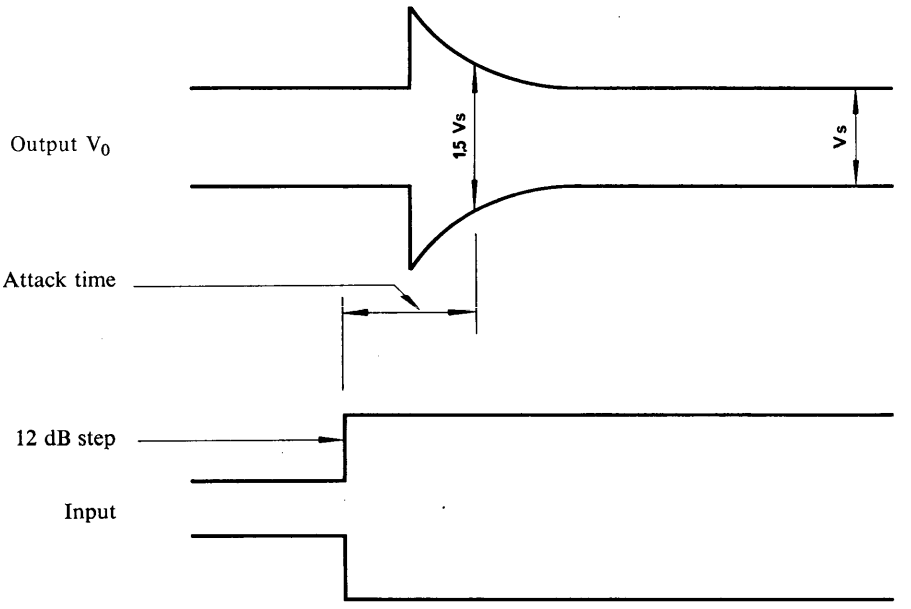


FIGURE 9*a*

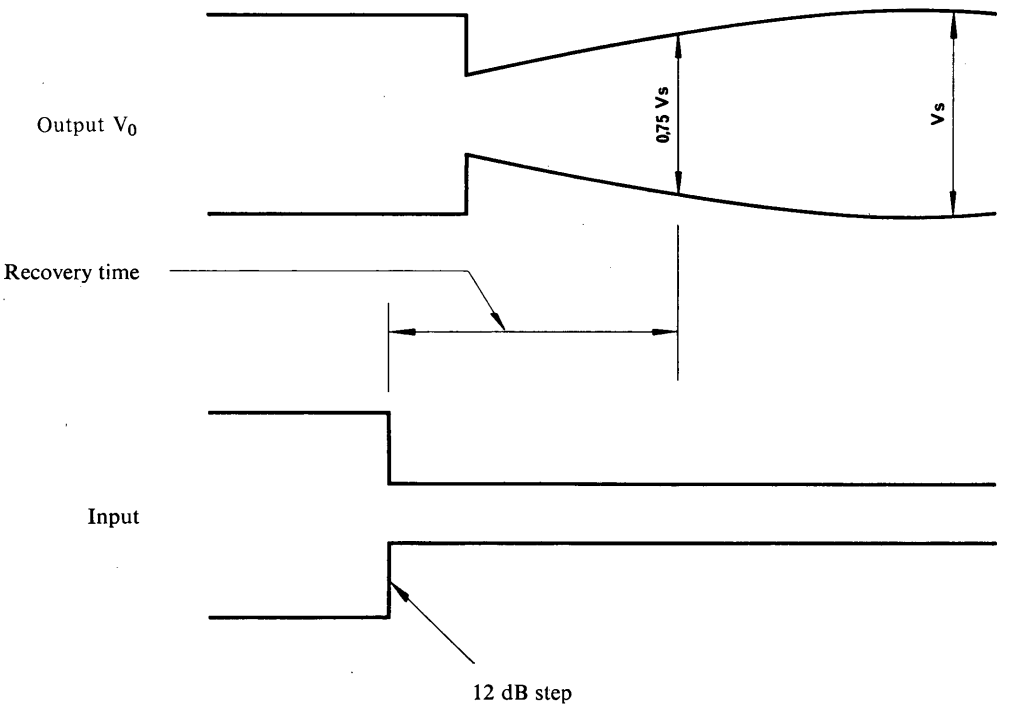


FIGURE 9*b*

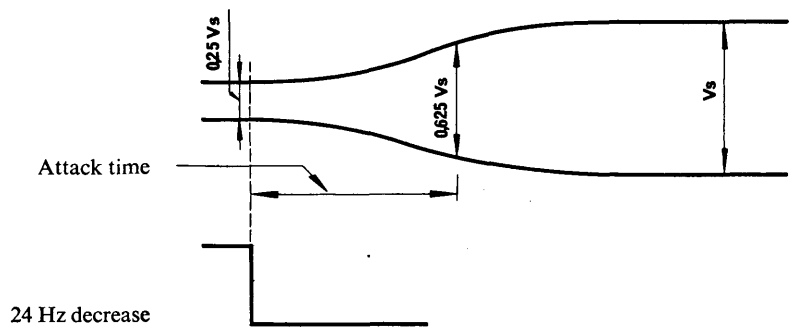


FIGURE 9*c*

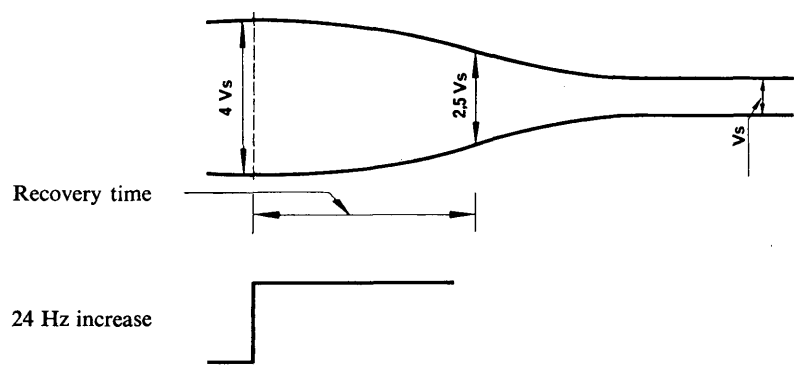


FIGURE 9*d*

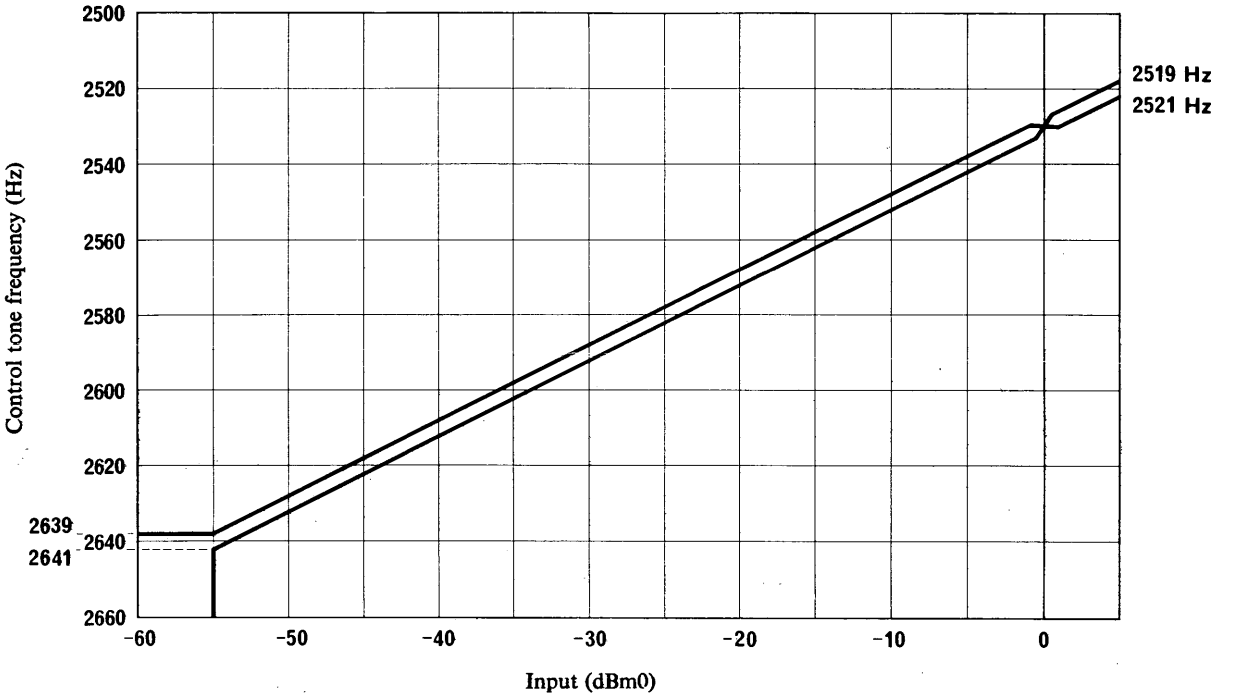


FIGURE 10

Variation of control tone frequency with changes of input level to the transmit side

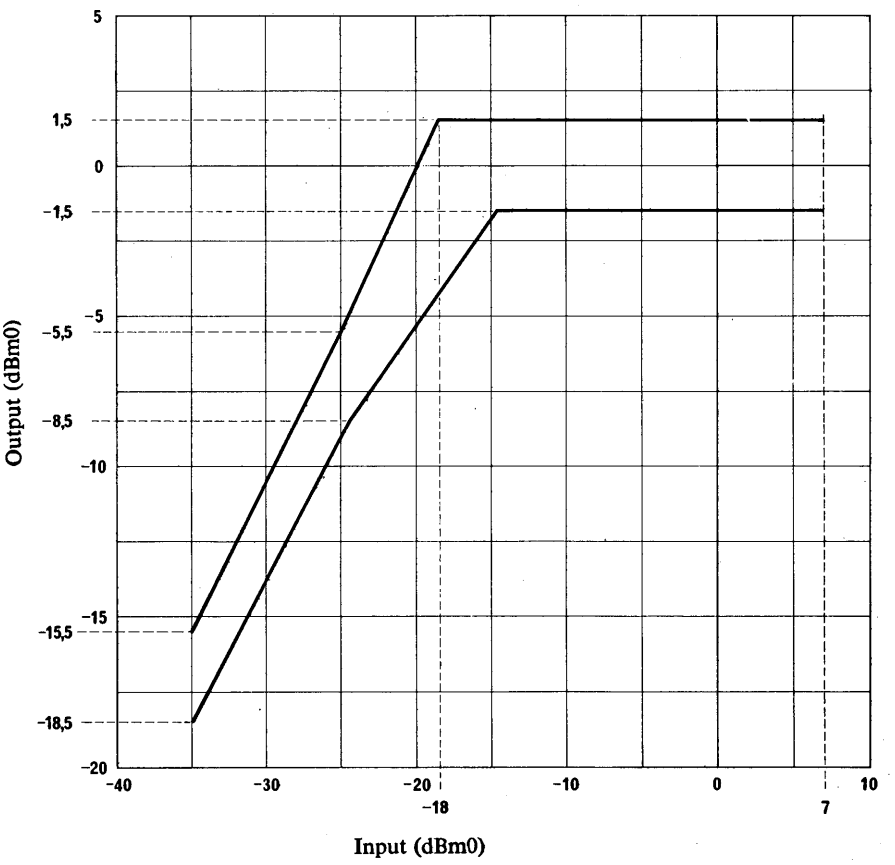


FIGURE 11

Input/output characteristic of fading regulator

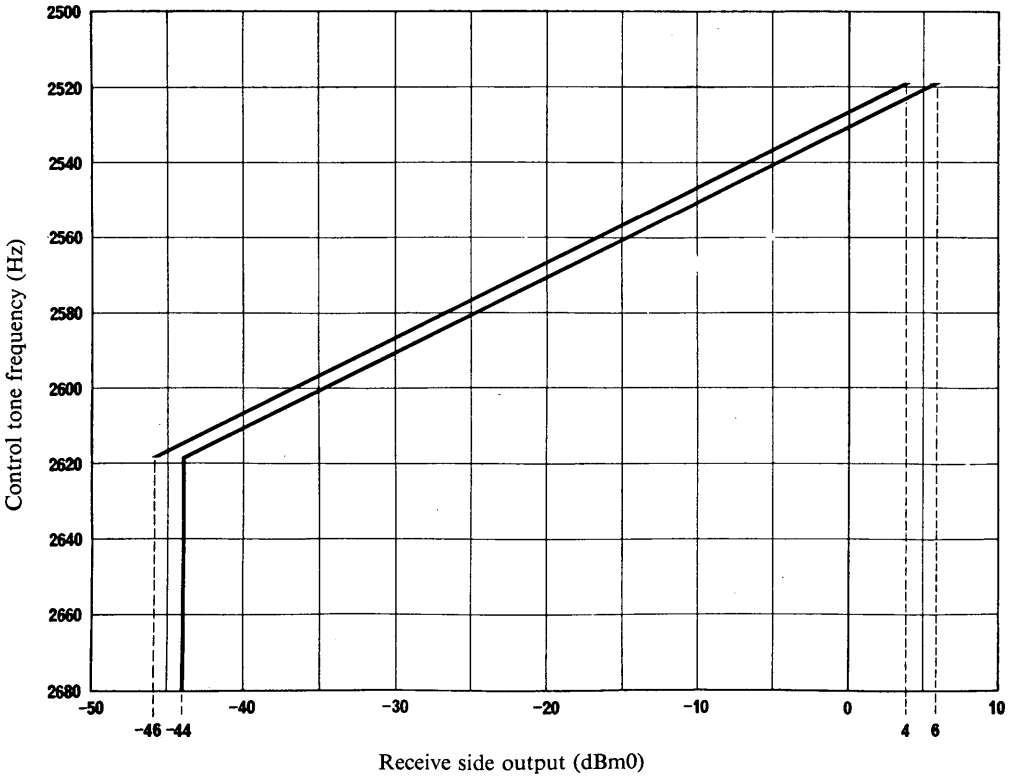


FIGURE 12
Variation of receive side output with changes of control tone frequency

ANNEX III

CHARACTERISTICS FOR SSB RADIO EQUIPMENT FOR OPTIMUM PERFORMANCE OF A LINKED COMPRESSOR AND EXPANDER SYSTEM

A linked compressor and expander system can be applied with full advantage to the maritime mobile service using either DSB or SSB systems.

To obtain the full advantages of the linked system when used with SSB radio equipment, the performance of the latter should meet the following requirements:

1. The short-term frequency stability of coast station transmitters should be within ± 2 Hz over a period of the order of fifteen minutes.

2. The short-term frequency stability of a ship station transmitter should be within ± 5 Hz over a period of the order of fifteen minutes.

3. To ensure sufficient overall gain stability of the system, for the duration of a call, facilities should be provided in coast station receivers to keep the end-to-end frequency error within ± 2 Hz; similarly, facilities should be provided in ship station receivers to keep the end-to-end frequency error within ± 5 Hz.

4. The permitted total amplitude variation in the radio transmitter over the 350 to 2700 Hz audiofrequency band should be 6 dB and the differential delay should not exceed 3 ms. The receiver should have at least the same standards of performance in these respects.

5. If the pilot carrier of a Type R3E emission is not used to provide a continuous signal for frequency and gain control of the receiver, for example where Type J3E emission is used, the initial tuning procedure will require the transmission for a brief period of a suitable reference tone (e.g. 1000 Hz ± 1 Hz) at a level of, say, −10 dBm0 ± 0.5 dB.

6. Where it is desired to use privacy equipment or speech inverters, it should be borne in mind that, in Annex I of this Recommendation, the upper audio frequency of the speech channel is 2380 Hz.

REPORT 500-3

IMPROVEMENTS IN THE PERFORMANCE OF RADIOTELEPHONE CIRCUITS IN THE MF AND HF BANDS

Linked compressor and expandor systems

(Question 11/8)

(1970-1974-1978-1982)

1. Introduction

1.1 Techniques for improving the maritime radiotelephone service were discussed at the interim meeting of Study Group 8 in Geneva in 1968.

1.2 Compandor techniques had recently been applied to the point-to-point services in a system called "Lincompex" with considerable success and this resulted in the acceptance of Question 11/8.

1.3 The United Kingdom indicated that tests had shown that the use of Lincompex in the Maritime Service would give similar advantages to those obtained on the point-to-point services. Moreover, the ability of the system to suppress interference would be of great advantage in the maritime services where interference is more frequently the limitation than it is in the point-to-point services [CCIR, 1966-69].

1.4 It was pointed out that the existing design of Lincompex equipment for point-to-point services required an upper limit of 3000 Hz whereas the audio bandwidth of the SSB maritime equipment was limited to 2700 Hz, in accordance with Appendix 17 of the Radio Regulations. The United Kingdom made proposals for a modified version of Lincompex specially designed to fit into the maritime channel allocations. The approved specifications were then incorporated into Recommendation 475.

1.5 At the final meeting of Study Group 8, Geneva 1978, Canada reported on the development and evaluation of equipment utilizing digital techniques and designed for use with equipment meeting existing maritime frequency stability requirements [CCIR, 1974-78; Chow, 1978]. The system is called "Syncompex" and differs basically from "Lincompex" in that digital rather than analogue techniques are used to modulate the control channel. A system description is contained in Annex I.

2. Tests in the HF (4 to 27.5 MHz) and MF (1.6 to 3.8 MHz) bands

2.1 Comparisons were made on ship-to-shore links in the HF and MF bands between Lincompex and the conventional system. The tests indicated that, during daylight, with Lincompex a good commercial SSB telephony circuit was obtained on the MF band over a distance of about 650 miles. This compared with less than 400 miles using conventional SSB. During darkness the advantages were even greater. Interference made the conventional system uncommercial when extended over the inland network, while the new system was generally satisfactory. Tests were also made on the HF bands and the results fully confirmed the improvements expected.

2.2 In relation to the Syncompex system, an experimental evaluation on an HF radio system was reported to be in progress in 1978.

3. General circuit parameters for linked compressor expandor systems

3.1 Standard syllabic compandors designed to the 13-segment A law [Bell Telephone Labs., 1970] cannot be used in links in which the signal levels can fluctuate as in a fading ionospheric channel because the companding action tends to accentuate the effects of the fluctuation by an amount equal to the compression ratio. Linked compressor expandors have special features which enable them to overcome this difficulty.

3.2 The use of linked compressor expandor systems on HF and MF circuits employing A3J emissions is extremely difficult unless care is taken to ensure that the information in the associated control channel is correctly received.

3.3 For the system described in Recommendation 475, the end-to-end frequency accuracy has to be better than ± 5 Hz, which may require the use of automatic frequency control.

For the system described in Annex I the control information is in digital form which gives it much greater tolerance to end-to-end frequency error.

3.4 Linked compressors and expandors provide satisfactory circuits when a signal-to-noise ratio of about 10 dB exists between the wanted and the interfering signal in the overall channel [CCIR, 1970-74a], although the control channel is more susceptible to discrete frequency interference than the voice channel [CCIR, 1970-74b].

3.5 Loss of intelligibility due to reduced audio-bandwidth is found to be negligible; furthermore, any penalty incurred through the use of the narrower voice channel is more than offset by the subjective signal-to-noise advantage resulting from the compandor action of the system [CCIR, 1970-74a and b].

3.6 The effect of noise caused by stays could be increased by the presence of the control signal [CCIR, 1970-74b]. However, interference resulting from audio rectification of the voice modulation is greatly reduced when the speech is efficiently compressed.

3.7 Emphasis is placed on the need to improve ship and shore installations and adjustment, with particular regard to transmission levels, so that operator attention can be reduced and circuit availability improved [CCIR, 1970-74a and c].

4. Modifications to the Lincompex system

4.1 The United Kingdom proposed a number of amendments to Annex III of Recommendation 475 aimed at enabling the technical requirements for the associated radio equipment to be simplified [CCIR, 1970-74d].

4.2 It also outlined the technical parameters for privacy equipment with 3000 Hz inversion frequency when used with Recommendation 475 equipment. However, it is noted that Recommendation 336 recommends that such equipment should not be used on SSB systems.

5. Echo suppression

5.1 Japan described an economical method of providing echo suppression by making use of the Recommendation 475 equipment itself. The levels of speech signals in the transmit and receive paths are compared in a level comparator whose output is used to control the frequency of the control-channel oscillator and hence to "open" or "close" the receive path at the distant terminal by controlling the attenuation of its expandor. The new system was designed to meet the requirements of CCITT Recommendation G.161. Tests showed that it was fully compatible with conventional echo suppressors and speech quality was satisfactory [CCIR, 1970-74e].

5.2 For distances greater than about 5000 km it was found desirable to use echo suppressors with the equipment described in Recommendation 475, [CCIR, 1970-74f].

6. Band compression

Japan described a band compression system in which the audio-frequency band is limited to 1.8 kHz at the transmitting terminal, the upper part of the audio-frequency spectrum being replaced at the receive terminal by harmonics generated from the received 0.3 to 1.8 kHz signal. It is considered that the study of band compression systems applicable to the maritime mobile service is important from the viewpoint of the limited frequency bands available. In practical tests using the Japanese language, the band compression system gave an improvement in overall speech intelligibility compared with the VODAS and unmodified Lincompex systems (Recommendation 475). The document suggests that the reduced bandwidth of the band compression system would allow either more channels to be provided in the maritime mobile bands or, alternatively, an in-channel selective calling facility could be accommodated within the present channel bandwidth [CCIR, 1970-74g].

Report 862 (Vol. III), based on Japanese tests, describes the possibility of reducing interference by band compression techniques. Report 176 contains some test results of these band compression techniques.

7. Compatibility

A considerable improvement in performance is derived from the use of efficient voice processing techniques at the transmitters of both coast and ship stations (voice operated gain adjusting devices for example).

It is possible that the compressor section of a linked compressor and expandor system could be used in conjunction with a distant station employing a conventional receiver. This would require the removal of the control tone and the setting of the receive-side expandor to a suitable constant gain and perhaps some modification of the compressor time-constants. Use of automatic gain control circuitry with rapid attack and long hangover times in the conventional receiver aids in the reduction of noise during speech pauses [CCIR, 1970-74h].

REFERENCES

Bell Telephone Laboratories [February, 1970] Transmission system for communications. 4th Edition, 501-583.

CHOW, S. [1978] Synchronized compressor-expandor (Syncompex). CRC Report No. 1716, Department of Communications, Ottawa K2H 8S2.

CCIR Documents

[1966-69]: XIII/80 (United Kingdom).

[1970-74]: **a.** 8/36 (USA); **b.** 8/35 (Germany (Federal Republic of)); **c.** 8/37 (USA); **d.** 8/185 (United Kingdom); **e.** 8/194 (Japan); **f.** 8/195 (Japan); **g.** 8/196 (Japan); **h.** 8/64 (Canada).

[1974-78]: 8/309 (Canada).

ANNEX I

SYSTEM DESCRIPTION OF SYNCOMPEX

The Syncompex system [Chow, 1978] is being developed to bring the advantages of linked compressor and expander systems to all classes of HF telephony service.

In its simplest application, Syncompex may be connected to a radio system at the audio input and output points. In equipment developed specially, the FSK control channel may be additionally used for automatic gain control and automatic frequency control by suitable connections to the radio-frequency circuits.

Block diagram of the system are shown in Figs. 1a and 1b.

1. Transmission

The output of the audio bandpass filter is sampled by an analogue-to-digital (A-D) converter at 9600 samples per second under the control of a microprocessor. The microprocessor stores 128 successive samples defined as a "syllable" with duration 13.33 ms. The microprocessor determines the instantaneous gain to be applied to each syllable. The compressor gain is limited to 6 dB steps from 0 dB to 48 dB with gain change limited to a single 6 dB step every 13.33 ms syllabic period. The direction of the gain change is determined by the instantaneous amplitude of the voice, an increasing amplitude causing a decrease in the gain of the compressor by 6 dB. The microprocessor, after applying the appropriate gain to the samples, drives a digital-to-analogue (D-A) converter which converts the samples to analogue form which after filtering constitutes the audio input to the transmitter.

The gain change applied in the compression process is available at a digital output port of the microprocessor which is used as input to a pair of FSK modulators. The FSK signals called the control channel are centred at 765 and 2125 Hz and have $\pm$ 42.5 Hz shift. The compressed voice is eliminated from two bands centred about 765 and 2125 Hz to allow the FSK signal to be transmitted. Identical information is transmitted in the two FSK channels to minimize the effects of selective fading and narrowband interference often encountered in HF circuits.

2. Reception

The receiver output is separated by filters into the two FSK signals and the compressed voice signal. Each FSK channel is separately demodulated. They are then diversity combined so that fading of one FSK channel does not cause errors to occur in the combiner output. The compressed voice, after appropriate filtering, is sampled by an A-D converter operating at 9600 samples per second under the control of the microprocessor. The microprocessor adjusts the gain of the syllable according to the information received in the control channel. A gain change of $+6$ dB in the compressor is matched with a -6 dB change in the expander. The analogue output is formed by filtering the D-A converter output.

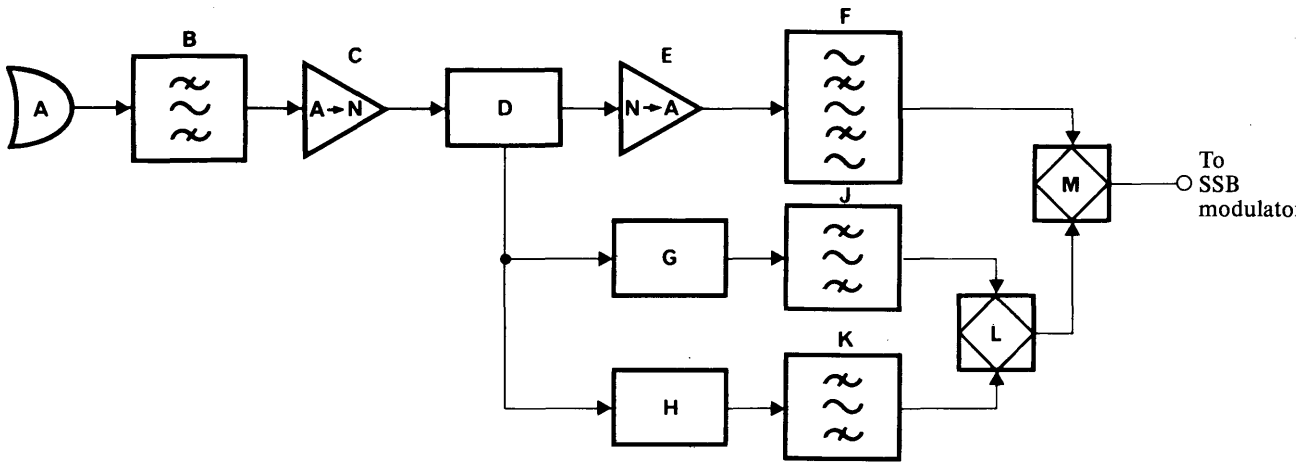


FIGURE 1a – *Block diagram of Syncompex compressor*

A: microphone
B: bandpass filter 300-2 800 Hz
C: analogue to digital converter
D: microprocessor
E: digital to analogue converter
F: band elimination filter
– stop bands at 765 and 2 125 Hz
G: FSK modulator 765 ± 42.5 Hz
H: FSK modulator 2 125 ± 42.5 Hz
J: bandpass filter 765 ± 125 Hz
K: bandpass filter 2 125 ± 125 Hz
L: combiner
M: combiner

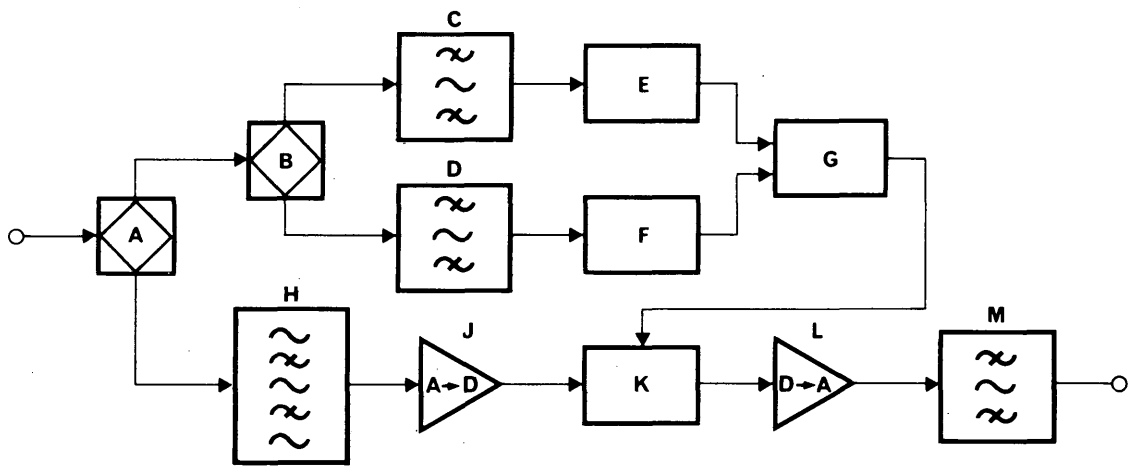


FIGURE 1b – *Block diagram of Syncompex expander*

A: audio splitter
B: audio splitter
C: bandpass filter 765 ± 125 Hz
D: bandpass filter 2 125 ± 125 Hz
E: FSK demodulator 765 ± 42.5 Hz
F: FSK demodulator 2 125 ± 42.5 Hz
G: diversity combiner
H: band elimination filter
– stop bands at 765 and 2 125 Hz
J: analogue to digital converter
K: microprocessor
L: digital to analogue converter
M: bandpass filter 300-2 800 Hz

REPORT 584

DIRECT-PRINTING AND OTHER DATA SIGNALS USING AUDIO-FREQUENCY TECHNIQUES IN THE VHF RADIOTELEPHONY CHANNELS IN THE MARITIME MOBILE SERVICE

(Question 14/8)

(1974)

1. Introduction

Five documents of the period 1970-1974, concerning the use of signals other than telephony in the VHF maritime mobile band were submitted to the Interim and Final Meetings at Geneva: [CCIR, 1970-74a, b, c, d, e].

2. Position at Interim Meeting 1972

2.1 [CCIR, 1970-74a] suggested that audio frequencies chosen from CCITT Recommendation R.31 should be used for the direct-printing service and from CCITT Recommendation T.15 for phototelegraphy or facsimile. [CCIR, 1970-74b] concluded after tests in the Rotterdam Harbour area that error correction was necessary in such areas and also that it would be wasteful to employ a full radiotelephone channel to accommodate a single 170 Hz frequency-shift direct-printing channel.

2.2 On the other hand, [CCIR, 1970-74c] considered that the natural redundancy inherent in plain language would make error protection unnecessary in the VHF frequency band considered and by thus allowing simpler equipment to be used encourage earlier development of the service. Results of field tests with an unprotected code are given in the document.

2.3 It was generally agreed, however, that more study and tests were needed in order to determine what degree of reliability could be achieved with unprotected direct-printing systems, particularly in congested harbour areas where propagation was difficult and, for example, it has been shown that rapid fading to a depth of 5 dB to 20 dB or more could often be experienced when receiving VHF signals on a moving vessel [Mossman, 1971].

2.4 It was further generally agreed that where connection into the public telex network was required the aim should be to meet the CCITT Recommendation R.54 standard of not more than 3 errors per 10^5 characters and that any error correction system employed should preferably be in accordance with Recommendation 476.

2.5 In the interests of economy, it was suggested that it would be desirable that vessels already equipped for VHF radiotelephony should be able to use existing radio equipment for direct-printing or data transmission and reception by adding normally available equipment (e.g. standard data modems).

2.6 There seems to be no advantage in locating a direct-printing signal in the upper part of the radiotelephony channel (2500-3000 Hz) as capture effect would make simultaneous use of a channel by separate ships impossible. If it were decided that for the immediate future it would be desirable to have one teleprinter emission per radiotelephony channel, the direct-printing carrier should be in the middle of the audio-frequency band.

2.7 If a block of closely spaced direct-printing channels is allocated, a very high degree of frequency stability will be necessary in the radio equipment. It may be possible to use a common reference pilot frequency in a harbour or area; this would require rather special receivers.

3. Position at Final Meeting, 1974

Further direct-printing tests were made by the United Kingdom and the Netherlands during the period between the Interim and Final Meetings.

3.1 [CCIR, 1970-74d] reported on tests carried out by the United Kingdom over an essentially open-sea path up to a distance of 100 km (Southampton to Cherbourg). Normal VHF radiotelephone equipment was used in conjunction with a standard low-speed data modem (CCITT Recommendation V.21) and teleprinter. The antennas of the coast station were approximately 280 m above sea level. No error protection was employed and no errors occurred in over 25 000 characters transmitted in the two-way test programme.

3.2 However, further tests were made by the Netherlands [CCIR, 1970-74e] in the Rotterdam Harbour area, typical of many dock and harbour areas where there are numerous buildings, port installations and ships which obstruct direct propagation paths. These tests indicated that the use of forward error correction improved the error rate from 10^{-2} (unprotected) to about 10^{-4} (error protected).

4. System proposals (1974)

[CCIR, 1970-74e] also includes proposed operational requirements for a direct-printing service in the VHF maritime mobile band and describes the technical features of a system which could provide up to 146 direct-printing channels spaced 340 Hz by the sub-division of two 25 kHz VHF radiotelephony channels. Initially, the system would employ 73 pairs of adjacent 340 Hz channels, one channel of the pair carrying the traffic information frequency shift signals ($\pm$ 85 Hz) and the other a pilot carrier for automatic frequency control purposes. The pilot-carrying channels could be converted into traffic information channels when frequency tolerances of future equipment were suitably tightened. The document emphasizes the need for early planning of channel arrangements and operational procedures and includes draft recommendations covering these aspects.

5. Future action

While the channelling arrangements and technical proposals contained in [CCIR, 1970-74c] appear to be attractive, it was generally agreed that more information on the practical performance of the system with a number of channels operating simultaneously would be needed before definitive recommendations could be adopted. Administrations are asked to give further consideration to this question.

REFERENCES

MOSSMAN, F. B. [1971] Rapid fading in the VHF Maritime Mobile Service. RTCM Assembly, Montreal.

CCIR documents

[1970-74]: **a.** 8/68 (Canada); **b.** 8/75 (Netherlands); **c.** 8/82 (Germany (Federal Republic of)); **d.** 8/186 (United Kingdom); **e.** 8/226 (Netherlands).

RECOMMENDATION 542-1 *

ON-BOARD COMMUNICATIONS BY MEANS OF PORTABLE RADIOTELEPHONE EQUIPMENT

(Question 18/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that common channels for on-board communications are necessary to meet world-wide requirements;

(b) that although the frequencies around 160 MHz as specified in Appendix 18 to the Radio Regulations are technically suitable for on-board communications, they are to an increasing extent required for other maritime needs;

(c) that frequencies in the UHF band around 460 MHz are technically suitable;

(d) that on larger vessels it may not be possible to obtain satisfactory communications at all desired locations between two hand-carried transceivers;

(e) that it is important to avoid interference from on-board communications stations to the fixed radio installation on a ship;

(f) that no tests have yet been carried out on frequencies above 470 MHz,

UNANIMOUSLY RECOMMENDS

1. that frequencies around 460 MHz are the most suitable of those so far tested for on-board communications, although other frequencies in the VHF and UHF bands are also technically suitable;

2. that the effective radiated power of on-board communication stations should be limited to the minimum required for satisfactory operation, but not exceeding 2 W ** in the UHF band up to 470 MHz and 1 W ** in the VHF band;

3. that the mode of operation between hand-carried transceivers should be single frequency simplex;

4. that, where the use of relays is necessary, frequencies with a spacing of the order of 10 MHz should be used for two-frequency simplex mode of operation, and the repeater stations should transmit only on the lower frequencies.

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* The Director of the CCIR is requested to bring this Recommendation to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO).

** For the purpose of type approval of equipment, the transmitter carrier power output terminated in its designed load impedance should not exceed 4 W and 2 W respectively (this takes into account typical feeder losses of relay transmitter installations and typical antenna efficiencies of hand-carried equipment).

Report 589-2

ON-BOARD COMMUNICATIONS BY MEANS OF PORTABLE RADIOTELEPHONE EQUIPMENT

(Question 18/8)

(1974-1978-1982)

1. Introduction

1.1 Administrations have made tests, some of a comprehensive nature, in order to determine the frequency bands, number of channels and effective radiated powers required for satisfactory on-board communications.

1.2 Comparison of reports on the results of the tests, together with practical experience, shows that there are many factors involved, and a common solution applicable to all ships and conditions may not be practicable.

1.3 Conventional field-strength measurements cannot always accurately determine the performance of portable radiotelephone equipment on board ships, due to significant multipath reflections. To overcome these difficulties, a pulse-counting technique (see Annex I) may be used.

1.4 The World Administrative Radio Conference, 1974, has defined an on-board communication station and its usage in No. 74 of the Radio Regulations.

2. Frequencies

2.1 Present systems operate in the VHF band (around 160 MHz, see Appendix 18 to the Radio Regulations) or in the UHF band (around 460 MHz, see No. 669 of the Radio Regulations). Frequencies from about 150 MHz to about 470 MHz are considered technically suitable, depending on particular circumstances.

2.2 It is further considered that tests might show that frequencies above 470 MHz could also be suitable for on-board communication purposes.

2.3 Some frequencies below 150 MHz have been tested [CCIR, 1974-78a]. The results show that use of frequencies in the 1.5 MHz band and in the 40 MHz band would not provide satisfactory communication.

2.4 Frequencies may have to be shared with other users. In this connection, the ultimate choice of frequencies is unlikely to depend solely upon technical considerations.

3. Number of channels required

3.1 A sufficient number of channels is required to permit ships to operate without harmful interference, particularly in harbours and congested areas.

3.2 The use of on-board communication is expanding rapidly, and it is impracticable at this time to determine the precise number of channels necessary to satisfy the requirements.

4. VHF operation

The 160 MHz frequency band is technically suitable, but there are operational problems since all the channels in Appendix 18 to the Radio Regulations are urgently required for other maritime needs. At present, on-board communications on channels 15 and 17 are permitted providing the effective radiated power is limited to 1 W.

5. UHF operation

5.1 The use of frequencies in the UHF band (about 460 MHz) has been studied in depth in the United States of America and shown to be practicable. Generally it was possible to obtain satisfactory communication between two hand-carried transceivers used at different locations on board small to medium size ships. Under these conditions, and using an e.r.p. of 2 W, the single frequency mode of operation could satisfy the requirements of these categories of ship.

5.2 Tests were carried out by the United Kingdom on board three larger ships [CCIR, 1974-78b] with two frequency simplex. The results showed that all the usual operational requirements of the ships were fully met with the use of hand-carried equipment.

5.3 Tests carried out by Poland [CCIR, 1974-78a] indicated that the use of a frequency in the order of 300 MHz provided similar results.

5.4 On very large ships, it was not always possible to obtain satisfactory communication at all desired locations between two hand-carried transceivers.

6. Improving performance over difficult communication paths

6.1 The difficulties mentioned in § 5.4 arise in areas within the ship where the structure forms a screen to the transmission of electromagnetic waves or where the particular geometry at a localized area causes substantial multipath fading. Such phenomena are not peculiar to UHF but occur at all frequency bands and the precise quantitative effect seems to depend more on local conditions than on any common factors.

6.2 The use of a two-frequency relay system providing for simplex operation has been shown to be one satisfactory means of covering all parts of a ship without resorting to the use of high power transmitters. Spacing between the transmit and receive frequencies of the order of 10 MHz permits the use of relatively inexpensive equipment. To prevent interaction occurring between neighbouring relay stations, it would be necessary to standardize the frequencies used for relay station transmitters.

6.3 Tests carried out in Japan [CCIR, 1974-78c] have indicated that the use of a form of selective signalling (e.g. continuous tone controlled squelch system) might be of advantage where a channel is used by several ships in the same vicinity.

6.4 Tests carried out in Japan [CCIR, 1978-82] have indicated that the non-boosted antenna repeater system *, distributed multi-antennas system and radiating cable system are effective for improving communication quality of internal communication on board ships.

7. Radiating cable systems

7.1 It has been suggested by the International Conference on High Tension Electric Systems (CIGRE) that on-board communication systems employing radiating cables could provide a satisfactory service. This section describes such systems; there is also useful information on radiating cable systems in Report 902.

7.2 Japan [CCIR, 1978-82] has conducted tests of on-board communication systems, including the use of radiating cables, non-boosted antenna repeaters, and distributed multi-antenna arrangements. The results of these tests indicate that a large improvement in on-board communication, over difficult transmission paths, can be realized using these systems.

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* A non-boosted antennas repeater system consists of two antennas at two different locations, connected by a coaxial cable with no amplifiers in the circuit. An RF signal received on the antenna at one location will be retransmitted, without amplification and subject to the system losses, from the antenna at the other location.

7.3 The most effective radiating cable system (operating around 460 MHz) proved to be one using a vertical cable between the ship's upper deck and the thirteenth car deck below the main deck. The cable had a 55 DB coupling loss at a point 1.5 m from the cable, a transmission loss of 40 dB/km, and a 50Ω characteristic impedance. It was found that the radiating cable system installed on existing vessels was approximately 5 to 10 times more expensive than the other systems which provided satisfactory performance. Installation of a radiating cable system when the ship is being constructed would significantly reduce the cost.

8. Summary and conclusions

8.1 The VHF band (around 160 MHz) and the UHF band (around 460 MHz) are the most suitable bands from those which have so far been tested but the VHF band mentioned in Appendix 18 is limited to two channels which will be insufficient to meet the requirements. The UHF band offers advantages, since no special precautions would be necessary to prevent interference to the fixed VHF radio installation in the ships by the operation of UHF on-board communication equipment.

8.2 In the VHF band, a maximum e.r.p. of 1 W * and in the UHF band a maximum e.r.p. of 2 W * is satisfactory to meet the operational requirements of most ships.

8.3 In the long term, on-board communications should operate solely in the UHF band. In this connection and in order:

- to prevent interaction occurring between ships using two-frequency simplex relay systems,
- to reduce interaction between ships using two-frequency simplex relay systems and ships using one-frequency simplex on the lower frequencies,

it is considered that only the three lower frequencies listed in Appendix 20 to the Radio Regulations should be used for transmissions from relay stations.

8.4 Radiating cable systems may be of use in increasing the effectiveness of on-board communications.

8.5 Studies to ascertain the suitability of frequencies above 470 MHz would be advantageous, as would a study of the use of radiating cables for maritime applications. Further study is also necessary to determine the number of channels necessary to satisfy the requirements for on-board communications.

REFERENCES

CCIR Documents

[1974-78]: **a.** 8/212 (Poland (People's Republic of)); **b.** 8/285 (United Kingdom); **c.** 8/265 (Japan).

[1978-82]: 8/25 (Japan).

ANNEX I

METHOD OF ASSESSING COMMUNICATION RELIABILITY IN CONFINED SPACES

1. Introduction

Propagation in confined spaces is mainly by multipath reflections; this poses problems when communication is required inside buildings, ships, tunnels etc. Small changes in the environment, such as opening a door, can cause wide variations in signal strength and, consequently, it is not feasible to make valid quantitative field-strength measurements using normal techniques.

The method described is designed to overcome these difficulties and to provide a means of quantitative measurement. The method is equally applicable to measurement in unconfined spaces.

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* For the purpose of type approval of equipment, the transmitter carrier power output terminated in its designed load impedance should not exceed 2 W and 4 W respectively (this takes into account typical feeder losses of relay transmitter installations and typical antenna efficiencies of hand-carried equipment).

2. Method

The carrier of a tone modulated base transmitter is switched by clock pulses of a known repetition rate. The received tone pulses are counted over a known time period and used to assess the signal strength. Counting and timing is achieved electronically to attain the necessary accuracy.

The system indicates only whether the mute is lifted or not; it cannot determine how much the signal is above or below the muting threshold. If the receiver is stationary during the measuring period, it will receive either all or none of the pulses; hence, it is necessary to move the receiver around the measuring area to obtain a meaningful reading.

It is normally possible to test only one direction of transmission at a time with this method; when testing in the base to mobile direction it is possible to have several mobiles making measurements simultaneously.

When using this technique, Table I indicates the communication quality to be expected for various percentages of pulses received.

TABLE I

% pulses received	Communication quality
< 50	Not normally usable
50	Poor
70	Fair
90	Good
100	Excellent

3. Circuit description

Figure 1 shows the block diagram of the system. The transmitter is tone modulated by an audio tone of approximately 1 kHz and the transmitter carrier is continually pulsed by a timer (T_1). The pulse (t_1) has a repetition interval of 2 s and a duration of 500 ms as shown in Fig. 2 and causes the transmitter to radiate a succession of tone bursts. The maximum repetition rate and the minimum pulse duration are determined by the response time of the receiver mute circuitry.

The tone bursts are received by the receiver and emitted from the loudspeaker. The bursts are then either acoustically coupled into the pulse counter or electrically coupled by using the earphone socket where fitted. The latter method is to be preferred, since it reduces the possibility of external interference. The burst is amplified and shaped to recover the original pulse. To start a count, the counter is first manually re-set and then manually started, which starts the timer T_2. Timer T_2 opens the gating circuit for the period t_2 [$t_2 = t_1 (N - ¼)$], which is the time required to allow N pulses to be received, without requiring the starting time of period t_2 to be synchronized with the start of a pulse. N is usually chosen to be between 10 and 100. With the gate open, the received pulses are fed to the counter. At the end of the period t_2 the "end of count" indicator is turned on so that the operator knows when the count has finished and the result can then be read from the display. Greater accuracy is achieved when N is large, but this involves a long measuring time. The maximum length of time that a mobile operator would normally remain in one place, if he was unable to obtain satisfactory communication, is about a minute. Hence useful compromise is for $N = 25$; this also has the advantage of being readily convertible to a percentage.

4. Conclusions

Operationally, the user of a mobile radio system is concerned with the percentage of time that communication is successfully achieved; this system of measurement enables the percentage to be measured quantitatively.

When using this technique, two-way speech can be considered possible in all areas where more than 50% of the transmitted pulses have been received.

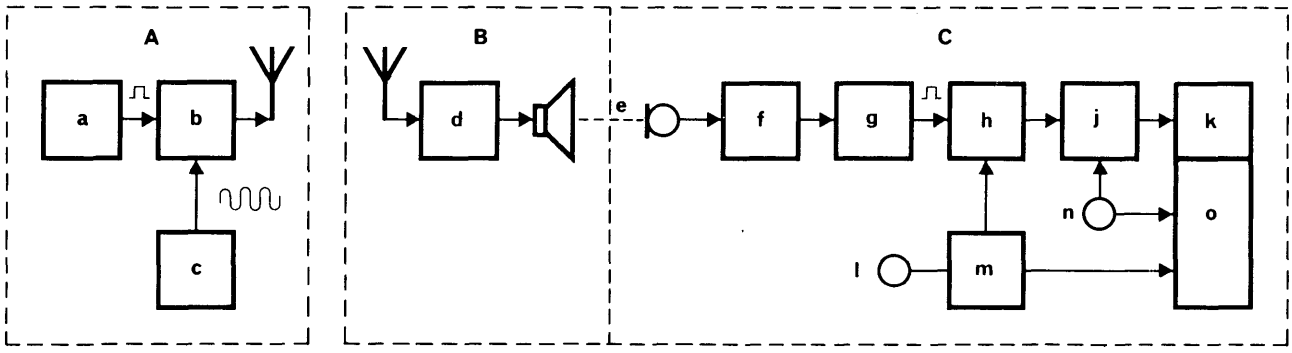


FIGURE 1 – *Block diagram of equipment used for tests*

A: transmitter B: receiver C: pulse counter

a: timer T_1
b: transmitter
c: tone
d: receiver
e: coupling
f: amplifier
g: shaper
h: gate
j: counter
k: display
l: manual start
m: timer T_2
n: reset
o: end of count indicator

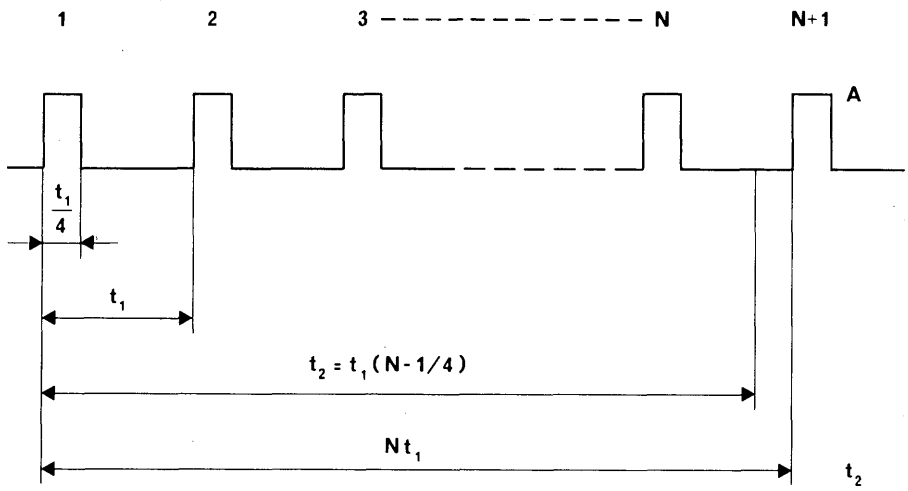


FIGURE 2 – *Relative pulse durations*

A: continuously transmitted pulses

t_2: period when receiver gate is open; start of t_2 not synchronized with pulses.

RECOMMENDATION 586 *

AUTOMATED VHF/UHF MARITIME MOBILE TELEPHONE SYSTEM

(Question 23/8)

(1982)

The CCIR,

CONSIDERING

(a) that an automated VHF/UHF maritime mobile telephone service would expedite the handling of traffic in the international maritime mobile service and increase the efficient use of radio channels;

(b) that there is an urgent need for such a service;

(c) that a system providing such a service could also allow for the transmission of, for example, telegraphy, facsimile and data;

(d) that international standardization is of great importance in the maritime mobile service;

(e) that the selective-calling system described in Recommendation 493 can form the basis for the signalling over the radio path and can provide for expansion to include other services;

(f) Recommendation No. 312 of the World Administrative Radio Conference (Geneva, 1979),

UNANIMOUSLY RECOMMENDS

1. that the automated VHF/UHF maritime mobile telephone system should be in accordance with either of the two configurations described in Annex I depending on channel availability, and geographical and other considerations;

2. that the signalling procedures to be used over the radio path should be in accordance with Annex II;

3. that the signalling messages to be transmitted over the radio path should be in accordance with Annex III.

Note. – Annexes IV and V provide supplementary information relevant to the operation of the automated VHF/UHF maritime radiotelephone system.

ANNEX I

SYSTEM DESCRIPTION

1. General

1.1 The two configurations described in this Annex differ only in their method of use of the calling channels. The marked idle channel (MIC) configuration is based on the assignment of non-shared channels to each coast station while the time division multiple access (TDMA) configuration is based on time sharing of a common calling channel by a number of coast stations.

1.2 Signalling procedures have been unified to the maximum extent feasible in order to minimize the additional cost for a ship station compatible with both configurations. Annex II to this Recommendation describes the signalling procedures in detail.

1.3 The signalling messages, described in Annex III to this Recommendation, are compatible with the digital selective-calling system (Recommendation 493).

1.4 In the following, a coastal area is defined as the geographic area covered by one or more coast stations controlled by a maritime switching centre (MSC). Note that the concept of a maritime switching centre does not preclude distributing the switching facilities at different locations.

2. Marked idle channel configuration

This configuration has the following characteristics:

2.1 Shore-to-ship calling should be carried out over a channel marked either as "calling channel" (see § 2.4) or as "calling/idle working channel" (see § 2.7).

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* The Director, CCIR, is requested to draw this Recommendation to the attention of the CCITT.

2.2 Ship-to-shore calling should be carried out over a channel marked either as "idle working channel" (see § 2.5) or as "calling/idle working channel" (see § 2.7).

2.3 There is no need for the assignment of a dedicated frequency pair for a calling channel. However, administrations could provide for one or more dedicated calling frequencies, if this can be justified with respect to the number of available channels.

2.4 When at one coast station two or more channels are not in use for traffic at a given time:

- one of these channels should be designated as the calling channel (for shore-to-ship calling) and should be marked with a unique "calling channel" signal M1;
- one or more of the remaining idle channels should be marked with a unique "idle working channel" signal M2.

The number of idle working channels so marked is dependent on the expected number of ship-originated call attempts and the related probability of interference, etc., and should be determined by the administration for each coast station.

2.5 Idle channels not carrying the unique "idle working channel" marking signals would normally first be used for shore-originated traffic.

2.6 The designated "calling channel" should not be used for traffic unless all other channels of the coast station are occupied.

2.7 If, at any time, only one channel is not used for traffic, this channel may be marked with a unique "calling/idle working channel" signal M3 to allow for use for both shore-originated and ship-originated calling.

2.8 If all channels are occupied for traffic, no marking signals are transmitted by that coast station.

2.9 If, starting from the situation that all channels are occupied, one channel becomes free of traffic, this may then be marked as a "calling/idle working channel".

2.10 If in addition to the "calling/idle working channel" a second channel becomes available, then the former channel should be marked (from that moment) with the "calling channel" marking signal. The second channel will then carry the "idle working channel" marking signal.

2.11 The marking signals should contain the coast station identification in accordance with Annex III to this Recommendation.

2.12 Since it is possible that more than one channel could be marked simultaneously with an "idle working channel" signal, ships should be provided with some means to randomize the selection of one of these idle channels for the call set-up procedure.

2.13 Marking signals sent on an idle working channels should be transmitted with reduced working power.

Marking signals on the calling channel may also be sent at reduced power. However, calling sequences and signalling sequences should be sent at full working power.

2.14 During the on-hook condition the ship station may lock on a channel marked either "calling channel" or "calling/idle working channel".

When the ship is within radio coverage of several coast stations, the selection of which "calling channel" will be locked on may be based on signal quality measurements, such as field strength level or error-rate. In addition, provision should be made for manual or automatic selection of predetermined coast station identities by ship stations, e.g. coast stations of a particular nationality.

2.15 If a ship to coast station call attempt is unsuccessful, a second call attempt may be made after initiating a new search for an M2 or M3 marked working channel. After two unsuccessful call attempts the ship station should abandon the call and provide an unsuccessful call attempt indication to the ship subscriber.

3. Time division multiple access configuration (TDMA)

This configuration has the following characteristics:

3.1 Shore-to-ship and ship-to-shore calling should be carried out over a dedicated calling channel which is a particular frequency pair, which may be time-shared by a number of coast stations.

3.2 The calling channel is marked with a unique "random access" signal M4 during the time periods it is available for ship-to-shore call initiation (see § 3.4).

3.3 In the shore-to-ship direction, coast stations within interference range of each other should coordinate their transmissions so that no overlap occurs. Such time-sharing may be either on the basis of pre-allocated time slots or on a demand basis. In the latter case, arrangements should be made to ensure that one high-traffic coast station does not lock out other participating coast stations for excessive periods of time.

3.4 In addition to time periods for shore station originated call attempts, time periods are provided on the calling channel to allow initiation of ship-originated calls using random access. During these periods the channel is marked with a unique "random access" marking signal. Each marking sequence should also indicate the number of random access time slots still to follow in the particular random access period.

3.5 Ship-to-shore call attempts should be transmitted only during the random access periods. Transmissions should be in time slots which are referenced to the "random access" marking sequences. To further enhance the channel capacity, ship stations should employ a means to randomize the choice of time slot following reception of a "random access" marking sequence, taking into account the number of time slots remaining (encoded in the marking sequence, see § 3.4).

3.6 When coast stations are allocated individual random access periods, coordination of the time periods is required between coast stations within interference range of each other.

When a random access period is common to a number of coast stations, coordination between those coast stations should be effected to ensure full area coverage and non-interference of marking signals.

3.7 Upon receipt of a properly addressed call attempt from a coast station, the ship station shall immediately transmit its acknowledgement over the ship-to-shore frequency of the calling channel.

3.8 Upon receipt of a call attempt from a ship station, the appropriate coast station transmits a call sequence addressed to that ship station during its subsequent calling period.

3.9 Upon receipt of a location registration call attempt from a ship station (during the random access period) the appropriate coast station shall immediately transmit its acknowledgement over the shore-to-ship frequency of the calling channel.

4. Channel supervision

If the quality of a speech channel decreases below a threshold level during the conversation, either the connection may be interrupted or a procedure may be started to switch the call-in-progress to a satisfactory working channel controlled by the same maritime switching centre (MSC).

Two methods of channel quality supervision are given in Annex V of this Recommendation. The choice of the method used by each coast station may be decided by each administration; however, ship stations should be provided with facilities to enable the pilot tone method to be used, unless they sail only in waters where the pilot tone method is not used.

5. Location registration

Location registration is defined as the procedure to be followed for the ship station identity to be entered in a ship location register at the controlling maritime switching centre (MSC).

5.1 To simplify the routing of calls in the shore-to-ship direction procedures are used to update the MSC's location register. An updating procedure should be started by the ship station when entering a new coastal area and when initially switching on a ship station.

5.2 *Marked idle channel configuration*

5.2.1 Location registration in the MIC configuration should take place on a working channel.

5.2.2 If during the on-hook condition the ship station loses the calling channel it is locked to, it will search for another calling channel. If the new calling channel marking signal indicates that the calling channel belongs to a different coast station, then the ship station may initiate a location registration procedure (see also Recommendation 587).

5.3 *TDMA configuration*

5.3.1 Location registration in the TDMA configuration takes place on the calling channel.

5.3.2 If during the on-hook condition the ship station loses a particular coast station's signal, it will search for another time slot. If the new coast station identification indicates that it is a different coast station, then the ship station may initiate a location registration procedure (see also Recommendation 587).

5.4 *In both configurations:*

5.4.1 Location registration is considered to be finalized after a confirmation by the new coast station.

5.4.2 If the ship does not receive a confirmation from the coast station, it repeats the transmission of the relevant signal. (In the MIC configuration the second trial should be made after initiating a new working channel search.)

5.4.3 If the ship has not received a confirmation after 2 successive trials, it should not make further trials to the coast station. In this case non-completion of the location registration procedure should be indicated on the ship's equipment.

5.4.4 Administrations are urged to issue guidelines to avoid transmission of unnecessary location registration signals.

6. Polling

Coast stations may be provided with facilities for polling. Polling is defined as the procedure by which an MSC can interrogate ships in order to verify whether they are still within radio coverage. Polling is done to keep track of ships already registered in the service area. Before deleting a ship from the register, several polling attempts should have been unsuccessful.

6.1 All signals necessary for polling should be transmitted on calling channels.

ANNEX II

SIGNALLING PROCEDURES

1. Introduction

1.1 *Purpose*

The purpose of this part of the Recommendation is to describe the calling and signalling arrangements to be used over the radio path. The description uses sequence diagrams to show how signals are exchanged between a coast station and a ship station.

In addition to the signalling over the radio path, interworking with the signalling over the public telephone network is necessary. Operation of the complete system is illustrated in Appendices I to VI (Note 1) using the specification and description language (SDL) developed by the CCITT. Appendix I provides a general introduction to SDL. Appendices II and III show logic procedures for land-originated calls at the maritime switching centre (MSC) and at the ship station, respectively. Appendices IV and V show logic procedures for ship-originated calls at the MSC and at the ship station, respectively. Appendix VI shows the procedure at the MSC for power level control and for switching call-in-progress.

Procedures are defined for both TDMA and MIC configurations (see Annex I). The procedures are such that the differences are as small as possible so that ship stations may operate in both configurations, if required.

Note 1. – Appendices I to VI are reproduced at the end of this Recommendation after Annex V.

1.2 *Definition of signals sent on the radio path*

1.2.1 *Marking sequences*

M1 – Signal used in MIC configuration to mark a channel as calling channel;

M2 – signal used in MIC configuration to mark idle working channels;

M3 – signal used in MIC configuration for combined calling/idle working channel marking;

M4 – signal used in TDMA configuration to indicate available slot periods for ship-to-coast station call initiation.

1.2.2 *Calling sequences*

C1 – Coast station to ship interrogation and polling signal;

C2 – acknowledgement by ship to C1;

C3 – coast station-to-ship call with indication of working channel;

C4 – acknowledgement by ship to C3;

C5X – coast station is unable to comply:

X = 0 no reason given,

X = 1 congestion at MSC,

X = 2 ship barred,

X = 3 queueing indicator (in TDMA configuration only),

X = 4, . . ., 9 reserved for future use;

C6X – ship-to-coast station call:

X = 0 no charging information requested,

X = 1 charging information requested;

C7 – signal sent by coast station in TDMA configuration to acknowledge C60 or C61. C7 includes indication of working channel;

C8X – ship is unable to comply:

X = 0 no reason given,

X = 1 busy,

X = 2 acknowledgement to C53 (in TDMA configuration only),

X = 3, . . ., 9 reserved for future use;

C10 – ship-to-coast station call for location registration;

C11 – acknowledgement by coast station to C10.

1.2.3 *Signalling sequences*

S10X – Coast station-to-ship signal to initiate continuity test of the working channel:

X = 0 charging information available,

X = 1 charging information not available;

S2 – acknowledgement by ship to S100 or S101;

S3 – ringing command coast station-to-ship;

S4 – answer signal from ship (off hook);

S5X – call unsuccessful:

X = 0 congestion,

X = 1 busy,

X = 2 send special information tone,

X = 3, . . ., 9 reserved for future use;

S6 – "selection" signal sent by ship for ship-to-coast station calling. (Includes the called subscriber's number);

S7 – acknowledgement by coast station to S6;

S8 – clearing by ship;

S9 – clear acknowledgement to S8;

S11 – clearing by coast station;

S12 – clear acknowledgement to S11;

S13 – coast station-to-ship signal used for power level control and/or switching call-in-progress;

S15 – coast station-to-ship signal to initiate continuity test on new working channel when switching call-in-progress;

S16 – acknowledgement by ship to S13 or S15;

S17 – coast station-to-ship signal to indicate start of chargeable duration and charging level, if available;

S18 – acknowledgement by ship to S17.

2. Call set-up and clearing procedures

2.1 *Land-originated calls*

2.1.1 *Marked idle channel (MIC) configuration. Channels with M1 marking sequences.*

The call set-up and clearing procedures are shown in Fig. 1.

2.1.1.1 If the MSC does not require a ship interrogation prior to assigning the working channel, it sends the call signal C3 on the calling channel of the appropriate coast station. C3 contains the channel number of the assigned working channel. The ship will acknowledge C3 by sending the C4 signal on the return frequency of the calling channel. The MSC may continue to set up the call without awaiting the receipt of C4. However, the MSC must recognize and act upon a C80 or a C81 signal.

2.1.1.2 If the MSC requires a ship interrogation prior to assigning the working channel (e.g. it does not have accurate knowledge of the ship's location), the MSC must transmit C1 on all coast stations in the required area. If the ship is in the required area, the MSC will receive the ship's acknowledgement signal C2 from the coast station, the calling channel of which the ship is monitoring. The call set up would then continue as in § 2.1.1.1 above.

2.1.1.3 After having sent the call signal C3 on the calling channel, the MSC initiates the continuity check of the assigned working channel by sending the signal S101 on that channel.

2.1.1.4 The ship will, after having sent C4, start monitoring the receive frequency of the assigned channel. The ship must not turn on its transmit carrier before S101 has been recognized. Upon recognition of S101 the ship returns the acknowledgement signal S2.

However, if S101 has not been received within three seconds, relative to the instant when C4 was sent, the ship should stop monitoring the working channel and reassume monitoring of a calling channel.

2.1.1.5 When the MSC recognizes the S2 signal, it will start transmitting the ringing command signal S3 and wait for the answer signal, S4, from the ship.

2.1.1.6 S101 should not be sent more than 8 times. If the MSC has not received an S2 signal during this time it should clear the land and radio connection.

2.1.1.7 When the ship station subscriber goes off hook, the ship station transmits S4. As soon as S4 has been recognized by the MSC it must stop transmitting S3 and wait for cessation of S4. If the ship fails to turn off S4 within three seconds after initial recognition of S4, by the MSC, the MSC should clear the call by sending S11.

2.1.1.8 A similar time-out supervision applies to the ship station. If S3 is still being received after S4 has been sent 8 times, the ship station should initiate clearing of the connection.

2.1.1.9 Through-connection at the MSC should not take place until cessation of S4 has been recognized.

2.1.1.10 Clearing may be initiated at any time during conversation by either party.

2.1.1.11 As soon as a clear forward signal is received from the telephone network, the coast station initiates clearing of the radio path by transmitting the S11 sequence to the ship. The MSC may either receive the acknowledgement S12 to S11 or the sequence S8 from the ship. The latter would occur if both parties clear simultaneously. The MSC deactivates the radio carrier as soon as the S12 or S8 sequence has been recognized.

2.1.1.12 If the ship subscriber clears first, i.e. the ship station has not recognized an S11 signal from the MSC when the on hook condition is detected, the ship station sends the S8 sequence. The ship station will either receive the acknowledgement S9 to S8 or the sequence S11. The ship station deactivates the carrier as soon as the S9 or S11 sequence has been recognized.

2.1.1.13 The station that sends an acknowledgement sequence should deactivate its carrier as soon as it ceases to receive the clearing sequence.

2.1.1.14 A clearing sequence or a clear acknowledgement sequence should not be sent more than 8 times. Upon time-out the station should deactivate its carrier.

2.1.2 *Marked idle channel (MIC) configuration. Channels with M3 marking sequences.*

The call set-up and clearing procedures are identical to those on channels with M1 marking sequences. However, it should be noted that:

- in this case calling sequences and signalling sequences are sent on the same channel, i.e. on the M3 marked channel;
- when a C3 signal is sent, the MSC must stop sending the M3 marking sequence until the channel has been released;
- any C60 or C61 sequences received from a ship should be ignored after the channel has been seized for a land-originated call.

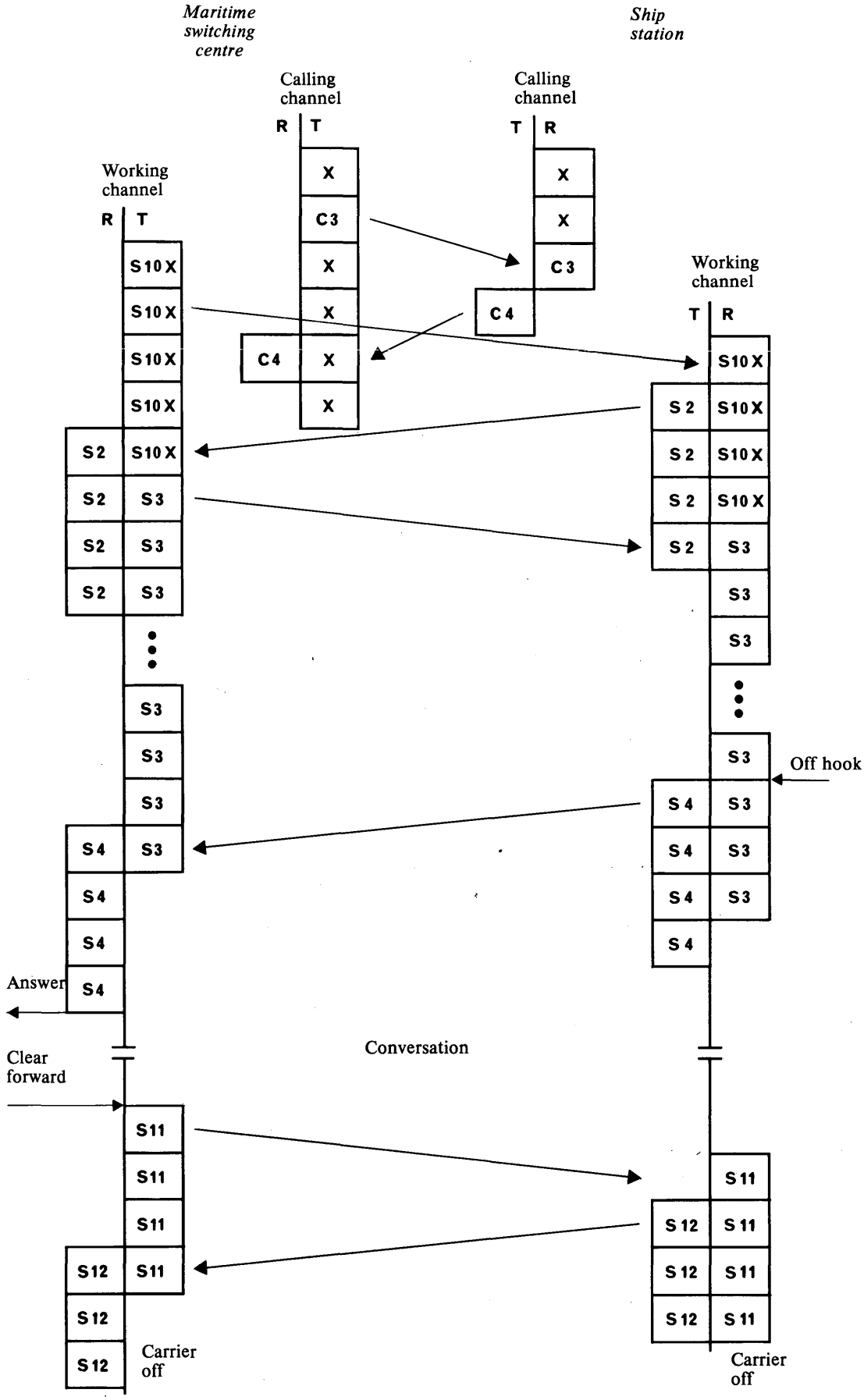


FIGURE 1 – *Call set-up and clearing procedures for land-originated call MIC configuration with M1 marking sequence*

X: any sequence (including M1 marking sequence) that may be sent on the calling channel.

2.1.3 *TDMA configuration*

The setting-up and clearing procedures are identical to that of the MIC configuration for channels with M1 marking.

2.2 *Ship-originated calls*

2.2.1 *Marked idle channel (MIC) configuration*

The set-up and clearing procedures are carried out on a working channel and are shown in Fig. 2.

2.2.1.1 When the MSC recognizes a C60 or C61 sequence it removes the M2 (M3) marking sequence (see § 2.1 of Annex IV).

2.2.1.2 If the received call sequence is C60, the MSC will transmit the S101 sequence in order to initiate the continuity check of the channel.

If the received call sequence is C61, the MSC will return:

- S100 if charging information can be provided. The detailed charging information will be provided later by use of the S17 sequence;
- S101 if charging information cannot be provided. This would enable the ship station to bar calls for which charging information cannot be obtained.

2.2.1.3 Upon recognition of the S100 or S101 sequence the ship will return the S6 sequence containing all digits of the called number (including prefixes).

If the ship station does not recognize S100 or S101 within three seconds, it may automatically start a search for a new M2 (M3) marked channel and repeat the call on that channel without disconnecting the subscriber (see Annex I, § 2.15).

2.2.1.4 Upon recognition of a valid S6 sequence the MSC will return the acknowledgement sequence S7 until it ceases to receive the S6 sequence. At this instant the MSC may through-connect the call.

2.2.1.5 The sequences S100, S101, S6 and S7 should not be sent more than 8 times. If no correct response is received within this time, the station times out and should clear the connection in the normal manner.

2.2.1.6 If the call sequence C61 was received from the ship, the MSC will send the sequence S17 upon detection of the answer signal from the telephone network. The ship will acknowledge S17 with S18. These signals are sent twice.

2.2.1.7 The ship station should be able to detect clearing by the on-board subscriber (on hook) at any time during the setting-up phase of the call and during conversation. In such cases the ship station should initiate clearing by transmitting the S8 sequence.

The MSC will acknowledge S8 by S9. However, S11 may be received by the ship station instead of S9 if simultaneous clearing takes place.

2.2.1.8 The ship station should respond to the clearing sequence S11 from the MSC by returning the clear acknowledgement sequence S12 provided that the ship has not already started sending S8. In the latter case it should deactivate its carrier upon completion of S8.

2.2.1.9 Release of the radio channel should take place as described in §§ 2.1.1.13 and 2.1.1.14.

2.2.2 *TDMA configuration without queueing*

The part of the call set-up procedure which takes place on the calling channel is shown in Fig. 3. The part of the procedure which will subsequently take place on the working channel is identical to that of the MIC configuration.

The ship transmits the call sequence C60 or C61 in a time slot during an M4 marked random access period.

The MSC will respond in its next assigned calling period with the sequence C7 which includes the channel number of the assigned working channel.

2.2.3 *TDMA configuration with queueing*

The part of the procedure which takes place on the calling channel is shown in Fig. 4.

The part of the procedure which would subsequently take place on the working channel is identical to that of the MIC configuration.

2.2.3.1 If there is no queue at the MSC when the call sequence C60 or C61 is received, the MSC acts as in § 2.2.2.

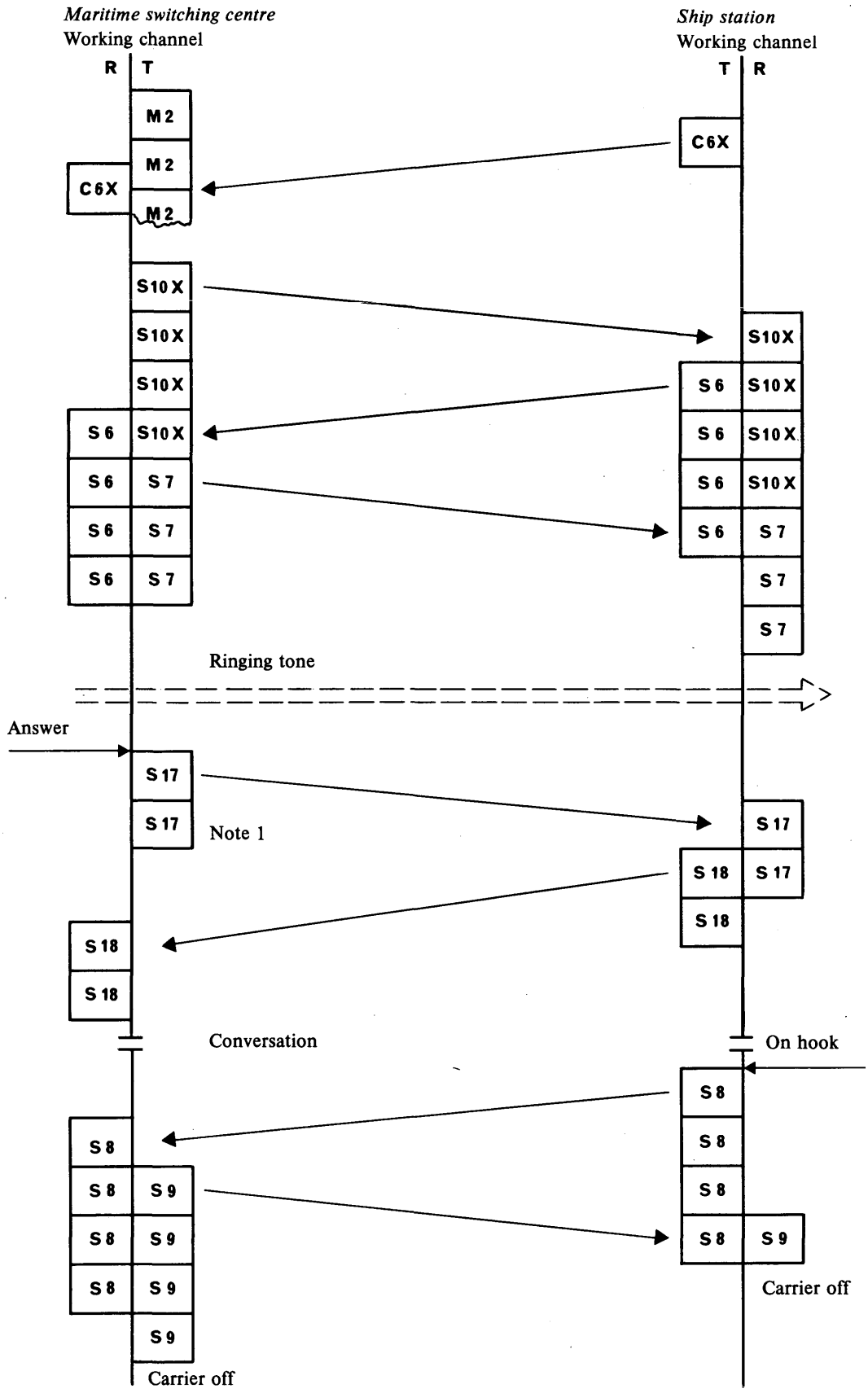


FIGURE 2 – *Call set-up and clearing procedures for ship-originated call. MIC configuration*

Note 1. – If requested by ship.

2.2.3.2 If there is a queue, the MSC will return C53 to indicate that the call has been placed in the queue. This signal is acknowledged with C82 by the ship. If no such acknowledgement is received within a predetermined time the MSC would assume that the ship has cleared.

The C53/C82 cycle is repeated at periodic intervals until a channel becomes available at which time the MSC returns the C7 sequence to the ship.

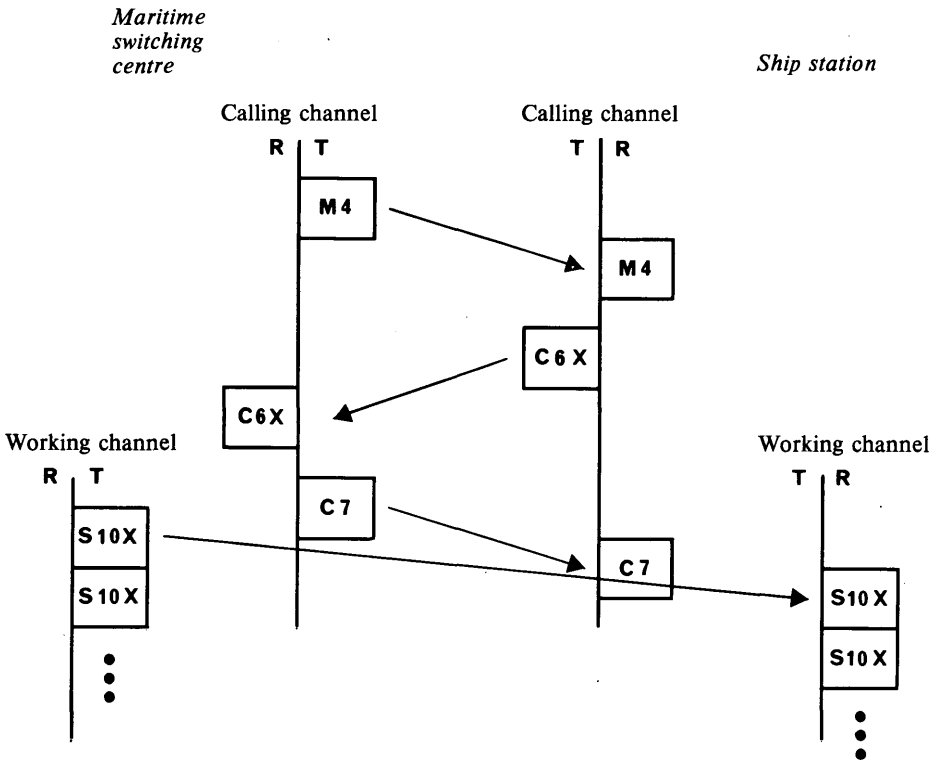


FIGURE 3 – *Call set-up procedure on calling channel for ship-originated call. TDMA configuration without queueing*

2.3 *Unsuccessful calls*

2.3.1 *Land-originated calls*

2.3.1.1 The ship station should have the capability of returning sequences C80 (unable to comply, reason not given) and C81 (busy). These sequences may be sent as a response to the call sequence C3.

2.3.2 *Ship-originated calls*

2.3.2.1 The MSC should respond to a C60 or C61 sequence by transmitting:

- the C51 sequence if there is congestion in the MSC;
- the C52 sequence if the calling ship is barred;
- the C50 sequence if the MSC cannot comply to the call for any other reason (e.g. a request for service which is not provided at the MSC).

On receipt of one of these sequences the ship station should provide an appropriate information to the on-board subscriber.

2.3.2.2 On receipt of an electrical signal from the telephone network indicating that the connection cannot be established the MSC should return one of the sequences S50, S51 or S52 as appropriate, followed by the clearing sequence S11.

The sequences S50, S51 or S52 should be sent twice.

3. Location registration procedure

3.1 When a ship station initiates a location registration procedure, it sends C10 to the appropriate coast station. Upon receipt of C10 without transmission errors the coast station returns C11 to the ship station. If the ship station does not receive C11, or if C11 is received with transmission errors, the ship station may repeat the location registration procedure or activate an indicator showing that the location registration was unsuccessful (see Annex I, §§ 5.4.2 and 5.4.3).

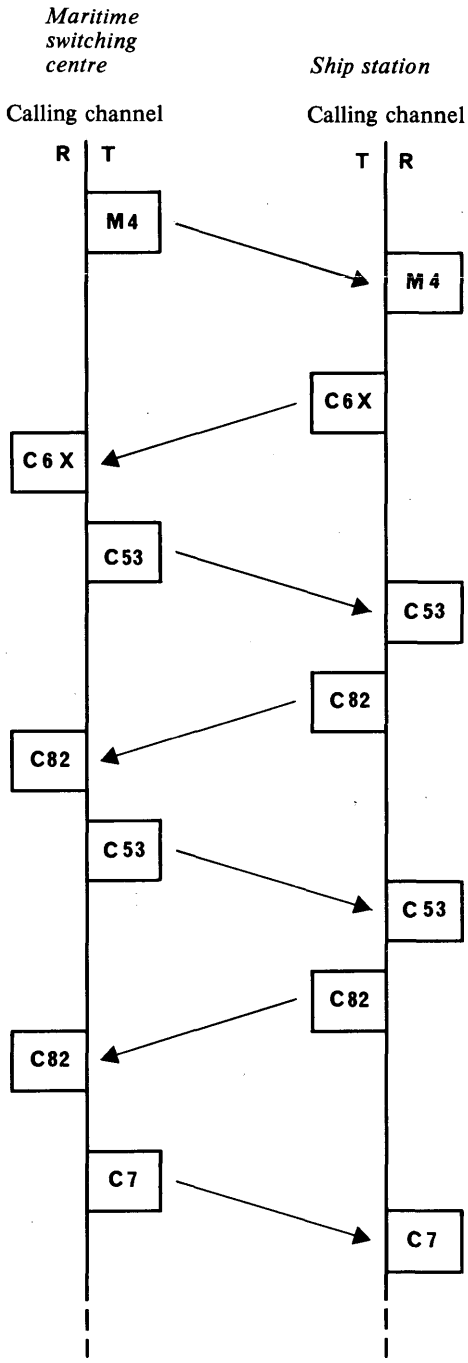


FIGURE 4 – *Calling procedure for ship-originated call. TDMA configuration with queueing*

4. Polling procedure

4.1 When the coast station wishes to ascertain whether a registered ship is still in its service area it transmits C1 to the ship. Upon receipt of C1 the ship station returns C2 to the coast station (see also § 2.1.1.2).

ANNEX III

SIGNALLING MESSAGES

1. General

The signalling required for setting up calls comprises:

1.1 *Marking sequences* to indicate:

1.1.1 in the marked idle channel configuration:

- calling channels (M1),
- idle working channels (M2),
- calling/idle working channels (M3);

1.1.2 in a time division multiple access configuration:

- time-shared dedicated calling channels (M4);

1.2 *calling sequences* to alert the required station;

1.3 *signalling sequences* to establish and to clear the speech path on the radio channel.

2. Technical characteristics

2.1 The system is a synchronous system with the following characteristics:

2.1.1 The modulation rate is 1200 bauds.

2.1.2 Signalling is provided by frequency-shift keying of a sub-carrier in the voice band; the frequency shift is 800 Hz, the sub-carrier is at 1700 Hz (which is compatible with CCITT Recommendation V.23). The lower frequency is referred to as the Y (binary 1) state and the higher frequency as the B (binary 0) state of the signal elements.

2.1.3 The code is a ten-unit error detecting code:

- the first seven bits are the information bits;
- the bits Nos. 8, 9 and 10 indicate, in the form of a binary number, the number of B elements in the seven information bits, as shown in Table I of Annex II to Recommendation 493;
- the seven information bits of the primary code express a symbol number from 0 to 127 inclusive as shown in Table I of Annex II to Recommendation 493;
- the symbols from 0 to 99 inclusive are used to code two decimal figures according to Table IVa of Annex II to Recommendation 493;
- the symbols from 100 to 127 inclusive are used to code service commands.

2.1.4 Apart from the phasing signals, each signal is transmitted twice in a time-spread mode; the first transmission (DX) of a specific signal is followed by the transmission of four other signals before the re-transmission (RX) of that specific signal takes place, allowing for a time-diversity reception interval of 33.3 ms.

2.2 *General format of marking, calling and signalling sequences*

The general format is shown in Fig. 5.

2.2.1 *The phasing sequence* is identical for all sequences and is composed of the signals 125 in the DX-position (four times) and sequentially the signals 109, 108, 107, 106, 105 and 104 in the RX-position as shown in Fig. 6.

2.2.2 *The format specifier* defines the type of sequence and is in accordance with Recommendation 493:

- signal 110 is used to define a marking sequence;
- signal 120 is used to define a calling sequence being a selective call directed to an individual station;
- signal 124 is used to define a signalling sequence.

Phasing sequence	Format specifier	Address	Category	Self-identification	Message		End of sequence	Check character
					Tele-command	Other information		
A	B	C	D	E	F1	F2	G	H

FIGURE 5 – *General format of sequences*

DX	125		125		125		125		110		X_1		X_2	
RX		109		108		107		106		105		104		110

Marking sequence

DX	125		125		125		125		120		X_1		X_2	
RX		109		108		107		106		105		104		120

Calling sequence

DX	125		125		125		125		124		X_1		X_2	
RX		109		108		107		106		105		104		124

Signalling sequence

FIGURE 6 – *Composition of the phasing sequence and the format specifiers*

X_1 and X_2: the first two characters of self identification (marking sequences) or address (calling and signalling sequences) in DX position.

2.2.3 *The end of sequence* consists in the DX-position of three identical signals (G_1, G_2, G_3) of which G_2 and G_3 are DX-stuffing signals to obtain time-diversity reception. In the RX-position only G_1 is sent as shown in Fig. 7.

In all types of sequences the G signal may be:

- 117, if the sequence requests an acknowledgement (RQ);
- 122, if the sequence is an acknowledgement (BQ);
- 127, if the sequence does not need to be acknowledged and is not an acknowledgement (END).

2.2.4 *The error check character* (E) is transmitted in the DX-position immediately after the signal X_{n-1} and in the RX-position immediately after the signal G_3 as shown in Fig. 8.

The seven information bits of the error check character are equal to the least significant bit of the modulo-2 sums of the corresponding bits of all information characters starting with the format specifier and including the end-of-sequence character (separator characters, if any, are also considered to be information characters).

DX	X_n		G_1		G_2		G_3	
RX		X_{n-2}		X_{n-1}		X_n		G_1

a) End of sequence for a single frame

DX	X_n		G_1		G_2		G_3		125		125
RX		X_{n-2}		X_{n-1}		X_n		G_1		109	

b) End of sequence for multiple frames

FIGURE 7 – *Composition of end of sequence*

DX	X_n		G_1		E		G_2		G_3	
RX		X_{n-2}		X_{n-1}		X_n		G_1		E

a) End of sequence and error check character for single frames

DX	X_n		G_1		E		G_2		G_3		125		125
RX		X_{n-2}		X_{n-1}		X_n		G_1		E		109	

b) End of sequence and error check character for multiple frames

FIGURE 8 – *The composition of the end of sequence when an error-check character is incorporated*

2.2.5 *The address and the self-identification* are the identities of the called and the calling station respectively and are coded in accordance with Table IVa of Annex II to Recommendation 493.

The ship identity comprises five signals:

$$NI\ DX_4\ X_5X_6\ X_7X_8\ X_90$$

The coast station identity also comprises five signals:

$$00\ NI\ DX_6\ X_7X_8\ X_90$$

(see Recommendation 587).

2.3 *Marking sequences*

The general format for marking sequences is given in Fig. 9 and the composition in Table I. The definition of marking sequences is given in § 1.2.1 of Annex II.

2.3.1 A marking sequence does not contain the address and the category.

2.3.2 The phasing sequence and the format specifier (110) are as shown in Fig. 6.

2.3.3 Self-identification is the coast station identity as defined in § 2.2.5.

2.3.4 The telecommand character identifies the type of marking sequence:

M1: 101
M2: 102
M3: 103
M4: 104.

Phasing sequence	Format specifier	Self-identification	Message		End of sequence
			Tele-command	Other information	
A	B	E	F1	F2	G

FIGURE 9 – *Format of a marking sequence*

2.3.5 Other information is as follows:

– Channel information and power level control comprising three characters:

$$8A_2\ A_3A_4\ A_5A_6$$

where A_2 indicates the power level as follows:

A_2 = 0, maximum power level;
A_2 = 1, power level not exceeded 2.5 W;
A_2 = 2, power level not exceeding 250 mW;
A_2 = 3 through 9 are reserved for future use;
and $A_3A_4A_5A_6$ indicates the channel number of the marked channel;

It should be mandatory that the ship station equipment is provided with the power levels corresponding to A_2 = 0 and 1. The level corresponding to A_2 = 2 may be used on a national basis. When only the mandatory levels are provided in the ship station equipment the response to $A_2 \neq 0$ should be the level corresponding to A_2 = 1.

Note. – In certain regions of inland waterways administrations concerned may mutually agree that only ship stations which are capable of a power level not exceeding 250 mW will be admitted to the service.

– In addition, the M4 sequence contains a message $9Z_2\ Z_3Z_4$ indicating the number of random access time slots still to follow. This information is separated from the above by signal 126.

2.3.6 The end of sequence 127 is sent as shown in Fig. 7.

2.4 *Calling sequence*

The general format of calling sequences is given in Fig. 5 and the composition in Table II. The definition of calling sequences is given in § 1.2.2 of Annex II.

2.4.1 The phasing sequence and the format specifier (120) are sent as shown in Fig. 6.

2.4.2 The address and the self-identification are as defined in § 2.2.5.

2.4.3 The category signal is 100 (routine) for all calling sequences.

2.4.4 The telecommand character is:

101 (telephony) for C3, C4, C60, C61 and C7;

121 (up-dating information) for C10 and C11;

103 (polling) for signals C1 and C2;

104 (unable to comply) for signals C50, C51, C52, C53, C80, C81 and C82.

Note. – If other services are introduced a telecommand character other than 101 should be used for signals C3, C4, C60, C61 and C7 in accordance with Tables Va and Vb of Annex II to Recommendation 493.

2.4.5 Other information includes:

– For signals C1, C3 and C7 the channel number and power level control indication of the actually used channel, comprising three characters, $8A_2\ A_3A_4\ A_5A_6$ where A_2 indicates the power levels as follows:

A_2 = 0, maximum power level;
A_2 = 1, power level not exceeding 2.5 W;
A_2 = 2, power level not exceeding 250 mW;
A_2 = 3 through 9 are reserved for future use;
$A_3A_4A_5A_6$ indicates the channel number of the channel on which the signal is sent.

It should be mandatory that the ship station equipment is provided with the power levels corresponding to $A_2 = 0$ and 1. The level corresponding to $A_2 = 2$ may be used on a national basis. When only the mandatory levels are provided in the ship station equipment the response to $A_2 \neq 0$ should be the level corresponding to $A_2 = 1$ (see Note in § 2.3.5).

- For signals C10 the character 80 and the channel number of the actually used channel $A_3A_4A_5A_6$;
- For signals C60 and C61 request for charging information and the channel number of the actually used channel $8A_2\ A_3A_4\ A_5A_6$ where

  $A_2 = 0$, indicates that no charging information is requested (signal C60);

  $A_2 = 1$, indicates that charging information is requested (signal C61);

  $A_3A_4A_5A_6$, indicates the number of the actually used channel;
- the symbols 100, 101, 104, 103, 100, 102 and 103 are used as a second telecommand character in the call sequences C50, C51, C52, C53, C80, C81 and C82 respectively. Sequence C53 may contain an additional character Q_1Q_2 indicating the length of the queue at the MSC;
- in addition the call sequences C3, C60, C61 and C7 include the character 90 followed by the characters B_3B_4 and B_5B_6 where $B_3B_4B_5B_6$ indicates the number of the assigned channel;
- in TDMA configurations the call sequences C60 and C61 may contain optional channel information for ships which do not have multi-working channel capability.

2.4.6 The end of sequence is sent as shown in Fig. 8 and has the values shown in Table II.

2.4.7 All calling sequences comprise an error check character E.

2.5 *Signalling sequences*

The general format for signalling sequences is given in Fig. 5 and the composition in Table III. The definition of the signalling sequences is given in § 1.2.3 of Annex II.

2.5.1 The phasing sequence and the format specifier (124) are sent as shown in Fig. 6.

2.5.2 The address and the self-identification are as defined in § 2.2.5.

2.5.3 The category character is 100 for all signalling sequences.

2.5.4 The telecommand character is:

100 for S100
101 for S101 and S2
102 for S3 and S4
103 for S8, S9, S11 and S12
104 for S17 and S18
105 for S7
107 for S13
108 for S15 and S16
109 for S50, S51 and S52.

For S6 the telecommand character is 105 if the called number (including prefixes) has an odd number of digits and 106 if it has an even number of digits.

2.5.5 Other information included in the signalling sequences S5X, S6, S9, S11, S13 and S17:

- the symbols Nos. 101, 102 and 100 are used in the signalling sequences S50, S51 and S52 respectively;
- S6 contains all digits of the called number. If the called number has an odd number of digits, a stuffing digit 0 will be used in the T_1 position (see Table III). Examples of coding of subscriber numbers of various length are given in Table IV;
- S9 and S11 contain information of the calling channel in use at the coast station, $A_3A_4A_5A_6$ indicating the calling channel number;
- S13 contains a channel indication $9B_2\ B_3B_4\ B_5B_6$ where B_2 indicates the power level as follows:

  $B_2 = 0$, maximum power level;
  $B_2 = 1$, power level not exceeding 2.5 W;
  $B_2 = 2$, power level not exceeding 250 mW;
  $B_2 = 3$ through 9 are reserved for future use.

The digits $B_3B_4B_5B_6$ are the channel number. If S13 is used for power level control only, $B_3B_4B_5B_6$ is the channel number of the channel in use. Otherwise it indicates the channel to which the call has to be switched.

It is mandatory that the ship station equipment is provided with the power levels corresponding to $B_2 = 0$ and 1. The level corresponding to $B_2 = 2$ may be used on a national basis. When only the mandatory levels are provided in the ship station equipment the response to $B_2 \neq 0$ should be the level corresponding to $B_2 = 1$ (see Note in § 2.3.5).

– S17 contains charging information $P_1P_2P_3P_4$. If charging information cannot be provided, $P_1P_2P_3P_4$ will be 0000 and S17 may be used to indicate the start of the chargeable duration.

2.5.6 The end of sequence is sent as shown in Fig. 8 and has the values shown in Table III.

2.5.7 All signalling sequences comprise an error check character E.

TABLE I – *Composition of marking sequences*

		M1	M2	M3	M4
	Format specifier	110	110	110	110
	Self-identification (coast station identity)	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90
Message	Telecommand	101	102	103	104
	Power level Own channel number	$8A_2$ A_3A_4 A_5A_6	$8A_2$ A_3A_4 A_5A_6	$8A_2$ A_3A_4 A_5A_6	$8A_2$ A_3A_4 A_5A_6
	Separator				126
	Number of random access time slots still to follow (TDMA only)				$9Z_2$ Z_3Z_4
	End of sequence	127	127	127	127
	Duration (ms)	283.3	283.3	283.3	333.3

TABLE II – *Composition of calling sequences*

		C1	C2	C3	C4	C50	C51	C52	C53	C60	C61	C7	C80	C81	C82	C10	C11
	Format specifier	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
	Address: ship - or coast-station identity	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90				00 NI DX_6 X_7X_8 X_90		NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90			00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90
	Category	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Self-identification: ship - or coast-station identity	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90				NI DX_4 X_5X_6 X_7X_8 X_90		00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90			NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90
Message	First telecommand	103	103	101	101	104	104	104	104	101	101	101	104	104	104	121	121
	Second telecommand					100	101	104	103				100	102	103		
	Other information, own channel number	$8A_2$ A_3A_4 A_5A_6		$8A_2$ A_3A_4 A_5A_6					Q_1Q_2	80 A_3A_4 A_5A_6	81 A_3A_4 A_5A_6	$8A_2$ A_3A_4 A_5A_6				80 A_3A_4 A_5A_6	
	Separator			126						126	126	126					
	Working channel number			90 B_3B_4 B_5B_6						90 B_3B_4 B_5B_6	90 B_3B_4 B_5B_6	90 B_3B_4 B_5B_6					
	End of sequence	117	122	117	122	127	127	127	127	117	117	122	127	127	127	117	122
	Error check character	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
	Duration of sequence (ms)	400	350	466,7	350	366,7	366,7	366,7	383,3	MIC: 400 TDMA: 466,7		466,7	366,7	366,7	366,7	400	350

TABLE III – *Composition of signalling sequences*

	S100	S101	S2	S3	S4	S50	S51	S52	S6(1)	S7	S8	S9	S11	S12	S13	S15	S16	S17	S18
Format specifier	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124
Address: ship - or coast-station identity	NI DX_4 X_5X_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90
Category	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Self-identification: ship - or coast-station identity	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90	00 NI DX_6 X_7X_8 X_90	NI DX_4 X_5X_6 X_7X_8 X_90
Message: Telecommand	100	101	101	102	102	109	109	109	105 106(1)	105	103	103	103	103	107	108	108	104	104
Message: Other information						101	102	100	T_1T_2 T_3T_4 T_5T_6 T_7T_8 T_9T_{10} $T_{11}T_{12}$ $T_{13}T_{14}$			80 A_3A_4 A_5A_6	80 A_3A_4 A_5A_6		$9B_2$ B_3B_4 B_5B_6			P_1P_2 P_3P_4	
End of sequence	117	117	122	127	127	127	127	127	117	122	117	122	117	122	117	117	122	117	122
Error check character	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Duration of sequence (ms)	350	350	350	350	350	366.7	366.7	366.7	> 350	350	350	400	400	350	400	350	350	383.3	350

(1) See § 2.5.4 for the use of symbols Nos. 105 and 106 as telecommand character.

TABLE IV – *Examples of coding of subscriber numbers of various length in the S6 sequence*

a)	*b)*	*c)*	*d)*	*e)*	
. . .	. . .	. . .	. . .	. . .	
X_90	X_90	X_90	X_90	X_90	
106	106	106	105	105	Telecommand
	11	00 12 34 56	00 01 23 45	03 11 23	
117	117	117	117	117	End of sequence
E	E	E	E	E	Error check character

a) No digit information required. Telecommand 106 (even number of digits) followed by end of sequence 117.

b) Prefix 11 only. Telecommand 106 (even number of digits).

c) Prefix 00 and international number 12 34 56. Telecommand 106 (even number of digits including prefix digits).

d) Prefix 00 and international number 123 45. Telecommand 105 (odd number of digits): stuffing digit 0 underlined.

e) Prefix 31 and number 123. Telecommand 105 (odd number of digits): stuffing digit 0 underlined.

ANNEX IV

TIMING REQUIREMENTS

1. Shore-originated calling

1.1 When a coast station transmits a call sequence on the shore-to-ship frequency of the calling channel the ship sends a reply or an acknowledgement sequence on the ship-to-shore frequency of the same channel. Overlap between successive reply sequences of different ships cannot occur since the coast station call sequences are sufficiently longer than the ship reply sequence.

1.2 The ship station response time is the time between the end of coast station calling sequence and the beginning of the call acknowledgement message sequence indicated as t_3 in Fig. 10. Typically t_3 may be 30 ms ± 10%. The following partial times are of interest:

– the time interval from the end of the calling sequence until the instant that the transmitter output power is 40 dB below its steady-state value is indicated as t_1 in Fig. 10;

– because of the reaction time of the coast station squelch, the ship station must always wait a time t_2 before data signalling starts. This time interval, taken from the time that the transmitter output reaches a value of 2 dB below its steady-state output power, is shown in Fig. 10. Provisionally, t_2 should be at least 7 ms;

– the transmitter decay time is defined as the time interval from the end of the call acknowledgement until the instant that the transmitter output power has decayed to a value of 40 dB below its steady-state value, and is indicated as t_4 in Fig. 10. Provisionally, t_4 should be less than 20 ms.

1.3 The above discussion is equally applicable to the MIC and the TDMA configurations.

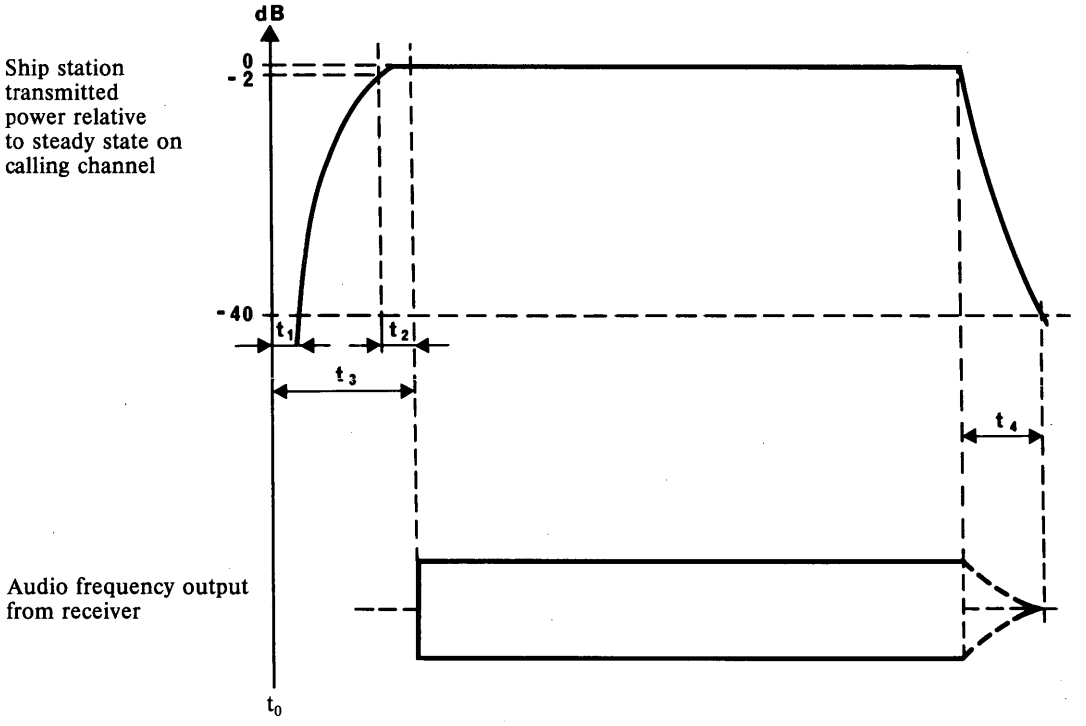


FIGURE 10 – *Timing diagram*

t_0: end of coast station-to-ship calling sequence.

2. Ship-originated calling

2.1 *Marked idle-channel (MIC) configuration*

When a ship seizes an idle working (or calling/idle working) channel, it is important that the coast station removes the marking sequence before the next marking sequence is completed. Otherwise, another ship might try to seize the channel on recognition of this next marking sequence and thus cause overlap transmission. Fig. 11 illustrates this procedure.

The delays between the end of the last complete marking signal and the interrupt are:

- twice the one-way delay encountered on the landline between coast station and MSC (if separated);
- maximum turn-around time of the ship station;
- signal acquisition and processing time at the coast station/MSC.

For very long feeder lines between coast station and the MSC a maximum (one-way) delay of 10 ms may be assumed reasonable, and a maximum ship's station turn-around time of 33 ms was indicated in § 1.2 above. With a minimum length of the marking signal of 283.3 ms the interrupt should occur before the first end-of-sequence character, i.e. within 233.3 ms. Using these values would put an upper bound on the combined signal acquisition and processing time of approximately 180 ms.

2.2 *TDMA configuration*

Determination of the length of the time slots in the random access period is based on the following assumptions:

- while on-hook, the ship's timer is resynchronized by each received signal;
- the maximum interval between received signals is 10 time slots;
- the accuracy of the ship's timer is at least ± 1%.

With a ship station turn-around time of 30 ms ± 10% (see § 1.2 above) and a ship's call request message length of 450 ms the minimum time slot length should be approximately 530 ms.

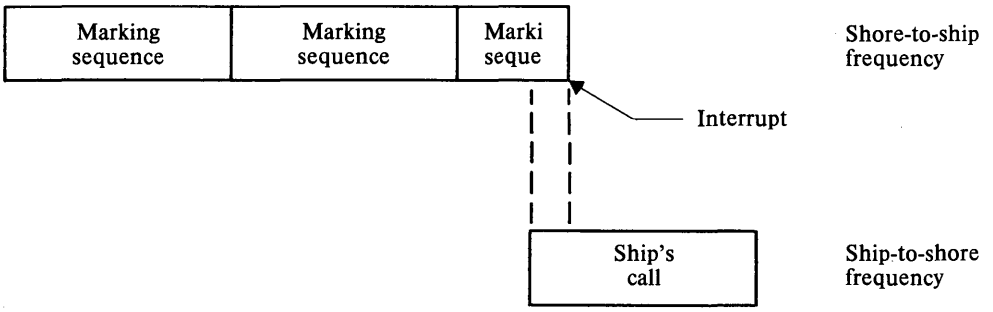


FIGURE 11 – *Interruption of marking sequence*

ANNEX V

CHANNEL QUALITY SUPERVISION

1. Channel quality supervision by means of carrier level measurement

The channel quality is supervised by continuously measuring the field strength of the radio carrier at the coast station. This method monitors only the ship-to-coast station direction of the radio path. No special provision is required at the ship station.

2. Channel quality supervision by use of pilot tones

2.1 *General*

The channel quality is continuously supervised at the coast station by modulating a pilot tone on the radio carrier together with the voice band signal. The ship stations must be capable of looping back such pilot tones on the return channel. With this method both directions of the radio path are monitored.

2.2 *Pilot frequency*

The pilot frequency could be any single tone within the frequency range 3900 * to 4100 * Hz. The ship station should be able to return any signal, including noise, received within a 6 dB bandwidth of 400 * Hz with a centre frequency at 4000 * Hz.

Pilot tone frequency offsets should be employed in multiple coast station areas to avoid interference problems.

2.3 *Peak frequency deviation*

The peak frequency deviation produced by the pilot tone both at the ship station and at the coast station should be 300 * Hz ± 30 * Hz.

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* Provisional value.

2.4 *Loop-back filter*

The attenuation characteristic of the loop-back filter is given in Fig. 12.

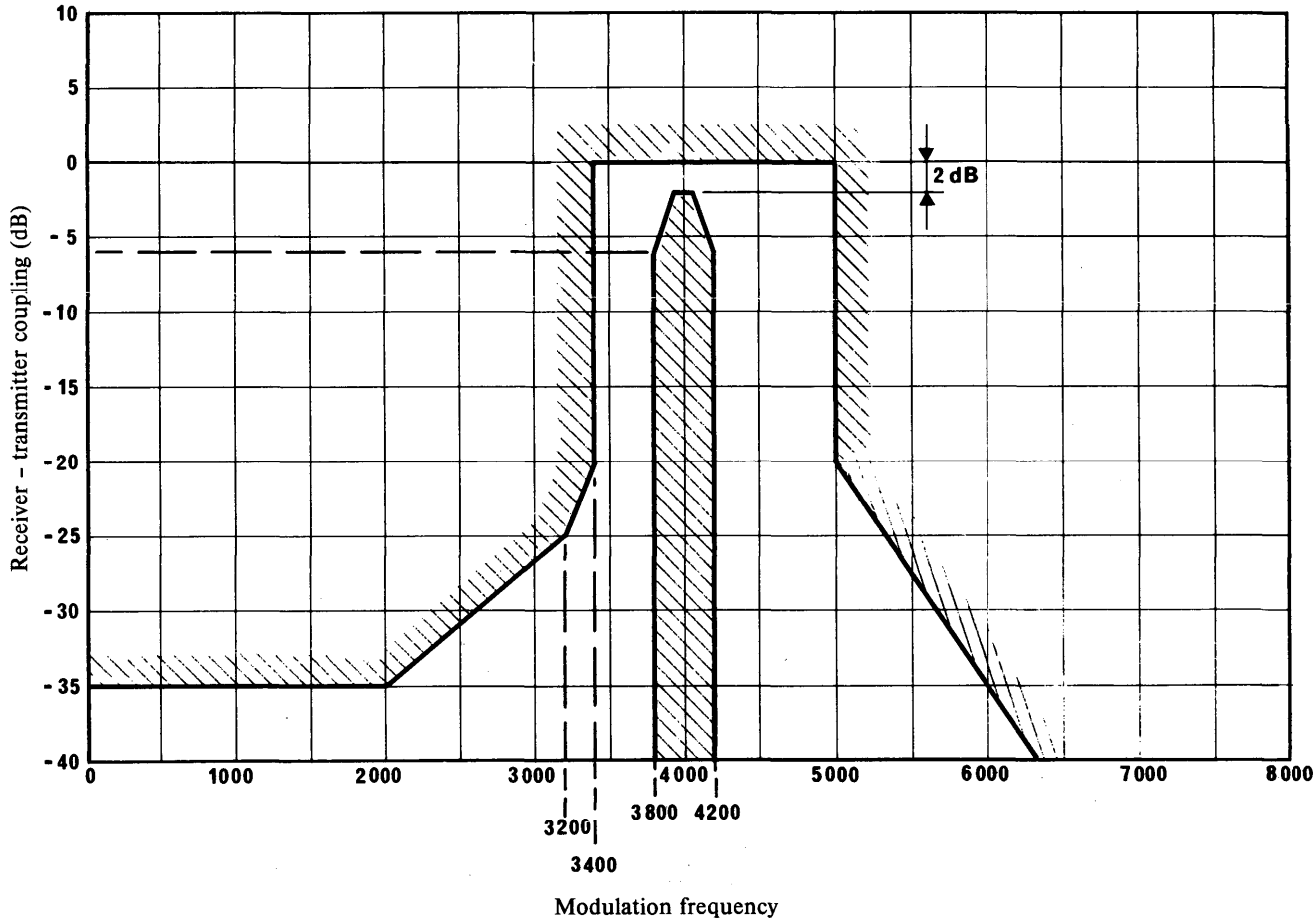


FIGURE 12 – *Attenuation characteristics for the loop-back filter in the mobile station*

APPENDICES (ANNEX II)

APPENDIX I

GENERAL INTRODUCTION TO SPECIFICATION AND DESCRIPTION LANGUAGE (SDL)

1. General

In Appendices II to VI the calling and signalling arrangements to be used over the radio path are illustrated using the specification and description language (SDL) developed by the CCITT.

A full description of SDL is contained in CCITT Recommendations Z.101 to Z.104. Application of SDL to interworking of telephone signalling systems is found in the Q.600 to Q.699 series of CCITT Recommendations.

2. Descriptive tools

2.1 *Basic concepts*

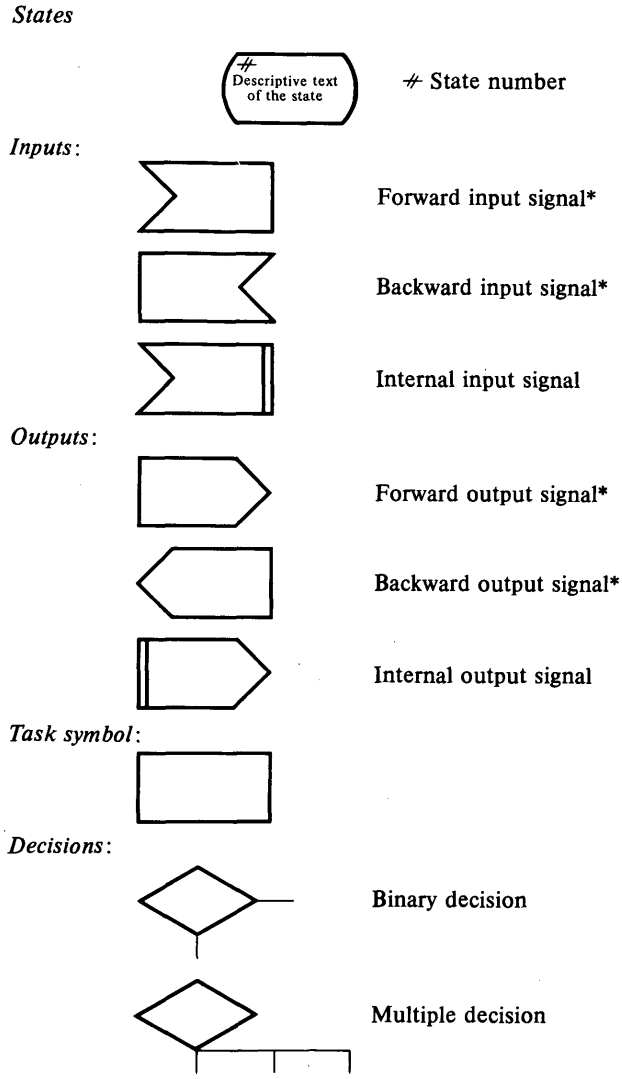
SDL is based on state transition diagrams. A signalling process consists of several states and the various transitions between them. The system is in a given state until an input signal is received.

The input will force the process to travel along a transition, executing tasks, generating outputs and branching on decisions until another state is reached.

The concepts of state, input, task, output and decision are represented with standard symbols. The interconnection of such symbols by flow lines represents the logical flow of a process.

2.2 *Graphical symbols*

Only a small set of graphical symbols is required to present a signalling system. The following symbols are required:

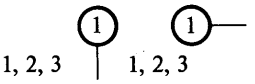


* A forward signal is sent in the direction of the called subscriber.
A backward signal is sent in the direction of the calling subscriber.

Connectors:

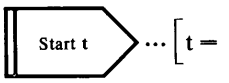


Out-connector No. 1: the corresponding in-connector is given on sheet 2.

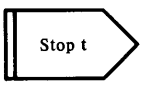


In-connector No. 1: the corresponding out-connectors are given on sheets 1, 2 and 3.

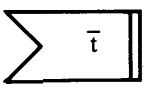
Timers:



Start of timer

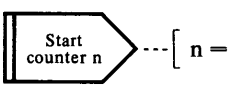


Stop timer



Expiry of timer

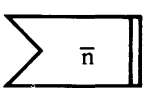
Counters are introduced as replacement of timers in cases where signals should only be sent a given number of times. The following symbols are used:



Start of counter



Reset of counter



Counter limit n has been reached

2.3 *FITEs, BITEs and SPITEs*

Forward interworking telephony events (FITEs) and backward interworking telephony events (BITEs) are used to standardize events that may occur on the interface between an incoming and an outgoing signalling system (e.g. between the incoming telephone signalling system and the MSC-to-ship signalling system). Switching process interworking telephony events (SPITEs) are used internally in the MSC.

Tables V, VI and VII list all FITEs, BITEs and SPITEs used in Appendices II and IV. These and other events have been specified by the CCITT and a full list is given in CCITT Recommendation Q.608.

TABLE V – *FITEs used in Appendices II and IV*

FITE No.	Meaning	Corresponding or equivalent call/ signalling sequence
1	Digit 1, 2, ..., 9 or 0; or end-of-pulsing	C3, S6
15	Calling party's category subscriber (routine)	C3 (telecommand character)
22	Clear forward	S8, S11

TABLE VI – *BITEs used in Appendices II and IV*

BITE No.	Meaning	Corresponding or equivalent call/ signalling sequence
5	Address complete, charge	S2
11	Call unsuccessful, switching equipment congestion	S50
16	Call unsuccessful, address complete, subscriber busy	S51, C81
20	Call unsuccessful, send special information tone	S52, C80
22	Answer, subscriber free, charge	S17, S4
25	Clear back	S8
27	Sending finished, set up speech condition	–
29(1)	Release incoming side	S11

(1) Not presently used by the CCITT.

TABLE VII – *SPITEs used in Appendices II and IV*

SPITE No.	Meaning	Symbol
1	Activate register function	task
3	Deactivate register function	task
4	Set up speech condition	task
6	Return appropriate tone (ringing tone, congestion tone, busy tone, special information tone)	task
6A	Remove tone	task
12	Perform digit analysis	task
13	Digit analysis cannot be completed	input
14	Routing information	input
15	Unallocated number	input
16	Unprovided routing	input
17	Barred routing	input
18	Switching equipment congestion	input
19	Circuit group congestion	input

2.4 The signals sent on the radio path are defined in § 1.2 of Annex II.

3. SDL diagrams

3.1 *Outgoing procedure at MSC (land-originated call)*

3.1.1 The SDL diagrams are given in Appendix II.

3.1.2 The following supervisory timers are used in the diagrams:

Type of timer	time-out	state	sheet
Timer t_1	1 s	02	1
Counter n_1	2 times	02	1
Counter n_2	8 times	04	2
Timer t_2	3 s	06	3
Counter n_3	8 times	08,09	3

3.2 *Incoming procedure at ship (land-originated call)*

3.2.1 The SDL diagrams are given in Appendix III.

3.2.2 The following supervisory timers are used in the diagrams:

Type of timer	time-out	state	sheet
Timer t_1	3 s	01	1
Counter n_1	8 times	02	1
Counter n_2	8 times	04	2
Counter n_3	8 times	06	2
		08	3
Timer t_2	3 s	07	3

3.3 *Incoming procedure at MSC*

3.3.1 The SDL diagrams are given in Appendix IV.

3.3.2 The following supervisory timers are used in the diagrams:

Type of timer	time-out	state	sheet
Timer t_1	1 s	01	1
Timer t_2	*	02	1
Timer t_3	*	03	1
Counter n_1	8 times	05,06	2
Counter n_3	2 times	09	3
Timer t_5	3 s	10	3
Counter n_4	8 times	12,13	4

3.4 *Outgoing procedure at ship (ship-originated call)*

3.4.1 The SDL diagrams are given in Appendix V.

3.4.2 The following supervisory timers are used in the diagrams:

Type of timer	time-out	state	sheet
Timer t_1	*	02	1
Timer t_2	*	04	1
Timer t_3	*	05	1
Timer t_4	3 s	06	2
Counter n_1	8 times	07	2
Timer t_5	3 s	08	2
Timer t_6	3 s	10	3
Counter n_4	8 times	11,12	3

3.5 *Power level control and switching call-in-progress control at MSC*

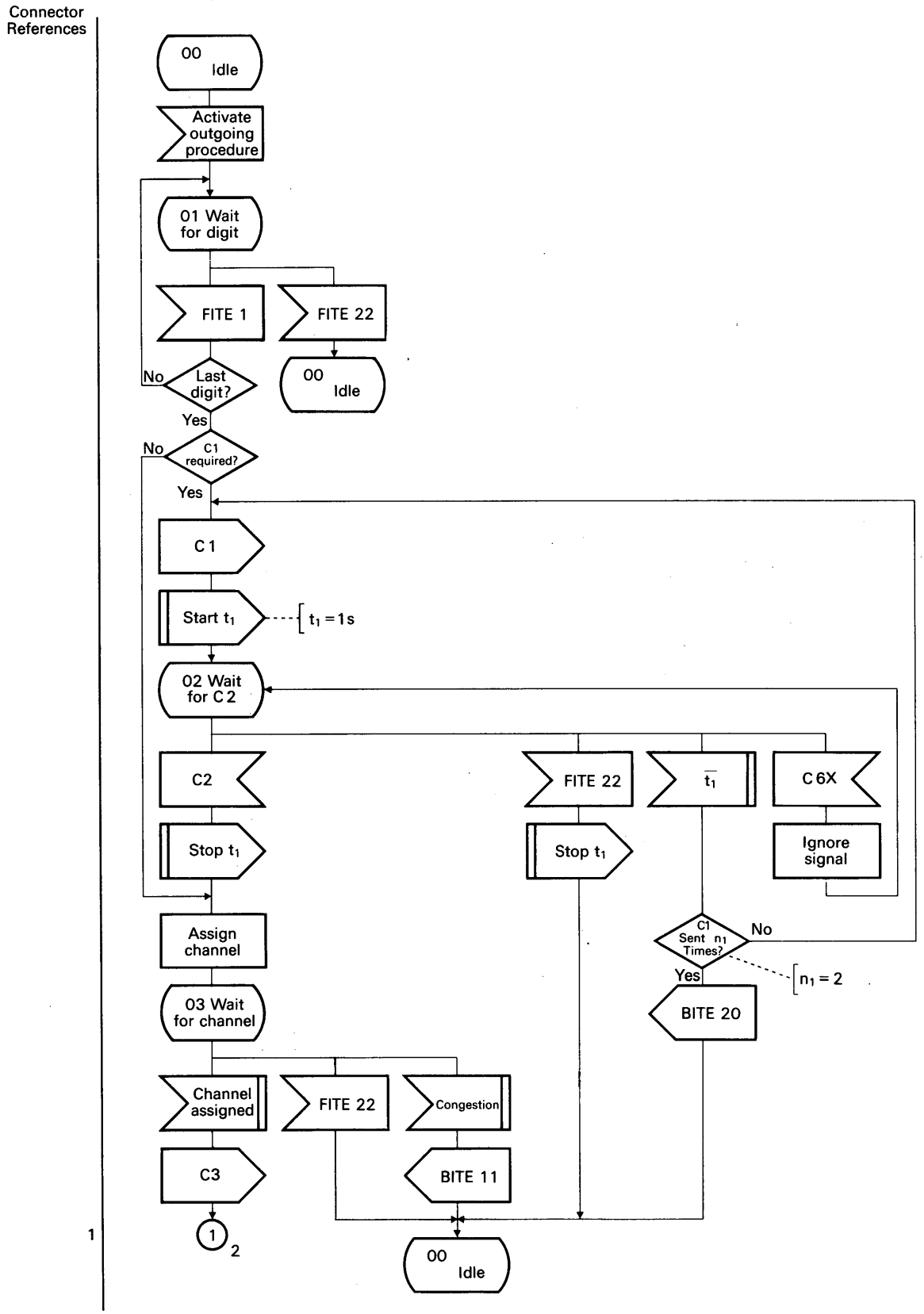
3.5.1 The SDL diagrams are given in Appendix VI.

3.5.2 The following supervisory timers are used in the diagrams:

Type of timer	time-out	state	sheet
Timer t_1	2 s	01	1
Timer t_2	3 s	03	2
Counter n_2	5 times	03	2
Counter n_1	3 times	03	2
Counter n_3	8 times	03,04	2

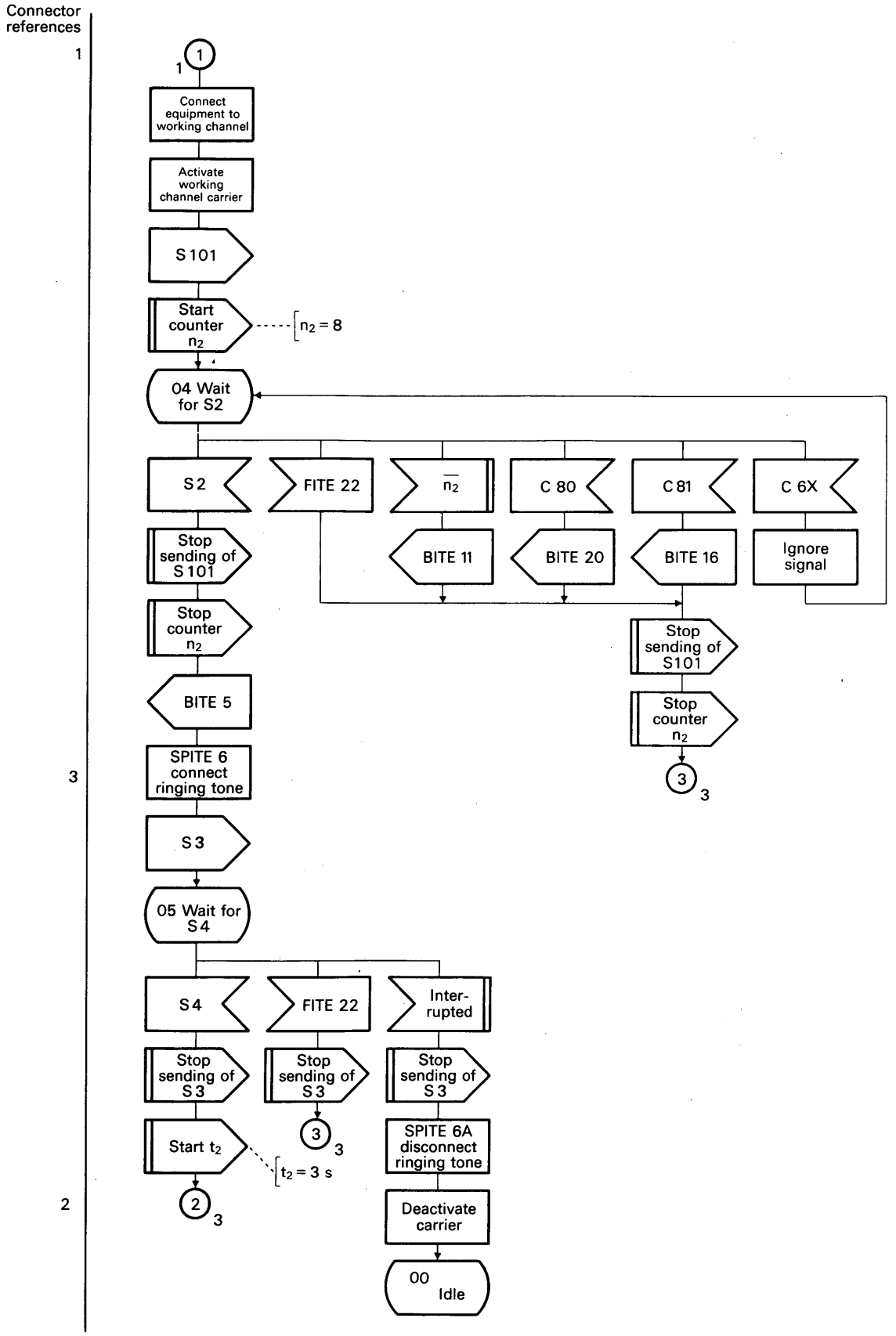
* Not yet defined.

APPENDIX II
Sheet 1

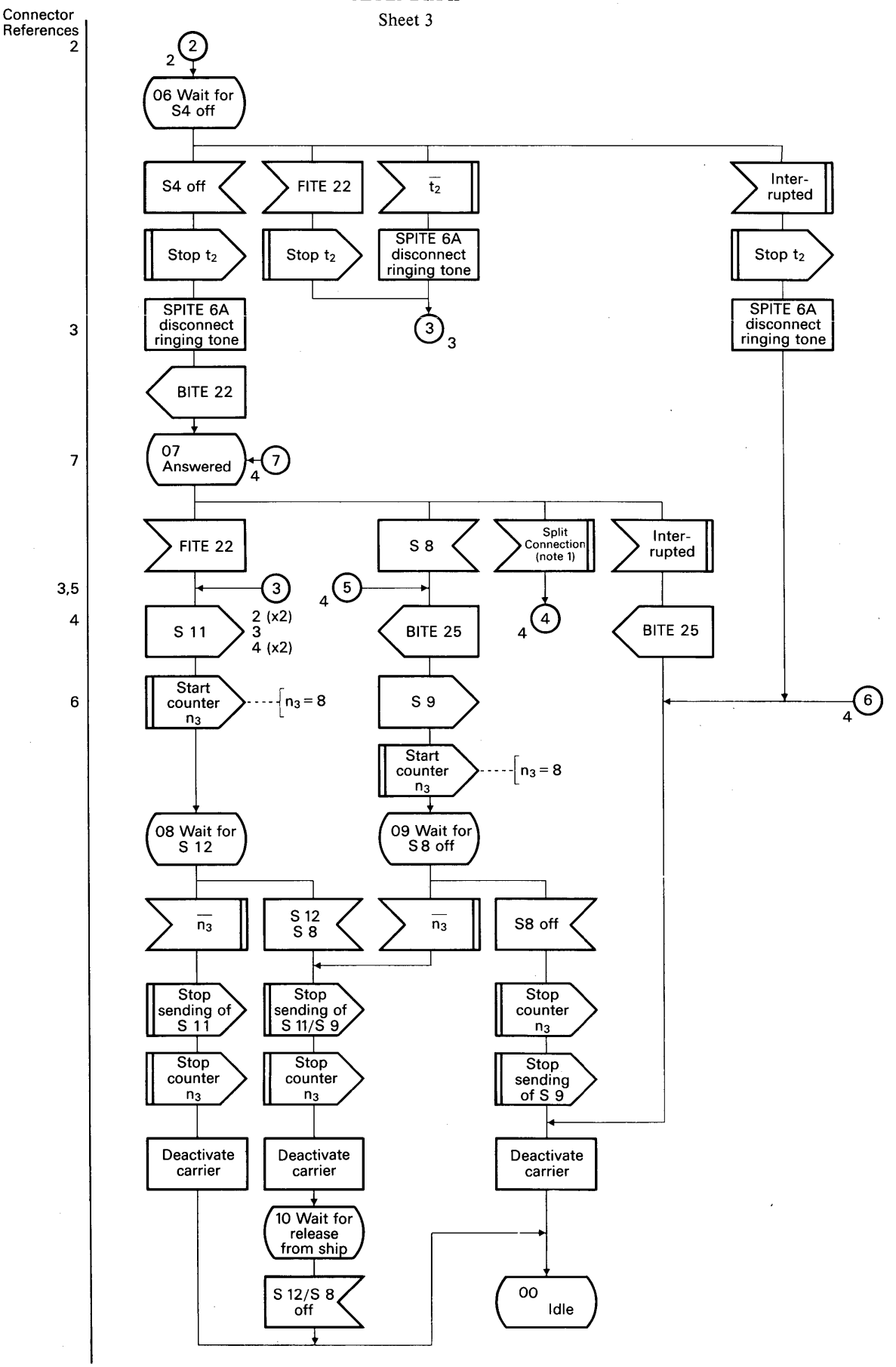


Outgoing procedure at MSC (land-originated call)

APPENDIX II
Sheet 2

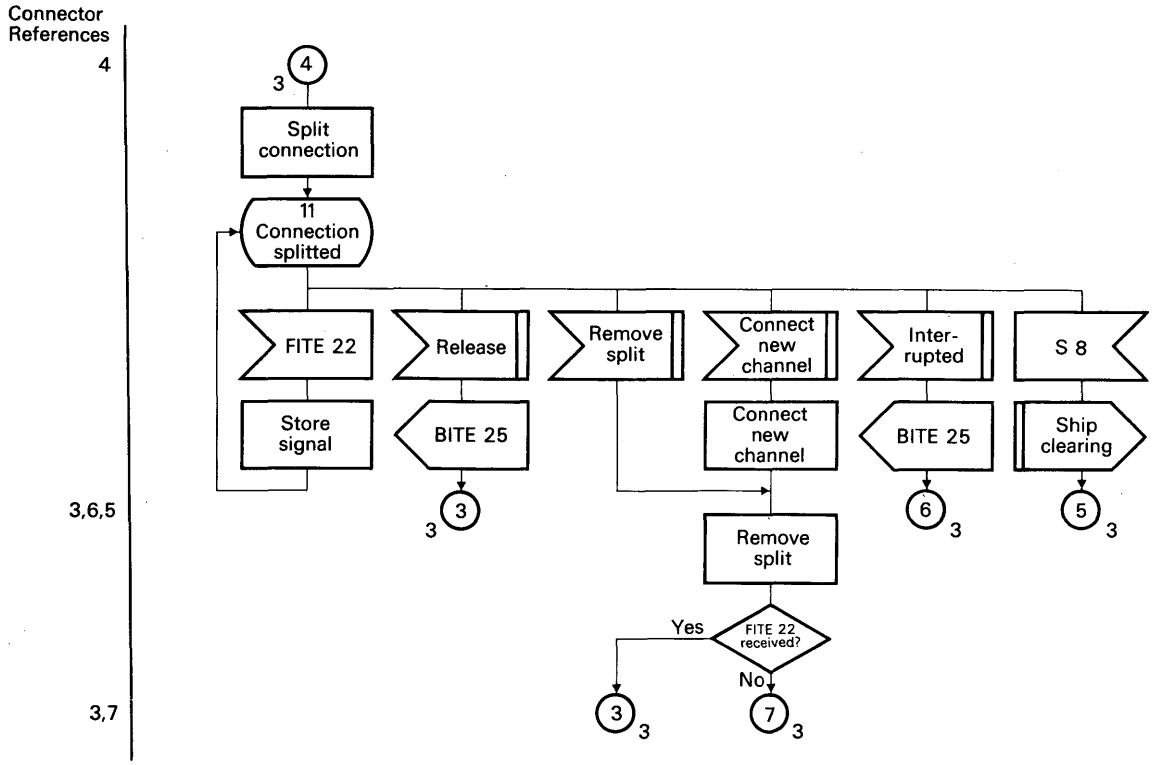


APPENDIX II
Sheet 3

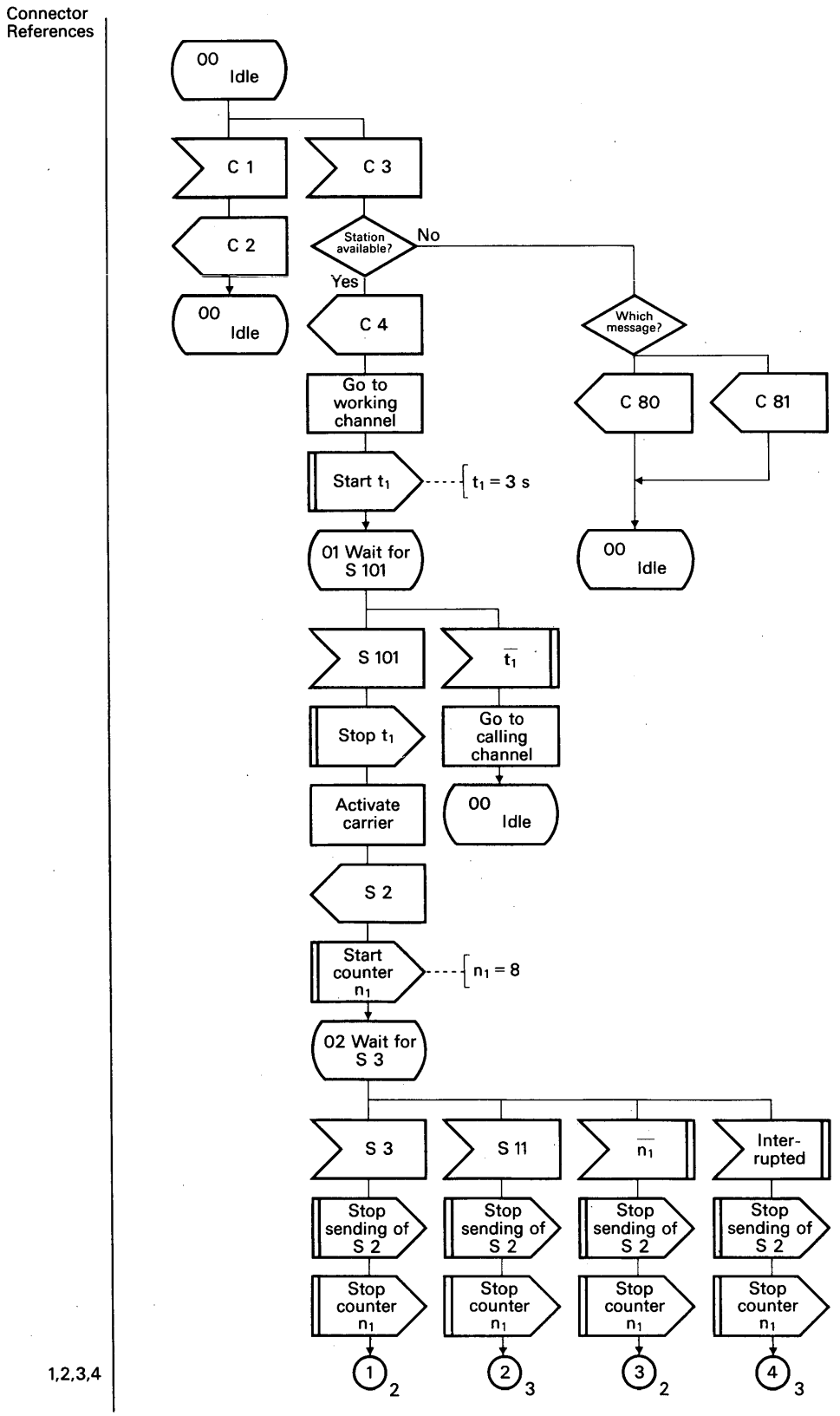


Note 1 – Signal used to initiate power level control and switching call-in-progress (see Appendix VI)

APPENDIX II
Sheet 4

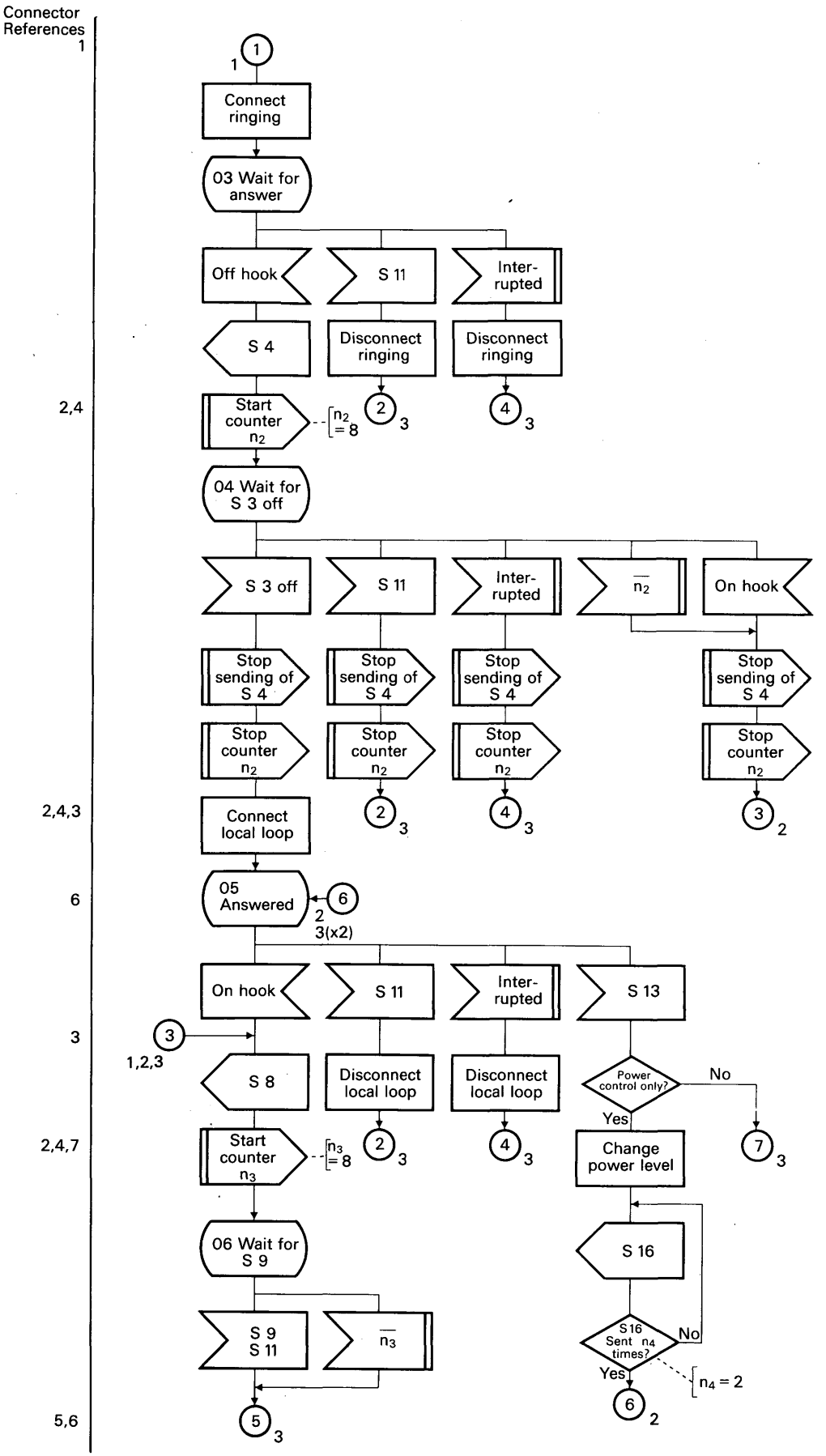


APPENDIX III
Sheet 1

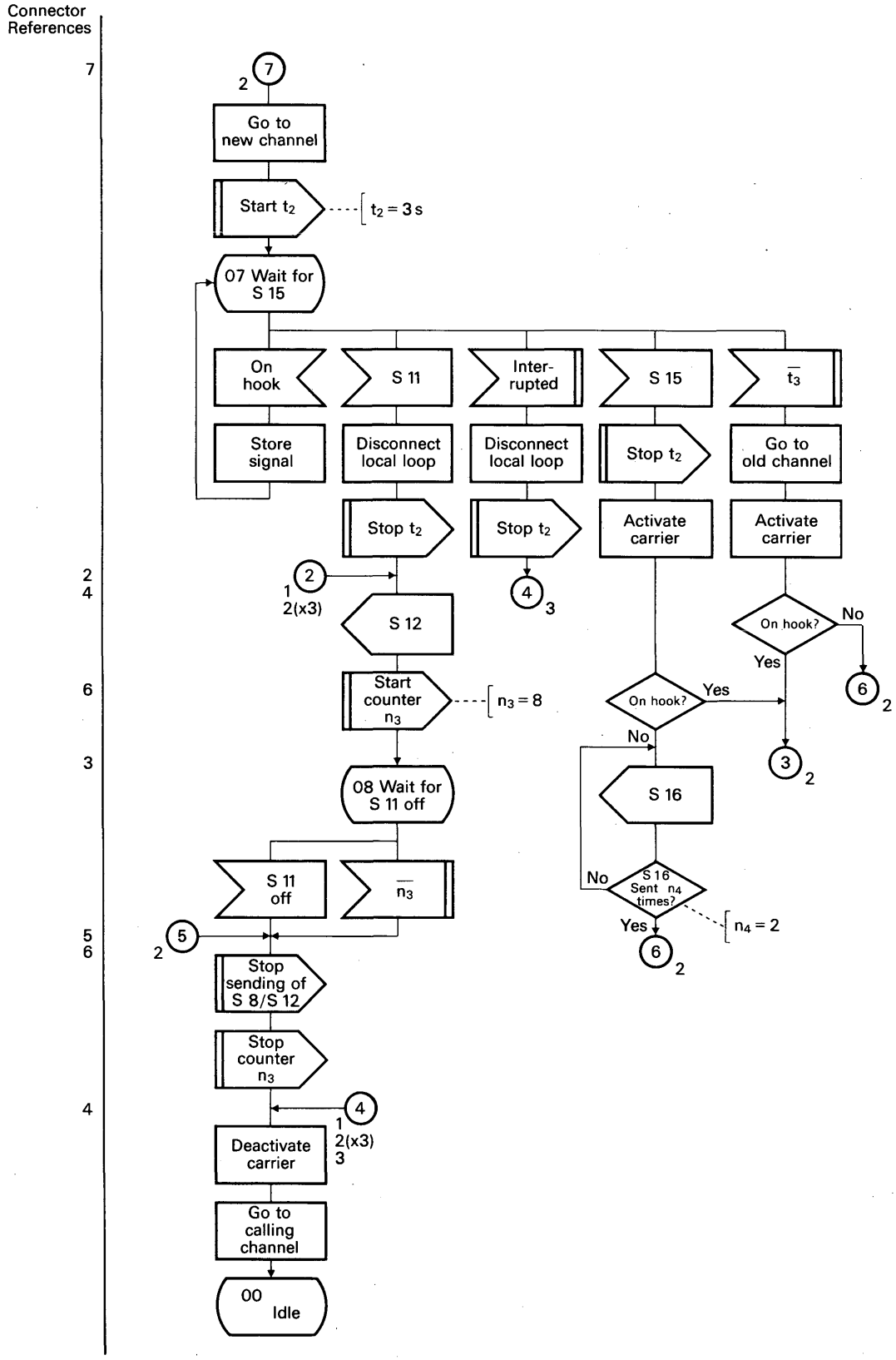


Incoming procedure at ship (land-originated call)

APPENDIX III
Sheet 2

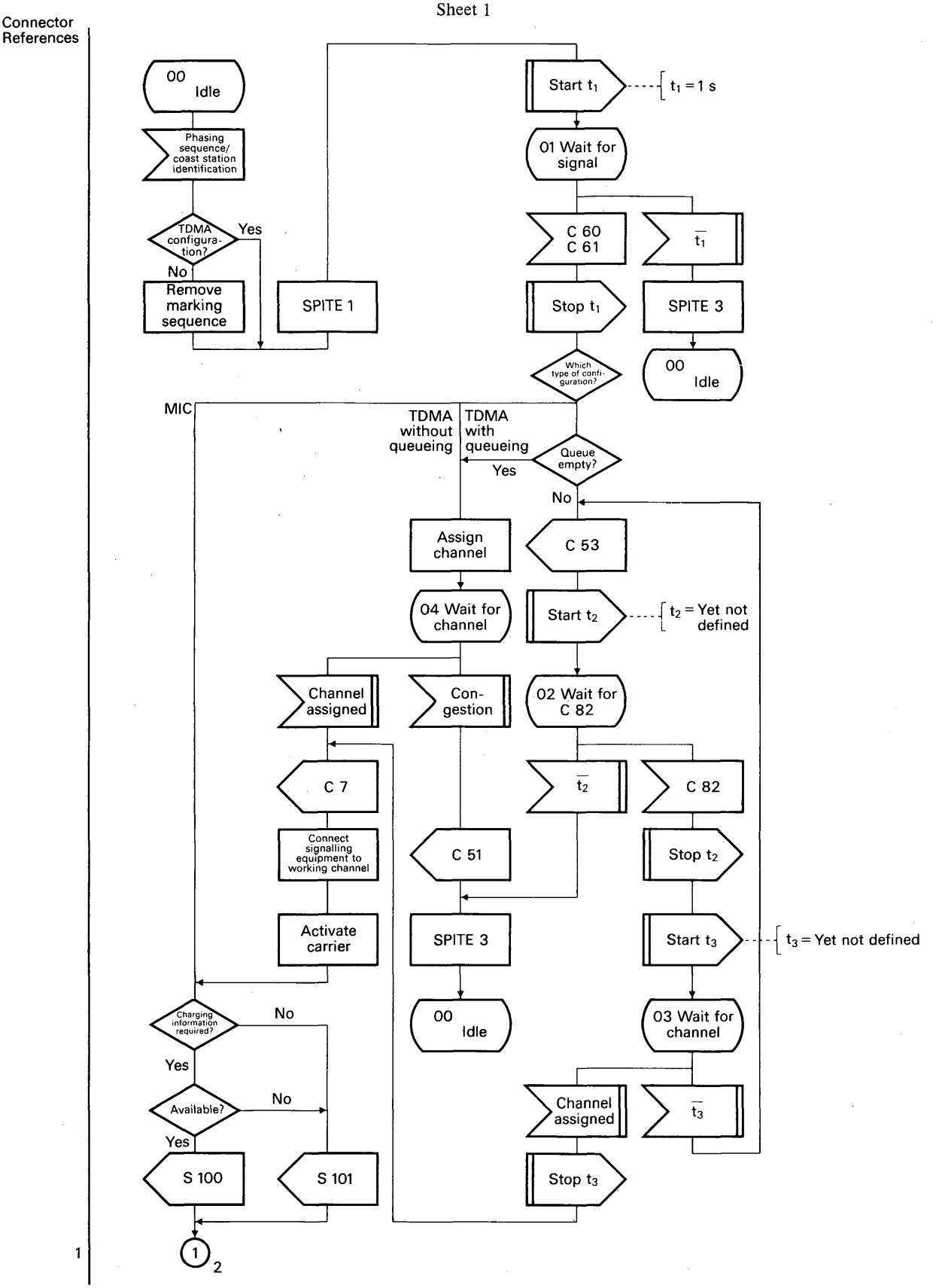


APPENDIX III
Sheet 3



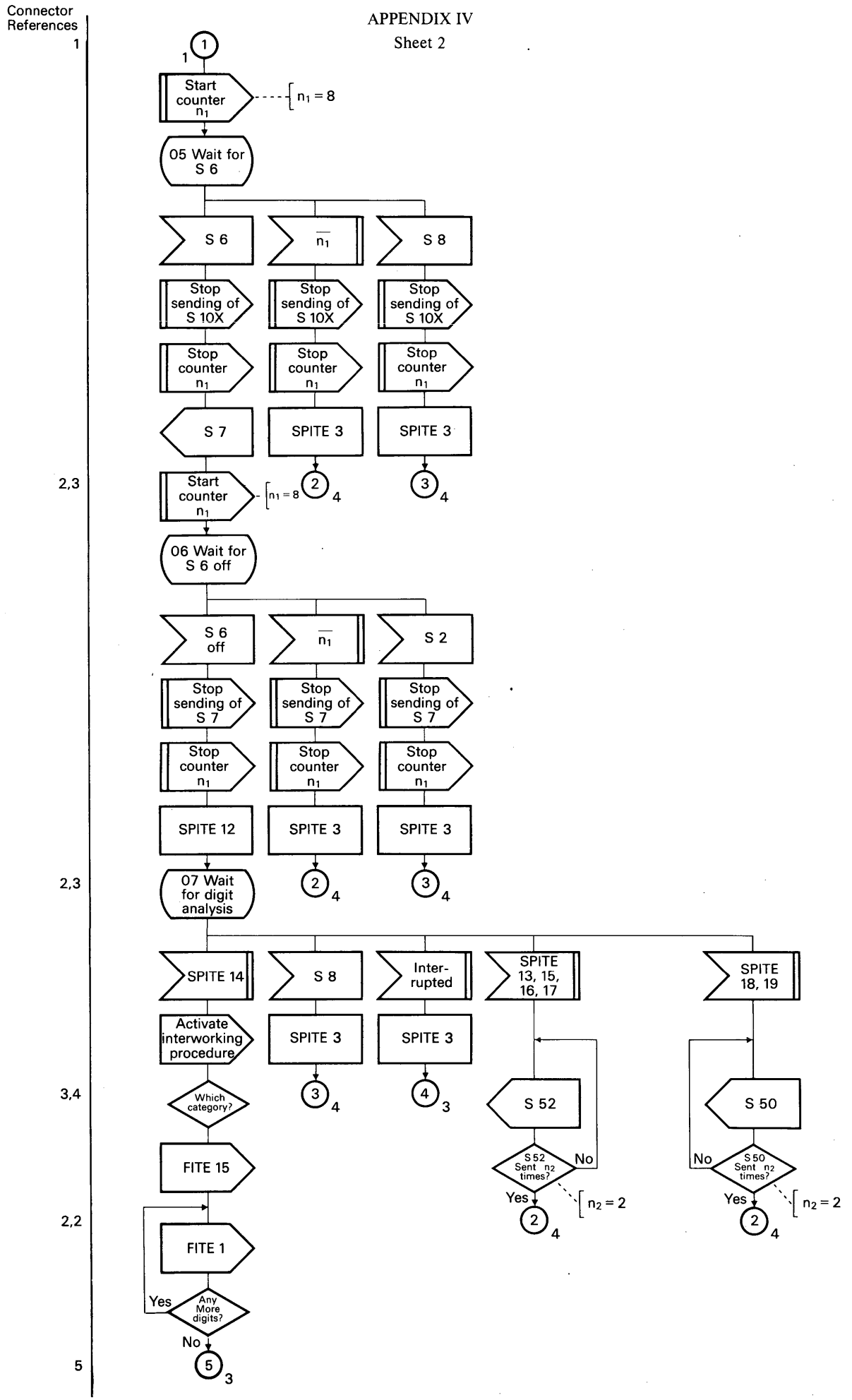
APPENDIX IV

Sheet 1

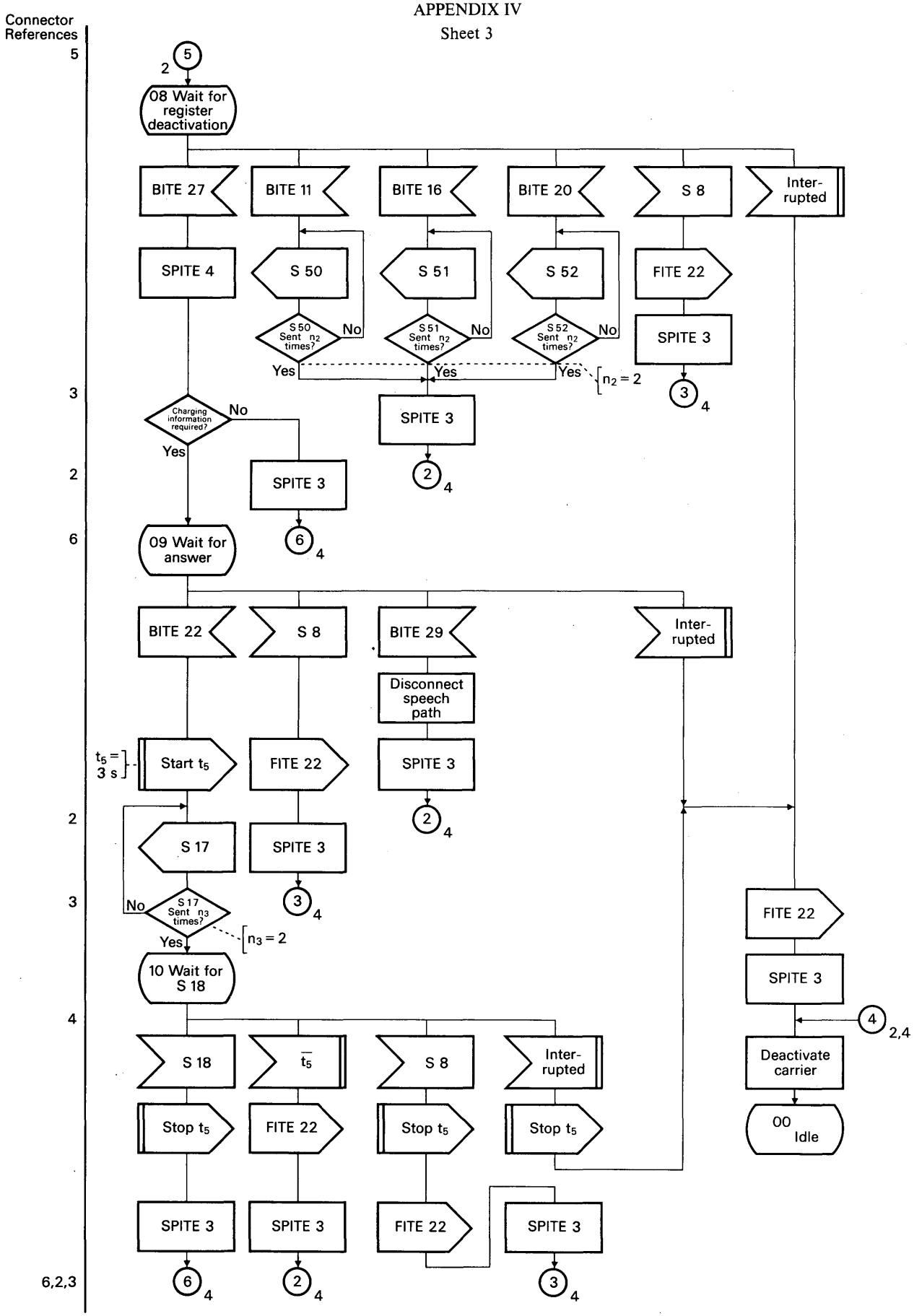


Incoming procedure at MSC (ship-originated call)

APPENDIX IV
Sheet 2

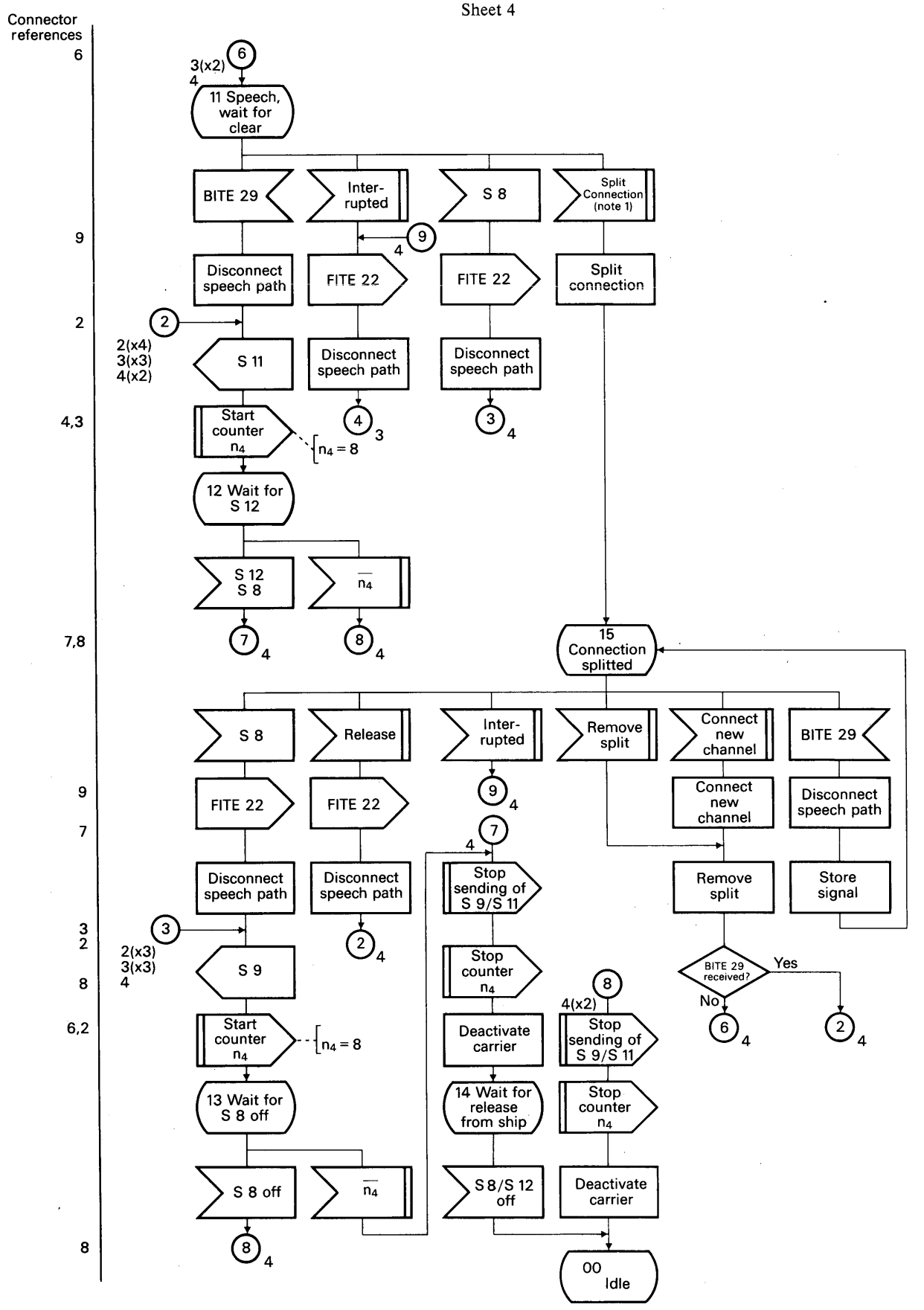


APPENDIX IV
Sheet 3



APPENDIX IV

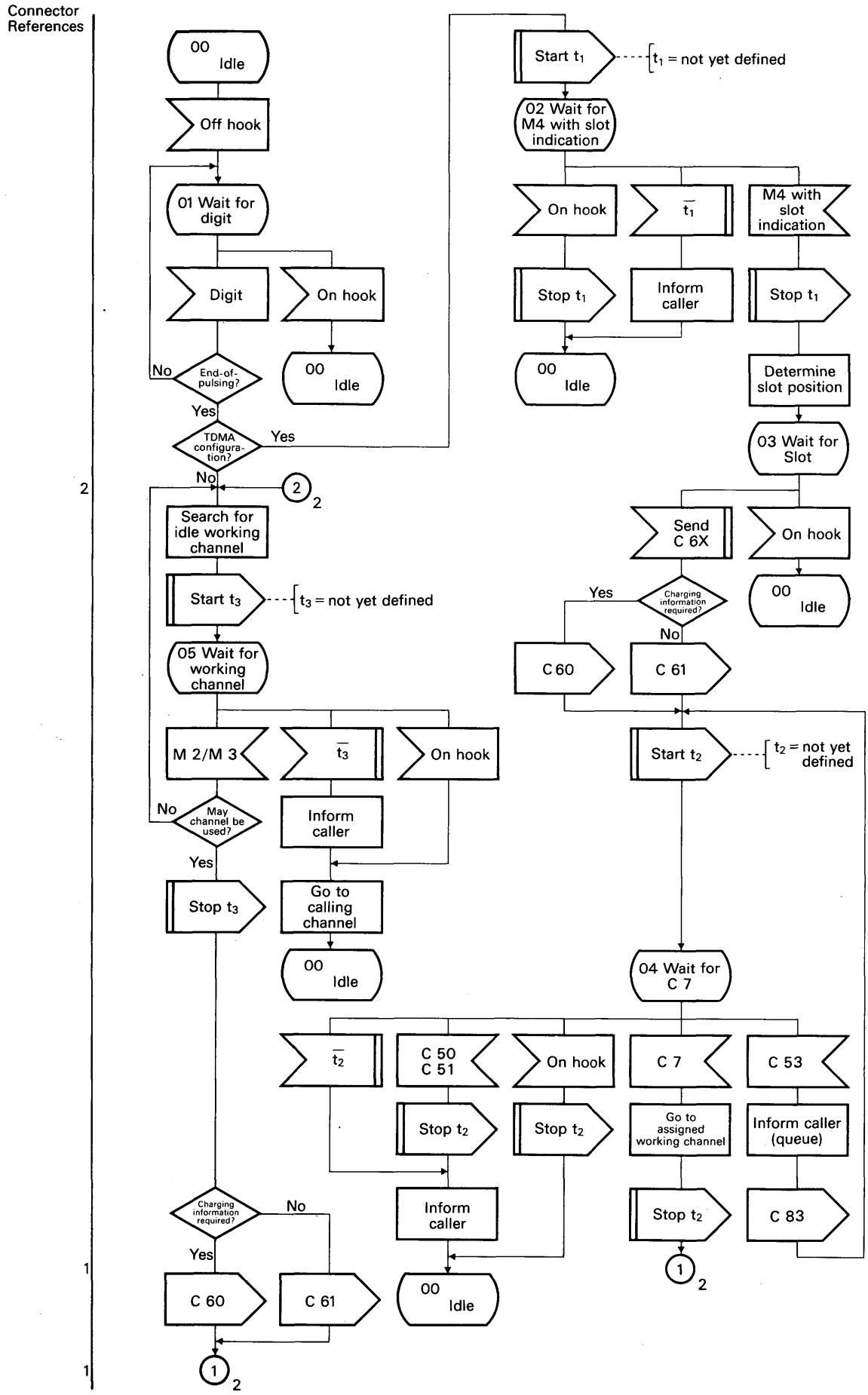
Sheet 4



Note 1 - Signal used for initiating power level control and switching call in progress (see Appendix VI).

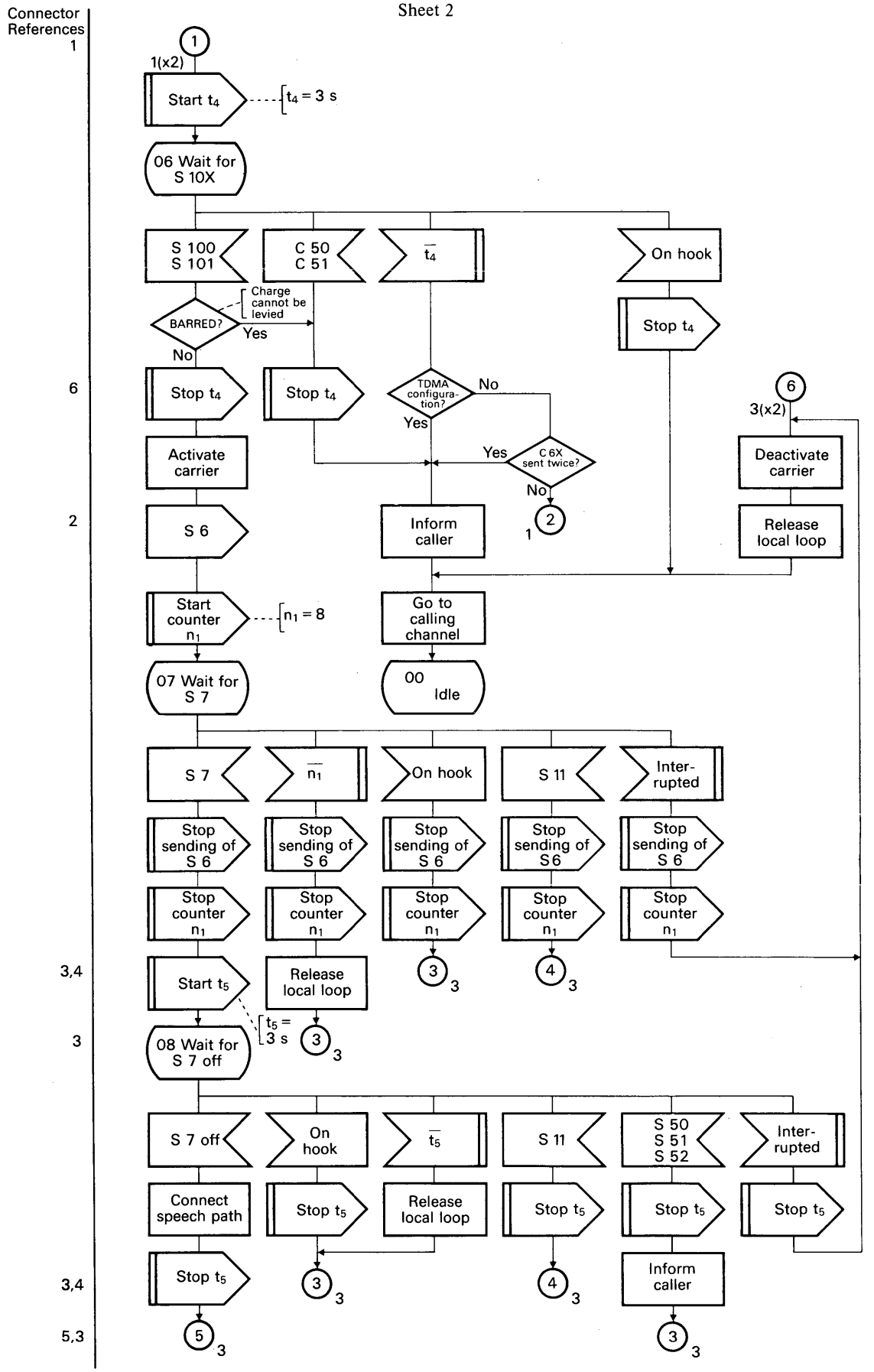
APPENDIX V

Sheet 1

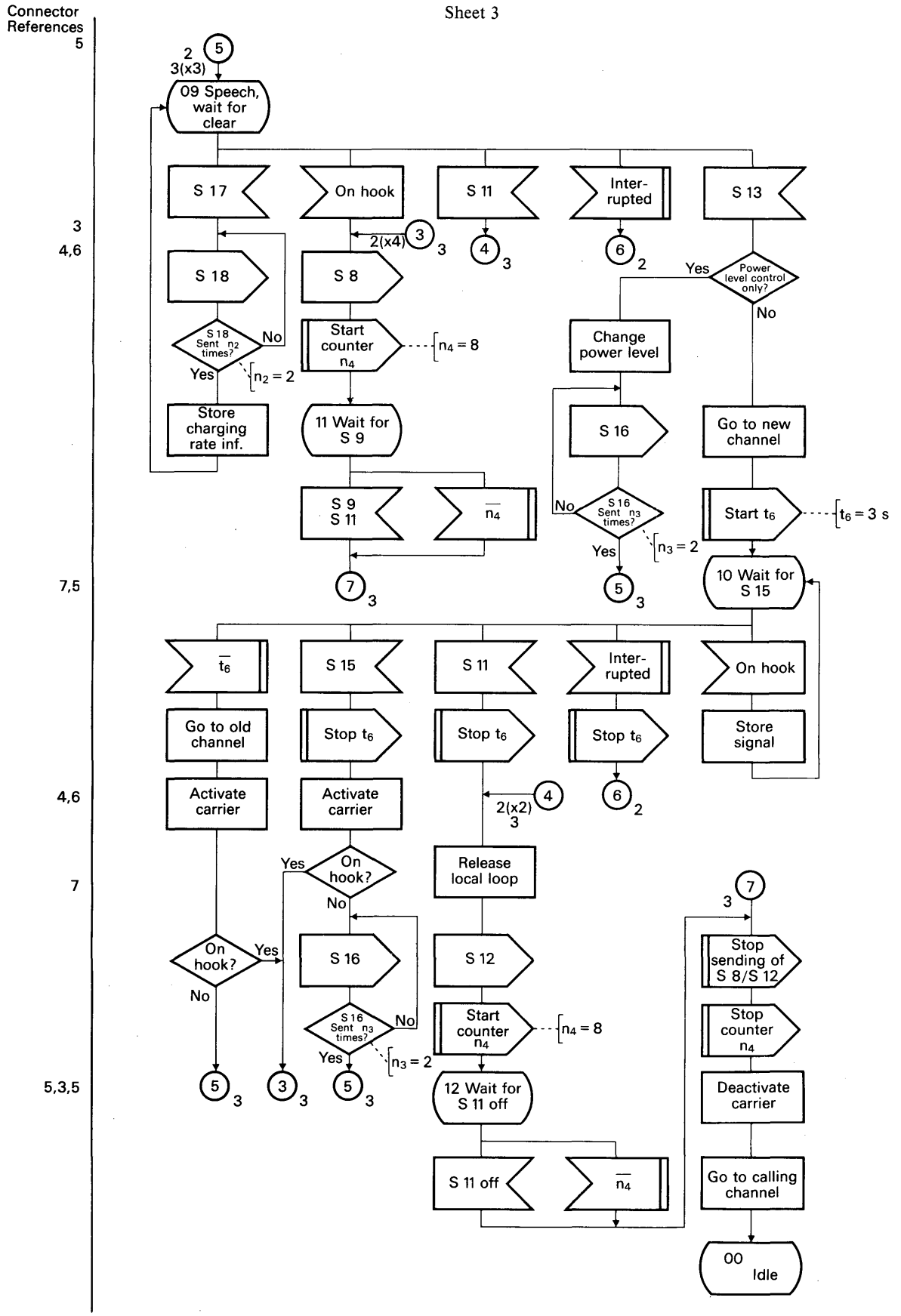


Outgoing procedure at ship (ship-originated call)

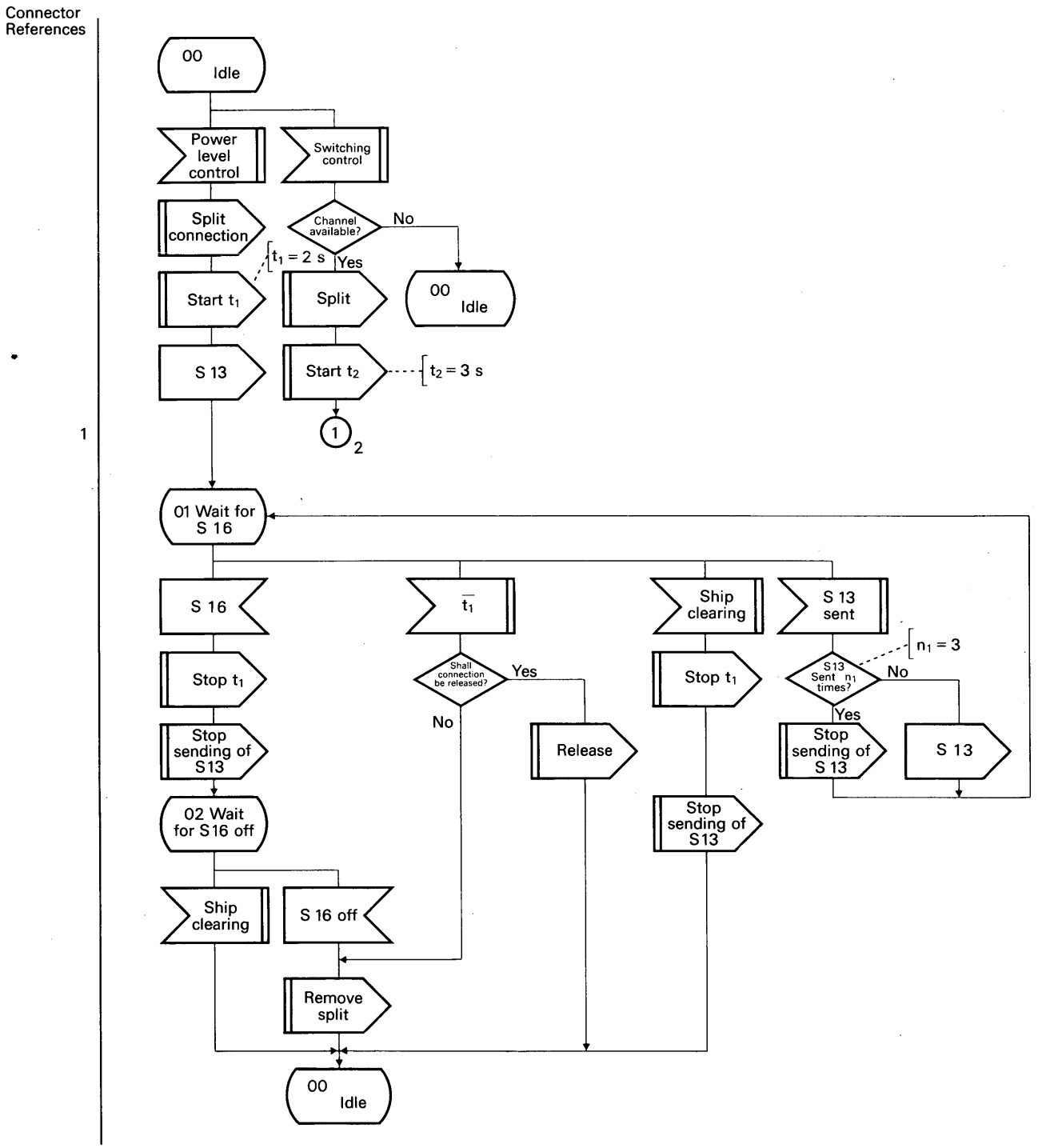
APPENDIX V
Sheet 2



APPENDIX V
Sheet 3

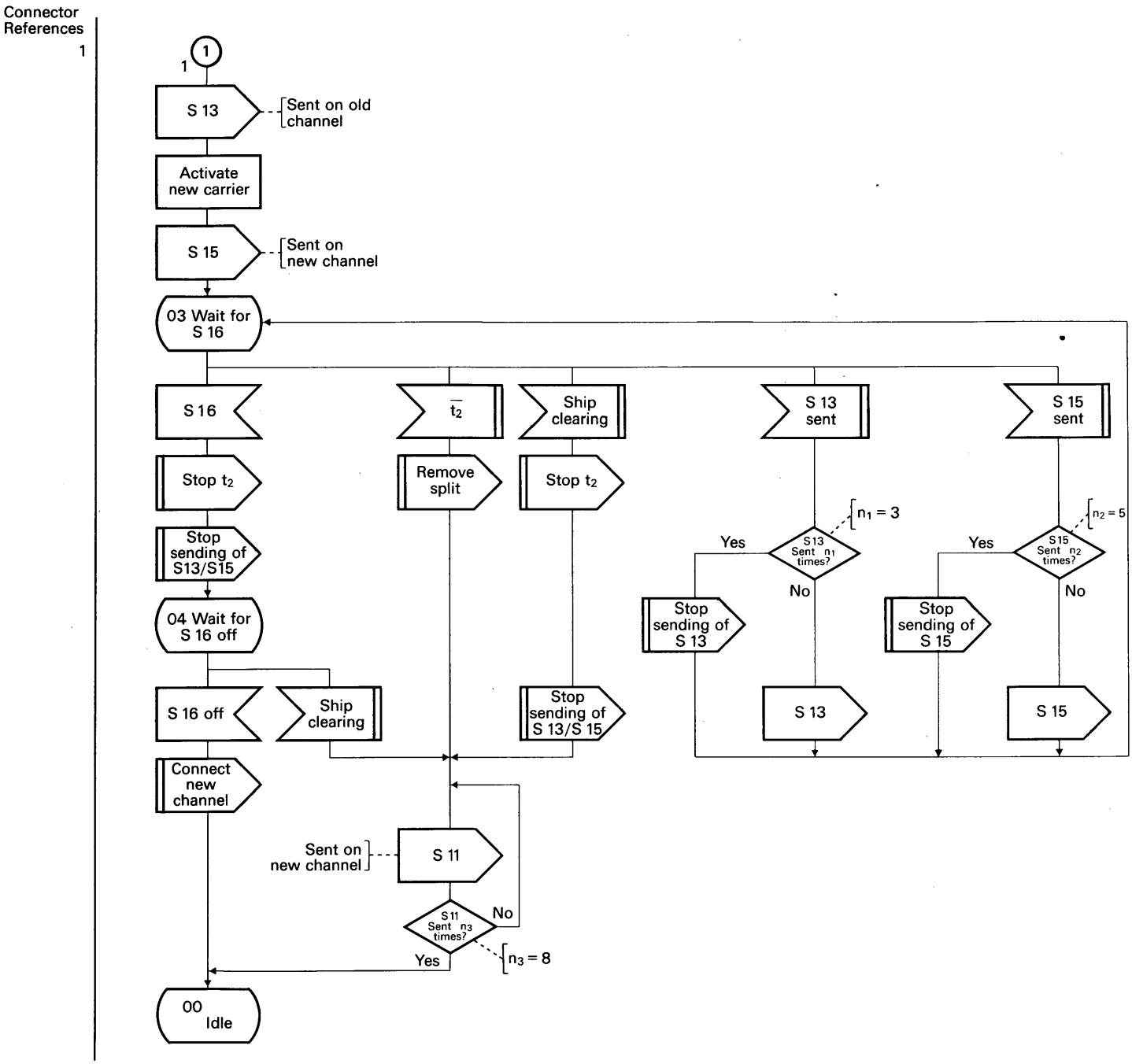


APPENDIX VI
Sheet 1



Power level control and switching call in progress control at MSC

APPENDIX VI
Sheet 2



RECOMMENDATION 587

COAST STATION IDENTITIES AND INITIATION OF LOCATION REGISTRATION IN AN AUTOMATED VHF/UHF MARITIME MOBILE TELEPHONE SYSTEM

(Question 23/8)

(1982)

The CCIR,

CONSIDERING

(a) Recommendation 586 (Automated VHF/UHF maritime mobile telephone system);

(b) that in accordance with Appendix 43 of the Radio Regulations (Geneva, 1979) and CCITT Recommendation E.210/F.120, coast station identities are formed as follows:

0 0 N I D X_6 X_7 X_8 X_9

where the NID reflects the country in which the coast station is located and X_6, X_7, X_8 and X_9 are any figure from 0 to 9;

(c) that location registration procedures are defined as those to be followed for a ship station identity to be entered in a location register of a maritime switching centre (MSC);

(d) that location registration procedures are initiated by ship stations;

(e) that up to 100 coastal areas may belong to one NID and no more than 100 coast stations need to be accommodated within one coastal area;

(f) that each individual coast station must have a unique identity,

UNANIMOUSLY RECOMMENDS

1. that for a given NID a coastal area be identified by the digits X_6 X_7;

2. that within one coastal area a coast station be identified by the digits X_8 X_9;

3. that the ship station initiates a location registration procedure when it detects a change in one or more of the digits of the sequence NID X_6 X_7 of the identity 0 0 N I D X_6 X_7 X_8 X_9 belonging to the received coast station.

REPORT 587-2 *

AUTOMATED VHF/UHF MARITIME MOBILE TELEPHONE SYSTEM

(Question 23/8)

(1974-1978-1982)

1. Operational requirements

1.1 The system should be suitable to use VHF channels according to Appendix 18 to the Radio Regulations and/or any other VHF/UHF channels allocated at a later date to the maritime mobile service.

1.2 The system should be suitable for international use.

1.3 The automated VHF/UHF service should as far as possible be compatible with other automated maritime services, e.g. a future maritime satellite communication service.

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* The Director, CCIR, is requested to bring this Report to the attention of the CCITT and the Inter-Governmental Maritime Consultative Organization (IMCO).

1.4 The system should not impede the use of channel 16 in the international maritime VHF safety service.

1.5 The operation of the system should not degrade the quality of the existing manual services.

1.6 The system should not necessitate modification of existing manual ship-borne equipment for use in the existing manual services.

1.7 The system should not necessitate modification of existing manual shore equipment in those areas where an automatic service is not established.

1.8 The ship's equipment should be capable of manual operation in areas where no automatic service is established.

1.9 The system should not require any significant changes in the public switched telephone network.

1.10 The system should not preclude the possibility of utilizing the same traffic channels for both manual and automatic services in a given coverage area.

1.11 The system should be designed to provide for automatic operation in both directions, but initially it should be possible to implement the system in the ship-shore direction only.

1.12 The system should permit transmission of charging information to the ship for ship-to-shore calls.

1.13 The operation of the equipment on board should be as simple as possible and the operational procedures should be as similar as possible to those used in the public switched telephone network.

1.14 The setting up of calls in the shore-to-ship direction should as far as possible be similar to the setting up of telephone calls in the public switched network. The system should not require the party initiating the call to know the exact position of the ship to be called.

1.15 The system should be cost effective with respect to the services provided.

1.16 The reliability of signalling over the radio path should be of the same order as the reliability of the signalling in the public switched telephone network.

1.17 The signalling system chosen for the radio path should, besides providing for the basic signalling necessary in an automated telephone system, be flexible enough to provide for existing and future optional signalling requirements.

2. Automatic location registration of ships

2.1 It was generally agreed that the implementation of ship location registration would be desirable in order to meet the operational requirements satisfactorily, especially from the land subscriber's point of view (see § 1.14). Furthermore, the restrictions on the length of the number to be dialled by the land subscriber limit the possibility of routing within the public switched telephone network. However, it was recognized that considerable economic, administrative and technical problems related with ship location registration on an international basis need to be solved. For these reasons further study on the practicability of the use of ship location registration on an international basis is required.

It was recognized that it would be desirable that ship stations be equipped with facilities for location registration (roaming procedures) even if the country of origin does not implement that facility.

2.2 The Netherlands and Spain, described in general terms systems using location registration of ships. These systems are based on the use of a maritime centre in each country or region to which all shore-to-ship calls initiated within that country or region are routed. The maritime centre updates the information on the position of the ships periodically [CCIR, 1974-78a and b].

Furthermore, these documents assume that for international maritime traffic, connections between the maritime centres will be established. The main advantage of the described systems is that no knowledge of the position of the ships is required by the land subscriber.

These two documents were sent to the CCITT for consideration, because these matters will involve the switched public networks and may affect charging arrangements. The CCITT has considered the matters and identified in its Recommendation E.211 as level 3 of automation the use of automatic ship location registration on a national basis.

In a French and two Norwegian contributions a system of location registration of ship stations was described. The ship station initiates an updating procedure when it detects that it has entered a new coastal area. The advantage of this solution is that frequent updating is avoided.

Studies on the feasibility of similar solutions on an international basis are continuing in the CCITT.

2.3 Japan outlined the ship location-registration techniques used in their national automatic maritime VHF service. This service operates in the 200 to 300 MHz frequency band with no attempt made to achieve compatibility with the existing international maritime VHF service. The ship location-registration information is signalled automatically by a ship to the coast station/control centre by means of in-band signalling over a working channel whenever it enters the service area of the particular coast station concerned. The choice of the coast station for use by a particular ship is based on a signal-to-noise ratio measurement of the coast station transmission made by the ship station receiver [CCIR, 1974-78c].

3. Supervision of channels

To ensure that reliable communications of acceptable quality are established and to avoid degradation due, for example, to radio interference or low field strength, the ship station equipment incorporates a facility for supervision of channels.

At present two methods have been proposed.

Japan described some details with respect to the signal-to-noise ratio detection method of channel supervision. A decision as to whether or not a call can be originated or received is made by comparing the signal-to-noise ratio of the received signal with a predetermined value [CCIR, 1974-78d].

Norway described a method of speech channel supervision where a continuous supervisory tone generated at the coast station is transmitted and looped at the ship station. The coast station takes the appropriate measures on the basis of the quality of the received looped signal.

4. Radio channel requirements

The Study Group further recognized the need for a satisfactory number of two-frequency channels in a fully automated VHF/UHF maritime mobile service, as it is of the greatest importance that the loss probability be kept at a tolerable level.

Norway estimated the situation to be expected in the most congested Scandinavian area if automation were to be introduced in the early 1980's on the basis of the present allocation in the Radio Regulations, Appendix 18, of two-frequency channels for public correspondence [CCIR, 1974-78e].

The conclusion reached in the document is that the traffic capacity of certain coast stations operating in congested areas would be exceeded within a few years after the introduction of an automated service.

Though these calculations are based on conditions that may be particular to Norwegian waters, discussions showed that the forecasts of other administrations in similar situations have indicated that the present number of channels available for public correspondence services is not sufficient to support an adequate VHF service, whether automatic or manual.

For the same reason the Japanese Administration introduced in 1979 the system referred to in § 2 in the 200 to 300 MHz band. Table I shows the results of measurements made on 4 selected base stations on 3 consecutive weekdays in this system. It will be seen that on the radio path, dialling and ringing occupied about 20% of the total time.

TABLE I – *Traffic measurement results – Japan*

Item		Selected base stations			
		A	B	C	D
Number of subscribers		37	71	21	5
Calls/subscriber/day		7.8	8.8	9.8	10.0
Busy hour concentration		0.13	0.11	0.13	0.21
Average holding time	conversation	2.65 min			
	switching	0.5 min (dialling 18s, ringing 12s)			
	total	3.15 min			
Busy hour traffic/ subscriber (Erlang)	conversation	0.048			
	dialling + ringing + conversation	0.057(1)			
Location registration/subscriber/day		5.8			
Ship-originated calls		63%			

(1) Traffic due to incomplete calls, location registration, etc. is not included.

The number of radio channels required for the operation of an automated system is closely related to the grade of service considered to be acceptable. In this respect it has to be realized that a loss probability has to be accepted which is higher than that generally acceptable in the public switched telephone network. A loss probability of about 5% was considered to be an acceptable figure; a traffic load corresponding to a loss probability of 10% (in a loss system) could be accepted if queueing in the shore-to-ship direction is introduced.

5. Procedure for setting up calls on the radio path

Based on the operational requirements of automated VHF maritime mobile telephone systems, laid down in § 1 of this Report, the Federal Republic of Germany described with the aid of flow charts, a procedure for setting up calls on the radio path. The operational requirements are fulfilled in so far as they have a direct bearing on the system proposed. In particular, the full compatibility with the existing manually operated system is stressed. Furthermore, the system proposed would be compatible with any reliable signalling system that might be proposed. However, the signalling system itself is not discussed in these documents [CCIR, 1974-78f and g].

A suggestion by the United Kingdom that the use of techniques whereby the ship is connected to the working channel only after the called party has answered (off-air call set-up) needs further study but Recommendation 586 allows for this facility by the use of currently unassigned codes.

When working out this new Recommendation on an automated radiotelephone system it was not possible to reach full agreement on a configuration. In those cases where an area is served by more than one coast station and only a small number of channels is available some administrations considered that efficient frequency planning did not permit the use of different calling channels for each individual coast station. In such cases a time division multiple access (TDMA) configuration provides an effective means for several proximate coast stations to employ the same calling channel. Other countries were of the opinion that a marked idle channel (MIC) configuration was preferred since TDMA may present difficult coordination problems and that if only a small number of channels were available implementation of an automated system should not be considered.

The two configurations described in the Recommendation differ only in their method of use of the calling channel(s). The MIC configuration is based on the assignment of non-shared channel(s) to each coast station while the TDMA configuration is based on the time sharing of a common calling channel by a number of coast stations. Signalling procedures have been unified to the extent that compatibility of ship stations with both configurations can be achieved with only minor additional equipment complexity.

Meanwhile the CCITT developed a system description language (SDL) which is particularly suitable to describe signalling procedures used in automated telephone systems (CCITT Recommendations Z.101 and Z.102). Because SDL allows for unambiguous definition of equipment characteristics this method is now used in Recommendation 586 rather than flow charts.

6. Signalling method

It was decided to use the technical characteristics and formats of the digital selective-calling system, described in Recommendation 493 as a basis for the study of the signalling method of the automated maritime VHF/UHF radiotelephone system.

The Administration of Norway reported on the laboratory test of the signalling system by the use of a fading simulator.

The conclusions are the following:

- the bit error rate performance is satisfactory;
- the Selcall code has an error correction capability equivalent to a 1/2 rate Hagelberger convolutional burst error correcting code;
- there is no significant difference between the lost frame probabilities for contiguous transmission of frames and isolated frames;
- for the isolated frames successful phasing occurs with the same probability whether or not the modem is equipped with data squelch;
- successful phasing occurs with the same probability independent of whether two characters or three characters are required for accepting the phasing sequence;
- the probability of successful receipt of frames is better than 85% down to speech quality threshold;
- a fairly high proportion of the frames had undetected errors when an error check character was not used. By using the error check character the number of frames with undetected errors became negligible.

However, some administrations expressed doubts whether the methods used in the digital selective-calling system would be suitable for the new automated system irrespective of the frequency band to be used.

7. Distress and safety calls

The automated VHF/UHF system could accommodate distress and safety calls within the signalling system specified in Recommendation 586.

Operational and technical implications, including whether priority access is practicable or cost effective, require further study.

8. Propagation tests

Propagation tests were performed in Finland in 1979 in the 450 MHz band on an 80 km path over open sea, and to a range of 80 km on a route between several coastal islands, using FFSK at 1200 bit/s from a coast station to a vessel travelling at speeds from 7 to 12 knots. The coast station antenna (a dipole) was at a height of 75 m and the ship antenna (a dipole) was at a height of 9.8 m. Over open sea, propagation varied widely from one weather condition to another. There were few short term variations typical of fast fading conditions, and error probability was low until the signal approached receiver sensitivity level. On the coastal islands route propagation resembled conditions normally found on a land path and errors occurred also when the signal was relatively strong.

Field trials with the signalling format defined in Recommendation 586 were performed in Norway in 1981 at two sites. The frequency used was 851 MHz. Both field strenght and frame error rates were measured continuously along three routes 70 to 80 km along covering both open sea and areas with coastal islands.

Both vertically and circularly polarized emissions were used at the coast stations for each route in order to investigate the influence of polarization on the fading. Circular polarization produced less fading than vertical polarization. There was, however, one exception which could be ascribed to difference in weather condition and sea state between the two measurements. Of the 150 000 frames which were transmitted 450 were received with errors. Such frames were received only when the ship antenna was in radio shadow and the received signal level was below 10 dB(μV) e.m.f. This occurred only at 14 points on the routes. With one or two exceptions, which accounted for 2/3 of the observed errors, the frame error rate at these locations varied between 1 and 10%.

9. Ship station and coast station identities

A new numbering system for ship stations and coast stations was established by the CCITT and CCIR (CCITT Recommendation E.210/F.120 and CCIR Recommendation 585 and Appendix 43 of the Radio Regulations, Geneva, 1979).

This system will be incorporated in the new automated VHF/UHF maritime mobile telephone system.

In order to facilitate automatic location registration Recommendation 587 was prepared dealing with coast station identities and initiation of roaming procedures.

Numbering and dialling procedures are defined in CCITT Recommendation E.211.

10. Cooperation with the CCITT

It was noted that CCITT Study Groups II and XI are studying technical and operational aspects concerning the interface with the land telephone networks and that CCITT Joint Working Party SMM is studying tariff and operating procedures for public correspondence. Other CCITT Study Groups may also be involved.

11. Automated VHF radiotelephone system in the ship-to-shore direction

France has presented a Report describing a system designed to operate on the channels indicated in Appendix 18 to the Radio Regulations. This system enables the subscriber aboard the ship to establish communications with the public switched telephone network by means of an external equipment which is added to the ship's transceiver, without any need to modify the transceiver. The external equipment comprises a keyboard which registers the number of the called subscriber and then transmits it automatically. The external equipment also transmits its own number for the purpose of identification and charging. The system comprises coastal control units which act as interfaces with the switched network and register the data required for monitoring and charging. Although ship-to-shore communication is established automatically, the operator remains at the coast station to deal with communications of non-equipped ships and shore-to-ship communications. The major part of the traffic can be expected to be handled automatically, thus reducing the load on the operators, despite a possible increase in traffic.

12. Technical characteristics of radio equipment for automated VHF/UHF maritime mobile telephone systems

In addition to the system specification in Recommendation 586, a technical specification for the radio equipment is necessary. This specification cannot be completed until determination of channelling requirements and the allocation of frequency bands; however, the parameters given in Annex I should be included.

13. Facsimile signal transmission over maritime VHF telephone speech channel

Japan described characteristics of facsimile signal transmission over a maritime VHF telephone speech channel together with experimental results [CCIR, 1978-82].

In transmitting the facsimile signal over a maritime VHF telephone speech channel, transmitted picture quality is affected mainly by fading and radio circuit S/N, and somewhat by additional attenuation distortion and phase distortion caused in the maritime telephone circuit.

The influence from these factors is to some extent dependent on the modulation system used in the facsimile equipments. In particular, when the facsimile equipments use the digital modulation system with the band compressed mode, the influence of fading becomes significant, and considerable degradation of picture quality may be caused.

Furthermore, when an in-band signalling method is used in the maritime telephone speech channel, interruption of facsimile signal transmission may be caused by wrong detection of the signalling constituents in the facsimile signal. It might be accordingly necessary to study on the prevention of the wrong signal detection, taking into account the CCITT Recommendations on facsimile equipment.

14. Conclusions

The present work is focused on the two configurations of the new automated VHF/UHF maritime mobile telephone system, the MIC and the TDMA configuration.

Although the future frequency allocation may influence some of the system characteristics (e.g. in the signalling system), the procedures and descriptions of Recommendation 586 would not need to be changed.

REFERENCES

CCIR Documents

[1974-78]: **a.** 8/368 (Annex II) (Netherlands); **b.** 8/466 (Spain); **c.** 8/13 (Japan); **d.** 8/266 (Japan); **e.** 8/60 (Norway); **f.** 8/91 (Germany (Federal Republic of)); **g.** 8/303 (Germany (Federal Republic of)).

[1978-82]: 8/385 (Japan).

ANNEX I

TECHNICAL CHARACTERISTICS OF RADIO EQUIPMENT FOR AUTOMATED VHF/UHF MARITIME MOBILE TELEPHONE SYSTEMS

In addition to the system specifications in Recommendation 586 a technical specification for the radio equipment is necessary. This specification cannot be completed until determination of channelling requirements and the allocation of frequency bands, however, the following parameters should be included.

1. General Characteristics

- Duplex operation
- Frequency tolerances
- Channel switching time
- Polarization
- Channel complement
- Overall bandwidth
- Channel quality supervision
- Data interface.

2. Transmitter Characteristics

- Necessary bandwidth and class of emission
- Modulation characteristics
- Out of band emissions
- Conducted spurious emissions
- Noise and hum
- Cabinet radiation
- Power level control
- Keying time.

3. Receiver Characteristics

- Reference sensitivity
- Modulation acceptance
- Demodulation characteristics
- Selectivity including adjacent channel
- Intermodulation, blocking and cross modulation
- Spurious responses
- Conducted spurious emissions
- Cabinet radiation
- Muting response times.

REPORT 744-1 *

USE OF CLASS J3E EMISSIONS FOR DISTRESS AND SAFETY PURPOSES

(Question 26/8)

(1978-1982)

1. Introduction

This Report discusses the use of class J3E emissions for distress and safety purposes on the carrier frequency 2182 kHz. The use of J3E emissions for distress and safety purposes on the carrier frequencies 4125 kHz and 6215.5 kHz is the subject of Recommendation 544. Recommendation 543 recommends that class R3E emission should not be used for distress and safety purposes.

IMCO recognized the significant advantages in using the class of emission J3E and the desirability of using it for distress and safety communications [IMCO a and b].

One of the major problems in the past was the compatibility of A3E, H3E and J3E alerting emissions on 2182 kHz. In the new distress and safety system mentioned below it is envisaged to discontinue the use of the alerting function of 2182 kHz.

Nevertheless, this Report contains also the compatibility considerations for alerting on 2182 kHz, for the case where these considerations might still be useful for IMCO when deliberating on the transitional plan.

However, the general introduction of J3E should not be realized before the Future Global Maritime Distress and Safety System becomes operational.

IMCO has prepared the operational requirements for the Future Global Maritime Distress and Safety System and was of the opinion that for this system, based on the use of automatic digital selective-calling alerting techniques, new equipment will need to be designed and manufactured for ships and survival craft. This new equipment will need to work with closer frequency tolerances and to higher technical standards than existing equipment.

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* The Director, CCIR, is requested to draw the attention of the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO) to this Report and invite their comments on this matter.

2. Operational considerations

2.1 The main operating advantage in using class J3E emission for distress is a power budget saving or alternatively an improved range of communications. Reliability and economy of ships's equipment would be enhanced because distress and commercial communication channels would use the same class of emission. There would also be an improvement in the utilization of frequency spectrum. However, there are large numbers of existing survival craft equipment, portable distress equipment and EPIRBs which use A3E or H3E emissions.

2.2 Recommendation 488 implies that for a given primary input power, the use of J3E would improve the range of operation of the equipment. This has been confirmed by practical experience. In a distress situation the greatest possible communication range is desirable.

2.3 Conversely, Recommendation 488 indicates that, for the same signal/noise ratio, a peak envelope power saving of approximately 10 dB could be achieved by the use of J3E compared with A3E or H3E. Such a saving would be particularly attractive where limitations of space and weight could impose serious problems. These circumstances apply to radio equipment intended for use in survival craft and for other mobile and portable equipment which is battery operated.

2.4 The atmospheric noise levels in temperate zones and the packaging constraints for 2182 kHz survival craft equipment and EPIRBs reduce their effectiveness in those zones.

3. Radio direction finding and homing on signals of classes of emission J3E and F1B

Present radio direction finding equipments in ships and coast stations are designed to locate emissions of a carrier with unvarying sidebands of sufficient duration to obtain a bearing. In this respect provisions 3119 and 3240 of the Radio Regulations are to be noted. The Future Global Maritime Distress and Safety System (FGMDSS) will include single-sideband emissions with suppressed carrier while maritime mobile stations will be equipped with single-sideband transmitters and with equipment for narrow-band direct printing (F1B) emissions.

Provision should be made so that in the FGMDSS the location of, and homing on J3E and F1B emissions is possible.

Studies are therefore urgently required on the technical and operational aspects of direction finding and homing on any of the frequencies that are envisaged for distress and safety purposes in the FGMDSS and on the emissions which will be employed on those frequencies.

4. Considerations with respect to the existing distress and safety system

4.1 *Compatibility of A3E, H3E and J3E classes of emission*

4.1.1 The problem to be solved before J3E class of emission could be introduced for distress and safety purposes is the difficulty of ensuring a satisfactory system, compatible with existing arrangements and capable of operation with A3E, H3E and J3E classes of emission.

4.1.2 Tests have shown that where operator-attended watchkeeping is provided by coast stations, the identification and reception of type A3E and H3E signals in a J3E system is practicable. Communication for distress and safety between ships and coast stations is, in these circumstances, therefore achievable. The United States [CCIR, 1978-82] has reported implementation of single sideband (J3E) distress frequency watchkeeping by national ships in US waters and by US Coast Guard stations, effective 1 September 1978. The implementation of J3E has significantly improved the transmitting range as compared to H3E or A3E emissions. J3E receivers precisely tuned on the carrier frequency 2182 kHz reproduce intelligible audio signals when receiving A3E or H3E emissions with carrier frequencies deviating not more than 100 Hz from 2182 kHz.

Distress alarm signals can still be detected by an operator when their carrier frequencies deviate up to 300 Hz from the nominal frequency 2182 kHz.

In this regard it is significant to note that the Radio Regulations at present permit survival craft radio equipment to deviate 660 Hz from 2182 kHz.

When an operator at a US Coast Guard station recognizes that he is receiving other than J3E signals he will use the double sideband mode for further reception or transmission of signals.

4.1.3 However, existing distress and safety requirements call for the reception of distress signals from ships, survival craft stations and EPIRBs by ship stations as well as by coast stations.

To achieve this it may be necessary to design a watchkeeping receiver which automatically inserts into its demodulator a locally-generated carrier when a J3E signal is received and which would ensure that this local carrier was not present when A3E or H3E was being received.

4.1.4 The presence of an A3E or H3E signal in a J3E receiver would produce an inter-carrier beat frequency which could have a maximum frequency depending on the frequency tolerance of survival craft transmitters (300 ppm, or 655 Hz at 2182 kHz). Allowing a tolerance of ± 10 Hz on the carrier re-insertion frequency, the maximum anticipated inter-carrier beat frequency would be 665 Hz.

4.1.5 Beats would also occur between the re-inserted carrier and the sideband frequencies which, when demodulated, would produce tones within the audio passband of the receiver. These tones would obviously detract from the aural effectiveness of the two-tone alarm by an amount depending on the relative frequencies of the wanted and the unwanted tones. If the receiver was used in conjunction with a filtering device, the audio tone filters might reduce the likelihood that unwanted tones would be heard.

4.1.6 The problem cannot be completely solved except by arranging for the re-inserted carrier to be injected only in the presence of a J3E signal, or, to be absent during reception of an A3E or H3E signal. This arrangement would in any case be necessary for the satisfactory reception of voice transmissions.

4.1.7 Watchkeeping receivers designed to be compatible with both A3E and J3E emissions are technically feasible and it is of note that IMCO (May 1981) requested CCIR to continue the study of a watchkeeping receiver capable of receiving single-sideband (J3E) and double sideband (A3E) emissions for possible use during a transitional period before the Future Global Maritime Distress and Safety System has been fully implemented.

4.1.8 In this respect the United Kingdom reported on tests in which the signal-to-noise ratios of two experimental receivers were evaluated in the A3E and J3E modes of reception to establish the levels at which the two-tone alarm signal was subjectively discernable and at which speech signals were intelligible.

A receiver whose RF imput passband was limited to that of the speech upper sideband, fed an envelope detector together with a 2182 kHz local oscillator signal. This gave satisfactory reception of both alarm and speech signals in the J3E mode with re-inserted carrier but with the detector efficiency reduced when compared with that possible from product detection. In the A3E mode, the re-inserted carrier failed to compensate fully for the power losses of RF filtering and removal of the lower sideband. While giving intelligible speech at high signal levels the required signal-to-noise ratio for the reception of A3E signals was unacceptable.

Further modification in the use of 2182 kHz local frequency re-insertion is proposed making use of a phase-locked-loop to lock onto the transmitted carrier frequency. This would permit RF amplification at full A3E bandwidth thus overcoming the power losses of RF bandwidth filtering while recognizing an anticipated penalty in J3E signal-to-noise ratio.

A second test receiver employing full double sideband RF bandwidth with subsequent manual signal switching to an appropriate detector was tested. For watchkeeping to detect two-tone alarm signals an envelope detector was preferred with local oscillator injection at 2185.5 kHz. The audio bandpass filtering was found to be inadequate to reject the 3.5 kHz intercarrier beat but this did not detract from reception of the alarm signals in either the A3E or the J3E modes of transmission. Further appropriate manual switching to give intelligible speech reception was indicated by the presence of an intercarrier beat frequency when switched first to the product detector for J3E reception.

Speech quality in both A3E and J3E modes was found to be satisfactory, however variation between the suppressed transmitter carrier frequency and the re-inserted carrier frequency modified the speech tone quality during J3E reception but speech intelligibility was not degraded when this frequency difference was within ± 150 Hz.

Any A3E transmissions received when the receiver was switched to the J3E mode caused an intercarrier beat frequency which however was at a lower detected level than the J3E signals and did not degrade J3E speech intelligibility.

It was considered that this test receiver was satisfactory for the reception of the two-tone alarm signal and distress speech messages in either the A3E or the J3E mode. Because of the RF bandwidth employed some of the inherent advantages of J3E over A3E emissions was forfeited. The requirement for manual switching to the appropriate mode of detection was also noted to be a potential operational disadvantage.

4.2 *Frequency accuracies and stabilities*

4.2.1 Before J3E can be introduced universally, some adjustments will be needed to the various frequency tolerances permitted by the Radio Regulations in distress equipment, particularly for satisfactory J3E operation with watchkeeping receivers using filters or a muting device.

4.2.2 The permitted long-term frequency tolerance on shipborne transmitters is 50 Hz for transmitters installed after 1 January, 1982. The permitted tolerance on the frequency of each of the tones of the two-tone alarm is ± 1.5% which, on the lower frequency tone of 1300 Hz, is ± 19.5 Hz (say ± 20 Hz). Typical requirements for the audio tone filter characteristic for watchkeeping receivers state that the response should be not more than 3 dB below the maximum response within 3% of the frequency of maximum response. This should occur within ± 1.5% of the tone frequency, and at least 20 dB below the maximum response at 15% of the frequency of maximum response.

4.2.3 If the frequency tolerance of ± 50 Hz for shipborne equipment was also applied to EPIRBs and survival craft equipment, the total system tolerance could be in the order of ± 120 Hz, or ± 9%, of the 1300 Hz tone. The effect of this in a J3E system would be that the tone frequencies at the receiver could vary between 1180 Hz and 1420 Hz, and between 2080 Hz and 2320 Hz respectively. However, the tone difference between the two notes should be reasonably constant at about 900 Hz and in most practical cases the variation of the tone frequencies would probably not exceed ± 50 Hz.

4.2.4 If watch for the two tones was kept aurally, it is unlikely that the variation in the tone frequencies would have any effect on the detection of the alarm signal because the distinctive "warble" would still be present. Similarly, if a muted watchkeeping receiver was used, the effect would probably be negligible because detection can be carried out by a combination of tone frequencies and the timing sequence. Provided the two tones are present and in the correct time relationship, such equipment should function correctly.

4.2.5 However, if a filtering device was used, the widening of the filters would increase the background noise possibly to the extent of defeating the purpose of the filters as a means of reducing the noise on a ship's bridge.

4.2.6 For satisfactory operation of a filtering device, or for the aural tones to be similar in note to the present system, considerably tighter tolerances will need to be applied to J3E equipment. In the present A3E and H3E modes the allowable tone frequency tolerance is applicable only to the tone generator in the transmitter. In the J3E mode the ± 20 Hz tolerance must be shared between the tone generator frequency, the transmitter carrier frequency and the receiver oscillator frequency, because in this mode the received tone frequency and amplitude depend also on the accuracy of the carrier re-inserted at the receiver.

4.2.7 Due to the frequencies involved, nearly all of the tolerance would have to be shared between the transmitter carrier frequency and the receiver oscillator, leaving a small tolerance of about ± 0.1 Hz on the frequency of the tone generator at 1300 Hz.

4.2.8 The division of the ± 20 Hz between different types of equipment will, in practice, probably be dictated by operational considerations and the current state-of-the-art of high stability oscillators. At present for equipment operating on the frequency 2182 kHz, the following tolerances, as shown in Table I, could be achieved at moderate cost:

TABLE I

Type of equipment	Temperature range	Frequency variation	
		with oven	without oven
Shipborne	0 to 40°C	±0.3 Hz	±10 Hz
Survival craft	− 25 to + 70°C	±0.3 Hz	±22 Hz

However, further study is required, in particular as regards the cost aspects.

4.2.9 Although it would be technically possible to provide survival craft equipment with temperature controlled ovens, this would introduce several problems, in particular the extra power which would be needed and the "warm up" arrangements. Under these circumstances, the necessary system tolerance of ± 20 Hz could not be met. However, if the shipborne equipment was temperature controlled, a worst system tolerance of ± 22.4 Hz could be achieved. This would be made up of ± 22 Hz for the survival craft equipment, ± 0.3 Hz for the shipborne equipment and ± 0.1 Hz on the frequency of the 1300 Hz tone generator. In view of crystal ageing etc., such requirements would require regular frequency verification of shipborne equipment. Other techniques providing stringent frequency tolerance in a hostile environment may be found to be applicable and study on this subject is necessary.

4.3 *Summary*

The advantages of J3E emissions are so significant that this class of emission should be adopted for distress and safety purposes. However, if a transitional period is considered in which both A3E, H3E and J3E emissions are employed, it will be necessary to:

4.3.1 Introduce effective watch at coast radio stations for A3E, H3E and J3E distress signals thus ensuring that the existing distress service is in no way degraded.

4.3.2 Introduce the capability for maintaining watch for A3E, H3E and J3E distress signals on all ships.

4.3.3 Improve the frequency accuracy and stability of equipment required to be used in distress situations. In this connection, the ability of survival craft radio equipment and EPIRBs to achieve and maintain a frequency tolerance of around ± 20 Hz and for ship equipment a tolerance of ± 0.3 Hz should be studied. Investigation into new techniques for SSB compatible auto-alarm signals would be helpful.

4.3.4 Assess in the present global philosophy of a 2182 kHz distress service the value of survival craft equipment and EPIRBs in relation to their dominant influence on the introduction of J3E emissions for distress and safety purposes.

4.3.5 Develop emergency equipment for J3E operation which is simple to operate and capable of reliable operation in widely variable environments after long periods of storage.

4.3.6 Take into account the IMCO Recommendation on operational standards for radiotelephone watch receivers (Resolution No. A.383(X)) which requires equipment provided with a filtering unit to select the frequencies 1300 Hz and 2200 Hz. These frequencies are subject to a tolerance of ± 1.5%. In such cases the following tolerances are required:

- shipborne equipment ± 0.3 Hz
- survival craft equipment ± 22 Hz
- tone generators ± 0.1 Hz

4.3.7 In most practical cases, the frequency tolerance could be expanded with little degradation of automatic detectability because of passband margin and moderate attenuation near band edges of the tone filter in the watch receiver. Further experimental investigations of the acceptable frequency tolerance for the radiotelephone watch receivers are required.

5. Considerations with respect to the Future Global Maritime Distress and Safety System

5.1 *The use of the frequency 2182 kHz*

The frequency 2182 kHz will be required to be a dedicated international frequency for distress and safety traffic. It will be used for this purpose by ship, aircraft and survival craft stations.

As there will be no requirement for retaining the alerting function of the frequency 2182 kHz and thus the radiotelephone alarm and vital navigational warning signals will lose their present essential function, the introduction of J3E could be made considerably easier.

However, the use of the frequency 2182 kHz for homing purposes should be taken into account.

5.2 *Frequency accuracies and stabilities*

When the Future Global Maritime Distress and Safety System is fully implemented there will be no requirements for the distress frequency watchkeeping receiver as mentioned in § 4.3.6. Without this constraint, a frequency tolerance of 50 Hz would therefore seem to be suitable for a J3E operation on 2182 kHz.

6. Conclusions

6.1 The schedule for the introduction of the use of J3E emissions for distress and safety purposes will depend on the requirements for transition to the Future Global Maritime Distress and Safety System as developed by IMCO.

6.2 Full consideration should be given to all necessary measures to be taken during a transitional period for the reception of A3E and H3E emissions on the frequency 2182 kHz.

6.3 Consideration will have to be given to the most effective homing techniques on equipment using J3E emissions on 2182 kHz.

REFERENCES

IMCO: **a.** Doc. COM XXI/12; **b.** Doc. COM XXII/12.

CCIR Documents

[1978-82]: 8/154 (USA).

RECOMMENDATION 543 *

THE USE OF R3E AND J3E EMISSIONS FOR DISTRESS AND SAFETY PURPOSES

(Question 26/8)

(1978)

CONSIDERING

(a) that the use of classes of emissions R3E and J3E for distress and safety purposes provides substantial operational advantages, particularly in terms of power saving;

(b) that of these two classes of emissions, J3E provides greater spectrum utilization efficiency;

(c) that system frequency stability requirements for class R3E and J3E services are similar;

(d) that the development and operational use of class J3E has proved satisfactory;

(e) that maritime public correspondence radiotelephone services have adopted class J3E;

(f) that no substantial operational, technical or economic advantage accrues from the use of the class R3E;

(g) that it would be an unnecessary and unjustified complication to introduce two new classes of emission for distress and safety purposes;

(h) that the use of class J3E on 2182 kHz is under study,

UNANIMOUSLY RECOMMENDS

that class R3E emissions should not be used for distress and safety purposes.

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* This Recommendation should be brought to the attention of the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO).

RECOMMENDATION 544 *

THE USE OF CLASS J3E EMISSIONS FOR DISTRESS AND SAFETY PURPOSES ON THE CARRIER FREQUENCIES 4125 kHz AND 6215.5 kHz

(Question 26/8)

(1978)

The CCIR,

CONSIDERING

(a) that the World Maritime Administrative Radio Conference, Geneva, 1974, recognized the need to supplement the radiotelephone distress frequency, 2182 kHz, in certain regions by the use of the carrier frequencies 4125 kHz and 6215.5 kHz;

(b) that in conditions of low shipping density, widely spaced coast stations and high medium frequency noise levels, a service has been successfully established using 4125 kHz and 6215.5 kHz for call, reply, distress and safety purposes;

(c) that these frequencies are not used for the two tone alarm signal, survival craft radio equipment and emergency position-indicating radio beacons (EPIRB);

(d) that communications on 4125 kHz and 6215.5 kHz are between coast stations and ship stations;

(e) that the frequency tolerance permitted in ship SSB transmitters is ± 50 Hz but ± 100 Hz for transmitters installed before 1 January 1978;

(f) that the maximum anticipated frequency translation error in a system between coast stations and ships is ± 300 Hz;

(g) that such a frequency translation error is within the range over which it has been proved that class J3E emission gives intelligibility equal to or better than that obtained with class H3E emission of equal peak envelope power;

(h) that the use of class J3E emissions for distress and safety purposes provide substantial operational advantages,

UNANIMOUSLY RECOMMENDS

that coast station J3E services should be introduced on the carrier frequencies 4125 kHz and 6215.5 kHz.

REPORT 745 **

THE CHOICE OF A FREQUENCY IN THE MARITIME MOBILE BANDS BETWEEN 1605 kHz AND 3800 kHz TO BE RESERVED FOR SAFETY REQUIREMENTS

(Question 29/8)

(1978)

1. Introduction

There are various technical, operational and economic aspects likely to affect the choice of a frequency in the bands between 1605 kHz and 3800 kHz to be reserved exclusively for distress, urgency and safety purposes. Some of the more important are:

- range and power budget requirements and propagation;
- survival craft antennas;
- homing facilities;
- operational considerations;
- medium range distress frequencies;
- existing equipment.

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* The Director, CCIR, is requested to bring this Recommendation to the attention of the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO).

** The Director, CCIR, is requested to draw the attention of Inter-Governmental Maritime Consultative Organization (IMCO) to this Report and invite their comments on this matter.

2. Range and power budget requirements and propagation

A frequency used for distress, urgency and safety purposes should be capable of providing reliable communication, throughout the 24 hours, over a certain distance. The International Convention for Safety of Life at Sea, 1974, specifies a daylight range of 150 nautical miles for ship's installations and for the purpose of this Report this distance is used. However, in distress situations, very low power transmitters are often used and the frequency should, if possible, be one which would provide the maximum possible range under such circumstances.

To achieve consistent communication throughout the 24 hours the optimum frequency should have adequate ground-wave coverage and be least affected, within the required range, by sky-wave propagation during the hours of darkness.

Figure 1 shows the attenuation, relative to that at 500 kHz, for a range of frequencies, of the ground wave over a sea path.

3. Survival craft antennas

An antenna used in survival craft or with portable equipment will, over the frequency bands in question, be small in height compared with a wavelength. Such an antenna may be regarded as a short monopole above a conducting plane.

Under these circumstances, for a given radiated power, the lower the frequency used the greater becomes the voltage developed across the antenna insulator. Assuming that a typical dimension for a survival craft antenna is 3 metres and its capacitance is 27.5 pF, Fig. 2 shows the variation of base voltage with frequency for a number of radiated powers. With such small antenna systems it is difficult to achieve high antenna efficiency (radiated power relative to input power). For a given antenna, the problem worsens with a reduction in frequency.

4. Homing facilities

In order to provide rapid assistance to vessels in distress the frequency in use should be suitable for "homing" purposes by ships and aircraft.

Recommendation 428 indicates that the accuracy of homing can be degraded by sky-wave components and by re-radiation from various parts of a ship's superstructures. In the frequency bands between 1605 kHz and 3800 kHz generally, the higher the frequency the greater the effects of both sky-wave propagation and ship's superstructures on the accuracy of the results obtained.

5. Operational considerations

In some areas the use of MF radiotelephony for maritime safety purposes is increasing and in many areas the watch on the present MF radiotelephone distress frequency is very difficult because of the large number of routine traffic calls sent on that frequency.

On the other hand some administrations believe that voice-calling should continue to be permitted on the distress frequency to increase the interest in listening and reduce the number of receivers required.

In the long term separate frequencies for safety purposes and for routine traffic calls would ensure that the use of each frequency was developed in the way most suited to the needs of the particular service.

There are, however, some other factors which should be taken into consideration. The VHF radiotelephone service is also expanding, probably at a faster rate than the MF service. It is therefore possible that much of the coast-to-shore traffic now handled on MF, both distress and calling, will in the future transfer to VHF. This is already the situation along the coast line in certain areas.

Watch is normally kept on a safety and distress frequency in the bands between 1605 kHz and 3800 kHz on the bridge of a ship. In order to minimize the effect of the noise level on a bridge it may be necessary to use either a "filtered" loudspeaker or a muted receiver. (At least one administration does not allow the use of filtered loudspeakers or muted receivers.) In this case it may be necessary to arrange for urgency and safety signals either to lift the mute or pass through the filter. However, if a dedicated distress urgency and safety frequency, which had little background noise, was introduced it might be possible to use an open loudspeaker for watch-keeping purposes.

The operational use of 2182 kHz has been the subject of previous liaison between IMCO and ICAO.

If a frequency lower than 2182 kHz is selected there will be serious technical problems arising from the limited frequency range of aircraft radio equipment in providing satisfactory operational watch-keeping coverage of the frequency by civil aircraft and helicopters. * If, on the other hand, a higher frequency is selected the ability of aircraft installations to operate on the frequency will be increased and the installations simplified.

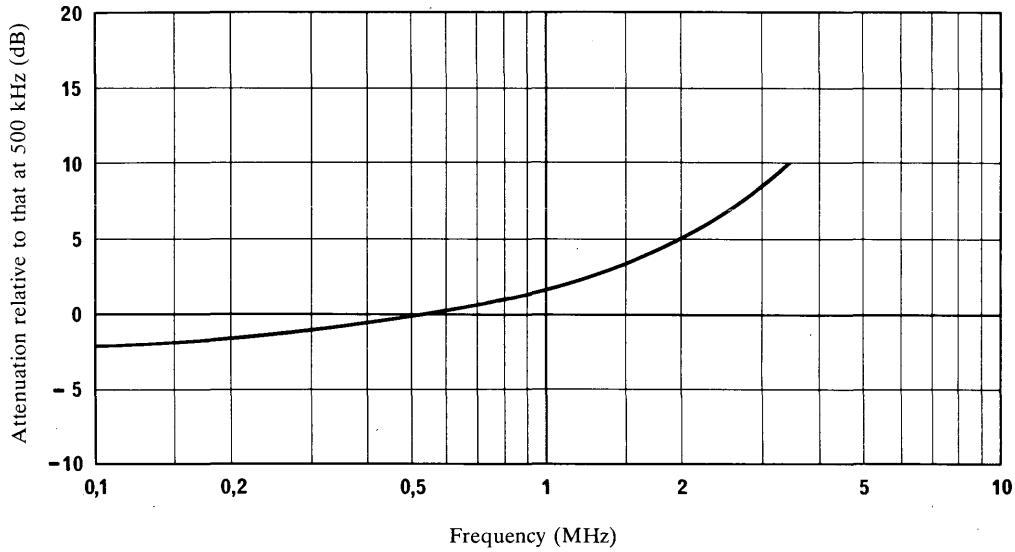


FIGURE 1 – *Relative attenuation/frequency of ground-wave over a sea path of 150 nautical miles*

6. Medium range distress frequencies

The need for all vessels to be able to communicate on one frequency for distress purposes has been recognized by IMCO Resolution A.335 (IX) which recommends the inclusion in ships' radiotelegraph installations of facilities for radiotelephony transmission and reception on 2182 kHz. If this is done, 2182 kHz – besides being common to all Convention ships – will also provide linkage between radiotelegraphy and radiotelephony equipped ships, thereby increasing the safety of all.

With the exception of survival craft equipment, the distress service operated on 500 kHz is normally reliable over a greater range than would be possible with any frequency in the bands between 1605 kHz and 3800 kHz. It is also operated by professional communicators and, as telegraphy is used, minimizes language problems.

Although not in the category of MF, it is recognized that because of different propagation conditions, particularly in the southern hemisphere, designated 4 MHz and 6 MHz frequencies are supplementing 2182 kHz and their use is very important to the safety of vessels operating in those regions.

7. Existing equipment

For many years 2182 kHz has been the distress, urgency, safety and calling frequency for ships equipped in the 2 MHz band. It is very likely that there are more existing equipments operating on this frequency than on any other maritime mobile frequency. Therefore the selection of a different frequency for this purpose would have a very large economic impact and its implementation would require interim operational procedures until the changeover was completed.

* Future avionic HF equipment design (ARINC (Aeronautical Radio Inc. Annapolis Maryland USA) Characteristic 559A, 1975) is now being limited to a frequency selection range of 2.8 MHz to 24 MHz largely due to the lack of operational use of frequencies below 2.8 MHz and due to technical factors associated with the matching of equipment to modern aircraft antenna systems and in particular, to helicopter antenna systems.

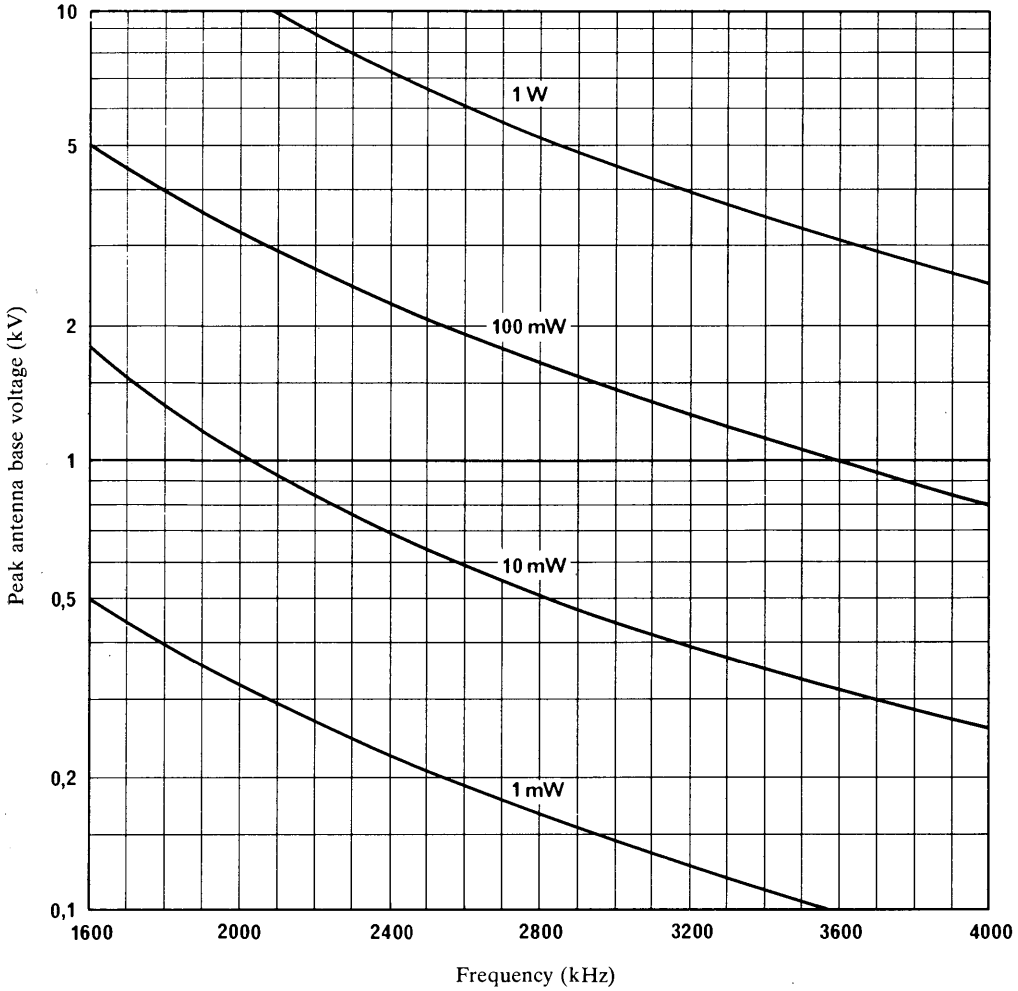


FIGURE 2 – *Variation of antenna base voltage with frequency for a number of radiated powers*

(Antenna assumed to be 3 metres in length and 27.5 pF capacitance)

8. Conclusions

8.1 Taking into consideration all the factors, technically there is little difference between the various frequencies in the bands between 1605 kHz and 3800 kHz. However, operational factors show that 2182 kHz is the most appropriate frequency for distress calls and messages and, possibly, urgency signals and messages, safety signals and certain safety messages in the maritime mobile service.

8.2 For calling purposes, a frequency in the vicinity of 2000 kHz to 2300 kHz would be most appropriate. However, there will be significant problems involved in removing calling from the frequency of 2182 kHz.

8.3 It would be advantageous for the future distress service, if the MF and HF radiotelephone frequencies were studied with the view of providing maximum world-wide distress coverage.

REPORT 748

IMPROVED USE OF THE HF RADIOTELEPHONE CHANNELS FOR COAST STATIONS IN THE BANDS ALLOCATED EXCLUSIVELY TO THE MARITIME MOBILE SERVICE

(Question 30/8)

(1978)

1. Introduction

Under Question 30/8 it was decided that the CCIR should consider the technical and operational criteria to be adopted to enable the best utilization to be made of the HF radiotelephone channels.

In the Conclusions of the Interim Meeting of Study Group 8, [CCIR, 1974-78a], the results of Interim Working Party 8/2 (Geneva, 1974) are set out. Interim Working Party 8/2 was initially set up to give provisional advice to the IFRB concerning the allocation of HF radiotelephone channels and later to study Question 30/8.

Norway gave special attention to the operational aspects of Question 30/8 [CCIR, 1974-78b].

2. Results of Interim Working Party 8/2

The Interim Working Party agreed to base its work on existing CCIR Recommendations and Reports, in particular Recommendation 339 and Reports 252, 322, 340 and 525. In addition, use was made of Report 358.

Values of signal-to-interference protection ratios were derived in §§ 7.4 and 7.5 of the Report of the second meeting of the Interim Working Party to provide the IFRB with a basis for its work in relation to the allocation of radiotelephone channels in the maritime mobile service. The figures recommended were:

12 dB for just usable circuit quality and

21 dB for marginally commercial circuit quality.

In § 7.7 of the Report of the second meeting it was suggested that means of providing propagation forecasts for ships were desirable to enable them to select the optimum frequency band. Administrations were encouraged to provide such information to their ship and coast stations.

In § 7.8 figures for the amount of channel time per hour to be considered in connection with determining sharing possibilities were proposed.

3. Operational method for improving channel utilization used by Norway, Sweden and Denmark

Norway described a particular method used by Norway, Sweden and Denmark (as from 1 January 1978) to assist in improving the utilization of radiotelephone channels assigned to all three countries [CCIR, 1974-78b].

The method is based on sub-dividing the channels into exclusive and common channels, allocation of the exclusive channels being on a traffic load basis.

A combined conference and signalling system was described which indicates the state of the channels (free or occupied) thus enabling the operators to coordinate the use of the channels.

It was noted that the sub-division of the channels may need revision in the light of further experience.

REFERENCES

CCIR Documents

[1974-78]: **a.** 8/205 (Conclusions of Interim Meeting of Study Group 8); **b.** 8/363 (Norway).

REPORT 909

TECHNICAL CHARACTERISTICS FOR MARITIME RADIO EQUIPMENT USING NARROWBAND PHASE-SHIFT KEYING (NBPSK) TELEGRAPHY

(Question 54/8)

(1982)

1. Introduction

Direct printing in the maritime mobile service is currently effected by class of emission F1B, with a shift of 170 Hz and a separation of 500 Hz. This class of emission is used owing to its comparatively inexacting requirements with regard to permissible frequency deviation and circuit stability, coupled with the possibility of operating directly from the telegraph equipment, i.e., using asynchronous methods.

In view of the new technical possibilities offered by maritime mobile service equipment, it is useful to examine keying techniques conducive to a more economical use of the frequency spectrum, thus making available a larger number of channels in the HF bands. One such technique is narrowband phase-shift keying (NBPSK). A number of theoretical and experimental studies, the findings of which are described below, were carried out to explore the possibilities for the use of this technique in maritime mobile channels.

2. General

The advantages of PSK over frequency-shift keying (FSK) are well known [Petrovich, 1965]:

- reduced necessary bandwidth,
- better noise immunity.

The bandwidth reduction stems from the fact that the main part of the energy of the PSK signal is concentrated in a band Δf which is defined as the reciprocal of the signalling rate.

One important shortcoming of PSK should be noted. While the spectrum component levels with FSK are substantially reduced on detuning from the assigned frequency, with PSK they are reduced in proportion to the component number. For purposes of illustration, Figs. 1*a* and 1*b* show the PSK and FSK signal spectra at phase and frequency keying speeds of 100 bauds. Figure 1 shows the discrete spectrum component levels, the total level for both the PSK and the FSK signal being taken as unity. The spectrum components of PSK signals are less reduced on detuning from the assigned frequency f_0 compared with FSK. For example, with a detuning by 5 F_0, F_0 being the keying frequency, the component level for PSK is 0.128 and for FSK, 0.042. Therefore, despite the smaller necessary bandwidth for PSK than for FSK with a shift of 170 Hz, the interference caused in the adjacent channels is much greater unless steps are taken to attenuate the higher order (equal to or greater than 3 F_0) spectral components of the PSK signal.

However, with such attenuation, the signal envelope undergoes considerable change (see Fig. 2) and there is no longer a constant envelope level. The simultaneous change in the signal phase and envelope produces qualitatively new signal properties:

- much lower level of out-of-band components;
- creation of extra out-of-band spectral components when the signal is passed through non-linear amplifiers;
- occurrence of inter-symbol interference, which impairs the performance of the system.

This PSK method with subsequent filtering of components of 3 F_0 and over is designated "narrowband phase-shift keying" (NBPSK).

Figure 3 shows the amplitude-frequency characteristic of a typical narrowband PSK signal-shaping filter.

The noise performance of narrowband PSK signals depends on the following factors:

- the noise level in the channel;
- inter-symbol interference;
- the bit energy.

Inter-symbol interference and bit energy depend on the passband of the transmitter's narrowband PSK signal-shaping filter and the receiver's main selection filter. For filters with a trapezoid amplitude-frequency

characteristic, the equivalent reduction in signal-to-noise power ratio Δh^2 due to inter-symbol interference is shown in Fig. 4, while that caused by the change in the bit shape is given in Fig. 5. In these diagrams, ΔF is the filter passband in hertz and T is the bit duration in seconds.

To ensure that NBPSK does not have a worse noise immunity than FSK, it is sufficient if $\Delta FT \geqslant 1$ (see Fig. 6) [Petrovich, 1965]. Assuming reasonable filter design criteria, combined with a condition developed in [Petrovich, 1965], the value $\Delta FT = 1.1$ to 1.2 (see Recommendation 328) should be adopted as the optimum passband for the NBPSK signal-shaping filter.

In this case, out-of-band radiation will be largely caused by the non-linearity of the transmitter's amplifying stages. In the passage through the amplifying channels, additional combination components $f_0 \pm (2n - 1) F_0$ will be created, where $n = 2, 3$, etc. Hence after the NBPSK signal-shaping stages, it is essential to ensure high linearity of the following amplifying stages and particularly of the transmitter output stage. Bearing in mind the requirements in [Petrovich, 1965], the combination component levels for the two-tone test signal should not exceed 31 dB for third-order components, 40 dB for fifth-order components and 50 dB for seventh-order components.

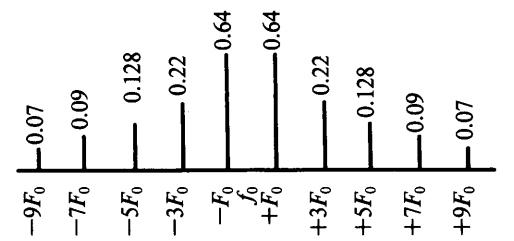
An important criterion [Zuako, 1972] of the efficiency (γ) of an information transmission system is given by:

$$\gamma = \frac{B}{\Delta f}$$

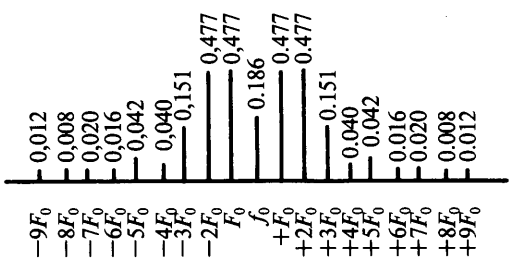
where:

B: bit rate (bit/s)

Δf: occupied bandwidth (Hz)



a) PSK



b) FSK $m = 1.7$

FIGURE 1

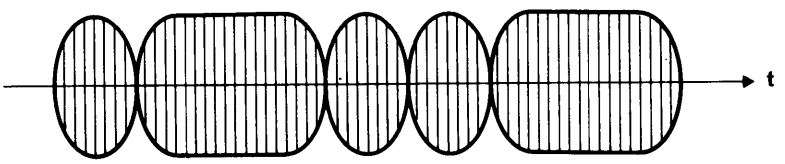


FIGURE 2

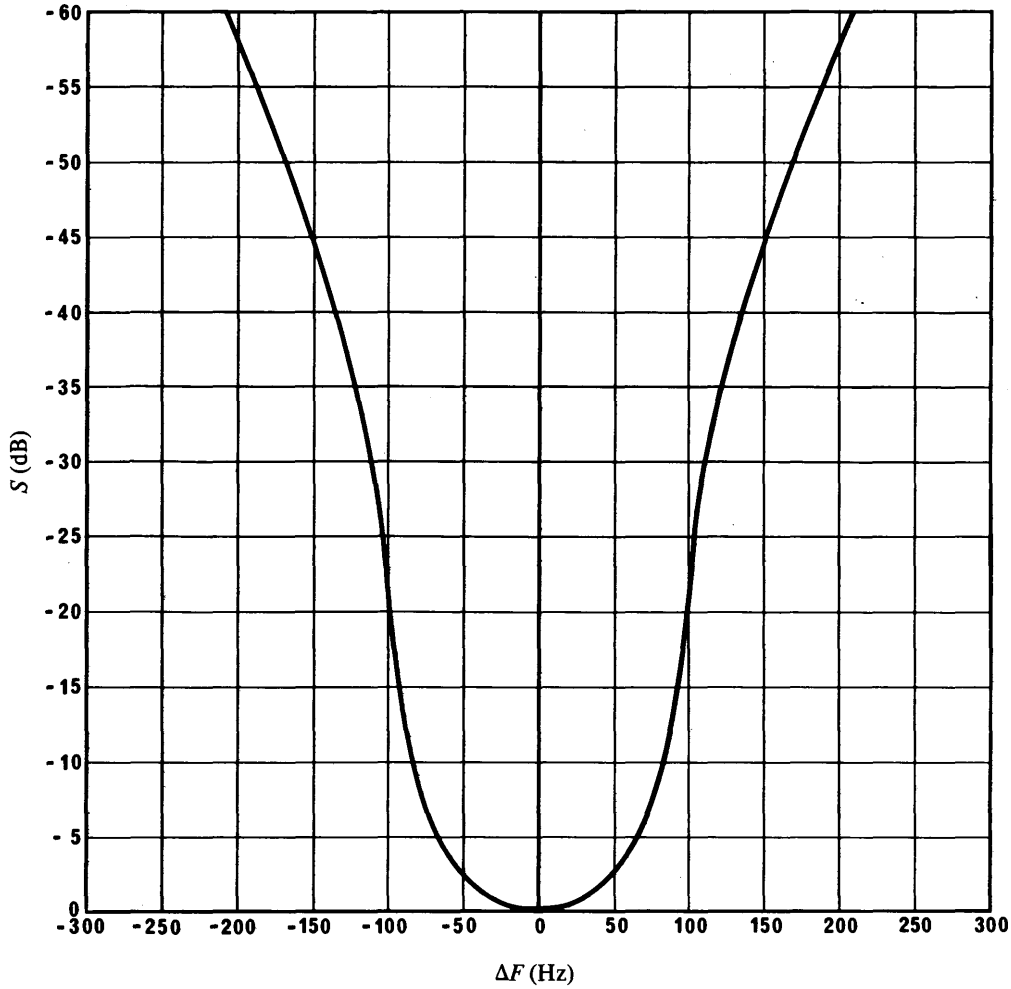


FIGURE 3

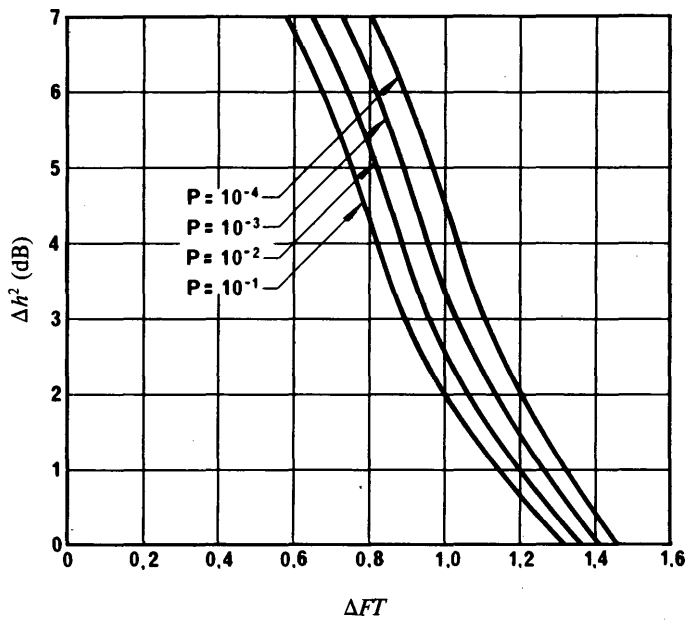


FIGURE 4

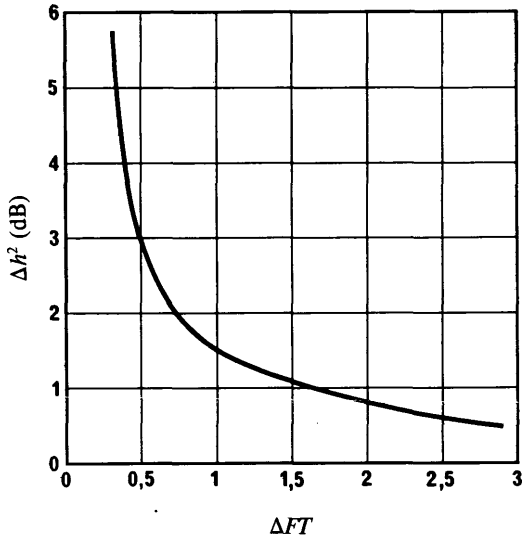


FIGURE 5

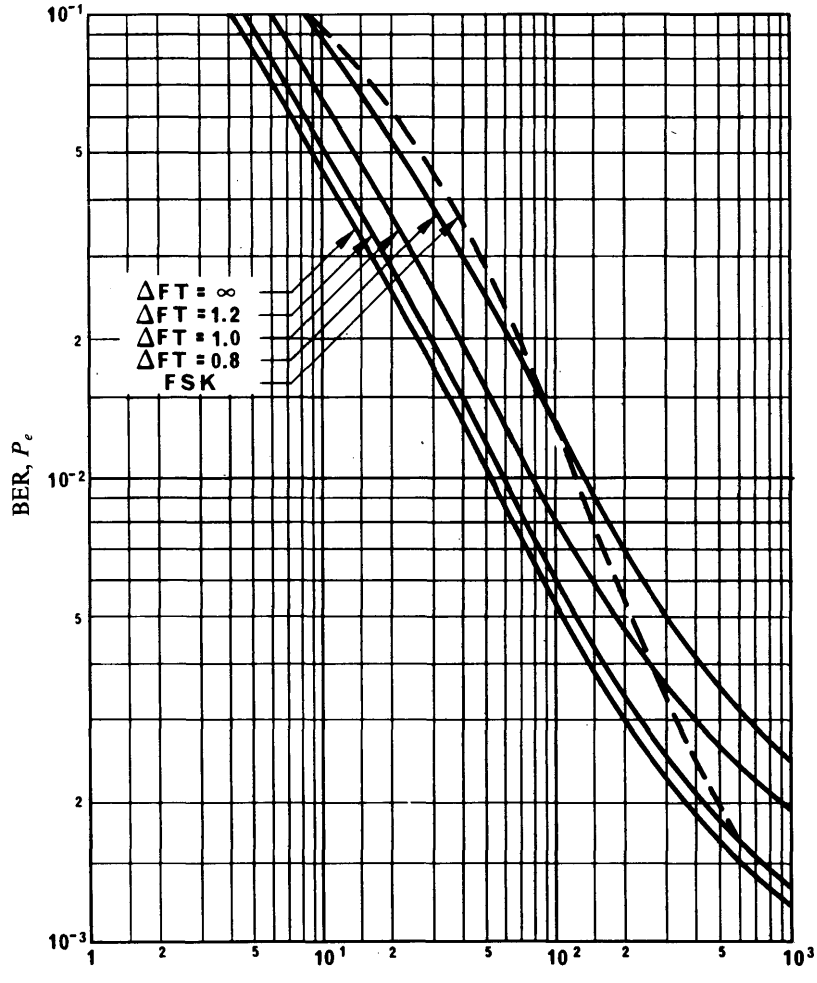


FIGURE 6

Table I lists the theoretical values of γ for the different keying modes, using the minimum values of filter bandwidth.

For FSK signals, it is assumed that the components above 6 F_0 are removed.

TABLE I

Class of emission	$\frac{\Delta f}{F_0}$	γ
FSK ($M = 1.7$)	6	0.33
PSK	9	0.22
NBPSK	2.4	0.83

F_0: keying frequency in Hz.

3. Tests

3.1 Laboratory tests were carried out to determine the effect on the received information quality of interference between two NBPSK channels, between one NBPSK channel and another FSK channel with a 170 Hz shift and vice versa, of the radio link frequency deviation from the nominal value and of a deviation of the bit duration.

3.2 *Inter-channel interference*

To determine the effect of inter-channel interference with different centre frequency separations depending on the keying mode (NBPSK and FSK) and on the type of test signal employed, a test link was used consisting of two transmitters, operating with NBPSK and FSK, whereby one of the transmitters imitated the signal and the other the noise. Arrangements were made for separate level regulation for each transmitter.

To ensure a minimum level of induced interference, the transmitters were placed in a screened chamber. A standard ship's receiver was used with FSK and a frequency shift of 170 Hz, and with NBPSK with a main selection filter passband of 160 Hz.

The passband of the NBPSK signal-shaping filter was 120 Hz, while the signalling rate in the signal and noise channels was 100 bauds. A pseudo-sequence of 512 bits or telegraph "dots" was used as test signal and interference.

Control was based on the bit edge distortion value. The minimum signal level at the receiver input was adjusted so that the edge distortions did not exceed 3 to 8%, and the maximum interference level so that the receiver operated on the linear part of the amplitude characteristic.

The interference effect measurement data obtained with various frequency separations and operating modes are shown in Table II.

TABLE II

1. Signal	NBPSK	NBPSK	NBPSK	NBPSK	NBPSK	FSK	FSK
2. Interference	NBPSK	NBPSK	NBPSK	FSK	FSK	NBPSK	FSK
3. Separation between centre frequencies (Hz)	200	250	300	350	400	350	500
4. Signal/interference ratio (dB)	− 28	− 40	− 40	− 28	− 39	− 37	− 29

It is clear from Table II that for narrowband direct-printing channels with a 500 Hz separation between the centre frequencies of the FSK channels, signal distortions are observed at an interference level 29 dB higher than the signal level.

In the case of NBPSK channels with a 250 Hz separation, mutual interference is observed when the interference level is 40 dB higher than the signal level. The NBPSK channels produce an insignificant effect on the FSK channels with a 400 Hz separation, while the same applies to the effect of FSK channels on NBPSK channels with a 350 Hz separation.

Laboratory measurements show that a single FSK channel designed for narrowband printing can accommodate two NBPSK channels, whereby the inter-channel interference does not exceed the levels which occur between FSK channels.

3.3 *Deviation of radio link frequency and bit duration from the nominal values*

To evaluate the effect produced by the deviation of the radio link frequency and modulation rate from the nominal values, a test assembly was used consisting of a ship's transmitter, a ship's receiver, a test signal generator and an edge distortion analyzer connected in series. The passbands of the NBPSK signal-shaping and selection filters are the same as in § 2 above. Telegraph "dots" were used as test signal. The NBPSK signal-shaping filter was disconnected for measurement of distortions caused by the signalling rate deviation.

The measurement data on the effect of the carrier frequency deviation from the nominal value are given in Table III, while those relating to the effect of the modulation rate deviation are shown in Table IV.

TABLE III

Frequency deviation (Hz)	0	+2	+4	+8	+10	+12	+14	+16	+20	+22
Distorsion (%)	4	4	4	7	9	12	16	19	34	45

Frequency deviation (Hz)	−2	−4	−8	−10	−12	−14	−16	−18	−20
Distorsion (%)	4	6	9	13	16	21	29	37	45

TABLE IV

Modulation rate (bauds)	100	96	92	88	84	80	104	120
Distorsion (%)	5	7	12	8	12	20	7	10

In analyzing the data in Tables III and IV, it was assumed that a high reception quality is obtained so long as the edge distortions do not exceed 10% and that communication is interrupted when the edge distortions exceed 40%.

3.4 *Conclusions on laboratory tests*

3.4.1 The inter-channel interference caused by NBPSK signals at a channel separation of 250 to 260 Hz is less than with FSK at a channel separation of 500 Hz. This makes it possible to accommodate two NBPSK channels in a single channel of 500 Hz bandwidth.

3.4.2 With NBPSK telegraphy, a high operating quality is ensured so long as the frequency does not diverge from the nominal value by more than ± 10 Hz, while communication is interrupted at a frequency deviation of more than ± 20 Hz.

3.4.3 The effect of the bit duration deviation from the nominal value on reception quality is insignificant. The effect on increased edge distortions does not become noticeable until a deviation of ± 20% and over.

4. Sea trials

4.1 Ship tests have been carried out to determine the noise immunity of narrowband PSK signal reception. For purposes of comparison, the noise immunity of FSK signal reception with a shift of 170 Hz was also tested.

4.2 *Test conditions*

The tests were conducted on a link between the ship "Shota Rustaveli" and the coast station "Leningrad - Radio" [Li Za Son *et al.*, 1977]. The ship was sailing in the eastern part of the Atlantic and in the Mediterranean; the length of the link was 1900 to 3400 km, the frequencies used were in the bands 12, 16 and 22 MHz, and the tests were conducted in the day-time. The purpose of the tests was to assess the comparative noise immunity of the FSK and NBPSK modes. Standard production models of a radio transmitter and receiver were used.

The bandwidth of the NBPSK signal-shaping filter in the transmitter was 120 Hz; the filter's amplitude-frequency characteristic is shown in Fig. 3. The frequency shift with FSK was 170 Hz. The receiver's main selection filter had a passband of 300 and 160 Hz for the reception of the FSK and NBPSK test signals respectively. The deviation of the link frequency from the nominal value was monitored during the tests and found not to exceed 1 Hz. Additionally, the signal voltage at the receiver input was sampled at the coast station at 10 second intervals. The test signal was transmitted from ship to shore. The transmission pattern was as follows: 4 minutes transmission of test signal in FSK mode; 1 minute pause; 4 minutes transmission of test signal in NBPSK mode; 1 minute pause. This test cycle was then repeated a number of times. At the coast station, the test signal was demodulated, analyzed by an error detection device and the bit error reception rate determined by the operator. The test signal used was a pseudo-random sequence consisting of 512 bits transmitted at a rate of 100 bauds.

4.3 *Test results*

Altogether, 15 test series were carried out. The data on the duty periods, the mean signal levels and the signal dispersions at the receiver input, the number of bits transmitted and mean error probabilities for each duty period, are given in Table V.

Sampling of the number of erroneously received bits was carried out at 10 second intervals; these intervals were taken as basic periods for each of which the error rate was determined.

During the tests, there were 5022 basic periods (of 10 seconds duration) for NBPSK signals and 4609 for FSK signals. The error-rate data obtained were arranged in predetermined intervals. This arrangement was then used as a basis for calculating the frequency and cumulative distributions of the error rate. The initial data and calculation results are given in Table VI, while the cumulative distribution curves for the FSK and NBPSK signals are shown in Fig. 7. Data on the reception of 5 million NBPSK bits and 4.6 million FSK bits were used to plot the curves in Fig. 7.

4.4 *Error probability*

4.4.1 In all the test periods, the mean error probability with NBPSK is less than with FSK.

4.4.2 The total improvement in mean error probability with NBPSK compared with FSK for all test periods is between 2.7 and 3.2, with a variation in mean error probability from 8×10^{-2} to 9×10^{-4}.

5. Conclusions

5.1 The permissible filtering limit is $\Delta FT = 1.2$. In a channel with Rayleigh fading, NBPSK noise immunity is superior to that of FSK with a bit error probability exceeding $P \geqslant 2 \times 10^{-3}$.

5.2 The occupied bandwidth for NBPSK can be 2.5 times less than for FSK.

5.3 To maintain the suppression of the out-of-band NBPSK spectral components the characteristics of the transmitting equipment must have a highly linear amplitude characteristic.

5.4 The bandwidth at the levels 30, 40, 50 and 60 dB for NBPSK is half that for FSK.

5.5 Two NBPSK channels can be accommodated in a single FSK narrowband direct-printing channel.

TABLE V

Frequency (kHz) Distance (km)	Date and time (Moscow time)	Mean signal level (μV)	Signal dispersion (μV)	Number of bits	Mean error-rate P_m per test series	
					NBPSK	FSK
1	2	3	4	5	6	7
16 598.4 1 975 km	15.05.79 13.50-14.20	17.9	596	96 000	3.3×10^{-2}	5.2×10^{-2}
16 598.4 2 360 km	16.05.79 10.05-10.20	48.7	5 053	49 000	6.5×10^{-4}	6.3×10^{-3}
16 598.4 2 440 km	16.05.79 13.20-14.55	41.2	82	255 000	6.5×10^{-4}	3.5×10^{-3}
16 598.4 2 580 km	17.06.79 19.40-20.55	10.1	194	127 000	5.6×10^{-4}	2.4×10^{-2}
16 598.4 2 738 km	21.05.79 10.00-10.25	9.9	16.4	88 000	3.2×10^{-4}	2.1×10^{-3}
16 598.4 2 900 km	21.05.79 13.10-14.55	14	230	280 000	4.8×10^{-3}	1×10^{-2}
16 598.4 3 375 km	22.05.79 17.40-18.25	5.9	19.6	143 000	4.1×10^{-3}	4.2×10^{-3}
22 142 2 600 km	23.05.79 10.10-10.20	-	-	21 000	6×10^{-3}	4.5×10^{-2}
16 598.4 3 000 km	6.06.79 13.30-16.25	74	3 637	469 000	1.7×10^{-3}	5.1×10^{-3}
16 598.4 3 000 km	7.06.79 17.20-18.25	164	10 360	236 000	1.5×10^{-4}	4.4×10^{-4}
16 598.4 3 000 km	7.06.79 19.30-20.44	129	2 994	163 000	9.5×10^{-4}	5.2×10^{-3}
16 598.4 3 000 km	8.06.79 9.20-10.25	38	813	240 000	1.02×10^{-3}	5.25×10^{-3}
16 594.4 2 535 km	11.06.79 13.30-16.15	33	393	213 000	2.2×10^{-3}	2.8×10^{-2}
16 598.4 2 800 km	12.06.79 9.20-10.15	82.8	26 692	225 000	7.8×10^{-4}	1.5×10^{-3}
12 449 2 600 km	23.06.79 17.10-18.55	58 7	8 798	210 000	1.9×10^{-4}	1.2×10^{-3}

TABLE VI

Error-rate interval	NBPSK		FSK	
	Number of basic periods	Relative number of periods	Number of basic periods	Relative number of periods
$1 \times 10^{-1} - 6.3 \times 10^{-2}$	35	0.007	469	0.102
$6.3 \times 10^{-2} - 4.0 \times 10^{-2}$	–	–	237	0.0514
$4.0 \times 10^{-2} - 2.5 \times 10^{-2}$	47	0.0094	76	0.017
$2.5 \times 10^{-2} - 1.6 \times 10^{-2}$	72	0.014	202	0.044
$1.6 \times 10^{-2} - 1 \times 10^{-2}$	64	0.013	218	0.047
$1 \times 10^{-2} - 6.3 \times 10^{-3}$	398	0.078	189	0.041
$6.3 \times 10^{-3} - 4 \times 10^{-3}$	227	0.045	561	0.122
$4 \times 10^{-3} - 2.5 \times 10^{-3}$	225	0.045	480	0.104
$2.5 \times 10^{-3} - 1.6 \times 10^{-3}$	471	0.094	567	0.123
$1.6 \times 10^{-3} - 1 \times 10^{-3}$	407	0.881	532	0.115
$1 \times 10^{-3} - 6.3 \times 10^{-4}$	584	0.116	363	0.079
$6.3 \times 10^{-4} - 4 \times 10^{-4}$	814	0.16	164	0.036
$4 \times 10^{-4} - 2.5 \times 10^{-4}$	472	0.094	151	0.033
$2.5 \times 10^{-4} - 1.6 \times 10^{-4}$	431	0.086	136	0.030
$1.6 \times 10^{-4} - 1.0 \times 10^{-4}$	160	0.032	42	0.009
$1.0 \times 10^{-4} - 6.3 \times 10^{-5}$	172	0.034	47	0.102
$6.3 \times 10^{-5} - 4 \times 10^{-5}$	388	0.077	175	0.038
$4.9 \times 10^{-5} - 2.5 \times 10^{-5}$	60	0.012	–	–
$1 \times 10^{-1} - 2.5 \times 10^{-5}$	5022		4609	

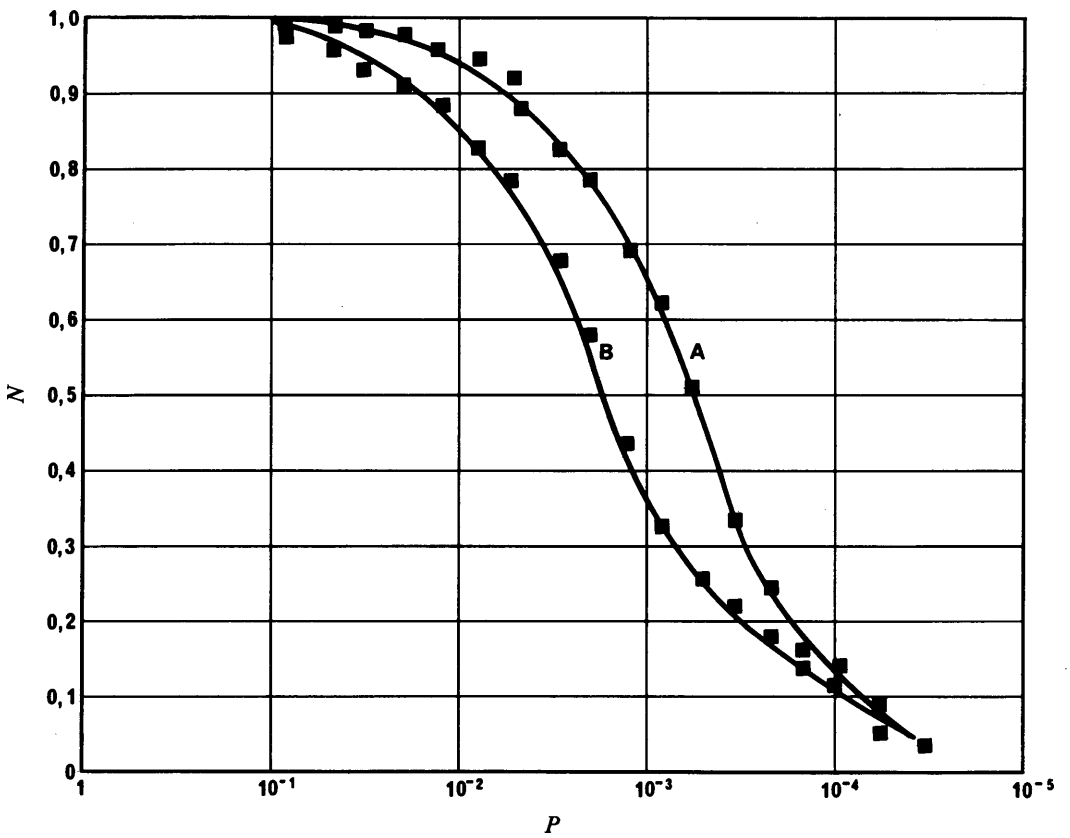


FIGURE 7 – *Error distribution using FSK and narrow-band PSK*

Curves **A**: NBPSK ($\Delta FT = 1.2$)
B: FSK shift = 170 Hz

REFERENCES

LI ZA SON, ZIRNIS, A. S. and SOKOLOV, B. P. [1977] Statistika oshibok pri rabote novoi sudovoi kanaloobrazuyushchei apparatury v rezhime ChT na razlichnykh skorostyakh peredachi informatsii (Error statistics obtained with operation of new ship channelling equipment using FSK at different signalling rates). Proc. Central Institute for Maritime Research, No. 224, Leningrad, "Transport".

PETROVICH, N. T. [1965] Peredacha diskretnoi informatsii v kanalakh s fazovoi manipulyatsiei (Discrete information transmission in PSK channels). Sovetskoe Radio, Moscow.

ZUAKO, A. G. [1972] Pomekhoustoichivost i effektivnost sistem sviazi (Noise immunity and efficiency of communication systems). **Sviaz**, Moscow.

REPORT 910

SHARING BETWEEN THE MARITIME MOBILE SERVICE AND THE AERONAUTICAL RADIONAVIGATION SERVICE IN THE BAND 415-526.5 kHz

(Question 53/8)

(1982)

1. Introduction

The frequency band 415-526.5 kHz is allocated to both the maritime mobile service and the aeronautical radionavigation service. In this band these two radio services have the following status (Region 1):

	Primary	*Permitted*	*Secondary*
415-435 kHz	Aeronautical radionavigation	Maritime Mobile	
435-490 kHz	Maritime mobile		Aeronautical radionavigation
510-526.5 kHz	Maritime mobile	Aeronautical radionavigation	

Because of differences in operational use, frequency planning, radiated power, etc., coexistence of these two radio services in the same bands may present problems. Particular attention is required with respect to the problems which have their origin in the difference in the power levels used.

The aeronautical radio navigation service, operating at power levels which are 20-30 dB lower than those of the maritime mobile service, has a more difficult problem in the protection against interference.

The aeronautical radionavigation service in the bands around 400 kHz employs non-directional radiobeacons (NDB) to provide essential basic navigational data to aircraft. These radiobeacons are used in all regions of the world. The relatively low cost of NDBs and their ability to be used by all types of aircraft ensure their continued use for many years. However, the exclusive spectrum available is insufficient to meet all the demands for NDB frequency assignments, especially in the European area and therefore maximum use must be made of the spectrum allocated on a permitted and secondary basis. This can only be achieved if suitable criteria are available, which will permit coexistence of the two services in the same band. It is essential that these criteria are developed as soon as possible.

The following examination is restricted to:

(a) geographical separation (co-channel);

(b) frequency separation (co-location);

(c) combination of (a) and (b) with variable geographical distance and frequency separation.

Also certain variations in the power level radiated by stations in the maritime mobile service and the effect of a more selective automatic direction finding (ADF) receiver are examined.

2. Factors involved

2.1 *Differences in radiated power levels*

2.1.1 The maritime mobile service provides communications between coast stations and ship stations or between ship stations. There are no protection criteria in the Radio Regulations governing the maritime mobile service in the bands between 435 kHz and 526.5 kHz.

The output power of coast station transmitters is of the order of 1-2 kW. With an aerial efficiency of 30% the e.r.p. is then 300-600 W.

Ship stations normally use 400 W transmitters. If the aerial efficiency is 10% the e.r.p. is 40 W.

2.1.2 In the aeronautical radionavigation service in most cases transmitters of about 50 W are used, but the e.r.p. is in the order of 0.5 W.

A typical aeronautical beacon in the European Region has a range of 50 NM with an e.r.p. of less than 1 W. The ICAO standard on radiated power states that, "The power radiated from a NDB shall not exceed by more than 2 dB that necessary to achieve the agreed rated coverage..." (Annex 10 to the Convention on International Civil Aviation, Vol. I, Part I, § 3.4.3.)

2.2 *Protection ratio desired/undesired signal in the aeronautical radionavigation service*

The protection figure of 15 dB quoted in the Radio Regulations No. 2854 applies to bands below those concerned in this Report. The Radio Regulations make no statement on the protection figure to be applied to aeronautical NDBs between 435 and 526.5 kHz. However, the figure of 15 dB has been taken as applicable for the purposes of this paper.

2.3 *Automatic direction finding (ADF) receiver selectivity*

The extent to which the ADF receiver is capable of suppressing undesired frequencies is governed by the ADF receiver selectivity curve. (See Fig. 1).

For a given frequency separation between stations, a selectivity curve with steeper slopes will reduce the minimum geographical distance required between stations in the maritime mobile service and the aeronautical radionavigation service. However, because the ADF receiver is required to receive signals with a bandwidth of about 2 kHz, steeper slopes will have a negligible effect for frequency separations less than 1 kHz.

2.4 The separation distance required between a NDB and a coast station once established will remain fixed provided their respective frequencies and powers do not change. The required separation between a NDB and a ship station will vary depending on the position of the ship, its transmitter power and its frequency. To allow for these variable parameters an area extending inland from the coast will require particular consideration.

3. Examples of planning calculations

3.1 For the examples of calculations given below the following assumptions are used:

3.1.1 *General*

Frequency:	500 kHz
Propagation conditions:	CCIR curve Recommendation 368 (Kyoto, 1978), Fig. 3 ($\sigma = 10^{-2}$ S/m; $\varepsilon = 4$) (only ground wave propagation has been taken into account).

3.1.2 *Maritime mobile service*

Coast stations:	e.r.p. 500 W
Ship stations:	e.r.p. 50 W.

3.1.3 *Aeronautical radionavigation service*

Field strength at limits of coverage:	70 μV/m (36.9 dB (1 μV/m)) (see Radio Regulations No. 2857)
Protection ratio (day-time):	15 dB
ADF receiver selectivity:	Convention on International Civil Aviation, Annex 10, Volume I, Att. B to Part II, § 3 (see Fig. 1, curve A).

3.2 The curves in Fig. 2 represent the minimum frequency separation between a station in the maritime mobile service and a station in the aeronautical radionavigation service as a function of the geographical separation between these stations.

The various curves refer to different service ranges of the aeronautical radio beacon.

If the coast station lies within the operational range of the aeronautical beacon, the minimum frequency separation is a function of the difference in field strength of each service at the location of the coast station. If the coast station lies outside the operational range of the aeronautical beacon then the frequency separation is determined by the difference in field strength of each service at the limit of the coverage of the aeronautical beacon.

The maximum frequency separation is required when the operational range of the aeronautical radiobeacon is equal to the geographical separation of the two stations involved. This frequency separation is 6.4 kHz in the case of a coast station with an e.r.p. of 500 W. It can also be concluded that with a distance of 650-700 km between the two stations the minimum frequency separation is 0 kHz.

Note 1. – For frequencies lower than 500 kHz this distance will increase; for a frequency of 400 kHz this distance is about 950 km.

Note 2. – For sea-path propagation conditions (σ = 5 S/m; ε = 80) the minimum distance in the co-frequency case is 1400 km (at 500 kHz).

3.3 Figure 3 shows how the minimum frequency separation is affected by the power of the coast station transmitter in the case of the aeronautical beacon operational range of 75 km.

3.4 Figure 4 shows the effect on sharing possibilities of different selectivity curves for the ADF receivers.

Details of the selectivity curves used are given in Fig. 1.

4. Conclusions

4.1 Coexistence of the aeronautical radionavigation service and the maritime mobile service is possible when account is taken of protection requirements, e.r.p. and propagation loss for individual cases.

4.2 Before a frequency could be assigned to an aeronautical radiobeacon a full assessment of the interference potential from the maritime mobile service would need to be made taking into account the following:

- the e.r.p. of the coast station, the highest possible ship station e.r.p. and the aeronautical radiobeacon e.r.p.;
- the protection requirements of each service;
- the assessed propagation loss between the stations of the two services, taking into account a mixed land and sea propagation path in the case of a ship station.

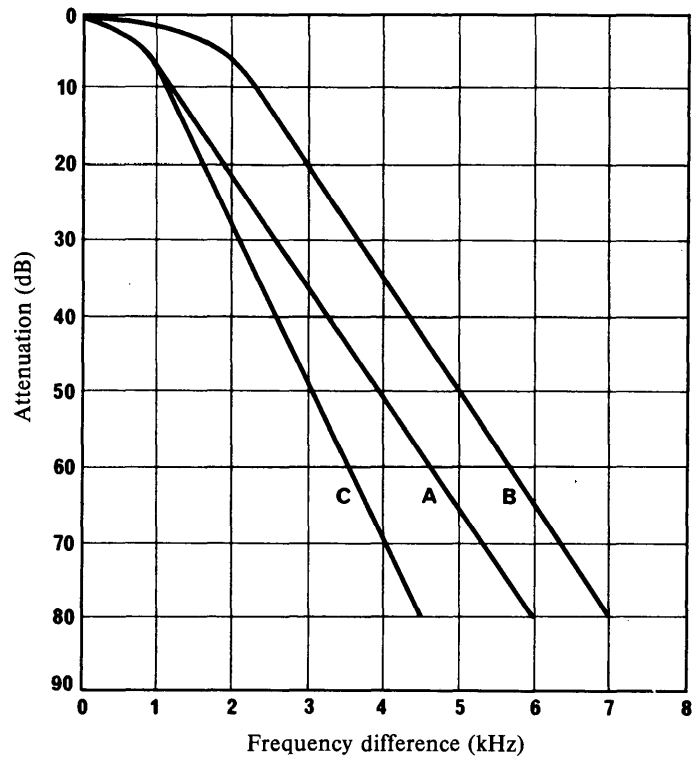


FIGURE 1 – *ADF receiver selectivity curves*

Curves **A**: Annex 10 Vol. I, Att. B to Part II, para 3
B: Annex 10 Vol. I, Att. B to Part II, para 2
C: arbitrary curve, better than A

Note. – In congested areas curve A is used when planning LF/MF beacons in the aeronautical radionavigation service. It is to be noted that there are ADF equipments currently being used, which have selectivity characteristics that are not as stringent as specified in Curve A.

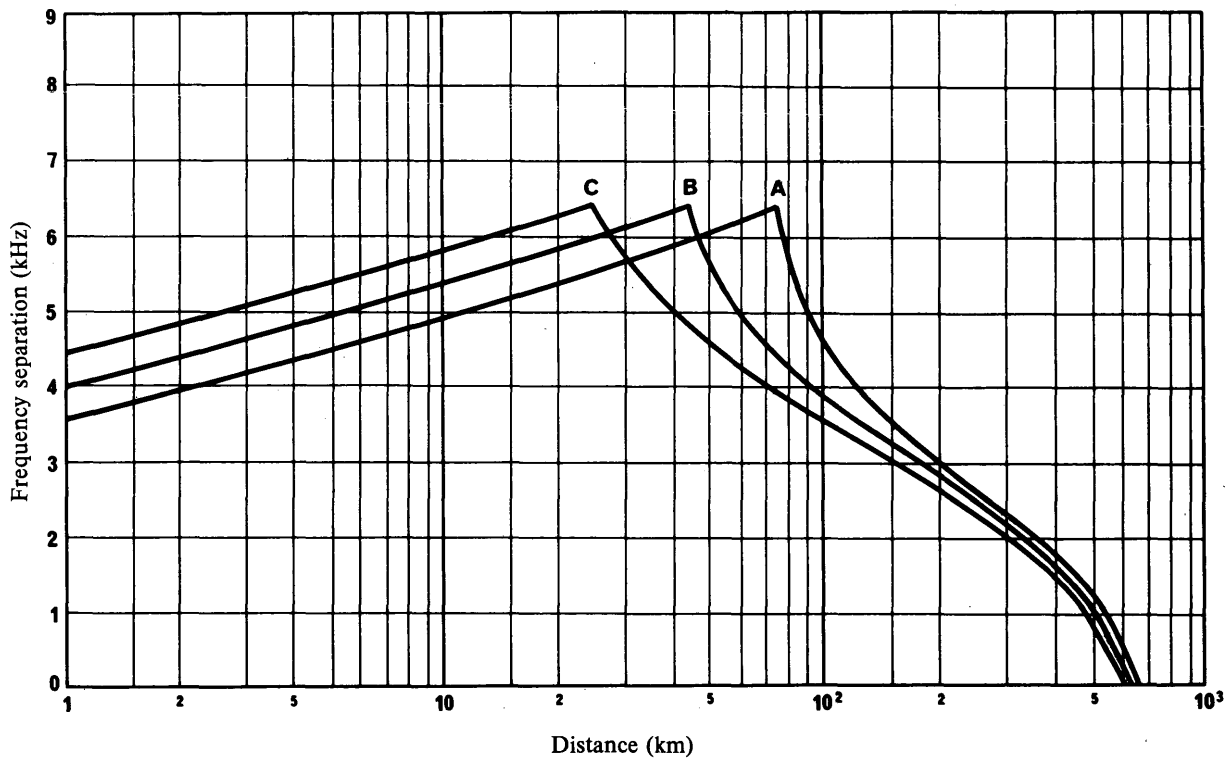


FIGURE 2 – *Minimum frequency separation between transmitters in the maritime mobile service and the aeronautical radionavigation service versus interference distance*

Curves **A**: – coast station: 500 W e.r.p.
– aeronautical beacon: range 75 km (40 NM)
B: – coast station: 500 W e.r.p.
– aeronautical beacon: range 45 km (25 NM)
C: – coast station: 500 W e.r.p.
– aeronautical beacon: range 25 km (15 NM)

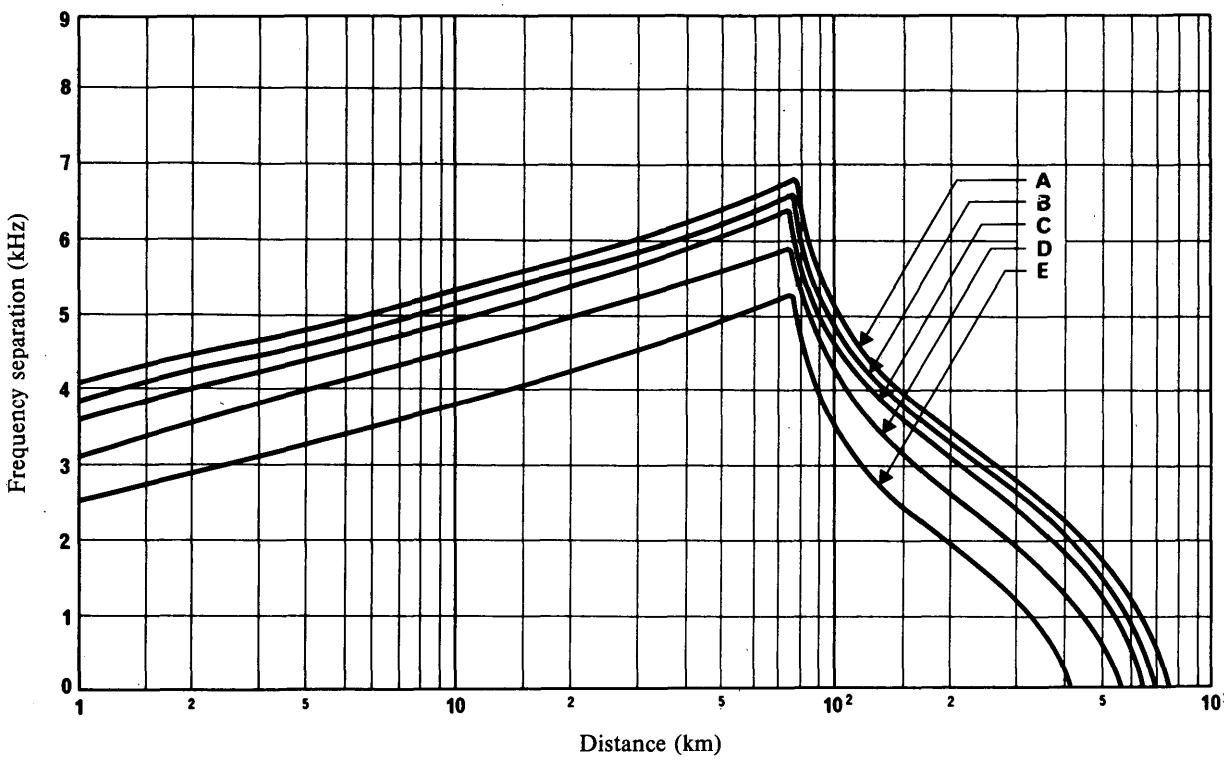


FIGURE 3 – *Minimum frequency separation between transmitters in the maritime mobile service and the aeronautical radionavigation service versus interference distance*

Curves **A**: – coast station: 2 kW e.r.p.
– aeronautical beacon: range 75 km
B: – coast station: 1 kW e.r.p.
– aeronautical beacon: range 75 km
C: – coast station: 0.5 kW e.r.p.
– aeronautical beacon: range 75 km
D: – coast station: 100 W e.r.p.
– aeronautical beacon: range 75 km
E: – coast station: 10 W e.r.p.
– aeronautical beacon: range 75 km

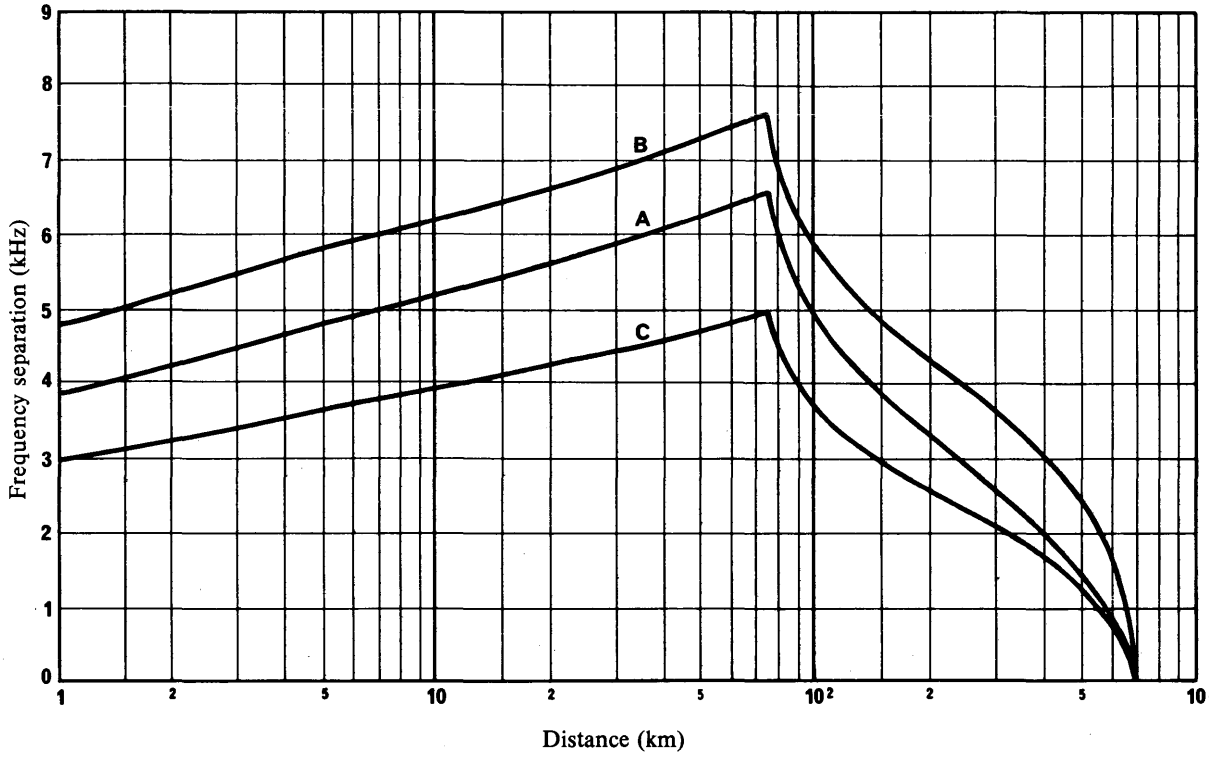


FIGURE 4 – *Minimum frequency separation between transmitters in the maritime mobile service and the aeronautical radionavigation service versus interference distance*

All curves: – coast station: 1 kW e.r.p.
– aeronautical beacon: range 75 km
Curves **A**: RF selectivity ADF Receiver (see curve A in Fig. 1)
B: RF selectivity ADF Receiver (see curve B in Fig. 1)
C: RF selectivity ADF Receiver (see curve C in Fig. 1)

REPORT 911

FREQUENCY SHARING BETWEEN SERVICES IN THE BAND 4 TO 30 MHz

(Question 56/8)

(1982)

1. Introduction

1.1 The World Administrative Radio Conference (Geneva, 1979) allocated several bands between 4 to 30 MHz on a shared basis to various services including the mobile services. At the Study Group 8 Interim Meeting, 26 November-19 December 1980, Question 56/8 was adopted.

1.2 This Report responds to that question by identifying technical parameters and operational considerations which should be taken into account to permit satisfactory frequency sharing between the fixed and mobile services in the frequency bands between 4 to 30 MHz.

2. Service requirements

2.1 The operational constraints for a particular sharing situation are related to the specific fixed mobile requirements involved. In the band 4 to 30 MHz, the following services have been allocated by the WARC-79 Table of Frequency allocations (Article 8) on a shared basis:

2.1.1 Fixed

2.1.2 Aeronautical mobile (OR)

2.1.3 Land mobile

2.1.4 Maritime mobile

2.2 The requirements of the fixed and mobile services are inherently different. As a result, the operational characteristics of the two services are correspondingly diverse. These characteristics are compared in Section 3 in order to identify general operational differences between the two services which may provide technical bases for frequency sharing.

3. Operational characteristics

3.1 The basic operational characteristics which will be addressed between the two services in this comparison are:

3.1.1 Power output

3.1.2 Emission characteristics

3.1.3 Bandwidth

3.1.4 Antenna characteristics

3.1.5 Link configuration

3.1.6 Path length variability

3.1.7 Circuit usage

3.1.8 Circuit predictability

3.2 A comparison of the fixed and mobile services with regard to the categories listed in § 3.1 leads to the following observations:

3.2.1 *Power output*

3.2.1.1 Stations operating in the fixed service generally operate with high transmit power output levels.

3.2.1.2 Stations in the mobile service, particularly those located on mobile platforms, normally operate at lower output levels than fixed.

3.2.2 *Emission characteristics*

3.2.2.1 Emission and modulation schemes may be more complex (voice and data) in the fixed service.

3.2.2.2 Mobile service emissions are normally simpler in nature than those of the fixed.

3.2.3 *Bandwidth*

3.2.3.1 As a result of § 3.2.2.1, the bandwidths are wide with respect to other services.

3.2.3.2 Bandwidths used by the mobile services are, in general, narrower than those used by the fixed service.

3.2.4 *Antenna characteristics*

3.2.4.1 Directional antennas are normally used in the fixed service.

3.2.4.2 The use of omni-directional antennas is more prevalent in the mobile service than in the fixed service.

3.2.5 *Link configurations*

3.2.5.1 The location of circuit link terminals in the fixed service is, correspondingly, fixed.

3.2.5.2 Mobile service operation, by its nature, requires the capability to communicate with or between stations at both known and unknown locations.

3.2.6 *Path length variability*

3.2.6.1 As implied in § 3.2.5.1, the path lengths in the fixed service are constant.

3.2.6.2 In most cases, for the mobile service, path lenghts vary from time-to-time and location-to-location.

3.2.7 *Circuit usage*

3.2.7.1 Full-time circuit operation is normal for the fixed service.

3.2.7.2 For mobile service requirements, usage is not deterministic, but transient and short-term.

3.2.8 *Circuit predictability*

3.2.8.1 For a fixed service circuit, changes in the E and F layers of the ionosphere are highly predictable over a period of time, i.e., certain frequencies are used at one time of the day, while other frequencies may be used at another.

3.2.8.2 The ionospheric circuit behaviour for stations in the mobile service that communicate with or between mobile platforms is more difficult to determine than for stations in the fixed service. This is attributable, in part, to the varying path lengths, which are normally not constant with respect to any certain period or time of the day.

3.3 Based on the fixed and mobile characteristics examined above, satisfactory sharing could be facilitated as a result of their diversity. For example, a channel used by a fixed station at a certain time of day may not be usable by the fixed station at another. In this case, the channel could in certain circumstances be available for mobile service use. Frequency sharing of this nature is based on the concept of maximum flexibility for the mobile station to choose or change to available frequencies which will be interference-free.

4. Conclusions

4.1 Because of the transitory nature of mobile platforms (especially aeronautical (OR) and maritime), mobile stations may be able to operate on shared frequencies which are not in use by the fixed service during certain times of day.

4.2 While preliminary theoretical studies (Report 658) have indicated that satisfactory sharing could be implemented under certain circumstances, further analyses should be made on a case-by-case basis to develop frequency-sharing criteria for the fixed and mobile services utilizing the 4 to 30 MHz band.

4.3 The implementation of sharing between the services concerned should be encouraged so that data may be collected for analysis to determine satisfactory sharing potentials.

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SECTION 8D: FUTURE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM AND RELATED SUBJECTS

Recommendations and Reports

RECOMMENDATION 545-1 *

THE CHOICE OF FREQUENCIES IN THE MARITIME MOBILE BANDS ABOVE 1605 kHz TO BE RESERVED FOR DISTRESS AND SAFETY PURPOSES

(Question 44/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that the WMARC, Geneva 1974, recognized the need to supplement the radio-telephone distress frequency, 2182 kHz, in certain regions by the use of the carrier frequencies 4125 kHz and 6215.5 kHz;

(b) that in conditions of low shipping density, widely spaced coast stations and high noise levels on the medium frequency bands, a service has been successfully established using 4125 kHz and 6215.5 kHz for call, reply, distress and safety purposes;

(c) that studies by IMCO and CCIR for a Future Global Maritime Distress and Safety System at sea indicate that this will require additional frequencies;

(d) that studies undertaken have concluded that frequencies in each of the 2, 4, 6, 8, 12 and 16 MHz bands would be required to provide an adequate communication capacity for a global distress and safety system,

UNANIMOUSLY RECOMMENDS

that to implement the Future Global Maritime Distress and Safety System:

1. frequencies in each of the 2, 4, 6, 8, 12 and 16 MHz maritime mobile bands be provided for digital selective calling (DSC), radiotelephony and narrow-band direct printing (NBDP) for distress and safety purposes, either in a composite arrangement or as individual allocations;

2. the bandwidth associated with each frequency should be sufficient to provide adequate protection against harmful interference.

REPORT 746-1 **

THE CHOICE OF FREQUENCIES IN THE MARITIME MOBILE BANDS ABOVE 1605 kHz TO BE RESERVED FOR DISTRESS AND SAFETY PURPOSES

(Question 44/8)

(1978-1982)

1. Introduction

1.1 For the exchange of public correspondence, the maritime mobile service has, in the HF range, frequencies in the 4, 6, 8, 12, 16, 22 and 25 MHz bands. However, except for 8364 kHz (for use by survival craft) and the *supplementary* radiotelephone distress frequencies of 4125 kHz and 6215.5 kHz, the only *designated* distress frequencies are VHF channel 16, and 500 kHz and 2182 kHz in the MF bands.

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* The Director, CCIR, is requested to bring this Recommendation to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Civil Aviation Organization (ICAO).

** The Director, CCIR, is requested to bring this Report to the attention of IMCO and ICAO.

1.2 Whilst use of the latter frequencies has provided a valuable alert capability, based on the need for a ship in distress to communicate with the nearest ship, there are many areas of the world of low shipping density, widely-spaced coast stations and different propagation conditions where the designated MF frequencies do not provide adequate communication coverage for distress and safety purposes. To improve the latter capability, many administrations are now using the radiotelephone frequencies of 4125 kHz and 6215.5 kHz. Experience has proved that frequencies in the 4 MHz and 6 MHz bands, although not designated exclusively for distress and safety purposes, provide a comprehensive coverage over a wide range of conditions. However, to fully utilize the available HF spectrum for distress and safety purposes, frequencies higher than 6 MHz are required.

2. Frequency bands

2.1 Some administrations have conducted tests of a comprehensive nature to determine the choice of a frequency, or frequencies, in the maritime mobile bands above 4000 kHz to be reserved for distress and safety purposes. Comparison of reports by the USA, Argentina, Canada and Australia, together with extensive theoretical analysis and operational experience, shows that a single HF frequency would be inadequate to provide coverage in most areas, particularly taking into account the recommended use of HF frequencies in a future global distress system (Report 747; IMCOa and b; CCIR, 1974-78 a and b).

2.2 In analyzing sky-wave propagation over night and day, summer and winter and levels of solar activity over conditions prevailing in the North Atlantic, South Atlantic and South Pacific Ocean regions, it is concluded that an allocation of frequencies in each of the 4, 6, 8, 12 and 16 MHz bands will be required to provide an adequate communication capability for a global distress and safety system. In relation to this system, an allocation of a frequency in each of the 4, 6, 8, 12 and 16 MHz bands would result in rationalization of the number of coast stations, particularly in providing surveillance for a global scheme.

2.3 Shipping, including small craft, sailing around countries with a large coastline might be adequately covered for distress and safety by a combination of 2182 kHz for ship-to-ship alerting, and a 4 MHz or 6 MHz frequency for ship-to-shore alerting. On long voyages away from the land, this combination might be augmented by one frequency in each of the bands from 8 MHz upwards, i.e. 12 and 16 MHz. The number of bands required and the number of shore stations selected in a coordinated plan to provide safety coverage would depend on the distances involved. The shore station coverage could well constitute a cohesive global network, interconnected to the various authorities, such as SAR, over existing terrestrial networks. Studies should include the formulation of a participating coast station coordination plan.

2.4 Whilst automated calling would be the preferred mode for alerting, voice calling should also be considered from vessels not equipped with an automatic device for the time being.

2.5 Studies (Report 745) have shown that in the frequency bands between 1605 kHz and 3800 kHz, the frequency 2182 kHz is the most appropriate for distress and safety purposes.

3. Frequencies for maritime distress and safety purposes

The Inter-Governmental Maritime Consultative Organization (IMCO) has set out its requirements for a future global maritime distress and safety system some details of which are given in IMCO documents MSC XLIII/18 Annex 8 and COM XXIII/13 Annex 7. These documents contain details of the requirements for frequencies and their proposed functions, although not all the frequencies included come within the scope of this Report.

4. Protection of maritime distress and safety frequencies

4.1 With the development by IMCO of a global maritime distress and safety system, based on the integration of satellite and terrestrial communication techniques, a need has been identified to study the bandwidth needed to permit adjacent mutually compatible channels for digital selective-calling, radiotelephone and narrowband direct printing in the maritime mobile bands.

4.2 Protection may be discussed in terms of:

- bandwidth needed for each functional channel (see § 4.3);
- frequency separation between the functional channels for protection against interference (see § 4.4);
- additional bandwidth which may be needed for guardbands between functional channels and other sources to ensure attainment of a desired performance criteria under the worst case conditions (see § 4.5).

4.3 *Bandwidth needed for each functional channel*

4.3.1 The bandwidth required for a radiotelephone signal is given in the Radio Regulations Appendix 17 as 350-2700 Hz. Current specifications allow for an additional 300 Hz for the filter response to provide a 40 dB attenuation, enabling the signal with its frequency tolerance to fit the existing channel spacing.

4.3.2 Digital selective calling and narrowband direct printing are specified in the Radio Regulations Appendix 38 as frequency shift keying systems each with a 500 Hz channel spacing and requiring about 240 Hz bandwidth.

4.3.3 Consideration may be given to the possibility of reducing the bandwidth of a combination of functional channels by various techniques in the future such as the use of special filters or modulation techniques, while recognizing protection criteria established for maritime distress and safety frequencies.

4.4 *Frequency separation between the functional channels for protection against interference*

In actual operation, simultaneous use of digital selective calling (DSC), radiotelephone and NBDP by individual stations is anticipated, and the DSC alerting should be protected with the highest priority. The time duration of NBDP transmission would generally be longer than that of DSC.

4.4.1 *Interference between radiotelephone channel and digital channel*

4.4.1.1 *Interference from radiotelephone channel to digital channel*

A characteristic of radiotelephony is that more energy is contained in the lower frequencies of the speech spectrum than in the higher frequencies. Also, tests have shown that power of the out of band emission from radiotelephone transmitters is lower on frequencies above the radiotelephone channel than those below that channel (see Fig. 4 in Annex I). It is therefore considered that the probability of interference to an adjacent channel above a radiotelephony channel would be less than that for a channel below it.

Both DSC and NBDP should be operative when the bit error ratio (BER) is less than 10^{-2} in accordance with Recommendation 493.

From the results of the experiment [1978-82a] shown in Fig. 5 of Annex I (interference from radiotelephone signal (J3E) to DSC or NBDP), the following frequency separation values indicated in Table I were obtained:

TABLE I

D/U ratio	(dB)	− 23	− 31	− 39
Necessary frequency separation between assigned frequencies of RT and DSC/NBDP (kHz)	BER 10^{-2}	1.5	2.0	2.8
	BER 10^{-3}	1.7	2.5	3.1

D: the desired signal power.
U: the undesired signal power.

4.4.1.2 *Interference from digital channel to radiotelephone channel*

The necessary frequency separation between assigned frequencies to obtain the permissible degradation of radiotelephone quality caused by interference cannot be decided due to a lack of data. However, a provisional value of 3.1 kHz is suggested by United States experiments [1978-82b] which gave 12 db SINAD for equal desired and undesired signal levels.

4.4.2 *Interference between digital channels*

The values of required frequency separation between digital channels were obtained as shown in Table II. (See Fig. 6 in Annex I.)

TABLE II

D/U ratio	(dB)	− 23	− 31	− 39
Necessary frequency separation between digital channels (Hz)	BER 10^{-2}	420 ~ 450	480	600
	BER 10^{-3}	430 ~ 460	500	700

4.5 *Additional bandwidth for guardbands*

4.5.1 Guardbands serve to allow a distress signal to be received when the distress transmitter has drifted from its nominal frequency (frequency stability).

Frequency stability of transmitters will improve in 1990, e.g. (from Appendix 7 of the Radio Regulations).

TABLE III

	1990		Until 1990
Ship station	MF	40 Hz	400 Hz
	HF	50 Hz	50×10^{-6} (200 - 850 Hz)
Survival craft station	MF	200 Hz	600 Hz
	HF	50×10^{-6} (200 - 850 Hz)	200×10^{-6} (800 - 3400 Hz)

It can be seen that only survival craft stations will have a significant tolerance. However, digital selective-calling is seen as an essential part of the distress system after 1990 and the required frequency stability for this is ±10 Hz (Recommendation 493). If a high stability oscillator is provided in a survival craft for digital selective-calling it is reasonable to assume that this oscillator will also control the frequency of other associated transmitters such as radiotelephony. It may then be assumed that with the implementation of the Future Global Maritime Distress and Safety System, the stability of all transmitters (MF, HF, ship and survival craft) will be within ±10 Hz.

Additional bandwidth for guardbands to allow for the frequency stability of transmitters will thus not be required.

4.5.2 *Ship to ship interference*

According to the operational requirements of the Future Global Maritime Distress and Safety System (FGMDSS) proposed by IMCO, the coverage area in the 2 MHz band is designated from 25 NM to 100 NM.

Considering that the maximum transmitting power of ship stations in the 2 MHz band is specified to be 400 W in Region 1 (RR No. 4357), the following D/U ratios in Table IV can be obtained for several cases.

TABLE IV

Power (DSC)	Distance (RT)	
	10 NM	25 NM
60 W p.e.p.	$D/U = -39$ dB	$D/U = -31$ dB
400 W p.e.p.	$D/U = -31$ dB	D/U – 23 dB

Where:

Transmitting power of RT station is 1500 W p.e.p.

Distance of the ship transmitting the DSC signal is 100 NM (50 dB propagation loss).

P: DSC transmitting power to RT transmitting power ratio

L: Propagation loss (Recommendation 368, Fig. 1)

$$P_1 = 10 \log \frac{60}{1500} = -14 \text{ dB} \qquad L\,(10 \text{ NM}) = 25 \text{ dB}$$

$$P_2 = 10 \log \frac{400}{1500} = -6 \text{ dB} \qquad L\,(25 \text{ NM}) = 33 \text{ dB}$$

$$D/U = P - 50 + L$$

NM : Nautical miles.

Therefore, the same concept as described in § 4.4.1 could be applicable for the determination of the bandwidth of the guardband required to protect the distress functions from other sources on adjacent frequencies.

4.5.3 *Interference to coast station reception*

While a coast station is keeping watch on the distress channel(s), it may need to transmit simultaneously (e.g. a radio telephone call) on a frequency adjacent to the band of the distress functions.

Therefore, either more bandwidth than that described in § 4.5.2 for guardbands or greater geographical separation between receiving and transmitting antennas at the coast station may be required. However the propagation loss varies in accordance with the conductivity of land and/or sea as shown in Recommendation 368, especially in the 2 MHz band. The required geographical separation between receiving antenna and transmitting antenna needs to be determined.

As the propagation loss by ground-wave in the HF bands is larger than in the 2 MHz band, less geographical separation is necessary.

4.5.4 *Simultaneous transmission and reception on board a ship*

In the case of reception on board a ship while transmitting, many administrations design their ship installations so as to disable their receivers during transmission. However, experience and theoretical analysis has established that there is insufficient physical space aboard ships to overcome interference by guardband separation.

5. Possible frequency arrangements

5.1 *2170-2194 kHz*

5.1.1 To encourage introduction of the new distress functions of DSC and NBDP, an early use of this equipment should be considered before full implementation of the FGMDSS whilst ensuring minimal interference to the operation of the large number of existing radiotelephone alerting equipment.

As the frequency tolerance of survival craft stations is approximately 600 Hz until 1990, the required frequency separation between channels should include this value.

Upon considering the above, the following two alternatives of frequency arrangements in the 2170-2194 kHz band are suggested for the introduction of the new distress function:

– Alternative 1 : Fig. 1

– Alternative 2 : Fig. 2

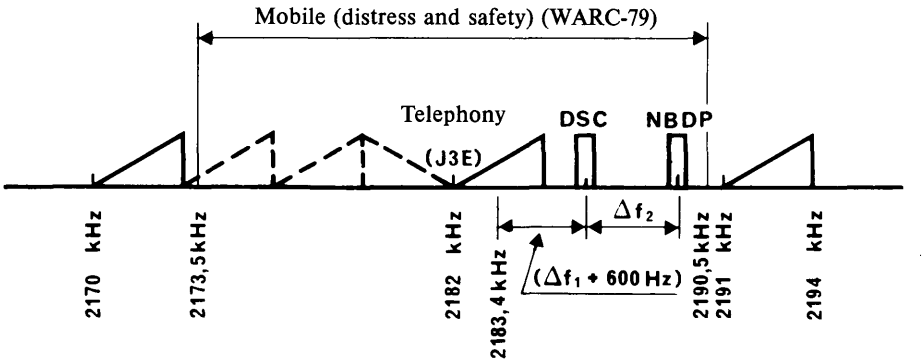


FIGURE 1 – *Alternative 1*

Δf_1: see § 4.4.1
Δf_2: see § 4.4.2

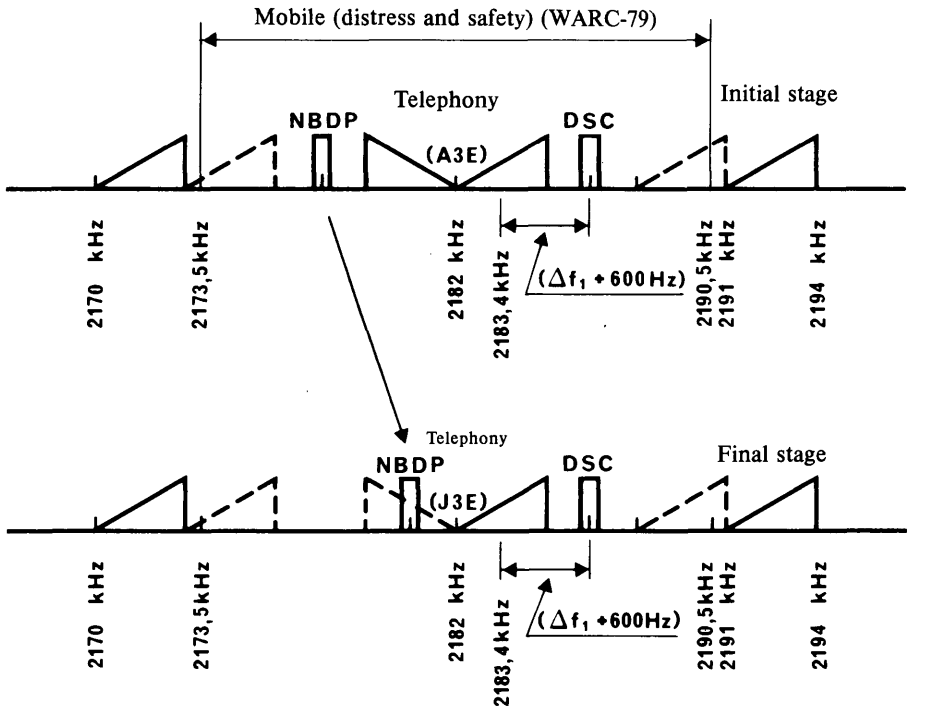


FIGURE 2 – *Alternative 2*

Note. – 2183.4 kHz indicates the assigned frequency of J3E emission.

5.1.2 *Consideration of the two alternatives*

(a) The frequency arrangement shown in Fig. 1 has the following features:

– There is no need to change the frequency designation of NBDP after full implementation of the new distress functions.

– The bandwidth for the distress functions may be subsequently further reduced from the beginning.

(b) The frequency arrangement shown in Fig. 2 has the following features:

- It further separates the two digital channels (DSC and NBDP) which reduces the possibility of interference in the event of simultaneous operation by a coast station.
- It has the disadvantage that the NBDP channel may require shifting at a later date for efficient utilization of frequencies.

5.1.3 From the technical point of view, possible frequency arrangements for distress functions, shown in Fig. 1 and Fig. 2, may be applicable in the 2170-2194 kHz band. However the selection of the two alternatives should also be discussed from the viewpoints of operation and management of frequencies.

5.2 *HF bands*

5.2.1 In the HF bands, the complication caused by the double sideband signal at 2182 kHz does not arise and the large frequency tolerance (600 Hz) of existing survival craft equipment is not found. Therefore, less bandwidth is needed for distress purposes in the HF band than in the 2170-2194 kHz band. However there are no frequencies allocated for distress purposes in the HF bands.

5.2.2 The arrangement in Fig. 3 shows the minimum bandwidth required if DSC, SSB and NBDP are accommodated in radiotelephony bands (Appendix 31, Radio Regulations).

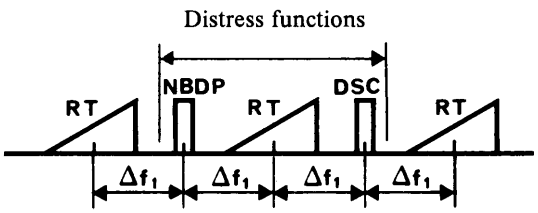


FIGURE 3

Δf_1: see § 4.4.1

Note. – The Δf_1 indicates frequency separation between the assigned frequencies of radiotelephony and digital channels.

5.2.3 With this arrangement difficulties will be experienced at coast stations where transmitters and receivers or their antennas are co-located or in close proximity in monitoring the DSC channel whilst transmitting on NBDP or radiotelephony. These difficulties could be overcome by assigning frequencies outside of the radiotelephone bands for NBDP and DSC or by providing adequate separation at the coast station between transmitting and receiving antennas.

5.3 *Summary*

5.3.1 This part of the Report has discussed certain technical matters which should be taken into consideration when assessing the need for guardbands for distress and safety frequencies and two possible arrangements for such frequencies. However, before conclusions can be reached on the most suitable arrangement some additional information is necessary on the following:

- operational differences in the MF and HF bands;
- operational implications in the simultaneous use of DSC radiotelephony and NBDP for distress and safety at coast stations and, possibly, on board ships;
- the minimum geographical separation between transmitting and receiving antennas likely to be necessary at coast stations for satisfactory operation of:
  - a composite arrangement; and
  - DSC, radiotelephony and NBDP when receiving on one channel and transmitting on an adjacent channel;
- the probable effect on shipborne equipment and, in particular, the suitability of present equipment for the different frequency arrangements.

ANNEX I

ASSESSMENT OF INTERFERENCE

1. **Out-of-band emission of transmitter** [CCIR, 1978-82c]

1.1 *Speech signal transmitter*

A marine SSB radiotelephone transmitter was driven by two sinusoidal tones until it produced intermodulation products 31 dB down on p.e.p. in the adjacent 3 kHz channels in conformity with the Radio Regulations Appendix 17. It was then driven to the same p.e.p. by white noise shaped by a roll off of 6 dB per octave above 1 kHz to simulate the speech power spectrum. The resulting output levels in 500 Hz bands are shown in Fig. 4. These are 10-20 dB below the two tone test levels and decrease by about 6 dB per 1 kHz. Real speech was then substituted for the shaped noise. The output level in any 500 Hz band was then very variable depending on whether the frequency components in the speech happened to produce a product in the band under investigation. The results are therefore given statistically and the figure shows levels which were not exceeded for 50% of the time and 90% of the time. These latter were about 5 dB greater than the results obtained with the shaped noise and for greater percentages of the time would tend to the two tone test levels. However, they appear to exhibit a decrease with frequency spacing similar to the shaped noise.

1.2 *Digital signal transmitter*

The output of one coast station transmitting a Narrow Band Direct Printing NBDP signal was observed with a spectrum analyzer. The approximate levels of out-of-band products were found to be -28 dB, -34 dB and -43 dB in the first, second and third adjacent 500 Hz channels (relative to p.e.p.), i.e., much the same levels as would be expected from a two tone test.

2. **Tests on interference from adjacent channel** [CCIR, 1978-82a]

2.1 The tests were carried out by using a typical HF receiver for reception of the FSK signal and two SSB transmitters for generating a desired FSK signal and an undesired FSK or speech signal.

2.2 The desired signal and undesired signal were combined and fed to the receiver.

2.3 The degradation of the digital channel by interference was assessed by measuring the BER (bit error ratio).

2.4 The results of tests are illustrated in Fig. 5 and Fig. 6 respectively.

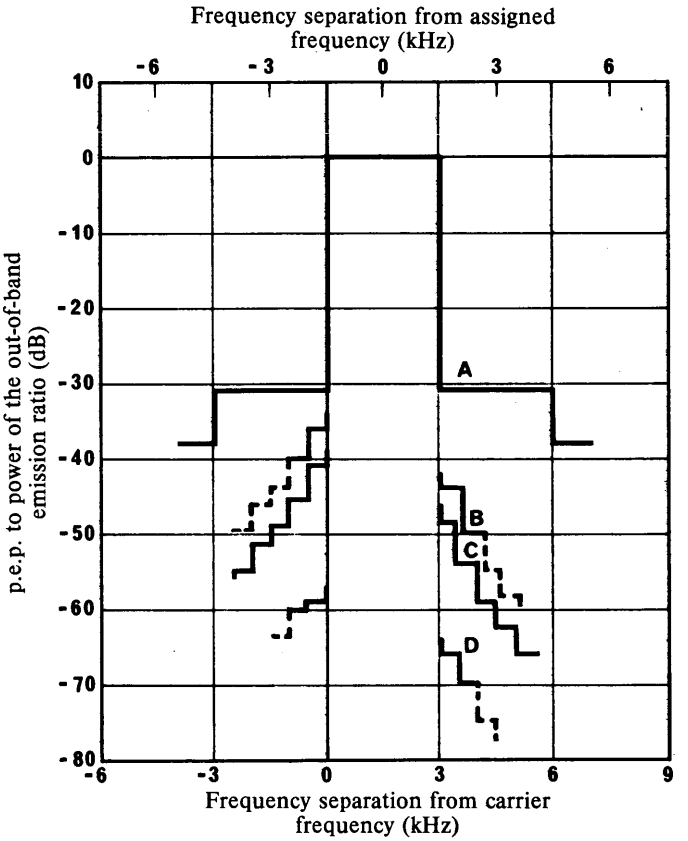
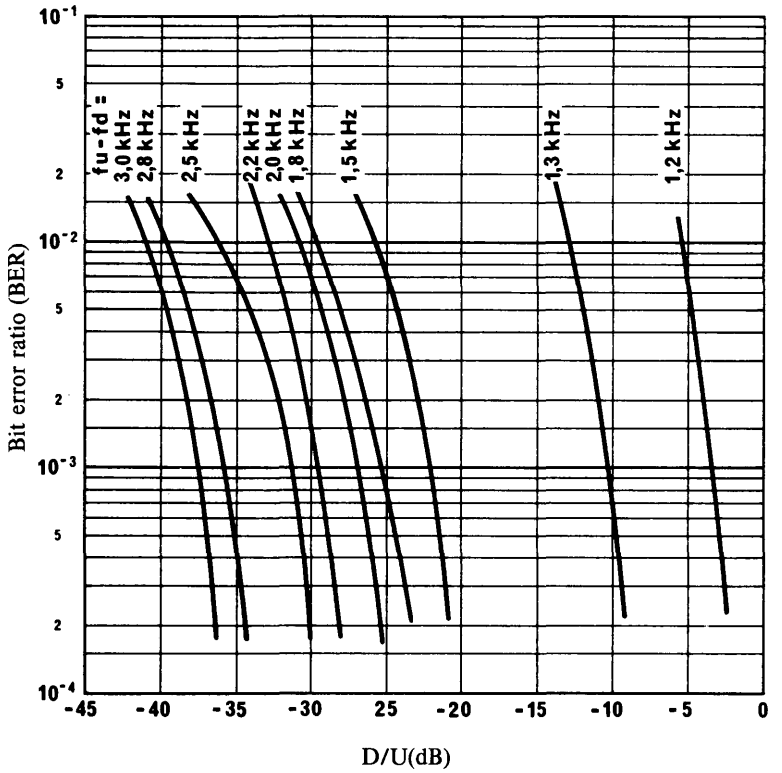


FIGURE 4 – *Out-of-band emission of speech signal transmitter*

A: 2 tone test levels Radio Regs App.17A
B: speech 90% of time
C: shaped noise
D: speech 50% of time



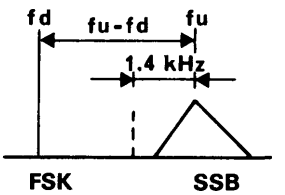


FIGURE 5 – *Results of experiment on BER (bit error ratio) versus D/U (interference caused to DSC or NBDP by SSB)*

Desired signal: FSK PN511 100 bauds (DSC or NBDP)
Undesired signal: SSB pseudo speech signal (CCITT Standard)

Bandwidth of IF Filter: 0.5 kHz
Receiver input level of desired signal: 20 dB(μV)

fd: the assigned frequency of desired transmitter
fu: the assigned frequency of undesired transmitter

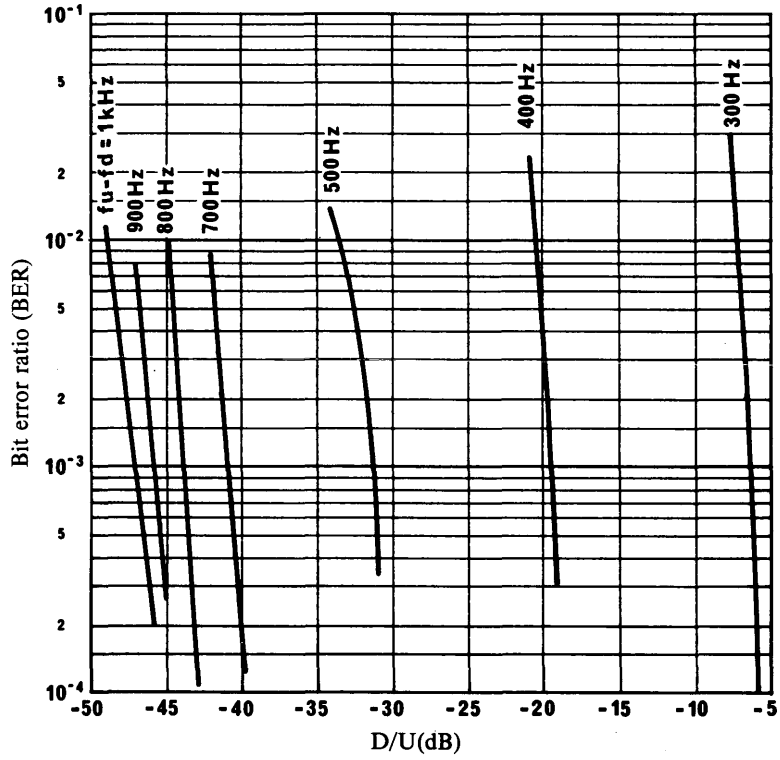


FIGURE 6 – *Results of experiment on BER (bit error ratio) versus D/U (interference caused between DSC and NBDP)*

Desired signal: FSK PN511 100 bauds
Undesired signal: FSK DOT 100 bauds

Bandwidth of IF filter: 0.5 kHz
Receiver input level of desired signal: 20 dB(μV)

fd: the assigned frequency of desired transmitter
fu: the assigned frequency of undesired transmitter

REFERENCES

IMCO [a] Doc. COM XVI/INF.2 (USA).
IMCO [b] Doc. COM XVIII/3(a)/2 Canada.

CCIR Documents

[1974-78]: **a.** 8/386 (Argentina); **b.** 8/406 (Australia).
[1978-82]: **a.** 8/490 (Japan); **b.** 8/494 (USA); **c.** 8/498 (United Kingdom).

REPORT 747-1 *

TECHNICAL AND OPERATING CONSIDERATIONS FOR A FUTURE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM

(Question 45/8)

(1978-1982)

1. Introduction

A future distress system should ensure the rapid receipt of all distress messages and provide the communication capabilities necessary to coordinate the rescue of survivors in order to promote safety at sea.

2. Present system

The present maritime distress system is based upon the requirement that certain classes of ships keep radio watch on one of the international distress frequencies when at sea, carry equipment capable of transmitting over a minimum specific surface distance and, where practicable, are required to assist another vessel in distress. To supplement the efforts of ships at sea, most maritime countries maintain a life-saving service for the rescue of people in distress around their coasts, although the particular search and rescue (SAR) organization varies from country to country.

In practice these arrangements have limitations, and various methods have been, or are being, implemented to try to reduce these. For example, the following developments have occurred during the last decade:

2.1 international agreement has been reached on the need for ships to be able to communicate on a common distress frequency;

2.2 there are advocates for the mandatory carriage of HF equipment for distress purposes and serious reservations have been expressed about the use of 500 kHz in survival craft;

2.3 aircraft of airlines are being pressed, through the International Civil Aviation Organization (ICAO), to improve the watch on 121.5 MHz when flying over ocean areas;

2.4 countries in some areas have implemented the use of frequencies in the 4 MHz and 6 MHz bands to supplement 2182 kHz;

2.5 some administrations have implemented the use of class J3E emission on 2182 kHz for safety purposes;

2.6 a number of countries have introduced legislation concerning the carriage of emergency position-indicating radio beacons (EPIRB).

2.7 *The introduction of selective calling*

Each development is beneficial under certain circumstances. However, one adverse result has been that for ships operating world-wide to obtain assistance rapidly, and at any time, equipment would need to be carried permitting use of each of the frequencies 500 kHz, 2182 kHz, 4125 kHz, 6215.5 kHz, 8364 kHz, 121.5 MHz, 243 MHz and 156.8 MHz. These developments have come about generally because of shortcomings of the present system, for example the difficulties in obtaining assistance when a distress situation occurs beyond the range imposed by the propagation limitations of existing distress frequencies and the problem of an alert not being transmitted in the event of a ship being suddenly overwhelmed.

The introduction of satellite techniques in the maritime mobile service introduces further considerations. A ship in distress fitted with a satellite terminal will be able to transmit an alert rapidly to an appropriate shore authority and SAR organization. However, until all ships can be contacted by satellite or by a selective calling system, there might be difficulty in contacting any which may be in a position to assist, particularly if the incident occurred beyond the range of coast radio stations.

To summarize, it can be seen that the present distress system, whilst adequate in particular circumstances, has resulted in general growth of small sub-systems and an increase in the number of frequencies needed by ships in order to improve the probability of a distress call being received. In addition, the use of satellites, whilst improving the distress communication of suitably equipped ships, will introduce greater shore authority involvement and, indirectly, promote the need for better long-range terrestrial distress communications as well as for the widespread use of selective calling.

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* The Director, CCIR, is requested to bring this Report to the attention of ICAO, IMCO and the INMARSAT Organization.

3. Future system

The Inter-Governmental Maritime Consultative Organization (IMCO) has set out its requirements of the Future Global Maritime Distress and Safety System which are given without any modification in the Annex to this Report.

IMCO is continuing its work on planning the future system with the objective of it being implemented in 1990. However IMCO recognizes that a number of administrative, technical and operating problems may arise and that these might affect the date of implementation.

4. Technical and operating factors affecting implementation

Special measures which should be undertaken by the CCIR to assist the implementation of such a system include the need to:

4.1 complete Recommendation 541 on the digital selective calling system and for operational trials to be carried out;

4.2 make recommendations on the frequencies and techniques to be used for alerting by satellite EPIRBs (Report 761 refers), and to coordinate trials of such systems;

4.3 study the possibilities for utilizing simple shipborne equipment for receiving shore-to-ship alerting via satellites (an initial technical approach is given in Report 921);

4.4 complete Report 746, particularly in respect of the maritime mobile VHF frequency band including the intended use in the Future Global Maritime Distress and Safety System of digital selective calling and direct printing in this band;

4.5 study the most suitable homing techniques to be used;

4.6 to study the most appropriate technical solutions and operational procedures for simple, fast and efficient handling of the equipment in distress situations;

4.7 provide technical advice which will enable the next competent WARC to authorize the use of F1B class of emission on appropriate frequencies in the bands 490-510 kHz and 2170-2194 kHz.

ANNEX I

REQUIREMENTS OF THE FUTURE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM

1. Introduction

1.1 The objective of the system is to provide for adequate communications in order to promote safety of life at sea. The system shall be in support of the International Convention on Maritime Search and Rescue, 1979.

1.2 The system shall ensure the rapid transfer of distress messages from those in distress to the units best suited for giving or coordinating assistance. It shall also ensure rapid receipt of all relevant distress and safety communications.

1.3 The Future Global Maritime Distress and Safety System shall provide for the integrated use of appropriate frequency bands to ensure the transmission and receipt of distress and safety calls and messages at short, medium and long ranges. By definition:

- short ranges do not exceed 25 miles;
- medium ranges do not exceed the order of 100 miles;
- long ranges exceed the order of 100 miles.

1.4 The Future Global Maritime Distress and Safety System shall use the numerical ship station identification system * prescribed in the Radio Regulations. This numbering system permits the assignment of unique numbers to each station.

1.5 Standard operational procedures and equipment standards shall be used in the Future Global Maritime Distress and Safety System.

2. System requirements

2.1 The future system should be global and designed with the objectives of ensuring that:

- the alerting, identification and positioning are quickly and reliably performed in all types of distress incidents;
- communications means exist to facilitate the rescue of survivors including their location and the coordination of rescue units;

* Referred to in the Radio Regulations (Appendix 43) as Maritime Mobile Service Identities.

– it is reliable, and equipment to be used by persons in distress is simple to operate. The equipment is to be capable of maintenance when necessary;

– it is able to accommodate coincident distress calls.

2.2 The system requirements are considered under the following general headings:

Distress alerting	Part 1
Identifying	Part 2
Positioning	Part 3
SAR coordinating communications	Part 4
On-scene communications	Part 5
Locating	Part 6
Preventive actions	Part 7

2.3 In these Parts each frequency requirement is identified by a three-character code. The first character is the letter "f" for frequency; the second character is a number indicating the frequency band in megahertz; and the third is a letter indicating as follows:

A – Digital selective calling, Simplex channel

B – Radiotelephony Simplex channel

C – Narrow band direct printing (NBDP) channel

ANNEX I

PART 1

DISTRESS ALERTING

1. Definition

Distress alerting means the successful reporting of a distress situation to a unit which can provide or coordinate assistance.

2. Operational requirement

The basic operational requirement for alerting is that in every distress situation it should be possible to rapidly alert the unit(s) able to give, as fast and efficiently as possible, the assistance required.

3. Alerting methods and ranges

3.1 Referring to Fig. 1, alerting may be achieved using the following methods:

– ship *-to-shore alerting (link A-1 and A-2),

– shore-to-ship alerting (link B),

– ship *-to-ship alerting (link C).

3.2 It has been agreed that in order to fulfil the operational requirement stated in § 2, the following range requirements should apply to the different alerting methods:

– ship-to-shore alerting: short, medium and long range;

– shore-to-ship alerting: short, medium and long range;

– ship-to-ship alerting: short and medium range.

3.3 Shore-to-ship alerting is closely related to SAR Coordinating Communications, and the methods are described in Part 4, § 3.

4. Operational characteristics

4.1 The future global maritime distress alerting system shall serve all ships and units suitably equipped.

4.2 The system shall provide for the receipt of distress alerts from units situated in all maritime areas.

4.3 The probability of alerting the unit(s) able to give, as rapidly and effectively as possible the assistance required, should be high, and the time required to alert should be short compared to the total rescue time.

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* Although the term "ship" is used, it also represents any unit in distress at sea.

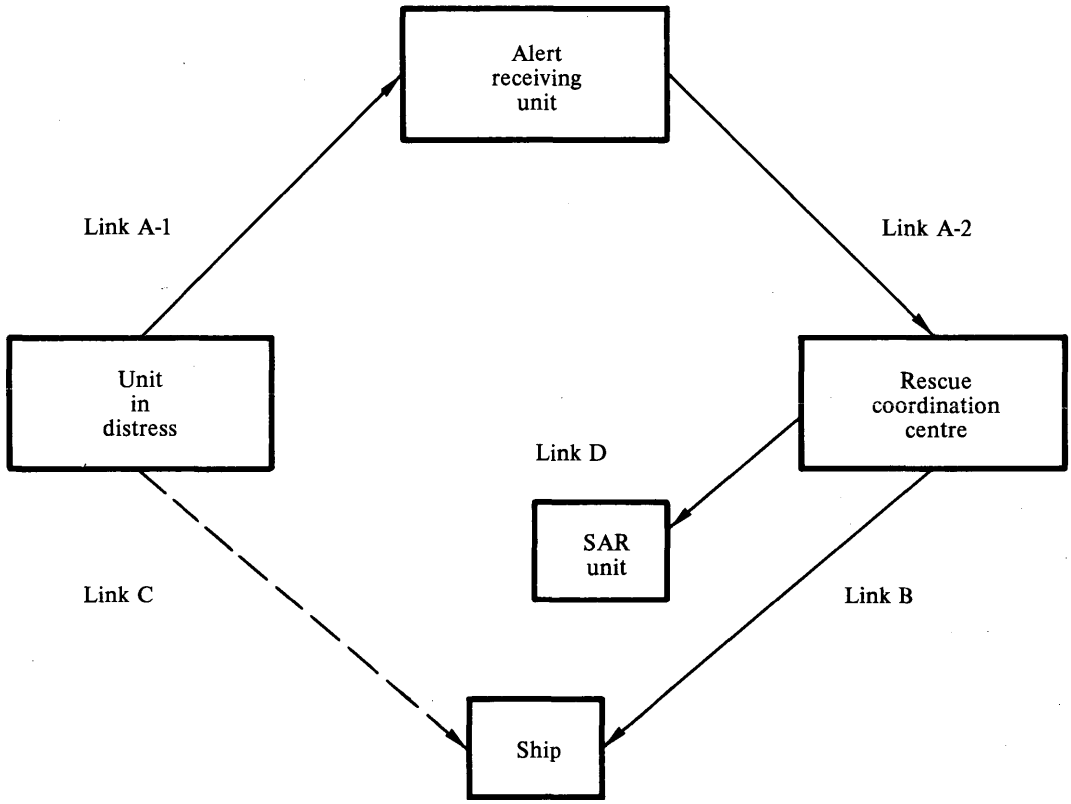


FIGURE 1

4.4 The system should allow for automatic and manual alerting, be simple to operate and maintain at full effectiveness, accommodate the probable number of coincident distress alerts, and be free of false alerts or be capable of discriminating between false and true alerts, as far as practicable.

4.5 To perform ship-to-ship alerting using terrestrial frequencies, the ships which are supposed to receive the alert must have a radio receiver operating on the frequency used by the unit in distress for transmitting the alert. If different frequencies for ship-to-ship alerting were to be utilized in different areas, this would imply that ships in world-wide trade must be equipped to transmit and receive on every frequency adopted. Thus it is desirable to adopt the minimum number of frequencies necessary for ship-to-ship alerting.

4.6 Dependent on the following conditions, there is no requirement for ships to be fitted with a common system to achieve ship-to-shore alerting:

- the unit in distress must be able to alert shore stations using one of the radio system elements included in the distress system;
- any ship must be able to be contacted in the shore-to-ship direction by use of one of the radio system elements included in the distress system;
- the shore stations of all radio system elements must be able to communicate with the appropriate Rescue Coordination Centres;
- facilities are provided to ensure that an alert received by any radio system element is forwarded to the Rescue Coordination Centre for the appropriate area, and to enable an area call or an individual call to be sent to ships.

4.7 Alerting can be achieved by:

- terrestrial communications within the limitations imposed by propagation characteristics as they relate to frequency, effective radiated power and distance between transmitter and receiver in the system;
- communications by satellite relay within the area of coverage of the satellite.

4.8 Selective calling shall be used for alerting purposes.

5. Terrestrial communications

5.1 *Long range alerting*

5.1.1 Two alternatives for long range alerting are available and may be summarized as follows:

- transmission on a comprehensive range of frequencies to include those which can be calculated to give the required field strength at a given receiving station;
- transmission on a limited number of frequencies calculated to allow for the geographic coverage area of the signal to be intercepted by a number of receiving stations at various distances from the transmitter.

5.1.2 The probability of receiving a distress alert is significantly enhanced by a comprehensive system of mutually coordinated receiving stations. A similar network of transmitting stations will also improve the probability of alerting ships.

5.1.3 With terrestrial techniques, shipborne equipment would need to be capable of transmitting on a frequency in each of a number of dedicated maritime HF bands.

5.1.4 It is complicated to provide an HF multi-frequency facility of transmission from survival craft and low powered distress transmitters.

5.2 *Medium and short range alerting*

5.2.1 Medium and short range alerting may be considered entirely as a function of ground wave propagation. All existing maritime distress systems are based on this method of propagation. It is considered that alerting using these methods of propagation will form an important part of the future distress system, as in many parts of the world, because of the local density of ship population, it will provide a rapid and reliable means of alerting. Where shore stations are situated within the range of the unit in distress, then alerting to the Rescue Coordination Centre is provided. This form of alerting will also help to reduce the load on the long range system.

5.2.2 Short range alerting is most commonly identified with line-of-sight paths such as applicable to the VHF or higher bands. These will continue to serve an essential role in close coastal waters where a majority of ship population occurs.

6. Satellite relay in alerting

6.1 The high technical performance of maritime communication by satellite relay is well established and documented. The reliability of the space segment in providing relay from geostationary orbit and polar orbit is similarly established and quantified. Distress alerting through satellites will therefore be included in the global system design and may be used for long, medium and short range alerting.

6.2 The provision of special facilities for alerting by geostationary satellite between installed ship earth stations, coast earth stations and Rescue Coordination Centres is already the subject of study for a future INMARSAT service; is a feature of the first commercial maritime satellite communication service, and will form an alerting capability for those ships fitted with such equipment.

6.3 Radiocommunication systems for ship-to-shore alerting via satellite from survival craft and other low powered distress transmitters are under development and may require special provision at the space segment. One design of transmitter might be used for these functions and from a ship itself, the only difference being in the "packaging" or protection provided.

6.4 Although the technique and system design for low powered distress transmitters has yet to be defined, such transmissions will form an essential component of a future global system.

6.5 The limitations of satellites in geostationary orbit and those in polar orbit need to be taken into consideration when assessing their effectiveness in meeting the requirement for receipt of distress alerts from units located anywhere at sea.

6.6 In order to achieve reliable shore-to-ship alerting, CCIR and the INMARSAT Organization are requested to study the possibilities for utilizing simple shipborne equipment for receiving shore-to-ship alerting via satellites.

7. Assessment of terrestrial and satellite techniques

7.1 From a consideration of the previous sections it has been agreed that the long range alerting function of the future global distress system will be based primarily on the use of satellite techniques and will include the use of low powered distress transmitters.

7.2 Low power distress transmitters should operate through geostationary satellites, but the use of polar orbiting satellites is also desirable.

7.3 It is desirable that a common frequency for low power distress transmissions should be provided for both geostationary and polar orbiting satellites. It is noted that 1.6 GHz is likely to be used in the initial plan of INMARSAT, and experiments are conducted with the use of 406 MHz by polar orbiting satellites.

8. Alerting based on the non-receipt of a scheduled reporting signal

8.1 Passive alerting is based on the non-receipt of radio signals:

- provided a highly reliable communication system is available, passive alerting may be used;
- passive alerting based on radio signals implies that central units guard each ship by receiving OK-signals transmitted at regular intervals by the ship. When a distress situation occurs, this transmission is stopped (manually or automatically) and this will be interpreted as an alert;
- an advantage of this type of alerting is that alerting will be obtained even if the radio equipment is damaged as a consequence of the distress incident. A disadvantage is that there may be a delay from when the distress situation occurs until an alert is registered (maximum delay equals the interval between each repetition of OK-signal). Another disadvantage is that false alerting may occur if the radio equipment malfunctions.

8.2 Equipment which monitors the OK-transmission must therefore be available in the ship. Furthermore, the ship must have some type of radio equipment in addition to the equipment used for the OK-signal, so that information regarding transmission problems may be given to the central unit, either directly or via another ship in the same area.

9. Combined active and passive alerting

Passive alerting only cannot be recommended, but a combination of active and passive alerting may have some advantages:

9.1 in most distress incidents it will be possible to achieve rapid alerting by active alerting;

9.2 in most, or possibly all situations where active alerting is precluded, passive alerting could take place;

9.3 when both active and passive alerts are registered, the probability of a false alert should be low.

10. Frequencies designated for distress alerting

10.1 *Short range distress alerting*

The frequency band 156 MHz should accommodate a Simplex channel dedicated for ship-to-shore distress alerting, shore-to-ship distress alerting and ship-to-ship distress alerting using digital selective calling (DSC) (hereafter referred to as f 156A). The same channel should also be used for safety calling.

10.2 *Medium range distress alerting:*

- a Simplex channel in the 2 MHz band should be dedicated for ship-to-shore distress alerting shore-to-ship distress alerting and ship-to-ship distress alerting using DSC. This channel is hereafter referred to as f 2A. This channel should also be used for safety calling;
- a frequency/ies in the 500 kHz band should be designated for shore-to-ship distress alerting (f 0.5A and/or f 0.5C). This/these frequency/ies could also be used for long range shore-to-ship alerting.

10.3 *Long range distress alerting:*

- a frequency should be dedicated in the 406 MHz and/or 1.6 GHz bands for ship-to-shore distress alerting using Low Power Distress Transmitters (LPDT's) operating through satellites (see § 7.3);
- a frequency should be dedicated for shore-to-ship alerting in the 1544-1545 MHz band (see § 6.6);
- a provision will be included in the future INMARSAT system for ship-to-shore and shore-to-ship distress alerting through geostationary satellites using a ship earth station in the frequency band 1530-1645.5 MHz;
- each of the frequency bands 4, 6, 8, 12 and 16 MHz should accommodate the following channel:

  A Simplex channel dedicated to ship-to-shore distress alerting and shore-to-ship distress alerting using DSC. (These channels are hereafter referred to as f 4A, f 6A, f 8A, f 12A and f 16A.) The same channels should also be used for safety calling.

ANNEX I

PART 2

IDENTIFYING

1. Definition

1.1 Identifying means the receipt of sufficient information in order to determine without ambiguity the unit in distress.

2. Operational requirement

2.1 The code to be used for identification shall be in accordance with the provisions described in Article No. 25, Appendix 43 and Resolution No. 313 of the Radio Regulations, taking into account relevant CCIR and CCITT Recommendations.

2.2 The distress alerting message must contain such identification of the unit in distress to enable the most effective assistance and SAR support.

ANNEX I

PART 3

POSITIONING

1. Definition

1.1 Positioning means establishing the geographical place of the unit in distress. It is normally expressed in degrees and minutes of latitude and longitude.

2. Operational requirement

2.1 The distress alert, when received, should enable the position of the unit in distress to be established for:

- selection of the most suitable rescue unit(s);
- the rescue unit(s) to choose a course not causing significant additional delays;
- the rescue unit to head for a position which is inside the range of the locating method, taking into account the possible drift of the survivors.

2.2 It is essential that the SAR units should have the best available information on the position of the ship in distress in order to carry out SAR operations rapidly and efficiently.

3. Possible methods

3.1 Positioning may be performed, using any of the following methods:

3.1.1 The unit in distress determines its position and transmits this information.

3.1.2 Radio signals transmitted by the unit in distress are used by other units participating in the system to determine the position. The following principles may be applied:

3.1.2.1 The position is determined by radio direction-finding from at least two different positions.

3.1.2.2 The radio signals transmitted by the unit in distress contain information derived from radionavigation signals received at the distress site. The position is determined by processing at the receiving site.

3.1.2.3 The radio signals transmitted by the unit in distress are received via satellite(s) in such a way that the position may be calculated by, for example:

- Doppler shift measurements via a low orbiting satellite;
- transmitting signals via two or more geostationary satellites.

3.1.3 The ships participate in a ship reporting system. Time of alerting plus the ship identification will define the approximate position.

3.1.4 In coastal areas the position of each ship is monitored continuously, e.g. by radars or optical instruments.

3.2 Where coastal positioning systems exist, e.g. direction-finding, radar, optical, effective communications between these stations and the SAR centre should be established for immediate reporting.

3.3 The positioning accuracy should be sufficiently high to avoid excessive search time.

3.4 Relevant combinations of methods for alerting and positioning are summarized in Table I.

TABLE I

Alerting			Positioning					
Principle	Radio system		Own positional data	Retrans. of navigational signals	Direction finding	Doppler principle	Ranging	Position, route/ speed reporting (Note 1)
Active alerting	Terrestrial	HF (long range)				Not applicable	Not applicable	Applicable
		MF (medium, short range)		Probably not applicable	Applicable	Not applicable	Not applicable	Applicable
		VHF/UHF (short range)	Applicable			Not applicable	Not applicable	Applicable
	Geostationary satellite system			Requires further study	Not applicable	Not applicable	Probably not applicable in 1st generation system	Applicable
	Low-orbiting satellite system		Applicable but unnecessary	Probably not applicable, and unnecessary	Not applicable	Applicable	Not applicable	Applicable
Passive alerting	Geostationary or low-orbiting system, or, highly reliable terrestrial systems				(Note 2)			Applicable and necessary

Note 1. – Position/route/speed reporting implies that central unit(s) keeps track of the ship's planned route. In principle, time of alert plus identification of the ship will be sufficient to determine the approximate position where the distress incident has occurred.

Note 2. – Positioning in connection with OK-signals may be obtained by using the same methods that are applicable for positioning in connection with active alerting in the relevant radio systems.

ANNEX I

PART 4

SAR COORDINATING COMMUNICATIONS

1. Definition

1.1 SAR coordinating communications mean the SAR communications other than on-scene communications necessary for the coordination and control of units participating in a distress incident. It includes control communications between the SAR shore authority and the on-scene commander or coordinator surface search.

2. Operational requirements

2.1 The system should provide communications with those units which are in the vicinity of the unit in distress, to enable the most effective employment of suitable assisting mobile unit(s).

2.2 These communications should provide the SAR coordinator with information regarding the distress situation and potential rescue units.

2.3 To fulfil the objective of the system, the SAR coordinator must be able to contact rapidly the specific potential rescue unit that is able to give the assistance as fast and efficiently as possible.

3. Coordinating methods

3.1 The SAR coordinator must have, or be able to obtain, information on the position of potential assisting units. Alternative methods for obtaining this information are:

3.1.1 for ships participating in a ship reporting system the SAR coordinator may obtain the information from the system;

3.1.2 ships equipped for receiving area calls by the use of a selective calling system could be notified automatically and then report their positions to the SAR coordinator;

3.1.3 ships not equipped as specified in § 3.1.2 above, but equipped for receiving an all-ships call, could be notified by this method. The all-ships call must be followed by a specification of what area is of interest. Ships within this area must report back. This method may be suitable in a short-range system, but has operational drawbacks if used in a long-range system.

3.2 The SAR coordinator must be able to contact selected units and give instructions and information. The method for contacting a specific unit will be related to the method available for obtaining the survey of potential units:

- for the conditions stated in §§ 3.1.1 and 3.1.2 the ship selected will be contacted by transmitting a selective call;
- for the conditions stated in § 3.1.3, an all-ships call must be subsequently transmitted associated with an identification of the ship selected.

3.3 Possible relay communications through another mobile unit in the event of communication difficulties.

4. Frequencies for SAR coordinating communications

4.1 In order to contact ships required to participate in SAR operations, the Rescue Coordination Centre should use the DSC channels for shore-to-ship alerting (see Part 1, § 10).

4.2 *Frequencies for SAR coordinating communications:*

4.2.1 Simplex channels should be dedicated for SAR coordinating communication by J3E voice communications and by narrowband direct printing (NBDP) in the bands 2 MHz, 8 MHz and 156 MHz. At this stage the channels will be referred as follows:

Voice : f 2B, f 8B, f 156B

NBDP : f 2C, f 8C, f 156C

These channels should also be used for safety traffic (see Part 7, § 2.1);

4.2.2 Simplex channels should be designated for SAR coordinating communication by J3E voice communications and by narrowband direct printing (NBDP) in the bands 4 MHz, 6 MHz, 12 MHz and 16 MHz. At this stage the channels will be referred as follows:

Voice : f 4B, f 6B, f 12B, f 16B

NBDP : f 4C, f 6C, f 12C, f 16C

These channels should also be used for safety traffic (see Part 7, § 2.1);

4.2.3 Provisions will be included in the future INMARSAT system for SAR coordinating communications through geostationary satellites in the frequency band 1530-1645.5 MHz.

5. Inter-SAR region coordination

Recognizing the Recommendations of the SAR Convention, effective communication links and procedures are essential between the rescue coordination centres (RCC) in each area. These communications will include the use of the international switched telephone and telex networks, ship earth stations located at the RCC and effective general maritime communications. Simplex techniques should be used between coast radio stations.

ANNEX I

PART 5

ON-SCENE COMMUNICATIONS

1. Definition

1.1 On-scene communications are those between the unit in distress and assisting units and between searching units and the on-scene commander or the coordinator surface search.

2. Operational requirements

2.1 The system should provide for communications between the unit in distress and assisting units.

2.2 The system should also provide for communications between the on-scene commander or coordinator surface search and other searching units.

2.3 It is essential that all on-scene units are able to share relevant information concerning the distress incident and consequently Simplex communications should be used.

3. Frequencies designated for on-scene communications

3.1 *Frequencies for ship-ship communications:*

3.1.1 the preferred frequencies to be used for on-scene communications are the following:

Voice : f 2B and f 156B

NBDP : f 2C and f 156C.

3.1.2 If the frequencies listed above are inadequate, any of the frequencies designated for SAR coordinating communications (see Part 4, § 4.2) may be used for on-scene communications. Due regard should be given to avoiding unnecessary long range.

3.2 *Frequencies for ship-aircraft communications:*

- the preferred frequencies to be used for ship-aircraft on-scene communications are the same as for ship-ship communications (see § 3.1.1);
- other frequencies may be utilized such as 3023 kHz, 5680 kHz, 121.5 MHz, 123.1 MHz and 243 MHz.

ANNEX I

PART 6

LOCATING

1. Definition

Locating is the finding of the unit in distress or its survivors by an assisting unit.

2. Operational requirements

The system shall provide means of facilitating the rendezvous between the unit in distress or survivors and the assisting unit. Effective locating methods could reduce or eliminate the search phase of many search and rescue incidents.

3. Locating methods

3.1 Provided equipment is available for indicating positioning continuously until rescue is completed, and if the positioning accuracy is sufficiently high, a separate method for locating may not be required.

3.2 If it is not possible to update positioning until rescue is completed, the range of the locating method must be sufficient to allow for possible drift in the position of those in distress in the interval between positioning and rescue.

3.3 The following methods are available for locating:

- homing on radio signals (including by means of radio direction-finding);
- search by active microwave instruments (radar);
- search by passive infra-red or microwave instruments that are able to detect radiation from those in distress;
- locating by updated and accurate positioning data (e.g. retransmission of electronic navigational aids);
- visual search;
- homing on light or sound signals from those in distress.

4. Frequencies for homing

4.1 Homing may be performed on any transmitting frequency used by a unit in distress.

4.2 Frequencies for homing should be provided in those frequency bands used for distress alerting which are most suitable for homing, i.e. 2 MHz, 156 MHz and possibly 406 MHz/1.6 GHz. In the 2 MHz and 156 MHz bands, the following channels should be considered for homing: f 2B, f 2C, f 156B, and f 156C.

4.3 In addition to the frequencies listed above, the frequencies 410 kHz, 121.5 MHz and 243 MHz are available for homing purposes, if voluntarily fitted with the necessary equipment.

ANNEX I

PART 7

PREVENTIVE ACTIONS

1. Definitions

Preventive actions means collecting, sorting and disseminating information or taking other actions which will either help reduce the number of distress incidents or, when they occur, will facilitate rescue or expedite the SAR process.

2. Methods and measures

2.1 *Urgency and safety messages:*

- provisions for urgency and safety calling and messages must be included in the future system. The frequencies proposed for distress alerting using DSC (see Part I, § 10) should be available for urgency and safety calling. The frequencies proposed for SAR coordinating communications (see Part 4, § 4.2) should be available for urgency messages, vital navigational messages and urgent cyclone warnings;
- provisions for the transmission of navigational and meteorological warnings using NBDP techniques on a common frequency in the 500 kHz band should also be included in the system.

2.2 *Ship position reporting:*

- the use of ship reporting systems will provide the RCC with an information base of surface units which may be suited to give assistance. Ship position reporting systems will contribute to avoiding delays and unnecessary diversions of assisting units;
- the systems employed should be designed to provide the best possible immediate information with the minimum effort by the participating ship;
- the following channels designated for SAR coordinating communications should be available on a non-interference basis for ship position reporting using NBDP techniques: f 4C, f 6C, f 12C and f 16C;
- channels should be designated in the HF band for ship position reporting using radiotelephony.

2.3 *Ship polling:*

– "ship polling" means the interrogation of ships by manual or automatic techniques and the response by the ships to the interrogating station. Ship polling may be performed using satellite ship-shore circuits or highly reliable terrestrial circuits;

– there may be operational advantages in combining ship polling with ship position reporting. Such a system may also be utilized for passive alerting (see Part 1, § 8).

2.4 *Ship movement services:*

– "ship movement services" is defined in the Radio Regulations and implies voluntary or mandatory participation in routing and traffic controls intended to reduce the risks of collisions while maintaining a maximum safe movement;

– ship movement services should be established in areas with high traffic density.

2.5 *Communication availability:*

– "communication availability" expresses the proper functioning of communication networks as a function of time;

– the communication availability should be high for maritime communication equipment, and in particular for equipment intended to be used in distress situations, so that each ship can maintain a continuous communication capability to shore and to other ships;

– the following factors affect communication availability: equipment reliability, preventive and corrective maintenance capability, training, spares, tools, test instruments, documentation, duplication of equipment, skilled maintenance personnel, operational training equipment design.

2.6 *Public correspondence systems:*

– effective global public correspondence systems and supporting communication systems are essential to the Future Global Maritime Distress and Safety System, and to support maritime safety in general.

2.7 *International cooperation:*

– preventive actions include the cooperative efforts among administrations to organize and commit resources to the support of SAR facilities in accordance with the SAR Convention, 1979, interconnections between rescue coordination centres, and to improve maritime safety in general. This includes continuing effort to improve systems, interconnections, techniques and procedures.

RECOMMENDATION 439-3 *

EMERGENCY POSITION-INDICATING RADIO BEACONS OPERATING AT THE FREQUENCY 2182 kHz

(Question 31/8)

(1966-1974-1978-1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 48 of the International Conference on Safety of Life at Sea, London, 1960;

(b) that Radio Regulations, Article 41, § 1 lays down the purpose and use of emergency position-indicating radio beacons (EPIRB) signals;

(c) that all passenger ships and cargo ships of 300 gross tonnage and upwards are required to keep continuous watch at the frequency 2182 kHz by the International Convention for the Safety of Life at Sea (1974);

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* The Director CCIR, is requested to transmit this Recommendation to the inter-Governmental Maritime Consultative Organization (IMCO), the International Civil Aviation Organization (ICAO) and to the General Secretariat of the ITU.

(d) that some administrations require other classes of ship to keep continuous watch at the frequency 2182 kHz;

(e) that in accordance with Regulation 10, Chapter IV, of the International Convention for the Safety of Life at Sea (1974), a radiotelephone distress frequency watch receiver preset to this frequency shall be provided. The receiver shall be provided with a filtering unit or a device to silence the loudspeaker, if the latter is located on the bridge, in the absence of a radiotelephone alarm signal. The device shall be capable of being easily switched in and out and may be used when, in the opinion of the master, conditions are such that maintenance of the listening watch would interfere with the safe navigation of the ship;

(f) that IMCO Resolution A383 (X) provides that the distress watch receiver fitted with a muting device should respond to the radiotelephone alarm and the vital navigation warning signal. In addition, the muting device may also respond to a keyed emission modulated only by a 1300 Hz tone, however, where such a facility is not provided the mute will not be lifted on distress watch receivers by EPIRBs transmitting such signals;

(g) that the definition of the duty cycle of the 1300 Hz tone modulated emission (Radio Regulation No. 3257) is suitable for reliable operation of muted watch receivers only if there are specific national provisions;

(h) that the Radio Regulations, Appendix 37 defines EPIRBs operating at the frequency 2182 kHz as type "L" or type "H", according to their output power;

(j) that it is desirable that both types of EPIRB perform an alerting function;

(k) that the signal emitted by an EPIRB should be suitable for reception by a watchkeeping receiver with a loudspeaker;

(l) that the signal emitted by an EPIRB should, as far as practicable, be clearly distinguishable from the radiotelephone alarm signal transmitted by ships still afloat or by portable radio apparatus;

(m) that the signal emitted by an EPIRB should not create harmful interference to other distress calls and messages;

(n) that the type and sequence of the signal to be transmitted by an EPIRB should facilitate homing by ships as well as by search and rescue (SAR) aircraft, taking into account their different speeds;

(o) that in the interests of high reliability and minimum expense the electronic and mechanical design of an EPIRB and especially of its keying device should be as simple as possible,

UNANIMOUSLY RECOMMENDS

1. that according to the provisions of Appendix 37 (paragraphs a), b) and c)) to the Radio Regulations:

1.1 "the power radiated by low-power EPIRBs (Type "L") shall be of a value necessary to produce at a distance of 30 nautical miles at sea level a field strength equal to or less than 10 micro volts per metre, with an initial field strength of at least 2.5 micro volts per metre;

1.2 the power radiated by high-power EPIRBs (Type "H") shall be of a value necessary to produce at a distance of 30 nautical miles at sea level a field strength greater than 10 micro volts per metre;

1.3 after a period of 48 h continuous operation the radiated power shall not be less than 20% of the initial power;"

2. that, noting the provisions of Article 41 (Nos. 3256 to 3258) and of Appendix 37 (paragraph e) of the Radio Regulations:

2.1 the keying signal for EPIRBs should consist of:

- the radiotelephone alarm signal with a keying cycle which consists of the keying signal for between thirty and fifty seconds followed by the Morse letter B and/or the call sign of the ship to which the radiobeacon belongs transmitted by keying a carrier modulated by a tone of either 1300 Hz or 2200 Hz, followed by a period of silence of between thirty and sixty seconds;
- a keyed emission modulated by a tone of 1300 Hz having a period of emission of 1.0 to 1.2 s and a period of silence (carrier suppressed) of 1.0 to 1.2 s;

2.2 "the audio-frequency tolerance of emissions are:

± 20 Hz for the frequency of 1300 Hz

± 35 Hz for the frequency of 2200 Hz;"

2.3 that the EPIRBs should be capable of double-sideband or single-sideband full carrier emissions, with a depth of modulation between 30 and 90%;

3. that the keying cycles may be interrupted for the transmission of information relating to the distress incident;

4. that the EPIRBs should be designed for the following temperature ranges:

- when stowed, at least −20 °C to +55 °C;
- when operated in the open air, at least −10 °C to +45 °C;
- when operating afloat, at least −3 °C to +35 °C.

Note. – Exceptionally for EPIRBs carried by ships operating in limited areas only, other temperature ranges may, due to special conditions in such areas, be more appropriate.

5. that if the EPIRBs are designed to come into operation automatically when floating, then overriding facilities should be provided to enable them to be switched on manually. All EPIRBs should be capable of being switched off manually;

6. that when primary batteries are used as a source of power for EPIRBs, arrangements should be made for the equipment to be labelled to indicate the date by which the batteries should be replaced;

7. that the mechanical design of EPIRBs should be such that they are capable of continuous operation, under all sea states, humidity and change of temperature likely to be experienced at sea and should take into consideration that such EPIRBs might need to be small, lightweight, floatable, water-tight and shock-resistant, dependent upon the operational requirements for the EPIRB.

REPORT 749-1 *

FUTURE USE AND CHARACTERISTICS OF EMERGENCY POSITION-INDICATING RADIO BEACONS IN THE MOBILE SERVICE AND THE MOBILE-SATELLITE SERVICE

(Question 31/8)

(1978-1982)

1. Introduction

To avoid confusion in using terms for low-power distress alerting and locating devices in the future there should be a distinction between:

- EPIRBs (homing on terrestrial frequencies) and
- satellites EPIRBs (alerting using satellite techniques).

The present Report reflects this distinction.

2. EPIRBs in the Future Global Maritime Distress and Safety System

The Inter-Governmental Maritime Consultative Organization (IMCO) has prepared requirements for the Future Global Maritime Distress and Safety System. These requirements relate to Recommendation No. 201 of the World Administrative Radio Conference (Geneva, 1979).

The basic operational requirement for alerting is that in every distress case it should be possible to rapidly alert the unit(s) able to give, as fast and as efficiently as possible, the assistance required.

Radiocommunication systems for ship-to-shore alerting via satellite from survival craft and other low-power distress transmitters (satellite EPIRBs) are under development and may require special provision at the space segment.

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* The Director, CCIR, is requested to bring this Report to the attention of ICAO, IMCO and the INMARSAT Organization.

Although the technique and system design for EPIRBs and Satellite EPIRBs has yet to be defined, such transmissions will form an essential component of the distress alerting and locating functions of the Future Global Maritime Distress and Safety System. In this context IMCO has prepared general requirements for EPIRBs and satellite EPIRBs covering these functions. These requirements are described in [CCIR, 1978-82].

3. EPIRBs using maritime VHF frequencies

One administration reported the use of EPIRBs operating on frequencies in the maritime mobile VHF band on a regional basis in coastal areas.

The description and the technical specifications of this type of EPIRB are given in Annex I. With the implementation of the Future Global Maritime Distress and Safety System, the specifications of these EPIRBs may be modified to those described in § 2.

4. EPIRBs using the aeronautical distress frequencies 121.5 MHz and 243 MHz

EPIRBs also form an essential part of the existing maritime as well as of the existing aeronautical distress and safety system. The main function of these EPIRBs is to locate those in distress.

The preferred technical and operating characteristics of emergency position-indicating radio beacons known as emergency location beacons aircraft (ELBA) in the aeronautical service and operating on 121.5/243 MHz have already been established by ICAO and no changes are contemplated. Any maritime use of EPIRBs on the frequencies of 121.5/243.0 MHz should therefore use signal characteristics which are in conformity with the relevant Standards of ICAO, Annex 10 to the Convention on International Civil Aviation, Vol. I. With regard to the frequencies 2182 kHz and 500 kHz, it should be noted that:

- 2182 kHz is normally not carried by aircraft, but the possibility that ICAO may eventually introduce a requirement for SAR aircraft to be able to home on 2182 kHz may be considered;
- aircraft are normally unable to communicate on 500 kHz but when fitted with ADF are normally able to home on this frequency.

Should, however, the study on this question consider the use of frequencies other than those MF, HF and VHF/UHF frequencies in common use, ICAO has stated that it would be prepared to make known its requirements to the CCIR.

Measurements and studies by one administration [Gillard, 1975] have shown that an alternating tone alert signal (similar to the radiotelephone alarm signal) is capable of providing an improved audio detection range and direction-finding performance compatible with existing search and locating equipment operating at frequencies of 121.5 MHz and 243 MHz, compared with the performance obtainable for existing EPIRBs which use swept tone modulation. Use of the alternating tone modulation also makes possible the incorporation of a very comprehensive identification coding system now that cheap and robust microprocessors are available.

Should continuing study on this question lead to the development of EPIRBs to operate on frequencies other than the exclusive aeronautical emergency frequency 121.5 MHz, a modulation, coding and identification system as described in Annex II and its Appendix may offer possible advantages.

REFERENCES

GILLARD, P. O. [December, 1975] Preliminary investigation into the performance of search and rescue locating systems using VHF beacons (EPIRBs) to meet Australian conditions. WRE-TM-1530(A), Dept. of Defence, Australia.

CCIR Document

[1978-82]: 8/157 (IMCO (§ 11.5)).

ANNEX I

DESCRIPTION AND TECHNICAL SPECIFICATIONS OF EPIRBs USING MARITIME VHF FREQUENCIES

1. Introduction

The use of emergency position indicating radio beacons (EPIRBs) operating on the frequency 121.5 and 243.0 MHz is limited in the United States to vessels which are engaged on voyages which require operation at distances beyond 32 km from shore. Carriage of this type of EPIRB is mandatory on US vessels which are subject to the Convention for the Safety of Life at Sea (SOLAS) (1974) and are generally not used by vessels in coastal traffic or by recreational vessels.

In the United States the need for an EPIRB for vessels operating in coastal waters is evidenced by statistics which indicate that 95% of the boating accidents, many involving loss of life, occur within 40 km of shore. In a great many cases the capability to transmit a signal for alerting and locating purposes could have improved the efficiency of search and rescue operations and in some cases prevented the loss of life. For these reasons, it is considered important that provisions should be made for the voluntary use of an EPIRB operating in the VHF maritime mobile band in US coastal waters.

2. Frequency of operation and modulation

The effectiveness of any distress system is directly related to the degree of monitoring which exists in the system. Channel 16 (156.8 MHz) is the international VHF maritime distress, safety and calling frequency. This channel is continuously monitored along the entire US coastline by the US Coast Guard. The radio watch which the Coast Guard provides on this frequency is further supplemented by ship and coast stations which operate in this frequency band. Accordingly, because of the monitoring provided in Channel 16, this frequency was chosen to be used for the alerting function. Channel 15 (156.75 MHz) was chosen to be used for location purposes.

The EPIRB transmits the international radiotelephone alarm signal (1300 and 2200 Hz tones repeated alternately) on Channels 15 and 16. The transmission on Channel 15 provides a signal suitable for homing purposes; the transmission on Channel 16 provides a signal suitable for alerting nearby vessels and coast stations to an emergency situation. The EPIRB will operate for a 24-hour period once activated after which time it will automatically turn off.

During the 24-hour period there will be four different cycles. The details of the EPIRB operation are specified in Table I and shown in Fig. 1 of the Appendix to this Annex. Each cycle is made up of a number of sequences and a sequence is made up of six periods. The number of sequences increases for each subsequent cycle. The sequences differ only in that periods 4 and 6 become progressively longer (40 to 320 s) for each subsequent cycle. If a 30-minute period is considered, it is noted that the transmission time on Channel 16 is approximately 47, 28, 16 and 8 s for cycle 1 through 4, respectively. Tests have shown that this sequential method of transmission on Channels 15 and 16 will not cause an unacceptable level of interference to normal traffic on Channel 16.

The technical specifications for this type of EPIRB are shown in the Appendix attached.

ANNEX I

APPENDIX

VHF – EPIRB FOR USE IN COASTAL AREAS

Frequency:	156.75 MHz and 156.8 MHz
Frequency tolerance:	0.001%
Peak radiated power:	1 W
Transmission life:	24 hours (automatic turn off)
Polarization:	vertical
Temperature for operation:	(1) 0 °C to 50 °C for 24 h continuous operation
	(2) −20 °C to 50 °C for 12 h continuous operation
Maximum frequency deviation:	± 5 kHz
Modulating frequency:	1300 Hz and 2200 Hz ± 5%
Tone duration:	250 ms ± 5%
Modulation format:	see Fig. 1 and Table I
Capable of floating:	yes

TABLE I – *Signal format for EPIRBs using maritime VHF frequencies*

Characteristic(1)	Cycle			
	1	2	3	4
Period 1 (channel 16)	1.5	1.5	1.5	1.5
Period 2 (channel 15)	14.5	14.5	14.5	14.5
Period 3 (channel 16)	1.5	1.5	1.5	1.5
Period 4 (no transmission)	40.0	80.0	160.0	320.0
Period 5 (channel 15)	14.5	14.5	14.5	14.5
Period 6 (no transmission)	40.0	80.0	160.0	320.0
Total time for 1 sequence	112.0	192.0	352.0	672.0
Duration of cycle	0.49 h.	1.7 h.	6.25 h.	15.53 h.
Number of sequences/cycle	15.75	31.87	63.92	83.19

(1) Time is in seconds unless otherwise specified.

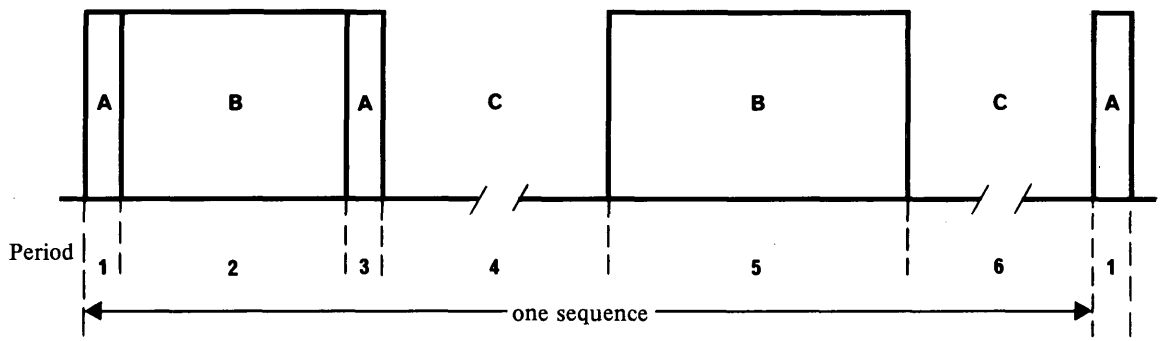


FIGURE 1 – *EPIRB signal transmission*

A: channel 16: transmission for 1.5 s
B: channel 15: transmission for 14.5 s
C: no transmission for 40, 80, 160 and 320 s during cycles 1, 2, 3 and 4 respectively.

ANNEX II

PROPOSAL FOR AN IDENTIFICATION CODING AND MODULATION SYSTEM FOR EPIRBs COMPATIBLE WITH EXISTING SEARCH AND LOCATION EQUIPMENT

1. Identification coding

1.1 The proposal is to use a pair of alternating audio tones for alert and identification coding. The alert tone sequence is interrupted periodically with a burst of code to provide identification of the country of origin of the beacon, the class of craft or vehicle with which it is intended for use, and the serial identification of the beacon. Morse is recommended in preference to other more efficient codes to facilitate early interpretation of distress signals by a wide range of observers. The code is designed to permit rapid verification of the authenticity of an alert in a given zone and hence to provide a means of estimating the scale of SAR resources likely to be required in rescue.

Although the code is primarily intended for maritime purposes, it possesses sufficient capacity to permit its use in Emergency Locater Transmitters (ELTs) and EPIRBs to be used in aircraft and other classes of vehicle.

1.2 The preferred format (see Figs. 2a and 2b) consists of three morse alphanumeric characters to provide an internationally recognized call sign prefix for the country of registration of the beacon, one character to allow identification of up to 34 (omitting letters I and O) classes of vehicle, and four characters to allow individual serial identification of up to 1 336 336 beacons within each class per country. Typically, a code would have a duration of approximately 15 s and would be repeated at two-minute intervals. It is proposed that the morse be transmitted on the lower audio tone and that the spaces be transmitted on the upper audio tone in order to maintain constant carrier power.

1.3 It is envisaged that the characters designated for various classes of vehicle would be internationally agreed, but that member nations would allocate serial identifications as required to meet national needs.

1.4 It is envisaged that beacons would be coded at the point of manufacture, that ownership would be controlled by permit, and that the registered owner would be responsible for notifying to the National SAR Authorities specified details of the intended use of each beacon at any time. The secondary purpose of identification coding is to provide a means of exercising some control of misuse of beacons.

2. Carrier modulation

2.1 The carrier modulation for distress alert consists of two audio tones having frequencies of 2184.53 Hz and 1310.72 Hz, the tolerance being 0.005%, and the tones alternating, each occurring for a period of 274.6 ms with phase continuity at the transitions.

2.2 The above audio tones are also used to generate the identification code characters to minimize beacon cost.

2.3 The coherent generation of common stable tone frequencies for both alert and identification coding and the use of an accurate modulation waveform and a stable carrier frequency allow use of optimum signal processing techniques to extract the alert signal and code in the presence of noise, and to extract Doppler information for location of a distress beacon by low polar orbiting satellites. It provides an overall system performance that is considerably better than that obtainable with the currently used non-coherent swept tone modulation and also provides improved probability of separating simultaneous distress signals.

2.4 The choice of tone frequencies of 2184.53 Hz and 1310.72 Hz is based on the use of already approved distress modulation tone frequencies of 2200 and 1300 Hz, the exact frequencies in this proposal being derived from a quartz watch crystal having a frequency of 32 768 Hz.

ANNEX II

APPENDIX

PROPOSED EPIRB CHARACTERISTICS

Frequency (Typical):	243.0 MHz ± 0.005%
Effective radiated power: (10° take-off angle – calm sea conditions)	100 mW (243.0 MHz)
Transmission life:	100 h minimum at 0 °C
Polarization: (rough sea conditions)	Vertical ± 45°
Temperature for operation:	0 °C to 55 °C (Australian conditions)
Carrier frequency stability: (at 243 MHz)	Better than ± 10 Hz over any 10 s period under constant conditions Better than ± 10 Hz for antenna mismatch of 10/1 SWR (simulating rough sea conditions) Less than 60 Hz/min from full sunlight to shade conditions
Modulation depth:	100%
Modulation duty factor:	50% ± 5%
Modulating frequencies:	1310.72 Hz 2184.53 Hz } ± 0.005%
Modulation format:	See Figs. 2a and 2b.

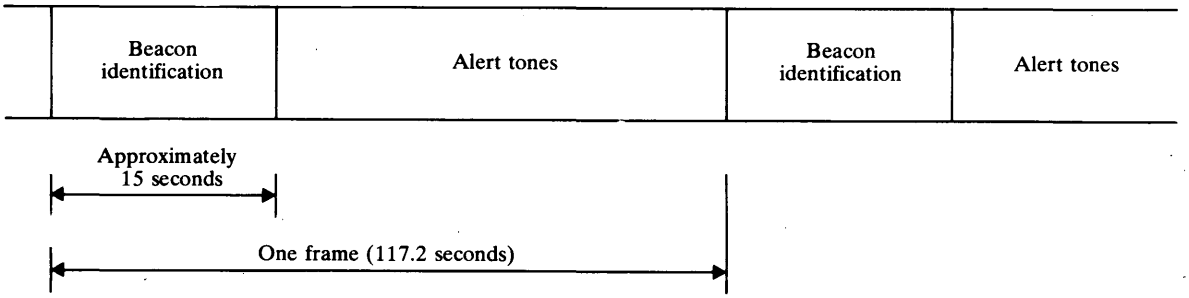


FIGURE 2a – *Modulation format*

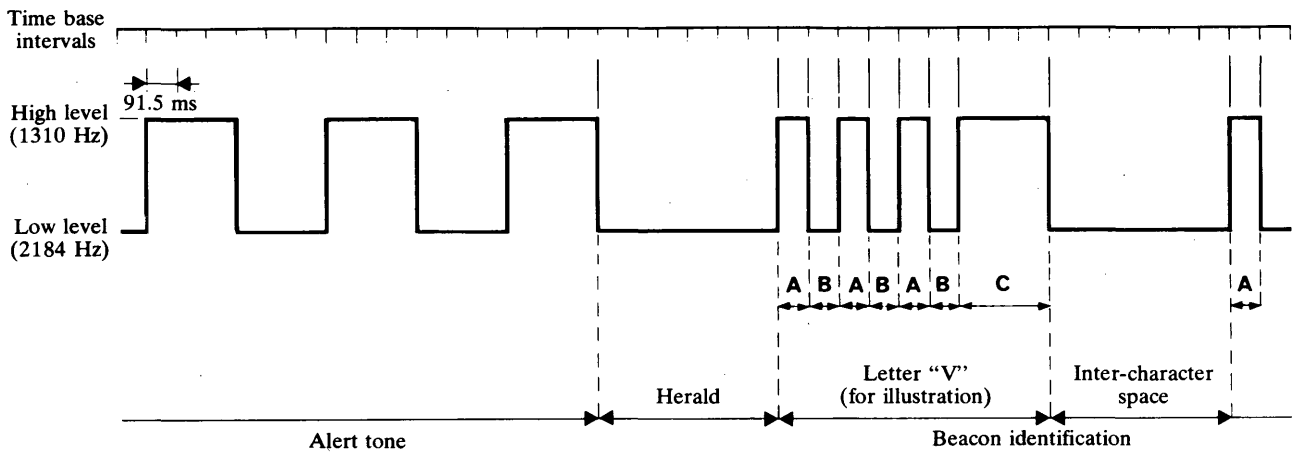


FIGURE 2b – *Segment of modulation illustrating commencement of coded identification*

A: dit
B: code space
C: dah

REPORT 912 *

OPERATIONAL AND TECHNICAL FACTORS RELEVANT TO GLOBAL DISTRESS SYSTEMS IN THE AERONAUTICAL MOBILE SERVICE

(Questions 17/8 and 31/8)

(1982)

1. Introduction

This Report seeks to identify relevant factors from the civil aviation distress environment which are expected to be significant in any detailed investigation of an operational requirement for an aviation distress location/alerting service using satellites.

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* The Director, CCIR, is requested to draw the attention of ICAO, IMCO and the INMARSAT Organization to this Report.

In this Report an aviation distress system is not intended to include the involvement of aircraft in maritime distress incidents.

2. Basic factors

Published statistics about aircraft accidents (some of which are included in Annex I) show two dominant features relevant to a possible future aviation distress system provided via satellites:

- The vast majority of accidents to large aircraft take place on or relatively near an aerodrome. Location of the accident is rarely a problem in these cases.
- There are very many more accidents involving general aviation (i.e. light aircraft predominantly) than air transport operations (i.e. large aircraft predominantly).

In 1978 there were approximately 325 000 civil aircraft in the world of which some 290 000 were classed as general aviation.

These facts strongly suggest that if a future operational requirement was to emerge for a satellite system for aircraft in distress then it would need to ensure that light aircraft operations and the en-route phase of flight are catered for, to realise the most significant benefits – although the needs of en-route large aircraft clearly must also be met.

This view is strengthened by consideration of the relative "survivability" of those involved in a light aircraft en-route accident compared with those in a large aircraft en-route accident. Examination of the relative airspeeds, manoeuverability, operating heights, etc., all point to a general conclusion that the occupants of light aircraft are likely to have a better chance of surviving such a crash than occupants of a large aircraft. Further study of aircraft accident statistics would be needed to quantify this "survivability" in absolute terms.

It is considered that a system meeting general aviation needs would also be very likely to meet the needs of air transport operations.

3. Discussion

If the above line of approach is accepted then it is possible to proceed further to identify some consequential operational and technical factors which would need to be taken into account in any future consideration of an aeronautical distress system using satellites:

3.1 To gain wide acceptance by the light aircraft owners and operators any on-board device would need to be lightweight, cheap and simple. If acceptable for light aircraft it could reasonably be assumed to be acceptable for large aircraft also.

3.2 The normal navigational and other equipment on light aircraft is likely to be limited. It would therefore seem inadvisable for system designers to assume that on-board-derived position information would or could be made available for transmission in the event of a distress incident.

3.3 Even if position information was available the speed of aircraft is such that an on-board device designed to store the latest aircraft position would require very frequent updating (every 5-10 min, say) to prevent an excessive area of search uncertainty. Point 3.2 above indicates that automatic updating should not be relied upon in light aircraft and flight deck workload would certainly rule out manual updating at the interval required.

3.4 Points 3.2 and 3.3 together strongly indicate that any position fixing for a global aeronautical system should be carried out without reliance on aircraft-derived navigational data transmitted by an on-board device, although it would seem desirable to permit the latter if this could be effectively included as an optional additional feature.

3.5 To be effective an on-board device would need to have facilities to permit both manual and automatic actuation of a distress alerting signal in the event of emergencies on either land or sea. The equipment will clearly need to be designed to withstand an aircraft crash.

3.6 A large number of general aviation and other aircraft are already required to carry emergency beacons on 121.5 MHz and 423 MHz and internationally-recognised transmission characteristics exist for these (in essence they are required to use amplitude modulation with a rapidly sweeping audio signal. Simultaneous transmission on 121.5 MHz and 243 MHz is required.) It would clearly be highly desirable for any proposed global distress system to utilize these existing types of equipment if the problem of the high incidence of false alarms can be resolved.

3.7 Notwithstanding § 3.6 above there could be operational advantages in using a totally new frequency band dedicated for global alerting and distress location (e.g. 406.1 MHz). However these possible advantages require further study and may, at least in part, be offset by the large-scale existing aeronautical investment and procedures associated with 121.5 MHz and 243 MHz. It would appear necessary to ensure that any future system takes into account both aircraft and survival craft equipments.

The results of studies being carried out under the various tests described in Report 761 will be of considerable interest in future considerations of the points under this section and section 3.6 above.

3.8 True global coverage would appear to be required. Coverage of the high Arctic latitudes would be essential as well as most of the world's land and sea areas. Closer examination of aircraft operations might reveal a few areas where lack of coverage might not be too serious.

3.9 Points 3.4 and 3.6 would bring a need for any position location system to have an accuracy significantly better than the "worst" expected line of sight range from the aircraft in distress and the search vehicles (e.g. surface to surface VHF/UHF line of sight range, say 5-10 miles).

3.10 On the question of capacity of a satellite-based distress system, the 1978 statistics given in Annex I permit a first assessment of the needs to be made (1978 was neither a particularly good year nor a particularly bad year for aviation accidents). The pure arithmetic average over all aircraft under all phases of flight gives a value of approximately 1 fatal accident every 6 hours of the day throughout the year (0.17 accidents per hour). Poisson probability theory indicates that, for this average frequency of occurrence, no more than 3 fatal accidents are likely in any 1 h period (99.9% probability level). Even if the 0.17 per hour overall average was considered to be unrealistic due to various reasons including daily and seasonal traffic variations, the 99.9% figure would only rise to no more than 4 or 5 per hour if the overall average was trebled. If accidents that occur in the same hour are regarded as "simultaneous" then it can be seen that a fairly modest maximum simultaneous capacity is required. However, consideration also needs to be given to the fact that a distress alerting service may well continue to transmit for several hours after the distress has been received by the search and rescue services – even after the aircraft has perhaps been located.

3.11 When a detailed assessment of the benefits of a global civil aviation distress system is made, there are three main areas for investigation:

a) rescuing survivors,

b) recovery of the aircraft for accident investigation purposes,

c) commercial salvaging.

In respect of a) the previous comments on "survivability" (see § 2) are also relevant. It is evident that any system must have a very high probability of alerting the search and rescue services within a few minutes of the activation of an on-board device.

4. Summary and conclusions

4.1 Although considerable aviation interest exists in the possibilities offered by satellite-based systems a firm preference for a global solution has not yet emerged.

4.2 There is strong evidence based on past aircraft accident statistics to suggest that if an operational requirement does eventually emerge then it will be of greatest benefit if it can cater for the needs of light aircraft as well as those of large aircraft. This stems mainly from the much larger numbers of general aviation aircraft and their significantly worse accident record. Also relevant to this is the fact that a very high proportion of accidents to large aircraft occur in circumstances where a distress location system would not appear to offer much assistance.

4.3 If a future system was matched to general aviation characteristics it could reasonably be expected to be compatible with large aircraft operations also.

4.4 In view of the current type of emergency beacons carried by many light aircraft there would appear to be strong advantages if any future proposed system could utilize such existing equipment. Internationally accepted standards exist for this equipment.

4.5 There appears to be some doubt that a global system could offer significant benefits unless it included both distress alerting and distress location.

4.6 There appears to remain some significant operational differences between the aeronautical and maritime cases. (See Report 595 also.) Therefore continuation of close cooperation between aeronautical and maritime interest is essential.

ANNEX I

1978 CIVIL AVIATION STATISTICS – WORLD

TABLE I

	General aviation	Air transport (large aircraft)	Total
1. No. of aircraft([1])	290000	35000	325000
2. No. of accidents with fatalities([1])	1426	27	1453
3. Total hours flown([1])	46.1 million	24.9 million	71 million
4. Fatal accidents per 100 000 h flown	3.1	0.11	2.05

([1]) from ICAO Annual Statistics 1978.

From these figures:

Average no. of fatal accidents per hour during the year $= \frac{1453}{365 \times 24} = 0.17$

Hence:

likely maximum no. of fatal accidents in any hour (Poisson 99.9%) = 3 approx.

ICAO world-wide accident statistics are divided into those with fatalities and those without. They include incidents outside the scope of this Report (e.g. ground movement incidents) as well as cases where fatalities are caused solely to people not in the aircraft which has crashed. It is not possible to provide precise statistics relevant to this Report but it is considered that the figures for "accidents with fatalities" are the closest to what is required.

REPORT 581-1 *

USE OF RADIO-BEACON STATIONS FOR COMMUNICATIONS

(1974-1978)

1. Introduction

This Report discusses the technical characteristics of supplementary modulations that can be superimposed on the carrier of a radio beacon in the LF or lower MF band. This Report is derived from the various submissions by administrations on this subject.

2. Protection of the primary function

It is important that any supplementary modulations superimposed upon the carrier of a navigational beacon should not degrade the prime function of the beacon in any way, although it is noted that in certain circumstances it is possible that information of a meteorological or safety nature might be even more important than the direction-finding function.

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* The Director, CCIR, is requested to draw the attention of ICAO, IMCO and IALA to this Report.

3. Reports of experience with supplementary A3E voice modulation

Japan reported modulating a non-directional A2A radio beacon with meteorological information using A3E, the duration of each meteorological transmission being one minute and thirty seconds. The carrier frequency was 313 kHz and the mean power 65 W. Direction-finding was possible at a distance of 150 km or more without prejudice to its accuracy, and the meteorological information was receivable at a distance of 100 km using a simple eight-transistor receiver. Studies continue.

Several administrations are making use of supplementary voice communications and weather broadcasts using amplitude modulation (A3E).

In the United States of America, a *T*ranscribed *We*ather *B*roadcast (TWEB) has been successfully superimposed on a number of aeronautical radio beacons using A3E emission. This is a recorded weather broadcast which, by updating the recording at frequent intervals, continuously provides current meteorological data.

After many years of operation, it can be concluded that these currently practised methods of voice modulation on radio beacons do not degrade or interfere with the direction-finding feature, and have provided worthwhile operational advantages.

4. Reports of experience

4.1 *Reports of experience with supplementary F1B emission*

Tests in Canada using direct-printing at various keying rates and with several carrier-shift rates have shown that use of carrier-shift modulation on a non-directional radio beacon has an adverse effect on the reliability of bearing information provided by some types of automatic direction-finding equipment in aircraft. The types affected appear to be those utilizing phase-locked loop synchronous detection techniques.

The intent of the tests was to show whether the performance of the beacon, as set down in the International Civil Aviation Organization (ICAO) Standards and Recommended Practices contained in Annex 10 to the Chicago Convention on International Civil Aviation, would be affected by carrier-shift modulation.

Tests were conducted with carrier frequency shift from ± 30 Hz to ± 85 Hz at keying rates from 30 to 200 bauds at signal levels of between 50 μV and 200 mV. Under no combination of these variables did the phase-locked loop synchronous detection automatic direction-finding equipment (ADF) under test lock on to or provide any bearing indication.

The effect that supplementary frequency-shift keying (FSK) modulation (F1B) has on ADF receivers appears to depend on the detection and demodulation techniques used by the different receivers. The frequency tolerance of .01% permitted by ICAO leads the engineer who designs a modern ADF to provide digital tuning to the nearest 0.5 kHz with a phase-lock fine tuning for final correction. If the response time of the phase-lock loop is short, the modern ADF with this feature remains in a continuous tuning mode when attempting to take a bearing on a beacon which has frequency-shift keying imposed upon it.

Some equipment using phase-locking happens to be designed with a longer response time, and is not adversely affected by the presence of frequency-shift keying. Equipment not having phase-lock loop synchronous detection is not adversely affected even if the carrier is shifted ± 150 Hz and A3E modulation is transmitted simultaneously.

Annex 10, Volume I, Part I, § 3.4.6, to the ICAO Convention permits supplementary modulation on radio beacons, provided that these additional modulations do not materially affect the operational performance of these radio beacons in conjunction with currently used airborne direction finders. A radio beacon with frequency-shifted carrier would not meet this criterion.

4.2 *Results of tests carried out with a supplementary sub-carrier phase modulation superimposed to an A2A carrier frequency of a maritime radio beacon*

A test was made in France of the transmission of "differential Omega" corrections to ships by phase modulating the carrier of a radio beacon. One of the essential conditions of this test was not to change the characteristics of the main function of the radio beacon, namely, range and radiogoniometric quality.

The experimental conditions were as follows:

- carrier frequency offset ± 10 Hz of its nominal value by modulating it with a low frequency sub-carrier. The modulation index was $\Delta\varphi \leqslant 0.6$;
- modulation as linear as possible, so as to limit the energy that may appear in the sidebands of a higher order than the fundamental;
- the information was transmitted by phase modulating the sub-carrier.

This is a very exceptional emission which used receivers specially designed for reception of these signals.

The first station was installed at the radio beacon on the Ile d'Yeu (Bay of Biscay) in 1973 and the second at the radio beacon on Cap Couronne (Gulf of Fos). A study was made of the effect of this modulation on the operation of ships' direction-finding equipment. So far no degradation has been noted in the bearing indications of a crossed-loop direction finder with goniometer and automatic display.

5. Aeronautical use

5.1 In the ITU Radio Regulations, the Table of Frequency Allocations does not prohibit voice communications in the aeronautical radionavigation bands used for aeronautical radio beacons.

5.2 ICAO has recommended at its various regional meetings that aeronautical radio beacons operating in the LF and MF bands be replaced, where possible, by VHF navigational aids and that meteorological and safety information to aircraft in flight be sent by:

- either request/reply transmissions on the operational air traffic control (ATC) air/ground channel in use;
- or HF/VHF broadcasts on dedicated Aeronautical Mobile Meteorological Service Channels (VOLMET).

5.3 In addition, ICAO, in its Standards and Recommended Practices (SARPs) contained in Annex 10 to the Chicago Convention on International Civil Aviation, has agreed international standards which recognize that in addition to NON, A1A or A2A emission, other types of modulation including voice may be utilized, although no voice communication function is specified. In the European and Mediterranean Region of ICAO there are some 1225 radio beacons and locators serving civil aviation and operating in the bands 255 to 285 kHz and 315 to 405 kHz. It would be difficult in such an environment to ensure adequate protection between adjacent channels if the carriers were subject to other forms of modulation.

5.4 ICAO Annex 10 also cautions that any such voice modulation should not degrade the primary service of the radio beacon, the direction-finding capability.

In particular, reliable performance of airborne automatic direction-finding (ADF) equipment may be seriously prejudiced if the beacon emission contains modulation by an audio frequency equal or close to the loop-switching frequency or its second harmonic. The loop-switching frequencies in currently used equipment lie between 30 Hz and 120 Hz.

5.5 To facilitate the planning of frequency assignments, Class A2A emissions are used in some areas to identify these radio beacons with a modulation frequency of 400 Hz ± 25 Hz rather than 1020 Hz ± 50 Hz to reduce occupied bandwidth. Airborne direction-finding equipment employs automatically switched antenna techniques and equipment could be sensitive to other types of modulation when using certain switching rates.

5.6 If any administration wishes to add supplementary modulation on beacons specified for aeronautical use, these administrations are required to notify this to the ITU. If such beacons are specified in an ICAO Regional Plan, then it would be desirable that ICAO should also be informed.

6. Maritime use

6.1 *Characteristics of maritime radio beacons*

Many maritime MF beacons transmit continuous carrier waves modulated by an AF tone which is keyed with an identifying code and a long dash (of the order of 25 s) to permit manual or automatic DF measurements. There are some beacons which could not be used for regular transmissions since in clear weather they may only transmit once every 30 minutes or even not at all.

The bandwidth of maritime radio beacons is normally 2 kHz in Region 1. Whilst this is satisfactory for the transmission of an audio frequency tone which does not exceed 1 kHz, it is unacceptable for the transmission of speech.

6.2 *Methods of superimposing modulation on existing beacon transmissions*

6.2.1 *Narrow band frequency modulation of the carrier within the permitted frequency tolerance, e.g. ± 10 Hz modulation*

The main advantage of this system is that it requires relatively simple modifications to transmitters. The disadvantages are that it requires the use of a high stability receiver otherwise spurious frequency modulation of the receiver's local oscillator due to vibration in a ship could be greater than the modulation. Existing receivers would also require modification if intermediate frequency outputs were not already provided.

A low data rate only is permissible since some automatic direction-finding receivers use a loop switching rate around 100 Hz and the data must not strobe with this rate. In addition, the short-term frequency stability of some existing beacons may be incompatible with the required frequency modulation deviation.

6.2.2 *Narrow band sub-carrier phase modulation of one or more very low frequencies, e.g. 10 to 20 Hz*

In this method, the relative phase angle of the low frequency represents data in an analogue or digital form. However, the frequency and deviation must be kept low in order to avoid problems with existing direction finder receivers.

This method can be used with a radio beacon using either A1A or A2A type of emission.

It might have advantages, in conjunction with a radio beacon using A1A emission, in conserving spectrum in areas of high beacon density.

A disadvantage is that modifications and additions are required to existing receivers. However, other specially designed receivers could be used.

6.2.3 *Narrow band frequency modulation of the beacon's audio frequency modulation tone, e.g. ± 10 Hz*

This system is relatively simple to execute at the transmitter and no modifications are required to existing receivers provided they have an audio frequency output connection or socket. An add-on unit can decode the digital data and present it in the required form irrespective of the type or manufacturer of the receiver.

The system allows the use of an address code for individual beacon transmitters or types of message so avoiding problems with time shared transmissions and the use of different modulation tones increases the number of usable data transmissions. Forward error correcting codes may also be employed.

A disadvantage of this method is that it can only be used with radio beacons using A2A emission and there might be problems associated with the different audio frequency modulation tones in use.

6.3 *Preferred operational practices*

6.3.1 No alterations should be introduced to a radio beacon which necessitate changes in the operational procedures at present used in the radionavigation (direction finding) mode.

6.3.2 When using maritime radio beacons for communications other than those relating to their main function:

- the emissions of maritime radio beacons closely concern the safety of ships and consequently must suffer no quality degradation due to supplementary modulation;
- the bandwidth of the emissions should in no case exceed the provisions of the Radio Regulations (Article 35, No. 2865).

6.3.3 The additional communications which can be emitted by maritime radio beacons should conform with the Maritime Radionavigation definitions in the Radio Regulations (Article 1, Nos. 11 and 42).

6.3.4 Any administration wishing to use a maritime radio beacon for purposes other than its main function should ensure that the use of supplementary modulation:

- is not liable to interfere with the operation of ship's direction-finding equipment;
- does not interfere with the quality of service provided by other radio beacons operating on the same or on an adjacent frequency;
- has been notified to the ITU for inclusion in the List of Radiodetermination and Special Services Stations, and to IMCO.

7. Conclusions

7.1 Any secondary modulation superimposed on a radio-beacon emission should not disturb the frequency relationship (separation) between the carrier and sidebands of the basic A2A emission.

7.2 The characteristics of the total emission should not result in greater interference with adjacent radio transmission than is caused by the basic A2A radio-beacon emission.

7.3 Although A3E emission is being used successfully by several administrations, a radio beacon emission should not be modulated by audio frequencies approximating to the ADF loop-switching frequency or its second harmonic [ICAO, 1972].

7.4 A radio beacon should not be frequency-shift modulated unless the response time of ADF receivers is sufficiently long for phase-locking to be maintained. Further investigations are required.

7.5 The addition of point-to-point or non-safety information to a radio-beacon emission should not prejudice the later addition of navigational or safety information.

7.6 In Europe, the Paris Regional Arrangement (1951) restricts the range of maritime radio beacons and groups them into threes and sixes, limiting the duration of emissions to two minutes or one minute respectively, which is just sufficient for a qualified operator to take a radio bearing.

7.6.1 The duration of emissions could not be increased without complete revision of the Paris Regional Arrangement (1951).

7.6.2 Emitting direction-finding signals and meteorological information alternately would diminish the efficacy of the radio beacon network in its prime function.

7.7 More information on operational requirements, both for the mobile services and other services in remote areas, is required before standards can be decided, particularly in respect of the means by which the information would be emitted (e.g. voice, facsimile, telegraphy).

REFERENCE

ICAO [1972] Annex 10 to the Chicago Convention on International Civil Aviation, 3rd edition, July 1972, Vol. I, Part I, § 3.4.6.5.

RECOMMENDATION 487 *

USE OF RADIO-BEACON STATIONS FOR COMMUNICATIONS

(1974)

The CCIR,

CONSIDERING

(a) Report 581 in answer to Question 15/8 on the use of radio-beacon stations for communications;

(b) the contents of Annex 10 to the Chicago Convention on International Civil Aviation, 3rd edition (July, 1972) Vol. I, Part I, § 3.4.6;

(c) that, although the International Civil Aviation Organization (ICAO) does not preclude the use of modulation for communications purposes on radio beacons, there are at present no operational requirements in the ICAO Regional Plans;

(d) that reliable performance of airborne automatic direction-finding equipment (ADF) may be seriously prejudiced if the beacon emission contains modulation by an audio frequency equal or close to the loop switching frequency or its second harmonic;

(e) that aeronautical automatic direction-finding equipment now used in modern high speed jet transport aircraft increasingly employs phase-locked loop local oscillator techniques, which are severely affected by frequency shift keying of the carrier frequency;

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* This Recommendation terminates the study of Question 15-1/8, which has been deleted.

(f) that in some areas maritime beacons are very numerous and have of necessity to be grouped, and operate on a time sharing basis;

(g) that there may be advantages for some users in the transmission of weather and other information as a secondary modulation of radio-beacon emissions and that some administrations are successfully using such services with A3E emissions,

UNANIMOUSLY RECOMMENDS

1. that for radio beacons in the aeronautical radionavigation service any modulation additional to that necessary to provide identification shall be such that airborne automatic direction finder performance is not unacceptably degraded; (see ICAO Annex 10 to the Chicago Convention on International Civil Aviation, 3rd edition, (July, 1972) Vol. I, Part I, § 3.4.6);

2. that in suitable areas, i.e. where inter-beacon interference can be avoided, use could be made of radio beacons in the maritime radionavigation service for other purposes. In such cases, the methods of modulation used should be such that marine direction-finders can continue to be used when signals are emitted other than those proper to the radio beacon itself;

3. that any such additional modulation should not affect the frequency of the carrier.

Note. – The Director, CCIR, is requested to bring this Recommendation to the attention of ICAO and the Inter-Governmental Maritime Consultative Organization (IMCO).

RECOMMENDATION 588

CHARACTERISTICS OF MARITIME RADIO BEACONS (REGION 1)

(Question 58/8)

(1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 602 of the World Administrative Radio Conference, (Geneva, 1979);

(b) that provisions aimed at preventing one radio beacon from causing harmful interference to another should be inserted in the Radio Regulations;

(c) that it is nevertheless essential to fix frequency spacings with sufficient flexibility to allow for the existing technical facilities;

(d) that these facilities will not require the maintenance in the future of as large a frequency spacing as that adopted for Region 1 in the Radio Regulations,

UNANIMOUSLY RECOMMENDS

1. that frequency assignments to maritime radio beacons operating in the bands between 283.5 kHz and 335 kHz should also be determined, assuming that the radiated power is maintained at the necessary minimum value to attain the desired field strength at the service range, by the need to ensure an adequate geographical separation to avoid harmful interference between radio beacons operating on the same frequency and at the same time;

2. that frequency assignments to maritime radio beacons should be based on multiples of 100 Hz. The adjacent frequency spacing should be sufficient to prevent one radio beacon from causing harmful interference to another in the same geographical area;

3. that the siting of maritime radio beacons should be based on regional or sub-regional arrangements;

4. that Administrations of Regions 2 and 3 should be invited to consider that arrangements should be made to ensure that frequency allocations are made on a compatible basis throughout the world.

REPORT 913 *

TECHNICAL CHARACTERISTICS OF MARITIME RADIO BEACONS

(Question 58/8)

(1982)

1. Introduction

Radio direction-finding has been used in navigation and search and rescue at sea for many years.

The International Convention for the Safety of Life at Sea (SOLAS), 1974, requires ships over 1600 tons gross tonnage to be equipped with a direction-finding (DF) receiver.

A regional agreement known as the Regional Arrangement concerning maritime radiobeacons in the European Zone of Region 1 (Paris Plan) was concluded in Paris in 1951.

The use of radio beacon stations for communications is covered by Report 581, and Recommendation 487.

The World Administrative Radio Conference, Geneva, 1979 (WARC-79) made provisions (RR No. 466) for the use of radio beacon stations in the maritime radionavigation service for transmitting additional navigation information using narrowband techniques, e.g. differential Omega corrections.

Also in 1979, IMCO recommended performance standards for Differential Omega Correction Transmitting stations (IMCO Resolution No. A425(XI)).

Recommendation No. 602 adopted by the WARC-79 considers the need for revision of the 1951 Paris Plan and to review the technical characteristics of maritime radio beacons in the European Zone of Region 1 concerned.

This Report relates to Recommendation No. 602 and contains those operational requirements which should be considered in preparing new characteristics for maritime radio beacons in the European Zone of Region 1.

2. Transmission modes currently in use for maritime radio beacons

2.1 A1A : the carrier is not modulated. it is keyed with the identification signal. (According to Article 25 of the Radio Regulations, any radio station must transmit an identification signal. In the case of maritime radio beacon stations, this consists of two or more Morse characters.)

2.2 A2A : the carrier is amplitude modulated by an audio tone; both carrier and modulation tone are keyed with the identification signal. (The depth of modulation modes (b) and (c) is at least 70% (RR No. 2866).)

2.3 A2A"*" : the carrier is amplitude modulated by an audio tone, but only the modulation tone is keyed with the identification signal. (The depth of modulation modes (b) and (c) is at least 70% (RR No. 2866).) A "*" is sometimes added after the emission symbol to distinguish mode 2.3 from mode 2.2.

2.4 H2A : "Dual carrier" transmission: two radio frequencies are transmitted with a frequency spacing equivalent to the wanted audio tone frequency (heterodyning instead of amplitude modulating); one frequency only is keyed with the identification signal.

In some geographical areas maritime radio beacons operating on the same frequency are combined into groups of up to six which operate in a time-sharing mode, assigning slots of one minute to each of the beacons. The main disadvantages are that the time availability of each radiobeacon is low, and that the time to obtain a position fix may be long.

3. Radiodirection finding methods

Methods currently in use are as follows:

a) Minimum-signal (aural) direction-finding, with or without a beat-frequency oscillator (BFO).

b) Automatic direction-finding (ADF).

c) Dual-channel visual (cathode-ray-tube direction-finding).

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* The Director, CCIR, is requested to bring this Report to the attention of the International Association of Lighthouse Authorities (IALA), of the Inter-Governmental Maritime Consultative Organization (IMCO) and of the International Civil Aviation Organization (ICAO).

The Paris Plan was designed primarily to accommodate a) above and any new system should also take the more recent methods of b) and c) into consideration.

4. Operational requirements

4.1 In developing technical characteristics for maritime radiobeacons, present and future operational requirements need to be taken into consideration. These include:

4.1.1 Radio beacon emissions should take into account the need for shipborne direction-finding equipment to be compatible with navigational functions and search-and-rescue (SAR) operations;

4.1.2 The use of geographic separation must take into account the numbers and location of radio beacons needed to satisfy the navigational requirements of the area.

4.2 International coordination needs to be achieved concerning frequency, location, and service range for optimum protection against interference.

4.3 The time required for position fixing should be related to the accuracy requirements for safe navigation in the area.

4.4 The system should be compatible with modern techniques, such as frequency synthesizers, automatic bearing measurements and decoding, alpha-numeric display and automatic calibration error corrections.

4.5 The system should use appropriate techniques to increase protection against interference.

4.6 The system should be compatible with the use of maritime radio beacons for transmitting additional navigation information in compliance with Recommendation 487 and according to IMCO Resolution No. A425(XI) and to RR No. 466.

4.7 The maritime radio beacon service should be suitable for use by all properly equipped ships and small craft. Performance standards should accommodate the requirements of all classes of ships and small craft.

4.8 Any new radio beacon systems should be compatible with the existing system at least for a transitional period.

5. Technical studies

To define the technical characteristics of marine radio beacons, and taking into account the operational requirements given in § 4, the following studies are required:

5.1 Determination of the necessary field strength values at service range, and methods and procedures by which the field strength could be periodically monitored.

5.2 Examination of the validity of propagation curves for night-time operation in the 300 kHz frequency band, as they appear in Document 3 of Paris [1951].

5.3 Examination of the possibility of reducing frequency separation between radio beacons, in particular consideration of:

5.3.1 the reduction in number and frequency of the modulation audio tones;

5.3.2 the type(s) of modulation to be adopted.

5.4 Investigation of the risks of interference occurring when diminishing frequency and/or distance separation between maritime radio beacons [Bukovski, 1965]. This involves study of protection ratios according to carrier frequency separation and modulation frequency, taking into account the possible adoption of modern techniques in the design of receivers, examination of filtering techniques in receivers, and of the practical ways of using them.

5.5 The preferred method of identifying a radio beacon transmission.

5.6 The optimum and maximum number of maritime radio beacons associated in groups on a single frequency in a time-sharing mode.

5.7 Examination of the possibility of diminishing the duration of a complete transmission cycle of grouped radio beacons, including the possibilities of a periodical rapid transmission cycle for use by automated receivers.

The above items should not be considered as exhaustive, and other aspects may appear in the course of the study.

A first preliminary study by IALA gives some indication about possible characteristics of the signal format (see Annex I).

REFERENCES

BUKOVSKI [1965] On the problem of permissible interference level for maritime radio beacons. International Conference on Lighthouses and Other Aids to Navigation, Rome, 7.1.11.

PARIS [1951] Documentation of the Conference for the preparation of the Regional Arrangement concerning maritime radio beacons in the European Area of Region 1.

ANNEX I

CHARACTERISTICS OF MARITIME RADIO BEACONS (IALA)

1. Objective

The characteristics, proposed by the International Association of Lighthouse Authorities (IALA) after a first preliminary study, are determined for the following purpose:

1.1 To eliminate the requirement for transmission of the audio modulation of the transmitted signal for direction finding purposes, as different audio modulations are not used in practice to provide the required protection ratio.

1.2 To eliminate the requirement for audio modulation of the transmitted signal to provide station identification.

1.3 To increase the number of carrier channels in the allocated frequency band to provide for additional radio beacon stations.

1.4 To allow the use of present direction finding receivers but also to enable for the future to automatically display radio beacon's bearing and receiver's position.

1.5 To limit the maximum number of radio beacon stations in a group.

2. Characteristics of the proposed maritime radio beacon signal format

These characteristics are shown in Fig. 1.

2.1 Each radio beacon should transmit during a one minute period a keyed frequency using Morse code of 8 s duration and a long dash of 40 s duration (see Fig. 1b).

2.2 This signal may be used by the presnt direction finding receiver in the narrowband mode.

2.3 Each radio beacon should transmit each minute sequentially of 4 s duration digital data by angle or frequency shift keying of the frequency (see Fig. 1d).

This narrowband angle modulation should be used by automatic direction finding receivers to provide station identification and frequent update of the position data displayed in latitude and longitude.

2.4 The signal uses narrow bandwidth emissions. The spacing between channels should be 1 kHz maximum. To facilitate the use of frequency synthesizers, carrier frequencies should be multiples of 100 Hz. The use of A1A emission is recommended, but if an audio modulation is required, an H2A type of emission can be used.

2.5 There should be a maximum number of three radio beacon stations in a group.

3. Implementation of the new format

3.1 The proposed arrangements for the interim period, up to the time the new signal format is introduced, is shown in Fig. 2, from 1985 to 1991. It is essential to ensure that the revised radio beacon signal format is compatible with those in existence, in the interim period.

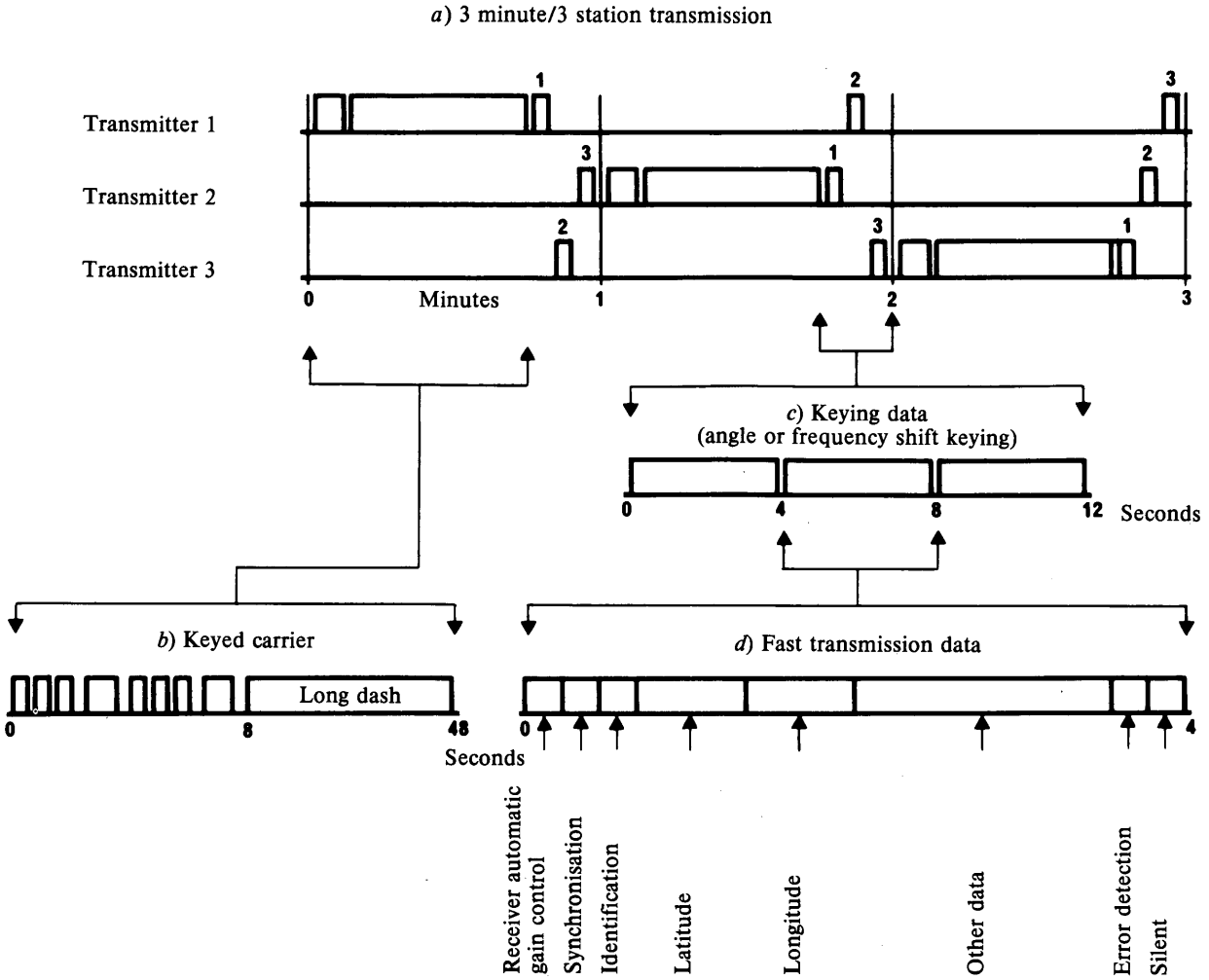


FIGURE 1 – *IALA technical proposals*

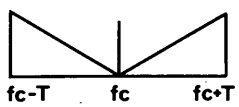
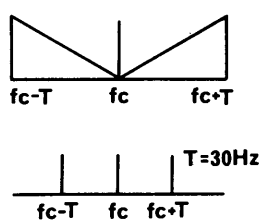
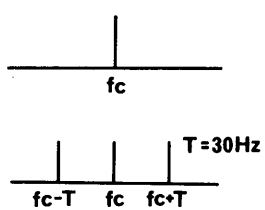
Notes:

1. Channel spacing in band 285 kHz to 315 kHz
1.1 Existing: 2.3 kHz spacing 12 Chs
1.2 Possible:
400 Hz spacing 73 Chs
500 Hz spacing 58 Chs
800 Hz spacing 36 Chs
1000 Hz spacing 29 Chs

2. Frequency shift keying data
Number of bits transmitted at various baud rates:

Baud	Number of bits (4 s of transmission)
50	200
75	300
110	440
150	600
200	800

Typical bandwidths required:
50 bauds ± 30 Hz: bandwidth 120 Hz
200 bauds ± 120 Hz: bandwidth 480 Hz

Year	Signal	Spectrum	Emission	Channel spacing	Signal character	Type of receiver	Type of transmitter	Remarks
1981 ↓ 1985	Amplitude modulated	Modulation index 70%  T = 354 Hz - 1052 Hz	A2A keyed carrier and modulation A2A carrier and keyed modulation H2A dual carrier	2.3 kHz	Morse identification (3-6) times 22 s Long dash 25 s Morse identification (1-2) times 8 s Silent 5 s total 60 s s = seconds	Wide band with or without beat frequency oscillator aural or automatic nulls	Power amplifier with double sideband drive unit or linear power amplifier with dual carrier	With dual carrier emissions less frequency spectrum used. Less interference between channels
1985 ↓ 1991	Amplitude and/or angle modulated (1)	T = 354 Hz to 1052 Hz  	A2A keyed carrier and modulation or A2A carrier and keyed modulation or H2A dual carrier and/or FID frequency shift keying	2.3 kHz	Morse identification (3-6) times 22 s Long dash 25 s Data 12 s Silent 1 s total 60 s or	Wide band with or without beat frequency oscillator aural or automatic null and/or narrow-band FSK with processor for station identification bearing and position	Power amplifier with double sideband drive unit or linear power amplifier with dual carrier and/or FSK with data input	Transition period for phasing out old system and introduction of new system
1991 ↓ ? ?	Carrier only and angle modulated (1)	 	AIA keyed carrier and FID frequency shift keying (FSK)	Max. 1 kHz	Morse identification Twice 8 s Long dash 40 s Data 12 s total 60 s	Narrow band with beat frequency oscillator aural or automatic null and narrow-band FSK with processor for identification bearing and position	Power amplifier stage with AI keyer unit and FSK keyer unit with data input	Changeover to new system 1991

(1) Angle modulation or frequency shift keying.

FIGURE 2 – *IALA proposed schedule*

REPORT 774-1 *

TECHNICAL PARAMETERS OF RADAR BEACONS (RACONS) FIXED-FREQUENCY RADAR BEACONS

(Question 27/8)

(1978-1982)

1. Introduction

Applications of radar beacons as an aid to the maritime radionavigation service have been under study in IMCO for some years.

1.1 *Radar beacon (racon)*

In the IMCO work, the use of the terms "radar beacon" and "racon" is considered to be reserved exclusively to those radar receiver/transmitters which are mounted on fixed structures or on floating platforms anchored at fixed locations to serve as an aid to navigation.

1.2 In the course of the study, an operational appraisal has been made during which present and planned uses of radar beacons by member states of IMCO have been surveyed. The following general principles have emerged from this study:

- significant degradation of the navigational radar display must be avoided;
- the proliferation and uncontrolled implementation of radar beacon services generally could lead to an unacceptable increase in beacon responses presented on a ship's radar display;
- radar beacons should be used only where an operational need has been established;
- to avoid confusion and ambiguity between radar beacon responses, it is important to have international agreement on the systems to be used.

2. Fixed-frequency radar beacons

2.1 A fixed-frequency radar beacon in the maritime radionavigation service is a receiver-transmitter device capable of receiving signals from any radar in its vicinity. The device, when triggered, is capable of responding automatically to any radar-equipped ship within its operational range and returns a distinctive signal on a fixed frequency. This signal can be displayed on the PPI of a suitably configured radar providing range, bearing and identification information.

2.2 The beacon will be triggered automatically by the transmissions of any radar operating in the appropriate frequency band.

2.3 The range, bearing and identification information from the beacon may be displayed continuously, either separately or superimposed on the radar picture, or may be switched off, at the option of the operator.

2.4 The World Administrative Radio Conference, 1974, approved the exclusion of shipborne radar from the two frequency bands 2900 to 2920 MHz and 9300 to 9320 MHz, making these two bands available for fixed frequency radar beacons in the maritime radionavigation service.

3. Operational uses

Operational uses which have been identified by IMCO include:

- ranging on and identification of positions on inconspicuous coastlines;
- identification of position on coastlines which permit good ranging but are featureless;
- identification of selected navigational marks both seaborne and land-based;
- landfall identification;
- identification of off-shore structures.

The operational standards to which such beacons should conform are contained in IMCO Resolution A.423 (XI).

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* The Director, CCIR, is requested to bring this Report to the attention of the International Association of Lighthouse Authorities (IALA), the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO).

4. Technical specifications for fixed-frequency radar beacons

Recommended technical parameters for fixed-frequency radar beacons are given in Table I. Some associated parameters of ship beacon receivers (see Annex I) are presented which would provide varying degrees of protection from potential interference by or to own or other ships' radar beacon receivers or beacons.

The design takes into account:

- minimum detection range of static beacon;
- maximum detection range of static beacon;
- traffic density in vicinity (i.e. operating detection range) of static or mobile user or both.

Of the fourteen static beacon parameters identified in Table I, eight are common to all systems (Section A), five (Section B) are range dependent with alternatives for each major group of beacon, and one parameter (Section C) is dependent upon traffic density.

Two families of parameters are presented in Table I and in Annex I.

A universally applicable fixed-frequency secondary radar system should be effective, technically simple and show a good return for capital investment. This latter implies long life before obsolescence, a major limitation of which could be the generation of unacceptable interference levels.

TABLE I

	Description	Specification
Section A	(1) *Static beacon*	
	1. Bandwidth allowance for transmitter frequency tolerance	9 MHz
	2. Form of identification Code (a)	Code must start with dash
	3. Form of identification Code (b)	1 dash = 3 dots = 3 spaces
	4. Antenna polarization	Vertical and horizontal
	5. Antenna aperture: elevation	$\leqslant 5°$
	6. Transmitter frequency:	Frequency bands: 9 300 - 9 320 MHz; 2 900 - 2 920 MHz — Assigned frequencies: 9 310 MHz; 2 910 MHz
	7. Receiver maximum blocking period	$\approx$ 30 µs after end of response
	8. Receiver frequency band:	9 320 - 9 500 MHz 2 920 - 3 100 MHz
Section B	9. Overall length of transmission	(1) 15 µs (2) 50 µs
	10. Primary radar pulse length detection	(1) $\leqslant$ 0.4 µs (2) 0.4-1.1 µs
	11. Transmission response(3): maximum delay	(1) 0.7 µs (2) 1.7 µs
	12. Transmitter power (effective):	
	Band 9 300 - 9 320 MHz	(1) 0.4 W (2) 3 W
	Band 2 900 - 2 920 MHz	(1) 0.15 W (2) 1.5 W
	13. Receiver tangential sensitivity:	
	Band 9 320 - 9 500 MHz	(1) - 67 dBW (2) - 79 dBW
	Band 2 920 - 3 100 MHz	(1) - 62 dBW (2) - 76 dBW
Section C	14. Antenna { Azimuth aperture Controlled paint rate	See Annex II

(1) Short-range: 0-10 nautical miles.

(2) Long-range: 10-30 nautical miles.

(3) Item 11 is related to Item 10 but is not, as such, an anti-interference parameter.

5. Interference

Interference may occur when several ships and radar beacons are in close proximity.

The band 9300 MHz to 9500 MHz is allocated to services in addition to the maritime service. There is permissive use of ground-based aeronautical radar beacons (ARB) and widespread implementation of airborne weather-mapping radar in this band and any proposals for change to maritime use of the band will need to take into account aeronautical use.

In the context of fixed-frequency radar beacon systems, interference arises from the generation and reception of unwanted information. The sources span three domains:

- space,
- time,
- frequency.

Methods applicable to the radar beacon are available which can provide varying degrees of interference reduction, most of which are independent. Neither the number of interference sources nor the methods of control of any one source of interference are exhaustive. Some aspects of interference and/or its control may be of more general application. Depending upon the circumstances, it is possible that some or all of the methods of interference control described could be applied to reduce the overall level of interference.

5.1 *Interference reduction in the space domain*

Interference in the space domain may arise when a number of functioning radars and a number of functioning radar beacons are located at any instant so that they are capable of detecting each other. Such interference can be materially reduced by controlling the designed aperture of the beacon antenna in both elevation and azimuth.

If the elevation aperture of the beacon antenna can be restricted to no more than 5° above the horizon, false triggering by overflying aircraft and the possibility of interference to aircraft radars would be minimized.

If the azimuth aperture of the beacon antenna was restricted for both reception and transmission, the beacon would respond to fewer interrogators and cause less interference compared with a beacon using an omni-directional antenna. For wide azimuthal cover with a narrow aperture antenna, the antenna must be rotated. This impinges on time domain aspects of interference reduction.

5.2 *Interference reduction in the time domain*

Interference in the time domain may arise when any given radar beacon generates more signals than are needed by a given radar. Such interference can be reduced by limiting the number of beacon responses.

If one or more antenna elements, each with a common limited azimuth aperture, are rotated together at a controlled rate, the number of interrogations and beacon responses will be a function of these three parameters. They can be adjusted as necessary to provide the recurrence rate of responses considered to be optimum for the particular application of the radar beacon. Annex II shows that a beacon array can be made up of any number of elements spaced symmetrically about the axis of rotation and each acting as an independent beacon to provide any solution.

Another method to minimize the number of times a radar beacon is unnecessarily triggered is to use circuits which identify the pulse length of signals received. Such circuits could be incorporated in the beacon receiver so that a beacon with a short range only responded to reception of up to about 0.4 μs pulses, whilst beacons with a long range only responded to reception of 0.4-1.1 μs pulses. A close limit should be placed on the maximum pulse length to which non-selective beacons will respond in order to preserve the freedom of particular systems to operate by selective recognition of coded pulse interrogation signals.

Beacon side-lobe responses may be eliminated from any display in the ship by using a separate beacon receiver channel associated with the ship's primary radar but with its own independent gain control.

The response from a beacon should be kept as short as is practicable. This would minimize the interference caused to other radars in the vicinity of the beacon and make available more time during which the beacon could be usefully interrogated by other radars.

5.3 *Interference reduction in the frequency domain*

Interference in the frequency domain may arise when a number of functioning interrogators operate on one frequency and/or a number of radar beacons operate on a single frequency (which may or may not be the same). Such interference can be reduced by minimizing transmission durations and by frequency separation.

In the frequency band 9300 MHz to 9500 MHz, only the sub-band 9300 MHz to 9320 MHz is available for fixed-frequency radar beacons. With the present state-of-the-art, the minimum channel bandwidth for such beacons is 14 MHz and consequently only one beacon channel can be accommodated. Evolutionary advances to simplify the technical problem to provide devices which can operate with less bandwidth and thus permit the 20 MHz sub-band to be divided into discrete beacon channels can be expected.

Complementary methods of reducing interference, but applicable to the beacon receivers associated with primary radars, are considered in Annex I.

5.4 *Interference reduction from ground-based aeronautical radar beacons (ARBs)*

Interference from an ARB may arise when signals from an ARB are intercepted by shipborne radars which are expecting to receive maritime racon signals on the same frequency. This may result in unwanted displays or degraded performance of the shipborne radar unless special measures are taken. Several techniques for spectrum sharing were considered in an analysis of compatibility between the ARB and the maritime racon. The method that was determined to be the most economical and technically feasible was that of pulse width discrimination.

The ARB will distinguish between aeronautical and marine radars by using this pulse width discrimination method. Maritime radars in the 9300 to 9500 MHz band operate with pulse widths of less than 1.1 μs. Aeronautical radars will interrogate ARBs with pulse widths of 2.35 μs. This difference will allow the ARB to use pulse width detection circuits to discriminate between the two types of radars.

As a result of the radar discrimination process, interference will be diminished because marine radars will not trigger aeronautical beacons and, therefore, will not receive unwanted replies.

5.4.1 *Technical information*

Technical information pertaining to a typical ground-based aeronautical radar beacon is given below:

Transmitter:

Frequency	9310 MHz
Necessary bandwidth (allowing for frequency tolerance of ± 3 MHz)	12 MHz
Power (measured at antenna terminals)	50 W
Form of identification	15 digital codes
Overall length of transmission	15.5 μs

Receiver:

Passband	9370 to 9380 MHz
Sensitivity	−55 dBm
Maximum blocking period	25 μs
Pulse length discrimination	2.35 ± 0.3 μs
Fixed delay in response	4.7 ± .01 μs

Antenna:

Gain	0 dB minimum
Beam width	azimuth: 360° elevation: 30°
Polarization	horizontal

6. Frequency requirements

An analysis of frequency requirements and necessary channel bandwidths is contained in Annex III. This analysis is limited to systems for the operational uses defined in § 3 of this Report.

7. Practical system tests

The Japanese Administration has reported the results of practical tests made with a system closely conforming to the parameters of Table I which confirm the suitability of such a system for operational use.

8. Conclusions

The defined operational requirements for fixed-frequency radar beacons in the maritime radionavigation service can be met by equipment having characteristics defined in this Report.

The frequency bands available at present permit operation (in 1978) on one frequency in each of the 2900 to 2920 and 9300 to 9320 MHz bands. The possibility ultimately to operate on more than one frequency in each band is foreseen.

Mutual interference problems have been analyzed and simple, inexpensive means have been defined for minimizing such interference in independent, progressive stages.

Two basic range-dependent groups of design criteria are recommended (Recommendation 554) together with special characteristics for operations in areas of high traffic density.

ANNEX I

INTERFERENCE REDUCTION AT THE MOBILE (PRIMARY RADAR) BEACON RECEIVER

The following methods of reducing interference could be applied to the shipborne equipment.

In the time domain, the shipborne beacon channel receiver may be switched on and off by an antenna controlled switch, so as to operate only over a limited sector of the horizon. This may be done on a continuous basis, covering either a pre-set or selected sector, and could be supplemented occasionally by an all-round scan. The effect of this would be to reduce the reception of unwanted beacon transmissions, whilst maintaining continuous beacon surveillance over the arc considered at the time to be the most important for the safe navigation of the ship.

In the time domain, the shipborne beacon channel receiver may be switched off except when it is required to make use of a beacon. This method would not stop the beacon from responding but only prevent the response from being displayed.

Table II gives system design specification options for mobile equipments which contribute varying degrees of protection possible from potential interference from other users.

Two parameters of the shipborne beacon channel receiver are common to all systems and two are both range and traffic density dependent.

TABLE II

Description	Specification	Where required			
		All	Short range 0–10 nautical miles	Long range 10–30 nautical miles	High traffic density
Mobile receiver					
1. Receiver type	Tuned	×			
2. Receiver bandwidth	10 MHz	×			
3. Side-lobe reduction			×		×
4. Limited arc of interrogation			×		×

ANNEX II

CONTROLLED PAINT RATE

1. In order for the beacon to "be seen" by any interrogating primary radar, the beacon must "look" at any point on the horizon for a period equal to or greater than the longest time taken by a radar antenna to scan the whole horizon (360°). This look must be repeated at the "paint rate".

2. If:

τ : beacon "look" time (s),

θ : beacon antenna azimuth aperture (rads),

n : number of beacon antenna elements,

N : required number of looks/min (paint rate),

R : beacon antenna array rotation rate (revs/min),

Then,

$$R = w \times \frac{60}{2\pi}$$

$$\therefore\ w = \frac{\pi R}{30} = \text{beacon antenna array rotation rate (rads/s)} \tag{1}$$

Now

$$R \times n = N, \text{ or } R = \frac{N}{n}$$

Also

$$\tau \leqslant \frac{\theta}{W} \leqslant \frac{\theta \times 30}{\pi R} \tag{2}$$

$$\therefore\ \theta \geqslant \frac{\sim \pi R}{30} \geqslant \frac{\pi R}{10} \text{ (rads)} \geqslant \frac{\pi R}{10} \times \frac{180}{\pi} \geqslant \frac{18N}{n} \text{ (degrees)}$$

given that

$$\tau < \frac{1}{20} \text{ min} \leqslant 3 \text{ s}$$

but since: N = 2 or 1.5 paints/min
= paint interval of 30 s or 40 s,

it is possible to define the antenna element beamwidth (θ) as a function of the number of elements in the antenna array (n) for the given values of N shown in Table III.

TABLE III

$N = 2$				$N = 1.5$			
n	$R = N/n$	θ		n	$R = N/n$	θ	
		rads	degrees			rads	degrees
1	2	0.628	36	1	1.5	0.471	27
2	1	0.314	18	2	0.75	0.236	13.5
3	0.66	0.209	12	3	0.5	0.157	9
4	0.5	0.157	9	4	0.375	0.118	6.8
5	0.4	0.126	7.2	5	0.33	0.105	6
6	0.33	0.105	6	6	0.25	0.079	4.5

ANNEX III

FREQUENCY REQUIREMENTS FOR FIXED-FREQUENCY RADAR BEACON SYSTEMS

1. Introduction

1.1 Two bands (2900-2920 MHz, 9300-9320 MHz) have been made available by the WARC-74 for the use of systems other than primary shipborne radar. It is necessary to assess the viability of these bands for fixed-frequency radar beacons and to determine whether they impose any constraints on such use.

1.2 The 20 MHz bands represent 0.6% of basic radio frequency in the 2900 to 2920 MHz band and 0.22% in the 9300 to 9320 MHz band. The more stringent allocation is therefore the one in the latter band and which is examined in this Report.

The minimum practical channel bandwidth needed for fixed-frequency radar beacon transmissions must make allowances for certain component frequency parameters in addition to the transmitted bandwidth. These former reflect current standards of commercial manufacture of solid state RF energy sources, e.g. Gunn diodes, etc., for beacon transmitters, and also for local oscillators of mobile receivers associated with primary radars that are used for reception of beacon transmissions. The frequency related parameters include:

- absolute setting up accuracy;
- intermediate term drift: temperature variation,
  power supply variations;
- long-term drift: aging;
- short-term: intra pulse.

Subsequently, the individual tolerances are viewed together to assess the minimum required single channel bandwidth.

2. Frequency: absolute: setting-up accuracy

2.1 Frequency parameters apply in two regions: the beacon transmitter and the mobile receiving equipment.

For devices being manufactured to operate on a fixed frequency of the order of 9.3 GHz, the working frequency of each device will need to be set up to some absolute standard of frequency. This implies two things:

- use of laboratory-standard test equipment;
- pre-set adjustments designed into components controlling frequency of RF energy sources.

It is estimated that a resultant tolerance of better than 0.5 MHz (2σ) can be achieved for these devices.

This tolerance, though small, must be assumed applicable to the worldwide manufacture of the RF devices concerned. 0.5 MHz (2σ) is believed to be within the state of the art and has been achieved for production quantities. The tolerance is treated as distinct from all other tolerances identified, e.g. drift.

3. Frequency stability with temperature variation

In both static (beacon) and mobile (ship) situations, the effect of temperature changes will be to cause the frequency of the energy sources to drift. Current performance suggests a drift figure of 1.4 MHz (2σ) over the temperature range 0-40 °C. Beacons may be required to operate outside this temperature range, and this would need the application of special techniques to maintain frequency stability to the above 2σ figure.

4. Frequency stability with power supply variation

Even allowing for normal stabilization of beacon power supplies, there will always be some residual variations in voltage. These will affect the frequency of the RF energy source independently from the temperature drift effects already considered. The effect of power supply variation is assessed as an independent tolerance of 0.1 MHz (2σ).

5. Frequency stability: long-term, aging

Unless special and costly precautions are taken, solid-state RF energy sources will exhibit symptoms of natural aging that include frequency drift. For equipment incorporating such devices that will be used unattended for long periods at a time, it is prudent to make an independent allowance of 3 MHz (2σ) for this source of drift.

6. Frequency stability: short-term, intra pulse variations

It is generally recognized that when solid-state RF oscillator devices are used in pulsed operation, the frequency generated changes during the period the device is switched on. The majority of this variation occurs during the initial period of operation and can be controlled using additional circuitry. Without these extra circuits, an additional independent frequency tolerance of 3 MHz (2σ) for this source of frequency variation must be made.

7. Minimum channel bandwidth

7.1 The minimum channel bandwidth required to span the likely transmissions of radar beacons using RF devices manufactured to a nominal fixed frequency is dictated by the overall frequency tolerance of those devices in and after manufacture. Using the figures presented in the foregoing paragraphs, the system tolerances are calculated and presented in Tables IV and V. This gives a $\pm 2\sigma$ figure of 9 MHz for devices operating in the region of 9.3 to 9.5 GHz. To this figure must be added the transmission bandwidth of 5 MHz, i.e. the bandwidth necessary to convey the correlated range information from the beacon to the mobile secondary radar receiver. Thus, the required minimum channel bandwidth for fixed-frequency radar beacon transmissions is 14 MHz.

TABLE IV

Notation n_k	Source of frequency variation	2σ frequency tolerance (MHz)
n_1	Absolute frequency setting up accuracy	0.5
n_2	Temperature variation (beacon)	1.4
n_3	Temperature variation (primary radar)	4
n_4	Power supply variation	0.1
n_5	Long-term aging	3
n_6	Short-term (intra pulse)	3

The overall system tolerances are calculated from the following equation:

$$(\sigma_s)\ \sqrt{\sigma_{n_1}^2 + \cdots\cdots + \sigma_{n_k}^2} \qquad (3)$$

where σ_{nk} relates to the k^{th} independent source of frequency variation and are presented in Table V.

TABLE V

Part of fixed-frequency radar beacon system	Relevant n_k (see Table IV)	Overall system tolerances ($2\sigma_S$) (MHz)
Transponder transmitter	n_1, n_2, n_4, n_5, n_6	4.5
Beacon receiver (Separate local oscillator)	n_1, n_2, n_4, n_5	3.35
Beacon receiver (Local oscillator common with primary radar)	n_1, n_3, n_4, n_5	5.03

7.2 It is clear, therefore, that on the basis of a required $\pm 2\sigma$ bandwidth the band allocation 9300 to 9320 MHz will accommodate a single fixed-frequency radar beacon transmission channel.

8. Nominal centre frequency of single channel

8.1 To minimize interference, an adjacent channel for similar system transmissions should preferably be separated by a guard band equal to the required channel transmission bandwidth; the initial selection of the centre frequency for a single channel in a limited bandwidth must be made with a clear understanding of future implications. Evolutionary advances in techniques and industrial processes will lead to tighter device specifications and, therefore, tighter frequency tolerances. This in turn will lead to smaller "$\pm 2\sigma$" figures and will permit narrower channel bandwidths.

8.2 The pattern for successive additional channel allocations should recognize and be consistent with existing allocations. This implies three things:

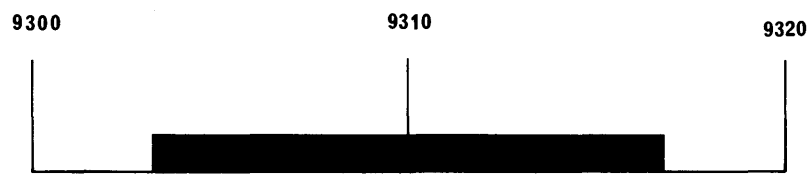
- the nominal centre frequency allocated to the first fixed-frequency radar beacon channel should be at the mid-band point (that is, 9310 MHz);
- any subsequent additional channel allocation should be in pairs of channels only;
- the centre frequencies of each additional pair of channels should be symmetrically spaced about the allocated beacon band mid-frequency point.

8.3 Theoretically, the number of fixed-frequency radar beacon channels that can be designated within a given available bandwidth will be restricted ultimately by the required transmission bandwidth of 5 MHz. If this remains the case, then the 20 MHz band – that is, 9300 to 9320 MHz – can never support more than one channel. If the transmission bandwidth can be reduced to say 2 MHz, then, as frequency tolerances fall, with advancing technology, it is reasonable to foresee that the band 9300 to 9320 MHz would be capable of supporting three fixed-frequency radar beacon channels with effective guard bands between each other and adjacent spectrum allocation.

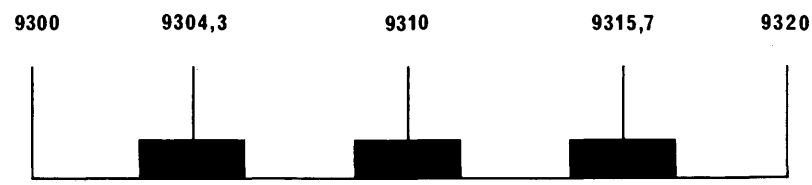
8.4 Any proposal on fixed-frequency radar beacon channel allocation must be related to:

- permitting the fullest effective use of the present band that is 9300 to 9320 MHz;
- operational needs with regard to acceptable levels of interference;
- operational needs with regard to system traffic density;
- the possible need to provide more channels within the same band as evolutionary advances in manufacturing performance and tolerances permit.

8.5 It is therefore proposed that 9310 MHz be used, in the first instance, as the nominal frequency for all fixed-frequency radar beacon systems operating in the band 9300 to 9320 MHz. This will permit successive generations of additional channel allocations to be made. The first and (a possible) second allocation are shown in Fig. 1.



(a) First generation: 1 channel: Bandwidth 20 MHz



(b) Second generation: 3 channels: Bandwidth 4 MHz

FIGURE 1 — *Successive spot frequency channels for fixed frequency beacons 9300-9320 MHz*

9. Mobile beacon-receiver bandwidth

9.1 There are two broad technical approaches to the design of the fixed-frequency radar beacon receiver associated with the primary radar:

- fixed-tuned;
- tunable.

9.2 For a fixed-tuned receiver, the receiver bandwidth requirements must be designed to accommodate the arithmetic sum of the following:

- the gross frequency tolerance of the beacon transmitter – 9 MHz,
- the information bandwidth of 5 MHz,
- the gross frequency tolerance of the beacon receiver local oscillator.

9.3 The cumulative bandwidth requirements of the 9300 to 9320 MHz band beacon transmitter frequency tolerance and the information bandwith is 14 MHz. To this figure must be added the radar receiver local oscillator frequency tolerance. This latter, since it will not be pulsed in the manner of the beacon transmitter and if it is a device separate from the radar receiver local oscillator, can be seen from Table V to exhibit an assessed $\pm 2\sigma$ figure of 6.7 MHz (7 MHz approximately). Thus the minimum theoretical fixed-tuned radar receiver bandwidth using a separate local oscillator device would be $14 + 7 = 21$ MHz.

9.4 If the receiver local oscillator is switched between radar and beacon channels, then the frequency tolerance figures used for temperature drift must be degraded to say 4.0 MHz for a temperature range of 0-40°. Then, again, from Table V it can be seen that the assessed $\pm 2\sigma$ figure degrades to 10 MHz, giving a minimum theoretical frequency preset receiver bandwidth requirement of $14 + 10 = 24$ MHz.

9.5 The bandwidth figures in §§ 9.3 and 9.4 have serious implications and are probably impractical for two reasons:

- the required receiver bandwidths equal or exceed the available band, thus leaving the receivers open to interference from authorized transmissions outside the band – as well as being wide open to all in-band generated interference;
- the required bandwidth unjustifiably lowers the ultimate receiver sensitivity, thus necessitating higher beacon powers for any given range performance and further aggravating potential in-band interference.

9.6 A third reason against the concept of the fixed-tuned beacon receiver is the added cost. The required minimum bandwidths are significantly larger than those presently in use. This implies that wide-band receivers would have to be specially manufactured, and this may involve relatively large increased costs.

9.7 For tuneable beacon receivers, provided they are capable of being tuned over the ranges identified in §§ 9.3 and 9.4 above, the receiver bandwidth theoretically need only be equal to the transmission bandwidth of 5 MHz. This is not realistic because of the practical problems of initially detecting the beacon transmission and then of tuning the receiver for best performance. Achieving an acceptable bandwidth is likely to involve a compromise technical solution using methods that permit significant reduction of the receiver bandwidth towards the beacon transmission bandwidth; e.g. one such method would be to apply frequency modulation to the local oscillator when it is being used to receive beacon transmissions.

This would mean that:

- beacon receiver channels can be produced having bandwidths chosen from the manufacturers' libraries of existing radar receivers,
- potential interference is reduced.

9.8 It is therefore considered that a frequency tuneable beacon receiver associated with the radar is the better solution.

10. Summary

A single fixed-frequency radar beacon channel can be supported within the 20 MHz bandwidth 9300 to 9320 MHz, made available by the WARC-74, based upon present (1978) component frequency stabilities.

It is considered that the initial beacon channel centre frequencies be 2910 and 9310 MHz.

It is considered that the available 20 MHz bandwidth may ultimately support three beacon channels.

It is considered that the beacon receiver in the radar should be tuneable.

RECOMMENDATION 554 *

TECHNICAL CHARACTERISTICS OF FIXED-FREQUENCY RADAR BEACONS (RACONS)

(Question 27/8)

(1978)

The CCIR,

CONSIDERING

(a) that the use of radar beacons to mark aids and hazards to maritime navigation has provided a significant improvement in the radar navigation of ships;

(b) that several administrations at present operating swept-frequency radar beacons to mark lighthouses, buoys and other aids, as well as hazards to maritime navigation, will continue to do so for an indefinite period of time;

(c) that several administrations are considering the introduction of fixed-frequency radar beacons in the future; and

(d) that the selection of the technical and other characteristics of radar beacons should be internationally agreed upon by the maritime interests and coordinated with other users of the same frequency bands whose operations might be affected,

UNANIMOUSLY RECOMMENDS

1. that the preferred technical characteristics for fixed-frequency radar beacons should be as given in Table I;

2. that in areas of high traffic density fixed-frequency radar beacons may, where necessary, use rotating antennas with the azimuth aperture suitably reduced. (See Annex II of Report 774.)

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* The Director CCIR is requested to bring this Recommendation to the attention of International Association of Lighthouse Authorities (IALA), International Civil Aviation Organization (ICAO) and Inter-Governmental Maritime Consultative Organization (IMCO).

TABLE I

Item	Characteristics	Specification
1.	Bandwidth allowance for transmitter frequency tolerance	9 MHz
2.	Form of identification Code (a)	Code must start with a dash
3.	Form of identification Code (b)	1 dash = 3 dots = 3 spaces
4.	Antenna polarization	Vertical and horizontal
5.	Antenna aperture: Elevation Azimuth	 $\leq 5°$ 360°
6.	Transmitter frequency: Band 9300 to 9320 MHz Band 2900 to 2920 MHz	 9310 MHz 2910 MHz
7.	Maximum receiver blocking period	$\approx$ 30 µs after end of response
8.	Receiver frequency band	9320 to 9500 MHz 2920 to 3100 MHz
9.	Overall transmission length	(1) 15 µs (2) 50 µs
10.	Minimum primary radar pulse length gating	(1) $\leq$ 0.4 µs (2) $\geq$ 0.4 µs and $\leq$ 1.1 µs
11.	Transmission response maximum delay	(1) 0.7 µs (2) 1.7 µs
12.	Transmitter power (erp): 9310 MHz 2910 MHz	 (1) 0.4 W (2) 3 W (1) 0.15 W (2) 1.5 W
13.	Receiver tangential sensitivity band: 9320 to 9500 MHz 2920 to 3100 MHz	 (1) −67 dBW (2) −79 dBW (1) −62 dBW (2) −76 dBW

(1) Short range 0 to 10 nautical miles.
(2) Long range 10 to 30 nautical miles.

REPORT 775-1 *

FREQUENCY REQUIREMENTS FOR SHIPBORNE TRANSPONDERS

(Question 28/8)

(1978-1982)

1. Introduction

Shipborne applications of transponders have been under study by IMCO and elsewhere for some years. In IMCO, Resolution No. A423(XI), a shipborne transponder is defined as follows:

Transponder a receiver-transmitter device in the maritime radionavigation service which transmits automatically when it receives the proper interrogation, or when a transmission is initiated by a local command. The transmission may include a coded identification signal and/or data. The response may be displayed on a radar PPI or on a display separate from any radar or both, depending upon the application and content of the signal.

In the course of the IMCO study the following observations were made concerning the future use and development of transponders.

Transponders offer a capability for the exchange of information between ships, and between a ship and shore. The use of transponders could therefore offer a potential for reducing collisions and other accidents which may be caused by inadequate knowledge of the identity, manœuvring characteristics, position, intended or actual movement of ships.

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* The Director, CCIR, is requested to bring this Report to the attention of the International Association of Lighthouse Authorities (IALA), the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO).

The proliferation and uncontrolled use of transponder devices generally could lead to an unacceptable increase in responses presented on a ship's radar display, degrading the usefulness of the navigational radar display, and causing confusion among multiple transponder responses.

Larger numbers of transponders might be supported by the use of selective interrogation, as well as by the international specification of technical parameters to be met by these devices.

Realization of most of the future benefits of some types of transponders requires modification or replacement of shipboard radars to provide radar equipment with the necessary transponder modes. The uncontrolled proliferation of transponders could produce incompatibilities among devices developed for different uses, or could necessitate a succession of modifications to shipboard radars to accommodate progressive developments of transponders.

The greatest value will be gained from these devices when navigational information derived from their responses is presented in a simple and straightforward form.

2. Operational characteristics

IMCO Resolution No. A423(XI) states that a transponder is a device which, when properly interrogated, can provide for:

2.1 ship radar target identification and echo enhancement with the proviso that such enhancement should not significantly exceed that which could be achieved by passive means on the radar PPI of an interrogating ship or shore station;

2.2 radar target correlation with voice or other radio transmission for identification on the radar PPI of an interrogating ship or shore station;

2.3 operator selectable presentation of transponder responses, either superimposed on the normal PPI display or free of clutter and other targets;

2.4 transfer of information pertinent to avoidance of collision or other hazards, manœuvre, and manœuvring characteristics, etc.

Transponders should be used to meet the following purposes:

- identification of certain classes of ships (ship-to-ship);
- identification of ships for the purposes of shore surveillance;
- search and rescue operations;
- identification of individual ships and data transfer;
- establishing positions for hydrographic purposes.

3. Basic concepts

It follows from the IMCO work that the broad heading of shipborne transponders covers simple systems involving a short transmission indicating only that an interrogation has been received, through target enhancement and identification, up to complex systems involving high data-rate exchange.

Therefore, a wide range of potential systems needs to be considered, taking account of the various technical parameters of the interrogating transmitters, the transponders and the receivers of transponder emissions to determine the optimum frequency requirements.

4. Present state of system development

4.1 *USA – Maritime Radar Interrogator-Transponder (MRIT)*

In the United States, development intended to assist in safe navigation of ships is being investigated.

4.1.1 *Technical description*

The technical development in 1976 had reached a stage whereby feasibility had been demonstrated. Fig. 1 shows a block diagram of the basic configuration of the MRIT as tested. The principal elements are:

- transceiver,
- microwave diplexer,
- omni antenna,
- antenna switch,
- control and display sub-system.

Preliminary tests have been made (at power levels of less than 100 W output) in the band 9300 to 9500 MHz, which is shared with other services.

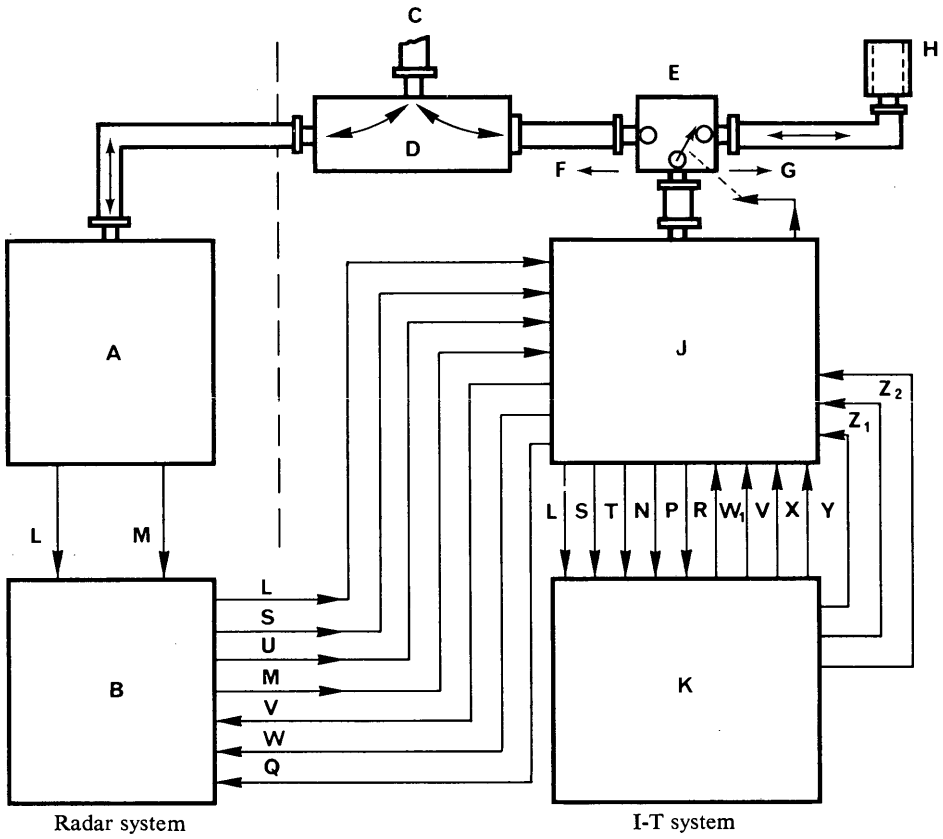


FIGURE 1 — *Block diagram of a Maritime Radar Interrogator Transponder (MRIT) (USA)*

A: radar transceiver unit
B: radar indicator
C: radar antenna
D: diplexer
E: antenna switch
F: interrogate
G: transpond
H: omnidirectional antenna
J: I-T transponder/transceiver unit
K: I-T control display (digital circuits)
L: trigger
M: video
N: R video
P: B video
Q: composite video
R: composite video to radar
S: variable range marker
T: range gate
U: end of range gate
V: delayed trigger
W: sweep start
W_1: delayed sweep start
X: antenna switch
Y: receiver inhibit
Z_1: data to modulator
Z_2: data detector

4.1.2 *Operation*

The MRIT is integrated into a standard shipboard radar and operates in two principal modes:

- interrogation – the operator interrogates all equipped vessels through an omnidirectional antenna or a particular vessel through the directional scanning antenna;
- response – the transponder responds through an omnidirectional antenna.

Specific interrogation and response messages are transmitted by coding of the pulse trains. The following information interchange transactions are examples:

Interrogation	*Abbreviation*	*Addressed to*	*Response of own identification and selected data*
Echo enhancement	EE	All	Automatic
Identification	ID	All	Automatic
Selective supplementary information	SSI	Selected vessel	Automatic
Direct communication	DC	Selected vessel	By operator

4.1.3 *Initial evaluation*

Tests on very simple MRIT configurations have demonstrated the technical feasibility of accomplishing the objectives of the system. Several problem areas were encountered which will require additional development or study. These include the most suitable order of frequencies and bandwidth required for this purpose. Technical parameters to be established for MRIT devices also must take into account electromagnetic compatibility with other services having allocations in the same band.

4.2 *U.S.S.R. – Shipborne Interrogator-Transponder (SIT)*

4.2.1 *Operational experience*

Studies and successful operational trials of shipborne Interrogator-Transponders (SIT) conducted in fishing vessels have demonstrated their utility as navigational and ship movement control aids.

The studies and tests carried out for many years past point to the convenience of secondary radar for fishing and merchant vessels.

Cumulative experience of shipborne SIT operation has demonstrated the usefulness of this equipment for:

- intership exchange of operational navigational data;
- individual vessel identification;
- discrimination of identification responses against a background of interference;
- extending the detection range for small vessels through active response.

4.2.1.1 *Operational requirements*

According to the results of the preliminary investigations, the main system requirements are as follows:

- to provide total identification (coordinate blips on the screen of the plan position indicator (PPI) of the ship's radar station close to the vessel blips);
- automatic reception of data from one of many vessels (display on a special digital panel of the parameters of the ship's movements or its anticipated manœuvres);
- equipment of all merchant vessels with interrogators-transponders;
- ensure that any mutual effects between SITs and the shipborne radar station or other shipborne radio equipment do not cause any interference.

4.2.2 *Operating principles*

The system presupposes that vessels are equipped with interworking SIT sets. Each SIT operates in conjunction with the ship's navigational radar. The pulses triggering the interrogation signal coder are sent from the radar to the SIT, and the pulses on the pindicator screen derived from the identification pips of the vessel equipped with a SIT are sent from the SIT to the radar.

Interrogation takes place on two frequencies, by the sounding pulse of the ship's radar (in the 9 GHz band) and by the coded interrogation pulse of the SIT (in the 3 GHz band).

The interrogation code pulses are emitted ahead of the radar main pulse. This 12 μs lead is essential for decoding by the interrogated vessel's responder.

A block diagram of a SIT operating in conjunction with a ship's radar is given in Fig. 2.

The SIT operates in both interrogation and response mode. It is normally in the response mode ("Interrogate" switch off). To receive information from a ship whose echo pulses are reproduced on the radar display screen, the navigator switches the SIT to interrogation mode.

4.2.3 *Interrogation frequency*

In the U.S.S.R. preference is given to the technique whereby interrogation is effected simultaneously on two frequencies – by the shipborne radar station in the 9 GHz band and by the shipborne interrogator-transponder on a fixed frequency in the band 2930 – 2950 MHz (No. 772 of the Radio Regulations). The design principle proposed differs from the radar frequency interrogation system described in §§ 4.1.1 and 4.1.2.

The advantages of the two-frequency interrogation method over systems using shipborne radar frequency interrogation are:

- improved noise-immunity of the interrogation channel;
- electromagnetic compatibility between shipborne radar and SIT;
- simple interworking of SIT with existing and future shipborne radar.

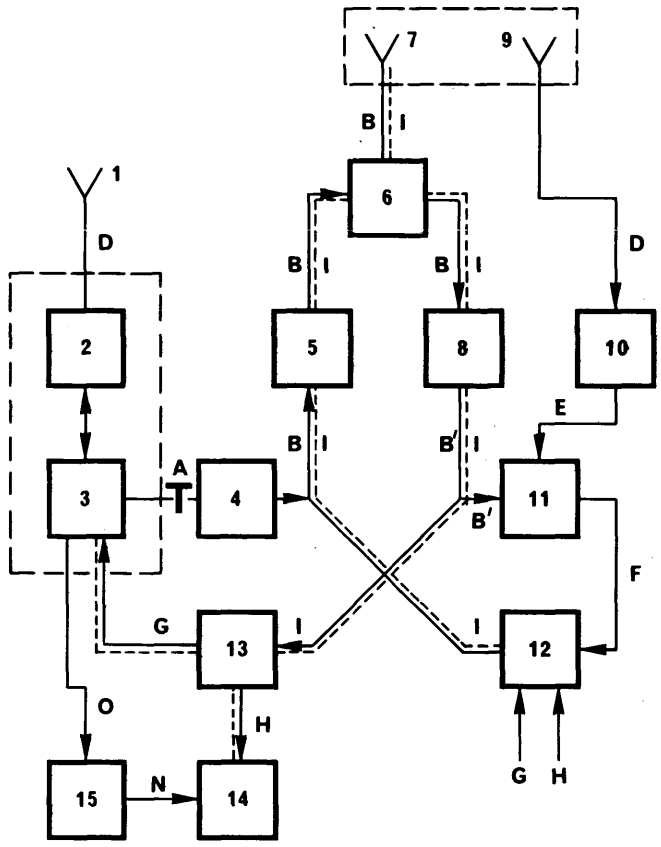


FIGURE 2 – *Shipborne interrogator transponder (SIT) (U.S.S.R.)*

——— { B interrogation signal
B' interrogation video signal
------ I response signal

The interrogation pulses (A) of the radar indicator (3) are sent to the coder (4) which forms the interrogation signal (B) to be emitted by the transmitter (5).

The coded interrogation signal (B) passes from the output of the transmitter (5) through the (Y)-circulator (6) for emission by the omnidirectional antenna (7). After the interrogation signal (B) has been emitted, the radar transceiver (2) emits the main pulse (D) by the narrow-beam radar antenna (1). The SIT of the interrogated vessel, which is in response mode, receives the interrogation signal via the antenna (7) and the main pulse (D) via the antenna (9). The interrogation signal (B) then passes through the (Y)-circulator to the receiver (8), is converted into the video signal (B') and is directed to one of the inputs of the decoder (11). Another input of the decoder (11) receives the pulse (E) from the output of the receiver (10); this pulse (E) is formed by detection of the main pulse (D) received by the antenna (9). When both signals from the pulse (F) match up, they trigger the coder of the response signal (12). The coded response (I) contains either the identification signal (G) or course and speed data (H), depending on the helmsman's requirements. The response code (I) is sent to the transmitter (5) and is then connected through (Y)-circulator (6) to the omnidirectional antenna (7) for emission.

The SIT antenna (7) on board the interrogating vessel receives the response signal (I), which reaches the receiver (8) via (Y)-circulator (6), and then passes to the response signal decoder (13). The identification pulse (G) transmitted for reproduction on the radar indicator (3) is extracted from one output of the decoder (13), while data on course and position (H), for example, reach the SIT digital display (14) from the other output. The digital display (14) also receives the strobe-pulse (N) generated by the SIT circuit (15) at a given instant corresponding to the angular position of the blip relative to the radar course blip pulse (0).

When these signals coincide on the digital display (14), the digital information is reproduced. The helmsman selects the blip on the radar screen on which it may be useful to obtain information.

The radar produces the triggering-lead pulse, the variable-range pulse and the course-blip pulse, while the identification video signal is sent from the SIT to the radar.

An omnidirectional antenna and a standard transceiver are used for interrogation and response.

The system capacity of 100 000 code combinations means that up to 100 000 ships can be individually identified.

4.2.4 *Technical specifications for a shipborne interrogator-transponder*

On the basis of operating experience with similar systems, the following requirements may be established:

- The range of detection of transponder signals with a probability of 0.5 for standard atmospheric refraction and seas of up to force 4 must be not less than 0.6 of the radio horizon.
- The minimum range must be not more than 500 m.
- The distance resolution must be not more than 400 m.
- The directional resolution must be not less than double the width of the radiation pattern of the shipborne radar station in the horizontal plane.
- The time stability of the response signal referred to the interrogation signal must ensure the high-precision autotracking of the response signal.
- The SIT must be easy to install and use in combination with all shipborne radar stations and ARPA equipment, and the transponder must be designed for use in combination with course and speed sensors.
- The transponder of the interrogated vessel must switch on automatically only on the simultaneous appearance at its receiver input of pulses of the radar station and the interrogator code at a frequency in the band 2930-2950 MHz.

4.2.5 *Interference*

On a secondary basis, SITs may not cause interference to radio reception on the ship.

The interrogator-transponder must be equipped for protection against the following interference:

- Interfering echo signals from the surface turbulence of the sea.
- Spurious interrogations by the sidelobes of the radar station antenna to which the interrogator-transponder is connected.
- The effect of the radar station transmitter and the transmitter of the shipborne satellite communications system on the SIT receiver.

4.3 *Japan-liferaft-borne transponders for search and rescue operations*

A swept-frequency in-band for operation at a frequency of 9320-9500 MHz has been developed for use on the inflatable liferafts generally used in Japan. The use of liferaft-borne transponders is an effective means for indicating the position of survival craft on a radar PPI and thus improving the consistency of urgent recognition of survival craft on the sea.

4.3.1 *Technical description and operation*

The transponder is composed of:

- an electronics package with an antenna, which is mounted on the canopy of the liferaft;
- a monitor speaker unit;
- a sea-water battery, which is thrown overboard.

The dimensions of the electronics package are 200 mm height and 60 mm diameter, and the weight is 120 grams. Fig. 3 shows a block diagram of the transponder. The transponder receives any signals in the 9 GHz band, and responds with a signal that paints a 20-blip display of an equivalent length of 8 nautical miles (NM) (100 μs) or 16 NM (200 μs) on a radar PPI to indicate the position of the transponder. On the liferaft, the beeping of a monitor speaker informs those in distress that a rescue vessel is approaching. The 20-blip signal used as the distress code is provisionally selected for the following reasons:

- The coded signal should be different from the swept-frequency radar beacon response codes for navigational aids recommended by IMCO.
- The oscillator circuit has to be simply constructed to assure high reliability.
- Harmful degradation of images on radar PPIs should be avoided. In the future, an international standard code for use with survival craft transponders should be discussed.

4.3.2 *Results of sea trials and computer simulations*

An interrogating radar with an antenna height of 14.8 m was able to recognize the transponder with 100% consistency at distances of 10 NM or more. In comparison with this, the maximum visual-search distances using binoculars were found to be 1 NM at night and 2-3 NM under day-time clear skies. By computer simulations, it was found that at Beaufort 8 sea conditions, obstruction of the propagation path by large waves and off-beam of the radar and/or transponder antenna caused the consistency of recognition to fall below 50%.

It was found that at a distance between 0.05 NM and 0.5 NM, as a result of multipath reflections and side-lobe response of the radar antenna, the chain of blips on the rescue vessel's radar scope broadens to form a series of concentric circles to indicate close proximity to the survival craft.

Signals emitted by several radars and the presence of several transponders did not cause harmful mutual interference or any deterioration of the usefulness of the normal radar PPIs. Therefore, it is possible to use this in-band transponder for enhancing the indication of the position of survival craft.

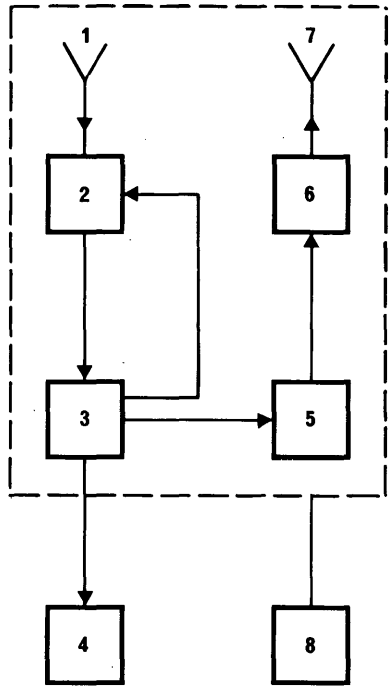


FIGURE 3 – *Block diagram of a swept-frequency in-band transponder for search and rescue operation (Japan)*

The interrogating radar signal is received using the horizontal omnidirectional antenna (1) and the wide band receiver (2). The gate generating circuit (3) generates a gate pulse of width 100μs or 200μs synchronized to the interrogating pulse train and used to drive the receive inhibit circuit and the monitor speaker (4) as well as being fed to the sawtooth deviation frequency modulator (5). The modulator generates 20 repetition of sawtooth signal for every gate pulse and this sawtooth signal is used to frequency modulate the solid state microwave oscillator (6) within a given frequency range (e.g. 9320–9500 MHz) the signal of which is radiated by a horizontal omnidirectional antenna (7). The output power of the transmitter is approximately 40 mW. Power supply (8) is a seawater battery developed for the transponder.

4.4 *United Kingdom – Interrogator-transponder*

A simple cross-band transponder system has been developed in the United Kingdom and equipment tests have been carried out successfully in the intended environment.

4.4.1 *Technical description and operation*

The transponder contains all the antennas, transmitters and receivers which are necessary for the system to operate in conjunction with a marine radar. There are two interconnections between the radar and the transponder, one to provide a synchronization pulse from the radar to the transponder and the other to provide a video return back to the radar.

Two-frequency interrogation is used in the system, one frequency being in the 5 GHz band and the other in the 9 GHz band at the frequency of the vessels' marine radar. The frequency in the 5 GHz band is also used for the response.

A two-pulse code is transmitted from the interrogating vessel's transponder at 5 GHz and, shortly afterwards, is followed by a transmission from the same vessel's primary radar. The 5 GHz pulse code is received by the second vessel's transponder, decoded and used to open a 9 GHz receiver in the transponder for long enough to enable the reception of the radar transmission from the interrogating vessel. The response, which is initiated by the correct reception of the radar emission, is transmitted at 5 GHz and consists of a four-pulse code. When received by the interrogating vessel the response is presented as a series of dots on the radar display. Figure 4 shows a block diagram of the system.

Identification of each vessel can be achieved by varying the spacing between the pulses in the four-pulse reply code. By using different pulse spacings in the two-pulse interrogating transmission a number of these transponders can operate satisfactorily in independent groups in the same vicinity, without interference between the groups.

The system can accept about twenty vessels, the actual number being determined primarily by the ease by which the response can be discerned on a radar display. Means of automatically decoding the response could be added and the system would then, theoretically, be capable of being used by up to one million vessels.

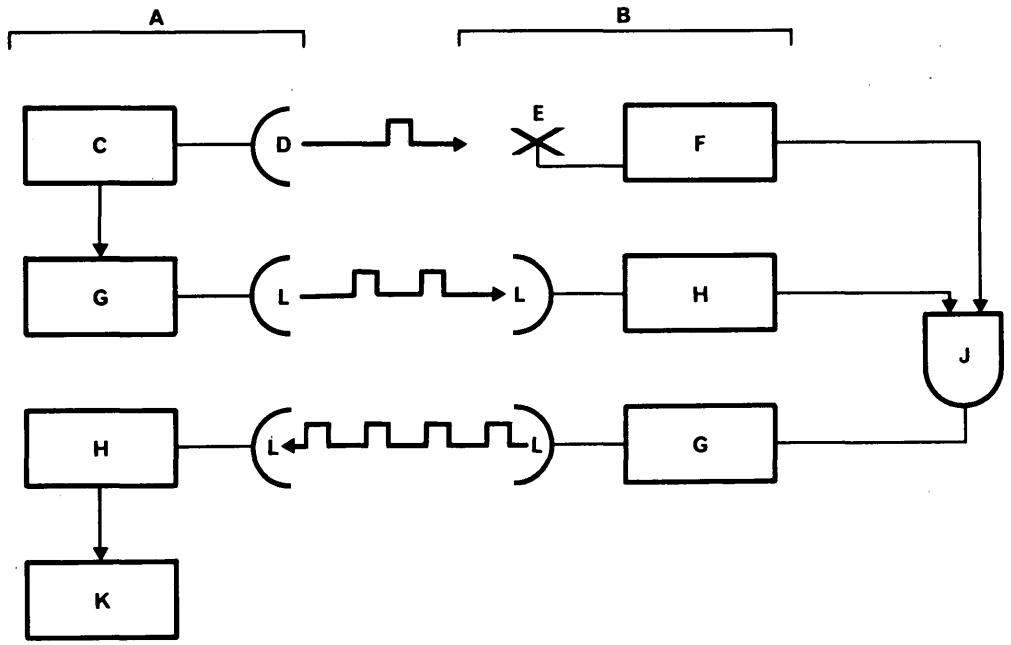


FIGURE 4 – *Interrogator-transponder system (UK)*

A: interrogating station
B: responding station
C: radar transmitter
D: radar antenna
E: omnidirectional antenna
F: 9 GHz band receiver
G: 5 GHz band transmitter
H: 5 GHz band receiver
J: "AND" gate
K: radar display
L: antenna with beamwidth of approximately 180° in azimuth

5. Other transponder types

In support of local and particular applications, transponders which use techniques and frequency bands different from those conventionally used by radars can be very effective.

In this respect, France has commenced experiments using low power transponders in the UHF band.

These experiments are associated with civil applications in providing navigational assistance to very large vessels entering and leaving harbours.

In the United Kingdom a system has been developed, and is now operational, to provide range and velocity information to vessels entering the narrow confines of the deep dredged channel of a particular harbour. The system interrogates and responds in that part of the 9 GHz band available for harbour surveillance radar systems.

6. Choice of frequency

Most marine radars currently operate in the bands 2900 MHz to 3100 MHz and 9300 MHz to 9500 MHz.

The band 9300 MHz to 9500 MHz is allocated to services in addition to the maritime service. There is widespread implementation of airborne weather/mapping radar in this band and any proposals for change to maritime use of the band will need to take into account the aeronautical use.

In some shipborne systems, there may be advantages in choosing a frequency that would permit the use of conventional radar antenna. This is because a narrow-beam rotatable antenna may be needed both to make possible the measurement of the bearing of a transponder with the necessary precision and reduce the intensity of interference between systems. However, for many systems other frequency bands may be more suitable.

Although it may also be necessary for interrogation purposes to use bands allocated for radionavigation, it would be more appropriate to use other maritime mobile bands for data responses.

A swept frequency in-band transponder designed to reduce the harmful deterioration of radar PPI displays can be used for search and rescue operations, and some administrations have identified that interrogator-transponder systems operating on the principle of two frequency interrogation, offer a number of advantages, and these are indicated in this report.

7. Interference

7.1 *Assessment of interference*

The basic information to be taken into consideration when evaluating interference includes:

- the physical environment, e.g. ship structure reflections and blind arcs, propagation over the sea and clutter;
- unavoidable engineering limitations, e.g. antenna sidelobes and limited available bandwidth;
- the level of interference as a function of possible systems parameters and the number of transponders in operation, including interactions between transponders and effects of different methods of display;
- the maximum density of the distribution of shipping likely to make use of transponding systems;
- the extent of the use by other services of the frequency bands allocated to radionavigation.

7.2 *Factors which may be taken into account to minimize interference*

Signals from a transponder are unintelligible unless received separately from other signals. Many transponders may share the same frequency band. Some of the techniques available for reducing the probability of interference are:

- selection of bearing by means of a directional antenna. This technique is limited by the response of the antenna to signals received from directions away from the main lobe. The sidelobe response may be no more than 20 dB below the main lobe response;
- selection by coded interrogation. This technique would not normally be used when interrogation by the primary radar is required, because of the difficulties involved in coding the pulse. It is most effective and minimizes interference to the transponder system when using a transmitter other than the radar (posssibly on another frequency) to interrogate the transponder. In the event the transponder receiver is operating on the frequency of a primary radar, a separate transmitter other than the radar might transmit in the interpulse period between primary radar transmissions and make use of the primary radar antenna.

8. Coding

Coding systems will need to be determined to satisfy applications such as ship identification, location of survival craft, and data transfer.

9. Summary

The development of transponder systems for shipborne information transfer has been reported from the USA, the U.S.S.R. and the UK for search and rescue operations from Japan, and for ship-to-shore applications from France and the United Kingdom.

IMCO Resolution A423(XI) recommends for transponders that:

- the design of transponder systems should ensure that there is no significant degradation of fixed-frequency radar beacons, and the response of a transponder should not be capable of being interpreted as being from a radar beacon of any type;
- where a transponder is to be used with a marine navigational radar, any modifications necessary to the radar should not degrade its performance, be kept to a minimum, be simple and, where possible, be compatible with a fixed-frequency radar beacon facility;
- in-band transponders should not be used to enhance the detection of marine craft, except when specially authorized by administrations for use in survival craft;

IMCO [1977] also considers that:

- the long-term aim should be to develop transponder systems which are compatible with each other. Work has only recently started in this field and the preparation of international operational standards should be deferred pending the results of further study into the operational requirements.

10. Conclusions

The most important requirement is to determine the interference between radar and transponder systems and the interference between transponder systems. Studies are required to achieve an acceptable interference model which should include those factors identified in §§ 7.1 and 7.2.

To achieve optimum results in these studies, it will be necessary to assume certain nominal values for the power spectra of current radar transmitters and the output of radar receivers as a function of frequency.

There is also a need to study the capacity and integrity of the coding systems that might be necessary, since they are likely to be significantly different and have a range of options of increasing complexity to satisfy the various operational requirements.

It will also be necessary to assess the likely degradation of data transfer in adverse environmental and propagation conditions and to determine the limits of acceptable error in the information received.

Assessment of future systems should include both radar and non-radar techniques.

A thorough investigation and evaluation into the techniques suitable for the various possible operational uses of transponders is necessary before the most suitable order of frequencies and bandwidths could be recommended.

REFERENCES

IMCO [September, 1977] NAV XX/10.

BIBLIOGRAPHY

SUEUCHI, K., KOTOH, K. and YAJIMA, T. [1980] Computer simulation of maritime search and rescue operation using newly developed radar beacon. 13th Annual Simulation Symposium, sponsored by the IEEE, ACM & SCS.

REPORT 914 *

EFFICIENT USE OF THE RADIO SPECTRUM BY RADAR STATIONS IN THE RADIODETERMINATION SERVICE

(Question 35/8)

(1982)

1. Introduction

1.1 Question 35/8 seeks to study what efficiency can be achieved in the radiodetermination service through the use of interference suppression techniques for radar stations (DECIDES 1), information on the technical characteristics of radar (DECIDES 2) and what radiodetermination services can utilize interference suppression techniques effectively (DECIDES 3).

1.2 This Report examines aspects of the Question relating to interference reduction techniques for maritime radionavigation shipborne radars, fixed radars in the radiodetermination service, and maritime radar beacons (racons) in the case involving unwanted signals from aeronautical radar beacons (ARBs).

1.3 The millimetric waveband between 30 GHz and 150 GHz is examined for the purpose of providing a general review of the likely use of this part of the spectrum for radar purposes.

2. Interference reduction: general

2.1 There are a number of methods to reduce mutual interference and enable stations of the radiodetermination service in close proximity to use the same frequencies.

Some of these techniques applicable to:

- shipborne radars;
- fixed radars; and
- frequency sharing between ground-based aeronautical and maritime radar beacons in the 9300 to 9320 MHz band are outlined below.

The techniques, however, are not necessarily interchangeable between categories; while interference suppression methods described for shipborne radars may be applicable to fixed radars on a case-by-case basis, the reverse is not necessarily true.

2.2 Techniques that might be capable of reducing radar-to-radar interference can be divided into the following groups:

- those techniques applied to a radar transmitter which reduce the quantity of unwanted signals generated that are likely to cause or create interference (primarily shipborne interference suppression);
- those techniques applied to a radar receiver which reduce the effects of any signals that cause or create interference (primarily shipborne interference suppression);
- those techniques applied to a radar receiver which allow it to discriminate between wanted and unwanted signal pulses (primarily fixed radar or aeronautical radar beacon interference suppression).

3. Interference reduction methods: shipborne systems

3.1 Techniques which are in principle capable of contributing to the reduction of radar-to-radar interference between shipborne primary radar systems can be used separately or together to reduce either the generation of interfering signals (or their strengths) by the user, or the effects of interference on the user. Methods which may be applied include:

- pulsed magnetron transmitted spectrum,
- transmitter modulator – and transmitted radio frequency – pulse profile,
- radar spurious emissions,
- radar receiver selectivity,
- video processing,
- random pulse repetition frequency,
- antenna gain and sidelobe performance.

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* The Director, CCIR, is requested to bring this Report to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO), the International Civil Aviation Organization (ICAO) and the International Association of Lighthouse Authorities (IALA).

3.2 *Pulsed magnetron transmitted spectrum*

Magnetrons employed in maritime radar systems may be expected to have a spectral bandwidth that is never better than 10 to 13 dB down from peak at

$$\pm \frac{5}{4 \times \text{Pulse Width } (\mu s)} \quad \text{MHz}$$

from natural centre frequency and will still be no better than about 26 dB down at ± 100 MHz from centre frequency at X-band (about 9 GHz). When this is related to the bandwidths allocated to maritime radionavigation systems at X-band and also to the vast and increasing number of operating systems on that band it is clear firstly, that any contribution to reducing the spectral emission from such magnetrons would tend to reduce levels of radar to radar interference and secondly, that there is considerable scope for dramatically reducing the current bandwidths and levels of spectral emission - even to the costly alternative of changing from magnetron devices to, for example, Klystrons. In any case reducing bandwidths and levels of spectral emissions in one type of radar transmitting equipment will always improve the performance of associated receivers and will reduce interference to other radar users.

3.3 *Transmitted pulse profile*

Techniques are available to control the profile of transmitted pulses. Radar range accuracy is largely dependent on the slope of the transmitted radar pulse leading edge. Thus, if there is a requirement for a given range accuracy this will control the minimum necessary pulse rise time. Shortening the rise time beyond that necessary value will involve transmission of sideband energy that:

- will not be used by the originating radar, and
- will cause interference to other radars.

The pulse leading edge should only be as short as is absolutely necessary to generate the required range accuracy.

A complementary argument applies in relation to range discrimination requirements. This is largely dependent on the slope of the pulse trailing edge (and also on pulse length). A requirement for a given target range discrimination will be a control on the minimum necessary pulse decay time and also on the pulse length. Shortening the pulse decay time beyond that necessary value will involve transmission of sideband energy that:

- will not be used by the originating radar, and
- will cause interference to similar radars.

The pulse trailing edge should only be as short as necessary to provide the required range discrimination.

At present the spectral profile of primary radar transmissions extends a long way in both directions from the centre frequencies of the transmissions. Only a limited proportion of this energy spectrum is used by the associated radar receivers, and the remainder need not be transmitted.

3.4 *Radar spurious emissions*

Pulsed magnetrons generate radio energy on spurious frequencies. These rarely bear any relationship to operational frequencies. These spurious emissions can be controlled by transmitter design. Interference could be reduced if acceptable levels were agreed on an international basis.

3.5 *Radar receiver selectivity*

There is a minimum receiver bandwidth required once range accuracy is specified. Other considerations, such as minimization of the effects of sea clutter, and requirements for automatic frequency control (AFC) have led to the design of receivers with special characteristics which require wider bandwidths than those resulting from only the range accuracy requirement. Such receivers are therefore more susceptible to interference from other radar transmissions. It would be possible, in principle, to specify minimum bandwidths. Beyond this bandwidth, receivers should reject heavily as much radiation as possible since it is not required. This could be achieved by using existing techniques.

3.6 *Video correlation techniques*

Radar receiver video correlation techniques may be applied to minimize the effects of some types of interference. Video echo information received from one (i.e. own) radar pulse is recorded. Video echo information received from the next succeeding, (own) radar pulse is then recorded and also compared with previously recorded echo data.

Several such systems are in practical maritime use. The main limitation of this technique is that it is not effective against sea clutter because such radar returns correlate over periods that are long compared with typical radar pulse repetition intervals. There is also some slight risk of reducing the capability to detect weak echo signals.

3.7 *Random pulse repetition frequency*

The use of a jittered or pseudo random variation in the pulse repetition frequency (PRF) could reduce radar-to-radar interference, if used in association with the video correlation techniques already described. By applying psuedo random variation to the radar pulses the time relation between them and any pulses received from any other radar in a potentially interfering configuration will be made random, and therefore the suppression action of the video correlation process will ensure that only a small proportion of the interfering pulses are displayed. If the video correlation is extended to 3 successive pulses the probability of an interfering pulse being displayed is very small indeed.

The principle is theoretically constrained, at least, in this application in two respects:

- the maximum PRF will be limited by the range scale selected;
- the minimum PRF will be limited by the need to avoid unacceptable loss of information. A jitter ratio of about 2 : 1 represents the theoretical scope safely available.

Systems incorporating this pseudo-random technique are not known to be in use at this time, although variable PRF techniques are already applied for other reasons. The only operational constraint is, as mentioned above, a slight but controlled reduction in the rate of information received.

3.8 *Antenna gain and sidelobe performance*

3.8.1 Typical present radar antenna performance is approximately:

- gain: ~ 24-30 dB;
- first major sidelobe level within $\pm$ *10° of antenna boresight:* more than 23 dB down on mainlobe;
- all other sidelobes more than $\pm$ *10° from antenna boresight:* more than 30 dB down on mainlobe.

3.8.2 The above performance can be improved to:

- gain: 40 dB;
- first sidelobe: 33 dB down on mainlobe, (gain = 7 dB);
- all other sidelobes: more than 40 dB down on mainlobe, (gain = 0 dB).

This design of antennas for shipborne use would involve an increase in size and weight and would necessitate considerable tightening of all mechanical tolerances. This would restrict application to larger vessels. It is also open to question whether the associated narrower main beam widths are advantageous e.g. with regard to sea clutter.

In addition, the improved antenna and associated receiver do not improve the performance of the antenna and receiver combination in the ability to reject interference from other radars.

3.8.3 A similar performance to that in § 3.8.2 has been attained by using sidelobe reduction techniques on the type of antenna in § 3.8.1, which would largely obviate the penalties mentioned in § 3.8.2.

3.8.4 To obtain the advantage of the last two antenna designs (see § 3.8.2 and 3.8.3) it would be necessary to reduce transmitter power to achieve the same e.i.r.p.

3.8.5 *Summary of shipborne interference reduction*

Table I lists the forms of interference reduction techniques described above and offers an indication of possible advantages and disadvantages. None of the techniques identified will cause significant loss of system sensitivity. However, certain techniques cause the loss of the display of radar beacon signals and of small targets. It is desirable in these cases for operational reasons to provide the capability for switching out the interference rejection circuitry. In specific instances, techniques in isolation or in combination could improve either sensitivity and/or range accuracy and/or range discrimination. This brief review of techniques available implies that several methods exist that could contribute to the reduction of interference. Some may appear unattractive for a variety of non-technical reasons. An important technical criterion of any method is that its use should preserve unimpaired the compatibility

between all systems. In only one instance, (see § 3.8), would an interference reduction technique limit future use of an assigned frequency. The narrower the antenna beam width (i.e. the higher the gain) the narrower becomes its usable bandwidth. This would prevent the use of a directive antenna for concurrent use with a radar beacon and/or shipborne transponder system operating at frequencies only about 3% away from own radar frequency.

4. Interference reduction methods: fixed radar systems

4.1 *Pulse repetition frequency discrimination*

4.1.1 In some areas of the world which have a high density of ship or aircraft traffic there is a need to operate several fixed radar installations within interference range of each other. Anomalous propagation conditions can, at certain times, increase the range at which interference occurs, particularly in lower latitudes such as the Mediterranean region.

4.1.2 Some of the techniques described in § 3 above, may be applied to reduce interference between fixed radar stations. Another technique involving pulse repetition frequency discrimination is described below.

4.1.3 Interference between fixed radar stations may be avoided by radio frequency separation or pulse repetition frequency discrimination (PRFD). The frequency band allocated to radio navigation may not be wide enough to assign separate frequency channels to all stations within interference range. This is particularly so when the radar stations are mobile, as on ships or aircraft.

TABLE I – *Interference reduction for shipborne mobile radars*

Interference reduction technique	Ease of use and operation	Reliability	Maintenance	Switched off when not in use	Remove beacon responses	Long term potential	Limitation of broadband use
1 Controlled transmitted pulse leading edge	E	NK	NE	NA	no	yes	no
2 Controlled transmitted pulse trailing edge	E	NK	NE	NA	no	yes	no
3 Reduce spurious emissions	E	NK	NE	NA	no	yes	no
4 Improve/substitute magnetron	E	NK	NE	NA	no	yes	no
5 Improve radar receiver selectivity	E	NE	NE	NA	no	L	no
6 Video correlation techniques	E	NE	SI	yes	no	yes	no
7 Random pulse repetition frequency	E	NE	SI	yes	no	yes	no
8 Improve antenna gain/sidelobes	E	NK	NE	NA	no	L	yes

E : easy
NK : not known
NE : no significant effect
SI : slight increase (additional circuits)
NA : non-applicable
L : limited

4.1.4 The effect of interference may be reduced if the pulses radiated from a radar can be given some characteristic such that only those received pulses conforming to this characteristic are displayed on the radar screen. By using different PRFs for different stations it can be arranged that a signal is only displayed when two successive pulses with the correct time delay are received back from a target. This method has been used successfully in the network of 600 MHz radar stations used for air traffic control purposes by the Civil Aviation Authority in the United Kingdom.

4.1.5 The methods for selecting suitable PRFs have been published [Blythe, 1970]. The selection is complicated because such radar stations use Moving Target Indicator (MTI) to differentiate between radar reflections from fixed or slowly moving objects, such as buildings and clouds, and those from rapidly moving aircraft which are required to be seen even in the midst of "clutter". Such MTI methods use phase comparison between successive reflected pulses to cancel out signals which are returned with the same phase relationship to the transmitted pulse. Unfortunately, as well as cancelling reflections from stationary objects, reflections from targets moving with certain radial velocities are also cancelled, and aircraft moving at these blind speeds are not displayed by the radar. To avoid loss of these targets the radar pulses are not emitted at a regular rate, but two or more different intervals are used in the train of pulses. This is known as pulse stagger.

4.1.6 The planning of the radar radio frequencies and the pulse repetition rates for both pulse stagger and PRFD will depend upon the relative locations of the radar stations and the propagation conditions in the area. By using PRFD the number of stations working without interference can be considerably increased and thereby the spectrum may be more economically used.

4.1.7 Taking these techniques into consideration, it was possible in the United Kingdom to plan to operate a number of high-power 50 cm radars in a relatively narrow frequency band; for example, seven such radars operate on the frequency of 591 MHz and five on the frequency of 597 MHz. These techniques also enable two high-power radars to operate at the same airport, and in the same frequency band, without unacceptable interference.

4.1.8 In the 600 MHz radar band, PRFD has been used in the United Kingdom to avoid the need to expand the spectrum required, and to enable the required number of radars to work in the restricted allocated band without causing unacceptable interference between themselves or to television reception in other countries.

4.2 *Asynchronous interference reduction techniques for fixed radar systems*

4.2.1 *Introduction*

The transmitter emission spectrum of a pulsed radar station in the radiodetermination service is usually much wider than the spectrum of general communications systems. It is sometimes very difficult to achieve interference-free operation between stations by frequency assignment procedures alone when such stations are within a certain range of each other. Consequently, in addition to frequency assignment procedures, interference reduction techniques are required to achieve interference-free operation. A type of interference reduction technique used in air traffic control (ATC) radars operating in the aeronautical radionavigation service is described herein.

4.2.2 Interference reduction techniques in the time domain are considered to be the most practical for ATC radars when considering the present ATC technology in the world and when comparing techniques in the frequency domain, time domain and mixtures of methods of both time and frequency domains. The Asynchronous Interference Reduction Techniques (AIRT) as described herein are in the time domain. They are utilized in Japan where their effectiveness is recognized. Peripheral techniques used to increase the effectiveness of the AIRT are also described.

4.2.3 *AIRT description*

Desired return data signals of a radar are received in the same range (or time) within a certain azimuthal angle while interfering signals from other radars are generally asynchronous to the desired return signals. Consequently, desired return signals can be extracted, for example, by storing the return data signals of two to four desired radar pulse periods. Such return data signals are stored in a memory and used to perform range (or time) correlation of the stored data and the latest return data signals. A description of the AIRT system used in the simulation study described herein is presented in Annex I.

4.2.4 *Factors impairing AIRT performance and improvement measures*

4.2.4.1 *AIRT performance deterioration*

The prerequisite for effective performance of the AIRT circuitry is to limit the width of a pulse signal entering the circuitry to a specific value or less. When this condition is not met and the pulse width is greater than the limited value, the required time correlation of the asynchronous signals will be increased and the effectiveness of the AIRT will decline. This is due to the wide pulse width and the excessive intensity of the interfering signal.

Figure 1 shows the relationship between the interfering signal intensity (relative to mean noise level) and the output pulse width. Fig. 2 shows the block diagram of the measurement circuit. The simulation of the deterioration of the AIRT performance caused by the wide pulse width was conducted by using the signals shown in Fig. 3. In this case, the pulse width in space for both the desired signal and asynchronous interfering signal is assumed to be one microsecond. As a result of this simulation, the boundaries causing interference are indicated by the solid line shown in Fig. 4a and 4b.

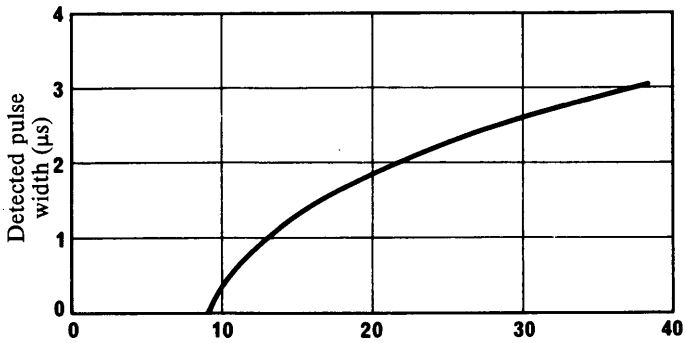


FIGURE 1 – *Detected pulse width versus input signal level*



FIGURE 2 – *Measurement circuit*

A: pulse modulated signal input, 1 μs

B: matched filter

C: threshold circuit, 10.8 dB relative to average noise level

D: detected pulse output

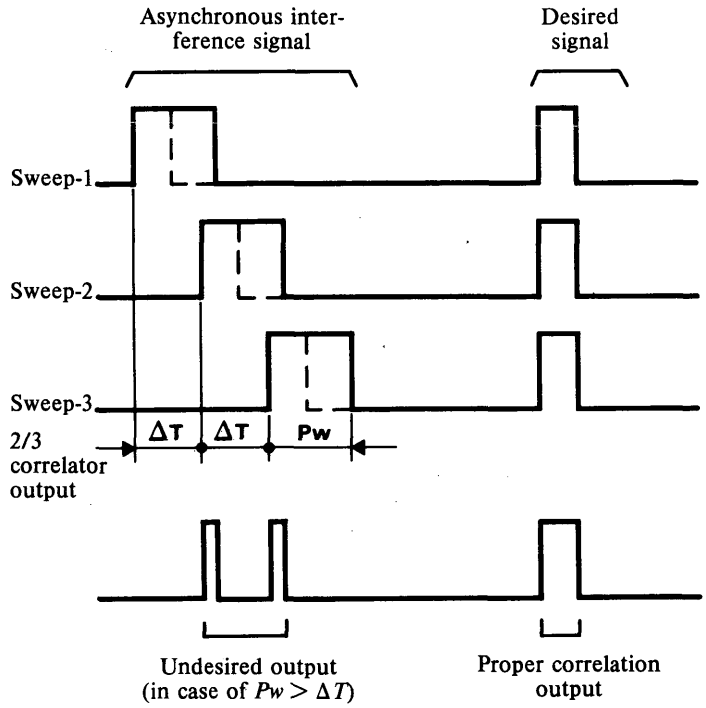


FIGURE 3 – *The restriction of interference suppression*

T: difference between desired signal pulse period and interference pulse period.

Pw: detected pulse width that is the function of interference signal strength as shown in Fig. 1. (The limited width waveform by the pulse width discriminator is illustrated in dashed line.)

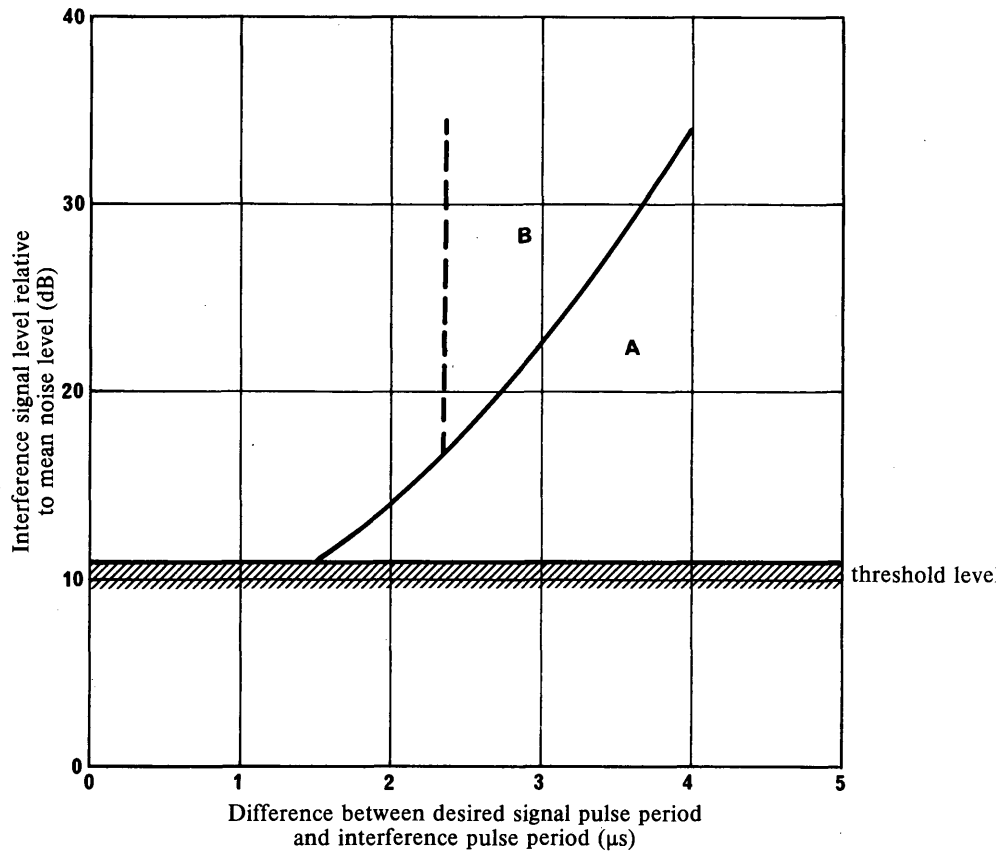


FIGURE 4a – *The suppressed regions for interference signals by 2/3 correlator*

A: suppressed region without pulse width discriminator
A + **B**: suppressed region with pulse width discriminator

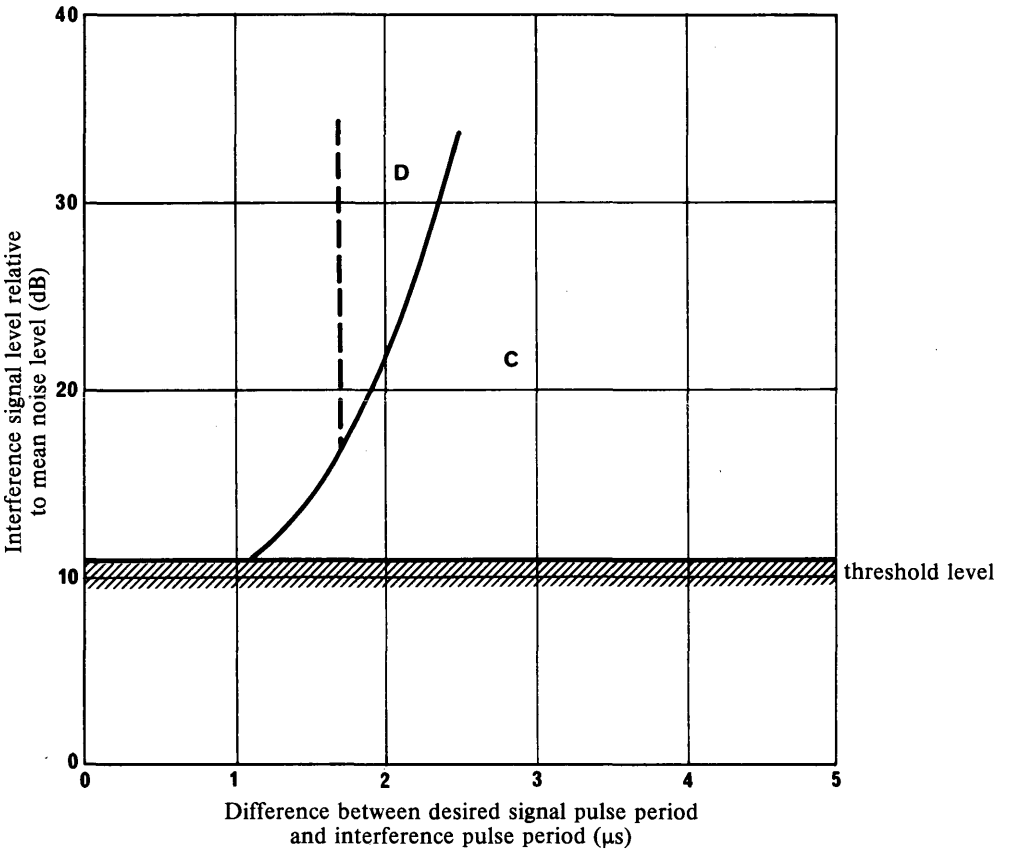


FIGURE 4b – *The suppressed regions for interference signals by 3/5 correlator*

C: suppressed region without pulse width discriminator
C + D: suppressed region with pulse width discriminator

4.2.4.2 *Alleviating AIRT performance deterioration*

In order to alleviate the AIRT performance deterioration produced by overly wide pulses, it is necessary to perform a pulse width discrimination before AIRT signal processing. Such pulse width discrimination is provided by the Moving Target Indicator (MTI) circuitry. The interfering signal is shaped into a specific width regardless of the input signal pulse width or level. Examples of the shaping circuitry are the Fast Time Constant (FTC) circuit and the Logarithmic/Constant False Alarm Rate (Long/CFAR) circuit. This pre-processing effect, as shown by the dotted line in Fig. 4a and 4b, ensures the effective operation of the AIRT when the interfering signal exceeds a certain pulse width or level.

4.2.5 *Techniques for improving AIRT performance*

4.2.5.1 *Reducing the degree of correlation*

The AIRT provides interference reduction by using the time (or range) correlation between the desired received signals and the interfering signals that are asynchronous to them. The AIRT performance can be improved by reducing the degree of correlation between the desired and interfering signals without deteriorating the minimum detectable signal level of the desired signals.

4.2.5.2 *Staggered PRF*

In order to improve the velocity response of the MTI, the ATC radar varies (at a certain ratio) the time interval between transmitted pulses. This is called staggering the pulse repetition frequency (PRF). If either of two radar stations provided with this staggered PRF reverses the sequence of the staggered pulse interval between them, the degree of correlation between them will decline, thereby increasing the AIRT performance.

4.2.5.3 *Increasing the number of samples of correlation*

Increasing the number of samples of correlation will increase the effect of the range correlation filter. For example, simulation was performed for the case where desired signals are those that are correlated two or more in three samples, and for the case where desired signals are those that are correlated three or more in five samples. The effect of the filter technology proved to be better in the latter case. The results are shown in Fig. 4a and 4b.

4.3 *Summary of fixed radar interference reduction*

4.3.1 *Pulse repetition frequency discrimination*

The technique of PRFD could be used in other frequency bands to improve the spectrum utilization and could, in principle, also be applied to pulse radar applications other than those described in this document. The application of the PRFD technique must be considered with other desired signal performance factors such as receiver sensitivity. In the case of mobile radars the benefits are limited by the impossibility of predicting the relative position of radars using the same pulse repetition frequency.

4.3.2 *Asynchronous interference reduction techniques*

4.3.2.1 The AIRT utilizing the asynchronous nature of interfering signals are extremely effective in ordinary ATC radar systems.

4.3.2.2 The following are required for improving the effect of the AIRT:

- provision of a pulse width discriminator before performing the processing by the AIRT,
- providing a function of reversing the staggered PRF sequence in the MTI radar having a staggered PRF,
- increasing appropriately the number of samples of the correlator of the AIRT.

5. Interference reduction methods: radar beacons

5.1 Maritime radar beacons (racons) operate in the 9300-9320 MHz band. Ground-based aeronautical radar beacons (ARBs) share this band on a non-interference basis to maritime radar beacons. An aeronautical radar beacon is a receiving and transmitting device operating at a fixed location for the purpose of aeronautical radionavigation. When triggered (interrogated) by an airborne radar, the ARB acts as a transponder and automatically identifies itself by returning a distinctively coded signal.

5.2 As stated in the Radio Regulations No. 825, ground based radar beacons are permitted in the band 9300-9320 MHz on condition that they do not cause harmful interference to the maritime radionavigation service. If interference suppression techniques are used, harmful interference to maritime radars from ARBs can be avoided.

5.3 Signals from an ARB could be intercepted by shipborne radars which are expecting to receive maritime racon signals on the same frequency. This may result in unwanted displays or degraded performance of the shipborne radar unless special measures are taken. Several techniques for spectrum sharing were considered in an analysis of compatibility between the ARB and the maritime racon. Among these techniques are: separation of frequencies, pulse coded interrogations, pulse repetition frequency (PRF) discrimination, geographical separations, antenna polarization discrimination, antenna vertical pattern control, and pulse width discrimination. The method that was determined to be the most economical and technically feasible was that of pulse width discrimination. There are two ways by which a maritime radar could receive signals from an ARB. The maritime radar could trigger the beacon and receive a synchronous reply, or another radar could trigger the beacon and the maritime radar could receive an asynchronous reply. The synchronous reply is a more serious interference problem but it can be avoided by pulse width discrimination.

5.4 The ARB will distinguish between aeronautical and marine radars by using this pulse width discrimination method. Maritime radars in the 9300-9500 MHz band operate with pulse widths of less than 2.0 μs. Aeronautical radars will interrogate ARBs with pulse widths of 2.35 μs. This difference will allow the ARB to use pulse width detection circuits to discriminate between the two types of radars.

5.5 As a result of the radar discrimination process, interference will be diminished because marine radars will not trigger aeronautical beacons and, therefore, will not receive unwanted replies. However, a marine radar may receive an asynchronous ARB signal if the beacon is first triggered by an aeronautical radar. This situation requires both radars to be within certain distances of the ARB at the same time. This rarely-occurring situation should considerably reduce the chance of interference. Also, ARBs and maritime racons are coded differently for identification purposes. This coding will allow processing in the marine radar to prevent falsely identifying an ARB as a maritime racon.

5.6 Apart from the techniques used by the ARB for interference reduction, several methods for promoting compatibility are discussed in Report 774, "Technical parameters of fixed frequency radar beacons (racons)".

5.7 *Summary of interference reduction ARB to racon*

5.7.1 As stated in the Radio Regulations, the aeronautical radar beacon operates in the band 9300 to 9320 MHz. It is greatly needed for helicopter navigation in poor weather and in many critical landing areas.

The ARB is in agreement with the frequency allocations of the Radio Regulations. The technical parameters for ARBs were developed considering operational performance in varying weather conditions, as well as compatibility with maritime racons. Frequency sharing between the aeronautical and maritime beacon systems will require careful planning to ensure compatible operations. Pulse width discrimination and discrete beacon coding for identification provide methods of achieving compatibility with maritime racons.

6. Characteristics of future radar equipments

6.1 Question 35/8 (see § 2) seeks information on the technical characteristics of radar. This section examines the millimetric waveband between 30 GHz and 150 GHz and provides a general review of the likely use of this part of the spectrum for radar purposes.

6.2 *Advantages and disadvantages of millimetric wavelengths for radar*

6.2.1 The main advantages of working in the millimetre wavelength region are:

6.2.1.1 The fact that relatively small antenna apertures can give high values of gain and very narrow beamwidths, the latter allowing good angular resolution and minimizing the unwanted effects of ground reflections and ground clutter even at quite low angles of elevation.

6.2.1.2 The large spectrum widths available, compared with those permitted at lower frequencies, allow excellent range resolution to be obtained. In addition, for the longer term, it will often be possible to have many radars in a band, all in close proximity geographically and even perhaps having frequency agile transmitters, without incurring serious mutual interference.

6.2.1.3 A lower probability of interference to other services because of the atmospheric attenuation effects and the narrow beamwidths likely to be used.

6.2.2 The principal disadvantages of these wavelengths for radar, many of which would also affect other possible applications in this region are:

6.2.2.1 The residual attenuation in clear air, especially for propagation at sea level, which is present even in the "windows" where most radar applications are likely to be located. (See Reports 719 and 721.)

6.2.2.2 The high additional attenuation, and the large amount of radar back-scatter, in rain, even of low intensity (though the narrow antenna beamwidths and good range resolution usually employed will help reduce the effects of the back-scatter). This characteristic would be likely to make these bands unsuitable for long range airborne weather radars.

6.2.2.3 With very narrow beams (which are more likely to occur in these bands, see § 6.2.1.1), it becomes more difficult to make the compromise between the number of pulses per illumination and the data renewal rate for continuously scanning radars, even with the higher PRF's which can be used in short range equipments.

6.2.2.4 The limited performance of many active and passive components. As a rough general rule the peak powers obtainable from a given type of transmitter tube are reduced in proportion to at least (wavelength)^2, and the problems of removing unwanted heat can mean an even more rapid fall in mean power; the receiver noise factors tend to increase with frequency, and attenuation losses in waveguide etc. become more and more significant.

6.2.2.5 The relative cost of components is currently higher than those for longer wavelengths, principally because of the high mechanical precision needed in their manufacture (though limited production volume is a factor).

The factors in § 6.2.2.1 to 6.2.2.4 above, mean that nearly all potential applications at millimetre wavelengths will be in relatively short range systems.

6.2.3 *Some possible applications of radar in the millimetre wavelength bands*

For the present purpose the potential future applications for radar in the millimetre wavelength region may be classified under four headings:

6.2.3.1 Ground radars such as airfield surface movement indicators taking advantage of the high angular ($\approx 0.1°$) and range resolutions obtainable at these wavelengths. They would be used continuously and with antenna rotation times typically in the order of a few seconds.

6.2.3.2 Certain airborne radar systems such as those for terrain following, and for obstacle and power-line avoidance in helicopters; they would utilize the good angular resolution ($\approx 0.5°$ to $1°$) obtainable with antennas of moderate size, and sector scan times would be in the order of 1 s or less. Another possibility is the high resolution ($\approx 0.1°$) sideways-looking (i.e. non-scanned) airborne radar for ground mapping, etc. Except perhaps in a few areas, for example near heliports, these would probably cause only relatively infrequent interference with other equipments on the same frequency.

6.2.3.3 A small number of ground radar applications such as short-range surveillance, tracking and guidance systems, the latter taking advantage in particular of the reduction of ground reflection effects etc. down to low angles of elevation which is made possible by the narrow antenna beamwidths ($\approx 0.2°$). The probability of these interfering with other equipments would seem to be small.

6.2.3.4 A very few extremely powerful systems for space tracking, planetary radars and similar purposes, with large antennas having high gain (≈ 80 dB) and very narrow beams ($\approx 0.02°$), and high power transmitters. These would not be scanned continuously but would be pointed in directions well above the horizontal so that atmospheric attenuation effects are kept to a minimum.

6.2.3.5 A few other possible very low power radar-like devices such as millimetre wave "security fence" type systems, motorway headway detectors etc. might also use these frequencies. However, with their low e.i.r.p.s and very restricted coverage it is unlikely that they would ever cause a significant interference problem, except in the vicinity of extremely sensitive receivers such as those used in radioastronomical observatories.

6.2.4 It is seen that there will probably be a wide diversity of millimetre wavelength radar systems, and radar parameters will depend very much upon the application. Thus very short range radars usually will have relatively modest antenna gains (≈ 30 or 35 dB) and low transmitter powers provided by solid state sources; "medium" range systems may have antenna gains in the order of 40 to 50 dB (i.e. about $1°$ beamwidth) and magnetron transmitters delivering several kilowatts of peak and a few watts of mean power, while the space radars will often require $G_T \approx 80$ dB and high power gyrotron transmitters.

6.2.5 The only common features will be that all radars will have quite short pulse lengths (in the order of 0.1 μs or less), or will obtain the equivalent good range resolution by using pulse compression techniques, so that the maximum spectral power density will tend to be comparatively low, and also that pulse recurrence frequencies will always be quite high. Depending mainly on the maximum range of the radars, the PRF's will be 3000 pps or more; the exceptions will be the space radars, but even here a high order of range ambiguity will be accepted.

6.2.6 *Summary of probable transmitter power capability at millimetre wavelengths*

6.2.6.1 The most promising form of pulsed sold state transmitter device appears to be the IMPATT diode. Because of heating effects during the pulse, it is thought that at around 100 GHz the highest power likely to be obtained from a single device in the foreseeable future will be in the order of 10 W peak, the maximum pulse length being limited to about 0.1 μs. It will, of course, be possible to obtain higher powers at longer wavelengths, and by combining the power from several diodes it is probable that at any frequency something like 5 times the power output of a single device will be obtained.

6.2.6.2 Performance of vacuum tube type transmitters is best summarized by giving the power levels already achieved in different frequency bands. Except where noted, the pulse length for pulsed transmitter tubes will be less than 1 μs; the frequencies and power levels quoted are only approximate.

Backward wave oscillators (BWOs): More than 50 W CW at 35 GHz; 40 W CW at 75 GHz.

Klystrons: 800 W CW at 55 GHz; 500 W CW in the 80 GHz region. It is also estimated that at about 80 GHz it should be possible to obtain 10 kW peak in 10 μs pulses with up to 0.005 duty ratio.

Travelling wave tubes (TWTs): 1 kW CW at 35 GHz; 150 to 200 W CW, or 5 kW peak, at 55 GHz; 100 W CW or 1 kW peak in the 80 GHz region.

Magnetrons: Up to 100 kW peak at 35 GHz; 5 to 10 kW peak in 50 ns pulses in the 80 GHz region; 2.5 kW peak at 120 GHz.

Gyrotrons: 100 kW CW, or at least 250 kW peak in long pulses with 0.05 duty ratio, at 35 GHz; 50 kW CW at 55 GHz; 15 kW CW near 80 GHz. These devices currently tend to be "noisy".

6.2.6.3 It is seen that in all frequency bands the gyrotron gives the highest powers so far achieved; but it should be remembered that this is a rather large device using megavolt (or near-megavolt) electronics, which could only be accommodated in large fixed radar installations.

6.2.6.4 While it would be rash to assert that no other forms of solid state or vacuum tube type transmitter will be developed for the frequencies of interest here within the next 20 years, it must be remembered that there will always be fundamental limitations to the peak and mean power outputs imposed by device size and heat removal problems. There are also limitations to the peak power levels which can be handled by conventional waveguide at atmospheric pressure (5 kW peak in WR 12 for use between 70 and 90 GHz, for example): these can be overcome to some extent, however, by pressurizing, or by filling the guide with, for example, sulphur hexafluoride gas, or – with care – by using overmoded (that is, oversize) waveguide.

REFERENCE

BLYTHE, J. H. [1970] Separation of radars on common frequencies by pulse-repetition frequency discrimination. GEC J. *Sci. and Tech.*, Vol. 37, **4**, 157.

ANNEX I

1. AIRT system description

A functional block diagram of the AIRT is shown in Fig. 5. Here the input signal is sent to the video switch gate circuit and to the threshold detector. Only a signal having a level above a certain value (for example, mean noise level + 10 dB) is detected by the threshold detector, and sent to the two-staged sweep memory.

Now the latest data A and the two sweep (transmitting period) data are sent to the sweep correlation circuit, which detects the absence or presence of an interfering signal in the same range of the three signals (a specified period after the transmitted pulse), and a gate signal which inhibits the video signal is made only when there is an interfering signal.

This circuitry functions in the same concept for either of the analogue and digital signals.

2. Conditions of AIRT simulation

- The amplitude response of the receiver filter in Fig. 2 is assumed to be a Gaussian characteristic;
- the criteria of the AIRT sweep correlation circuit permit correlation for data within the range of 0.5 μs (half the pulse width) before and after (along the time axis) of an input signal in view of the target detectability;
- the threshold level of the threshold detector is to be set at a value that meets the false alarm probability and probability of detection to be specified at the video output.

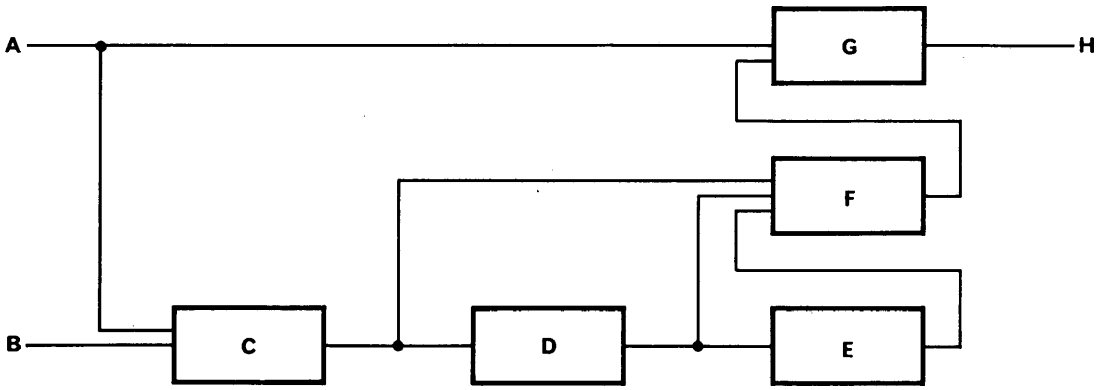


FIGURE 5 – *Asynchronous interference reduction circuit block diagram*

A: radar video signal input
B: threshold control data
C: threshold detector
D: sweep memory
E: sweep memory
F: sweep correlation
G: video switch
H: radar video signal output

RECOMMENDATION 589 *

INTERFERENCE TO RADIONAVIGATION SERVICES FROM OTHER SERVICES IN THE BANDS BETWEEN 70 kHz AND 130 kHz

(Question 33/8)

(1982)

The CCIR,

CONSIDERING

(a) that radionavigation systems exist or are being implemented in the three Regions;

(b) that various services, including radionavigation systems, operate in frequency bands between 70 kHz and 130 kHz;

(c) that radionavigation being a safety service, all practical means consistent with the Radio Regulations should be taken to prevent harmful interference to any radionavigation system;

(d) that users of phased pulsed radionavigation systems in the band 90-110 kHz receive no protection outside that band, yet may receive benefit from their signals outside the occupied bandwidth;

(e) that in the band 90-110 kHz, different phased pulsed radionavigation systems may operate in adjacent areas, on the same assigned frequency and within the same occupied bandwidth,

UNANIMOUSLY RECOMMENDS

1. that for CW-radionavigation systems in the frequency bands 70-90 kHz and 110-130 kHz the parameter to be used in planning, to avoid harmful interference, should be the protection ratio in terms of wanted to unwanted signals;

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* The Director, CCIR, is requested to bring this Recommendation to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO), the International Civil Aviation Organization (ICAO), the International Association of Lighthouse Authorities (IALA) and Study Group 7.

2. that the protection ratio, for CW-radionavigation systems with characteristics sush as an existing system (see Report 915) that presently operates in the same bands, should be 15 dB within the receiver passband of ± 7 Hz at 3 dB;

3. that information be exchanged between the authorities operating radionavigation systems in the band 90-110 kHz with those operating other systems outside the band employing highly stable (atomic reference) transmissions;

4. that administrations operating radionavigation systems in the band 90-110 kHz in adjacent areas coordinate the technical characteristics of their individual systems in accordance with the Radio Regulations.

REPORT 915 *

INTERFERENCE BETWEEN FIXED AND MARITIME MOBILE AND RADIONAVIGATION SERVICES IN THE BANDS BETWEEN 70 kHz AND 130 kHz

(Questions 1/8 and 33/8)

(1982)

1. Introduction

In each of the separate allocation bands between 70 kHz and 130 kHz, a number of different services have been approved for transmission to be made on specific frequencies.

It is necessary to recognise that safety aspects of these radionavigation services make it essential that they are able to operate free from harmful interference.

This Report is concerned with the particular case of the Decca Navigator system and the Loran system and gives detailed guidance on the protection necessary in order to operate satisfactorily.

2. Protection of Systems

2.1 *Decca Navigator (DN) system*

2.1.1 *A description of the system*

The DN system uses low power CW transmissions from groups of three or four transmitting stations (termed a Decca chain) that are switched according to a fixed sequence which cycles around the three or four stations every 20 s.

Five frequencies are used for each chain, all frequencies bearing a strict harmonic relation to the other four, and each lying in one of five sub-bands allocated in the Radio Regulations as follows (f = fundamental frequency):

$5f$	in band	70- 72	kHz
$6f$	in band	84- 86	kHz
$8f$	in band	112-115	kHz
$9f$	in band	126-129	kHz
$8.2f$	in band	115-117.6	kHz

The five frequencies transmitted from all stations of each chain are phase locked to each other. The stability of transmission from each station is at least one to three parts in 10^6, although in certain cases (approximately 10% of the DN chains operational today) stabilities of the order of 1 part in 10^{11} will be found due to the use of rubidium frequency standards in the transmitting equipment.

The higher standard of frequency accuracy is sometimes required in certain areas because, during night time when strong sky-wave signals may give rise to poor phase lock, it may be necessary to allow a slave station to run free and to substitute the normal master/slave phase lock by rubidium standards at both master and slave stations.

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* This Report should be brought to the attention of Study Group 7, the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Association of Lighthouse Authorities (IALA).

In this way the necessary degree of effective phase lock between master and slave transmissions is maintained during the night periods.

Currently produced receivers have very narrow band for all frequencies, being approximately 10 Hz at −6 dB points.

2.1.2 *Sources of interference*

The described system is liable to suffer interference from the carrier or side bands, including any spot line frequency in the spectrum, of a transmitter using any of the following types of transmission:

2.1.2.1 CW – continuous wave;

2.1.2.2 modulated CW and/or frequency shift keying;

2.1.2.3 pulsed.

Generally the frequency stabilities of the three sources of interference will be:

(a) Of the order required by the Radio Regulations or as used by some quartz controlled stations (about 10^{-4} to 10^{-8}).

(b) Highly stable as accepted for modern standard frequency and timing purposes which is achieved by use of high stability standards e.g. caesium, rubidium (about 10^{-11} to 10^{-12}).

The effects of the two types of stability (*(a)* and *(b)* above) can be different depending on the spacing between the wanted (DN) carrier and the unwanted (interfering) carrier frequencies, and the degree of stability of the DN carrier.

2.1.3 *Results of interference*

The DN system could be prone to the following four forms of interference from one or more of the six sources identified above (being a combination of those given in §§ 2.1.2.1, 2.1.2.2 or 2.1.2.3.

2.1.3.1 *Co-channel interference* *

Co-channel interference is that experienced in a DN receiver channel from another transmission whose carrier or line frequencies fall within ±5 Hz (but more than ±1 Hz, see § 2.1.3.3 below) of a DN transmission frequency. Interference arises because the DN receiver offers little or no rejection to the interfering signal, which if it is strong enough and is sufficiently phase stable will beat with the wanted DN transmission, and will at a level of the order of +12 dB (wanted/unwanted) signals show considerable distortion in the accuracy of the phase output of the affected channel. Further at +15 dB (wanted/unwanted), triggering of the lane identification signal will be affected if the interference is on the $6f$ or $8.2f$ channels.

2.1.3.2 *Adjacent channel interference* *

Adjacent channel interference is that experienced in a DN receiver from another transmission near to but differing by more than ± 5 Hz from a DN transmission frequency. The interference created by the unwanted signal, being incoherent with respect to the wanted signal, is treated by the DN receiver as if it were noise. The accepted level of interference to the $5f$, $8f$ and $9f$ channels at the input to the DN receiver is +8 dB (wanted/unwanted) while the $6f$ and $8.2f$ triggering remains as in § 2.1.3.1 at +15 dB(wanted/unwanted). Typical DN receiver selectivity characteristics are as follows:

± 10 Hz separation: −6 dB
± 20 Hz separation: −10 dB
± 50 Hz separation: −25 dB
± 100 Hz separation: −37 dB
± 200 Hz separation: −48 dB
± 500 Hz and greater separation: better than −60 dB

In practice the true degree of DN receiver rejection to an interfering signal does depend on the bandwidth of that signal, especially as the wanted DN frequency is closely approached. Signals that are, by their nature (intentionally or otherwise), wideband may not be subject to the degree of rejection expected. Transmission spectrum analysis and local geographical knowledge of the interfering transmitter are therefore all-important for an accurate assessment of the degree of interference to a particular DN chain.

* The expression "wanted-to-unwanted signal ratio" when used in conjunction with an interfering pulsed transmission must be interpreted as "wanted CW to unwanted peak-signal-ratio".

2.1.3.3 *Synchronous interference* *

Synchronous interference will be experienced in a DN receiver from another transmission on a frequency very close (less than +1 Hz) to the DN frequency, especially when the interfering transmission frequency and the DN frequency are each separately stabilised by their own high stability standards.

This is clearly a special, and very serious, case of "co-channel" interference. It can arise if the interfering signal is CW in nature with an effect similar to that caused by co-channel interference with the difference that the DN phase information will in general tend to drift possibly in a slow oscillating manner or at worst (and most dangerous) could be nearly static over long periods of time with large phase errors and/or poor signal/noise characteristic.

The effects very much depend on the wanted-to-unwanted ratio of signal strengths but a +15 dB (wanted/unwanted) figure would keep the phase excursions within acceptable limits.

As regards the lane identification triggering requirement, the (wanted/unwanted) figure for CW interference and sideband interference would be similar to § 2.1.3.1 but if the interference was due to pulse energy (which would not be in existence long enough to cause persistent phase errors but could blank out triggering information for long periods) then this would be "time interference" which is covered in the next paragraph.

The side band or pulse spectral line energy although not in existence long enough as previously stated, to cause persistent phase errors, can upset the channel, causing hunting of the oscillators. A factor of 12 dB (wanted/unwanted) is required.

2.1.3.4 *Time interference*

2.1.3.4.1 *Time interference I*

Time interference will in general only be experienced in the $6f$ or $8.2f$ channels of a DN receiver in the presence of a pulsed interfering transmission. A persistent effect will only be experienced:

- if the interfering transmission is of significantly long duration with respect to the shortest switching period of the DN system (i.e. lane identification triggering – 0.05 s);
- if the pulsed transmission is time coincident with the DN lane identification switching period;
- if the peak spectral line power of the pulsed transmission is strong enough; and
- if it is stable enough.

The effect on the DN receiver is a loss of triggering and the +15 dB (wanted/unwanted) protection factor is required.

2.1.3.4.2 *Time interference II* *

A pulsed transmission can, in specific conditions, cause different interference effects in a DN receiver. If the peak spectral line power of the pulse transmission at a particular location is very much greater than the power of the DN $6f$ or $8.2f$ transmission then the pulsed transmission will shock excite the DN lane identification $6f$ or $8.2f$ triggering. The effect is that the DN receiver will be made to produce false triggers with associated false phase indications. The degree of effect depends on the closeness of the spectral line frequency of the interference transmission to the DN frequency and the pulse repetition rate.

2.1.4 *DN field strength*

As a guide in assessing the degree of interference that a DN receiver can tolerate in any part of a DN chain coverage, Annex I tabulates the following data, together with an example of a calculation of acceptable interference:

Table I : Typical station radiated powers.

Table II-a and II-b : Ground-wave field strengths assuming 100 W radiated power for 70 kHz and 127 kHz for various ground conductivities.

Table III : Typical ground conductivities for various types of terrain.

A safety factor of 6 dB in favour of DN is required for sky-wave effects at night. This effect can cause a decrease in the wanted DN (ground-wave) field and additionally this effect can cause an increase in the strength of the interfering signal if the unwanted signal sky-wave is in phase with its own ground-wave component.

* The expression "wanted-to-unwanted signal ratio" when used in conjunction with an interfering pulsed transmission must be interpreted as "wanted CW to unwanted peak-signal-ratio".

2.1.5 *Quality of data*

The interference protection ratios for DN systems will only be realistic in the solution of problems where there is full knowledge of the characteristics of the interfering transmissions.

2.1.6 *Conclusions*

The Decca Navigator system, in spite of its narrow band design, can suffer a degree of interference from transmission both in its own allocated bands and also from transmissions located in adjacent bands but radiating significant spectral power ('overspill') outside those bands. Care should always be taken to assign frequencies which tend to conform to those outlined in this Report in order to reduce interference to permissible levels. For general planning purposes a wanted/unwanted protection ratio of +15 dB should be adopted with the proviso that, in the decision-making, special care be taken when the transmitted centre frequency, the shift frequency or the spectral line frequency are within close limits of the particular Decca Navigator frequency involved. For the reasons stated in § 2.1.4 it is necessary to include the 6 dB safety factor.

2.1.7 *Interference measurements*

One administration has carried out laboratory interference measurements with Decca Navigator receivers. The description of the measurements and the results are given in Annex II.

The receivers used for these tests were manufactured by that administration and were licenced for use only in the domestic waters of that administration.

2.2 *Loran system*

2.2.1 *Introduction*

The users of phase pulsed hyperbolic radionavigation systems, also identified as Loran, place reliance upon its normal navigational role. When harmful radio interference occurs, the navigational information display ceases and appropriate warning signals appear. The user, however, is neither able to identify the interfering source nor able in many cases to retune filter traps. This is because the receiver output is designed for navigational displays and provides no audible outputs to monitor the interfering signal as is possible in communication services. Even if provided, the navigational user is unqualified to identify the harmful interference. For these reasons and the significance of navigational failures, it is essential that administrations support measures to prevent harmful interference through technical monitoring and cooperative approaches.

Present receivers have significant technical design improvements over early Loran radionavigation receivers. Similarly, considerable effort is devoted to transmitter design and continuous monitoring of spectral output. The reduced costs of radionavigational receivers for Loran in no way reflect any reduced technical design. In fact, present receivers surpass all performance specifications of early generations including selectivity and processing as can be easily verified.

Regardless of technological advances, certain types of signals in the time-domain and in relative amplitude relationships can seriously impact upon safe radionavigational use including transmissions outside but in proximity to the radionavigation band. In addition, operation of radionavigation systems within the authorized band must be coordinated among operating administrations. These are described generally herein.

2.2.2 *Highlights of the radionavigation service as affects interference considerations*

Pulsed hyperbolic radionavigation systems utilize a chain of three to five transmitting stations in which the master and secondary stations transmit synchronized pulses at precise time intervals. In all Loran stations, the transmissions are controlled in absolute time by atomic clock. The time difference as received is measured in millionths of a second and displayed for either plotting a line-of-position on nautical charts or, in some equipment, is further processed by microprocessor to display latitude and longitude. For technical accuracy, receiver processing tracks the envelope and the third zero-crossing of each pulsed train of eight or nine for the secondary or master respectively.

The Loran signal is an amplitude modulated burst of energy which rises to a peak in 60 μs and decays to zero in approximately 300 μs. The signal contains 99% of its energy between 90 and 110 kHz. Stations in each chain are assigned specific group repetition intervals (GRI) and by which the receivers servo loops identify the transmitters being tracked. The frequency modulated on the analog pulse is related to the GRI assigned as:

$$f = \frac{1}{2\,(GRI)}$$

This product is a precise value for any chain in the neighbourhood of 5000 Hz, atomic clock controlled.

In order to control skywave contamination or confusion between skywave and the desired groundwave, system design for any coverage area ensures that all processing information is within 40 μs. This is because the first reflection skywave typically arrives 30 to 50 μs after the groundwave. Unfortunately, as the receivers band limiting filter is configured to reject energy beyond the 90-110 kHz band, the filter disperses the pulse in time which makes it more difficult to separate the time differences.

The receiver performance accordingly may be viewed in simplification as susceptible to two forms of interference. It is first susceptible to any amplitude form that masks the ability to faithfully track the zero-crossing of the radionavigation signal or the amplitude modulation of the envelope. It is secondly highly susceptible in the time domain to any signal which is precisely synchronous or near synchronous. In order to control the effects of strong signals in amplitude, slot filters are included in receivers. However, if too close to the amplitude modulated radionavigation signal band, slot filters degrade the faithful reproduction of the necessary envelope.

Lastly, it is the responsibility of the operating administration to ensure proper transmitted signals. This is accomplished by continuous monitoring, both in time as well as spectrum, by a radionavigation system monitoring station in the region of coverage. It is this station which is capable of identification, as least by frequency, of interfering sources to the radionavigation service. The lack of user interference reports may be misleading since only the monitoring station has the necessary equipment and records. In fact, the monitoring station advises the users of necessary slot filter adjustment.

2.2.3 *Amplitude signal impacts*

This form of interference results in masking or desensitizing of receiver input, within the radionavigation band approximately 10 to 15 kHz bordering the radionavigation band limits. The degree of this problem is related conventionally to spectral-geographical considerations based upon the relative signal densities.

The most common form of this interference is from communication services. The keying rate or modulation is not significant, but the relative power ratios are when sufficient to offset the time systems. Slot filters provide narrowband rejection in most cases, provided that no more than approximately four separate cases exist.

The worst case interference of this nature stems from bandwidth of the transmitted signal where the signal, such as multiplexed printers, exceed the rejection band of conventional slot filters.

The other type of communications interference stems from daily or hourly changes in the center of emissions as an example. A backup communications system which is activated at random is extremely difficult to cope with. That is, it is on or off faster than users can adjust its rejection as notified by monitoring stations.

2.2.4 *Time domain, navigation-to-navigation system*

This type of interference is related to the provisions of Radio Regulation No. 453, and applies to radionavigation systems operating in the band 90-110 kHz. All administrations operating radionavigation systems in the band are urged to coordinate technical and operating characteristics so as to avoid system-to-system interference. This is accomplished by GRI and timing since all stations are on the same center frequency (100 kHz).

Analytical techniques using computers are available to designate the necessary time-domain characteristics of phase pulsed systems and confirm accurate coverage of the required service area. The United States, as one of several administrations operating Loran, is prepared to provide advice for any planned system or recommend suitable timing characteristics to the mutual benefit of all users.

Although a formal coordinating mechanism is not established pursuant to the intent of Radio Regulation No. 453, direct coordination has been accomplished on an ad hoc basis among several administrations concerned. Representatives of the United States and of the Soviet Union met in June and December of 1980 in regard to coordination of overlapping systems. Ad hoc meetings have also been conducted with representatives of the United States and the United Kingdom.

2.2.5 *Time domain, frequency and time standard broadcasts*

This interference is most severe from atomic clock controlled emissions outside of the radionavigation band where the signals in absolute time are either in precise or near synchronous with the Loran signal. The extreme sensitivity through coherent processing in the radionavigation receiver makes it susceptible to precise time emissions at frequencies greatly beyond those adjacent to the radionavigation band. Any emission which generates 5000 Hz in absolute time disrupts the proper functioning of the tracking loops.

An example is the transmission of standard frequencies in the United States (Boulder, Colorado) on 60 kHz which requires special filters in all radionavigation receivers utilized near U.S. waters. In laboratory controlled tests, an interfering signal on 85 kHz caused receiver (100 kHz) malfunction within 0.02 Hz of precisely 85 000 Hz. Degrees of moving interference existed in all cases approaching 5000 Hz multiples. All emissions of a precise time structure should consider using odd multiples of 2.5 kHz insofar as low frequency time and frequency standard services may be broadcast near maritime regions., The availability of phase locked loops and synthesizers provide inexpensive means to convert such transmissions to any standard frequency desired by the user.

A form of precise frequency interference in the time domain has been observed in the case of major radio transmitting complexes where a precise clock is used to synthesize all transmit frequencies for communication transmitters. In all cases investigated, the interference was corrected by careful tuning of the synthesizer outputs. These investigations continue and may result in recommendations as to tuning procedures or offsets of a major degree.

ANNEX I

DATA AND EXAMPLE

TABLE I

Frequency	Radiated power (W)	
	100 m single mast	50 m 3-mast T
5*f*	93.8	43.0
6*f*	97.9	49.5
8*f*	116.8	58.0
8.2*f*	122.0	62.5
9*f*	131.5	66.5

TABLE IIa – *Ground-wave field strength at 70 kHz (dB(μV/m)) for radiated power of 100 W, for 6 conductivity values*

Conductivity (S/m)		5	10^{-2}	2×10^{-3}	10^{-3}	5×10^{-4}	10^{-4}
Range (km)	(NM)	Field strength (dB(μV/m))					
50	(27)	65	65	64	63	62	56
100	(54)	59	59	58	57	56	48
150	(81)	55	55	54	53	51	41
200	(108)	52	52	51	49	46	34
250	(135)	50	50	48	46	43	30
300	(162)	48	48	46	44	39	25
350	(189)	46	46	44	41	36	21
400	(216)	44	44	42	39	33	18
450	(243)	43	43	40	37	30	15

NM: nautical miles.

TABLE IIb – *Ground-wave field strength at 127 kHz (dB(μV/m)) for radiated power of 100 W, for 6 conductivity values*

Conductivity (S/m)		5	10^{-2}	2×10^{-3}	10^{-3}	5×10^{-4}	10^{-4}
Range (km)	(NM)	Field strength (dB(μV/m))					
50	(27)	64	64	63	61	58	49
100	(54)	58	58	57	55	52	36
150	(81)	55	55	52	50	45	28
200	(108)	51	51	49	45	38	21
250	(135)	49	49	46	41	33	16
300	(162)	47	47	43	38	28	12
350	(189)	45	44	40	34	24	8
400	(216)	44	43	38	31	19	4
450	(243)	42	41	35	28	16	0

NM: nautical miles.

TABLE III – *Typical conductivity data*

Quality	Example of medium	Value (S/m)
Best	Sea water	5
Good	Land of South England, East Anglia	1×10^{-2}
Average	Approaches to Pennines	2×10^{-3}
Poor	Pennines, Exmoor, sandy desert	1×10^{-3}
Bad	Scottish Highlands, parts of Scandinavia	5×10^{-4}
Very bad	Parts of Norway, North Canada (Laurentian Shield), Greenland	$\leqslant 1 \times 10^{-4}$

EXAMPLE

Question

What CW (0.1 A1) interference level is tolerable at 170 nautical miles over poor terrain if the Decca Navigator station 6*f* transmission is 50 W (from a 50m, 3-mast T antenna)?

Answer

Conductivity (see Table III)	=	10^{-3}
Ground-wave field strength: 100 W (see Tables II-a and II-b)	=	38 dB(μV/m)
Correction for 50 W transmitted power	=	−3 dB
Correction for sky-wave (see § 2.1.4)	=	−6 dB
Protection requirement	=	−15 dB
Therefore:		
If no DN receiver circuit rejection	=	+14 dB(μV/m) tolerable (upper limit)
If CW interfering signal frequency 500 Hz removed from DN signal frequency (see § 2.1.3.2)	=	+60 dB
Therefore if full DN receiver circuit rejection	=	+74 dB(μV/m) tolerable (upper limit)

ANNEX II

INTERFERENCE TO DECCA NAVIGATOR SYSTEM – LABORATORY MEASUREMENTS (JAPAN)

1. Test outline

1.1 *Instrumental configuration*

Figure 1 shows the block schematic where a Decca signal generator and an interference signal generator feed wanted and unwanted signals to the test receiver, respectively. Simulating various interference conditions with this instrumentation, the Decometer and the LI indications were taken to determine the wanted/unwanted signal ratio.

1.2 *Test signal*

The unwanted CW frequency was varied around the wanted Decca frequency to monitor close interference. The point frequencies were chosen as the ones being separated by 0.4 Hz, 1.0 Hz, 5.0 Hz, 20.0 Hz and 100.0 Hz from the wanted. (For some tests, the unwanted frequencies were set at the points over 100 Hz from the wanted.)

To examine the influence of keyed signals, the unwanted input signals at the frequency of each CW above were keyed to have a 100 ms-period and synchronized to the LI signal.

2. Test results

The results are summarized in Fig. 2 to Fig. 6.

Figures 2, 3 and 4 present the influence of the unwanted signals on the Decometer indications.

Where:

in Fig. 2 – parameter, lane error, test receiver; MS-5A, wanted level; 40 dBμV, unwanted mode; CW;

in Fig. 3 – parameter; lane error, test receiver; MS-3A, wanted level; 40 dBμV, unwanted mode; CW;

in Fig. 4 – lane error; constant (0.01 lanes), test receiver; MS-3A, wanted level; 40 dBμV, unwanted mode; CW.

Figures 5 and 6 display the influence of the unwanted signals on the Decca lane values.

Where:

in Fig. 5 – parameter; lane identification probability, test receiver; MS-5A, wanted level; 40 dBμV, unwanted mode; CW,

in Fig. 6 – parameter, lane identification probability, test receiver; MS-5A, wanted level; 40 dBμV, unwanted mode; keyed.

3. Summary

In this Report it is concluded that for general planning purposes there should be a wanted/unwanted protection ratio of 15 dB, and an additional 6 dB for safety factor on account of the skywave at night.

The test result indicated that, if a Decometer indication error of 0.01 lanes is considered to be acceptable, the value 0.01 lanes is always retained when the wanted/unwanted ratio was 15 dB or more.

Additionally, from Fig. 5 which shows the results at a specific test condition for the given receiver, it is shown that for example, an 80% probability of lane identification requires approximately 19 dB of the wanted/unwanted ratio when skywave contamination is not taken into account.

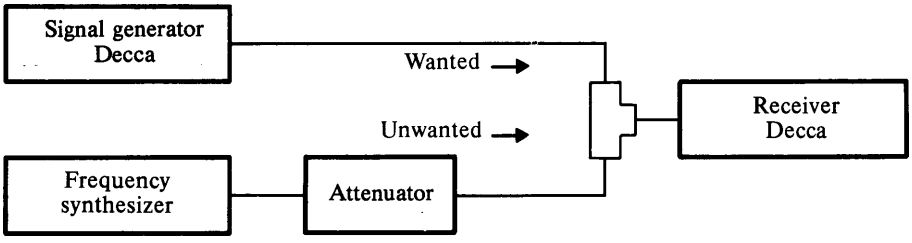
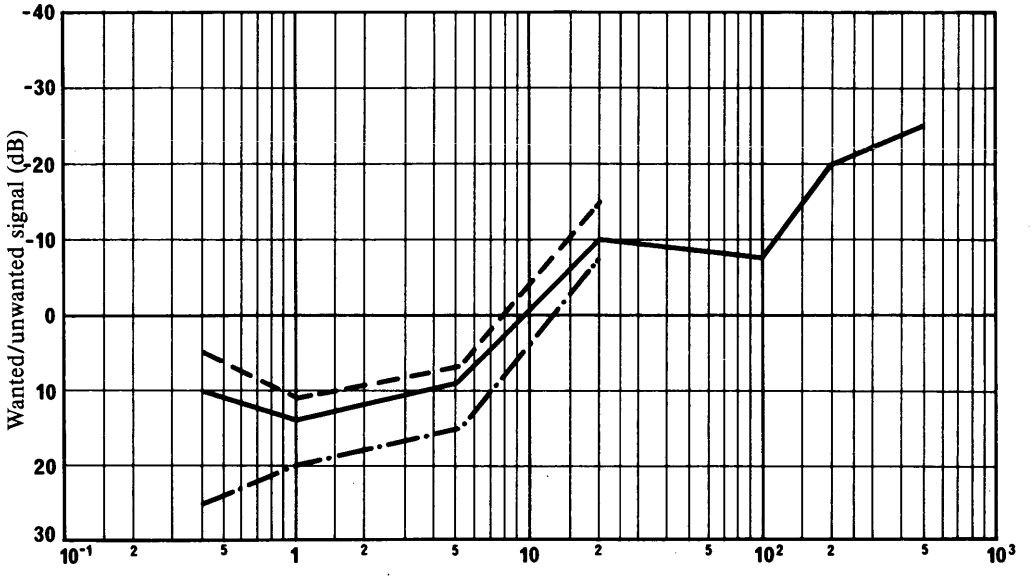


FIGURE 1 – *Test configuration block diagram*



Deviation of unwanted frequency from wanted (Hz)

FIGURE 2 – *Interference to Decometer indication*

– – – – : lane error ± 0.02

——— : lane error ± 0.01

—·—·—· : lane error ± 0

Center frequency: 85.005 kHz
Chain code: 5C
Wanted level: 40 dB(μV)
Decca pattern: red
Unwanted mode: CW
Frequency code: 6*f*

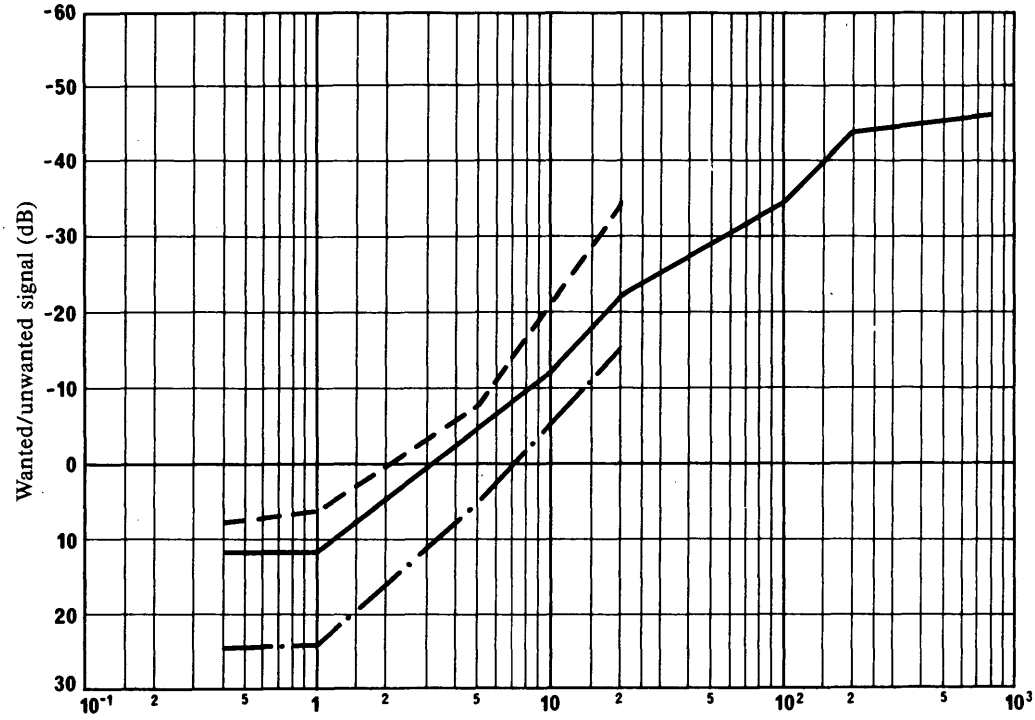


FIGURE 3 – *Interference to Decometer indication*

– – – – : lane error ± 0.02

——— : lane error ± 0.01

—·—·— : lane error ± 0

Center frequency: 85.005 kHz
Chain code: 5C
Wanted level: 40 dB(μV)
Decca pattern: red
Unwanted mode: CW
Frequency code: 6*f*

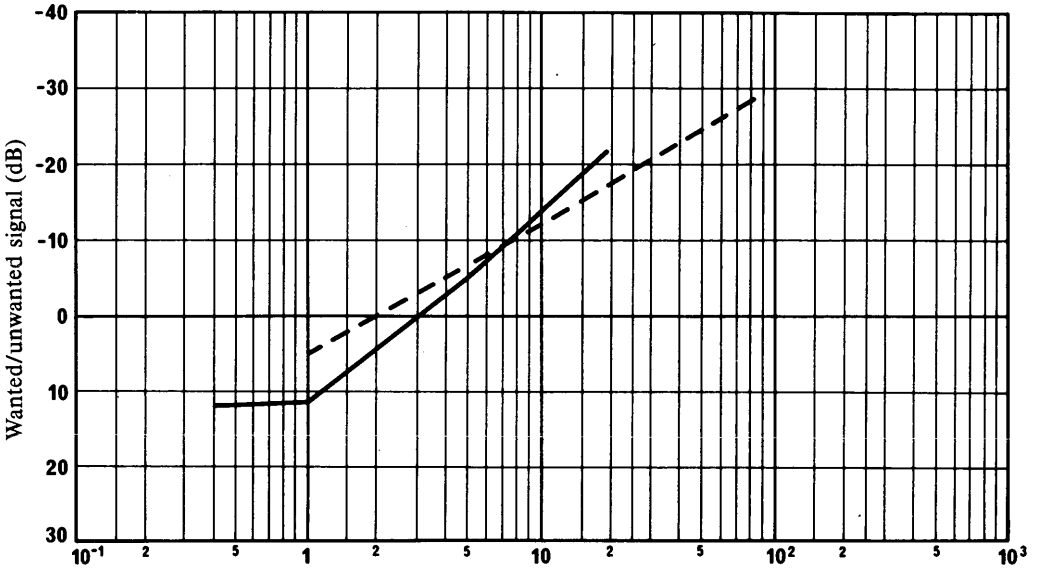


FIGURE 4 – *Interference to Decometer indication*

– – – – – : unwanted 100 ms keying

——— : unwanted CW

Center frequency: 85.005 kHz
Chain code: 5C
Wanted level: 40 dB(μV)
Indication lane error: 0.01
Frequency code: 6*f*

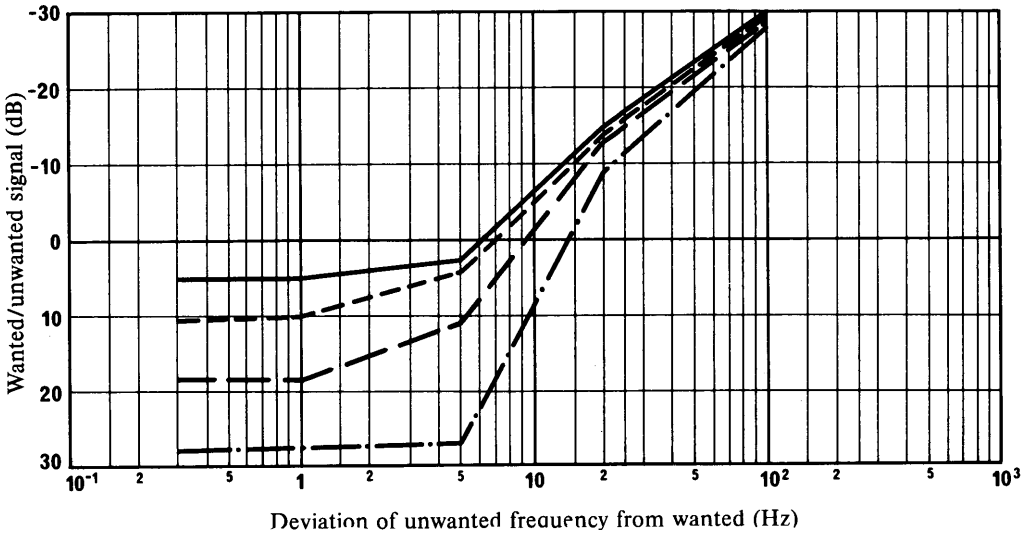


FIGURE 5 – *Interference to lane identification*

Parameter: lane identification probability

——— : 0%

– – – – : 50%

— — — — : 80%

—·—·— : 100%

Center frequency: 85.005 kHz
Chain code: 5C
Wanted level: 40 dB(μV)
Unwanted mode: CW
Frequency code: 6*f*

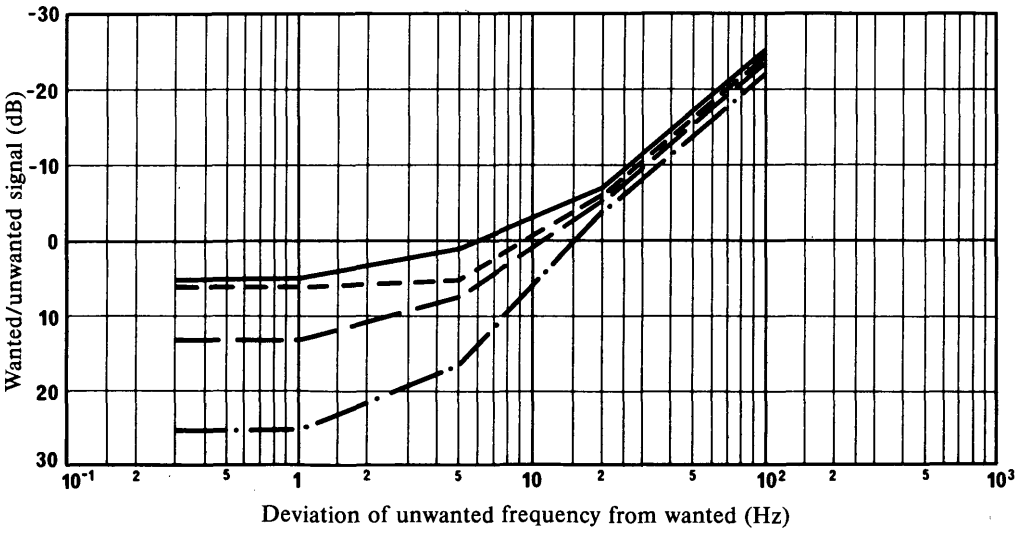


FIGURE 6 – *Interference to lane identification*

Parameter: lane identification probability
——— : 0%
– – – – : 50%
— — — : 80%
—·—·— : 100%

Center frequency: 85.005 kHz
Chain code: 5C
Wanted level: 40 dB(μV)
Unwanted mode: pulse
Frequency code: 6*f*

RECOMMENDATION 590 *

SHARING POSSIBILITIES BETWEEN THE RADIONAVIGATION-SATELLITE SERVICE AND THE FIXED AND MOBILE SERVICES IN THE BANDS 149.9 - 150.05 MHz AND 399.9 - 400.05 MHz

(Question 59/8)

(1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 703 of the World Administrative Radio Conference (Geneva 1979) (WARC-79), and in particular;

(b) that the frequency bands 149.9-150.05 MHz and 399.9-400.05 MHz have been allocated to the radionavigation-satellite service on an exclusive worldwide basis by the WARC-79;

(c) that the radionavigation-satellite service has been implemented in these bands globally;

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* This Recommendation should be brought to the attention of Study Group 9.

(d) that many countries throughout the world currently operate earth-based receivers that use satellite signals provided by this service, and have considerable monetary investment therein;

(e) that interference to the radionavigation-satellite service by the fixed and mobile services in the bands concerned could constitute a hazard to safety of life and property;

(f) that a theoretical analysis of interference to radionavigation-satellite receiving equipment on the earth currently operating in these bands from fixed and mobile services, using propagation curves contained in Recommendation 370, indicates that separation distances of many hundreds of kilometres would be necessary to prevent typical fixed and mobile services transmitters from causing co-channel interference to radionavigation-satellite receivers,

UNANIMOUSLY RECOMMENDS

1. that sharing between the radionavigation-satellite service and the fixed and mobile services in the bands 149.9-150.05 MHz and 399.9-400.05 MHz is not practicable or feasible, (see Report 916);

2. that in response to Recommendation No. 703 of the World Administrative Radio Conference (Geneva, 1979) (WARC-79), Administrations be urged to cease fixed and mobile services operations in the bands 149.9-150.05 MHz and 399.9-400.05 MHz as soon as practicable.

REPORT 916 *

SHARING POSSIBILITIES BETWEEN THE RADIONAVIGATION-SATELLITE SERVICE AND THE FIXED AND MOBILE SERVICES IN THE BANDS 149.9-150.05 MHz AND 399.9-400.05 MHz

(Question 59/8)

(1982)

1. Introduction

The United States of America operates a radionavigation-satellite system called Transit that transmits in the bands 149.9-150.05 MHz and 399.9-400.05 MHz allocated exclusively for that purpose by the World Administrative Radio Conference, Geneva 1979 (WARC-79). The Transit system was put into operation in 1964 and in 1967 was made available to users of all nations. There are currently over 6000 users of the system worldwide. A partial list of countries that own or have used receivers utilizing this radio navigation-satellite system include: Germany (Federal Republic of), Angola, Saudi Arabia, Argentina, Australia, Burma, Bolivia, Brazil, Canada, Chile, China, Colombia, Egypt, Spain, the United States, France, Greece, Greenland, India, Indonesia, Israel, Italy, Japan, Libya, Mexico, Norway, New Zealand, Papua New Guinea, the Netherlands, Poland, United Kingdom of Great Britain and Northern Ireland, Singapore, Sweden, Tanzania, Turkey, the U.S.S.R. and SFR of Yugoslavia (Socialist Federal Republic of). Civil users worldwide have a current investment in equipment totalling more than 25 million (US) dollars.

The system provides high-precision positioning for applications such as scientific exploration, oil exploration, land survey, ship positioning and navigation. The system employs four satellites in approximately circular polar orbits at altitudes of 600 nautical miles, normally. The satellite orbital planes intersect at the earth's rotational axis and are 45° apart in longitude.

2. Transit system characteristics

The dual channel system, which employs class B9 modulation, provides a short-term positioning accuracy of better than 0.1 nautical mile, and an order of magnitude of greater precision over long integration periods. Satellite parameters and orbital position information are digitally encoded and transmitted by each satellite as phase-modulated information on both carrier frequencies. Each satellite has an equal angular spiral slot antenna with a beamwidth of 80° in azimuth and elevation. Transmitted information, combined with the Doppler shift in the transmitted signals produced by the motions of a satellite and the receiving platform, are processed in a digital computer to derive the position fix.

The most sensitive 150 MHz and 400 MHz receivers designed to operate with this system have -150 dBm and -145 dBm threshold signal levels, respectively, to give $+3$ dB signal-to-noise ratios. The 150 MHz receiver uses a 20 Hz tracking-loop bandwidth, while the 400 MHz receiver has a 40 Hz bandwidth. The same thresholds would be obtained when using the receiver antenna for radiated signals of 0.043 μV/m and 0.15 μV/m, respectively.

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* This Report should be brought to the attention of Study Group 9.

3. Transit receiver interference thresholds

3.1 *150 MHz*

Transit receiver specifications require that, with the antenna connected, the receiver shall maintain phase lock to a radiated signal with a field strength at the antenna of 0.043 μV/m or −27.3 dB (μV/m). This level provides a received signal-to-noise ratio of +3 dB. If the potential interference source has an emission bandwidth of 20 kHz and its power is distributed uniformly across this bandwidth, then the field strength of the interference source corresponding to the noise threshold of the Transit receiver will be −0.3 dB (μV/m). This is derived as follows:

$$S_i = S_1 + 10 \log \frac{B_i}{B_d} - 3 \qquad (1)$$
$$= -27.3 + 30 - 3 = -0.3 \text{ dB } (\mu V/m)$$

where

S_i: radiated sensitivity of the Transit receiver to a 20 kHz bandwidth interference source, (dB(μV/m));

S_1 : Transit receiver radiated sensitivity, (dB(μV/m));

B_i: interference source emission bandwidth, (Hz);

B_d: Transit receiver phase lock loop bandwidth, (Hz).

3.2 *400 MHz*

Transit receiver specifications require that with the antenna connected, the receiver shall maintain phase lock to a radiated signal with a field strength at the antenna of 0.15 μV/m or −16.5 dB (μV/m). This level provides a received signal-to-noise ratio of +3 dB. If the potential interference source has an emission bandwidth of 20 kHz, and its power is distributed uniformly across the bandwidth, then the field strength of the interference source corresponding to the noise threshold of the Transit receiver, using equation (1), will be +7.5 dB (μV/m).

4. Minimum separation requirements to protect transit, over-sea paths

4.1 *150 MHz*

VHF propagation curves for over-sea paths were used (Recommendation 370, Fig. 4b and 4c) to establish minimum separation requirements. These curves were first adjusted upward to reflect a receiving antenna height of 30 m, using a height-gain factor of 7.8 dB computed from Report 567, and the electrical characteristics of sea water from Recommendation 527, Fig. 1.

From the above referenced curves, the following minimum separations apply as a function or e.r.p. of the interference source:

TABLE I

e.r.p. of interference source	Minimum separation distance (km)	
	North Sea	Mediterranean
1 kW	750	> 1000
100 W	550	950
10 W	400	550
1 W	300	350

These separations apply for an interference source vertically polarized antenna height of 37.5 m, and correspond to an interference level of −0.3 dB (μV/m) being exceeded 1% of the time at 50% of the receiver locations.

4.2 *400 MHz*

UHF propagation curves for over-sea paths were used (Recommendation 370, Fig. 16a and 16b) to establish minimum separation requirements. These curves were first adjusted upward to reflect a receiving antenna height of 30 m, using a height-gain factor of 9.5 dB computed from Report 567, and the electrical characteristics of sea water from Recommendation 527, Figure 1. While the lower limit for these curves is 450 MHz, they were nevertheless used to reflect minimum requirements.

From the above referenced curves, the following minimum separations apply as a function of e.r.p. of the interference source:

TABLE II

e.r.p. of interference source	Minimum separation distance (km)	
	North Sea	Mediterranean
1 kW	> 1000	> 1000
100 W	850	> 1000
10 W	650	925
1 W	500	700

These separations apply for an interfering source vertically polarized antenna height of 37.5 m, and correspond to an interference level of +7.5 dB (μV/m) being exceeded 1% of the time at 50% of the receiver locations.

5. Minimum separation requirements to protect transit, land paths

5.1 *150 MHz*

VHF propagation curves for land paths were used (Recommendation 370, Fig. 4a) to establish minimum separation requirements. These curves were first adjusted upward to reflect a receiving antenna height of 30 m, using electrical characteristics of ground from Recommendation 527, Fig. 1 and Report 567. Height-gain factors of 9.4 dB and 9.5 dB were computed for wet ground and very dry ground, respectively.

From the above referenced curves, the following minimum separations apply as a function of e.r.p. of the interference source:

TABLE III

e.r.p. of interference source	Minimum separation distance (km)
1 kW	500
100 W	400
10 W	290
1 W	180

These separations apply for an interference source vertically polarized antenna height of 37.5 m, and correspond to an interference level of −0.3 dB (μV/m) being exceeded 1% of the time at 50% of the receiver locations.

5.2 *400 MHz*

UHF propagation curves for land paths were used (Recommendation 370, Fig. 11) to establish minimum separation requirements. These curves were first adjusted upward to reflect a receiving antenna height of 30 m, using a height-gain factor of 9.5 dB computed from Report 567, and the electrical characteristics of wet ground and very dry ground from Recommendation 527, Fig. 1. While the lower limit for these curves is 450 MHz, they were nevertheless used to reflect minimum requirements.

From the above referenced curves, the following minimum separations apply as a function of the e.r.p. of the interference source:

TABLE IV

e.r.p. of interference source	Minimum separation distance (km)
1 kW	350
100 W	220
10 W	130
1 W	70

These separations apply for an interference source vertically polarized antenna height of 37.5 m, and correspond to an interference level of +7.5 dB (μV/m) being exceeded 1% of the time at 50% of the receiver locations. A terrain irregularity parameter of $\Delta h = 50$ m applies.

6. Conclusion

That separation distances of many hundreds of kilometres would be necessary to prevent interference to Transit terrestrial receivers by typical fixed and mobile services' transmitters operating co-channel, therefore, co-equal sharing of the bands 149.9-150.05 MHz and 399.9-400.05 MHz by the radionavigation-satellite service and fixed and mobile services is not considered practical or feasible.

SECTION 8E: MARITIME MOBILE-SATELLITE SERVICE; INTERFACE AND ACCESS

Recommendations and Reports

RECOMMENDATION 546-1 *

HYPOTHETICAL TELEPHONE REFERENCE CIRCUIT IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that it is desirable to establish a hypothetical telephone reference circuit for systems in the maritime mobile-satellite service, including its associated feeder links, to afford guidance to designers of equipment and systems for use in telephone networks;

(b) that the hypothetical telephone reference circuit given in Recommendation 352, whilst relevant for the fixed-satellite service, may not satisfy the needs of the maritime mobile-satellite service;

(c) that, in a system in the maritime mobile-satellite service, including its associated feeder links, many technical characteristics of the link in the shore-to-ship direction may differ substantially from those of the link in the ship-to-shore direction and hence two hypothetical telephone reference channels are required,

UNANIMOUSLY RECOMMENDS

1. that the hypothetical telephone reference channel in the shore-to-ship direction should consist of one coast earth station-to-satellite-to-ship earth station link (see Fig. 1);

2. that the hypothetical telephone reference channel in the ship-to-shore direction should consist of one ship earth station-to-satellite-to-coast earth station link (see Fig. 2);

3. that the hypothetical telephone reference circuit should comprise a link between a 4-wire coast earth station audio-frequency band interface and a 4-wire ship earth station audio-frequency band interface as defined in Fig. 3;

4. that echo suppressors should not be included within the hypothetical telephone reference circuit;

5. that should any voice processing equipment be used, for example, compandors, coders, decoders or voice-activated carrier switches, such equipment should be included within the hypothetical telephone reference circuit.

* The Director, CCIR, is requested to bring this Recommendation to the attention of the CCITT.

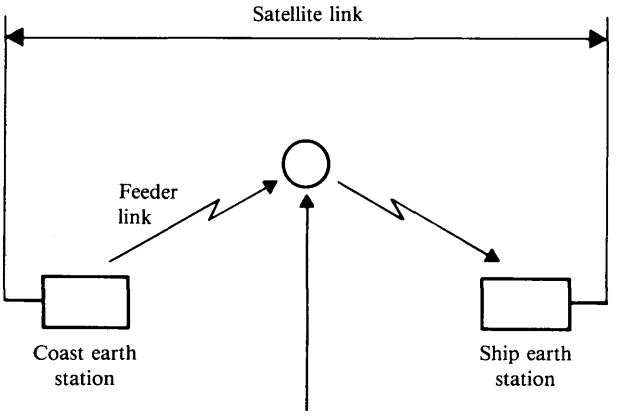


FIGURE 1 – *Shore-to-ship hypothetical telephone reference channel*

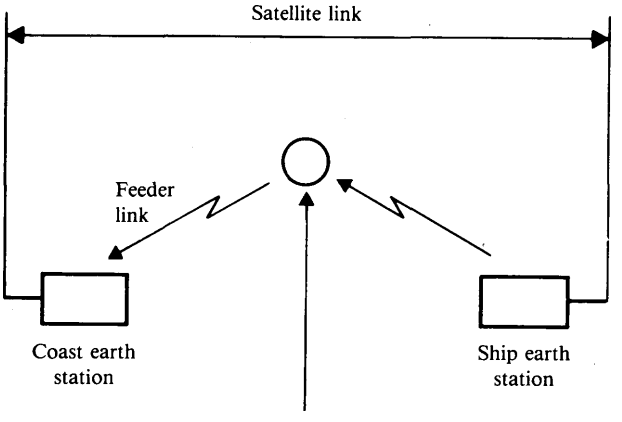


FIGURE 2 – *Ship-to-shore hypothetical telephone reference channel*

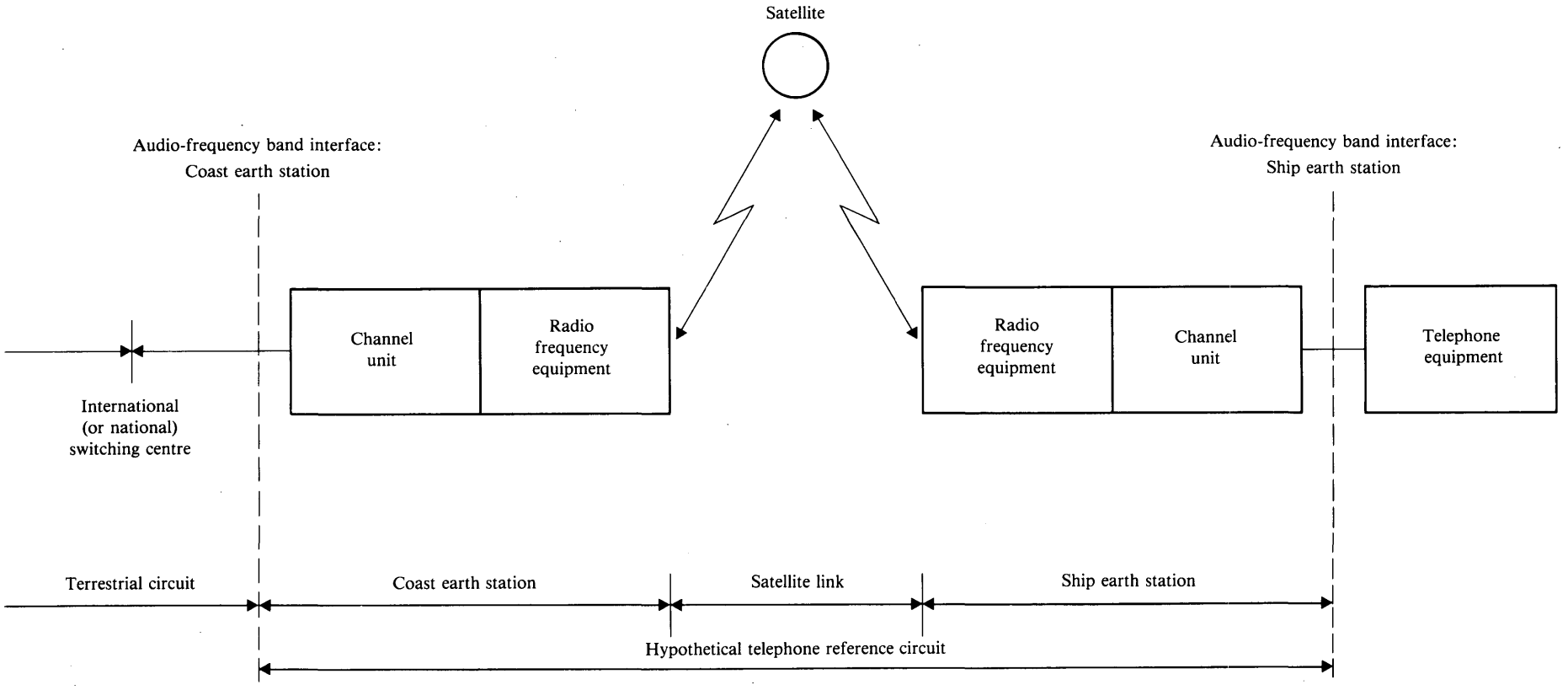


FIGURE 3 – *Functional block diagram of a maritime mobile satellite system defining the hypothetical telephone reference circuit*

RECOMMENDATION 547

NOISE OBJECTIVES IN THE HYPOTHETICAL REFERENCE CIRCUIT FOR SYSTEMS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

(a) that the hypothetical reference circuit is intended as a guide to the design and construction of actual systems;

(b) that the costs of establishing and maintaining maritime mobile satellite systems are critically dependent on the overall signal-to-noise performance requirements;

(c) that maritime mobile satellite systems will be connected to the international telephone network implying that CCITT Recommendation G.473 should be met;

(d) that the total noise power in the hypothetical reference circuit (subjectively equivalent) should not unduly degrade conversation in most telephone calls;

(e) that voice companding most probably will be used in order to reduce the constraint imposed by power limitation of the satellites;

(f) that the extent of fading cannot be determined fully until more experimental data are available;

(g) that the fading will depend on the elevation angle of the ship-borne antenna, the antenna directivity, the occurrence of calm sea conditions in various ocean areas, and the location of the ship-borne antenna relative to the reflecting surfaces of the ship;

(h) that operator-to-operator calls should be possible even at small angles of elevation though with a degraded performance;

(j) that there may be other sources of noise of short duration,

UNANIMOUSLY RECOMMENDS

1. that the subjectively equivalent speech signal to psophometrically weighted noise ratio in the hypothetical reference circuit as defined in Recommendation 546 should exceed the values shown in Fig. 1;

2. that these values of signal-to-noise ratio should be referred to non-faded conditions and to an angle of elevation of 10° of the ship-borne antennas;

3. that the modulation technique should give an acceptable decrease in quality with decreasing carrier-to-noise density ratio;

4. that the modulation technique and voice processing method adopted should permit quality comparable to that obtained in the fixed-satellite service when more satellite power is available.

Note 1. – The noise objectives indicated in RECOMMENDS 1 above should include the effect of interchannel interference noise, co-channel interference noise, intermodulation noise as well as noise from atmospheric sources.

Note 2. – The noise objectives stated in this Recommendation are applicable to systems using ship terminals with high-gain antennas (see Report 594).

Note 3. – The requirement for non-faded condition will probably be met for more than 80% of the time. When sufficient data on fading become available, this Recommendation should be supplemented to give noise objectives in terms of two percentages of time, e.g. 80% and 99%.

Note 4. – The requirement in RECOMMENDS 1 corresponds to a noise level of 10 000 pW0p for speech levels below −35 dBm0 and of 25 000 pW0p at a speech level of −20 dBm0. For speech levels above −20 dBm0, the speech signal to psophometrically weighted noise ratio should exceed 26 dB.

Note 5. – The speech level is defined as the mean (time average) speech power while active.

Note 6. – As soon as sufficient experimental and theoretical data for a particular system are available this Recommendation should be supplemented by a Recommendation stating the performance objectives in terms of measurable quantities such as idle channel noise power and test-tone-to-noise ratio.

Note 7. – It is assumed that noise surges and clicks from power supply systems and from switching apparatus are reduced to negligible proportions and therefore will not be taken into account when calculating the noise power.

Note 8. – This Recommendation does not take into account requirements to be met if facsimile and data transmission are required over telephone channels.

Note 9. – In order to assure proper quality for high speech levels the minimum overload point of the channel should be defined.

It should be taken into account that the average speech level and the range of variation of level as will be experienced at the inputs to the satellite system, may be different for shore originated and ship originated calls.

It should be further noted that different modulation techniques may require different overload levels in order to yield an optimum performance.

Note 10. – For an explanation of subjectively equivalent noise, and for methods by which it can be derived, see Report 751.

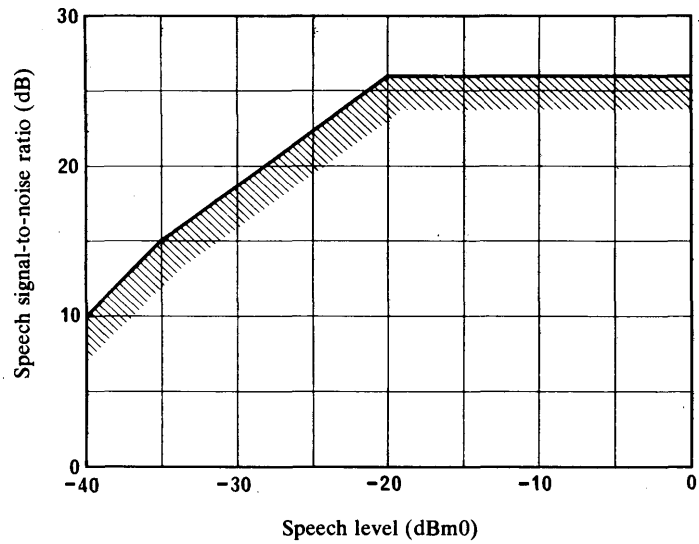


FIGURE 1 – *Limits of subjectively equivalent speech signal to psophometrically weighted noise ratio as a function of speech level*

REPORT 751 *

METHODS FOR THE SUBJECTIVE ASSESSMENT OF SPEECH QUALITY IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

1. Introduction

The assessment of the performance of a telephone connection involving a maritime mobile satellite system, which may be connected to switched national or international circuits, presents some complications in view of the diversity of conditions and degradations likely to be encountered in a typical connection. At least one of the links will always introduce a long propagation time of the order of 270 ms (mean one-way); echo suppressors and possibly other voice-switched equipment will be necessary. Other forms of degradation such as loss, circuit noise, attenuation/frequency distortion and, possibly, quantizing distortion will be contributed by the various circuit elements that form the connection containing the maritime system. It must also be taken into account that the mean speech and noise levels over the satellite link may be different in the two directions of transmission.

Ideally, the ultimate criterion of performance of such a connection is its performance in service when providing communication between customers drawn from the population of potential users. Under such conditions, all talking, listening and conversation degradations will be present. Such an approach, however, may not be practicable for various reasons, and the communication efficiency of the system must be tested by alternative methods. Laboratory simulation of both-way connections for conversation tests is feasible, provided the connections are truly representative and the tests are carried out in a methodical manner. Listening-only tests have a place in the assessment process, but it would be imprudent to attempt to predict entirely on the basis of results of listening-only tests the performance of maritime satellite systems under conversational conditions.

The purpose of this Report is to summarize various methods that could be used for listening-only and for conversational tests. The Report suggests which methods are most appropriate to study the effects of various types of degradation that may be encountered in establishing a maritime mobile-satellite service and which are most appropriate to establish the various performance requirements.

2. Transmission objectives

A major aim in establishing a maritime mobile-satellite service is to enable connections to be made between ships and terrestrial subscribers that are as good as, or nearly as good as, normal terrestrial connections. Several decisions have to be made in developing the service and the following is a list of areas where assessment methods play a part in making the decisions:

- determination of the most suitable speech modulation system;
- for modulation systems that produce speech correlated noise, the determination of the level of white noise that is subjectively equivalent to the speech correlated noise (see Report 750, Kyoto, 1978);
- the determination of the minimum performance standards for distress communication;
- the determination of the effect of delay, echo, and voice activated carrier switching;
- the determination of the required performance of the overall system;
- the in-service investigation whether the service meets the required level of performance and where particular areas of difficulty may exist.

3. Listening-only tests

There are many types of listening-only tests, but they can be divided into two broad categories: those that measure the intelligibility of speech received over the channel under test and those that measure the overall quality of the received speech.

Articulation tests are used for the former purpose. These are relatively simple to perform, although requiring trained subjects, and the analysis is straightforward.

Opinion scales and isopreference tests are amongst those used for the latter. In general, these methods require untrained subjects.

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* The Director, CCIR, is requested to bring this Report to the attention of the CCITT.

3.1 *Articulation tests*

3.1.1 *General principles*

The purpose of articulation tests is to obtain a measure of the intelligibility of the speech transmitted over the channel under test.

Generally, the tests are conducted by reading standardized speech material over the channel under test. The percentage of speech sounds received correctly by a team of listeners is taken as a measure of the intelligibility of the channel. This may be expressed as word, logatom, sound, consonant, or vowel articulation.

A great variety of practical methods exists, differing mainly on the speech material used and the general experimental conditions, and are well suited for the determination of the minimum performance standards for distress communications.

The task presented to the subjects is simple and tests of this kind are relatively easy to perform. The analysis of the results is also straightforward. The interpretation of results will depend upon the specific experimental method used.

3.1.2 *Logatom articulation method*

Logatoms are meaningless syllables consisting of three components as follows:

consonant(s)-vowel-consonant(s).

Each of the sounds constituting the logatom is chosen at random from a list of phonemes which are representative of different languages.

The method of forming logatoms is described in detail in CCITT Recommendation P.45, Red Book, Volume V, page 74.

The method consists of having at the receive end of the channel under test a trained subject listen to a logatom list. At the other end, the logatoms (without a carrier phrase) are enunciated either directly by speakers or by means of a previously recorded magnetic tape. (A complete test may comprise 500 logatoms, pronounced by several speakers.) The subject writes down the sounds he hears, thus making a list of "received" logatoms, which are then compared with those of the list read out.

The percentage of correctly received logatoms is called "logatom articulation".

3.1.3 *Sound articulation method*

A complete test comprises 100 syllables (each consisting of one or more sounds), which are chosen at random from a given language (e.g. Japanese).

A trained speaker pronounces these syllables at a constant speaking level and a subject writes down the syllables he hears. The percentage of correctly received sounds is called "sound articulation".

3.1.4 *CCITT articulation method*

Attention is also drawn to the method specified in (CCITT Recommendation P.45, Red Book, Volume V, pages 69-114).

This method was originally designed for the measurement of Articulation Reference Equivalents (AEN), but may be used for other purposes.

3.1.5 *Phonetically balanced word method (PB)*

Attention is further drawn to voice intelligibility measurements using the PB-50 word test of the American National Standard S3.2-1960: Method for the Measurement of Monosyllabic Word Intelligibility.

Experiments have shown that the PB-50 word tests can be modified from the standard procedures without significantly affecting measurement reliability and accuracy [Milner, 1973; Milner and Golab, 1975]. In order to conduct a comprehensive intelligibility test programme within a limited time in both maritime and aeronautical experiments over ATS-6, the reading rate was increased to one word per 2.5 s, the carrier phrase was dropped, the tests were limited to 400 words per test, and 68 scrambled orders of the word lists were created. These modifications in the American National Standard PB word test procedures did not comprise listener performance. Listener memorization was precluded and a wide range of parametric conditions were accommodated while maximizing the efficiency of use of satellite and flight test time (see Report 599).

3.2 *Opinion scales*

The opinion-scale methods seek to characterize speech transmission channels by using a limited set of verbal descriptions (opinion scale) of the channel quality. After listening to speech transmitted through the channel under test, untrained subjects are asked to indicate which quality description is the most appropriate for this channel.

The results from tests of this kind may be expressed as the percentage of responses in each of the various categories adopted.

In addition, certain categories may be grouped together – for example, if a seven-point scale is used, adding together groups 4, 5 and 6 will give the percentage of satisfied users and adding together groups 3, 4, 5 and 6 will give the percentage of fairly satisfied users. If a five-point scale is used, the corresponding groups are A and B and A, B and C.

A mean opinion score may also be computed if numerical values are allocated to the categories.

In general, opinion tests are easy to administer and the analysis of the results is straightforward. In this method, however, the task of the listeners is difficult in the sense that they must express their opinion by choosing one of a set of quality descriptions. The results are dependent upon the scale description which must adequately reflect the quality range covered in the test. When adequate formulations are used, the interpretation of the results is then straightforward.

Furthermore the results can be used to calculate by interpolation the level of white Gaussian noise that would be subjectively equivalent to the level of speech correlated noise. The subjects would listen to channels containing speech correlated noise and to channels containing white Gaussian noise (reference channels). The noise levels introduced into the reference channels should cover a range of Mean Opinion Score (MOS) values larger than the channels containing speech correlated noise.

Two typical opinion scales are given below:

3.2.1 7-point scale

Score	*Quality description*
6	Ideal circuit.
5	Excellent circuit. Possible to relax completely during call. Very agreeable.
4	Good circuit. Necessary to pay attention, but not necessary to make a special effort. Agreeable circuit.
3	Fair circuit. A moderate, but not too great, effort is necessary. Not a very agreeable circuit.
2	Poor circuit. Listening is possible, but somewhat difficult. Listening disagreeable.
1	Bad circuit. Can be used only with great difficulty. Listening very disagreeable.
0	Very bad circuit. Practically unusable.

3.2.2 5-point (listening effort) scale (Reference: Annex 5 to Question 1/XII, Part C, CCITT Green Book, Volume V)

A	Complete relaxation possible: no effort required.
B	Attention necessary: no appreciable effort required.
C	Moderate effort required.
D	Considerable effort required.
E	No meaning understood, even with considerable effort.

One of the problems of the above scales is that they are not easily translated into other languages, causing difficulties to subjects in their understanding of the difference between scale points. A possible consequence is that tests conducted in different languages but otherwise with the same parameters may not be comparable. To overcome this language problem a simple scale, easy to translate into different languages – such as very good, good, fair, poor, very poor – might be used. It is, however, very important in using such a scale that the correct question is presented to the subject; otherwise it may not be clear whether the speech or the channel is being judged, the results being as a consequence inconsistent.

Opinion scale methods are suitable for assessing the effect of most types of degradation, especially when the transmission aim is for good quality rather than mere intelligibility. They are not able to assess the effects of delay and echos.

3.3 *Comparison methods for determination of equivalent noise*

3.3.1 *General*

The use of equivalent noise is motivated by the need for assessing the effect on overall transmission quality of circuits introducing speech correlated types of distortion. For this purpose, the equivalent noise of the "unknown" system can be determined for this system alone without any additional degradation introduced (Report 750, Kyoto, 1978). The overall quality of various connections may then be calculated using ordinary transmission performance calculations. (Reference: CCITT Orange Book, annexes to Question 7/XII).

Being concerned with basically ordinary telephone connections, the subjective assessment methods used to determine equivalent noise should be based on judgement of overall quality. Also, if consistent results are to be obtained, this judgement process should obey a transitivity law, i.e., if A = B and B = C then C = A.

The tasks presented to the subject in the methods described below are somewhat different, asking for preference, similarity and rank order respectively. It is believed however that the methods are all based on overall quality judgements.

3.3.2 *Isopreference method*

In the isopreference method, the channel under test is assessed by comparison with a reference channel which carries varying amounts of noise. For each pair of reference and test channels, the subject is asked to indicate which of the two speech samples he or she would prefer to listen to. The isopreference (noise) level is then the value where 50% of the listeners prefer one channel and 50% the other channel. Since, in practice, the isopreference level is unlikely to be obtained, an interpolation procedure is used to arrive at the isopreference level and tests have shown that the transitivity requirement is met by this method.

3.3.3 *Adjustment method*

This method is also called the method of average error. In this method, the subjects control the noise power in the reference channel. They are asked to adjust the reference channel by selecting the amount of noise required so that this channel and the channel under test are equivalent with respect to overall quality. In this method, the equivalent noise level is obtained directly by the setting of the noise level.

Tests have shown that the transitivity requirement is also met by this method.

3.3.4 *Rank order method*

The method consists of rank ordering a mixture of known and unknown processing techniques in order of performance and is known in statistical experimentation as the Youden Squares (YS) design. The term "known" transmission technique refers to one where the subjective quality is known in terms of an analogue signal with Gaussian noise. An "unknown" transmission processing technique is any technique for which the quality is to be determined.

The mixture of known and unknown transmission techniques is composed such that, by careful preselection, the quality range of the known techniques embraces those of the unknown techniques. Then the equivalent noise values for the unknown techniques are obtained by interpolation.

The Youden Squares design allows the subjective rank ordering of many stimuli such as speech samples processed by different techniques by presenting only a small fraction at one time to test subjects. This fraction is called a block. For example, one can rank order thirteen stimuli by presenting only blocks of four at a time and the design is called a 4 × 13 YS. The stimuli, as used here and designated S_i, are recorded speech samples processed by different techniques under specified conditions.

The Youden Square assures that the division into blocks for ranking maintains a certain balance, in particular, that each stimulus S_i is listened to an equal number of times in the experiment and each possible pair of stimuli occurs equally often in an equal number of blocks.

Because it is generally too difficult for most people to compare more than 4 samples at a time, the 13 × 4 Youden Square design is most often used. In this design 6 "unknown" systems are mixed with 7 systems of known analogue signal to noise ratio.

For each block the subject is asked to rank the 4 stimuli by assigning numbers from 1 (for the best) to 4 (for the worst) to the speech samples in accordance with his own preference.

The coefficient concordance test should be performed to ensure a high probability that the observed rank order exists. The analysis consists of computing the mean rank for each system. For the conversion from rank order to equivalent noise, a regression curve mean rank versus S/N, for the analogue treatments is determined. The mean ranks of the unknown treatments are transferred to the S/N domain with this regression curve.

Example of the use of this method may be found in Report 752, Annex II.

4. Conversational tests

4.1 *General principles*

Conversational tests are primarily concerned with the overall quality of telephone connections. The effects arising in a conversation are taken into account in as realistic a way as possible.

The tests are performed by having pairs of untrained subjects conduct conversations over the connection under test. Immediately after having completed the conversation task without any disturbance, the subjects are examined on their opinion of the circuit. The method might therefore be used on either real or simulated connections.

The questionnaires used may vary, but generally an opinion scale is included. The subjects are asked to indicate which quality description is in accordance with his opinion of the circuit quality. In addition, subjects may be asked whether they experienced difficulty or not. If they did, further questions may be asked to probe the nature of difficulty, but without suggesting possible types of difficulty. The subjects are interrogated independently and they are not allowed to discuss their opinions (Reference: Appendix 2 to Annex 2 to Question 4/XII, CCITT Green Book, Volume V).

The conduct of conversation tests is very time-consuming, since the subjects are allowed to perform their task at their own speed. The generation of a realistic conversation between them is one of the main problems posed in experiments of this kind.

The method of analysis of the results is similar to that used in opinion scale testing. The mean opinion score and the percentage score in each category and in groups of categories are computed. In addition, the percentage of subjects who experienced either difficulty or any of the special kinds of distortions listed in the questionnaire is also given.

4.2 *Practical methods*

A particular method of carrying out conversational tests is described in Annex 2 to Question 4/XII, CCITT Green Book, Volume V. A five-point rating scale is generally used and contains, for example, the quality descriptions "Excellent", "Good", "Fair", "Poor" and "Bad". The mean Opinion Score (MOS) is computed as follows:

$$\text{MOS} = (4E + 3G + 2F + P)/N$$

where,

E: number of calls rated excellent,
G: number of calls rated good,
F: number of calls rated fair,
P: number of calls rated poor,
N: total number of calls.

(The number of calls rated "Bad" is given a zero coefficient and affects the MOS by being included in N.)

5. Experimental set-up

Figure 1 shows a laboratory simulation of a typical subscriber-to-subscriber connection which includes degradations that might be experienced on a maritime satellite call. When listening-only tests are performed, some of these degradations cannot be evaluated and equipment such as propagation delay equipment and echo suppressors can be removed from the simulated connection.

For practical reasons, it may be desirable to carry out listening-only tests over the satellite link taken in isolation. However, care must be taken in drawing conclusions from such tests, since, ideally, these tests should take into account factors such as loss, distortion and circuit noise which may influence the speech signal applied to the satellite system modulators, both at the ground station and at the ship terminal; also the presence and characteristics of any ambient noise at the listening locations must be considered. Tests should be conducted, separately, in both directions of transmission.

The noise arising in the terrestrial extension and which is to be injected into the simulated connection needs to be determined and will have to take into account the fact that terrestrial extensions will vary considerably in length.

For comparison purposes during tests, a reference connection is needed; this should be similar to the connection under test, but the maritime link should be replaced by a fixed service satellite link.

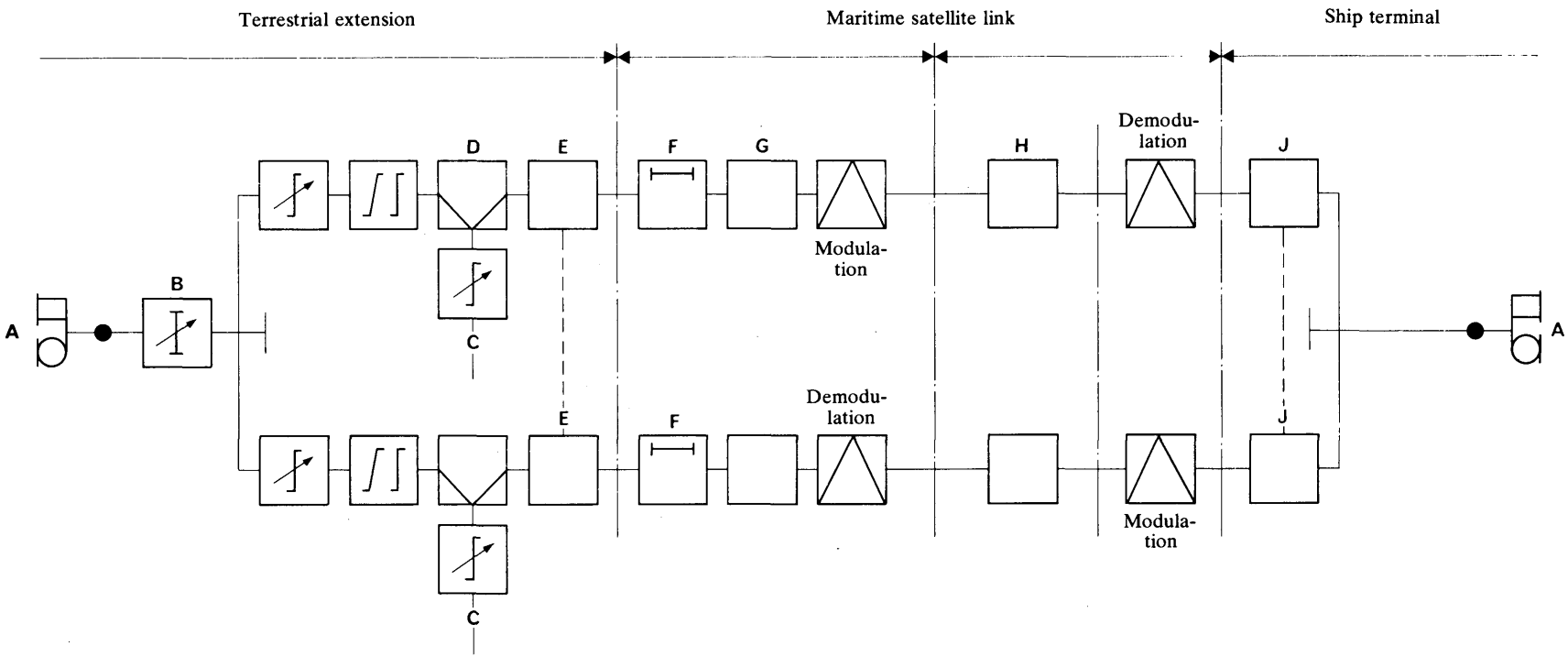


FIGURE 1 – *Laboratory simulation of typical subscriber to subscriber connection*

A: ambient noise
B: artificial line of variable length
C: noise
D: noise inject pad
E: half-echo suppressor
F: delay
G: voice activator
H: satellite simulator
J : half-echo suppressor

Note. — With four-wire telephone system on board ship the four-to-two-wire terminating set will not be required. See also Recommendation 550 as regard the half-echo suppressor at the ship end of the connection.

6. Conclusions

Subscriber-to-subscriber conversation tests are the only satisfactory method of evaluating the performance of a telephone connection involving a system in the maritime mobile-satellite service. Such tests are the only ones that can take into account the degradations introduced by propagation delay through the satellite. Unfortunately, conversation tests are difficult and time consuming to carry out; listening-only tests are simpler to carry out and have a place in certain aspects of evaluation, but their limitations must be borne in mind when making decisions based on results from such tests.

Especially, it should be recognized that articulation tests are not very suitable for the assessment of ordinary telephone connections. These methods, however, may be applied for special purposes, e.g. determination of the effect of voice activated carrier switching (trunkation of initial syllables) and performance standards for distress communication.

For the determination of the most suitable speech modulation method and assessment of equivalent noise levels of the satellite link, listening-only methods assessing overall quality should be used.

The following recommendations are submitted:

- listening-only tests may be used in preliminary tests for the comparison of modulation methods; ideally they should be carried out over a complete connection;
- listening-only tests assessing the equivalent noise of the modulation methods may be carried out to enable transmission performance calculations to be performed on a variety of representative complete connections;
- conversational laboratory tests over a simulated connection should be carried out, preferably under the auspices of an international forum;
- eventually, in-service conversational tests should be performed.

REFERENCES

MILNER, P. [June, 1973] Advantages of experienced listeners in intelligibility testing. *IEEE Trans. Audio and Electroacoustics*, Vol. AU-21, 161-165.

MILNER, P. and GOLAB, J. [April, 1975] Intelligibility of voice transmission through a satellite relay system. *J. Acous. Soc. of Amer.*, Vol. 57-Supp. **1**, 23.

BIBLIOGRAPHY

KENDALL, M. G. [1974] *Rank correlation methods*, Chapters 9 and 10. Charles Griffin & Co., Ltd.

RECOMMENDATION 548

OVERALL TRANSMISSION CHARACTERISTICS OF TELEPHONE CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

(a) that, when studying the interworking of a maritime satellite system with the automatic telephone network, a maritime satellite system can, from the technical point, be regarded as somewhat analogous with a national network and the ship terminals regarded as somewhat analogous to subscribers' locations within that network, implying the network configuration of Fig. 1 (Note 1);

(b) that, although several CCITT Recommendations of the G Series should apply to the maritime systems, these could involve requirements which would be too stringent for the maintenance of performance of ship terminal equipment;

(c) that relaxed requirements could be permitted where they will not cause a significant deterioration in the performance of the international network as experienced by subscribers in the existing terrestrial networks;

(d) CCITT Recommendation G.473,

UNANIMOUSLY RECOMMENDS

that the design of the various items comprising a maritime system should permit the following transmission characteristics to be met:

1. the nominal frequency-band of a maritime satellite circuit should be either 300 to 3000 Hz or 300 to 3400 Hz.

From a transmission performance point of view the latter is desirable but economic and/or technical considerations may favour the former;

2. the attenuation/frequency characteristics of any pair of ship terminal and shore station equipment should be within the limits shown in Fig. 2, referring to 800 Hz;

3. at 800 Hz the difference between the mean value (over time and over circuits) and the nominal value of the transmission loss of a maritime satellite circuit should not exceed 1 dB, and the standard deviation of the variation in transmission loss should not exceed 2 dB;

4. the linear crosstalk ratio (for potentially intelligible crosstalk only) between any two maritime satellite circuits should not be less than 58 dB, and between the go and return channels of any circuit not less than 55 dB;

5. if a maritime circuit is to be interconnected to a special quality leased international telephone circuit, then the group-delay distortion of the maritime circuit should not exceed the following limits:

500 Hz to 2800 Hz: 3 ms
600 Hz to 2600 Hz: 1.5 ms
1000 Hz to 2600 Hz: 0.5 ms

Note 1. – Figure 1 illustrates three possible configurations for the shipboard installations and defines the nomenclature used for transmission study purposes in this Recommendation. This nomenclature is in accordance with the conventions of Recommendation 546.

Note 2. – According to the conventions of CCITT Study Group IV, 800 Hz is the recommended frequency for single-frequency maintenance measurements on international circuits. However, by agreement between the administrations concerned, 1000 Hz may be used for such measurements. Multifrequency measurements made to determine the loss/frequency characteristic will include a measurement at 800 Hz, and therefore the reference for such characteristics can still be 800 Hz.

Note 3. – Experience has shown that, in the case of equipments and apparatus complying with CCITT Recommendations, the level of non-linear distortion encountered in the general telephone network has no unacceptable effects on speech transmission, or on the various non-speech signals conveyed by the network (e.g.: signalling, voice-band data, etc.).

Note 4. – The attenuation/frequency characteristics given in § 2 of this Recommendation could be apportioned equally between the shore station equipment and the ship terminal equipment or, if advantageous, be apportioned unequally to the various elements comprising a maritime system.

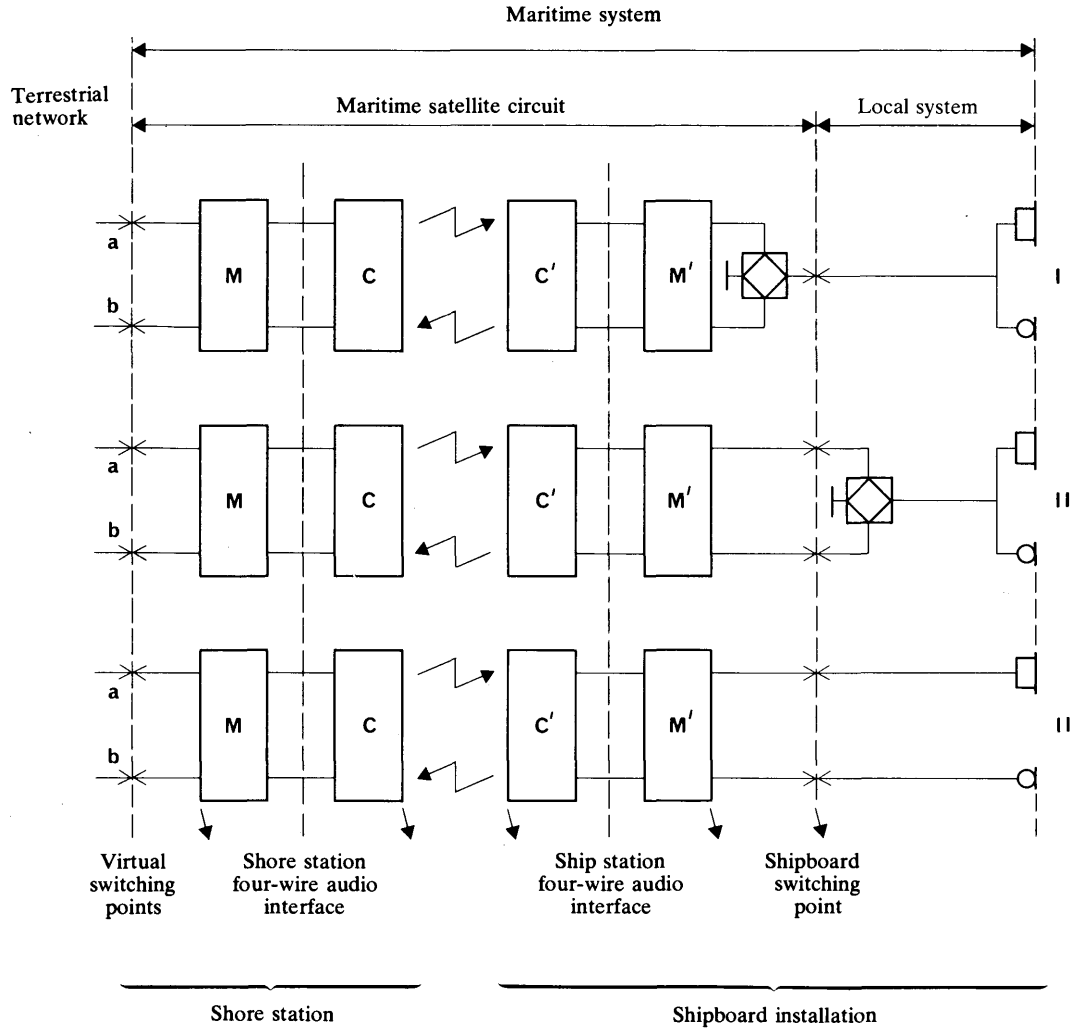


FIGURE 1 – *Interconnection of circuits in the Maritime Mobile Satellite Service to the terrestrial network and corresponding nomenclature*

Notes:

(1) From the point of view signalling and switching the shore station performs some of the functioning of an international transit centre (CT).

(2) *a* and *b* are the virtual switching points of the most-directly connected international circuit in the terrestrial network.

(3) *M* and *M'* are the miscellaneous telephone equipment needed for the maritime satellite circuit, eg: signalling terminations, echo suppressors.

(4) *C* and *C'* are the channel units (i.e.: the channel transmitting and receiving equipments) which include voice-processing apparatus, eg: voice activated switches, companders, etc.

(5) The attenuation-distortion of the two-wire/four-wire terminating unit is taken to be negligible over the band 300 to 3400 Hz.

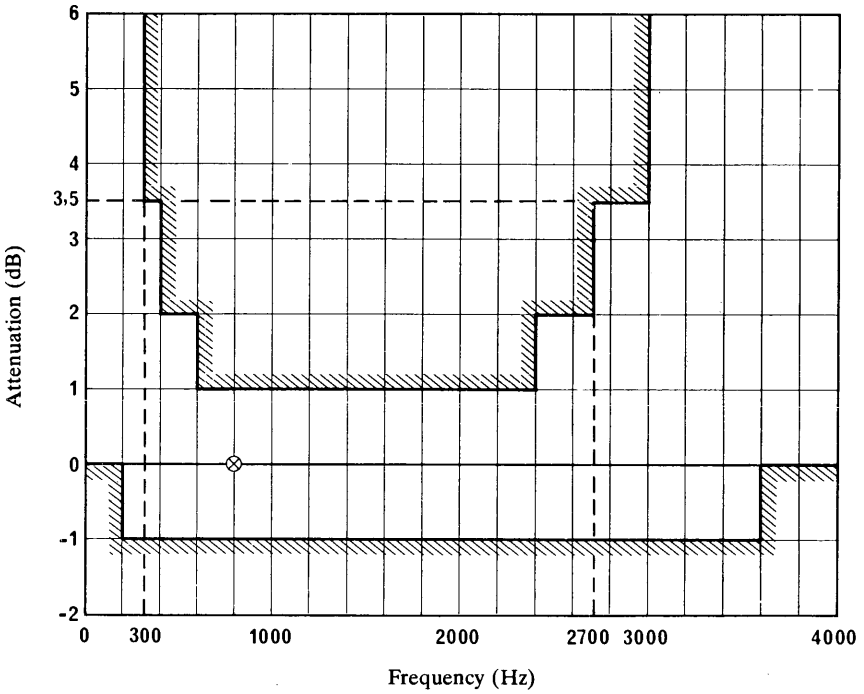


FIGURE 2 – *Attenuation/frequency characteristics*

REPORT 509-3

SIGNAL QUALITY AND MODULATION TECHNIQUES FOR RADIOCOMMUNICATION AND RADIODETERMINATION-SATELLITE SERVICES FOR AIRCRAFT AND SHIPS *

(Study Programme 17A/8)

(1970-1974-1978-1982)

1. Introduction

This Report contains, in §§ 2 and 3, a discussion of the signal quality specifications and the power efficiency characteristics of various voice and digital data modulation techniques for radiocommunication services by space techniques for aircraft and ships. It can be shown that if a system is designed to accommodate voice links, sufficient power would be available in that system to accomplish data transfer at rates of about 3 kbit/s.

The parameter used for specifying link conditions will be the carrier-to-noise density ratio, denoted C/N_0. The statistical distribution of C/N_0 will be part of the argument in selecting an optimum modulation technique. It should be noted that, unlike carrier-to-noise ratio, carrier-to-noise density ratio is independent of the radio-frequency bandwidth occupied.

* See also Report 526 (Vol. I) and Report 599.

In §§ 4 to 6, a review is given of several existing and proposed modulation techniques for radiodetermination based on distance, distance-rate and angle measurements performed from satellites. The techniques are discussed in terms of principles of operation, satellite power efficiency, multipath immunity, and complexity in implementation. The essential characteristics of these techniques are summarized in § 4.

The basic methods of using satellites for radiodetermination are described in Report 216 (Vol. VIII, Geneva, 1974).

The criteria for selection of a suitable modulation technique will, in general, include the energy efficiency, bandwidth utilization, fix-rate potential, compatibility with communications requirement, accuracy potential, effects of propagation, and equipment complexity, cost and reliability.

2. Voice communications *

2.1 *Voice channel signal quality*

The basic goal of a voice communications service for aeronautical and maritime traffic and operational control is to convey an adequate level of message intelligibility with very high reliability. A level of intelligibility, coupled with high reliability which eliminates the need for repeats and permits a higher word rate to be employed, would be advantageous. Furthermore, in an aeronautical satellite communications service, it is likely that the routine pilot/controller messages will be carried on data channels leaving voice communications for non-routine and emergency use only. Thus it is extremely important to determine accurately the minimum required signal quality for each type of service. In addition, because communication is a statistical process, the channel quality should be specified for more than one design point.

Intelligibility in a speech circuit has been measured by the percentage of correctly received monosyllabic nonsense words in an uncorrelated sequence by trained test crews. A modified rhyme test (MRT) has been designed to evaluate the intelligibility of a communications system using both untrained talkers and listeners. The use of standard procedures and vocabulary in Air Traffic Control (ATC) contributes substantially to obtaining adequate intelligibility particularly during routine communications. An ATC message text was used to estimate the worst case condition that experienced users could utilize for a communication transaction and the MRT was used for the inexperienced user [O'Brien and Busch, 1969].

The articulation index (AI) of a speech circuit indicates the effective proportion of an ideal voice channel (with respect to intelligibility) which that circuit will provide under the given signal and noise conditions [Beranek, 1947]. The audio band is unequally divided into 20 segments, each of which contributes equally to the intelligibility of speech. This contribution is independent of what happens in other segments. To achieve an articulation index of 1.0, a signal-to-noise ratio of 30 dB must be provided in each of the segments, i.e. each contributes 5% of the articulation index when the speech spectrum is not masked by noise and is sufficiently loud to be above the threshold of audibility. Noise density may or may not be constant over the audio baseband so the effect in each segment will vary.

Articulation index (AI) as a function of C/N_0 can be used for theoretical comparisons of modulation techniques [Campanella and Sciulli, 1972] since there is a correlation between AI and intelligibility.

The relationship between articulation index and intelligibility obtained from subjective talker/listener intelligibility test scores for the modified rhyme tests and the air traffic control message texts is shown in Fig. 1 [O'Brien and Busch, 1969]. It is known that when messages depart from routine, requests for repeats from both aircraft and ground stations sometimes occur. It is believed that the modified rhyme test vocabulary is more representative for non-routine and emergency messages than air traffic control message texts. However, it could be argued that other test vocabularies are more appropriate. Taking the modified rhyme test vocabulary as an example, an articulation index of 0.6 would provide a word intelligibility of 90%.

In situations where there is high acoustical noise as in some aircraft due to the noise level on the flight deck, the microphone should be positioned close to the lips to maintain an adequate and reasonably constant noise level. The background noise limits the amount of speech processing which can be employed without introducing bursts of noise between words. The degree of speech clipping, baseband truncation and acoustical noise levels should be taken into account when calculating or measuring the intelligibility of a voice channel.

* §§ 2.1, 2.2 and 2.3 are not applicable to ships with high gain antennas.

The above assumes that it is the intelligibility of speech rather than the flawless reproduction or fidelity of speech that is of prime importance in mobile communications. Sufficient realism in the speech sounds as received by the ear is an important factor in determining the acceptability of the signal quality of a communications service, particularly for public correspondence. Even if the message content is intelligible the degree of fidelity in speech reproduction may be unacceptable. Even for services intended for use between experienced operators, the fidelity of speech reproduction should be considered in addition to intelligibility because a harsh, distorted form of speech can rapidly cause listener fatigue. The effect of distortion in speech by the transmission medium in the presence of noise when using certain modulation techniques has not yet been investigated sufficiently to enable it to be included quantitatively in the factors affecting either high grade communications or threshold performance.

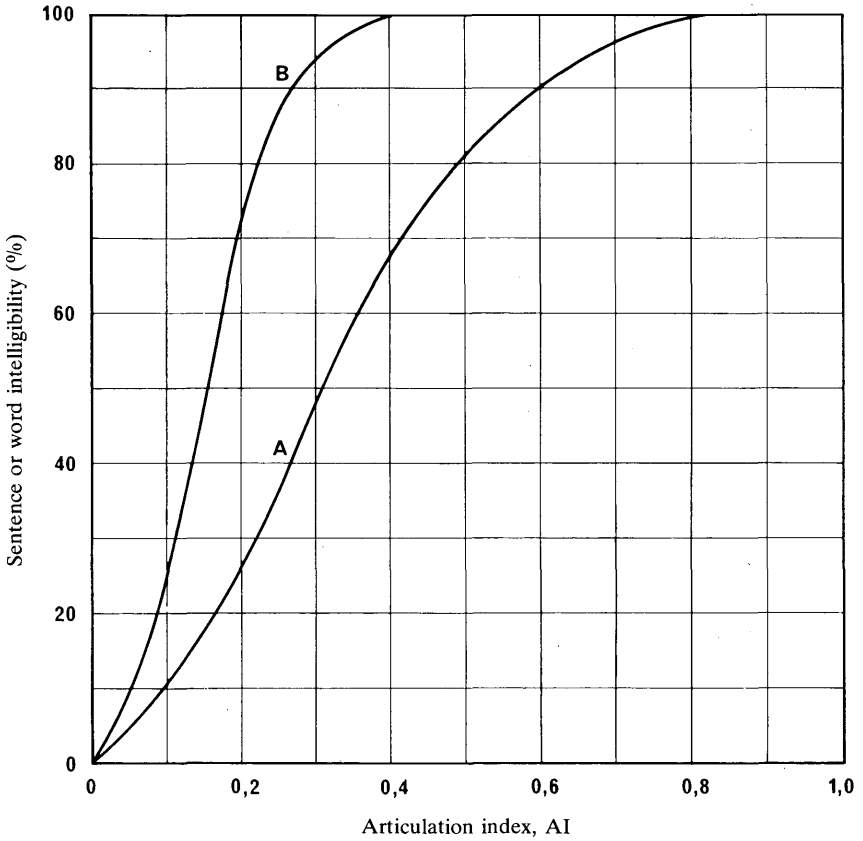


FIGURE 1 – *Percentage intelligibility as a function of articulation index*

A: modified rhyme tests
B: air traffic control message tests

2.2 *Analogue voice-modulation techniques*

Both frequency modulation and single-sideband have the potential for providing the aforementioned voice communications channel signal quality at reasonable expenditures of satellite power. Other factors, such as aircraft or ship equipment complexity, reliability and cost will probably bear heavily on the choice of modulation scheme.

The design parameters of a frequency modulation voice communications system which has been optimized to operate above receiver threshold and provide an articulation index of 0.6 with the minimum total signal power is as follows:

- direct carrier narrow-band frequency modulation (NBFM);
- audiofiltering 200 to 3000 Hz;
- no pre-emphasis;
- clipping such that the peak-to-r.m.s. ratio of the modulating wave form is 6 dB;
- radio-frequency bandwidth of 10 kHz;
- use of phase-locked demodulator with threshold extension.

A reduction of the baseband signal to 2 kHz bandwidth and use of a 5 kHz radio-frequency bandwidth improves the intelligibility slightly for the condition of very weak signal levels; however, the upper band of articulation index achievable will be less than that achievable by wider base bandwidth systems. Correspondingly, an increase of radio-frequency bandwidth to 18 kHz lowers performance under marginal signal conditions but yields a higher level of articulation index when exceeding receiver threshold. The phase-locked demodulator is slightly more complex than the conventional frequency-modulation discriminator; however, a significant advantage of 4 dB in threshold level is obtained. In the near future, the phase-locked demodulator will require a very small additional investment. For a frequency-modulation system, power levels in the satellite must be such that the system operates above the receiver threshold most (e.g. > 95%) of the time.

At lower articulation indices (< 0.5), the FRENA (Frequency and Amplitude) technique [de Jager and Greefkes, 1957-1958], which transmits an infinitely clipped single-sideband signal and a low frequency replica of the voice signal's amplitude variations, is more power efficient than narrow-band frequency modulation; however, it cannot achieve the high articulation-indices that are possible with narrow-band frequency modulation or single sideband. The transmitted spectrum occupies a radio-frequency bandwidth of 3 kHz.

A single-sideband system designed to provide the highest articulation index for any given signal power would have the following parameters:

- 6 dB per octave pre-emphasis above 800 Hz in baseband;
- 5 kHz baseband truncation;
- radio-frequency clipping with a peak-to-r.m.s. ratio of 6 dB.

Reducing the base bandwidth would require additional power in order to produce any given articulation index. For single-sideband operation, it is noted that clipping of the radio-frequency signal introduces significantly less distortion than clipping of the baseband signal.

2.3 *Comparison of analogue modulation technique performance*

The relation between articulation index and signal-to-noise density at the receiver is shown in Fig. 2 for various modulation techniques. For example, for the condition of a peak power limited satellite and a signal-to-noise density of 46 dBHz, it is noted that single-sideband yields an articulation index of 0.43 and that frequency modulation using bandwidths of 8 kHz and 18 kHz yields articulation indices of 0.53 and 0.57, respectively. This C/N_0 is 1 dB above the threshold value of an 8 kHz system and is 3 dB below threshold point of an 18 kHz system. A signal-to-noise density of 49 dBHz yields articulation indices of 0.52 for single-sideband, 0.60 for 8 kHz frequency modulation and 0.68 for 18 kHz frequency modulation, and is above threshold in both of these frequency-modulation systems.

The results shown are based upon a theoretical analysis of data generated by tests with the English language.

In addition to voice quality and satellite radiated power requirements, other factors must be considered before selecting the modulation technique. Some of these factors are: current user equipment, spectrum requirements, effects of oscillator instabilities and Doppler shifts, system reliability and costs.

2.4 *Comparison of digital voice transmissions by delta modulation and pulse-code modulation techniques* [Tomozawa and Kaneko, 1968; de Jager and Greefkes, 1968]

The transmission of voice by digital techniques could employ pulse-coded modulation (PCM) using an 8 kHz sampling rate and 16 quantization levels. This system would deliver a maximum sinusoidal signal to quantization noise ratio of approximately 26.5 dB in a 300 to 3400 Hz audio bandwidth.

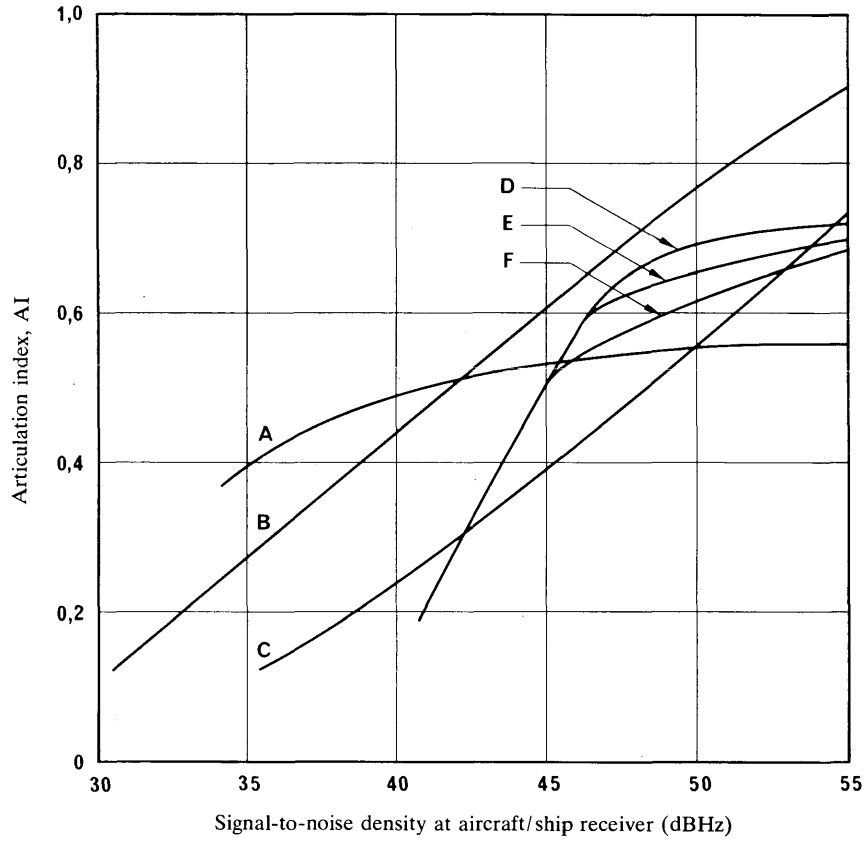


FIGURE 2 – *Comparison of analogue voice modulation techniques*

A: FRENA (Frequency and amplitude)
B: 5 kHz single sideband-mean radio-frequency power
C: 5 kHz single sideband-peak radio-frequency power
D: frequency modulation (18 kHz)
E: frequency modulation (10 kHz)
F: frequency modulation (8 kHz)

The system requires a data rate of 32 kbit/s which can be accommodated in a radio-frequency bandwidth of 32 kHz assuming 2-phase coherent phase-shift keying (PSK). An error rate of better than 10^{-3} would probably be required, necessitating a predetection carrier-to-noise ratio of 7 dB which corresponds to a 52 dBHz carrier-to-noise density ratio in the 32 kHz bandwidth.

A delta modulation system could also be employed. At bit rates less than 50 kbit/s, delta modulation provides a higher signal-to-quantization distortion ratio than an equivalent rate PCM system. For example, delta modulation operating at 18 kbit/s can deliver a sinusoidal signal-to-quantization noise of approximately 22 dB in a 300 to 3400 Hz bandwidth. Such a system could employ PSK modulation, requiring only 18 kHz radio-frequency bandwidth.

Four-phase coherent PSK modulation could also be used, requiring a pre-detection carrier-to-noise ratio of approximately 10 dB, but having a radio-frequency bandwidth half that of a 2-phase system.

It is to be noted that:

- at the data rate of 18 kbit/s and with an infinite pre-detection signal-to-noise ratio, delta modulation provides an SNR after decoding which is 5 dB better than PCM;
- delta modulation has the advantage of tolerating higher rates of transmission error than PCM; thus, for the same data rate, the carrier-to-noise density can be slightly reduced.

3. Digital modulation

The implementation of a digital data link provides an efficient means for the transfer of position reports, maintenance data, and other record messages [Cahn, 1959; Shaft, 1962; Becker and Lawton, 1958]. The use of this link would off-load a significant amount of communications time from the normal voice links.

3.1 *Compatibility with voice channel*

To minimize the overall aeronautical maritime satellite service costs and to provide a maximum of operational flexibility, it is desirable that the basic system be capable of interchanging either digital data or voice modes in a typical voice channel and that common hardware be utilized.

3.2 *The human-machine interface problem*

Alphanumeric digital communication, such as via direct-printing radiotelegraph, can convey information to humans at nearly the same rate as voice, but through a much narrower bandwidth. Conversely a much higher rate of information may be contained in the same bandwidth.

Machines, such as digital data systems, cannot always interpret these human language alphanumeric messages. For this reason, it becomes necessary for the operator to translate his message into machine language or for this to be done after reception. Various coding (or "canned message") systems have been proposed with the objective of originating the human's message in machine language as all or part of a relatively short binary number. These systems range from the use of a simple pushbutton for each possible message to sequentially coded techniques capable of providing a high degree of message flexibility with a corresponding degree of compression.

These sequential techniques generate binary numbers in which the meanings of digits depend on their location in the number, according to the format of the selected message. Any stored data such as the transmitting craft's identity and any pertinent instrument data can be entered automatically, so only the human information need be entered manually, in the code and sequence appropriate to the message format. The element of message information associated with any given key is changed in a manner depending on the sequential order in which the keys are actuated. Keyboards exist which facilitate this entry by providing for sequential change of key designations. These changes may be accomplished by projection by a key-tape transport mechanism or by any other suitable means.

3.3 *Link capacity and quality*

The relationship between data rate and data quality may be adjusted in order to take maximum advantage of the specific link signal strength for particular applications. A nominal bit error probability of one in 10^5 bits may be used as a design goal for a typical application [US Technical Commission]. Error correction codes may be employed if higher data quality is desired for a particular data service.

It is anticipated that the total data load to be relayed from mobile craft to ground based terminals may be significantly larger than the reverse path. It is also important to note that the technical and economic constraints which limit the selection of equipment for the relatively few earth terminals are much less severe than those limiting the implementation in the great number of mobile craft.

3.4 *Digital data modulation techniques*

The most efficient of the angle modulation techniques is direct carrier phase-shift keying (bi-phase PSK) with coherent demodulation; however, this approach requires relatively complex automatic frequency control (AFC) tracking because there is no strong radio-frequency carrier signal. In order to maintain coherent reception, either a "times-two loop" or an "in-phase quadrature loop" is required, and resynchronization must be accomplished if modulation is not continuous. Some carrier power can be transmitted continuously if the modulation index is reduced. This reduces the link efficiency by about 1.7 dB but would alleviate the automatic frequency control tracking problem.

The use of differentially coherent PSK also alleviates the problems associated with coherent synchronization; however, it is about 0.6 dB less efficient than bi-phase PSK when compared at a bit error ratio (BER) of 10^{-5}.

The subcarrier PSK (PSK/PM) technique provides a radio-frequency carrier signal component which can be continuously tracked by all users. However, this method requires twice the bandwidth of the previously described techniques and the link efficiency is about 1.7 dB below that of coherent PSK.

The use of direct carrier frequency shift keying (FSK) would permit data to be time division multiplexed with frequency modulation voice and would enable common modulator/demodulator equipment to be utilized. However, this technique is 2.6 dB less efficient than bi-phase PSK. Predetection intermediate-frequency bandwidths of the order of the bit rate can be employed because of the unique nature of the FSK spectrum [Link and Eatough, 1962].

The use of subcarrier FSK (FSK/PM) would reduce the time required for initial acquisition and would provide continuous synchronization. This technique requires twice the spectrum of PSK and two demodulators in the receiver.

A comparison of the characteristics of candidate digital data modulation techniques is given in Table I. In addition to spectrum and power efficiency, other factors must also be considered before selecting the modulation technique. Some of these are: current user equipment, compatibility with voice equipment, propagation effects, and system costs.

TABLE I

Comparison of data modulation techniques

Characteristics	Digital data modulation techniques					
	Coherent demodulation PSK (bi-phase)	Differentially coherent PSK	PSK with carrier	Subcarrier PSK/PM	FSK (PCM/FM)	Subcarrier FSK/PM
Communications efficiency: Required C/N_0 for 600 bit/s with b.e.p. = 10^{-5} (dBHz) (1)	38·0	38·6	39·7	39·7	40·6	42·3
Data capacity: Max. data rate for b.e.p. = 10^{-5} and C/N_0 = 45 dBHz (bit/s) (1)	3000	2600	2100	2100	1700	1100
Relative amount of spectrum occupied by transmitted signal (Hz/bit/s)	2	2	2	4	2	4
Equipment complexity: Transmitter Receiver	Minimum Significant	Slight Significant	Minimum Moderate	Slight Moderate	Minimum Minimum	Slight Slight

(1) b.e.p.: bit error probability

3.5 *56 kbit/s data transmission field tests via Marisat*

During the latter part of November, 1978, Marisat facilities were used to perform ship-to-shore data transmission at a rate of 56 kbit/s. The data was transmitted from a small ship operating in the North Sea via the Marisat F-1 satellite located at 15° West over the Atlantic Ocean. The data was received and measurements were recorded at the Marisat coast earth station in Southbury, Connecticut, USA.

The ship was a seismic exploration vessel, the M/V J. E. Jonssen, 168 feet long, displacing 1008 gross tons and equipped with a Marisat terminal. Modulation and forward error correction (FEC) equipment elements augmented the existing terminal equipment on the ship and at the shore station. Rate one-half convolutional encoding was built into the quadriphase shift keyed (QPSK) modulator used on the ship and the input data stream to the coder/modulator was provided by a bit error ratio tester operating at 56 kbit/s. The 112 kbit/s signal from the modulator interfaced with the terminal at IF. Comparable decoding and demodulation equipment was located at the shore station. For this test, the ship terminal e.i.r.p. was 38.6 dBW.

A wide range of environmental and ship operational conditions were encountered and the elevation angle from ship to satellite ranged from 17° to approximately 23°. Over a two-week test period, 136 hours of experimental tests were performed. During the tests the link "availability" was defined as that percentage of time, after initial carrier acquisition, when carrier lock was maintained and data was being received. The minimum time period for loss of acquisition under this definition was 1 s because of test equipment limitations. The BER was defined as the ratio of bits in error to the total number of bits transmitted during a period of availability. The results of the test are summarized in Table II. Prior to the shipboard tests, laboratory experiments had indicated that the shore-station, soft-decision-decoding/QPSK modulation equipment would provide a bit error ratio (BER) of better than 1×10^{-5} at E_b/N_0 above 5 dB to 6 dB. This theoretically calculated performance was confirmed during the shipboard tests with shore station measurements.

These tests demonstrated that reliable, ship-to-shore data transmission at rates up to 56 kbit/s and with BER better than 1×10^{-6} can be provided in a variety of rough sea state conditions by interconnecting compact, state-of-the-art equipment components with existing Marisat ship terminal equipment.

TABLE II — *Summary of 56 kbit/s test results*

Total test hours	Availability (%)	BER	Sea environment and vessel motion
29.7	100.00	2.1×10^{-8}	Quiescent
32.5	97.2	1.8×10^{-7}	Winds generally 20 to 30 knots, reaching 70 knots. Waves of 3 to 8 feet reaching 30 feet. Rapid ship roll motions of 5° to 10°, at times reaching rolls of 20°.
17.8	98.4	7.4×10^{-8}	Calm waters. Ship motion — rolls typically of 0° to 3°.
6.2	92.4	5.3×10^{-8}	Some very heavy seas but generally winds of 20 to 40 knots. Wave height from 3 feet to 10 feet. Ship generally running with wind. Rapid pitch motion predominated. At times, pitch angles were as large as 20° but generally were 3° to 7°.
50.2	95.6	1.6×10^{-6}	Skies cloudy and rainy much of the time. Some heavy seas but ship motions not erratic. Rapid pitch motions 2° to 7° peaking at about 12°. Roll motions generally 2° to 5°, occasionally going to peaks as high as 10°.

4. Modulation techniques for measurement of distance

4.1 *Single-pulse amplitude modulation*

Single-pulse amplitude modulation is the most basic concept for distance measurement. In this method, the distance from a satellite of known location, to a user whose location is unknown, is determined by measuring the elapsed round-trip propagation time of a pulse signal transmitted to the user via the satellite. The one-way distance, r, is determined from the relationship:

$$r = \tfrac{1}{2}c\,(\tau - T_0) \tag{1}$$

where

c: speed of radio wave propagation;

τ: total measured time between transmitted and received pulses;

T_0: total time delay introduced by the satellite and user equipment circuits.

The satellite serves as a relay for the pulsed signals, and the satellite transmitter is required to produce peak powers that are the highest of all the modulation methods considered. This requirement for high peak satellite power poses an implementation problem.

The relationship between measurement error, bandwidth, and signal-to-noise ratio can be expressed by:

$$\sigma_\tau = 1/(\beta R^{1/2}) \tag{2}$$

where

σ_τ: standard deviation of the time measurement;

β: effective bandwidth of the pulse;

R: ratio received signal energy in the pulse to the noise density [Woodward, 1953].

Single-pulse distance measurement is susceptible to impulse noise interference. Noise or multipath reflected pulses can be mistaken for the true pulses and cause errors in system operation. In cases where the noise or multipath pulses differ in amplitude, duration or expected time of reception, means can be provided to minimize the errors. Errors in the distance measurements may result, however, if the interfering pulses are similar to the wanted signal and occur within expected reception periods.

Single-pulse distance measurement is efficient compared to other methods in terms of the energy required for a distance measurement, if the noise in the channel is Gaussian and if only one user is interrogated at a time. The slightly greater efficiency that may be achieved using single-pulse distance measurement is, however, of minor significance and the high peak power may be an overriding disadvantage. In addition, the energy needed for addressing users and furnishing communications is much greater than that required for the actual distance measurement itself.

It is generally found that other methods of measuring distance compromise between time and bandwidth to reduce peak power, but do not save energy over single-pulse measurement. However, these methods may provide better protection against impulse noise for a given energy per interrogation.

The ultimate position fix rate is limited by the differential propagation time to the various users. Interrogations may be interleaved so that several can be made in the propagation time from the ground station, through the satellite, to the user and back. Various procedures for address coding and use of *a priori* knowledge of user ranges may be used to programme interrogations.

Although single-pulse distance measurement is well adapted to time division multiple access it is not well adapted to frequency division. The bandwidth of a pulse signal is wide compared to other signal waveforms so that a relatively small number of channels may be accommodated within a given bandwidth. The user equipment required, however, is not complex, and envelope detection and threshold decision circuits can be employed [NASA, 1967].

4.2 *Multiple-pulse train distance measurement*

In the multiple-pulse train distance measurement technique, the signal consists of a group of pulses rather than a single pulse. The basic limitation on distance measurement precision is given by the error in measurement of propagation time delay. Because the precision of a distance measurement depends primarily upon the signal waveform bandwidth and the energy it contains, pulse trains have several desirable features. One is that the energy can be increased by increasing the number of pulses without increasing the peak power, an important consideration because of practical satellite peak power limitations. The transmission of multiple pulses permits an averaging of measurements, and the averaging of N independent pulses decreases the standard deviation of the measurements by $\sqrt{N}$. Another advantage exists if it is necessary to address or interrogate one of many users. In this case, the pulse train can be coded, for example, by coding the pulse spacing so that the pulse train serves both as the distance measurement waveform and the address.

For pulse-train distance measurement, it is possible to use the pulse envelope or alternatively pulse-to-pulse variation of spacing, or of carrier frequency or of carrier phase. The peak power needed for a distance measurement transmission will be reduced if a longer pulse is used, but to retain the timing accuracy for accurate distance measurement a unique modulation pattern must be applied to this lengthened pulse. This is normally an angle modulation, so that the amplitude of the pulse may be maintained throughout its duration. Modulation in the form of a code may be advantageous in the instrumentation of such a system in that the energy is maximized, while, owing to the coding, the bandwidth required for measurement precision and the possibility of constructing various address codes is retained [NASA, 1967].

4.3 *Frequency-modulation pulse compression*

Frequency-modulation pulse compression is a means of achieving "trade-offs" between energy bandwidth, time and precision in a distance measurement system. The technique can be used with either single pulse or pulse-train distance measurements described in the two preceding sections.

In this technique wide frequency-swept pulses are transmitted and, at the receiver, these pulses are compressed in time to produce narrow pulses of increased amplitude; thus the distance measurement accuracy of a narrow pulse system is obtained without the need for large peak powers. The transmitted frequency is usually made to vary linearly with time across the channel bandwidth during each pulse. Thus a pulse train is a frequency-modulation transmission, the modulating waveform in the time/frequency domain being a succession of saw-teeth. Receivers which are matched to the predetermined time/frequency relationship are necessary to form the narrow pulses which are then processed in the distance measurement circuits.

Pulse dispersion can be achieved by using a narrow pulse to excite a bank of filters with adjacent passbands, the filter outputs then being applied to a delay line which inserts progressively longer delays across the total band for each adjacent bandpass filter. The output of the delay line is a stretched pulse progressively increasing or decreasing in a step fashion in frequency. Alternatively, the dispersed pulses can be directly produced by using a saw-tooth waveform generator to frequency modulate a CW transmission.

Reconstitution of the narrow pulses at the receiver requires the use of either a complementary bank of filters and a tapped delay line or a dispersive delay line.

The output signal-to-noise ratio of an ideal pulse compression signal in the presence of white noise is given by:

$$\frac{S}{N} = \left(\frac{C}{N}\right)_p \times f_m t = \left(\frac{C}{N_0}\right) \times t \qquad (3)$$

where

$(C/N)_p$: carrier-to-noise ratio of the swept pulse before compression:

(C/N_0): carrier-to-noise density ratio of the swept pulse;

f_m: width of the frequency sweep;

t: duration of the swept pulse.

The width of the compressed pulse is the reciprocal of the frequency sweep; thus the time measurement discrimination depends directly on the bandwidth available for the swept transmission. The peak power transmitted is smaller by the factor $f_m t$ than that required for an unswept pulse producing the same S/N ratio. For a given transmitter power and channel bandwidth, the duration of the swept pulse should be as long as possible for maximum S/N ratio but there are instrumental limitations to the value of the product $f_m t$.

For the user, frequency-modulation pulse compression results in a rapid acquisition time and also provides good multipath rejection properties. Multipath interference can occur only when the time difference between direct and reflected pulses is of the order of the compressed pulse duration. The transmitted energy is uniformly distributed across the frequency channel and so the effects of interference are minimized.

In a multiple-pulse distance measuring system, address coding (and data transmission) can be readily achieved in a binary manner, the binary states being increasing and decreasing frequency sweeps, i.e. positive and negative slopes of the saw-tooth frequency modulation [NASA, 1967].

4.4 *Continuous audio-frequency modulation*

4.4.1 *Analogue techniques*

Distance measurement can also be accomplished by means of phase comparison techniques in which a transmission consists of a signal modulated by one or more sinusoidal audio frequencies. The signal is retransmitted by repeaters located in the vehicle and at the satellite, and the total round-trip propagation time delay observed at the originating station is determined by measuring the phase of the received signal with respect to the transmitted one. If the one-way distance is r, then the difference in phase, φ, between the transmitted and received signals is:

$$\varphi = 4\pi r f_m / c \text{ radians} \tag{4}$$

where

f_m: modulating audio frequency;

c: speed of radio wave propagation.

For a given phase difference measurement error, the corresponding distance error is inversely proportional to the audio frequency. To minimize distance errors, therefore, it is desirable to use as high a ranging audio frequency as possible. The relationship between the distance measurement precision (σ_r) due to noise, and post-detection audio-frequency signal-to-noise ratio (S/N) is, disregarding integration improvement:

$$\sigma_r = \frac{c}{4\pi f_m \sqrt{2S/N}} \tag{5}$$

The choice of audio frequencies above the maximum frequency of speech may permit the audio frequencies to be transmitted simultaneously with voice or data, without interference, since they can then be separated by filtering from the speech signals.

Another factor affecting the choice of audio frequencies is the ambiguity distance. Since a phase measurement can only be made over an interval of 360°, there is an ambiguity in the number of full cycles of phase delay, and this phase measurement ambiguity corresponds to an ambiguity (r_{amb}) in the distance measurement of:

$$r_{amb} = \frac{c}{2f_m} \tag{6}$$

The ambiguity can be resolved by employing additional audio frequencies, or by coding the signals, e.g., sending the audio frequencies in bursts.

Address coding (and data transmission) can be achieved by using a modulated sub-carrier, the same sub-carrier functioning as one of the distance measurement frequencies.

In general, continuous audio-frequency modulation does not provide the same type of immunity to the effects of multipath found with some of the other modulation techniques, because it becomes difficult to separate in time the direct and multipath-reflected signals. In some cases, however, it may be possible, using filters with narrow passbands, to filter the signal waveform to average out the multipath error. For ships these errors can be neglected. A further discussion of the effects of multipath is given in Report 505-2 (Kyoto, 1978), [Klein, 1970].

4.4.2 *Digital techniques*

A digital tone-ranging technique has been developed in Japan to offer measured range data to a PCM-TDMA satellite communication system for its initial acquisition. In this digital tone-ranging technique the rectangular waveform is used as a measurement signal, and in this respect it differs from the analogue techniques described above, where the sinusoidal waveform is used. In this technique, the measurement principle, the estimated measurement error, the necessity of ambiguity check and the multiple path effect are all similar to the analogue techniques. However, in addition, this technique has the following unique feature: low frequency signals for ambiguity removal are inserted in a burst form into the precision measurement signal.

This measurement signal, with a frequency high enough for obtaining the necessary measurement accuracy, is shaped into a rectangular waveform. A small part of the rectangular waveform is replaced with a pseudo-noise code signal, synchronized with the low frequency ambiguity removal signal. A carrier signal is phase-modulated by this digital waveform, and is transmitted and received through a satellite. The range is obtained by measuring the round-trip propagation time delay of the pseudo-noise code extracted from the digital waveform.

By utilizing such a digital waveform in a range measurement system, the number of low-frequency signals necessary for ambiguity check can be made smaller than that of the analogue techniques. This is because the zero-crossing of the low-frequency signal is determined by detecting the pseudo-noise code inserted, with the same bit rate as the rectangular high-frequency signal.

Many experiments have been conducted to verify this digital tone-ranging technique by using an Intelsat-III satellite. Only two low-frequency signals were required for ambiguity check, even in the case where S/N was only 3 dB in 200 kHz bandwidth. Compared with this, the analogue techniques would require from three to seven signals of low frequency for ambiguity check even in a higher S/N ratio than 3 dB.

This technique can simplify the operation and the configuration for ambiguity check and, accordingly, the measurement can be made very rapidly. Furthermore, this technique can be applicable to the narrow-band system, and can easily be made compatible with digital data-transmission systems [Kurihara and Takenaka, 1971].

4.5 *Pseudo-random noise codes*

In digital code-ranging systems, a binary sequence is transmitted, and the phase of the sequence is determined at the receiver. A high-precision distance measurement is obtained from a phase measurement at the clock frequency of the sequence, and measurement ambiguity is resolved by measuring a time reference point in the sequence to within ½ bit interval. The distance measurement accuracy is a function of the bit rate of the binary sequence. To resolve measurement ambiguity to any practical value, the binary sequence is generally chosen to be thousands of bits long.

The phase of the binary sequence can be determined by correlating the received sequence with a replica, or reference sequence, in the receiver. Equipment limitations prevent the use of simultaneous correlation, and excessive acquisition time results from sequential correlation. Consequently, special binary sequences are employed to reduce the number of required correlations and the correlation time.

A usual form of *p*seudo-*r*andom *n*oise (PRN) code is a sequence of binary digits having a random distribution within the length of the code. It may be generated in n stages of a shift register, with one or more feedback paths, driven by a regular pulse stream from a timing clock. With suitable feedback connections a repeating pattern $(2^n - 1)$ bits long may be produced; in this pattern any sequence of n bits is not repeated, and the sequence contains all the combinations of n bits except the all-zero code.

The acquisition of the code phase is accomplished in several steps. First, the clock phase is acquired by a phase-lock loop. Next, the component sequence phases are acquired in time sequence by correlating the received code with a reference code in the receiver. The total code phase can then be determined from the separate phases of the component sequences by an algorithm.

The reference code, consisting of each component sequence in turn, is advanced in phase in one-bit steps and correlated with the received code by the phase-lock loop. The correct component phase is assumed to be equal to the bit advance with results in maximum correlation level in the loop quadrature detector.

The distance measurement accuracy of a pseudo-random noise code is dependent on the phase noise in the clock phase-lock loop. If the loop is tracking square-waves, the r.m.s. phase measurement error due to thermal noise will be:

$$\sigma_\varphi = \pi \sqrt{8\,(S/N)_c} \tag{7}$$

where $(S/N)_c$ is the code signal-to-noise ratio after complete correlation in the clock phase-lock loop.

In actual practice, a bandpass filter is placed in front of the loop to restrict the clock signal to the fundamental of the square-wave, or this filtering may occur as a result of the limited bandwidth of the transmitter or of the intermediate-frequency amplifier of the receiver. In this case, the clock waveform will be a sine wave instead of a square-wave and the phase measurement error due to noise will be:

$$\sigma_\varphi = \pi / \sqrt{16\,(S/N)_c} \tag{8}$$

An alternative method of ranging systems using two pseudo-random noise codes can be accomplished. In this method, measurement ambiguity is removed by using a slow bit rate pseudo-random noise code in addition to the other pseudo-random noise code sequence which has a clock frequency high enough for obtaining the measurement accuracy. In this case, the pseudo-random noise code for ambiguity check is conventionally generated by the clock having the same period as the frame interval of the high bit rate pseudo-random noise code sequence. At the first stage of range measurement, two pseudo-random noise codes mixed together are transmitted and received. After removing ambiguity by using the slow bit rate pseudo-random noise code, only the high bit rate pseudo-random noise code is transmitted and received, and high-precision range measurements can be accomplished. This method would be suitable for a spread spectrum system and the range measurement can be conveniently made by using the pseudo-random code used for station identification.

A significant advantage of the pseudo-random noise code technique is protection from interference and the adverse effects of multipath propagation. This protection results because unwanted signals, including delayed replicas of the wanted code, delayed by at least one bit, will produce very little correlation in the receiving equipment [Garabedian, 1969; Tsukamoto *et al.*, 1972].

4.6 *Binary Optimum Ranging Code*

The *Bin*ary *O*ptimum *R*anging (BINOR) Code is equivalent to a fixed-audio-frequencies system where square-waves are used instead of sinusoidal signals. The code is a binary sequence generated from a series of "n" coherent square-waves which are harmonically related by multiples of two; a frequency ratio that tends to result in minimum signal power. The code is generated by subtracting the number of square-waves in binary state "zero" from the number of square-waves in binary state "one" during each half cycle of the highest-frequency square-wave. If the result is zero or positive, a binary "one" is generated. If the result is negative, a "zero" is generated. The code bit rate is equal to twice the highest frequency square-wave (the code clock), and the code period is equal to the period of the lowest-frequency square-wave. The BINOR binary code is much more readily implemented for large values of n.

The acquisition procedure for the code consists of first acquiring the clock (highest-frequency square-wave) with a phase-lock loop as in the pseudo-random noise technique. The clock acquisition is followed by $n - 1$ correlations of the code with $n - 1$ square waves from a divide-down chain of flip-flops driven by the acquired clock. The correlations are made in sequence starting with the correlation using the one-half clock frequency square-wave and going down in frequency to the last correlation using the lowest-frequency square-wave. Each correlation will be positive or negative, depending on whether the square-wave is in or out of phase with the code. A total of n binary decisions are required to resolve the phase of a 2^n bit long code. The BINOR code lends itself to rapid acquisition, and since each acquisition step involves only a binary decision, the mechanization of the code acquisition is simplified considerably. The acquisition time is inversely proportional to the signal-to-noise ratio and the square of the sine of the modulation index.

The distance measurement is achieved by measuring the phase of the lowest-frequency square-wave. The period of this wave is identical to the period of the code and determines the distance ambiguity resolution. The accuracy of the distance measurement is determined by the phase noise in the clock loop, since this same noise appears on the lowest-frequency square-wave through the divide-down flip-flop chain. Therefore, the equations for the pseudo-random noise codes of § 4.5 also apply here for the distance measurement precision, providing there is complete correlation in the clock loop [Stiffler, 1966; T.R.W., 1967].

5. Distance-rate and angle-measurement systems

Distance-rate and interferometer angle-measurement radio-determination techniques generally require frequency or phase measurements on received carrier signals. Thus, the measurements are performed on unmodulated CW signals.

Distance-rate is determined by measurement of the Doppler shift of a CW signal radiated by a satellite [Guier and Weiffenbach, 1960]. Angle measurement may be accomplished by measuring the difference in the phase of signals arriving at, or transmitted from, two or more satellite-borne interferometer antennas [Keats, 1965].

The precision (σ_φ) with which phase difference measurements can be made is related to the post-detection signal-to-noise ratio (S/N) by the relationship $\sigma_\varphi = 1/\sqrt{2S/N}$. In the case of a satellite-borne interferometer, the error (ε_θ) of each angle measurement is related to phase-measurement error (ε_φ) by:

$$\varepsilon_\theta = \frac{\lambda}{2\pi D \cos\theta}\ \varepsilon_\varphi \tag{9}$$

where

λ : wavelength of transmission;

θ : angle of arrival of the wave;

D : spacing between interferometer antennas.

The individual phases of the received signals are sensitive to multipath for measurements made on the carrier itself. However, the phases at the two antennas can be correlated (the amount of correlation depending upon D/λ, the elevation angle, and user altitude), thus reducing the effect of multipath upon angle measurement. A certain amount of multipath protection can be achieved through the use of wide bandwidths achieved by employing frequency-modulation or pseudo-random noise codes, discussed in § 4.

6. Summary

6.1 The precision of a distance measurement system depends upon the bandwidth of the transmitted signal and the energy it contains. Single-pulse amplitude modulation is the simplest and most straightforward concept for distance measurement, but requires high peak satellite transmitter power and bandwidth, particularly for high-precision systems. Protection against interference and multipath effects is possible if time discrimination is used in processing the received signals.

6.2 Multiple-pulse train distance measurement requires less peak transmitter power than the single-pulse technique and offers the possibility of coding the pulse train to provide a discrete address. Protection against interference and multipath effects is achieved by pulse-averaging or by time discrimination of the received signals.

6.3 Frequency-modulation pulse compression offers a trade-off between peak power, precision and bandwidth and requires less peak transmitter power than the single-pulse technique. The frequency-modulation pulse technique offers a significant degree of immunity to interference and multipath effects.

6.4 Continuous audio-frequency modulation can be employed as an alternative to pulse techniques and offers a trade-off between average transmitter power, bandwidth, measurement time and precision. This method of distance measurement generally has less discrimination against multipath errors than pulse techniques, but filtering using narrow-band filters can be employed to reduce the effects of interference and multipath.

6.5 Pseudo-random noise codes can also be used to trade between power, precision and bandwidth and offers a very high degree of protection against the adverse effects of interference and multipath.

6.6 The BINOR code has characteristics similar to both continuous audio-frequency modulation and pseudo-random noise codes with the advantage that rapid signal acquisition is possible.

6.7 Distance-rate and angle-measurement satellite techniques generally require frequency or phase measurements on unmodulated carrier signals. Such unmodulated carrier signals are subject to multipath effects, but require the least amount of spectrum (bandwidth).

6.8 Multipath errors due to the time delay between the direct and reflected rays can be neglected for ships because of the very small difference in path length.

REFERENCES

BECKER, H. D. and LAWTON, J. G. [May, 1958] Theoretical comparison of binary data transmission systems. Cornell Aeronautical Laboratory Report CA-1172-S-1 (ASTIA Document AD 148-803).

BERANEK, L. L. [September, 1947] The design of speech communication systems. *Proc. IRE*, Vol. 35, 880-890.

CAHN, C. R. [May, 1959] Performance of digital phase modulation communication systems. *IRE Trans. Comm. Sys.*, Vol. CS-7, 3-6.

CAMPANELLA, S. J. and SCIULLI, J. A. [Spring, 1972] A comparison of voice communication techniques for aeronautical and marine applications. *COMSAT Tech. Rev.*, Vol. 2, **1**, 173-174.

DE JAGER, F. and GREEFKES, J. A. [1957-1958] FRENA – A system of speech transmission at high noise levels. *Philips Tech. Rev.*, Vol. 19, 73-83, Philips Co. of Holland.

DE JAGER, F. and GREEFKES, J. A. [1968] Continuous delta modulation. *Philips Res. Rep.*, Vol. 23, 243-246.

GARABEDIAN, A. [October, 1969] Ranging signal design. Notes for UCLA short course on satellite based navigation, traffic control and communications to mobile terminals, Los Angeles, California.

GUIER, W. H. and WEIFFENBACH, G. C. [April, 1960] A satellite Doppler navigation system. *Proc. IRE*, Vol. 48, 507-516.

KEATS, E. S. [8 February, 1965] Navigational satellites: beacons for ships and planes. *Electronics*, **38**, 79-86.

KLEIN, P. I. [6-8 April, 1970] Extension of aeronautical communications satellites to aircraft position determination (surveillance) within narrowband channels. Paper No. 70-490, AIAA 3rd Communications Satellite Systems Conference, Los Angeles, California.

KURIHARA, H. and TAKENAKA O. [29 March-2 April 1971] Range and range-rate measuring equipment for communication satellite. Paper No. 16G, International Conference on Space and Communication, Paris.

LINK, W. F. and EATOUGH, C. D. [September, 1962] Experimental optimization and evaluation of telemetry systems. *IRE Trans. on Space Electron. and Telemetry*, 239-246.

NASA [June, 1967] Modulation techniques for range measurements from satellites. Final Report No. ERC/R&D 66-1017 for NASA Contract No. NAS 12-1246 by General Electric Co.

O'BRIEN, P. J. and BUSCH, A. C. [March, 1969] Effects of selective system parameters on communications intelligibility. Department of Transportation, Federal Aviation Administration, Report No. NA-69-21 (RD-68-59).

SHAFT, P. D. [July, 1962] Error probabilities in binary data transmission. A Review, Philco WDL, Communication Sciences Department, Technical Memorandum 45.

STIFFLER, J. J. [1 October-20 November, 1966] Block coding and synchronization techniques; rapid acquisition sequences. *JPL Space Programme Summary*, 37-42, Vol. IV, 191-197.

TOMOZAWA and KANEKO [February, 1968] Companded delta modulation for telephony transmission. *IEEE Trans. Comm. Tech.*, Vol. Com 16.

T.R.W. [December, 1967] (T.R.W. Systems, Inc.) Study of a navigation and traffic control technique employing satellites. Vol. I, Interim Report No. 08710-6012-R000, prepared under NASA Contract NAS 12-539.

TSUKAMOTO, K., IMAI, F., YAMADA, K., MATSUMOTO, H. and ITO, H. [28-30 November, 1972] A small station satellite system using digital lock-loop. Paper No. A4, Second International Conference on Digital Satellite Communication, Paris.

US TECHNICAL COMMISSION. Digital communications system. Report SC 110/111. Radio Technical Commission on Aeronautics, USA.

WOODWARD, P. M. [1953] *Probability and Information Theory with Applications to Radar.* Pergamon Press, London.

REPORT 752-1

MODULATION TECHNIQUES AND VOICE PROCESSING FOR TELEPHONE CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

In the following delta modulation (DM) and narrowband frequency modulation (NBFM) are evaluated in the light of requirements identified in § 2 below.

2. Basic requirements

- a maritime mobile-satellite system should be such as to permit services normally provided over international telephone connections, e.g., data transmissions, facsimile, etc. It may also be required that special leased data circuits should be extended over the maritime system.
- the quality objectives of Report 750 (Kyoto, 1978) should be met,
- the radio frequency spectrum should be efficiently utilized,
- the satellite power should also be efficiently utilized,
- graceful degradation of speech quality with decreasing carrier-to-noise density (C/N_0) should be ensured.

3. Evaluation of modulation techniques

3.1 *Delta modulation*

From Annex I, III and [Campanella *et al.*, 1977], it is seen that the speech channel quality of delta modulation with phase shift keying (DM/PSK), with a sampling frequency of 32 kHz, can meet the quality objectives of Report 750 (Kyoto, 1978). Furthermore, when forward error correction (FEC) is applied, the value of carrier-to-noise-density ratio (C/N_0) required to meet these quality objectives can be reduced significantly (see Annex III). Annex III and [Campanella *et al.*, 1977] show that a quality corresponding to 10 000 pW0p or better is achievable with 32 kbit/s delta modulation.

For such a bit rate [May *et al.*, 1975] have shown that delta encoded systems can accommodate data channels with bit rates up to 2400 bit/s. For higher bit rates the data signal is deteriorated due to slope overload such that bit error ratios less than 10^{-5} are unachievable. However, if predistortion techniques are employed it is expected that the performance of delta modulators to data signals can be significantly improved.

3.2 *Narrow band frequency modulation*

From Annexes I and II and [Campanella *et al.*, 1977] it is seen that a subjective quality meeting the requirements of Report 750 (Kyoto, 1978) is easily achieved with companded NBFM systems, for C/N_0 values of 52 to 53 dBHz. Moreover, it is seen that the degradation is graceful.

There are reasons to believe that the compandor should be disconnected for data calls because of the distortion this device may introduce to high speed data signals (CCITT Handbook on Transmission Planning) [Campanella *et al.*, 1977]. This is undesirable since it will not permit automatic through-connection at the shore station for data calls coming from the switched network. (It will normally not be possible to identify data calls as such in the existing international telephone network. This is so because national networks do not in general provide for this category marking, so that even though some international signalling systems (i.e. No. 6 and R2) do provide for the data call category, there will be no possibility to establish it from the signals received from the national network.)

For shore originated high speed data calls, losses encountered over long and complicated terrestrial connections may result in reduced input levels to the modulator. This would result in reduced quality.

Filtering at both the upper and lower part of the audio frequency spectrum may result in group delay variations (see CCITT Recommendations H.12 and M.1020) (Recommendation 548) requiring equalization for data transmission. This may be achieved by employing data modems with adaptive group delay equalization.

The IF bandwidths of typical NBFM systems are 26 to 28 kHz which can be accommodated in a channel spacing of 50 kHz. With 25 kHz channel spacing, the IF bandwidth may have to be reduced requiring more satellite power in order to maintain the same performance. This question requires further study.

4. Conclusion

The results obtained indicate that there are only small differences between delta modulation systems and narrowband frequency modulation systems for a channel spacing of 50 kHz, as far as the requirements given in this Report are concerned.

For a channel spacing of 25 kHz an NBFM system probably will require more satellite power than a DM system with a comparable performance. Further study on this question is required.

REFERENCES

CAMPANELLA, S. J., SUYDERHOUD, H. G. and WACHS, M. [March, 1977] Frequency modulation and variable-slope delta modulation in SCPC satellite transmission. *Proc. IEEE*, Vol. 65, **3**, 419-434.

MAY, P. J., ZARCONE, C. J. and OZONE, K. [December, 1975] Voice-band data modem performance over companded Delta modulation channels. *IEEE Trans. Comm.*, Vol. COM-23, **12**, 1495-1502.

ANNEX I

RESULTS OF SUBJECTIVE ASSESSMENTS OF SPEECH QUALITY OF NBFM AND DM/PSK IN THE MARITIME MOBILE-SATELLITE SERVICE

1. Introduction

This Annex summarizes the results of comparative subjective assessments of speech quality for the two modulation techniques in the maritime mobile-satellite service, Narrow Band Frequency Modulation (NBFM), and Delta Modulation (DM/2Φ-PSK).

Logatom/Sound articulation tests and opinion score tests were conducted to measure the intelligibility and speech quality in the laboratory; these tests were carried out in France, Japan, Norway and the United Kingdom using French, Japanese, Norwegian and English language respectively for the speech quality evaluation.

Logatom and opinion scale tests were also conducted by France during the course of tests performed with the ATS-6 satellite in Spring 1975 using a ship cruising off the Azores. These tests were carried out in French language for the speech quality evaluation. DM with 2 different bit rates and NBFM were assessed during these tests.

2. Outline of the tests

2.1 *Modems used for the tests*

The main characteristics of the modems used for the tests are summarized in Table I.

2.2 *Intelligibility tests*

The logatom articulation method and the sound articulation method described in §§ 3.1.2 and 3.1.3 of Report 751 were used to measure the intelligibility of speech in France (laboratory and ATS-6 tests) and in Japan (laboratory tests) respectively.

The laboratory tests were carried out in both places by transmitting pre-recorded logatom/sound material through both modems, and recording the output signals on magnetic tapes. The ATS-6 tests were carried out by transmitting pre-recorded logatom material through both modems via the satellite. In Japan, the laboratory tests were supplemented by a similar test through the Marisat satellite.

In all cases, the output tapes were played back into telephone handsets to a group of trained subjects. The percentages of correctly received syllables were computed to give the articulation score.

2.3 *Speech quality tests*

Speech quality tests were carried out in all countries using the opinion score method described in §§ 3.2 and 4.2 of Report 751.

In France, Norway and the United Kingdom, listening only tests were carried out using a recording procedure similar to that described in § 2.2. The output material was first partially randomized (keeping parts at one talker level together) and then presented to a panel of untrained listening subjects. In Japan conversational tests were conducted by twelve untrained listening subjects. After conversation through either the NBFM or the DM channel, the subjects selected the most appropriate quality to describe the quality of the channel.

The listening effort scale used was the 5-point scale in the case of laboratory tests, and the 7-point scale in the case of the ATS-6 tests. The subjects were placed in a quiet listening location. No external room noise was added.

2.4 *Test set-up*

A simplified block diagram of the test set-up to produce the output tapes for the listening-only laboratory tests is shown in Fig. 1. The ATS-6 test set-up was similar in principle, but using an actual connection through the satellite. A set-up similar to Fig. 1 was used for the conversational tests carried out in Japan (see Fig. 2).

The various test conditions are summarized in Table II. In the European laboratory tests, the same voice input signals were transmitted through a reference channel with injected white Gaussian noise at levels of 10 000 and 50 000 pW0p.

TABLE I – *Main characteristics of modulation system*

NBFM

Countries	France Norway United Kingdom	Japan	France
Type of test	Laboratory	Laboratory	via ATS-6
Voice bandwidth	300-3000 Hz	300-3000 Hz	300-3000 Hz
1 kHz peak test tone deviation (kHz)	5.8 at 0 dBm0	12 at 0 dBm0	7.8 at +4 dBm0
Companding	2:1 syllabic	2:1 syllabic	2:1 syllabic
Pre-emphasis	first order time constant 159 ns	–	–
Clipping level (dBm0)	+3.5	0	
RF bandwidth (kHz)	30	30	25
Demodulator	Phase locked loop	Phase locked loop	Phase locked loop

DM/2Φ-PSK

Countries	France Norway United Kingdom	Japan	France
Type of test	Laboratory	Laboratory	via ATS-6
Voice bandwidth	300-3400 Hz (1)	300-3000 Hz	300-3000 Hz
Bit rate (kbit/s)	32	28	32 and 18
Companding law	syllabic, digital	syllabic, digital	syllabic
Clipping level (dBm0)	+6	0	
RF bandwidth (kHz)	43.6	31	
Demodulator type	coherent demodulation	coherent demodulation	coherent demodulation

(1) The channel was band limited to 3000 Hz.

TABLE II – *Test conditions*

Countries	France Norway United Kingdom	Japan	France
Type of test	Laboratory	Laboratory	via ATS-6
C/N_0 (dBHz)	49 51 53 55	46 48 50 53 56	49 50 51 52 53
Speech input levels (dBm0) "loud" "median" "soft"	 – 6 –16 –28	 –10 –20 –30	 none none –26
Number of syllables/sounds for articulation tests	2400	2000 (1)	2400

(1) All sounds from Japanese language were used (e.g.: A, PE, GYU, CHO, etc. Each sound consists of one vowel or consonant(s) plus one vowel).

3. Results

3.1 *Intelligibility tests*

The logatom articulation tests were reported to result in high values (higher than 80%), which can be considered as satisfactory in accordance with § 2.1.2 of Report 750 (Kyoto, 1978). These results were obtained for both modulation methods with the exception of the soft talker at the lower C/N_0 value. The results for DM are slightly higher than those for FM. There was a good agreement between results obtained in laboratory and with ATS-6.

The results of the sound articulation tests are shown in Figs. 3, 4 and 5. The result obtained with the Marisat Satellite (see Fig. 3) was well in agreement with those obtained in the laboratory.

3.2 *Speech quality laboratory tests*

The results of the conversational tests are shown in Fig. 6.

In the case of the laboratory listening-only tests, each of the European administrations calculated mean opinion scores. From these results "overall mean opinion scores" were calculated, yielding the average test results of the three Administrations, as given in Fig. 7. The individual results were very similar to the overall results presented in this Report.

In addition, the percentage of "satisfied" users and "fairly satisfied" users were determined by adding up the percentages of scores in categories A and B, and those of A, B and C of the 5-point opinion scale respectively in accordance with § 3.2 of Report 751. The results are shown in Fig. 8.

3.3 *Speech quality tests with ATS-6*

In the case of the ATS-6 listening-only tests the French Administration calculated the percentage of "satisfied" users and "fairly satisfied" users by adding up the percentages of scores in categories 4, 5, 6 and those of 3, 4, 5, 6 of the 7-point opinion scale respectively defined in § 3.2 of Report 751.

With regard to the percentage of satisfied users (see Fig. 9a) the results show:

- almost identical performance of NBFM and delta modulation at 23 kbit/s in terms of C/N_0, the latter modulation having the better performance of the two above 52 dBHz;
- poor performance of delta modulation at 18 kbit/s.

As to the percentage of fairly satisfied users (see Fig. 9b) the results show:

- a substantial advantage of NBFM over delta at 32 kbit/s; this advantage becomes negligible when C/N_0 reaches 51 dBHz and disappears at 51.5 dBHz, above which value both types of modulation afford 100% listening quality;
- poor performance of delta modulation at 18 kbit/s, which is "outstripped" by delta modulation at 32 kbit/s when C/N_0 reaches about 50 dBHz.

Table III gives the minimum C/N_0 values required for each type of modulation to meet the overall speech quality criteria set out in § 2.1.3 of Report 750 (Kyoto, 1978).

TABLE III – *C/N_0 requirements*

Criterion	Requirements (%)	C/N_0 (dBHz)		
		Delta 32 kbit/s	Delta 18 kbit/s	NBFM
Satisfied users	50%	51	-	51
Fairly satisfied users	80%	50.5	52	49.5

Table III shows that the required carrier-to-noise density value is about 51 dBHz for both NBFM and delta modulation at 32 kbit/s.

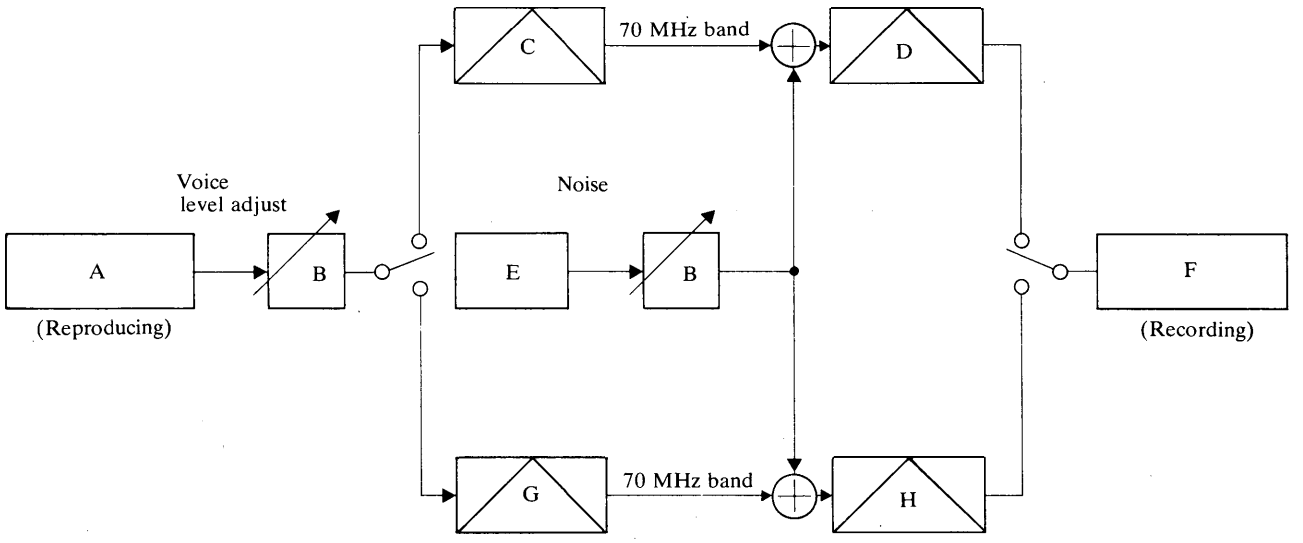


FIGURE 1 – *Configuration for recording test tapes*

A: tape recorder – A (reproducing)
B: attenuator
C: FM modulator
D: FM demodulator
E: noise generator
F: tape recorder – B (recording)
G: DM/PSK modulator
H: DM/PSK demodulator

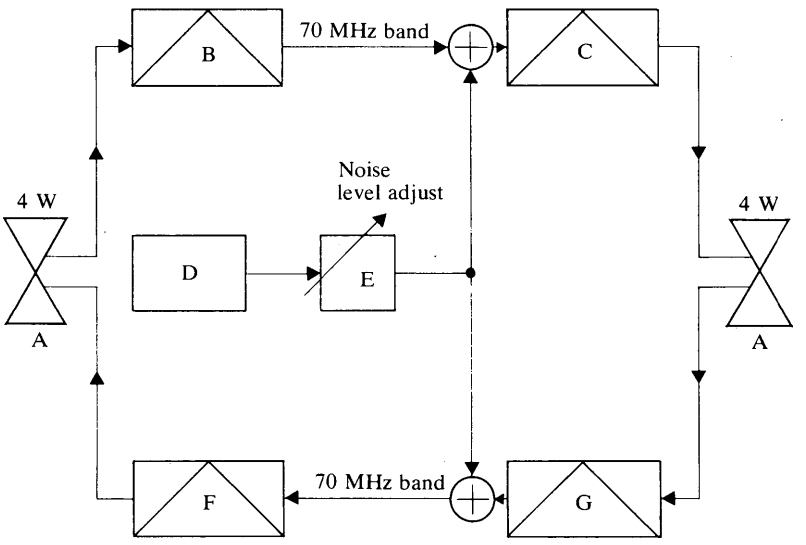


FIGURE 2 – *Configuration for conversational test*

A: telephone
B: modulator (FM or DM/PSK)
C: demodulator (FM or DM/PSK)
D: noise generator
E: attenuator
F: demodulator (FM or DM/PSK)
G: modulator (FM or DM/PSK)

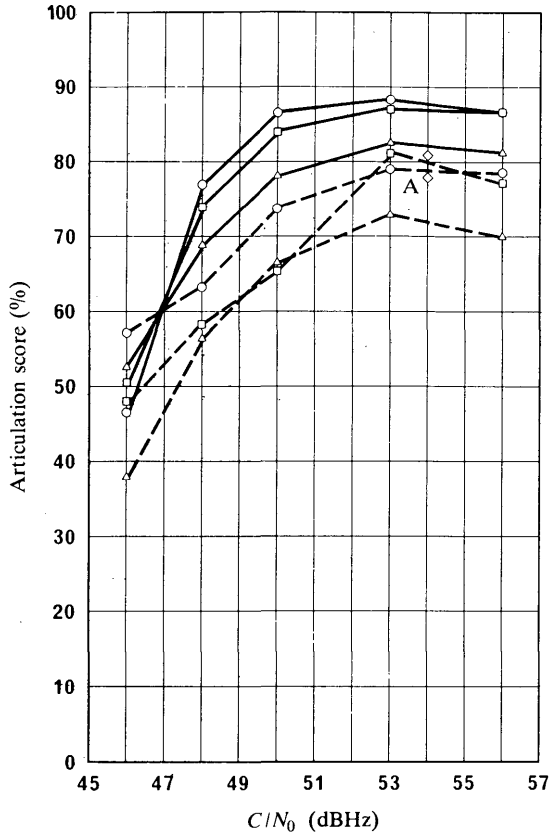


FIGURE 3 – *Articulation score (Male)*

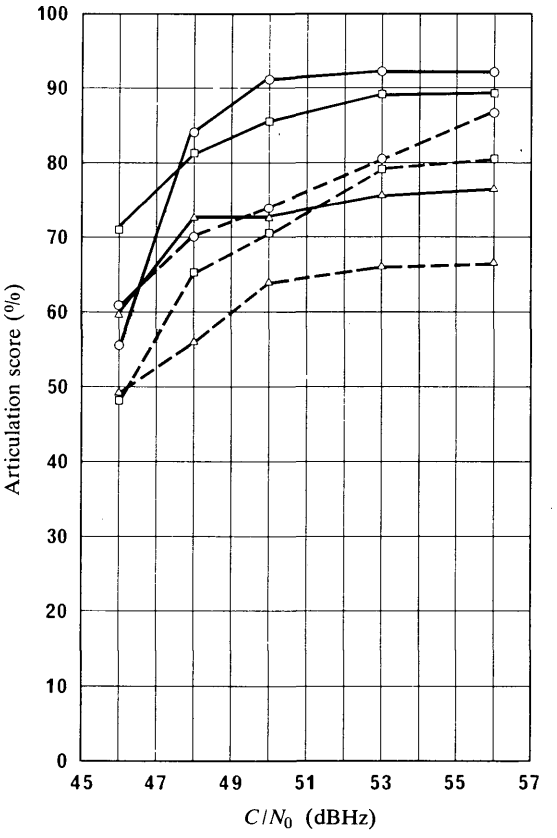


FIGURE 4 – *Articulation score (Female)*

◇ A: actual MARISAT circuit
——— : △ M/PSK
– – – : NBFM

Speech level { ○ : Soft, □ : Median, △ : Loud

——— : △ M/PSK
– – – : NBFM

Speech level { ○ : Soft, □ : Median, △ : Loud

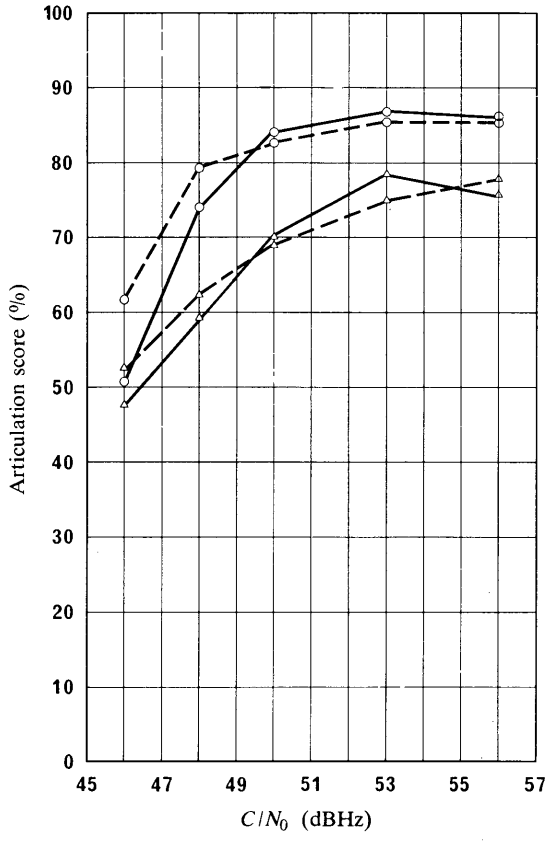


FIGURE 5 – *Articulation score*
(Average for the three speech levels)

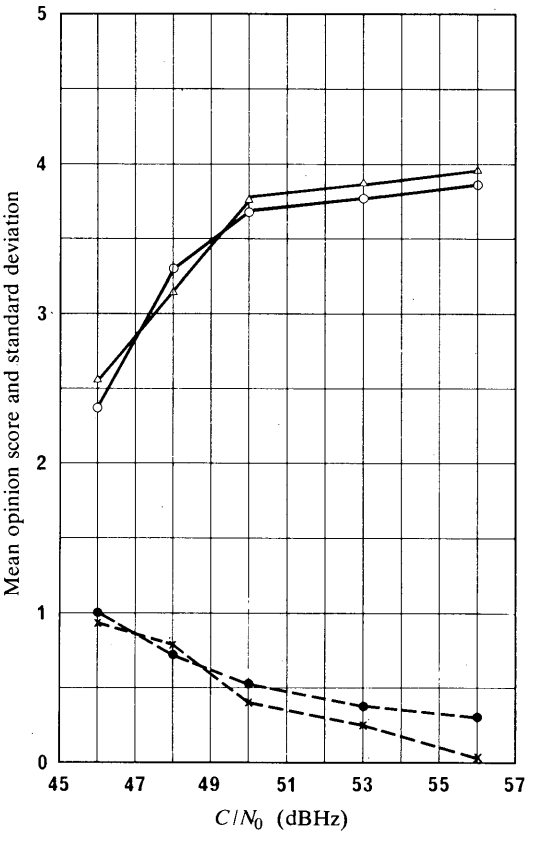
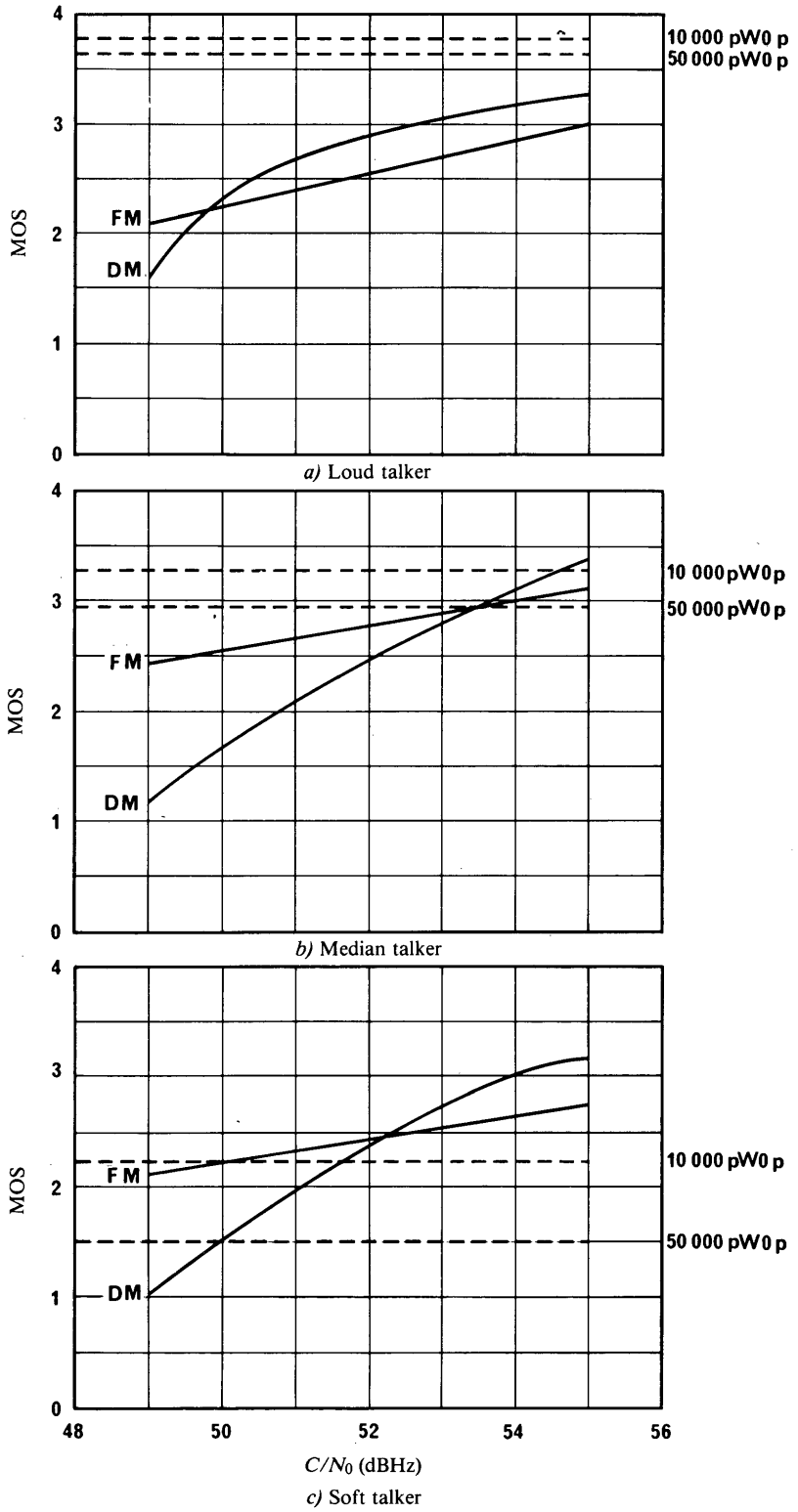


FIGURE 6 – *Opinion score*
(Mean and standard deviation (S.D.))

—○— : △ M/PSK, male
– –○– – : △ M/PSK, female
—△— : NBFM, male
– –△– – : NBFM, female

—○— : Mean, △ M/PSK
—△— : Mean, NBFM
– –●– – : S.D., △ M/PSK
– –×– – : S.D., NBFM

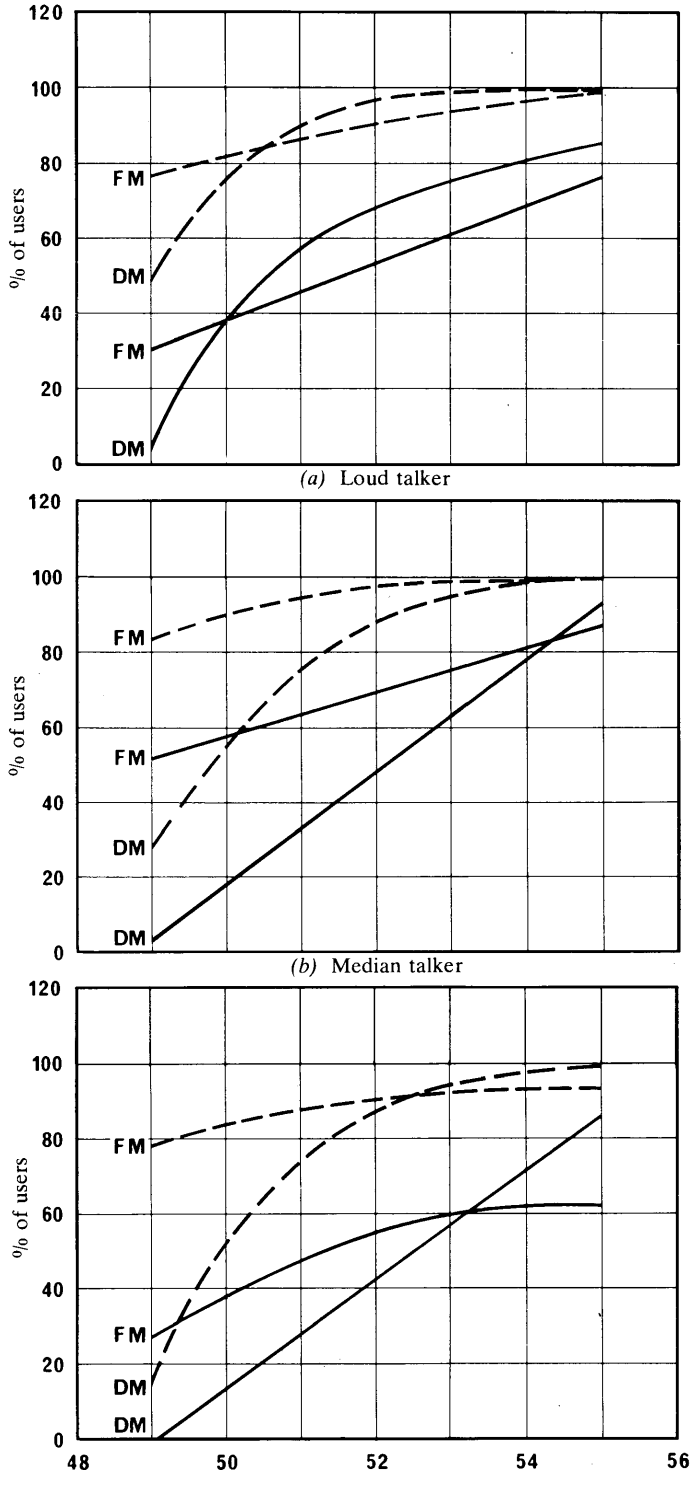


a) Loud talker

b) Median talker

c) Soft talker

FIGURE 7 – *Overall mean opinion score (MOS) curves*



(a) Loud talker

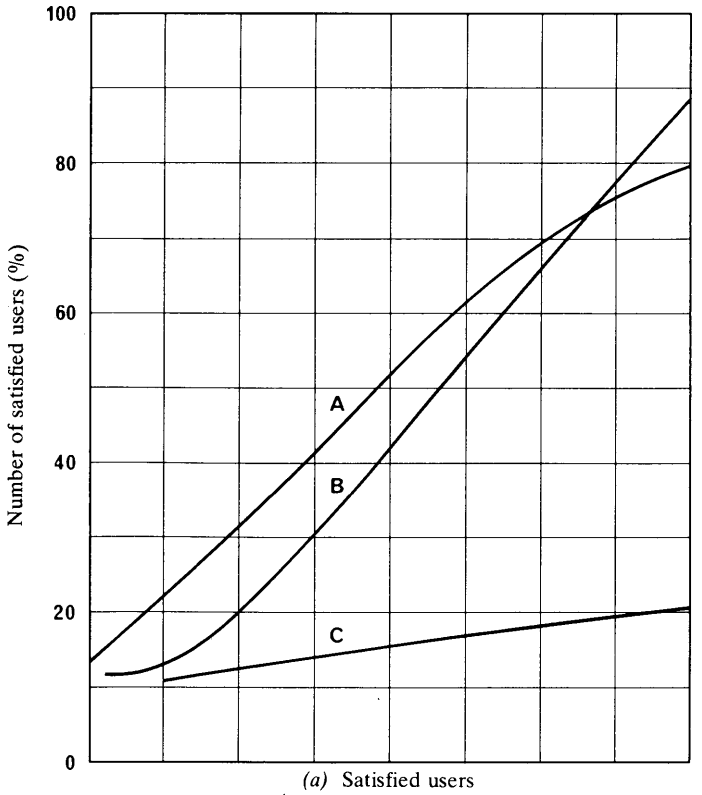
(b) Median talker

(c) Soft talker

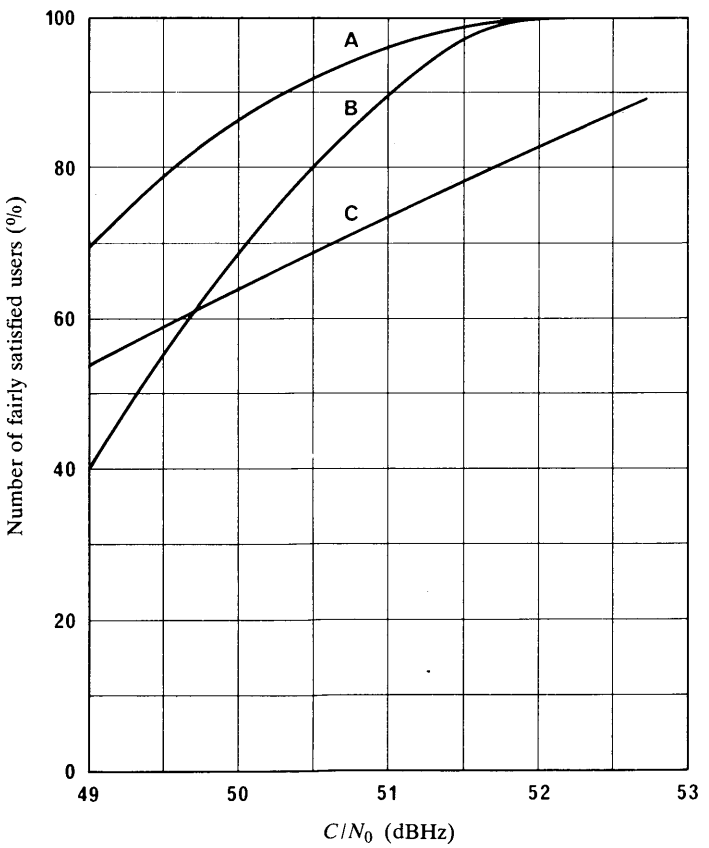
FIGURE 8 – *Overall appreciation curves*
(laboratory tests)

——— Satisfied users

– – – – Fairly satisfied users



(a) Satisfied users



(b) Fairly satisfied users

FIGURE 9 – *Overall appreciation curves (ATS-6 tests)*

A: NBFM
B: delta 32 kbit/s
C: delta 18 kbit/s

ANNEX II

SUBJECTIVE EVALUATION RESULTS OF A FREQUENCY MODULATION EQUIPMENT FOR USE IN THE MARITIME MOBILE SATELLITE SERVICE

1. Introduction

This Annex presents results of subjective tests performed on frequency modulation (FM) equipment designed for use in the maritime mobile satellite service. The same modem was used for assessment in both Norway and the United States. Characteristics of the FM equipment are presented in Table IV. In both cases, the subjective quality is expressed as equivalent signal-to-noise ratio as a function of speech input level with carrier-to-noise density ratio taken as a parameter. Additive white Gaussian noise was used in both tests.

TABLE IV – *Characteristics of the FM equipment*

Audio:	Bandwidth	300-3 000 Hz
	Clipping level	0 dBm0
	Compandor unaffected level	0 dBm0
	Companding	2:1 syllabic
	Pre-emphasis	none
IF:	Frequency (in test)	89 MHz
	RMS test tone deviation (at 0 dBm0)	8.5 kHz
	Threshold extension technique	Regenerative-feedback IF limiter
	Receive noise bandwidth	28 kHz

2. Norwegian tests

The assessment method used was the "adjustment method" described in Report 751, § 8.3.3. In this method the equivalent noise level is obtained directly as the setting of the noise level made by each subject.

Recordings through the FM equipment were made for 3 different levels of IF carrier-to-noise density ratio: 51, 53 and 55 dBHz and at 4 speech input levels: −5, −10, −20 and −30 dBm0.

The test material was presented to the subjects via a headset. No room noise was added for this experiment. The subjects were also allowed to adjust the listening volume according to their own preference. 15 male and female listeners participated in the tests and each subject assessed each condition twice.

The equivalent noise results are shown in Fig. 10 in terms of signal-to-psophometrically weighted noise as a function of speech input level. Parameter of the curves is the carrier-to-noise density ratio. Also shown in Fig. 10 are noise objectives of 25 000 pW0p (as proposed in Report 750, Annex II) and 10 000 pW0p.

3. United States tests

Recordings through the FM equipment were made for six values of IF carrier-to-noise density ratio (47, 49, 51, 53, 56 and 60 dBHz) and four talker levels (−5, −15, −25 and −35 dBm0) resulting in 24 conditions for evaluation.

The test recordings consisted of English language sentences read into a Western Electric type 500 handset and conditioned by the equivalent of a 2.74 km local telephone loop. The conditioning was included to give the speech samples realistic frequency shaping before transmission through the maritime satellite system FM equipment.

In order to equate that given test condition to a known form of speech signal transmission, speech perturbed by band limited Gaussian noise was selected as the standard of comparison.

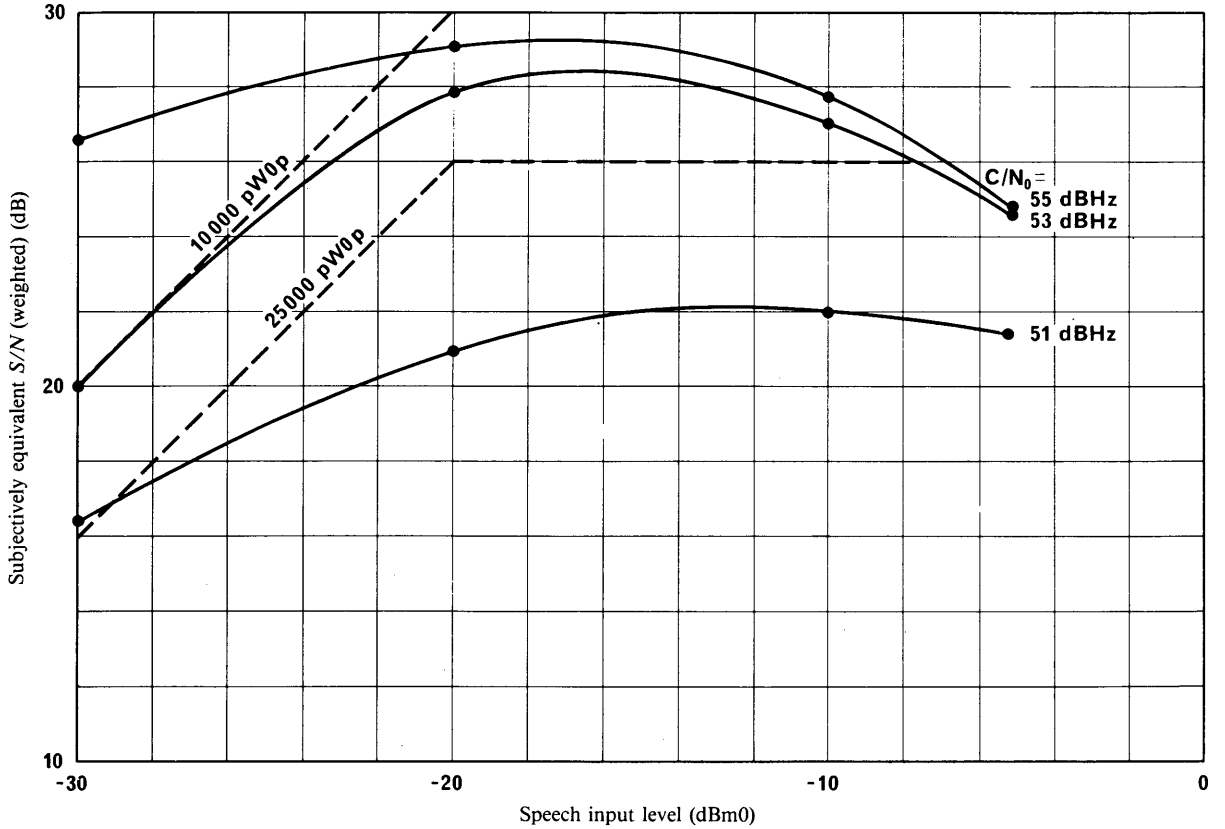


FIGURE 10 – *Equivalent signal-to-noise ratio as a function of speech input level obtained in the Norwegian tests. Parameter of the curves is the carrier-to-noise density ratio (C/N_0 in dBHz)*

The technique chosen for evaluation was those of a multiple comparison test known as the Youden Square method, which is a statistical method of data collection using a balanced incomplete randomized block design (Report 751, § 3.3.4). The word "incomplete" refers to the fact that the group of items for evaluation is divided into smaller sub-groups which are presented to listeners rather than presenting the entire group. In these tests, groups of 13 conditions were tested four at a time, thus forming a 13 × 4 Youden Square.

Each group of 13 conditions was formed as follows:

- The 24 sample recordings through the FM equipment were divided into four groups of six, each group chosen to include both bad and good conditions. Each group of six was evaluated in a separate Youden Square experiment.

- Seven reference conditions of analogue speech with different amounts of psophometrically weighted noise were then selected to bracket the quality of each group of six samples.

- Recordings of the test sentences under the seven reference conditions were then interleaved with each group of six sample recordings to form a set of 13 recordings.

Approximately 170 individuals participated in the tests. Each individual was asked to rank only four recordings at a time from best to worse after listening to the four recordings twice through. Test subjects listen to the speech samples through a telephone handset at a nominal listening level of −26 dBm. The recordings were evaluated in the presence of 63 dBA room noise at the listeners position, frequency shaped according to Fig. 11, to simulate the ambient noise conditions in the radio room of a merchant marine vessel (see Report 753 (Kyoto, 1978)).

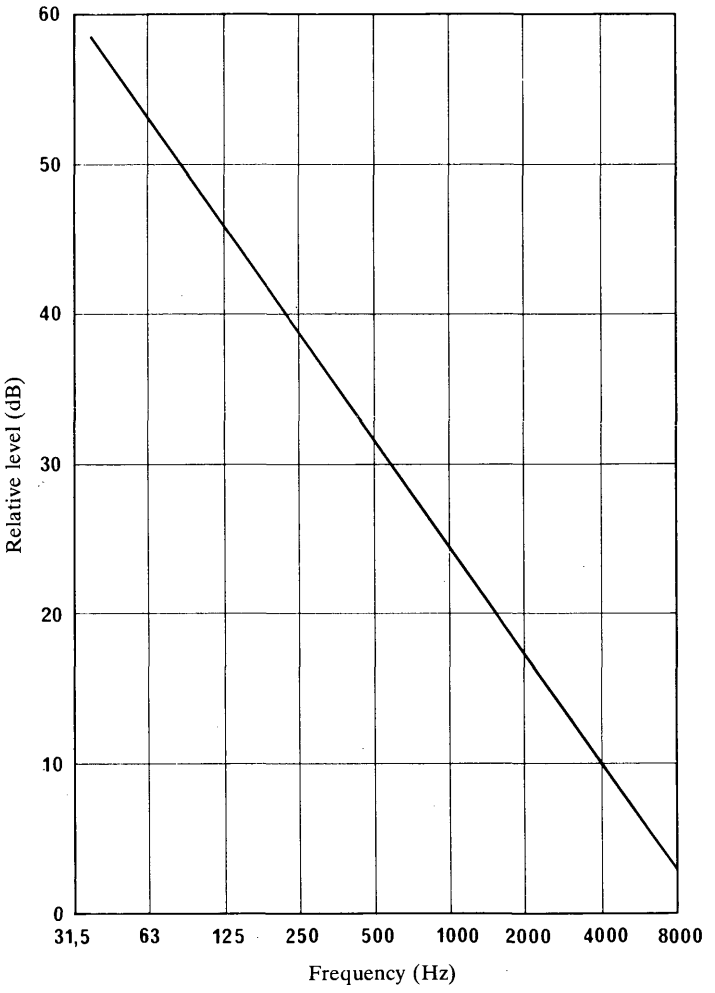


FIGURE 11 – *Frequency shaping of room noise*

When the evaluations of a 13 × 4 Youden Square were completed, each of the 13 recordings in the set had accumulated a mean rank value between 1 (for best) and 4 (for worst). The seven analogue conditions were fitted with a least squares curve of mean rank versus noise. The six FM link conditions under test with their scored mean rank values were subsequently interpolated on the curve and the resulting noise (or speech-to-noise ratio) read off the noise axis and termed "equivalent noise" for the particular conditions.

Four Youden Squares experiments were completed in order to correlate all 24 sample recordings through the FM terminal with the reference signal-to-noise values.

The results of the tests are given in Figs. 12 and 13.

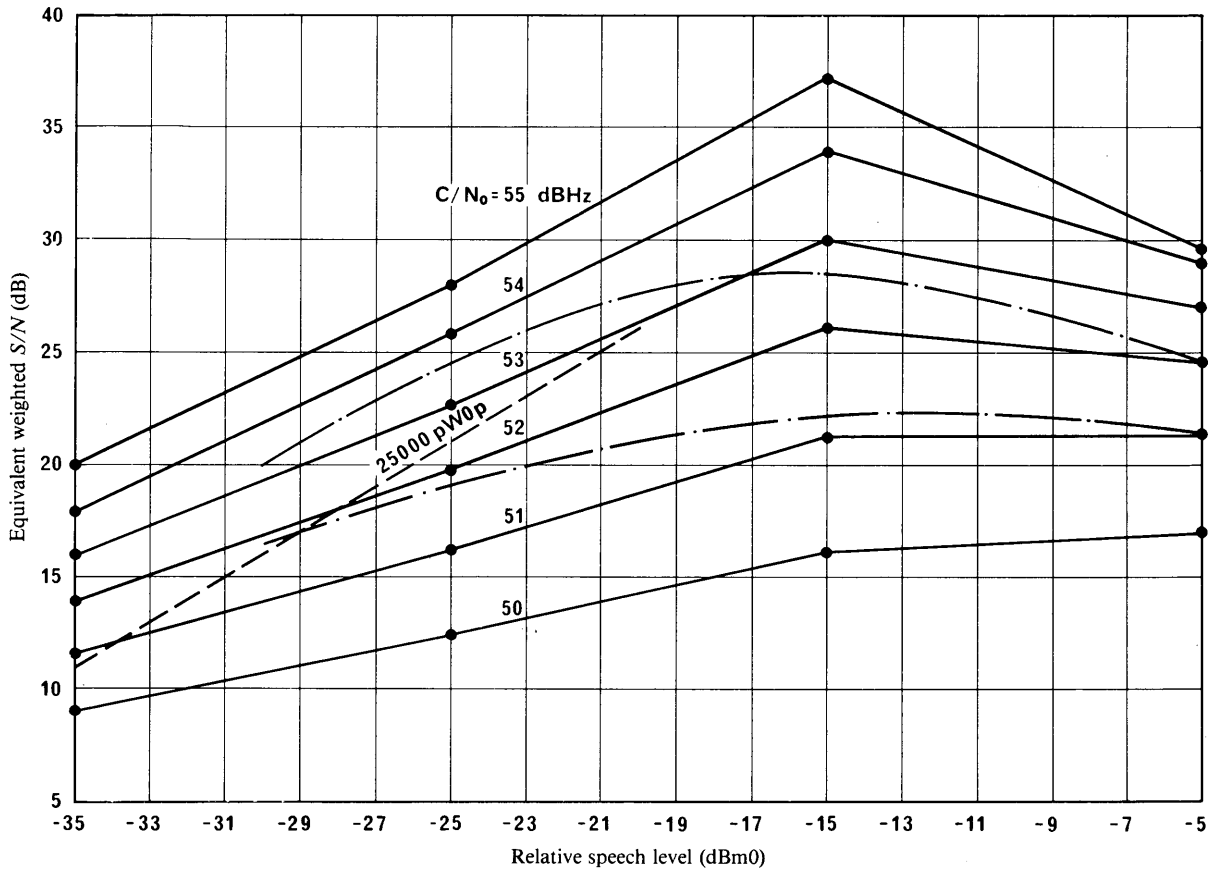


FIGURE 12 – *Equivalent signal-to-noise (S/N) vs. speech level relative to full deviation with carrier-to-noise density as parameter (C/N_0 in dBHz) obtained in the United States of America tests*

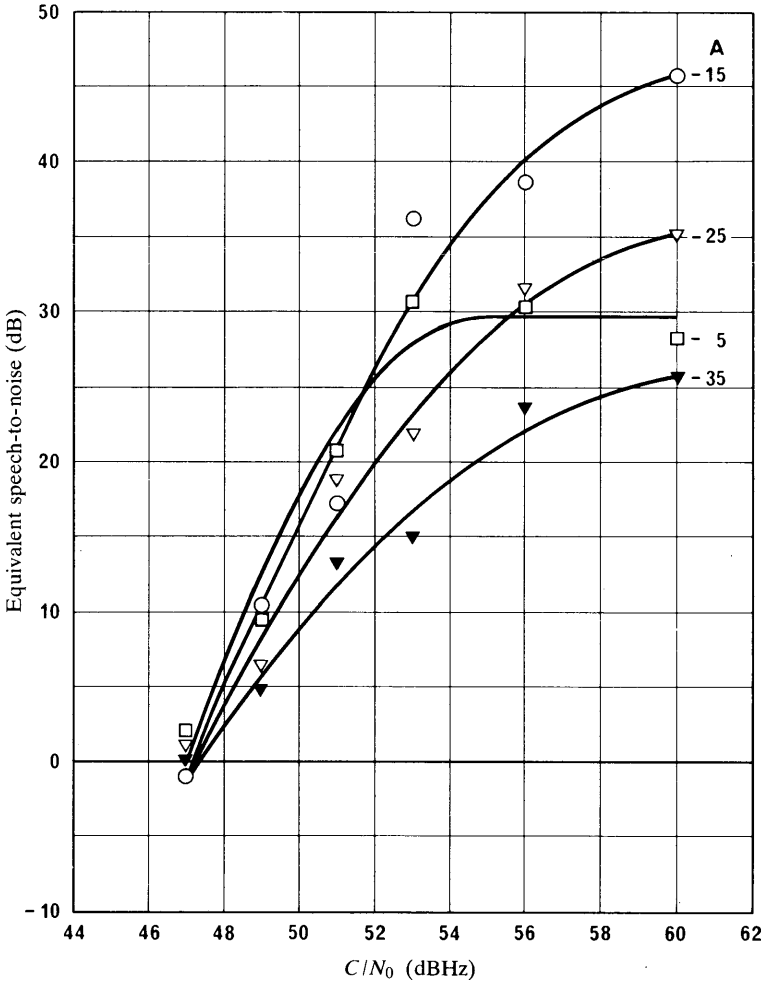


FIGURE 13 – *Results of subjective assessments in terms of equivalent noise of a −15 dBm0 talker as a function of* C/N_0

A: talker level (dBr) (r.m.s. power relative to r.m.s. sinusoid causing full deviation)

4. Conclusions

For carrier-to-noise density ratios 51 and 53 dBHz, the two tests are in good agreement, the Norwegian signal-to-noise results being somewhat higher at low talker levels. The difference is in the same order of magnitude as the 95% confidence limits of the Norwegian tests and may be accounted for by listener variability to be expected in subjective tests. At 55 dBHz however the results differ very markedly, the United States results being as much as 7 dB higher at −15 dBm0 speech input level. The explanation for this may probably be found in differences in the experimental procedure, especially the inclusion of ambient room noise, which will mask low levels of circuit noise through the sidetone and earcap leakage paths of the handset. It should also be noted that the subjective test methods themselves were different.

Despite these differences, both tests indicate that the performance proposed in Report 750 (Kyoto, 1978) (25 000 pW0p below −20 dBm0) is attained for a C/N_0-value between 52 and 53 dBHz.

ANNEX III

RESULTS OF THE SUBJECTIVE ASSESSMENT OF THE SPEECH QUALITY OF DM/PSK WITH FORWARD ERROR CORRECTION (FEC) FOR TELEPHONE CHANNELS IN THE MARITIME MOBILE SATELLITE SERVICE

1. Introduction

This Annex summarizes the results of the subjective assessment on the speech quality of DM/PSK channels with Viterbi decoding; this method of decoding is known to be one of the most powerful FEC techniques [Heller and Jacobs, 1971]. The tests were carried out in Japan.

2. Outline of the tests

The subjective assessment of the overall quality and intelligibility of the speech was carried out using both the opinion scale test and the syllable articulation test. The listening-only test method described in Report 751 was adopted for the tests.

Although the main purpose of the tests was to assess the speech quality of DM/PSK channels with Viterbi decoding, tests were also conducted with DM/PSK channels without FEC, a narrow-band frequency modulation (NBFM) channel with companding, and a reference channel to which various amounts of baseband noise were added. This enabled the speech qualities obtained to be compared.

The circuit diagram for recording test tapes is shown in Fig. 14. The voice signal was reproduced from the source tapes for both the opinion scale test and the syllable articulation test at a level of -20 dBm0, and was transmitted through each channel to which either IF band or baseband noise was added. The level of IF band noise was adjusted so as to obtain values of C/N_0 within the range of 40 dBHz to 56 dBHz, and the baseband noise level was set within the range 1000 pW0p to 1 000 000 pW0p. The received signal through each channel was recorded into test tapes.

All the test tapes were played back into telephone handsets in a quiet room with 45 dB insulation of ambient noise, where subjects listened to the speech and assessed the quality.

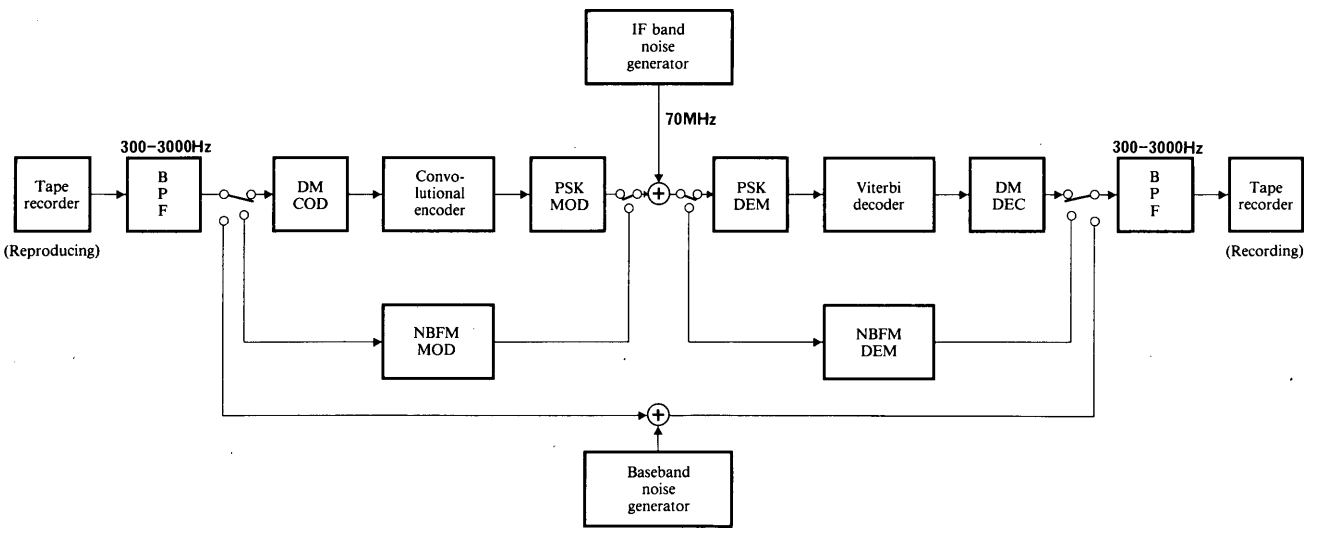


FIGURE 14 – *Circuit diagram for recording test tapes*

2.1 *Codecs and modems used for the tests*

The characteristics of the DM codecs are summarized in Table V.

TABLE V — *Characteristics of DM codecs*

Voice band	300–3000 Hz
Sampling frequency	32 kHz, 16 kHz
Companding law	Syllabic, 3-bit detection
Overload level (900 Hz)	0 dBm0
Maximum S/N_q (900 Hz)	34 dB (32 kHz), 20 dB (16 kHz)

The parameters of both the convolutional encoder/Viterbi decoder and the PSK modems used for Viterbi decoding are summarized in Table VI.

TABLE VI — *Parameters for Viterbi decoding*

Convolutional code	Information bit rate (kbit/s)	PSK MODEM keying speed (kbit/s)	PSK MODEM	Viterbi decoding
(2:1) - code	32	64	4 phase PSK	8-level soft decision
	16	32	2 phase PSK	
(4:3) - code	32	42 ⅔	2 phase PSK	

The NBFM modem design parameters were in accordance with the specification of the Marisat system. The characteristics are described in Table I of Annex I.

2.2 *Opinion scale test*

In the source tape, weather forecasts spoken by a trained male speaker in Japanese were recorded.

The test tapes were made for the following channels:

- 32 kHz DM/PSK with (2 : 1)-code
- 32 kHz DM/PSK without FEC
- 16 kHz DM/PSK with (2 : 1)-code
- 16 kHz DM/PSK without FEC
- NBFM with companding
- Reference channel.

The subjects comprised 29 male students, each of whom listened to the speech from the test tapes and selected the most appropriate score from the 5-point scale described in Report 751. Then the mean opinion score (MOS) was computed according to the method described also in Report 751.

The results are shown in Figs. 15 and 16.

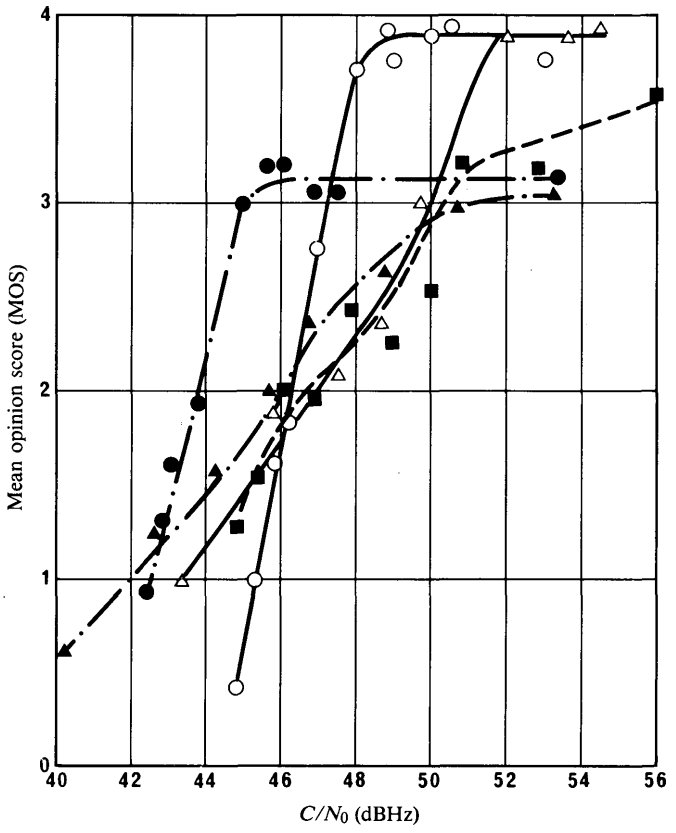


FIGURE 15 – *Mean opinion score vs.* C/N_0

Although the bit errors after Viterbi decoding tend to occur in burst, there is no significant difference between the MOS of DM/PSK channel with Viterbi decoding and that of DM/PSK channel without FEC, when the BERs at the input of DM decoder are the same (see Fig. 16). Hence, the application of Viterbi decoding is effective for both the 32 kHz and 16 kHz DM/PSK channels, since it can improve the speech quality in the reduced C/N_0 condition in the region where the BER is improved (see Fig. 15).

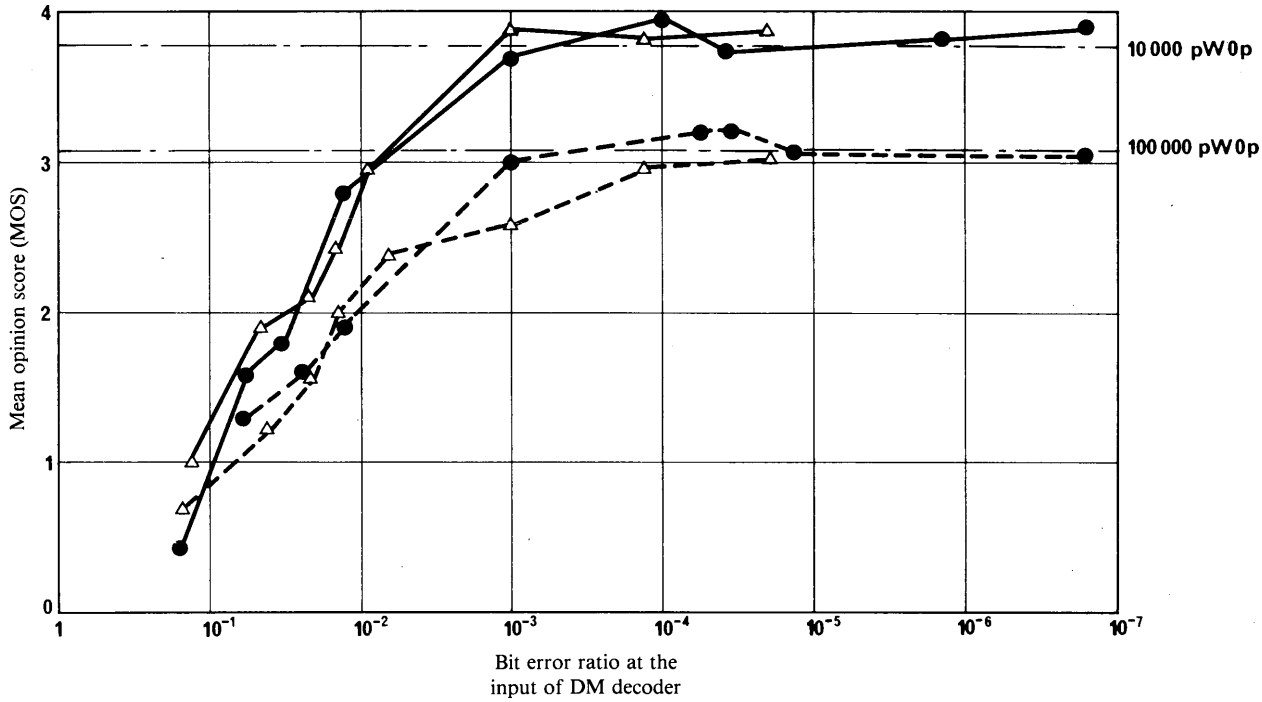


FIGURE 16 – *Mean opinion score vs. bit error ratio*

2.3 *Syllable articulation test*

In the source tape, test syllables pronounced at random by a trained female speaker were recorded.

The channels used for recording test tapes were as follows:

- 32 kHz DM/PSK with (2 : 1)-code
- 32 kHz DM/PSK with (4 : 3)-code
- 32 kHz DM/PSK without FEC
- 16 kHz DM/PSK with (2 : 1)-code
- 16 kHz DM/PSK without FEC
- NBFM with companding.

Five trained male subjects listened to the test tapes and wrote down the syllables they heard. Then the percentages of correctly identified syllables were computed to give the articulation scores.

The results are shown in Figs. 17 and 18.

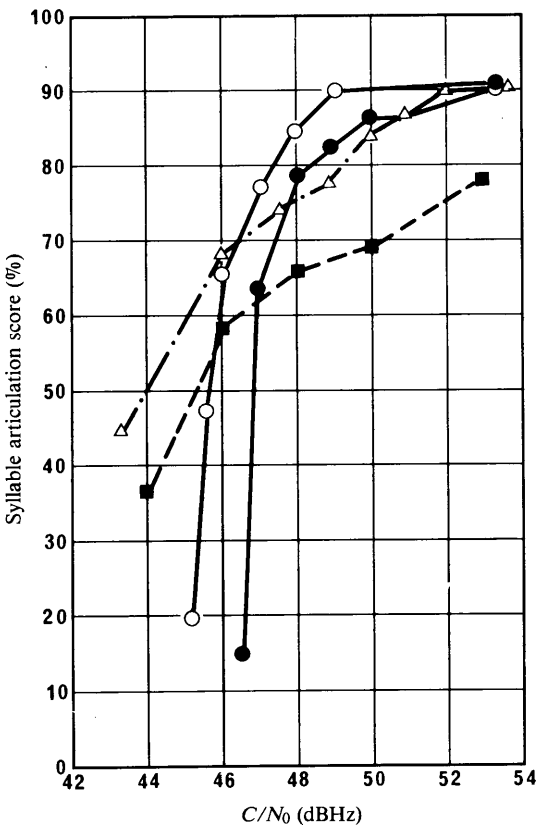
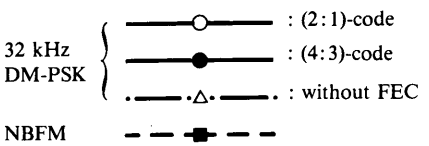


FIGURE 17 – *Syllable articulation score vs. C/N_0*



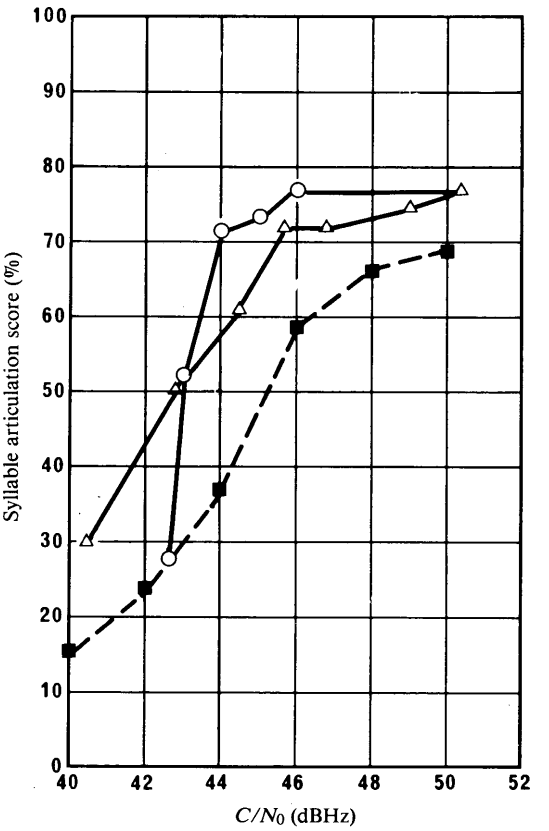
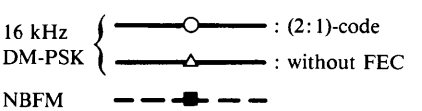


FIGURE 18 – *Syllable articulation score vs. C/N_0*



As shown in Figs. 17 and 18, the application of Viterbi decoding is effective when the C/N_0 is above a certain specific value. However, the improving effect is not so great as in the case of mean opinion scores. This is because the articulation of voice in DM channels is more robust to the effect of bit errors.

3. Conclusions

From the results of the subjective assessment, it is concluded that the application of forward error correction (FEC) such as Viterbi decoding is effective for both 32 kHz and 16 kHz DM/PSK channels for telephony. A significant reduction in C/N_0 for DM/PSK telephone channels can be expected for a given speech quality.

REFERENCE

HELLER, J. A. and JACOBS, I. M. [October, 1971] Viterbi decoding for satellite and space communication. *IEEE Trans. Comm. Tech.*, Vol. COM-19, **5**, 835-848.

RECOMMENDATION 549-1

SIDE TONE REFERENCE EQUIVALENT OF HANDSET USED ON BOARD A SHIP IN THE MARITIME MOBILE-SATELLITE SERVICE AND IN AUTOMATED VHF/UHF MARITIME MOBILE RADIOTELEPHONE SYSTEMS

(Study Programme 17A/8)

(1978-1982)

The CCIR,

CONSIDERING

(a) that the ambient acoustic noise to be expected on board ships is often significantly higher than on terrestrial telephone locations;

(b) that room noise picked up by the side tone path of the handset should not introduce any further transmission impairment;

(c) CCITT Recommendation G.121, Section E,

UNANIMOUSLY RECOMMENDS

that the side tone reference equivalent of the handset in the ships' installation should be at least 17 dB.

Note 1. – Noise levels in the range 50 to 80 dBA are to be expected on board ships, the actual level being dependent on locations on board ship, the ship's size and structure.

Note 2. – The need for a side tone may be discussed in view of the degradations it can create. Even when the value 17 dB is attained, room noise at expected levels may still have an adverse effect (CCITT Recommendation G.121). The recommended value is a compromise between the need for limiting impairment due to room noise and the possible need for a certain "liveliness" in the handset.

Note 3. – The CCITT Recommendations on side tone could be subject to change as all aspects of side tone are under review.

REPORT 754 *

USE OF VOICE ACTIVATED CARRIER SWITCHING IN MARITIME MOBILE-SATELLITE SYSTEMS

(Study Programme 17A/8)

(1978)

1. Voice activated carrier switching may be used to increase the capacity of the satellite. The voice activated carrier switch switches off or reduces the carrier during speech pauses.

2. The following factors should be considered when designing the voice activated carrier switch:

2.1 It should be insensitive to noise and unsuppressed echo arising in the connection so as to avoid unwanted activation of the carrier.

The threshold could be set at a fixed level or be adaptive, i.e. depend upon the actual speech and noise levels; an adaptive level will have the advantage that it may allow for a greater variation in both speech level and noise level and thus reduce the possibility of unwanted activation of the carrier and also allow proper operation for low level speech signals.

Switches situated at shore stations will have a wide variety of noise levels presented to them corresponding to the wide variety of possible connections. In such locations adaptive threshold is preferable. A reasonable design criterion might be that the carrier should not be activated for more than 1% of the time by circuit noise of a circuit meeting CCITT circuit noise objectives (CCITT Recommendations G.152, G.153).

Switches situated at ship stations will have presented to them less variation in noise level as well as a higher mean speech level. This might allow a fixed threshold setting. A value could be -31 dBm0 (as for echo suppressors), to be confirmed by further study; one might choose alternatively the threshold recommended for TASI-B which is dynamically variable between -40 dBm0 and -20 dBm0.

However, when voice activated carrier switches and echo suppressors are cascaded, a lower threshold level should be used in order to avoid that the speech is chopped during the time when both parties are talking simultaneously.

2.2 Clipping of initial syllables may impair the overall quality. This may be avoided by inserting an appropriate delay into the speech path and/or by designing the voice detector to detect low energy phonemes. It should be noted that this delay will be a component of the total transmission delay.

2.3 Chopping on low energy phonemes, such as stop consonants within words and clipping of the end of the speech burst may also degrade the quality. This problem may be mitigated by an adequately long hangover time and by having a short operation time. The operation time for echo suppressors and TASI equipment is 5 ms. Experiments have shown that the speech quality may be severely degraded if the hangover time is shorter than 150 ms [Barnes, 1972]. In a recent Digital Speech Interpolation (DSI) design 170 ms has been used [Jankowski, 1976]. In TASI-B the hangover time is typically 278 ms.

3. Further study is needed of the permissible degradation of performance due to voice activated carrier switching. One possible assessment method could be to use articulation tests. Other assessment methods could be listening-only tests and conversational tests where the quality impairment could be shown in terms of increased percentage of difficulty (Report 751). Objective methods have been used where a set of test signals simulating speech is designed [Jankowski, 1976].

4. It may be required that the voice activated carrier switch be automatically disabled if some types of services other than the telephone service are required over the voice channels. This should be taken into account when designing the signalling system.

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* The Director, CCIR, is requested to bring this Report to the attention of the CCITT.

5. Squelch circuits or the like will be required at the receiving end to avoid an increase of the idle channel noise power level during speech pauses. The operation of the squelch circuit could be followed by a rapid change from noisy to quiet line condition giving the impression that the connection has been interrupted. As far as the shipboard subscriber is concerned, this effect could be reduced by designing the squelch circuit to allow some noise to be present during speech pauses. As far as the terrestrial subscriber is concerned, the exchange and circuit noise of the terrestrial portion of the connection may be sufficient to mask the effect. If not, the same design of squelch circuit can be employed at both ends. On board a ship the line noise contribution may in many cases be negligible so that the effect may still persist and must therefore be taken into account when assessing the voice performance of the circuit.

6. The demodulator should have a short acquisition time so as to avoid clipping of the syllables.

7. More studies are required to establish recommendations concerning the use and the characteristics of voice activated carrier switches.

Such studies should at least comprise:

- preferred subjective assessment methods and objective test methods, as well as associated quality objectives;
- design parameters such as hangover time, response time, threshold levels and adaptiveness, immunity to false detection of noise.

REFERENCES

BARNES, G. J. [1972] Voice switching parameters in telephony. *Elec. Comm.*, Vol. 47, **3**.

JANKOWSKI, Jr. J. A. [Spring, 1976] A new digital voice activated switch. *COMSAT Tech. Rev.*, Vol. 6, **1**.

RECOMMENDATION 550

USE OF ECHO SUPPRESSORS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

(a) that maritime mobile-satellite systems will be interconnected with the international telephone network;

(b) that in order to achieve transmission objectives for the maritime mobile-satellite service which are in accordance with those of other international telephone connections, it is necessary to take into account the effects of echo;

(c) CCITT Recommendation G.131 concerning the rules governing the use of half-echo suppressors;

(d) CCITT Recommendation G.161 concerning the characteristics of half-echo suppressors;

(e) CCITT Recommendation Q.115 regarding control of echo suppressors,

UNANIMOUSLY RECOMMENDS

1. that half-echo suppressors shall be fitted in the terrestrial part of the connection;

2. that if two-wire telephone sets are used at the ship terminal, a half-echo suppressor shall be fitted at the ship end of the connection;

3. that if echo suppressors are fitted, they should have characteristics in accordance with CCITT Recommendation G.161;

4. that it should be possible to disable echo suppressors, as described in CCITT Recommendation G.161, in both the terrestrial and the ship end of the connection;

5. that control of echo supressors in the terrestrial connection should follow the requirements established in CCITT Recommendation Q.115;

6. that manual disabling of echo suppressors at the ship end of the connection should be possible;

7. that enabling of the echo suppressor, located at the ship end of the connection, must be done automatically when a call is terminated, independently of the disabling technique used.

Note 1. – If 4-wire telephone sets are used at the ship terminal, no significant echo via electrical paths is normally returned to the international network assuming that go/return crosstalk is of negligible level, and therefore no half-echo suppressor is required at the ship end of the connection. CCITT Study Group XVI has expressed the opinion that the level of acoustic coupling introduced by hand-set telephone instruments used in normal conversational conditions by members of the public may cause echo difficulties to the terrestrial subscriber, and a half-echo suppressor is required for this reason even in wholly four-wire shipboard installations. However, there is little experimental data on this topic, and further study is required.

Note 2. – The use and characteristics of other types of echo controlling devices may be recommended by the CCITT in the future. If so, this Recommendation should be amended to cover such devices also.

Note 3. – When tone disabling is used precautions must be made to ensure that the echo suppressor is not disabled by speech.

REPORT 758

BROADCAST CALLS TO SHIPS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

1. Types of broadcast calls

The following types of broadcast calls have so far been identified:

- broadcast to national groups of ships,
- broadcast to a fleet,
- broadcast to all ships in a service area,
- broadcast to all ships in given geographical areas.

2. Transmission mode

By broadcast call it is understood that a call is capable of being received simultaneously by groups of ships. This implies that no return link from the ships will be made available during the call and hence that the calling customer will not know which of the ships concerned have actually received the call.

If it is essential to the calling customer that all ships in the called group have received the message, the calling customer should be advised to use, for example, multi-address telex call facilities or to contact each individual ship sequentially using normal telephone or telex set up procedures.

For the purpose of this Report it is assumed that there may be a demand for broadcast calls over telephone channels (voice, facsimile, data), telegraph channels and data channels.

3. Barring of non-authorized broadcast calls

3.1 It is essential that only authorized customers are given access to broadcast facilities. Therefore, it must be possible to bar the access to these facilities for ordinary subscribers.

Barring should be possible in both automatic and semi-automatic systems.

It is further assumed that the ship's numbers used to gain access to broadcast calls are composed in a similar way as the numbers used to identify a unique ship. However, the numbers used for broadcast calls to all ships in given geographical areas may be an exception to this general rule as discussed in § 4.

It is most likely that a ship's international number (or broadcast number) will be composed as follows for all services concerned (see Note):

$$I_1\ I_2\ I_3\ N_1\ N_2 \ldots N_k$$

where $I_1\ I_2\ I_3$ is the country code (including the coverage area code) assigned to the Maritime Mobile Satellite Service. The number of digits in the ship's number, k, has still to be decided but that decision will not alter the conclusions below.

Note. – See Recommendation 585 on Assignment and use of Maritime Mobile Service Identities.

3.2 It must be possible to establish the authority of subscribers who are permitted to place broadcast calls. This may be done in several ways:

- by allowing such calls to be set up over leased circuits only. In this case no identification of the calling customer is required;
- by only allowing such calls to be set up semi-automatically on a reverted call basis. In this case the identity of the calling customer is inquired by the operator handling the call;
- by making use of automatic identification of the calling customer's number (not generally possible in existing networks);
- by requiring the insertion of an authorization code by the calling customer.

The actual procedure should be left to the administrations concerned.

3.3 Barring of non-authorized broadcast calls can, in principle, be done anywhere in the connection depending upon the sophistication of the network and the way in which permitted broadcast calls are set up (§ 3.2), i.e.:

- at the outgoing international switching centre;
- at an international transit centre;
- at the shore stations.

It may be advisable to leave open all possibilities so that the administrations concerned can choose an approach which is optimum for their networks and in agreement with principles established by the system manager. It should be noted that non-authorized broadcast calls may be set up from a ship. In order to avoid that such calls are connected, barring facilities should also be provided at the shore station, in particular so if ship-to-ship calls are permitted to be set up automatically. It should be further noted that some ships may be authorized for certain types of broadcast messages.

For routing purposes, an international telephone switching centre should be capable of analyzing at least the first five digits of the international number. If such a centre were to perform the barring using the routing facilities for number analysis, it would be advisable that a broadcast call be identifiable from one or both of the digits N_1 and N_2 of the ship's number. However, since barring functions have to be provided at the shore station, it should further be considered whether the duplication of the functions is desirable. If barring at places prior to the shore station is not desirable, the ship's number need not satisfy the suggested constraint that a broadcast call be identifiable from the first two digits.

4. Broadcast to geographical areas

4.1 Broadcast to all ships in a given geographical area may be required for the following purposes:

- distribution of meteorological and navigational warning data;
- distribution of regular weather reports etc.;
- coordination of search and rescue operations.

4.2 For transmission of such information, it is assumed that direct printing telegraphy or facsimile will be used. But there may also be a requirement for voice transmission.

Broadcast calls of this kind may require priorities not provided for on terrestrial switched networks. This may imply that such calls must be set up over leased circuits. However, it should be further studied whether it would be desirable that new signalling systems for international networks should provide for the priorities envisaged for maritime mobile-satellite systems, bearing in mind that calls with high priority should always be given access to the network.

4.3 In order to set up a broadcast call to all ships in a given geographical area, the geographical area code must be sent over the control channel. The control channel may also contain a code identifying the call as a geographical area broadcast.

From an operational point of view it may be desirable that geographical areas are defined in the same way for the maritime mobile-satellite Service as for maritime services employing digital selective calling. This may imply that the code used to identify the area will have a different composition than the number used to set up other broadcast calls or calls to a single ship. In order to achieve a sufficient degree of accuracy, it may even be required that more digits are needed for this purpose.

Another possible solution could be to use the geographical area defined in the IHO/IMCO Plan for international coordination of promulgating navigational warnings to shipping. This plan would provide coarse geographical resolution. Higher resolution of geographical areas could be obtained with a plan having essentially the same operational capabilities as those of the digital selective system described in Recommendation 493.

RECOMMENDATION 552

QUALITY OBJECTIVES FOR 50-BAUD START-STOP TELEGRAPH TRANSMISSION IN THE MARITIME MOBILE-SATELLITE SERVICE *

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

(a) that proper interworking of this telegraph transmission with the international telegraph services must be ensured;

(b) CCITT Recommendation F.10 concerning character error rate for telegraph communications,

UNANIMOUSLY RECOMMENDS

that, for the shore station-to-mobile terminal and mobile terminal-to-shore station links, sufficient margin should be included to overcome adverse propagation conditions. The objective should be that propagation conditions should not contribute any character errors for at least 95% of all calls with mobile terminals within the satellite service area. With the exception of blockage effects, propagation conditions should not contribute more than 8 errors in 100 000 characters with a 99% confidence level for mobile terminals at the edge of the service area.

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* This Recommendation corresponds to CCITT Recommendation F.112.

RECOMMENDATION 553

INTERFACE REQUIREMENTS FOR 50-BAUD START-STOP TELEGRAPH TRANSMISSION IN THE MARITIME MOBILE-SATELLITE SERVICE *

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

(a) that proper interworking of this telegraph transmission with the international telegraph services must be ensured;

(b) that the shore station equipment will interface with the international terrestrial telegraph networks and will therefore need to conform to CCITT Recommendations where applicable;

(c) that the ship station will include a local end with its termination consisting of start-stop equipment using International Telegraph Alphabet No. 2,

UNANIMOUSLY RECOMMENDS

1. that the shore station equipment interfacing with terrestrial telegraph channels should conform to CCITT Recommendation R.101 (see Annex I) as applicable to 50-baud services:

1.1 for signals from the terrestrial network entering the shore station, the relevant points are:

TABLE I

Item	Parameter	Recommendation R.101 Point
a	Input modulation rate	2.1
b	Isolated character stop elements	2.2
c	Minimum interval between start elements	2.3
d	No restrictions on the use of combinations of International Telegraph Alphabet No. 2	2.4
e	Effective net margin	2.5
f	Minimum input start element duration	2.6

1.2 for signals from the shore station entering the terrestrial network, the relevant points are:

TABLE II

Item	Parameter	Recommendation R.101 Point
g	Output distortion	3.1
h	Output modulation rate	3.2
i	Minimum output stop element	3.3

2. that the transmission characteristics of the ship terminal start-stop equipment should conform to CCITT Recommendation S.3 as applicable to 50-baud services.

* The CCITT is at present considering the adoption of a similar Recommendation.

ANNEX I

The relevant sections of CCITT Recommendation R.101 * are reproduced below for information:

"**2. Start-stop channel inputs**

2.1 The maximum speed tolerance that shall be accepted on continuous incoming 50-baud start-stop signals where a stop element of 1.4 units is employed shall be ± 2%.

2.2 The system shall accept isolated incoming 50-baud start-stop signals that have a 1-unit stop element.

2.3 The minimum interval between start elements of undistorted successive continuous characters that may be presented at the channel input when the nominal modulation rate is 50 bauds shall be 145 5/6 ms.

2.4 There shall be no restriction on the continuous transmission of all characters specified in 1. above (e.g. combination No. 32 of International Telegraph Alphabet No. 2) when they are presented at the maximum permitted rate.

2.5 The effective net margin on all channel inputs when undistorted signals are received from a transmitter having a nominal character length and rate shall be at least 40%.

2.6 To be recognized as valid, an input character start element shall be of at least 0.4 units' duration at the nominal modulation rate of the input channel.

3. Start-stop channel outputs

3.1 The maximum degree of gross start-stop distortion shall be 3%.

3.2 The maximum difference possible between the mean modulation rate of the channel output signals and the nominal modulation rate shall be 0.2%.

3.3 When 50-baud characters are presented at any input rate within the specified range of this Recommendation, the minimum stop element duration released at the output shall be 1.25 units."

REPORT 917 **

PERMISSIBLE LEVELS OF INTERFERENCE INTO TELEPHONE CHANNELS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Question 17/8)

(1982)

1. Introduction

Consideration is given in this Report to the possible effects of interference on telephone channels in the maritime mobile-satellite service. Particular attention is given to the shore-to-ship direction, and to the effects of interference on satellite channel quality and capacity.

It is assumed that interference could arise from other services sharing the same frequency bands, i.e. from the fixed and fixed-satellite services. Based on satellite characteristics which are typical of those being considered for maritime mobile-satellite systems, a possible interference noise power budget and interference protection criteria are proposed.

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* This Recommendation is at present under study and may be modified.

** The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Satellite Organization (INMARSAT) and Study Group 4.

2. Sources of interference

Interference may enter the channels of a maritime satellite network via the receivers of the 4/6 GHz feeder links (i.e. at coast earth stations and at the satellite), and also via the receivers of the 1.5/1.6 GHz links between ships and the space station (i.e. at ship earth stations and at the satellite). Most of this interference is expected to originate from the transmitters of stations in those services which share the same frequency bands as the maritime mobile-satellite service. Potential sources of interference therefore include the fixed-satellite service operating at 4/6 GHz, and terrestrial services operating at 4/6 GHz and 1.5/1.6 GHz. Further potential sources of interference into a maritime mobile-satellite network are the links of another maritime mobile-satellite system. In the case of the 1.5/1.6 GHz links, the intereference mechanism arises because of the relatively broad beamwidth of ship earth station antennas and their resultant poor discrimination characteristics. Such interference can therefore be reduced only by an efficient design of maritime mobile-satellite systems; this will be an important consideration in the design of future systems. On the 4/6 GHz feeder links, coast earth station antenna discrimination characteristics are superior to those for ship earth stations at 1.5/1.6 GHz. Nevertheless, interference from other satellite systems in the 4/6 GHz bands might be a critical factor in coordinating suitable geostationary satellite orbit positions for space stations in maritime mobile-satellite systems.

3. Performance objectives for telephony

Performance objectives for telephone channels in the maritime mobile-satellite service are given in Recommendation 547, in terms of the permissible subjectively-equivalent noise power. As an example, the permissible subjectively-equivalent noise power in a telephone channel for a speech level of −20 dBm0 is assumed to be 25 000 pW0p. Tests conducted with typical voice modems (Report 752) indicate that the 25 000 pW0p objective can be achieved with a carrier-to-noise density ratio (C/N_0) of between 52 and 53 dBHz.

4. Typical satellite link characteristics

In terms of satellite output power requirements and system capacity, transmission parameters in the shore-to-ship direction are far more critical than in the ship-to-shore direction, and hence are the only ones considered here. Table I shows the main noise contributions on the shore-to-ship link, assuming satellite characteristics which are typical of those being considered for maritime mobile-satellite systems (Report 760). No allowance has been made for interference in Table I.

TABLE I — *Typical parameters for shore-to-ship transmission*

Parameter	Value
Up-path C/N_0 (thermal noise) with 5° coast earth station elevation (dBHz)	70
Coast earth station C/I_0 (intermodulation noise) (dBHz)	75
Satellite C/I_0 (intermodulation noise) (dBHz)	63.8
Down-path C/N_0 (thermal noise) with 10° ship antenna elevation angle (dBHz)	53.5
Overall $C/(N_0+I_0)$ for satellite link (dBHz)	53
Satellite nominal e.i.r.p. required to achieve overall $C/(N_0+I_0)$ channel objective (dBW)	18.1 per carrier

5. Effects of interference

In considering the effects of interference, it is useful to recall the permissible interference limits for the fixed-satellite service. For the fixed-satellite service, the total noise power allowance under clear-sky conditions is 10 000 pW0p (Recommendation 353), of which 20% can be contributed by interference from other networks in the fixed-satellite service (Recommendation 466) and a further 10% can arise from interference from terrestrial line-of-sight radio-relay systems (Recommendation 356). The total permissible interference noise contribution can thus be as much as 30% of the total noise power, or 3000 pW0p. In considering the applicability of such limits to the maritime mobile-satellite service, it should be noted that satellite output stages in current maritime mobile-satellite systems are severly power-limited in the satellite-to-ship path, and hence the contribution of interference to the total permissible noise power could have a significant effect on channel quality or system capacity. In order to compensate for this, speech processing is now used in maritime mobile-satellite systems, and hence the interference (which is assumed to be noise-like), as well as internal system noise, must be considered in terms of its subjective effect.

Future satellites might not be so power-limited, making an overall noise objective of 10 000 pW0p attainable and resulting in performance comparable to that of the fixed-satellite service. Consequently, it is reasonable to allocate no more than 3000 pW0p to interference from other systems to a maritime mobile-satellite system.

6. Noise power budget

From the above considerations, a possible noise power budget can be derived as shown in Table II. Values of C/N_0 corresponding to the noise allocations in Table II assume linear relationships between subjectively-equivalent noise power and pre-detection RF noise power.

TABLE II — *Noise power allocations for telephone channels*

Noise source	Equivalent C/N_0 (80% of the time) (dBHz)		Noise budget (subjectively-equivalent noise power) (pW0p)	
Satellite link:				
up-path thermal		70(1)		
coast earth station intermodulation products		75(1)		
satellite intermodulation products		63.8(1)		
down-path thermal		53.5(1)		
Total satellite link:		53		22 000
Interference:				
satellite systems	63.4		2 000	
terrestrial services	66.4		1 000	
total interference		61.7		3 000
Total channel noise:		52.5		25 000

(1) Typical parameters for shore-to-ship direction.

The total satellite link noise power of 22 000 pW0p has not been broken down in Table II for the various components of the link. In addition, the total interference noise power allocation of 3000 pW0p is assumed to apply in both directions of transmission to all sources of interference on both up and down links. Individual allocation of either satellite link or interference noise would be determined by the particular maritime-satellite system being considered and by the relationship between up-path and down-path noise which would differ for each direction of transmission. This allocation of interference noise requires further study.

It can be seen from the down-path C/N_0 in Table II that the interference allowance necessitates an addition 0.5 dBW of satellite e.i.r.p. in order to maintain an overall channel quality of 53 dBHz. This corresponds to a capacity loss of about 11%.

7. Provisional permissible interference protection criteria

It has been assumed in Table II that interference allocations for other satellite systems and the terrestrial services are the same as the corresponding protection criteria adopted for the fixed-satellite service. Assuming further that the same criteria can be applied for single-entry interference, the following provisional interference protection criteria might be used for the maritime mobile-satellite service:

7.1 *Interference from satellite services:*

- total interference from satellite systems should not exceed 2000 pW0p in the hypothetical reference circuit for more than 20% of any month;
- interference from a single satellite system should not exceed 600 pW0p in the hypothetical reference circuit for more than 20% of any month.

7.2 *Interference from terrestrial services:*

- total interference from terrestrial systems should not exceed 1000 pW0p in the hypothetical reference circuit for more than 20% of any month;
- interference from a single terrestrial station should not exceed 333 pW0p in the hypothetical reference circuit for more than 20% of any month.

8. Conclusions

A preliminary assessment of the effects of interference on telephone channel quality and capacity in the maritime mobile-satellite service has been made, with respect to satellite systems currently being planned. It is proposed that the permissible level of interference in a telephone channel should not exceed 3000 pW0p for more than 20% of any month. Allocations for individual interference entries have been suggested. These allocations and other aspects of interference into a maritime mobile-satellite network require further study.

REPORT 918 *

AVAILABILITY OF COMMUNICATIONS CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17F/8)

(1982)

1. Introduction

The availability of communications circuits in the maritime mobile-satellite service needs to be defined in order to provide guidance to system planners and equipment manufacturers, and thus to provide an adequate standard of service to the user. In deriving a suggested philosophy for availability criteria, differences between the maritime mobile-satellite service and the fixed-satellite service are identified. However, it is considered that the concept of availability for the maritime mobile-satellite service should, as far as possible, be compatible with similar concepts adopted for the fixed-satellite service (Report 706) and for radio-relay systems (Report 445).

2 General definitions and philosophy

2.1 *Definition of circuit availability*

The availability of communications circuits in the maritime mobile-satellite service will depend on the availability objectives set for each component part of the circuit. In this Report, consideration is given to availability objectives for the space sector, earth-station equipment and auxiliary functions, and for the radio paths between satellite and earth stations. The overall availability of the communications circuit is thus determined.

In the maritime mobile-satellite service, circuit availability (A) can be derived from the duration and rate of occurrence of interruptions to the component parts of the circuit, and can be defined as follows:

$$A = \frac{\text{(scheduled operating time)} - \text{(down-time)}}{\text{(scheduled operating time)}} \times 100 \quad (\%)$$

where scheduled operating time is the time during which the circuit of interest is expected to perform its intended function, and down-time is the cumulative time of circuit interruptions within the scheduled operating time.

When the concept of availability is applied to individual component parts of a circuit, and in particular to equipment at coast earth stations and ship earth stations, the definition of availability for these component parts (A') may be written in terms of mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR), as follows:

$$A' = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100 \quad (\%)$$

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* The Director, CCIR, is also requested to bring this Report to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Maritime Satellite Organization (INMARSAT) and to the CMBD.

When considering the availability of telephone circuits, use can be made of the hypothetical reference circuit (Recommendation 546).

The time for which a communications circuit is said to be unavailable should include delays in setting up the call arising from failures in the satellite signalling system. Failures in the shore-to-ship signalling channel, the ship-to-shore random access channel or the shore-to-shore signalling channel, due to adverse propagation conditions on the radio paths, would result in a lost call, but it is difficult to quantify the effect on a communications circuit in terms of the time for which that circuit is unavailable. However, it is expected that signalling channels will be designed to a high reliability, and that signalling outage effects will be insignificant compared to other possible causes of interruptions to communications circuits. It is therefore proposed that such effects should not be taken into account in availability considerations.

Calls lost due to congestion in the terrestrial network or the satellite network are not included in availability considerations as they relate to grade-of-service requirements rather than to availability.

2.2 *Definitions of interruption*

The following sections give definitions of interruption for telephony and telegraphy. In view of the differing nature of these services, different availability criteria may be required for them, and this should be the subject of further study. Interruptions to data channels are also considered below.

2.2.1 *Telephony*

The following definition for interruption to telephony circuits in the maritime mobile-satellite service has been suggested in [CCIR 1974-78]:

A telephone circuit in the maritime mobile-satellite service should be considered to be interrupted if a channel experiences one of the following conditions for more than 10 consecutive s:

- the wanted signal entering one end of the channel is not received at the other end,
- for analogue transmission, the unweighted subjectively equivalent noise power in the telephone channel exceeds 10^6 pW0p.

This definition of interruption is consistent with that proposed for the fixed-satellite service (Report 706).

2.2.2 *Telegraphy*

The following definition for interruption to telegraphy circuits has also been suggested in [CCIR 1974-78]:

A telex circuit in the maritime mobile-satellite service should be considered to be interrupted if N character errors are detected in a time interval less than 1.5 N s, where N is between 10 and 20.

This definition is considered to provide for sufficient measurement time and accuracy, and to take account of character error rates of the order of one error in 10 characters, but further study may be required.

2.2.3 *Data*

The availability of data channels will require study once the service has been defined. The definition of interruption will depend on the bit rate adopted for the service, the required error rate and the distribution of the errors.

2.3 *Scheduled operating time*

Availability criteria proposed for the fixed-satellite service apply to the availability of full-time circuits (telephony and television), where the scheduled operating time is the same as the calender time. In the maritime mobile-satellite service the shore-to-ship telegraphy/signalling channels will be operated on a full-time basis in that the carriers will be permanently activated, but telephony channels (shore-to-ship and ship-to-shore) and the telegraphy/signalling channels transmitted by ships will only be activated for the duration of the call. It is anticipated that equipment availability at coast earth stations and ship earth stations will not be affected significantly by the inherently demand-assigned nature of the maritime service (compared to the availability of essentially the same equipment operating with permanently activated carriers), and hence it is proposed that scheduled operating time be provisionally equated to calendar time for all equipment.

In this Report, no account has been taken of the fact that ships spend a considerable proportion of their time in port, and of the fact that in this circumstance, transmission by ship radio equipment is not permitted by some administrations.

2.4 *Factors affecting availability*

The overall availability of circuits in the maritime mobile-satellite service will depend on the availability criteria adopted for the following:

- *Space sector*, including satellite equipment, the effects of satellite manœuvres and the provision of spare satellites;
- *Coast earth station equipment*, including the effects of natural phenomena on equipment performance (e.g., sun interference and natural disasters), and the effects of human error;
- *Ship earth station equipment*, including the effects of natural phenomena on equipment performance (e.g., sun interference and environmental conditions), and the effects of human error;
- *Auxiliary functions*, such as might be performed by control coast earth stations (e.g. frequency control, power control and channel assignment);
- *Shore/satellite and ship/satellite RF links*, in particular the effects of attenuation and excess noise due to precipitation, the effects of multipath fading and the effects of interference such as might arise from terrestrial and space services.

In determining realistic availability objectives, it would not be feasible to take account of all the above eventualities. The philosophy adopted here is to consider only those factors which can be accommodated by adequate system planning, equipment design and maintenance procedures.

2.5 *Influence of natural or extreme phenomena*

For the purpose of availability considerations for coast earth station and ship earth station equipment, interruptions may be classified as follows:

- *Foreseen interruptions:* either unscheduled interruptions which are known to occur at some time and which can be tolerated for relatively short periods (e.g. equipment faults, propagation fading), or scheduled interruptions which are known to occur at specific times (e.g. certain types of preventive maintenance on equipment, sun interference at coast earth stations);
- *Unforeseen interruptions:* those interruptions whose occurrence or duration cannot be predicted and which could cause prolonged outages (e.g. natural disasters such as earthquakes, high winds or exceptionally severe sea conditions, and natural blockage effect such as shielding by mountains).

For the coast earth stations and ship earth stations, interruptions due to unforeseen circumstances should be excluded from availability considerations, and account should be taken only of foreseen interruptions. In addition, for ship earth station equipment, the following foreseen interruptions should be ignored:

2.5.1 *Interruptions due to sun interference*

With fixed earth stations, outages due to excessive noise on the down-path when the sun passes through the antenna beam can be predicted; durations of outages will depend on individual station locations, but degradations will be encountered for about 30 min for 3-4 days twice a year. Adverse effects on the service can, therefore, be minimised by arranging to pass traffic via alternative routes. With mobile stations, such as ship earth stations, the occurrence of sun interference will depend on the ship's route, which will vary from ship to ship, and this phenomenon could therefore be encountered several times in the course of a year by particular ships. The duration of the interference would be longer than for shore stations because of the relatively broad beamwidth of the ship-borne antenna, although the degradation in receiver noise temperature would be less severe.

2.5.2 *Interruptions due to severe weather conditions*

Current ship earth station equipment is designed to withstand severe environmental conditions such as temperature variations, humidity, precipitation, wind and vessel motions; typical conditions are given in [INMARSAT, 1978]. Additional protection to the above-deck equipment is provided by a radome, but at some time most ships will encounter weather conditions which will render the equipment inoperable, e.g. inability to maintain antenna-pointing due to high sea state conditions. It is therefore considered that such interruptions should not be included in the assessment of ship terminal availability, although equipment manufacturers and system planners should not be discouraged from investigating means of maintaining ship terminal operation under extreme conditions.

2.5.3 *Interruptions due to antenna blockage effects*

Although ship owners and manufacturers should be encouraged to install ship earth stations in locations which minimize the probability of antenna blockage, such locations may not be available in all cases. It is therefore proposed that these outages be excluded from availability criteria.

2.6 *Measurement of circuit availability*

Taking account of the exceptions outlined in § 2.5 above, the following expression should be used for the measurement of communications circuit availability in the maritime mobile-satellite service:

$$A = \frac{T_s - (T_{sat} + T_1 + T_2 + T_{shore} + T_{ship} + T_{aux})}{T_s} \times 100 \qquad (\%)$$

where:

T_s: scheduled operating time;

T_{sat}: cumulative time of circuit interruptions caused by failures of the satellite;

T_1: cumulative time of circuit interruptions attributable to factors on the shore-to-ship radio path

(i.e. $T_1 = T_{shore/sat} + T_{sat/ship}$,

where $T_{shore/sat}$ refers to the shore-to-satellite link, and

$T_{sat/ship}$ refers to the satellite-to-ship link);

T_2: cumulative time of circuit interruptions attributable to factors on the ship-to-shore radio path

(i.e. $= T_2 = T_{ship/sat} + T_{sat/shore}$,

where $T_{ship/sat}$ refers to the ship-to-satellite link, and

$T_{sat/shore}$ refers to the satellite-to-shore link);

T_{shore}: cumulative time of circuit interruptions caused by failures of shore station equipment and communications capability;

T_{ship}: cumulative time of circuit interruptions caused by failures of ship terminal equipment and communications capability;

T_{aux}: cumulative time of circuit interruptions caused by failures of auxiliary functions at ship earth stations.

In the event of two or more items occurring simultaneously, only the duration of the longest interruption should be taken into account.

3. Assessment of availability objectives

3.1 *Space sector*

The likely availability of the space sector for the maritime mobile-satellite service can be assessed from past experience with the fixed-satellite service, and in particular from the in-orbit performance of INTELSAT satellites. Over the period 1970-73, in-orbit INTELSAT space sector availability was 99.988%, 99.997%, 99.998% and 99.999% respectively. [Edelson *et al.*, 1975]; the main operational satellites during this period were of the INTELSAT IV type. Since 1973, the average space sector availability with the INTELSAT IV and IVA generations has been of the order of 99.999%. Such a figure would be a reasonable availability objective for the maritime mobile space sector.

3.2 *Earth station equipment*

Availability criteria for coast earth stations can be derived from experience gained with earth stations in the fixed-satellite service, and may therefore be readily defined. The derivation of availability criteria for ship earth stations, however, cannot be obtained so precisely, for the following reasons:

- the performance of ship earth stations is not under the direct control of operating administrations, and cannot be easily monitored full-time on a long-term basis;
- compared to earth stations on land environmental conditions for ship earth station operation are more severe, and facilitites available on ships at sea for repair and maintenance purposes are limited; furthermore, both the environmental conditions and the maintenance facilities will vary from ship to ship.

Account should be taken of the respective roles of coast earth station operators and ship earth station users: an outage at a coast earth station would result in loss of service to a considerable number of ships, whereas an outage of a ship earth station would generally affect only that ship. Hence, in theory, the availability objectives for shore stations should be higher than for ship earth stations.

Auxiliary functions provided by control stations will affect all coast earth stations and ships in the coverage area, and hence an outage could lead to complete system disruption. Availability objectives for these functions will therefore need to be high.

3.2.1 *Coast earth stations*

Examples of the availability achieved by earth stations in the fixed-satellite service are given in Report 706 , from which the average availability achievable would appear to be 99.9%. The availability of US coast earth stations operating in the MARISAT system was 99.962% for 1978. Until further experience has been gained from operation in the maritime mobile-satellite service the following availability objectives should be provisionally adopted for coast earth stations:

- a station availability of 99.9%, based on the sum of out-of-service time due to faults and out-of-service time due to routine or preventive maintenance,
- a minimum availability of 99.95% for each communications circuit, based on the out-of-service time for channel equipment and common equipment.

3.2.2 *Ship earth stations*

Faults on ship terminal equipment can occur at any time, and it would be unreasonable to assume that ships will carry sufficient spare components and maintenance expertise to cope with all eventualities at sea. Availability criteria should, therefore, take account of the prolongation of outages caused by a ship having to make port in order to effect repairs and an estimate of the average down-time, including the time taken to make port, would be about 3 days. (It should be recognized that this figure is strongly dependent upon the maintenance organization.) This figure may then be equated to MTTR in the expression for A' in § 2.1.

An MTBF objective of 6000 h would be compatible with current and future equipment designs. The corresponding availability objective would be of the order of 99%, or about 80 h down-time per year.

The above considerations apply to standard A ship earth station of -4 dB (K^{-1}), G/T, as defined in [INMARSAT, 1978], and assume that satellite-pointing is maintained towards the satellite.

3.2.3 *Auxiliary functions*

The maritime mobile-satellite service will require the provision of auxiliary functions for network coordination purposes, and these could include power control, frequency control and channel assignment functions. These could be provided either at coast earth stations or at separate control stations. If any function is so essential that loss of that function will adversely affect operation of the total network a very high availability objective should be established for that function e.g. 99.999%. Such an objective would require a high redundancy provision, with at least 2 stations per coverage area being capable of performing the auxiliary functions and each station have an availability of the order of 99.95%.

3.3 *Radio paths*

For telephony, the performance objective under non-faded conditions requires that the subjectively equivalent noise power should not exceed 25 000 pW0p (Recommendation 547). In order to render the channel unavailable, 10^6 pW0p of noise would be required (see § 2.2.1), which from Report 752 would require a fade on the radio path of 5 to 6 dB.

Similar considerations would apply to telegraphy.

3.3.1 *Shore-to-ship path*

3.3.1.1 *General*

The shore-to-ship radio path comprises a shore-to-satellite link (assumed here to be in the 6 GHz frequency band) and a satellite-to-ship link (1.5 GHz). The more critical of these is the 1.5 GHz link to ships, where satellite power is likely to be at a premium and hence a large allowance for fading is not feasible.

3.3.1.2 *Up link*

On the 6 GHz up link, a margin of around 2 dB would enable the required performance objective under fading conditions to be achieved for 99.99% of the time at 5° elevation angle; the actual margin for up-path fading required at each coast earth station will depend on local climatic conditions. In order to render the circuit unavailable, a fade of 5 to 6 dB would be required on the up link; the corresponding percentage time for which such a fade would apply is estimated at less than 0.005%, even under the most unfavourable propagation conditions i.e. corresponding to an availability figure of 99.995%. The use of up-path power control at shore stations would improve link performance and availability still further.

3.3.1.3 *Down link*

On the satellite-to-ship link at 1.5 GHz, fading is caused primarily by multipath reflections. In the worst case, which is defined here as occurring at the edge of the satellite service area (i.e., at a ship earth station elevation angle of 5°, see [INMARSAT, 1978]), fading statistics indicate that a fade of 4 to 5 dB would be encountered for 1% of the time, and hence the percentage time applicable to a 5 to 6 dB fade would be somewhat less than 1%.

3.3.1.4 *Worst case* (case of a ship at 5° elevation angle).

Bearing in mind the small contribution from the 6 GHz up-path, and taking account of interference effects on both the up-path and the down-path, an objective availability of 99% would be reasonable.

3.3.1.5 *General case* (case of a ship travelling in regions where multipath effects are insignificant). The down-time due to fading is negligible in this case.

3.3.2 *Ship-to-shore path*

The ship-to-shore radio path comprises a ship-to-satellite link (1.6 GHz) and a satellite-to-shore link (assumed here to be at 4 GHz). Multipath fading will again be the dominant effect, and hence from considerations in § 3.3.1 the availability under worst-case conditions will be of the order of 99%, but for the general case the down-time will be negligible.

3.4 *Overall availability objective*

The expression for communications circuit availability (A) in the maritime mobile-satellite service can be written in terms of percentage down-time ($D = 100 - A$), as follows:

$$A = \frac{T_s - (T_{sat} + T_{ship} + T_{shore} + T_{aux} + T_1 + T_2)}{T_s} \times 100 \quad (\%)$$

$$= 100 - D_{sat} - D_{ship} - D_{shore} - D_{aux} - D_1 - D_2 \quad (\%)$$

Concerning D_1 and D_2, it is shown in § 3.3 that these outages are due predominantly to multipath fading effects on the satellite-to-ship and ship-to-satellite links respectively. Fading on these links at 1.5/1.6 GHz will be correlated i.e. the effects will occur simultaneously and hence only the outage of longest duration should be considered. This may be denoted by $D_{1,2}$.

From considerations in this and previous sections, down-time values for the various component parts of the communications circuit may be assumed to be as shown in Table I. The overall circuit availability is then about 99% in the general case and 98% in the worst case. If account is taken of the time for which ships are in port and are not permitted to transmit, the availability would be considerably reduced.

4. Conclusions

The availability objectives applicable to component parts of communications circuits in the maritime mobile-satellite service have been considered taking into account not only experience gained from operation with the fixed-satellite service but also the characteristics of the maritime mobile-satellite service and likely user requirements. Based on this information and on the limited experience to date with Marisat operation it is proposed that the circuit availability objective be set provisionally at 99% in the general case, (case of a ship travelling in regions where multipath effects are insignificant), and 98% for the worst case (case of a ship at 5° elevation angle). These figures take account of factors which can be accommodated by adequate system planning and equipment design procedures.

It is recommended that the circuit availability objective be reassessed periodically and if necessary revised once sufficient operational experience has been acquired with the service.

TABLE I — *Down-time for component parts of a communication circuit in the maritime mobile-satellite service*

Symbol	Component part	Down-time (%)	Notes
D_{sat}	Space sector	0.001	
D_{shore}	Coast earth station equipment	0.05	
D_{ship}	Ship earth station equipment	1	(1)(2)(3)
D_{aux}	Auxiliary functions	0.001	
$D_{1,2}$	Radio paths	General case: 0 Worst case: 1	
D_{total}	Total circuit down-time	General case: 1 Worst case: 2	

(1) Assumes ship terminal antenna pointing can be maintained.
(2) No consideration given to times when ship is in port in a territory where its use may be prohibited.
(3) Assumes standard A ship earth station G/T of -4 dB (K^{-1}).

REFERENCES

EDELSON, B. I., STRAUSS, R. and BARGELLINI, P. L. [1975] INTELSAT system reliability. *Acta Astronautica*, Vol. 2, 672-691, Pergamon Press.

INMARSAT [July, 1978] INMARSAT Preparatory Committee Technical Panel. PREPCOM/TECH/REPORT 4, Annex V.

CCIR Documents

[1974-78]: 8/260 (Norway).

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SECTION 8F: MARITIME MOBILE-SATELLITE SERVICE; RADIO AND RELATED SUBJECTS

Recommendations and Reports

REPORT 760-1

LINK POWER BUDGETS FOR A MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The purpose of this Report is basically two-fold:

- to list the parameters which must be taken into account when determining link power budgets for a future maritime mobile-satellite system, and the conditions under which these parameters apply;
- to provide examples of link power budgets to illustrate the application of these parameters.

Link power budgets are required in order to determine the likely power requirements and physical characteristics of the space sector (satellite) and the earth sector (coast earth stations and ship earth stations). The overall design for a future system will rely to a great extent on the experience acquired in the development and operation of existing and planned maritime satellite systems, and hence considerable guidance on the choice of suitable power budget parameters can be obtained by reference to the INMARSAT system [INMARSAT, 1978; MARISAT, 1977].

2. Power budget philosophy

The philosophy adopted in this Report is to assume a "reference" system configuration from which corresponding parameters for other configurations may be derived. From the propagation viewpoint, the channel quality obtained with a maritime satellite system will be strongly dependent on the satellite elevation angle, and so it would appear reasonable to adopt the elevation angle as one of the parameters on which to base the reference system. The reference configuration for the power budgets is assumed here to apply at satellite elevation angles of 5° for coast earth stations and 10° for ship earth stations; corresponding parameters and resultant channel qualities for elevation angles other than these may then be derived.

A further criterion adopted here is to assume that parameters for the earth sector are the same as for existing, or planned, systems; in particular, INMARSAT standard-A ship earth stations are assumed.

3. Telephony channel parameters

Telephony is expected to be the dominant service in terms of system power requirements and hence the power budgets are based on a telephony channel.

For the purpose of presenting information on link budget examples in this paper, as a reference it has been assumed that an overall carrier-to-noise density ratio (C/N_0) of 53 dBHz should be achieved for at least 80% of the time in both directions of transmission, with satellite elevation angles of 5° at coast earth stations and 10° at ship earth stations and with no multipath fading on ship/satellite links. This objective has been used as the reference configuration for the power budgets, as shown in the extreme right-hand column of Tables I and II. The current CCIR telephone channel quality objective for telephone channels in the maritime mobile-satellite service corresponds to an overall C/N_0 of about 52 to 53 dBHz (see Recommendation 547 and Report 752 [INMARSAT, 1978].

In addition to the reference configuration, example power budgets are shown in Tables I and II for ship elevation angles of 5° and 10° when multipath fading occurs on ship/satellite links. The fading parameters are assumed to be applicable to conditions obtaining for at least 99% of the time. However, insufficient experimental data is available to reliably establish required fading margins for any confidence level.

Single-channel-per-carrier operation in frequency division multiple access is envisaged for telephony, with narrowband frequency modulation and speech processing (e.g. 2 : 1 syllabic companding). With C/N_0 of 53 dBHz at the demodulator input, a suitable receiver noise bandwidth would be 30 kHz with 50 kHz channel spacing; the corresponding carrier-to-noise ratio (C/N) would be about 8 dB.

Threshold extension demodulators, with a nominal threshold of around 50 dBHz, would be required to ensure a graceful degradation of speech quality with reducing signal level.

4. Space sector parameters

The space sector configuration assumed here is based on global coverage in both shore-to-ship and ship-to-shore directions of transmission. Assumptions regarding the characteristics of the 1.5/1.6 GHz antenna and the intermodulation noise performance of the transponders are summarized below.

4.1 *1.5/1.6 GHz antenna*

The critical transmission path, from the viewpoint of satellite power requirements, is that in the satellite-to-ship direction at 1.5 GHz. Efficient use of the available satellite power for earth coverage may be obtained by assuming a shaped beam antenna [Wood and Boswell, 1974; Lancrenon *et al.*, 1976]. The trade-off between beam-centre and beam-edge gain with this antenna provides an almost constant received flux density at the earth's surface for all elevation angles, and thus optimizes system performance for those ship earth stations at the edge of the coverage area where propagation effects are at their most severe. Similar compensation may also be provided on the up-path at 1.6 GHz.

4.2 *Intermodulation noise performance*

The satellite amplifier carrier-to-intermodulation-noise density ratio (C/I_0) in Table I for the shore-to-ship link is shown to be a limiting factor in determining the resultant C/N_0 and therefore must be optimized against amplifier output power. For typical amplifiers and suitable frequency plans that minimize intermodulation noise in occupied channels, a C/I value of about 19 dB in a 30 kHz bandwidth may be reasonably achieved with significant satellite amplifier loading. This results in the assumed C/I_0 of 63.8 dBHz for the shore-to-ship direction.

In the ship-to-shore direction, as given in Table II, a C/I_0 of 70 dBHz has been assumed as the satellite amplifier is not expected to be as power limited as in the shore-to-ship direction.

5. Earth sector parameters

The following ship earth station and coast earth station radio frequency characteristics have been adopted as the basis for the power budgets:

Ship earth station G/T : -4 dB(K^{-1}) (Standard-A);

Ship earth station e.i.r.p. : 37 dBW;

Coast earth station G/T : 32 dB(K^{-1});

Coast earth station e.i.r.p. : 60 dBW.

5.1 *Ship earth station*

The assumed G/T of -4 dB(K^{-1}) is a net value which includes allowances for power losses due to pointing accuracy, misaligned polarization ellipses, diplexer and dry radome; an additional allowance is shown in the link budgets for loss due to a wet radome. This sensitivity may be achieved with an antenna of 23 dBi gain and a transistorized receive amplifier of 500 K total system noise temperature. An appropriate antenna would be a paraboloid of 1.2 m diameter, with 60% illumination efficiency, and a beamwidth of approximately 10° to the -3 dB points; an axial ratio of about 2 dB has been assumed. For the purposes of the link budget calculations, the pointing and polarization losses have been considered separately.

No allowance has been made in the power budgets for blockage effects from the ship's superstructure; these would depend on the individual ship and could, in theory, be eliminated by choosing an unobstructed site.

5.2 *Coast earth station*

For a clear-sky G/T of 32 dB(K^{-1}) at 5° elevation, a total system clear-sky noise temperature of 100 K has been assumed for the calculation of noise temperature degradation under fading conditions. Fading parameters for 4/6 GHz links are assumed to be applicable to propagation conditions obtaining for 99.99% of the time; the channel quality of the overall links between coast earth stations and ship earth stations is thus mainly determined by the loss parameters on ship/satellite links at 1.5/1.6 GHz.

An appropriate coast earth station's antenna diameter would be 13 m, assuming an illumination efficiency of 60%. The antenna axial ratio has been assumed to be 0.5 dB; for the purposes of the link budget calculations, polarization and pointing losses have been considered separately.

The up-link intermodulation noise from all coast earth station transmit amplifiers has been assumed to result in a total up link C/I greater than 30 dB in a 30 kHz bandwidth. This assumption is consistent with the current INMARSAT Coast Earth Station Technical Requirements Document and the expected performance of typical frequency plans that could be employed. This results in the C/I_0 value of 75 dBHz used in Table I.

6. Derivation of link margins

The margins necessary to achieve the desired objectives for the satellite links are dependent upon many factors including the satellite characteristics, ship earth station and coast earth station characteristics, weather, sea states and satellite elevation angles. The overall system design should include link margins consistent with the following factors:

- minimum elevation angle considered for service;
- tolerable performance degradation for elevation angles lower than the minimum design point.

The choice of link margins in relation to elevation angle (α) and the system design will affect the performance of the entire system (as seen from the terrestrial network). A system designed to achieve a specified quality for a stated percentage of time, with margins to allow for degradations occurring at low elevation angles, will achieve this quality for much higher percentages of time when calls to and from all ships within the coverage area are considered.

The margins required to compensate for losses other than the basic free space path loss can be grouped into categories of long-term (fixed and random losses) and short-term.

6.1 *Long-term losses*

Long-term losses may be defined as those which would tend to last for a period of at least a minute per occurrence.

6.1.1 *Fixed long-term losses*

Long-term losses which occur with certainty should be included in the path loss for all calculations. The composite margin for these losses in dB is their sum:

$$L_f = \sum_j L_{f,j} \tag{1}$$

6.1.2 *Random long-term losses*

Several of the long-term losses tend to occur randomly and are generally independent of each other. The cumulative mean loss ($\bar{L}_l$) and variance (σ_l^2) may be obtained by summing the individual means and variances:

$$\bar{L}_l = \sum_j \bar{L}_{l,j}\,;\ \sigma_l^2 = \sum_j \sigma_{l,j}^2 \tag{2,3}$$

6.2 *Short-term losses*

Short-term losses may be defined as those which would tend to last for a period of less than a minute per occurrence. Since the occurrence of a significant short-term fading period may be infrequent, uncertain, or may only occur at certain times of the day, consideration should be given to the fading statistics when establishing fade margins.

Short-term losses tend to be independent of each other and to have different statistical distributions. The cumulative margins needed for these losses may be strongly dependent on elevation angle (α), since the elevation angle independent losses are relatively small or infrequent.

The cumulative mean loss ($\bar{L}_s$) and variance (σ_s^2) for the cumulative short-term losses may be obtained by summing the individual mean losses and variances:

$$\bar{L}_s = \sum_i \bar{L}_{s,i} \; ; \; \sigma_s^2 = \sum_i \sigma_{s,i}^2 \tag{4,5}$$

6.3 *Cumulative margins for all losses*

Since the long-term and short-term losses are reasonably numerous and independent, the total margin requirements can be approximated by a normal loss distribution having a mean given by:

$$L \simeq L_f + \bar{L}_l + \bar{L}_s \qquad \text{dB} \tag{6}$$

and standard deviation given by:

$$\sigma \simeq (\sigma_l^2 + \sigma_s^2)^{1/2} \qquad \text{dB} \tag{7}$$

The appropriate cumulative margin in dB, corresponding to time-percentages of 80%, 99% and 99.99%, would then be given by:

$$\begin{aligned} M\,(80\%) &= L + 0.85\,\sigma \\ M\,(99\%) &= L + 2.33\,\sigma \\ M\,(99.99\%) &= L + 3.72\,\sigma \end{aligned} \tag{8}$$

7. Margins at 1.5/1.6 GHz for ship/satellite links

7.1 *Long-term losses*

Long-term losses for which margins may be needed are as follows:

$L_a(\alpha)$: atmospheric absorption in dB: a function of the ship-to-satellite elevation angle (α); derived here from Report 714;

$L_e(\alpha)$: excess attenuation in dB, exceeded for not more than 20% or 1% of the time; this is considered to be negligible at 1.5/1.6 GHz;

L_r : radome (if used) loss in dB; the losses due to a dry radome (0.2 dB) may already be accounted for in the definition of ship earth station antenna gain and receive sensitivity (G/T), as is assumed here;

L_p : polarization coupling loss in dB: a function of ship earth station antenna and satellite antenna axial ratio (2 dB and 3 dB respectively); the worst case is misaligned polarization ellipses;

L_b : ship structure blockage loss in dB: a function of antenna placement, size and shape of the obstruction, direction and ship earth station antenna beamwidth.

Additional degradations due to an increase in system noise temperature caused by various losses are as follows:

DT_r : ratio in dB of the system noise temperature, when a radome is fitted to the system noise temperature without the radome; this may already be accounted for in the G/T value, as has been assumed here, but an allowance is required for the degradation in noise temperature due to a wet radome;

ΔT_a : temperature increase due to atmospheric absorption; this is considered negligible for a system noise temperature of 500 K.

7.1.1 *Fixed long-term losses*

The composite margin for fixed long-term losses is given by:

$$L_f(\alpha) = L_a(\alpha) + L_r(\text{dry}) \tag{9}$$

7.1.2 *Random long-term losses*

Cumulative statistics for random long-term losses would include, for example, L_p and L_r (wet); typical means and standard deviations for these loss factors might be as follows:

Loss factor	*Mean Loss (dB)*	*Standard deviation (dB)*	
L_p	0.2	0.09	
L_r (wet)	0.2	0.13	
DT_r (wet)	0.1	0.09	(reference noise temperature = 500 K)

The inclusion of blockage loss (L_b) in the margin calculations may not be consistent with ship earth station installation practice and operational objectives. Normal practice may be to install the ship earth station antenna with a completely unobstructed view for elevation angles above the system design point and not to provide a system-wide margin for blockage, as has been assumed here.

7.2 *Short-term losses*

Short-term losses for which margins may be needed are as follows:

L_t : ship earth station transmitter power level fluctuations: are assumed here to be $\pm$ 0.5 dB for about 95% of the time, corresponding to a mean loss of 0 dB and a standard deviation of 0.25 dB;

ΔG : ship earth station antenna pointing loss in dB: a function of the ship antenna pointing system performance which tends to be worse in high sea states; some designs may exhibit high tracking errors at certain orientations such as in the zenith direction;

L_i : ionospheric fading loss, in dB, due to scintillation; a function of ship location, season and time of day;

$L_m(\alpha)$: multipath fading loss, in dB, due to reflections from the sea and ship structure: the magnitude of the loss for a given percentage of time, and the rate at which the loss varies, will depend upon the sea state, elevation angle (α), link polarization, ship antenna pattern, ship antenna axial ratio in the direction of the reflection region, antenna height above the sea, and antenna system pointing accuracy.

7.2.1 *Antenna pointing loss*

The antenna pointing loss (ΔG) may be small, especially if the ship earth station antennas are equipped for automatic pointing. Typical pointing errors may be normally distributed with a standard deviation of 0.1 beamwidth or less under worst case design conditions, and the corresponding loss distribution would be chi-squared. For simplicity, a 99% loss figure of 0.5 dB has been assumed with a mean loss of 0.3 dB and a standard deviation of 0.09 dB.

7.2.2 *Ionospheric scintillation loss*

Band 9 fading losses due to ionospheric scintillation tend to be noticeable only in the spring and autumn equinox seasons, and primarily near the geomagnetic equator and at high geomagnetic latitudes [Canada, 1973; Golden and Sessions, 1972]. Furthermore, the fading near the geomagnetic equator tends to be more severe than at the high latitudes, and the periods of such fading range from about one to three hours and occur shortly after local sunset. Measurements indicate that maximum fading losses below free space are normally in the range of 3 to 5 dB for the worst fading days and that the deepest fades usually last less than 15 s. During fading periods a loss of about 1.1 dB is expected to be exceeded for not more than 1% of the hours, and 1.8 dB is expected to be exceeded for not more than 0.1% of the hours [Golden and Sessions, 1972]. Cautious estimates of the corresponding standard deviation would be 0.6 dB.

Inclusion of the ionospheric scintillation loss in the cumulative margin would yield the worst case statistics, which would be applicable for a very short time during a few days of the year and to limited geographical locations. For some systems it may be the governing short-term loss and should, therefore, be considered in the selection of "worst hour" margins, but for the purposes of this Report it will not be included.

7.2.3 *Multipath fading loss*

Multipath fading loss statistics are very dependent on elevation angle and could be the dominant factor in the link margin requirement. A considerable number of studies and experiments have been performed to assess the effects of multipath fading; see also Reports 505 (Kyoto, 1978), 599 and 763 [ESRO, 1974; IMCO, 1973; ESA, 1976].

With normal sea conditions in most ocean areas, multipath reflections from the sea surface will be predominantly diffuse and the composite indirect signal will have narrowband Gaussian statistics. Unlike the ship earth station receiver noise, the received carrier-to-multipath-interference ratio (C/I_{mp}) will not be reduced by increasing the satellite transmitter power. Consequently, margins provided for diffuse multipath interference do not serve to increase C/I_{mp}, but only to provide an adequate carrier-to-receiver-thermal-noise ratio such that the ship earth station receiver performance is still acceptable when the multipath fading occurs.

Once the expected value of C/I_{mp} is established for the minimum design elevation angle, the fade depths not exceeded for more than p% of the time can be determined. For example, extrapolation from measured test data shows that a directive antenna with 24 dBi nominal beam-centre gain (10° beamwidth) in a circularly polarized link at 5° elevation would normally enjoy a $C/I_{mp} \simeq 16$ dB. The fading depth would be expected to be less than 2.5 dB for at least 99% of the time [ESRO, 1974; Norton *et al.*, 1965]. In deriving this result, the following assumptions have been made:

(a) the discrimination angle to the reflecting area is approximately 10°;

(b) the antenna pointing system uses a reference independent of the received signal in compensating for ship roll and pitch etc.;

(c) the polarization efficiency factor of the antenna to the multipath energy is unity (i.e. cross-polar response).

Such extrapolations, although useful in deriving an order of magnitude for typical fade depths, should be treated with some caution; in particular, the assumption (c) above would not apply in practice as the cross-polar response of the antenna is expected to be worse off-axis than at beam centre. Furthermore, the corresponding fade depth adopted in existing and planned systems is 4 dB at 5° elevation and 1.8 dB for 10° elevation. These values are in reasonable agreement with the results given in Report 763.

On the basis of analysis and some experiments, the margins required for low percentage fading ($p \leqslant 99\%$) with diffuse multipath fading will be larger than the maximum specular fade for the same conditions.

Loss statistics for diffuse multipath fading are approximately Gaussian for high direct to indirect power ratios ($C/I_{mp} > 10$ dB). The cautious approximation adopted here is to use a zero average ($L_m = 0$ dB) and a standard deviation estimate which is based on the 99% loss values given above.

7.3 *Cumulative margins*

It may be seen that inclusion of margins for blockage and ionospheric scintillation loss may be significant; the approach adopted here is to assume no normal blockage and scintillation losses in establishing the system-wide margins. However, these losses should be included in a "worst case" margin which may be used in conjunction with a "marginally acceptable" quality objective lower than the normal quality criterion for telephony.

8. Margins for feeder links

8.1 *Fixed long-term losses*

The only fixed long-term loss occurring in the power budgets is atmospheric absorption, $L_a(\alpha)$.

8.2 *Random long-term losses*

Random long-term losses include:

L_p: polarization coupling loss: mean loss = 0.05 dB, standard deviation = 0.02 dB for shore/satellite antenna axial ratios of 0.5 dB/3 dB.

L_t: transmitter power fluctuations for 6 GHz operation: mean loss = 0 dB, standard deviation = 0.12 dB.

$L_e(\alpha)$: excess attenuation exceeded for not more than 0.01% of the time: mean loss = 0 dB, standard deviation = 0.27 dB for 6 GHz operation and 0.14 dB for 4 GHz operation.

8.3 *Random short-term losses*

Coast earth station antenna pointing loss is assumed here to be 0.2 dB with a mean loss of 0 dB and a standard deviation of 0.05 dB. No allowance has been made for ionospheric scintillation in the 99.99% loss figures.

$DT_s(\alpha)$: degradation due to excess sky noise in dB : mean loss = 0 dB standard deviation = 0.32 dB.

9. Link power budgets

Cumulative random loss margins in Tables I and II have been calculated from the loss values assumed for each parameter and have been calculated independently for each part of the overall link. The power budgets may be used to determine likely system power requirements and are based on an assumed resultant C/N_0 requirement of 53 dBHz for the telephony reference budget; this assumes 5° elevation at coast earth stations, 10° elevation at ship earth station and no multipath fading on ship/satellite links. The C/N_0 values when multipath fading does occur on ship/satellite links are also indicated, for ship elevation angles of 5° and 10°. It is assumed that the contribution due to all translation local oscillator phase noise is negligible and consequently is not included in the link power budgets.

10. Other factors affecting the link power budget

10.1 *Relative transponder loading*

Since the satellite capacity is designed to meet traffic requirement at a specified grade-of-service, on the average substantially fewer than the full load number of carriers will be busy during the busiest hour. Due to the non-linear amplification characteristic typical of most satellite amplifiers near saturation, the e.i.r.p. per carrier increases in almost direct proportion to the decrease in the number of carriers from full load. Consequently the average per carrier e.i.r.p. during the busiest hour will be greater than the full load e.i.r.p. over a small range of about 1 dB.

For single channel per carrier (SCPC) telephony systems in which blocked calls are cleared (erlang B), the probability, $P(n)$, that exactly n channels or less out of s channels are in use during the busy hour is given by [Cooper, 1972],

$$P(n) = 1 - \sum_{j=n}^{s} p_j$$

where, p_j is the probability that exactly j channels are in use, and is given by

$$p_j = \begin{cases} B(s,a) & \text{for } j = s \\ \dfrac{B(s,a)}{\prod_{k=j+1}^{s} a/k} & \text{for } j < s \end{cases}$$

where $B(s, a)$ is the busy hour blocking probability [Dill and Gordon, 1978], and "a" is the busy hour offered traffic (erlangs).

Assuming that the transmitter is operated at saturation, the increase in the per carrier e.i.r.p. relative to the full load per carrier e.i.r.p. is with probability $P(n)$,

$$\Delta = 10 \log(s/n)$$

Table III provides several numerical examples in the range of interest. It should be noted, that during the busy hour, all channels or less are in use for $(1 - B(s,a)) \times 100\%$ of the time. For a 2% blocking probability ($B(s,a) = 0.02$), this amounts to 98% of the time.

10.2 *Adaptive control of satellite transmitting power*

In the previous sections, fixed satellite transmitting power is assumed. However, in an SCPC system, in which satellite transmitting power can be changed by controlling coast earth station transmitting power for each SCPC carrier, shore-to-ship satellite link quality (C/N or S/N) could be maintained at the required constant value. This can be achieved by sending back the shore-to-ship satellite link quality measured at the ship earth station through the ship-to-shore link and adaptively controlling the shore earth station transmitting power using the sent back information.

By applying this power control method, random slow variations in satellite link quality caused by satellite antenna gain differences, precipitation or fading can be almost compensated for. Consequently, the number of SCPC channels in the satellite transponder could be increased [Egami *et al.*, 1980].

The study of adaptive power control methods, as a possible means of making more efficient use of satellite power in the long term, should include consideration of the practical, operational and economic effects on current designs of coast earth stations, ship earth stations and the satellite signalling system.

11. Summary

This Report has illustrated how fixed and variable link parameters may be taken into account when developing link power budgets for a maritime mobile-satellite system.

The cumulative loss statistics used to derive the margins have been approximated as normal, with the mean and variance taken to be the sum of the means and the variances of the individual losses.

The independence of the loss factors and the normal distribution assumptions should be checked for any particular link budget design.

Further study will be required on the power budgets for services other than telephony, and for ship earth stations having a G/T other than -4 dB(K^{-1}). Further study is also required into the relationship between traffic, satellite capacity and e.i.r.p. requirements.

TABLE I — *Shore-to-ship link power budget*

	Units	Satellite elevation angle		
		5°		
1. *Shore-to-satellite* (6.42 GHz, 99.99% time)				
Coast earth station e.i.r.p. per channel (nominal value)	dBW	60		
Loss due to transmitter power fluctuations(1)	dB	[0.5]		
Loss due to pointing errors(1)	dB	[0.2]		
Free space path loss	dB	200.9		
Atmospheric absorption loss	dB	0.5		
Excess attenuation due to precipitation(1)	dB	[1.0]		
Polarization coupling loss(1)	dB	[0.1]		
Total margin for random losses	dB	1.2		
Satellite G/T	dB(K^{-1})	−16		
Boltzmann's constant	dB(J/K)	−228.6		
Up-path C/N_0 (thermal noise)	dBHz	70		
Coast earth station C/I_0 (intermodulation noise)	dBHz	75		
Satellite transponder C/I_0 (intermodulation noise)	dBHz	63.8		
Transmitted $C/(N_0+I_0)$	dBHz	62.6		
		99% time		80% time
		5°	10°	10°
2. *Satellite-to-ship* (1.54 GHz)				
Satellite e.i.r.p. per channel (useful power)	dBW	18.0	18.1	18.1
Free space path loss	dB	188.5	188.4	188.4
Atmospheric absorption loss	dB	0.4	0.2	0.2
Multipath fading loss(1)	dB	[4.0]	[1.8]	[0]
Wet radome additional loss(1)	dB	[0.5]	[0.5]	[0.4]
Noise temperature degradation(1)	dB	[0.3]	[0.3]	[0.2]
Polarization coupling loss(1)	dB	[0.4]	[0.4]	[0.3]
Loss due to tracking errors(1)	dB	[0.5]	[0.5]	[0.4]
Total margin for random losses	dB	4.8	2.7	1.1
Ship earth station G/T	dB(K^{-1})	−3.5	−3.5	−3.5
Boltzmann's constant	dB(J/K)	−228.6	−228.6	−228.6
Down-path C/N_0	dBHz	49.4	51.9	53.5
Transmitted C/N_0+I_0)	dBHz	62.6	62.6	62.6
Resultant $C/(N_0+I_0)$	dBHz	49.2	51.5	53.0

(1) Random loss; figures indicated [ ] are not included directly in budget, but are combined as described in § 6.3.

TABLE II — *Ship-to-shore link power budget*

	Units	Satellite elevation angle		
		99% time		80% time
		5°	10°	10°
1. *Ship-to-satellite* (1.64 GHz)				
Ship earth station e.i.r.p. (nominal value)	dBW	37	37	37
Loss due to transmitter power fluctuations(1)	dB	[0.5]	[0.5]	[0.5]
Loss due to pointing errors(1)	dB	[0.5]	[0.5]	[0.4]
Wet radome additional loss(1)	dB	[0.5]	[0.5]	[0.4]
Free space path loss	dB	189.0	188.9	188.9
Atmospheric absorption loss	dB	0.4	0.2	0.2
Multipath fading loss(1)	dB	[4.0]	[1.8]	[0]
Polarization coupling loss(1)	dB	[0.4]	[0.4]	[0.3]
Total margin for random losses	dB	4.8	2.6	1.0
Satellite G/T	dB(K^{-1})	−12.2	−12.1	−12.1
Boltzmann's constant	dB(J/K)	−228.6	−228.6	−228.6
Up-path C/N_0 (thermal noise)	dBHz	59.2	61.8	63.4
Satellite transponder C/I_0 (intermodulation noise)	dBHz	65.8	68.4	70
Transmitted $C/(N_0+I_0)$	dBHz	58.3	60.9	62.5
		5°		5°
2. *Satellite-to-shore* (4.20 GHz, 99.99% time)				
Satellite e.i.r.p. per channel (useful power)	dBW	−12.3	−9.7	−8.1
Free space path loss	dB	197.1	197.1	197.1
Atmospheric absorption loss	dB	0.5	0.5	0.5
Excess attenuation due to precipitation(1)	dB	[0.5]	[0.5]	[0.5]
Degradation due to excess sky noise(1)	dB	[1.2]	[1.2]	[1.2]
Polarization coupling loss(1)	dB	[0.1]	[0.1]	[0.1]
Loss due to tracking errors(1)	dB	[0.2]	[0.2]	[0.2]
Total margin for random losses	dB	1.4	1.4	1.4
Coast earth station G/T(clear-sky)	dB(K^{-1})	32	32	32
Boltzmann's constant	dB(J/K)	−228.6	−228.6	−228.6
Down-path C/N_0	dBHz	49.3	51.9	53.5
Transmitted $C/(N_0+I_0)$	dBHz	58.3	60.9	62.5
Resultant $C/(N_0+I_0)$	dBHz	48.8	51.4	53.0

(1) Random loss; figures indicated [ ] are not included directly in budget but are combined as described in § 6.3.

TABLE III — *Relative e.i.r.p. per carrier for 2% blocking probability*

Busy hour offered traffic (Erlang) (a)	Number of channels (s)	Number of channels (n)	$P(n)$ (%)	Δ (dB)
17.5	25	21	79.6	0.76
21.93	30	26	81.3	0.62
31.00	40	36	83.4	0.46
40.26	50	45	79.9	0.46
87.97	100	94	80.8	0.27

REFERENCES

CANADA, Government of [10 September, 1973] High latitude ionospheric fading measurements at 254 MHz and 1550 MHz at Churchill, Manitoba. IMCO Panel of Experts on Maritime Satellites, Third Session, MARSAT III/3/4.

COOPER, R. B. [1972], *Introduction to Queueing Theory.* Macmillan Co., New York.

DILL, G. D. and GORDON, G. D. [Fall, 1978], Efficient Computation of erlang Loss Functions. *COMSAT Tech. Rev.*, Vol. 8, **2**, 353-370.

EGAMI, S., OKAMOTO, T. and FUKETA, H. [February, 1980] K-band mobile earth station for domestic satellite communication. *IEEE Trans. Comm.*, Vol. COM-28, 291-294.

ESA [1976] European communications experiments in L-band with ATS-6 (European Space Agency Bulletin), Vol. III (March, 1976) and Vol. IV (December, 1975).

ESRO [February, 1974] A ship-balloon communication experiment 1973, Vol. 1, (European Space Research Organization/European Space Agency).

GOLDEN, T. S. and SESSIONS, W. V. [1972] Simultaneous L-band and ionospheric fading effects at the geomagnetic equator. Presented at International Union of Radio Science, 1972 Spring Meeting, Washington DC.

IMCO [1973] Panel of Experts on Maritime Satellites – Second Session (30 April-4 May, 1973). Theoretical estimates of multipath parameters for L-band satellite-ship links. MARSAT II/4/4, Note by the US Government.

INMARSAT [July, 1978] INMARSAT Preparatory Committee Technical Panel. PREPCOM/TECH/REPORT 4, Annex V.

LANCRENON, B., STECIW, A. and VANDENKERCKHOVE, J. A. [May, 1976] Maritime satellite payloads. *ESAASE Bull.* (European Space Agency), **5**, 50-53.

MARISAT [March, 1977] MARSAT system description. COMSAT General Corporation, Washington DC. Presented at INMARSAT Preparatory Committee Technical Panel Meeting, 9-13 May 1977, Paris.

NORTON, K. A., VOGLER, L. E., MANSFIELD, W. V. and SHORT, P. J. [October, 1965] The probability distribution of the amplitude of a constant vector plus a Rayleigh-distributed vector. *Proc. IRE*, Vol. 43, 1354-1361.

WOOD, P. J. and BOSWELL, A. [30 May, 1974] Optimization of antenna gain for earth coverage from a geostationary satellite. *Electron. Lett.*, Vol. 10, **11**, 227-228.

REPORT 761-1 *

TECHNICAL AND OPERATING CHARACTERISTICS OF DISTRESS SYSTEMS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17B/8)

(1978-1982)

1. Introduction

The use of maritime mobile satellites for the handling of safety and distress communications is a matter of increasing importance. The Inter-Governmental Maritime Consultative Organization (IMCO) is placing a major reliance on the use of satellites for the relay of distress signals in the development and design of their Future Global Maritime Distress and Safety System (FGMDSS), which is scheduled to become operational in the early 1990s. IMCO has requested that the International Maritime Satellite Organization (INMARSAT) include an emergency position-indicating radio beacon (EPIRB) service in the initial INMARSAT satellite system.

This Report considers the major factors influencing the design of maritime distress systems using satellites and the associated technical and operating characteristics. § 1 reviews the present terrestrial system, the development of the satellite EPIRB concepts and the developing operational requirements for a future system. § 2 discusses some of the considerations to be taken into account when deciding on the development of such operational requirements. The technical requirements will depend on the various techniques used in individual systems; however, some of the considerations that will need to be taken into account, when deciding on technical trade-offs, are reviewed in § 3. Current and planned experimental programmes are reviewed in § 4. The conclusions in § 5 recommend subjects for further study. A comparison of the proposed technical and operating characteristics of the various systems is given in Annex I.

* The Director, CCIR, is requested to bring this Report to the attention of IMCO and the INMARSAT organization.

The concept for a very low G/T ship earth station in the receive-only mode for distress alerting as well as for receiving navigational and meteorological warnings in the shore-to-ship direction is described in Report 921.

1.1 *Present terrestrial system*

Statistics published by Lloyds of London show that there was an annual loss of 465 vessels of over 100 gross tons for the year 1979. The growth of worldwide shipping and the introduction of larger, faster, more capital-intensive vessels will result in an increasing threat to loss of life and property at sea.

The probability of human survival decreases rapidly with time following a distress occurrence, in particular, in cold weather conditions or where the survivors are in the sea. It is, therefore, fundamental to any distress system that the existence of the distress occurrence is made known to those capable of rendering assistance in the minimum practical time. The present maritime distress system is based on a complicated interlinking of several elements, and uses telephony, morse code telegraphy or EPIRBs on existing allocated terrestrial frequencies. In most cases, the transmission of the message requires manual activation and manual operation. The successful receipt of a distress message depends on the propagation characteristics of the various available frequencies which in turn depend on the geographical location, the time of day and season. Delays of several hours may result. Past failure to successfully execute rescue in some cases has raised considerable concern internationally about the adequacy and effectiveness of the distress and safety communications.

In order to overcome some of these problems EPIRBs using terrestrial frequencies were developed for alerting ships in the vicinity, overflying aircraft and the shore, of the occurrence of a distress. These EPIRBs have two separate designs:

- float/free, which is automatically activated in the event of a ship sinking,
- manually activated, to be carried in each survival craft.

The advent of maritime communication satellites presents the possibility of overcoming all these problems referred to above.

Chapter III of the Convention for the Safety of Life at Sea, 1974, which refers to life saving systems, and Chapter IV, which deals with radiocommunications, are being revised (1980).

The draft revised Regulations state that every ship to which the Convention applies shall carry a float-free EPIRB and every survival craft carried on ships to which the Convention applies will be fitted with a manually activated EPIRB. An EPIRB shall operate on 2182 kHz and/or on 121.5 MHz and/or on 243 MHz.

1.2 *Space systems*

Satellite links are largely unaffected by propagation variations. A vessel in distress fitted with a satellite communication terminal would have a priority channel available for the transmission of the distress message. Such a service capability is currently provided by the present MARISAT system, and is under development for the future INMARSAT system.

In view of the high cost not all vessels can be expected to be fitted with satellite terminals. There also remains a need for automatic distress alerting in the event of a sudden foundering. Furthermore, if the crew of a vessel in distress take to survival craft, the use of the satellite system to maintain two-way communication with the shore or rescue vessels raises technical problems because survival craft cannot carry antennas of sufficiently high gain.

In order to meet these needs, the concept of a satellite EPIRB dedicated to providing distress alerting via satellite has evolved. Such equipment should be capable of fulfilling an alerting role in the following three applications:

- manual activation from on board ship;
- float-free and automatic activation in the case of a sudden foundering;
- manual activation from on board a survival craft.

The same signalling techniques could be used in the three applications.

1.3 *Operational requirements*

The IMCO Sub-Committee on Radiocommunications has defined the following operational requirements for satellite EPIRBs:

(a) The Satellite EPIRB system should be part of the Future Global Maritime Distress and Safety System (FGMDSS) and so configured as to promote safety of life at sea in the highest possible manner.

(b) To achieve this aim, the system should cover all navigable waters including those north of 70° N and south of 70° S. From considerations within IMCO it has been agreed that the long range alerting function of the FGMDSS will be based primarily on the use of satellite techniques and will include the use of satellite EPIRBs. In COM XXII/12 IMCO stated: "Low-power distress transmitters should operate through geostationary satellites, but the use of polar orbiting satellites is also desirable." On the basis of currently planned systems, the combination of a geostationary system with a low polar orbiting system most nearly meets these requirements.

(c) From an operational point of view, no clear choice of a particular frequency exists. However, it is highly desirable that the future satellite EPIRB is designed in compliance with a single international standard and transmits on only one satellite frequency. It is desirable that a common frequency for satellite EPIRB transmissions should be provided for both geostationary and polar orbiting satellites. It is noted that 1.6 GHz band will be used in the first generation INMARSAT satellite, and that experiments are to be conducted with the use of 406 MHz by polar orbiting satellites.

(d) The satellite EPIRB system should take into consideration requirements of the aeronautical mobile service where a shared system might yield mutual benefits to both services and to search and rescue organizations.

(e) Provision should be made in the system for satellite EPIRB signals to be treated as distress messages and correctly routed to the appropriate search and rescue authorities.

(f) The satellite EPIRBs should operate for sufficient time to ensure a 0.99 probability of distress message reception and interpretation. It is desirable to achieve this probability as quickly as possible; however, the exact specification of this time will be dependent on system characteristics and implementation.

(g) In regard to the number of simultaneous transmissions of satellite EPIRB alerting signals in any one ocean area, IMCO is of the opinion that a satellite EPIRB system should support at least 20 satellite EPIRBs in a 10 min interval. In obtaining this estimate, both IMCO convention and non-convention vessels were considered in an entire ocean area. The system should support this with a probability of 0.95.

(h) As a minimum, the satellite EPIRB system should provide the following information:

- distress alerting;
- identification of the unit in distress;
- data which enables the SAR authorities to determine the position of the unit in distress.

(j) Optionally, and in addition to the above minimum, the satellite EPIRB system could provide information concerning the nature of distress.

(k) A capability for homing is required. However, this is a terrestrial communication function which must operate and be compatible with the Future Global Maritime Distress and Safety System under consideration by IMCO.

2. Operational considerations

The operational requirements identified by IMCO for satellite EPIRBs listed in § 1.3, call for worldwide coverage with negligible delay in the receipt of the distress message, together with a capability for the simultaneous reception of multiple transmissions. It can be assumed that these criteria will apply equally to ship and survival craft satellite EPIRBs. The preparation of operational requirements for a maritime distress system is the responsibility of IMCO. However, the following considerations are thought to be relevant to the development of these requirements:

- time taken to achieve a certain probability of error-free message transfer;
- system performance during simultaneous distress transmissions;
- effect of various sea states on performance;
- coverage;
- contents of distress message;
- methods of positioning;
- the complexity and cost of distress equipment, satellite and ground terminal equipment.

2.1 *Time taken to achieve a certain probability of error-free message transfer*

The time taken to achieve a 0.99 probability of error-free message transfer will depend on message length and on various geographical, atmospheric, oceanographic and radio propagation conditions. Interference from other sources, including interference from other distress messages which may be transmitted simultaneously, will also affect this probability. This subject requires further study.

2.2 *Coverage*

Systems designed to use geostationary satellites will have their coverage limited to latitudes approximately between the 70° parallels but would still serve the majority of world shipping. However, to provide coverage of the polar regions polar orbiting satellites would be necessary. With polar orbiting satellites, distress alerting delays due to the intermittent passing of satellites result. This delay is greatest at the equator and depends on the number of satellites and ground receiving stations. One advantage of polar orbiting satellites is that real-time positional information is obtainable by Doppler measurement of the received satellite EPIRB signal. There is also a saving in satellite EPIRB power due to lower path losses compared to geostationary systems (see § 3.1).

There would appear to be a case, therefore, for combining the advantages of geostationary and polar orbiting systems.

2.3 *Contents of distress message*

The distress message should contain, as far as possible, an essential amount of information about the incident. However, in the interest of decreasing the probability of error and also message acquisition time, the contents of the distress message should be limited. The possible contents of the message and the number of bits are shown in Table I in order of priority.

TABLE I — *Possible contents of distress message*

Item	Contents	Approximate No. of bits
1.	Ship station identity	30
2.	Position co-ordinates: latitude (min) hemisphere symbol longitude (min) hemisphere symbol	 13 1 14 1
3.	Time of position update (min)	11
4.	Time of activation (min)	11
5.	Course (360° rotation)	9
6.	Speed (up to max. 63 knots)	6
7.	Nature of distress	4

Note. — Position, time of position update, time of activation, course and speed would not be necessary if position is determined by Doppler measurement techniques.
Items 3, 4, 5 and 6 may not be required if position updating is continuous, or at short intervals.
Item 4 may not be required if acquisition time is short.

2.4 *Methods of positioning*

Upon determination that an emergency or distress exists, the problem becomes one of determining the geographical position of the distress to sufficient accuracy so that assistance can be effectively rendered.

Geostationary satellites can be used for position location by ground stations using ranging techniques, re-transmission of signals of existing radio navigation systems, and transmission of position data obtained on board ship. Low orbiting satellites can use any of these methods or can determine satellite EPIRB position by Doppler shift measurements.

2.4.1 *Techniques for geostationary satellite systems*

Range measurement techniques use multiple satellites for simultaneous ranging on the satellite EPIRB. Although the system allows position determination quickly, it requires at least 3 satellites within visibility and high accuracy in determining positions of the ranging satellites. Errors in the latter may produce large errors in the satellite EPIRB position.

Transmission of position information by the satellite EPIRB appears to be practicable in the foreseeable future and may be in one of two forms. The satellite EPIRB may re-transmit navigation signals it receives or may re-transmit position information it has processed from received navigational signals. Although the system allows quick position determination, satellite EPIRB complexity (and cost) are increased and errors and ambiguities inherent in the navigational system are carried over (and possibly increased).

Difficulties may occur in reception during specific time slots for some of the radionavigation systems in the case of re-transmission of navigation signals.

Hybrid techniques are also possible using a combination of ranging and information from navigation systems.

Alternatively, the satellite EPIRB could transmit position information loaded into it prior to the distress. This could be accomplished either manually or by electrical attachment to existing shipboard navigational equipment [Kimura, *et al.* 1978]. This reduces the complexity from the technique above (no integral navigation receiver required); however, in the case of manual entry, the position transmitted by the satellite EPIRB may not represent the position of the distress. In this case, the SAR authorities must be provided with the information given in items 3, 4, 5 and 6 of Table I to determine the distress position.

2.4.2 *Techniques for low orbiting systems*

In addition to the techniques noted for geostationary systems which also may be used with low orbiting satellites, Doppler shift measurements are possible. This technique allows use of a very simple satellite EPIRB. A disadvantage of the system is that there is a wait time between satellite passes. This time is a function of latitude, orbit, and the number of satellites employed.

2.5 *The complexity and cost of distress equipment, satellite and ground terminal equipment*

In the interest of widespread acceptance, the cost of the system should be minimized. In particular the cost to the user, that is, the cost of the shipboard equipment, should be as low as possible.

3. Technical considerations

3.1 *Satellite orbits*

Two alternative satellite orbits are being considered : geostationary (at an approximate altitude of 35 800 km) and low altitude near-polar (at an approximate altitude of 850 km). The satellite EPIRB should provide sufficient energy for maximum operational slant ranges. At 5° elevation angle these respective ranges are approximately 41 130 km and 2890 km.

Another parameter to be considered in the orbit evaluation is the resultant satellite earth coverage antenna beamwidth at the half power points. In the case of the geostationary satellite this beamwidth is around 17.3°, and for the low altitude satellite it is about 123°.

Thus, in the analyses of the power requirement advantages of each orbit, considering both the slant range and the satellite antenna half power beamwidth, it can be shown that the low orbit system has an overall 6 dB power advantage. Also, its antenna size (assuming that in both cases a dish antenna is used) is reduced by a factor of 7.

3.2 *Frequency considerations for distress systems*

Significant changes in frequency allocations for satellite distress system operations were effected by WARC-79. The band 406-406.1 MHz is now exclusively allocated to the mobile-satellite service (Earth-to-space) for satellite EPIRB use and development. The band 1645.5-1646.5 MHz is also allocated exclusively to the mobile-satellite service (Earth-to-space) and limited in use to distress and safety operations. The bands 121.45-121.55 MHz and 242.95-243.05 MHz are allocated by footnote to the mobile-satellite service for reception on board satellites of EPIRBs transmitting at 121.5 MHz and 243 MHz.

As a practical matter the up-link frequency choice is limited to the 406 MHz and 1646 MHz bands. Either of these could be used with geostationary or near-polar orbiting satellites. However, experiments with near-polar orbiting satellites are planned at 406 MHz while preference for geostationary satellites is at 1646 MHz since normal communications occur at 1.6 GHz.

The WARC-79 also allocated the band 1544-1545 MHz exclusively to the mobile-satellite service (space-to-Earth) for distress and safety operations which would include low power EPIRB systems down links. Down links could also operate in fixed-satellite service bands used for normal satellite-to-Earth communications (e.g. 4 GHz band). Either down link could accommodate geostationary satellite operations. However, feeder links for near-polar orbiting satellites would be limited to 1545 MHz, where experiments are planned since geostationary satellites have priority in fixed-satellite bands (RR No. 2613) and power flux-density limits in the 4 GHz band make large earth station antennas necessary.

The other frequencies allocated in the maritime mobile satellite service may be used for distress and safety purposes.

3.2.1 *Earth-to-satellite frequencies*

The major factor influencing the selection of a suitable frequency from the available bands is the increased free space loss of approximately 12 dB for the 1.6 GHz band as compared to the 406 MHz band, assuming that the satellite antenna aperture is configured to allow for earth coverage in both cases. The magnitude of this degradation for the 1.6 GHz band, which holds for both the geosynchronous and the low altitude satellites, may be decreased by the ionospheric and the multipath effects. Additional work is necessary to refine the estimate of degradation due to these latter effects.

Thus, approximately an order of magnitude reduction in satellite EPIRB power is possible if the 406 MHz band is used. This reduction is important since the satellite EPIRB antenna gain will be low in order to be consistent with hemispherical coverage and minimum pointing requirements. This reduction in satellite EPIRB power can reduce cost, size, and weight of the satellite EPIRB. These factors are very important to user acceptance of the system. However, the disadvantage of the 406 MHz band is that the satellite antenna size must be increased by a factor of 4 as compared to the 1.6 GHz case (assuming a dish antenna is used) to provide the same coverage of the earth from the satellite.

The COSPAS/SARSAT system using low altitude, near-polar orbiting spacecraft has adopted the 406 MHz band for the reasons outlined above.

The initial INMARSAT geostationary satellite system will not have a 406 MHz capability.

Thus, practical considerations preclude operation at 406 MHz in the initial INMARSAT satellite system and dictate the use of a 1.6 GHz satellite EPIRB regardless of the link penalty.

3.2.2 *Satellite-to-Earth frequencies*

Geostationary satellites to be used for maritime communications will operate in fixed satellite bands (e.g. 4 GHz band) for communications from satellite to the coast earth station. Operation of the satellite EPIRB feeder link in these bands would require co-ordination with other users such as the fixed satellite service.

The band 1544 MHz to 1545 MHz can be used for feeder links between satellites and satellite EPIRBs and between satellites and coast earth stations as well as for distress and safety communications between satellites and ship earth stations.

The size of a coast earth station antenna operating at 4 GHz is controlled by the power flux-density specified for the fixed satellite band.

3.3 *Special satellite payload configurations for distress*

A special high gain channel could be used in order to increase the satellite transmitted power level of the distress signal. This solution has been adopted for the Marecs satellites by incorporating an additional 15 dB gain IF amplifier before the TWT amplifier.

This increases the (C/N_0) at the coast earth station by about 8 dB.

3.4 *Required bandwidth*

The required bandwidth for transmission of distress messages depends largely on the system employed, and particularly on such factors as the modulation method and the required number of simultaneous transmissions.

3.5 *Burst duration of distress message*

The burst duration of the distress message will depend on the system used.

3.6 *Interference considerations*

The bands for the space-to-Earth feeder link (e.g. 4 GHz band) are heavily used for fixed-satellite systems. These bands are also allocated to other services such as fixed and mobile services. At this time, a channel is not allocated exclusively for satellite EPIRB use. The two bands 1544 to 1545 MHz and 1645.5 to 1646.5 MHz are allocated on an exclusive basis to the mobile-satellite service and are limited by a footnote to distress and safety operations.

The frequency band 1626.5 to 1645.5 MHz is also allocated on a primary basis by a footnote, to the fixed service in seventeen countries. Low power distress transmitters used in this band should be designed to operate reliably in the presence of anticipated interference since safety of life at sea is involved. Further study is therefore needed into the magnitude of the potential interference and the satellite EPIRB design implications.

3.6.1 *Interference from radio relay equipment*

A particular site selection for radio relay equipment could cause interference to a satellite EPIRB signal under certain rare circumstances. This small probability of intereference could be eliminated by avoiding use of those specific channels used by satellite EPIRBs.

The use of suitable frequency co-ordination techniques, such as avoiding pointing at the geostationary orbit, could eliminate even this small probability.

The elimination of any possible interference could also be effected by the use of design techniques for the satellite EPIRB which could make the system more immune to interference.

3.7 *Link budgets*

Link budgets for satellite EPIRBs operating in the 406 MHz and 1.6 GHz frequency bands have been considered.

An example of a satellite EPIRB-to-satellite link budget is given in Table II. A point which may be questioned is the propagation margin; the required margin depends on the type of modulation and signal processing schemes adopted, as systems are based on message repetition.

To derive the overall link budget, the NOAA-E (406 MHz) and the Marecs (1.6 GHz) satellite data have been used. Care should be taken when applying the results to other satellites.

The results corresponding to various system configurations at 1.6 GHz are given in Table III. No allowance has been made for interference from other systems, or for simultaneous transmissions.

TABLE II — *Satellite EPIRB-to-satellite up link*

Parameter	Units	Geostationary satellite (Marecs)	Low-altitude satellite (NOAA-E)
Up-link frequency	MHz	1 645	406
Transmitter power	dBW	7	7
Net antenna gain (including pointing and cable losses)	dBi	−0.5	−3
e.i.r.p.	dBW	6.5	4
Link margin	dB	−6.5	−3
Free space path loss(1)	dB	−189	−152.4
Polarization losses(2)	dB	−0.4	−
Satellite G/T	dB(K^{-1})	−12.1	−32.5
Up-link C/N_0	dBHz	27.1	44.7

(1) 5° elevation angle at 1 645 MHz and 10° elevation angle at 406 MHz.

(2) This loss is computed on the bases of the following assumptions:

— at 1 645 MHz the axial ellipticity ratios of the satellite EPIRB and the satellite antennas are 2 dB and 3 dB; the antennas are of the same polarization and the angle between the major axes of the two ellipses is 90°;

— at 406 MHz the polarization loss is included in the antenna gain.

TABLE III – *Overall* C/N_0 *with alternative MARECS system configurations*

Spacecraft e.i.r.p. (dBW)	Coast earth station G/T (dB(K^{-1}))	Overall C/N_0 (dBHz)
−29.2(1)	32	26.0
−42.2	32	19.2
−42.2	40.7	23

(1) Dedicated SAR channel.

4. Experimental systems

Experiments have been carried out with geostationary satellites using the Federal Republic of Germany's Distress Radio Call System, (DRCS), and the USA Satellite-Aided Maritime Search and Rescue System (SAMSARS). Experiments will be carried out with low altitude near-polar orbiting satellites through a joint effort between Canada, France. USA and the U.S.S.R. called COSPAS/SARSAT. Experiments with the ARGOS system and future activity were also reviewed.

4.1 *Distress Radio Call System (DRCS)*

DRCS is a satellite EPIRB system. It contains a float-free device and a portable distress keyboard sender and meets the requirements of § 1.2 and § 2.3.

After automatically floating free, the float-free device transmits the ship station identity of the unit in distress and a position information derived and updated from the ship.

The portable distress keyboard sender is able to transmit not only the ship station identity but also an individual message of alphanumeric characters which may be fed into a memory by means of a keyboard.

The keyboard sender can be installed on the ship, using the vessel's power supply and connected to a fixed antenna. Under these circumstances it can be used as a reserve transmitter in case of distress. The same distress keyboard sender may also be easily disconnected in order to be used in a survival craft. The power is then supplied by an internal battery and the signal is transmitted via an antenna which is integral with the equipment. Additionally, the float-free device includes a transmitter for homing purposes on the maritime radiotelephone distress frequency 2182 kHz.

In order to overcome the high attenuation of the transmission path between the DRCS and the geostationary satellite, a specific technique of modulation, reception and processing was developed and successfully tested in several trials with the ATS-6 satellite in 1975/1976. [ESTEC, 1975; ESTEC, 1977].

The narrowband DRCS signal is FSK modulated and transmitted at a frequency of 1.6 GHz. In the satellite it is coherently up-converted to the appropriate frequency of the down-link feeder link and then down-converted to 70 MHz in the coast earth station. This signal is input to a standard receiver using a special tuner and down-converted to the first IF of 50 MHz. The second IF of 10 MHz is fed to a special down-converter without any demodulator to obtain the FSK signal at audio frequencies in a filter bank. Each of the filters has a bandwidth approximately equal to the bit rate. The modulation index is chosen such that the frequency spacing comprises 4 channels for the float-free device and 8 channels for keyboard sender.

All filter outputs enter the signal detection unit. There they are rectified and each connected with an integration circuit with a time constant of several seconds. The output levels are permanently monitored by a multiplexer and an amplitude comparator to detect channels of higher amplitude than the noise level. In a correlation circuit these channels are examined for correct channel spacing. If this procedure results in the identification of two probable channels, they are combined to a single line signal, sampled at ten times the information bit rate, switched to an analogue/digital converter, and stored in a memory not synchronized to the data frame.

The continuously transmitted data frames of constant time duration are superimposed. The signal-to-noise ratio increases up to 15 dB for 64 superpositions. After bit synchronization, bit decision and "sync-word" detection, the frame beginning is identified and the message can be decoded and printed out on an alphanumeric printer.

Theoretical calculations on the possible number of simultaneous alerts were made for the DRCS under the assumption that the frequency assignments to both the satellite EPIRBs and the keyboard senders will be in steps of 1 kHz, that the transmission duration will be 8.5 min with a 2-h interval, and that the long-term frequency stability of the oscillator will be 1×10^{-6}.

Assuming 0.95 probability of no occurrence of mutual interference and 53 kHz bandwidth a total of 200 simultaneous distress calls is derived. For a total of 20 simultaneous alerts, a bandwidth of only 5 kHz is required.

Future sea trials are to be conducted starting in September 1982, using a Marecs spacecraft with the aim to optimize overall system performance. These trials will be conducted together with the UK, USA, U.S.S.R. and Norway in a Coordinated Trials Programme (CTP).

In order to supplement these experiments with respect to multipath and wave shadowing effects it is planned to carry out laboratory simulator tests by applying the stored channel principle. The simulator is controlled by the recorded variation of the distorted radio link under a broad range of realistic conditions.

4.2 *SAMSARS Spread Spectrum System*

The concept of the Satellite-Aided Maritime Search and Resue System (SAMSARS) is based upon the utilization of the ground and space elements of the INMARSAT system for the rapid transmission to the cognizant rescue forces of the distress alert, vessel identification, position location, and other emergency related information.

The distress data is relayed by a 5 W transmitter using a 25 to 75 kHz wide portion of the 1.6 GHz band distress channel. Resistance capability for numerous near-simultaneous distress transmissions and the immunity to terrestrial and satellite originated interference is inherently provided through the employment of the direct sequence, bi-phase PSK modulated, spread spectrum technique. The required rapid detection is achieved by the use of a charge transfer device (CTD) filter which is matched to a maximum length, pseudo-random noise (PRN) code [Peterson and Weldon, 1972]. In order to reduce the receiver complexity and to lower the production costs of the transmitter, a single 127 chip code is employed in the system. Further transmitter cost reduction, as well as an increase in the system capacity is achieved through the employment of a low stability carrier oscillator in the transmitter. This approach, however, requires more sophistication in the receiver provided through the employment of a digital mini-computer that performs most of the receiver functions.

SAMSARS transmits a data message of up to 102 bits in 17 blocks of six bits. Each six-bit block defines one of 64 orthogonal symbols having a duration of 1.98 s. The 17 data symbols, plus 3 sync symbols, are repeated up to 10 times during a message burst. The SAMSARS system thus provides the high communication efficiency of M-ary orthogonal signalling and the interference resistance of the PRN code format. A design message error probability of 5×10^{-3} has been adopted, consistent with the IMCO operational requirements stated in § 1.3.

Though the method of positioning has not yet been finalized for SAMSARS, the various alternatives discussed in § 2.4.1 could be incorporated into the system.

The SAMSARS receiver consists of 64 pre-processor sections which are connected to a common multiport mini-computer central processor. Each pre-processor detects signals within 50 Hz band of carrier frequency uncertainty. While searching for signals, the central processor scans each pre-processor through 10 centre frequencies in order to cover a total of 50 Hz $\times$ 64 $\times$ 10 = 32 kHz = $\pm$ 16 kHz of carrier frequency uncertainty. Upon detecting a signal, a pre-processor section alerts the central processor, which then verifies the signal presence, acquires code and symbol timing, integrates successive messages, performs message quality checks, and decodes the data.

The ground-satellite-ground tests of a previous SAMSARS design, SAMSARS-A, [Fee *et al.*, 1980], conducted in November 1979 via the Pacific Marisat satellite, provided the following results:

- In the absence of an external terrestrial interferer, 0.99 probability of error free distress alert was achieved with a single transmission burst at a C/N_0 of 26 dBHz. This signal quality was attained at a satellite EPIRB e.i.r.p. of 2.5 W.

- In the presence of a 1600 W 1.6 GHz band FM terrestrial interferer, with an approximate bandwidth of 215 kHz, the same result was achieved at a 10 W e.i.r.p. level.

- In the presence of a 500 W 1.6 GHz band FM terrestrial interferer, with an approximate bandwidth of 20 kHz, the above performance was achieved using a 10 W e.i.r.p. level. In the presence of the same interferer, but of a 1600 W level, five transmission bursts were required to attain the same performance.

However, the present design, described above (SAMSARS-B), is intended to improve the performance of SAMSARS-A by about 8 dB, with some lowering of immunity to terrestrial and satellite originated interference levels.

Further planned developmental efforts include construction of a prototype satellite EPIRB with a 102 bit message handling capacity, and the installation of sufficient computer capacity to handle the full message length and to expedite the message processing. A series of laboratory and satellite tests, using INMARSAT spacecraft, are also being considered for the purpose of verifying the equipment performance in multipath and wave shadowing environments and for the establishment of a new data base. Starting in September 1982, these latter tests will be conducted together with other countries as part of the Coordinated Trials Programme (CTP).

4.3 *Systems using the frequency band between 406.0 MHz and 406.1 MHz with low orbiting satellites (COSPAS/SARSAT)*

Several administrations have agreed to conduct an experimental project to demonstrate and evaluate the use of low altitude, near polar orbiting satellites to receive and process distress alerting, reporting and position location transmissions from satellite EPIRB operating in the 406.0-406.1 MHz band. The project combines the United States of America, Canada and France SARSAT project and the U.S.S.R. COSPAS project into a joint COSPAS/SARSAT project [Redisch and Trudell, 1978; Zurabov, *et al.*, 1979].

For the SARSAT project, a special instrument package will be placed on board at least three satellites operated by the United States National Oceanographic and Atmospheric Administration (NOAA). The first instrument package is scheduled for launch aboard NOAA-E (fifth in the series of Tiros-N satellites) in the second quarter of 1982. The nominal orbital altitude is 850 km, inclined 98.6° with respect to the equator.

This satellite system will significantly augment existing terrestrial distress alerting, reporting and position location facilities by providing global coverage, increasing the probability of detecting a distress event and by decreasing the time elapsed between the occurrence of a distress event and its detection.

A description of the major elements of the SARSAT system and the technical characteristics of the satellite EPIRB have been published [GSFC, 1979; Redisch and Trudell, 1978].

The instrument package contains receivers operating at 121.5, 243.0 and 406.025 MHz, frequency translators, a signal processor, and a phase modulated transmitter operating in the 1544-1545 MHz band.

Signals received by the satellite in the 121.5, 243.0 and 406.025 MHz bands are linearly down-converted and frequency division multiplexed before phase modulating (FDM-PM) the 1544.5 MHz transmitter. The signals received in the 406.025 MHz band receive additional processing. A two channel signal processor similar to the ARGOS processor (Report 538) has been included in the instrument package. The processor demodulates the digital message from the received satellite EPIRB carrier and measures the carrier frequency to an accuracy of $\pm$ 0.5 Hz. Two channels of received digital messages and carrier frequency measurements are time tagged, formatted, bi-phase-L encoded and transmitted in real time at a 2.4 kbit/s rate by direct phase modulation of the 1544.5 MHz carrier.

The real time information is also stored in the spacecraft mass memory for later readout on command. It is this feature that provides global coverage independent of earth station location.

The 1544.5 MHz transmissions are received by Local User Terminals (LUTs). These earth stations use a three metre diameter tracking parabolic antenna to achieve an antenna gain-to-noise temperature ratio (G/T) of 3 dB(K^{-1}). The 2.4 kbit/s bit stream is obtained by coherent demodulation of the carrier and is demultiplexed to obtain the satellite EPIRB message, frequency measurements, and time tags. The satellite EPIRB position is computed using the spacecraft ephemeris and the time tagged Doppler shift embedded in the satellite EPIRB carrier frequency measurements. Position location accuracy on the order of 2 to 5 km is expected.

The linearly translated 406.025 MHz spectrum is also recovered by the coherent demodulation of the carrier and will be used primarily for the purpose of characterizing the 406.025 MHz Earth-to-space channel. Additional processing to recover individual satellite EPIRB transmissions is not planned at this time in the 406 MHz band.

The data stored in the spacecraft mass memory will not be directly available to the LUT in SARSAT. This mass memory is associated with the meteorological mission of the NOAA satellite and will be read out only on command by the NOAA command and acquisition earth station. A 15 month demonstration and evaluation phase will be conducted when the first COSPAS/SARSAT spacecraft will be launched and is successful in operation (1982-1983).

4.4 *ARGOS Experiment – France*

In May-July 1979, an ARGOS maritime experiment was conducted using the Tiros-N satellite operating at 401.6 MHz in a low polar orbit. Argos is a location and meteorological data collection satellite system implemented in co-operation between USA and France. Forty boats participating in a 6000 mile yacht race from

France to Bermuda and back, were each fitted with an Argos transmitter, operating at 3 W, and a deck mounted 30 cm, disc-shaped antenna. The transmitter was additionally fitted with a special distress switch.

More than 10 000 positional and meteorological messages were received over a 70 day period. The positional accuracy given by the system was, on the average, better than one nautical mile (2 km). During the race four distress incidents occurred. The ARGOS system provided the initial alarm in two cases and position data for rescue purposes in all cases.

A further experiment was performed in June 1980 during a trans-Atlantic sailing race involving 110 boats.

4.5 *Norway*

The system is designed for use in a maritime communication satellite system operating at 1.6 GHz. Two spacecraft configurations are considered:

- A Marecs satellite with a narrow band (200 kHz) high gain (15 ± 2 dB) transponder in the ship-to-shore direction.
- A maritime transponder (MCS) on an Intelsat-V spacecraft (no additional amplification in the ship-to-shore direction).

The required distress transmitter output power will depend on the required up link margin, the spacecraft transponder characteristics and the receiving earth station performance. With the enhanced gain transponder the output power could be substantially reduced.

Selection of transmission technique for the satellite EPIRB system has been made in view of the low signal levels encountered and other system constraints, such as:

- phase noise on the satellite EPIRB signal introduced by the satellite EPIRB and the satellite transponder;
- uncertainties and instabilities of the satellite EPIRB signal frequency;
- interference from other signals in the satellite:
- deep signal fadings, *inter alia*, due to multipath transmission and screening by waves;
- mutual interference between several satellite EPIRB signals.

The technique makes use of a 240 Hz sub-carrier phase-modulating the 1.6 GHz carrier at a low modulation index (m = 1.2). This provides a stable reference free from phase noise. In the first part of the transmission sequence (the alarm phase), the sub-carrier is unmodulated, enabling high detection probability and low false alarm probability. The alarm signal is used to determine and track the received carrier frequency and to preset the phase of the receiver's sub-carrier reference, for use in the data demodulation. The alarm phase is followed by the information transfer phase, in which the sub-carrier is PSK-modulated in synchronism with the sub-carrier (60 bauds). In order to minimize the transmission error probability, each 6 bit information character is transmitted in the form of a 31 chip code word, all words forming a bi-orthogonal code. The transmission sequence is repeated a number of times to overcome link interruptions and to improve the signal quality by message integration.

The selected technique is based on a theoretical study and simulations made by the European Space Agency (ESA) and the parameters are shown in the Annex I, Table V. Trials and operational demonstration with the system are planned for 1982-1983 as part of the Coordinated Trials Program (CTP).

4.6 *United Kingdom*

The system uses a direct sequence spread spectrum technique with bi-phase PSK modulation. To ensure compatibility with the dedicated enhanced gain channel in Marecs a code clock-rate of 100 kHz is used giving a 200 kHz bandwidth. A 1023 bit maximal linear spreading code is used. A 21 bit Neuman-Hofman synchronization code has been chosen together with 7 bit Barker coding of the 100 bit data message.

The transmitter design uses conventional techniques and will provide a 5 W output. Surface acoustic wave (SAW) oscillators are being considered for use as the frequency source.

The receiver will interface with the coast earth station at an intermediate frequency of 70 MHz. Digital matched filters and a Costas loop are used for carrier acquisition and tracking in combination with a delay lock loop for PRN code acquisition and tracking. The receiver will operate under software control.

4.7 *Japan*

In Japan, activities have been directed towards the development of satellite EPIRB systems at 406 MHz. Several possibilities of satellite field trials are considered so as to examine the performance of the systems.

4.7.1 *Narrowband FSK system using geostationary satellites*

Narrowband FSK satellite EPIRB system using 406 MHz band in a geostationary satellite system has been proposed [Kimura, *et al.*, 1978]. The system concept is basically similar to the DRCS narrowband system described in § 4.1

By 1978, laboratory tests of the system via a simulated geostationary satellite have been conducted to evaluate the performance at low carrier-to-noise density power ratio C/N_0. The demodulator used in the receiver applies a digital superposition technique to improve bit error ratio resulting from the low C/N_0. FSK demodulation is accomplished through the filter-bank system which is composed of a number of narrowband band-pass filters spaced every 60 Hz across the baseband. This method is useful in detecting frequency deviated signals without using any AFC device.

In 1979, simulated sea trials of the system were carried out. A buoy type satellite EPIRB was floated at sea within one nautical mile off the shore. A receiving station was installed on a cliff at the shore with the antenna height being 57.5 m above the sea level.

The station consisted of an antenna system that combined horizontally and vertically polarized three elements Yagi arrays, simulated geostationary satellite and receiver with demodulator made up of narrowband filter bank. In order to attain the same low C/N_0 as in the satellite link, an RF attenuator and a noise signal generator were connected to the receiving system.

Elevation angles to the receiving antenna at the satellite EPIRB were varied from 3° to 1.5° and the heights of the sea waves were about 3 m. The height of the top of the transmitter from the sea level was about 1.3 m. Therefore, the strength of the received signals from the transmitter and the values of the C/N_0 fluctuated several decibels as the result of the shielding effect of the waves.

The results of the trials show that BERs of non-superposition detection can be improved approximately by a factor of ten times or more by using 2 times superposition detection within the value of C/N_0 from 23 dBHz to 33 dBHz. A change of the frequency to be used for this system to 1.6 GHz is expected in the near future.

4.7.2 *Spread spectrum PSK system*

It is planned to test in the near future a satellite EPIRB system at 406 MHz and 1.6 GHz using direct sequence spread spectrum bi-phase PSK technique.

The major characteristics of the system are as follows:

Transmit system:

Oscillator stability :	$\pm 6 \times 10^{-6}$
Bandwidth :	0.1 MHz
PRN code duration :	0.051175 s corresponding to 15 352.5 km (PRN code duration multiplied by the speed of light ($c = 2.997\,925 \times 10^5$ km/s)).
PRN code length :	2047 chips
PRN chip rate :	4×10^4 chips/s
PRN code rate :	19.54 codes/s
Data bit rate :	2.5 bits/s = 1 bit /8 codes
Data length :	511 bits, PRN pattern
PRN modulation type :	BPSK $\pm \pi/2$
Data modulation type :	modulo-2 added synchronously to PRN code, differential encoding.
e.i.r.p. :	−13 dBW and 7 dBW at 1.6 GHz −20 dBW and 0 dBW at 406 MHz
Duty factor :	95% and 5%, respectively

Receive system:

Bandwidth :	0.12 MHz
C/N_0 :	> 20 dB Hz
Sweep width :	± 20 kHz
Doppler measurement accuracy :	± 1 Hz
Range measurement accuracy :	± 3 m
Message code demodulation error rate :	$< 10^{-5}$

A continuous transmission will not only make possible the continuous determination of the position of the satellite EPIRB by Doppler shift relayed from low orbiting satellites, but will also improve the locating of the transmitter by the direction-finders during the final positioning (homing) stage.

The communication satellite relay experiment at 1.6 GHz will transmit and receive the EPIRB signals via the INMARSAT space segment and the Japanese geostationary communication satellite to simulate not only the simultaneous alerting and ranging but also sharing communication systems between usual communications and SAR alerts.

The satellite sea trials of the satellite EPIRB system at 406 MHz are expected to use the Japanese Marine Observation Satellite (MOS-1) which is scheduled to be launched in 1984. The other possibility under consideration is to use the NOAA-E satellites.

4.8 *U.S.S.R.*

The U.S.S.R. is developing a satellite EPIRB system, utilizing the 1.6 GHz band, which will use the Inmarsat geostationary satellite. A preliminary decision has been made to use a narrowband modulation technique similar to the Federal Republic of Germany's DRCS.

In 1981, the development of the spread spectrum system was begun. The proposed system – System of Automatic Delivery of Correspondence for Distress (SADCO in Russian abbreviation) – will be based on the usage of the multiposition FSK signals with good auto-correlation and cross-correlation abilities, making it possible to linearly separate them by matched filters.

The basic signal specifications are:

- duration of signal : 5 ms
- frequency bandwidth : 24.4 kHz
- number of chips in signal : 11
- bandwidth-time product : 121

4.9 *Summary of system requirements and proposed systems*

A comparison of the advantages and disadvantages of system options is given in Annex I, Table IV. The proposed technical and operational characteristics of the various systems are shown in Annex I, Table V and in Annex II. It should be noted, however, that not all of the required information is available at this time, and many parameters shown are estimates based on interpretation of available specific data. In particular, the assessment of the 0.95 probability of the number of simultaneous alerts that may be received is based upon certain assumptions.

5. Conclusions

The opportunity to achieve a means of long range distress alerting by the use of satellite techniques has been identified. The possible considerations to be taken into account when deciding on the operational requirements have been suggested.

Technical requirements will develop from these and the results of future trials.

Extensive experimental work has already been carried out with favourable results. Further experiments with improved systems and new techniques are being planned with demonstration trials scheduled during 1982 and 1983.

Operational requirements have been identified by IMCO for satellite EPIRBs. It has been assumed that these will apply equally to ship and survival craft satellite EPIRBs. For ships with satellite communication terminals, the operational procedures for distress situation reporting should make use of standard communication channels with priority access.

Further investigation is needed into the following:

- the effects of potential interference from other sources;
- the radiating efficiency of satellite EPIRB antennas when mounted on the decks of ships, carried in survival craft or floating in the sea under various sea states;
- the response of various modulation techniques to propagation effects and, in particular, multipath, wave shadowing effects and worst case ionospheric scintillation effects;
- the effects of simultaneous transmission satellite EPIRBs;
- a method of providing position data;
- a means of providing input data.

Investigation of the technical possibility of a return link to low power distress transmitters may also be required.

IMCO's attention should be drawn to the need to study release mechanisms and activation.

The frequency allocations at 1.5/1.6 GHz provide for both communications and distress and safety operations, whereas the allocation at 406 MHz provides an exclusive band for satellite EPIRBs in the earth-to-space direction. Frequency allocations appear to be adequate and experiments are planned in these frequency bands.

A Future Global Maritime Distress and Safety System may include the use of geostationary and low altitude near-polar orbiting satellites. The technical, operational and economic impacts of satellite EPIRBs operating at one or more frequencies via one or more satellite systems on both the satellites and coast earth stations need to be assessed.

It is highly desirable operationally that the systems conform to a single international standard.

ANNEX I

TABLE IV — *Summary of the IMCO operational requirements*

IMCO operational requirements	Geostationary satellite	Low altitude polar orbiting satellite	Combined geostationary and low altitude polar orbiting satellite
Immediate alerting	Immediate alerting within coverage area	Average of 1 hour for a 4 satellite system	Immediate alerting except average of ½ hour in polar regions with a 4 satellite low altitude polar orbiting system [ORI, May 1979]
Identification	In message content	In message content	In message content
Positioning	Re-transmission of NAVAIDs or ship's position	Doppler measurement and possibly re-transmission of NAVAIDs or ship's position	Doppler measurement and possibly re-transmission of NAVAIDs or ship's position
Global coverage	Limited to approximately between 70°N and 70°S	Global	Global
Nature of distress (optional)	In message content	In message content	In message content
Simultaneous transmissions (20 in 10 min)	Awaits evaluation	Awaits evaluation	Awaits evaluation

TABLE V — *Summary of expected system parameters*

System / Parameter	COSPAS/ SARSAT	DRCS, Germany (Fed. Rep. of)	FSK(1) Japan	SAMSARS, USA	United Kingdom	PN-PSK, Norway/ESA	EPIRB, U.S.S.R.	PN-PSK(1) Japan
Satellite orbit	Polar about 850 km	Geostationary	Geostationary	Geostationary	Geosataionary	Geostationary	Geostatinonary	Polar/ Geostationary
Minimum No. of satellites	3 NOAA and 2 COSPAS(1)	3	3	3	3	3	3	—
Type of distress equipment	121.5/243 MHz ELT/EPIRB 406 MHz: — float free — on board ship — survival craft	— float free — on board ship — survival craft	— float free — on board ship — survival craft	— float free — on board ship — survival craft	— float free — on board ship — survival craft	— float free — on board ship — survival craft	— float free — on board ship — survival craft	— float free — on board ship — survival craft
Message type	IMCO requirements	IMCO requirements and individual telegraph message	IMCO requirements	IMCO requirements	IMCO requirements	IMCO requirements	IMCO requirements	IMCO requirements
Position information	Doppler measurement, ship derived position	By up-dating of ship's derived position information	By up-dating of ship's derived position information	Position information or NAVAID retransmission or Doppler measurement	By up-dating of ship's derived position information	By up-dating of ship's derived position information	By up-dating of ship's derived position information	Doppler measurement/ Ranging measurement
Time: for transfer (mean)(2)	Midlatitude Mean 1. 5.5 h 2. 2.5 h 3. 1.5 h 4. 1.3 h	1-8 min	2 min	2.5-7.0 min	10 min	< 5 min	5 min	see COSPAS/ SARSAT/ < 5 min
Frequency Up link, MHz	121.5, 243 and 406	1645.5-1646.5	406 and 1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	406 and 1645.5-1646.5
Transmitter power e.i.r.p.(3)	121.5, 243 MHz: −11.3 dBW 406 MHz: 7 dBW	Float free: 10 dBW Keyboard: 13 dBW	7 dBW	7 dBW	7 dBW	7 dBW	7 dBW	0 dBW/7 dBW
Information bit rate/modulation	400 bits/s, PM	32 bits/s, non-coherent FSK	63 bits/s FSK	0.2-0.7 bits/s, bi-phase PSK	10 bits/s, bi-phase PSK	11.61 bits/s, PSK on a sub-carrier	24 bits/s, FSK / 0.6 bits/s, FSK	2.5 bits/s, bi-phase PSK

TABLE V — (continued)

System / Parameter	COSPAS/ SARSAT	DRCS, Germany (Fed. Rep. of)	FSK(1) Japan	SAMSARS, USA	United Kingdom	PN-PSK, Norway/ESA	EPIRB, U.S.S.R.		PN-PSK(1) Japan
Required bandwidth	< 100 kHz	100 kHz(4)	100 kHz	25-75 kHz(4)	200 kHz	awaits evaluation	5 kHz for 20	24.4 kHz	100 kHz
Theoretical simultaneous alerts, 0.95 probability	121.5/243 MHz for 10; 406 MHz for 100	53 kHz for N = 200(4)	136	42 with 26 dBW interference	awaits evaluation		awaits evaluation		above 200
Experiments carried out	1975 (OSCAR), land trials; 1979 ARGOS sea trials	1975/1976 (ATS-6) sea trials	1979 sea trials, but simulated satellite	1979 MARISAT, land trials	None	None	None		None
Date of operational trials	1982	1982	1982-1983(5)	1982	1982	1982	1982		1982-1983(5)

(1) Initial system.
(2) Time between initiation of transmission and read out of error free message at ground station.
(3) This value does not consider the affects of external terrestrial interference.
(4) Depends on the number of simultaneous alerts (N).
(5) Provisional.

REFERENCES

ESTEC [1975] European communications experiments in L-band with ATS-6. Vol. 6, Distress buoy, System Design, Instrumentation and Experiment.

ESTEC [1977] European communications experiments in L-band with ATS-6. Vol. 11, Distress keyboard sender, System Design, Instrumentation and Experiment.

FEE, J. J., KAMINSKY, Y., SCALES, W. C. and TODD, R.E. [November, 1980] Development of an experimental spread spectrum maritime communications system : Phase II. U.S. Maritime Administration, Dept. of Commerce, Report MA-RD-940-80043.

GSFC [15 August, 1979] Specifications for the electronics for use in experimental 406 MHz ELTs and EPIRBs. NASA Goddard Space Flight Centre.

KIMURA, K., KIMURA, M., HATA, T. and YOSHIMURA, H. [7-9 March, 1978] Emergency position indicating radio beacon system using 406 MHz band mobile service. IEE International Conference on Maritime and Aeronautical Satellite Communications and Navigation, London.

ORI [11 May, 1979] Satellite search and rescue coverage, SARSAT and COSPAS. Technical Report No. 1500, National Aeronautics and Space Administration, Greenbelt, Maryland 20771, USA.

PETERSON, W. and WELDON, E. [1972] *Error-correcting codes.* MIT Press, 2nd ed.

REDISCH, W. and TRUDELL, B. [9 November, 1978] The search and rescue satellite mission – A basis for international co-operation. IEEE Position Location and Navigation Symposium (PLAN-78), San Diego, Ca., USA.

ZURABOV, Y.G., PCHELIAKOV, L.S., BOGDANOV, V.A. and BRONITSKY, I.S. [17-22 September, 1979] COSPAS project – A satellite aided experimental system for SAR applications. XXX Congress, International Astronautical Federation, Paper IAF-79-A-33, Munich, Germany (Federal Republic of).

ANNEX II

THE USE OF COSPAS/SARSAT TYPE EXPERIMENTAL EPIRB WITH A GEOSTATIONARY SATELLITE SYSTEM

1. Introduction

The use of satellites for the handling of safety and distress communications is a matter of increasing importance. Both low altitude polar orbiting systems and geostationary systems are under development and evaluation and these systems are complementary in terms of their ability to provide safety and distress communication. For example, a geostationary satellite system can provide near instantaneous alerting between the 70° parallels but not in the higher latitude regions. However, to provide coverage of the polar regions, deployment of polar orbiting satellites is necessary. These are subject to distress alerting delays due to the intermittent passing of satellites. The delays are greatest at the equator and they depend on the number of satellites and on the number of ground receiving stations. One advantage of polar orbiting satellites is that real-time position information is obtainable by Doppler measurement of the received satellite EPIRB signal. There are also larger signal margins or higher link reliabilities due to lower path losses compared to geostationary systems.

There is a case, therefore, for combining the advantages of geostationary and polar orbiting systems. The purpose of this paper is to show how a 406 MHz EPIRB developed for use with the COSPAS/SARSAT low altitude satellite can also be used with a future geostationary satellite and to further describe experiments which can be conducted in the near future with an existing satellite such as GOES operating at about 400 MHz.

2. Description of the 406 MHz experimental EPIRBs

The similarities which exist in the requirements for monitoring EPIRB beacons and data collection platforms mean that much of the development effort used for data collection platforms is applicable to experimental 406 MHz EPIRBs (Report 919). To maximize the capacity or the ability to provide service to a number of users of the 406 MHz system, the 406 MHz EPIRB is designed to operate in a random time and frequency division burst mode over the allocated band. A low-level signal at 121.5 MHz is also included in the EPIRB in order that currently equipped search aircraft and vessels may home on this frequency during the final search phase of a search and rescue mission. The characteristics of the new EPIRB are chosen to make its use compatible with future satellite monitoring from geostationary altitude as well as from low altitude polar orbiting satellites. The characteristics of the 406 MHz EPIRBs are given in Table VI.

TABLE VI — *406 MHz experimental EPIRB characteristics*

Parameter	Value
RF Signal:	
Frequency	406.025 ± .001 MHz
Stability	1 part in 10^9 in 100 ms 3-5 Hz in 15 min 2 kHz in 5 years
Power Output	5 W + 1 dB; − 2 dB into 50 ohms
Spurious	50 dB below 5 W in 5 MHz Carrier harmonics 30 dB below 5 W
Data Encoding	Bi-Phase *L*
Modulation	Phase modulation 1.1 ± 0.1 radians peak
Modulation Rise Time	The rise and fall times of the modulation waveforms must be less than 0.25
Digital Message:	
Repetition Rate	50 s ± 5%
Transmission Time	440 ms ± 1%
CW Preamble	160 ms ± 1%
Digital Message	280 ms ± 1%
Bit Rate	400 bit/s ± 5 bit/s
Bit Sync	All "Ones" (Fifteen "ones")
Frame Sync	000101111
Continuous Emission	Not to exceed 45s

Two short message formats are provided for 406 MHz EPIRBs. The standard short message includes a unique identification and an indication of the nature of the emergency, or as an option, this data is alternated with a message giving the time elapsed since the distress occurred. These message formats are shown in Fig. 1.

The optional long message format shown in Fig. 2 allows for additional data transmission which may include, as an example, the last known position derived from on-board navigation system.

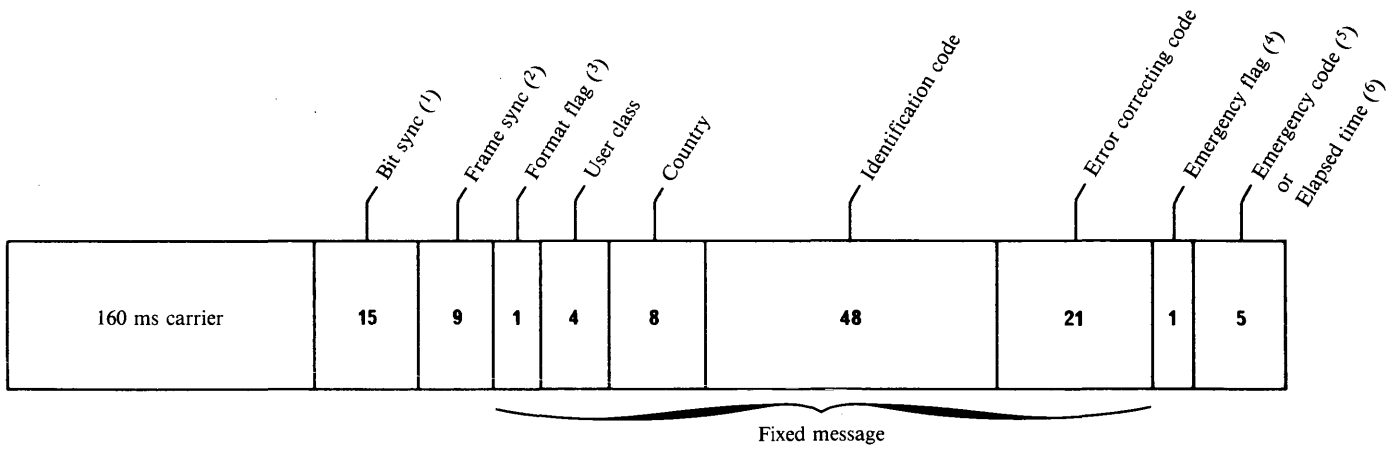


FIGURE 1 – *406 MHz message format (standard short)*

(1) Bit sync – 15 «1» bits
(2) Frame sync – 000101111
(3) «1» bit indicates long message format
«0» bit indicates short message format
(4) «1» bit indicates emergency situation code
«0» bit indicates elapsed time
(5) Last bit of emergency code used for parity
(6) Elapsed time in one hour increments; count held at 32 hrs.
(7) Total message duration: 110 ms

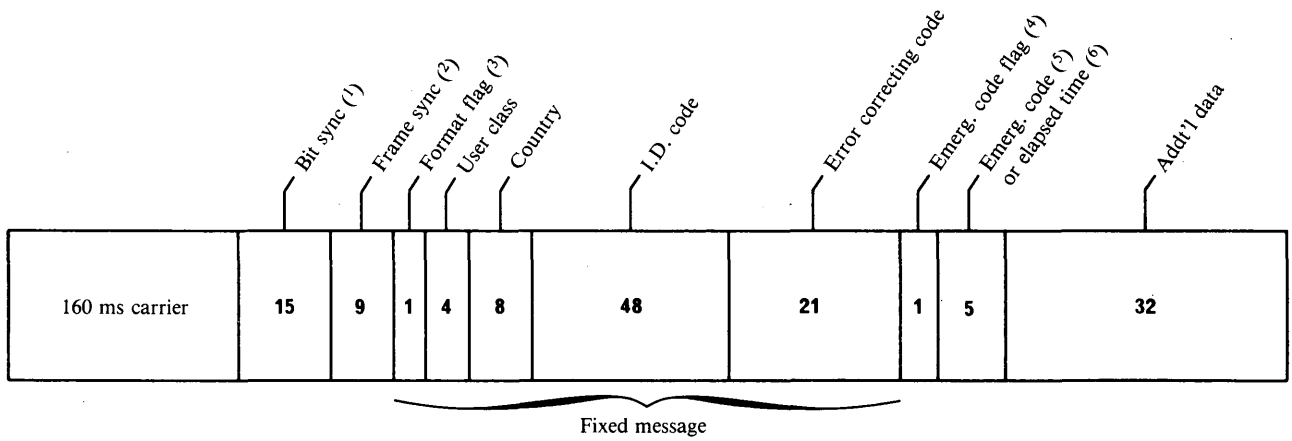


FIGURE 2 – *406 MHz message format (optional long)*

(1) Bit-syno – 15 «1» bits
(2) Frame sync – 000101111
(3) «1» bit indicates long message format
«0» bit indicates short message format
(4) «1» bit indicates emergency situation code
«0» bit indicates elapsed time
(5) Last bit of emergency code used for parity
(6) Elapsed time in one hour increments; count held at 32 hours.
(7) Total message duration: 520 ms

3. System aspects

3.1 *Up-link budget for a future geostationary satellite using the 460 MHz frequency band and the experimental COSPAS/SARSAT EPIRB*

The up-link budget in Table VII shows the feasibility of using the experimental beacons with a geostationary satellite and the derivation of the required antenna gain for such a satellite.

TABLE VII — *Up-link budget*

Parameter	Units	Values
Up-link frequency	MHz	406
Transmitter power	dBW	7.0
Net antenna gain (1)	dBi	−3.0
e.i.r.p.	dBW	4.0
Link margin	dB	6.0
Free space path loss (5° elevation angle)	dB	176.9
Minimum required satellite antenna gain	dBi	G
Satellite noise temperature	K	600
Minimum required G/T	dB(K^{-1})	$G-27.8$
Receive carrier-to-noise density	dBHz	$G+21.9$
Required E_b/N_0 (2)	dB	7.8
Data rate	bit/s	400
Loss due to satellite down-link	dB	1.0
Required signal-to-noise density	dBHz	34.8
Minimum satellite antenna gain over the coverage area	dBi	12.9

(1) This includes line, pointing and polarization losses.
(2) This E_b/N_0 results in 10^{-3} BER. The resulting message reliability for the fixed message, is improved by the error correcting code bits.

The required 12.9 dB minimum spacecraft antenna gain does not require a parabolic dish, but can be realized with a circularly polarized helix having about 14 dBi on axis gain. This antenna would have a half power beamwidth of approximately 33° or roughly twice earth coverage and have physical dimensions of about 0.75 m in diameter and 2 m in length.

3.2 *Satellite down link*

Table VIII shows a representative calculation of the parameters for a satellite down link operating in the 4 GHz band. The resulting degradation in the overall carrier-to-noise density is shown to be less than that allocated in Table VIII.

TABLE VIII — *Down-link budget*

Parameter	Units	Values
Satellite down-link e.i.r.p. per EPIRB carrier	dBW	−15.7
Path loss at 10° elevation angle	dB	−196.7
Earth station receive antenna gain	dBi	50.0
Received carrier power per EPIRB	dBW	−162.4
Earth station receiving system noise power density (220 K)	dB(W/Hz)	−205.2
Down-link C/N_0	dBHz	42.8
Up-link C/N_0	dBHz	34.8
Overall C/N_0	dBHz	34.2
Degradation in Up-link C/N_0	dB	0.6

3.3 *Message integration and alerting time*

The use of multiple messages (e.g. majority logic decoding) may reduce the necessary threshold levels. This in turn may reduce satellite antenna gain or increase signal margins but will increase the time necessary for alerting. The alerting time for the concept presented here also depends on the number of users. The detailed tradeoffs for system capacity and alerting have not yet been undertaken for the geostationary system using the 406 MHz beacons. However, a first estimate may be obtained by considering only message overlap probability with no majority logic decoding.

The probability of mutual interference is given by [Texas Instruments, 1977].

$$P_I = 1 - \left(1 - \frac{2\tau}{T} \cdot \frac{2\Delta f}{F}\right)^{N-1}$$

where,

P_I = the probability of mutual interference

N = the number EPIRB's in the field of view

τ = the duration of a burst transmission in seconds (440 ms)

Δf = the total signal bandwidth in kHz (1.5 kHz for −10dB bandwidth

T = the period between burst transmissions in seconds (50 s)

F = the total search spectrum in which signals may exist in kHz (F = 8 kHz)

The quantity F is the band of frequencies over which the EPIRB center frequencies are distributed. The value for F is estimated from the total search bandwidth of the onboard processor in SARSAT which is 24 kHz (SARSAT, 1979] reduced by the total Doppler excursion (± 8 kHz) which only exists for the low altitude satellite system.

Substituting,

$$P_I = 1 - (0.9934)^{N-1} = 0.4809$$

The probability of no interference on the first burst is P where $P_s = 1 - P$ and on subsequent bursts the probability of at least one burst in j tries without interference is given by:

$$P_{sj} = 1 - P_I^j = 1 - \binom{j}{0} p_s^0 (1 - P_s)^{j-0}$$

The parameter j is related to the maximum delay in alerting, T_a, by $T_a = (j\text{-}1)\mathrm{T}$

For N = 100 platforms j = 1 and T = 0 s

P_{sj} = 0.52

For j = 7, T_a = 300 s

P_{sj} = 0.99

Using this preliminary analysis it is possible for the geostationary system to provide alerting within 6 min when 100 EPIRBs are within the coverage area. It is necessary to further refine this analysis to carefully consider and include the effects of the actual dispersion of frequencies and the likelihood of detecting and correctly decoding the transmitted messages.

3.4 *Message reliability*

The experimental 406 MHz EPIRB message contains a BCH error correcting code capable of correcting 3 bit errors in the fixed portion of the EPIRB message (82 bits). Using this code, the probability of a message error in the fixed (see Fig. 1) portion of the message is the probability of the occurrence of four or more errors. Assuming that the errors are independent, the probability of a resulting message error is:

$$p_{mf} = \sum_{i=4}^{82} \binom{82}{i} P_e^i (1 - P_e)^{82-i}$$

where P_e is the probability of a bit error.

For the varying portion of the short message (6 bits) the probability of a message error is not improved by the code and is given by:

$$P_{mv} = 1 - (1 - P_e)^6$$

For the optional long message (32 additional bits) the probability of a message error is given by:

$$P_{ml} = 1 - (1 - P_e)^{32}$$

Table IX gives results for two different bit error probabilities.

TABLE IX

P_e	P_{mf}	P_{mv}	P_{ml} (optional long)
10^{-2}	8.0×10^{-3}	5.9×10^{-2}	0.28
10^{-3}	1.8×10^{-5}	6.0×10^{-3}	3.2×10^{-2}

Thus for a 10^{-3} bit error probability, the message error is reasonably small in all cases ensuring correct reception within a few message repetition intervals.

4. Geostationary experimental configuration

The National Oceanic and Atmospheric Administration (NOAA) GOES data collection satellites operating in the 401.7 to 402.1 MHz band provide an opportunity to verify the performance levels predicted for geostationary satellites and to demonstrate performance of the experimental 406 MHz COSPAS/SARSAT type EPIRB with a geostationary satellite. Table X suggests that an experiment with this satellite is feasible for the COSPAS/SARSAT experimental EPIRBs retuned to operate in the GOES satellite frequency band.

TABLE X — *Experimental link with GOES*

Parameter	Units	Values
Frequency of Operation	MHz	401
EPIRB Power	dBW	7
EPIRB Antenna Gain (1)	dBi	0
EPIRB e.i.r.p.	dBW	7
Path Loss at 5°	dB	−176.8
Multipath Loss	dB	3.0
Polarization Loss	dB	1.0
Satellite G/T (1)	dB(K^{-1})	−21.0
Received C/N	dBHz	33.8
Bit Rate	bit/s	400
E_b/N_0	dB	7.8
Modulation Index	radians	1.1
Resulting Bit error-rate		1×10^{-3}

(1) Minimum over the coverage area.

The result of this link calculation indicates that an expriment with GOES appears feasible and will provide useful data for the design of a future geostationary satellite operating at 406 MHz. Further study of an experiment design and implementation will be performed. Preliminary planning suggests that EPIRBs modified to operate in the 401 MHz band can be deployed during the COSPAS/SARSAT Demonstration and Evaluation Phase.

5. Conclusions

The advantages of the low altitude and geostationary satellite systems for distress alerting and location are complementary. The COSPAS/SARSAT experimental EPIRB operating at 406 MHz is capable of working with both types of satellite systems. An experiment demostrating this compatibility is being planned with GOES.

REFERENCES

SARSAT [October, 1979] Performance specification of the SARSAT SAR Processor (SARP). SARSAT Document No. D-3.

TEXAS INSTRUMENTS [May, 1977] Final Report for a study of satellite emergency locator systems. Texas Instruments, NASA Contract, NAS5-23676.

REPORT 919

PERFORMANCE OF LOW ALTITUDE, POLAR ORBITING SATELLITE EPIRB SYSTEMS

(Study Programme 17B/8)

(1982)

1. Introduction

This Report presents data on the expected performance of low altitude, polar orbiting satellite EPIRB systems operating in the 406 MHz band as extrapolated from about 5 years of testing and operating experience with satellite-based data collection systems operation in the 402 MHz band.

As an indicator of performance expected on the SARSAT Program, this Report summarizes the results of testing and experimental operations of the Nimbus-6 Random Access Measurement System (RAMS) and the Tiros-N ARGOS System launched in 1975 and 1978, respectively. Since then location and data collection operations have been carried out daily over the entire globe. The ability to locate reliably to within ± 5 km while maintaining a bit error ratio better than 10^{-4} has been firmly established and is now providing operational services.

2. Systems descriptions

2.1 *Nimbus-6 Random Access Measurement System (RAMS)*

The use of random access schemes in combination with Doppler tracking techniques emerged after earlier development of ordered or interrogated multiple access techniques proved too costly for user platform equipment.

This technique was developed and tested on the Nimbus-6 satellite, was incorporated into the operational ARGOS system developed in France, and will be used on the SARSAT Program.

In 1975, the RAMS was launched aboard the Nimbus-6 satellite as part of the Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE). The RAMS system provides a means of tracking and collecting data from instrumented balloon platforms. In operation, the RAMS system performs satellite onboard processing of up to eight platform transmissions simultaneously, following signal search and detection. Received data is stored aboard the satellite for readout every 108 min (orbital period). Platform locational coordinates and/or velocity components are determined in a central ground data processing facility. The system accuracy design goals were: ± 5 km position location, ± 1 m/s velocity; the system capacity can accommodate up to 1000 platforms per orbit.

As depicted in Fig. 1, essential elements of the experiment configuration are:

- meteorological balloons (platforms) carrying transmitting and sensory electronics;
- the Nimbus-6 satellite carrying the RAMS equipment;
- a ground acquisition facility located at Fairbanks, Alaska;
- a ground data processing facility located at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

The balloon platforms transmit meteorological data once every minute for a duration of 1 s. The 1 s transmission period consists of 320 ms of unmodulated carrier followed by 100 bit/s data rate. Of the 64 bits of data transmitted, 32 bits consist of sensor data, 12 bits consist of platform identification and subcommutation level identification, 12 bits are used for word synchronization, and 8 bits are used for bit synchronization.

Spacecraft processing of the received platform transmissions consists of signal search and acquisition followed by measurement of received frequency, time tagging of frequency measurement, demodulation of sensory data, and formatting and storage of the processed data onto an onboard tape recorder.

The satellite orbit provides an average of 10 passes a day over the ground station in Alaska. During the pass over, the contents of the tape recorder are read out and transmitted to GSFC over ground-based data lines. At GSFC, balloon positions and velocity parameters are derived from the relative motion between the satellite and the platforms as determined by the frequency/time measurements made by RAMS. The parameters are computed on the basis of signals received on any two of three successive orbital passes from each balloon. In addition, the recovered sensory data is formatted. The resulting information is disseminated for the TWERLE scientific investigators at the National Center for Atmospheric Research (NCAR) and the University of Wisconsin.

The system approach together with specifications and performance parameters were devised for TWERLE through studies and analytical modelling of system variables; results are summarized in Table I. Further details on system design and operations are contained in [Cote, *et al.*, 1973; Coates, 1975].

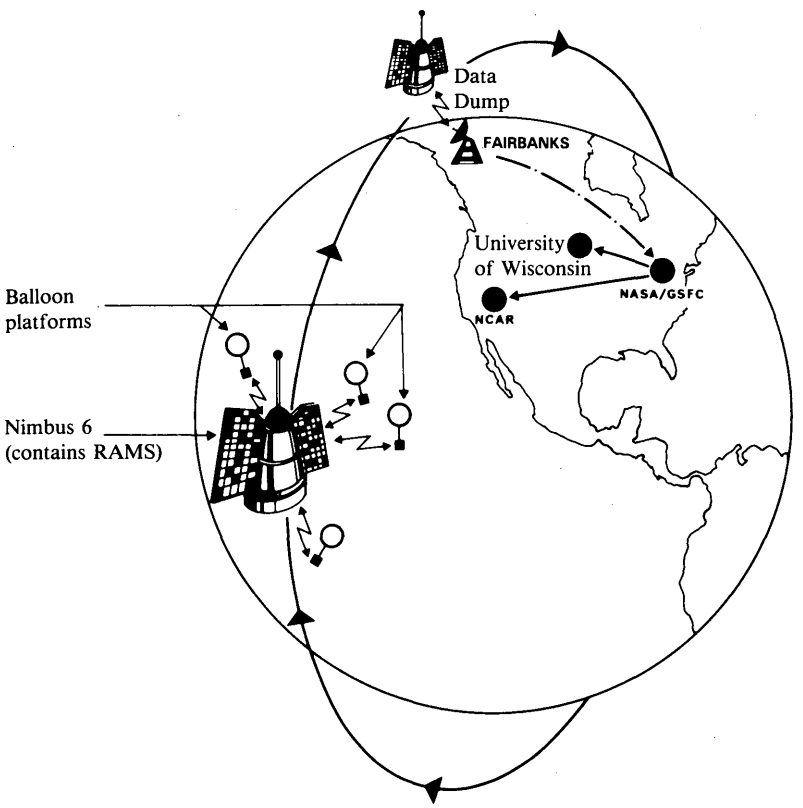


FIGURE 1 – *TWERLE configuration*

TABLE I — *TWERLE/RAMS overall performance goals*

Position location accuracy	±5 km
Velocity determination accuracy	±1 m/s
Frequency measurement accuracy	±1 Hz
Time tag accuracy	±0.1 s
Maximum number of ballons simultaneously in view	200
Maximum number of balloons	1 000
Probability of detection	0.95
False alarm rate	5×10^{-4}
Probability of mutual interference	0.2
Predetection bandwidth	30 kHz
Nominal transmitting frequency	401.2 MHz ± 5 kHz
Balloon transmitter power	600 mW

2.2 *ARGOS*

The ARGOS data collection and location system offers capabilities similar to Nimbus-6/RAMS for the location of fixed and mobile platforms and for the collection of data generated by platform sensors.

ARGOS is a cooperative project between the Centre national d'etudes spatiales (CNES), the U.S. National Aeronautics and Space Administration (NASA), and the U.S. National Oceanic and Atmospheric Administration (NOAA). The ARGOS system as shown in Fig. 2, is comprised of a network of user platforms, the satellite onboard instrument (Tiros-N), ground processing centres and a data distribution system. In concept, ARGOS and RAMS are identical; variations exist in transmit bit rate and the frequency and time measurement accuracies. Further details are contained in Report 538.

3. RAMS engineering evaluation

Following pre- and post-launch testing, in-flight evaluation of the RAMS system was carried out in May 1976, following one year of orbital operation. The objective was to verify long-term stability of critical system parameters. Eight ground transmitters were used to simulate a field of 200 remote platforms. The transmitters (hereafter, referred to as simulators) were varied in time, power and frequency to determine mutual interference and random access performance over the dynamic range of the system.

To satisfy a total system probability of mutual interference of 0.2 or less, RAMS must receive time overlapping transmissions of equal power separated by 500 Hz without suffering interference from adjacent signals. The inability to detect and acquire lock on either of a pair under these conditions constituted a theoretical loss of both signals in the system calculation of 0.2. During tests, signal pairs were transmitted throughout 2 orbits at minimum signal power (−128 dBm received at satellite). The total probability of success was approximately 95% on each orbit. A second test was conducted using signal pairs differing in amplitude by 9 dB (dynamic range) with frequency separations of 800 Hz. The total probability of success each orbit was 90%. These results agreed identically with labortory tests prior to launch.

Random access testing consisted of programming the 8 simulators to transmit at intervals of time and frequency producing the pattern shown in Fig. 3. The overall probability of success was 93.6% as shown in Annex I. The majority of misses occurred during the initial 3.6 min of the 17.5 min satellite field of view time. During the final 13.2 min the success rate was 98%. This also correlated with previous laboratory tests where detection probabilities decreased in the upper region of the band. This is caused by increased effects of quantization errors in the digital signal processor. With a 98% probability for 13.9 min, the system was proven capable of receiving up to eight randomly timed transmissions with 500 Hz separation. During this test approximately 100 transmissions per minute were present; for a 2 s interval 3.3 simultaneous signals simulated 200 platforms in view. All performance parameters measured during testing were found to be within specification. These tests demonstrated acceptable performance under simulated worst case conditions with eight randomly timed transmissions with frequency of 500 to 800 Hz over the full dynamic range. The RAMS system has been in continuous operation since launch in 1975.

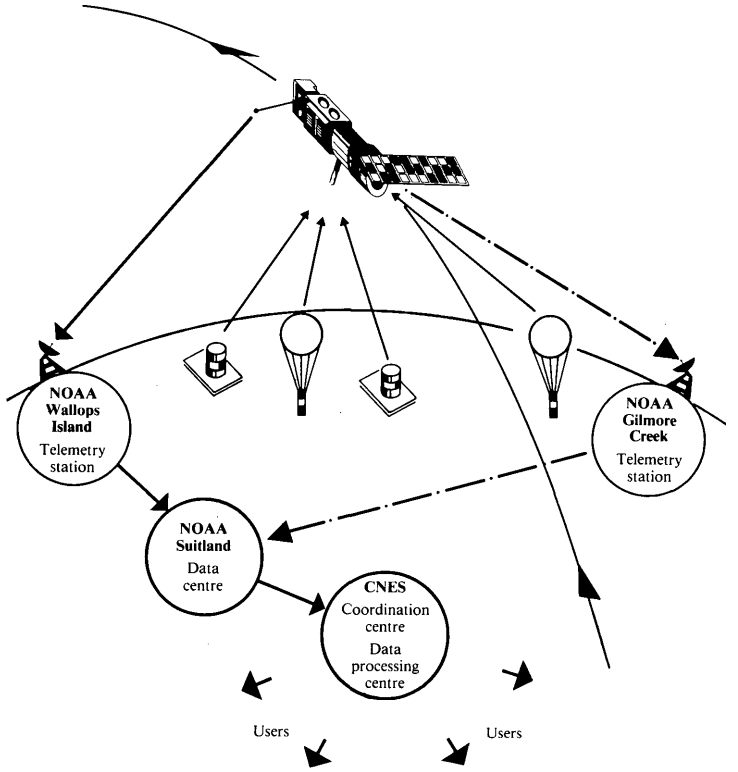


FIGURE 2 – *ARGOS system*

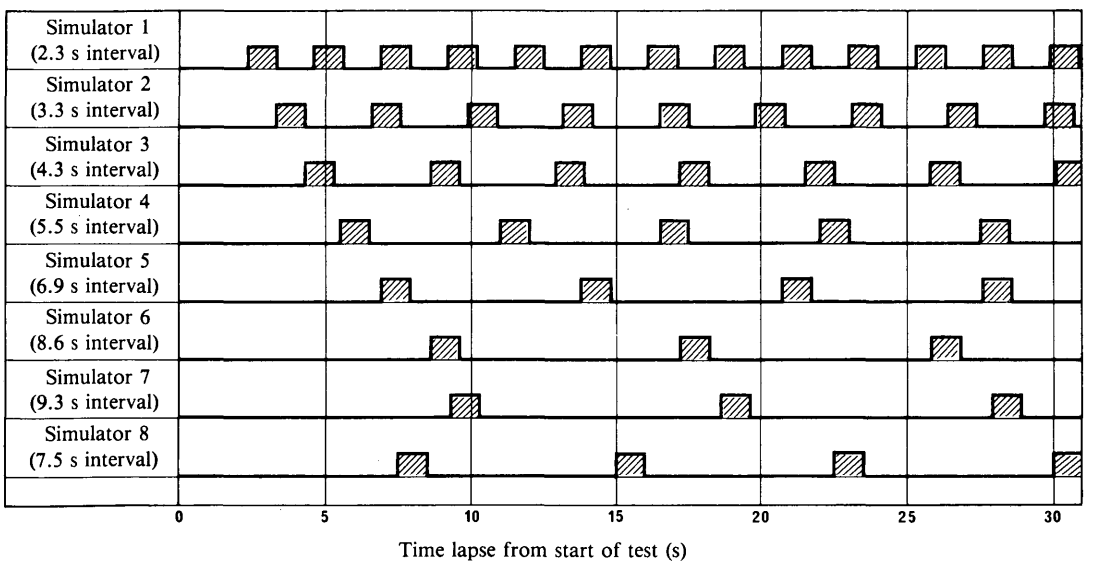


FIGURE 3 – *Time order configuration random access test*

4. Experimental operations

4.1 *Nimbus-6 RAMS*

During the period from January 7 to June 12, 1976, 45 experiments were in planning or underway; Table II is a listing of participating organizations. This time span covered 2100 orbits during which time locations and data collection operations were carried out daily. The global distribution of user platforms is shown in Fig. 4. From this field, the system averaged approximately 1 message reception every 9 s during 5800 h of operating time. A total of 1 471 220 platform transmissions were received and processed; this rate of activity existed for approximately 3 years. As a measure of design sensitivity and balance, records were compiled from spacecraft telemetry to indicate levels of activity within the eight phase lock loops. The results were:

Loop 1 184 817 transmissions received
Loop 2 182 171 transmissions received
Loop 3 183 796 transmissions received
Loop 4 185 667 transmissions received
Loop 5 182 237 transmissions received
Loop 6 184 614 transmissions received
Loop 7 183 745 transmissions received
Loop 8 184 173 transmissions received

A sample of location computations, from randomly selected orbits, for a reference platform situated in Alaska is shown in Table III. Accuracies were held well within the system specification of ± 5 km. The low elevation angles and corresponding long slant range achieved confirmed proper performance of the communications link which was designed for threshold at 5°. The ground data processing functions used for location computation and data distribution are shown in Fig. 5. In subsequent years the system continued to serve experimenters around the world. An example of highlights for the year 1977 are summarized in Annex II.

4.2 *ARGOS*

ARGOS is currently providing reliable location and data collection services on an operational basis to over 100 organizations thoughout the world. In general, location accuracies fall within 1 to 3 km – well within specified tolerances. The capability to transmit up to 256 bits of sensor data per transmission (32 bits-Nimbus) provides an additional degree of flexibility to many operations.

A typical example of ARGOS performance occurred during the First GARP Global Experiment (FGGE) in February 1979. In support of FGGE constant level balloons and drifting buoys were used to support data gathering periods where multiple systems were used to gather qualitative data to improve weather forecasting models. In Fig. 6 the 149 buoy array supplied by participating organizations is shown. The data collected from the array was transmitted to investigators via the GTS (Global Telecommunications System). Based on comparisons with reference platforms, the accuracies were estimated in the 1-3 km range, with a standard deviation less than 1 km. On the basis of this and similar successes, ARGOS has now served approximately 155 user organizations and has located and/or collected data from approximately 1700 platforms. User interest and participation appears to be increasing on a monthly basis.

For the period from January 1979 to January 1980, ARGOS provided the following services to U.S. user organizations:

Total number of platform days	37 400
Total number of platform days with location	34 800

TABLE II — *TWERLE users*

No.		Country	Type	Total	Active	Inactive
2	NCAR	U.S.	Balloons	356	76	260
6	AIDJEX	U.S.	Buoys	34	24	10
7	Atlantic Oceanographic & Meteorological Labs/National Oceanic & Atmospheric Administration	U.S.	Buoys	45	12	33
8	NCAR	U.S.	Carrier Balloons	21	0	21
9	Norske Meteorologiske Inst.	Norway	Buoys	2	2	0
10	Woods Hole Oceanographic Inst.	U.S.	Buoys	4	3	1
11	Columbia University	U.S.	Buoys	24	4	20
12	Scripps Inst.	U.S.	Buoys	16	0	16
13	Naval Ocean	U.S.	Buoys	2	0	2
15	Fish and Wildlife Service, Alaska	U.S.	Animal	2	0	2
16	Polar Research Lab., Inc.	U.S.	Buoys	5	3	2
17	Brazil	Brazil	Buoys	2	0	2
18	Commonwealth Scientific & Industrial Research Org.	Australia	Buoys	14	9	5
19	Commonwealth Scientific & Industrial Research Org.	Australia	Buoys	4	0	4
20	Centre National pour l'Exploitation des Oceans	France	Buoys	6	2	4
21	Norsk Polar Inst.	Norway	Buoys	7	6	1
22	Council for Scientific & Industrial Research	S. Africa	Buoys	10	3	7
23	Dept. of Meteorology	U.S.	Buoys	7	5	2
27	Texas A. & M. University	U.S.	Buoys	25	7	8
28	Australia	Australia	Buoys	6	5	1
29	France	France	Balloons	47	0	47
30	Marine Science	Canada	Buoys	35	1	34
31	France	France	Buoys	5	3	2
32	United Kingdom	U.K.	Buoys	6	1	5
33	NOAA-Data Buoy	U.K.	Buoys	24	11	13
34	United States	U.S.	Buoys	6	0	6
35	University of California	U.S.	Buoys	1	0	1
36	Canada	Canada	Buoys	4	2	2
38	University of Wisconsin	U.S.	Buoys	10	3	7
39	USCG Oceanographic Unit	U.S.	Buoys	1	0	1
40	Innovative Ventures LTD.	Canada	Buoys	2	0	2
45	Koah Pacific Marine Env. Lab.	U.S.	Buoys	3	1	2

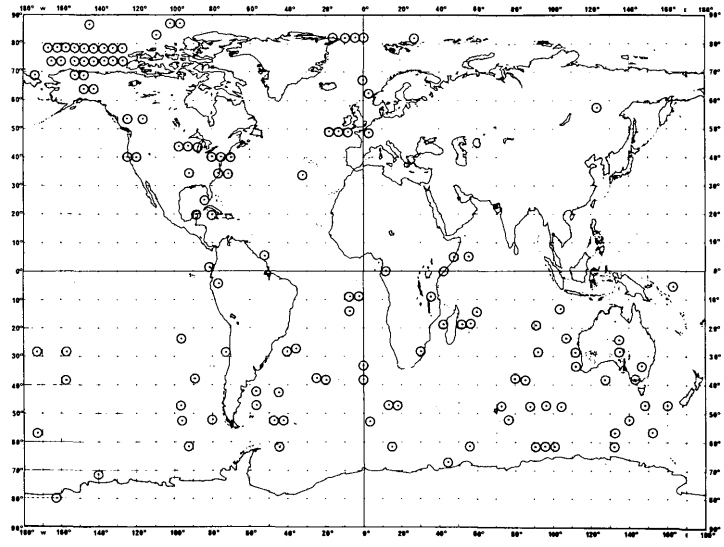


FIGURE 4 – *Global distribution of TWERLE platforms*

TABLE III — *Alaska reference platform responses*

Error Lat. (km)	Error Long. (km)	1st pass response	2nd pass response	Orbit	Elevation angle (degrees)	Max. range (km)
−0.47	−0.11	10	11	3114	3	3544
0.96	0.70	13	0	3191	5	3391
−0.04	0.39	10	0	3263	5	3325
−0.69	1.71	11	0	3290	4	3497
0.13	0.33	9	11	3355	2	3629
0.70	0.07	9	8	3408	4	3501
−1.67	0.62	15	13	3452	2	3708
1.73	0.79	6	9	3527	4	2877
1.04	0.94	12	9	3572	3	3593
−1.04	0.29	7	15	3667	4	3521
0	0.22	15	12	3720	3	3613
−0.61	−1.64	7	8	3770	6	3251
1.03	−0.99	9	10	3848	6	3251
0.37	1.37	9	10	3904	3	3604
0.79	1.62	11	0	3959	3	3542
0.85	1.38	9	6	4010	8	3088
−1.14	−0.21	15	9	4082	2	3646
0.76	−0.43	9	11	4146	2	3627
1.11	−0.11	9	12	4172	4	3517
−0.44	0.41	8	15	4248	6	3254
−0.26	−1.31	10	10	4307	6	3315
−0.64	−0.28	9	8	4371	1	3739
−0.26	0.18	9	14	4416	7	3172
1.28	−0.73	11	11	4481	5	3396
−0.89	0.19	15	0	4570	5	3351
1.92	1.20	9	4	4639	11	2844
−1.48	−0.70	6	0	4737	10	2971
0.18	1.69	11	13	4790	7	3114
−0.01	−0.67	15	12	4853	1	3300

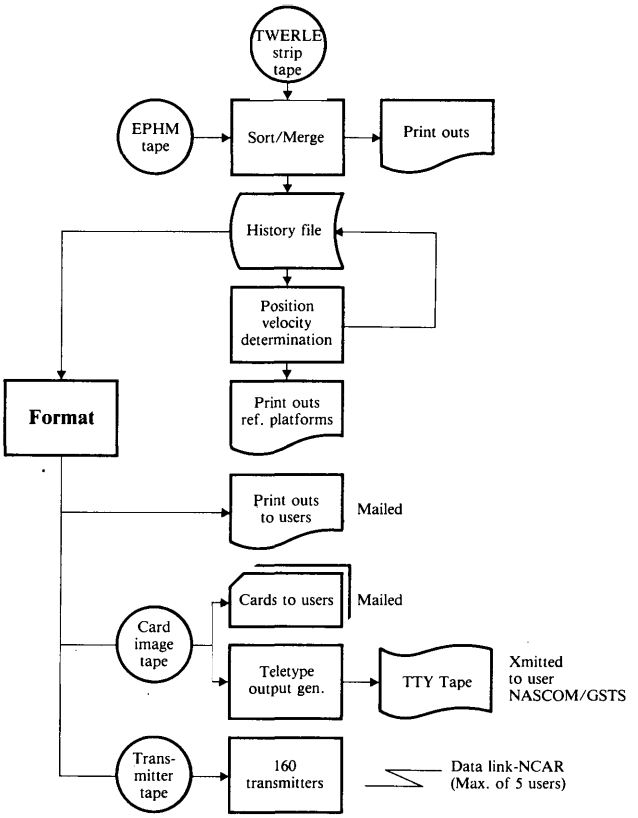


FIGURE 5 – *TWERLE processing and outputs*

(EPHM tape: a tape containing ephemeris data)

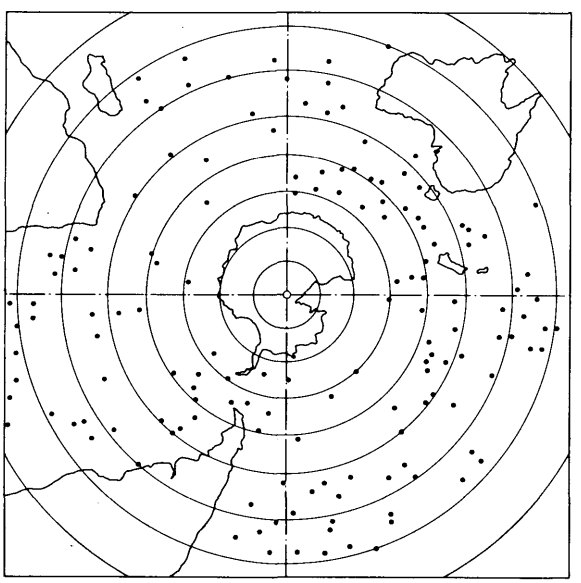


FIGURE 6 – *Buoy array as at 9 February, 1979 based on GTS Report*

5. Conclusions

The development and application of location and data collection systems have made significant improvements to the global acquisition of quantitative and qualitative data related to the Earth and its environs. Conceptually, these systems are analogous to the SARSAT System and can be expected to peform in a similar fashion. The similarity between data collection and the SARSAT distress alerting and location system using low altitude, polar orbiting satellites operating in the 406 MHz band is no coincidence – the SARSAT system is a direct spin off of this developed technology.

REFERENCES

COATES, J. L. [January, 1975] The NIMBUS F random access measurement system (RAMS). *IEEE Trans. Geosci. Electron.*, Vol. GE-13, **1**, 18-27.

COTE, C. E., DUBOSE, J., and COATES, J. L. [March 1973] The NIMBUS F random access measurement system. Fifth Annual Southeastern Symposium on System Theory.

ANNEX I

SUMMARY RANDOM ACCESS TEST ORBIT No. 1

Total number of received transmissions :	1749
Total number of successfully received transmissions :	1637
Probability of success :	93.6%
Duration of message receptions :	17 min 31 s
Average number of received transmissions/second :	1.66
Simulated number of platforms in satellite field-of-view :	100

TABLE IV – *Time-overlapping reception analysis*

Number of overlapping transmissions	Percentage of missed transmissions (%)
1	6.25
2	13.40
3	31.25
4	25.00
5	8.93
6	15.18
7	0
8	0

ANNEX II

NIMBUS-6 HIGHLIGHTS

- 150 Drifting buoys reporting;
- oil spill trajectory models;
- iceberg tracking:
  - 335 days, 2300 nautical miles,
  - 414 days, 2000 nautical miles.
- Polar bear tracking;
- 1-year successful operation of meteorological buoy relaying pressure and temperature;
- France, Canada, Norway contributing drifting buoys to FGGE;
- tracked oil spill from the ship ≪Argo Merchant≫;
- Norway planning use of buoy data for aid in forecasting.

REPORT 762-1

EFFECTS OF MULTIPATH ON DIGITAL TRANSMISSION OVER LINKS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The effects of multipath propagation on digital transmission have been theoretically analyzed and experimentally evaluated.

The theoretical analysis performed by Japan results in a prediction of error rate performance for two-phase coherent PSK and two-frequency non-coherent FSK modulations.

The theoretical analysis carried out by the United States gives the error rate for differentially-encoded PSK modulation; the results of United States experiments with the ATS-6 satellite determine the range of multipath values used in the theoretical model. The calculated error rate is compared with measurements made using a laboratory channel simulator.

The tests performed in 1975 by France with the ATS-6 satellite have made it possible to obtain curves representing the bit error ratio for two-phase PSK digital transmission for different satellite elevation angles.

In tests performed in 1979 by the Federal Republic of Germany with the aid of the Marisat tracking beacon, the amplitude and phase response of the satellite-to-ship multipath signal was recorded on-board ship for various receiving antennas and elevation angles. The recordings were used to control a laboratory channel simulator (the stored channel principle) to determine the fading margin for various data transmission methods. The amplitude response was statistically evaluated and compared with theoretical models.

2. Theoretical analyses

2.1 *Rice-Nakagami or m-distribution*

2.1.1 *General*

This work assumes that the amplitude distribution of the sea-reflected signal follows the *m*-distribution function and derives the probability distribution for the fading amplitude [Nakagami, 1960]; this distribution is also known as the Rice-Nakagami distribution and is general enough to describe most fading phenomena including Rayleigh fading.

An example of the *m*-distribution using "*m*" as a parameter is shown in Fig. 1. It should be noted that this figure represents one-sided Gaussian fading when $m = ½$ and Rayleigh fading when $m = 1$, where m is the inverse of the normalized variance of the reflected signal amplitude squared.

2.1.2 *Probability of error*

The probability of error, $p(\rho, C/M, m)$, corresponding to the Rice-Nakagami distribution has also been derived [Mizuno *et al.*, 1975] for the cases two-phase coherent PSK and two-frequency non-coherent FSK. In this notation ρ is the energy per bit-to-noise power density ratio (E/N_0) at the demodulator, and C/M is the direct signal-to-multipath signal power ratio.

2.1.3 *Results of calculations*

Figures 2 to 4 illustrate the bit error ratio characteristics calculated using the analytic methods referenced above.

Figure 5 shows the relation between direct signal-to-multipath signal power ratio and the equivalent degradation value of carrier-to-noise power ratio. The equivalent degradation value is the difference in the E/N_0 values required to obtain a bit error ratio of 10^{-5} in the presence of thermal noise, between the case when a sea-reflected signal exists and the case when no reflected signal exists. In other words, it corresponds to the fading margin to be assigned for multipath interference for the particular modulations discussed.

The following can be concluded from Fig. 5:

- When C/M is constant, the degradation due to the multipath effect increases as m decreases.
- When the fading is deep or m is smaller than 1, the equivalent degradation value of E/N_0 for the two-phase coherent PSK is larger than that for the two-frequency non-coherent FSK.
- For a given m, the required margin necessary to achieve a bit error ratio (BER) of 10^{-5}, represented as a degradation of E/N_0 in Fig. 5, increases as C/M decreases. For a C/M of 12 dB and $m = ½$, which corresponds to a Gaussian scatter process for the multipath, an increase in signal of about 11 dB is required to give the same bit error ratio for a two-phase coherent PSK receiver as is obtained in the presence of thermal noise alone. It may also be noted in this case that a small decrease in the direct signal to multipath ratio, C/M, produces a large increase in required margin.

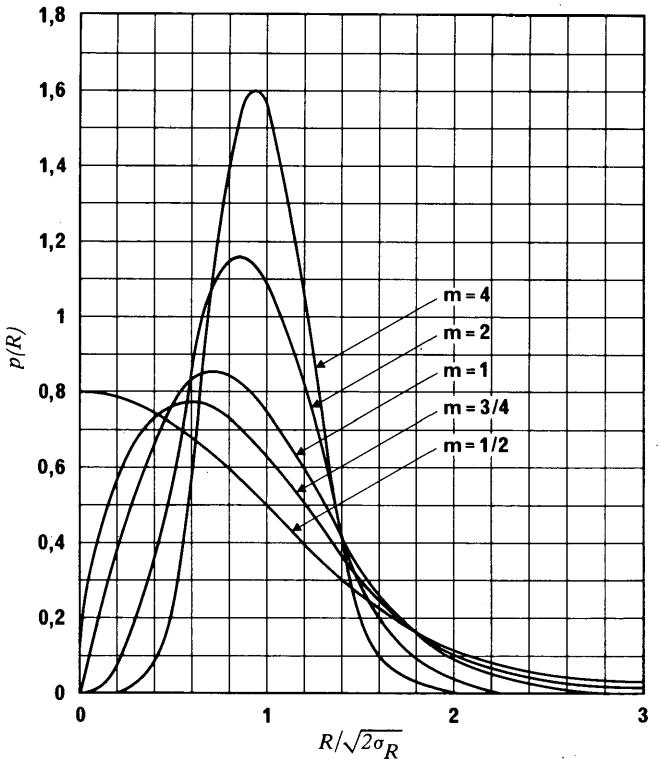


FIGURE 1 — *m-distribution*

R: amplitude of the reflected signal
σ_R: r.m.s. value of the reflected signal

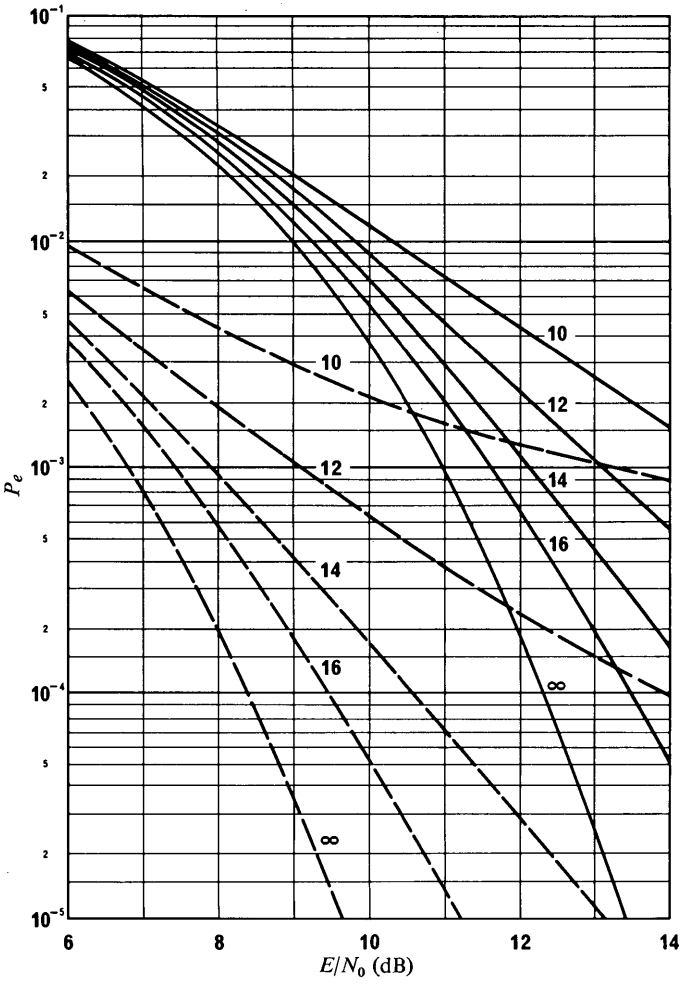


FIGURE 2 — *Error probability for the two-phase coherent PSK and the two-frequency non-coherent FSK (m = ½)*
(Parameter is C/M, in dB)

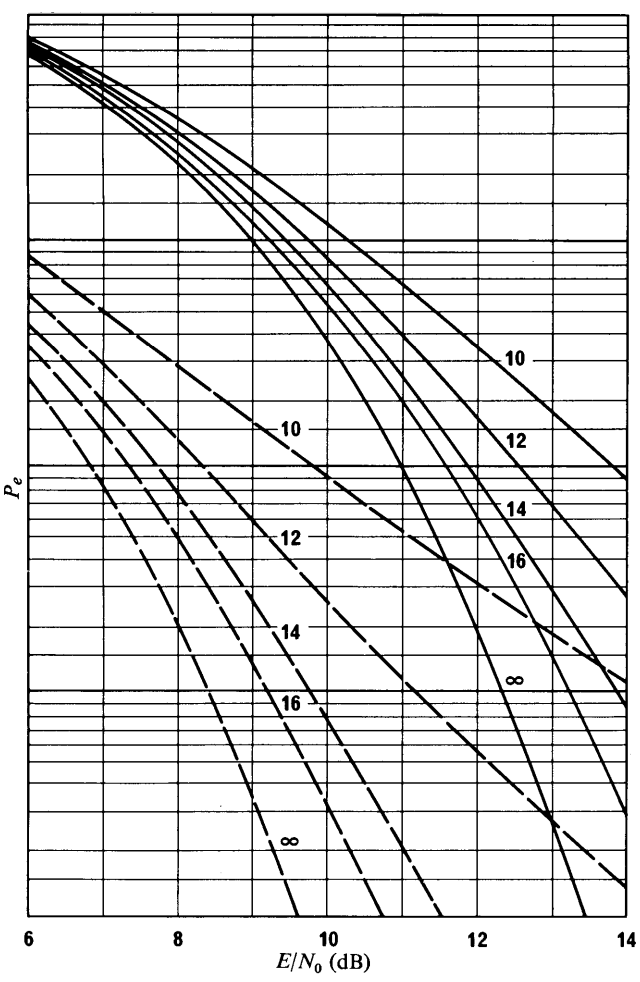


FIGURE 3 — *Error probability for the two-phase coherent PSK and the two-frequency non-coherent FSK (m = 1)*
(Parameter is C/M, in dB)

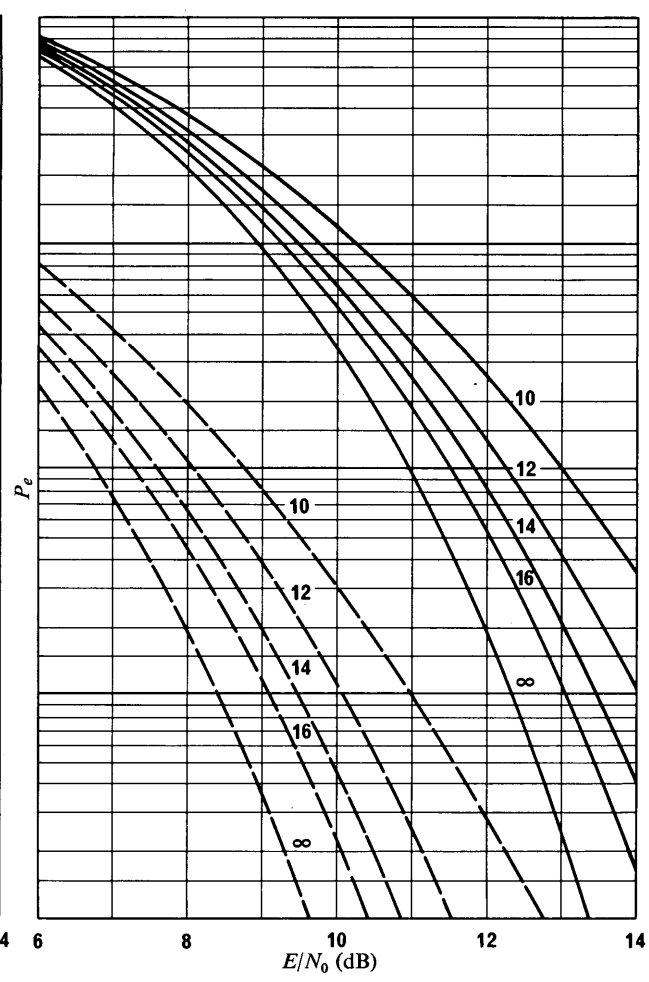


FIGURE 4 — *Error probability for the two-phase coherent PSK and the two-frequency non-coherent FSK (m = 4)*
(Parameter is C/M, in dB)

— — — — 2CPSK
——— 2NFSK

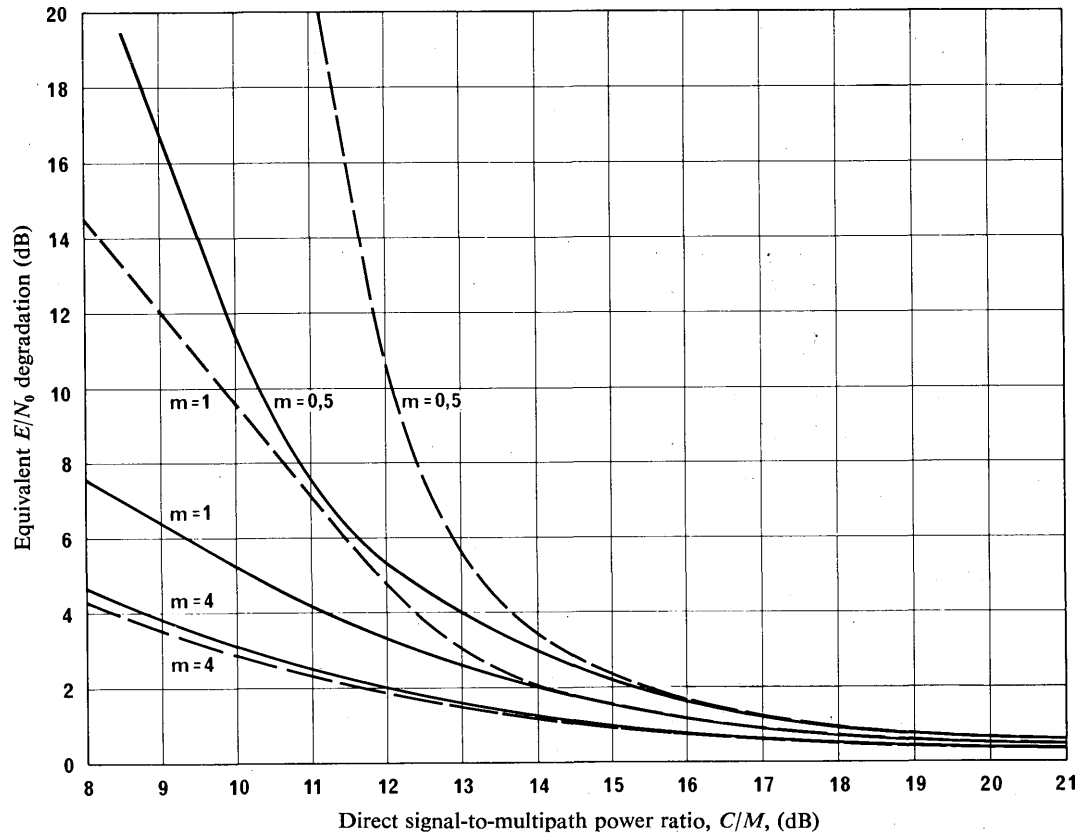


FIGURE 5 — *Equivalent degradation of E/N_0*
(BER = 10^{-5})

— — — 2CPSK

——— 2NFSK

2.2 *Modestino-Mui analysis*

2.2.1 *General*

The maritime satellite channel can be modelled as shown in Fig. 6. This model is based on previous analytical studies [Salwen, 1972].

The channel model of Fig. 6 can accommodate either specular or diffuse multipath reflection conditions. As the multipath becomes more specular in nature, the mean-square multipath power (M) tends to increase while the bandwidths of the in-phase and quadrature components of the complex envelope which characterize the multipath envelope tend to zero.

The data collected during the ATS-6 maritime satellite tests support the conclusion that the reflected multipath is diffuse. In particular, it was found that the multipath energy arrives from a broad region on the ocean's surface rather than from the multipath specular reflection point.

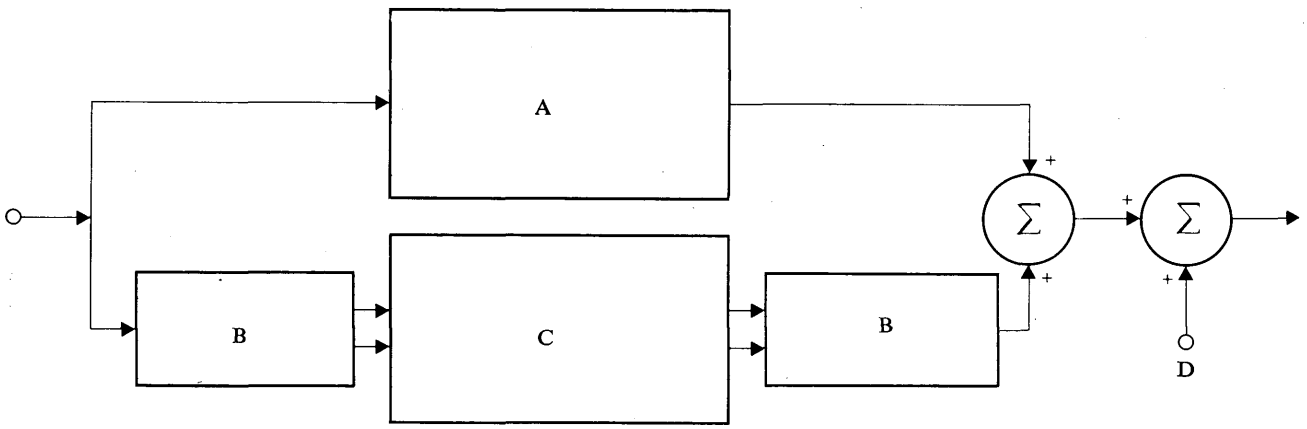


FIGURE 6 — *Channel model representative of a satellite-ship link*

A: direct path (constant complex gain factor)

B: quad hybrid

C: multipath (time varying complex gain factor)

D: $n(t)$ (noise)

2.2.2 *Probability of error*

The probability of bit error for a coherent PSK system in which there is a slowly varying carrier tracking error and a slowly fading amplitude (the fade is slow relative to the bit rate), has been derived [Modestino and Mui, 1976] for the case of two-phase coherent PSK. Their results are extended to the DECPSK case by noting that the probability of bit error for DECPSK is approximately $2P_b$ when $P_b \ll 1$.

2.2.3 *Results of calculations*

Figure 7 shows the expected value of the probability of bit error for DECPSK as a function of C/N_0 and C/M which are obtained by digital computer solution of the theoretically derived expression [Modestino and Mui, 1976]. The curves shown in Fig. 7 assume a 15 dB signal-to-noise ratio in the carrier tracking loop. At that level, carrier tracking errors have very little effect on probability of bit error.

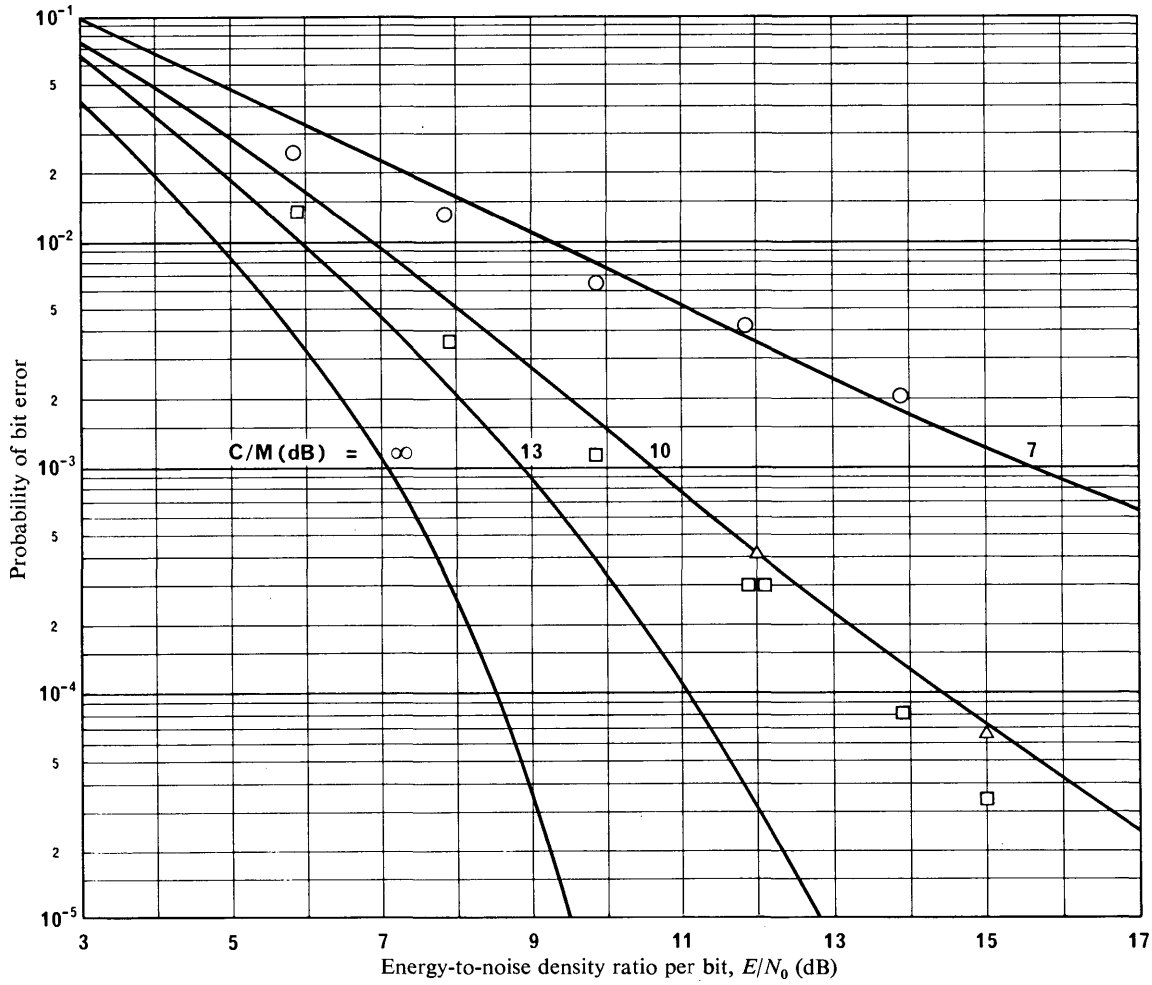


FIGURE 7 — *Performance of DECPSK modem at 1200 bit/s in multipath with simulator*

Notes:

— Solid curves are theoretical results with Doppler spread (fading rate) much less than bit rate.

— Simulator data : ○ C/M = 8 dB

△ C/M = 10 dB

□ C/M = 11 dB

3. Experimental results

3.1 *Tests performed by United States with ATS-6 and with channel simulator*

3.1.1 *Tests performed by United States with ATS-6*

Figure 8 shows the observed multipath power, relative to the power in the direct path signal for data collected during the ATS-6 tests. The relative multipath power is in the range from 5.7 dB to 8.8 dB. These values exclude antenna discrimination effects but do include polarization discrimination effects. The actual C/M ratios observed, including the antenna directivity factor, were typically 10 dB or greater. However, in some cases, C/M ratios as low as 6 dB were measured [Engels *et al.*, 1976].

Table I summarizes the averaged multipath data collected at low elevation angles during the ATS-6 maritime satellite tests. The ship antenna has a 35° beamwidth.

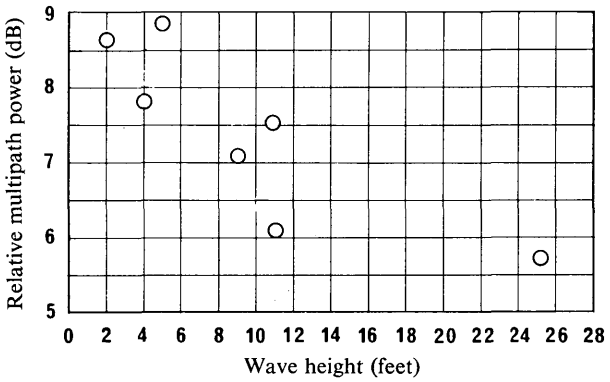


FIGURE 8 — *Dependence of relative multipath power on sea surface wave height*

TABLE I – *ATS-6 Multipath data*

Satellite elevation (°)	Sea condition (peak to through) (m)	Date	C/M (dB)	−20 dB linewidth (Hz)
8.2	2.4-3.0	13 November, 1974	10.02	4.5
8.3	7.5	14 November, 1974	8.65	5.35
8.4	3.0-3.6	15 November, 1974	9.1	4.55
16.9	1.2	19 November, 1974	14.2	5.5
16.9	3.3	20 November, 1974	14.76	3.75
17.0	1.5	21 November, 1974	16.2	4.47
17.0	0.6	31 March 1975	15.65	3.35

3.1.2 *Tests performed by United States with channel simulator*

The analysis outlined in § 2.2 was tested experimentally using a DECPSK modem and a laboratory channel simulator; the results obtained are superimposed on the theoretical results in Fig. 7. [Salwen and Duncombe, 1975; Salwen, 1975]. There is close agreement between theoretical and experimental data. The experimental results of Fig. 7 are for the best modem tested in an extensive laboratory test effort [Salwen and Duncombe, 1975]. The performance of other DECPSK modems tested was substantially worse under simulated multipath conditions.

The margins required to achieve 10^{-4} and 10^{-5} error rates can be derived for a DECPSK modem based on the results shown in Fig. 8. These margins are shown in Table II.

TABLE II – C/N_0 *margins*

C/M (dB)	Margin (dB) for $P_e = 10^{-4}$	Margin (dB) for $P_e = 10^{-5}$
13	2.5	3.2
11	5.3	7.4
10	5.5	9
8	–	30 (estimated)

Under the best conditions, a 5 dB margin would permit 10^{-5} error rate performance when C/M was on the order of 12 dB. However, in most cases a larger margin would be required in order to allow for other performance degradation factors such as:

- antenna pointing error,
- ionospheric losses,
- atmospheric losses,
- modem performance degradation (in presence of multipath).

3.2 *Tests performed by France with the ATS-6 satellite*

3.2.1 *Type of transmission*

A two-phase PSK 19.2 kbit/s digital channel transmitted through the ATS-6 satellite was received on board a ship operating off the Azores. A pseudo-random sequence transmitted on this channel was compared with an undisturbed sequence in order to determine the bit error ratio.

3.2.2 *Ship antenna*

The antenna used was a quadhelix antenna with a maximum gain of about 20 dB and a half power beamwidth of 14°. The height of the antenna above the sea was about 20 m. The antenna was stabilized to about 1°, using a vertical reference and the ship's gyrocompass.

3.2.3 *Sea conditions*

The measurements were carried out under rough sea conditions corresponding to a mean peak-to-peak wave height of about 3 m.

3.2.4 *Results obtained*

Figure 9 shows the bit error ratio curves for two-phase coherent PSK as a function of the E/N_0 expressed in dB, for elevation angles of 5°, 10°, 15° and 20°. It also shows the theoretical curve for the performance in presence of thermal noise only.

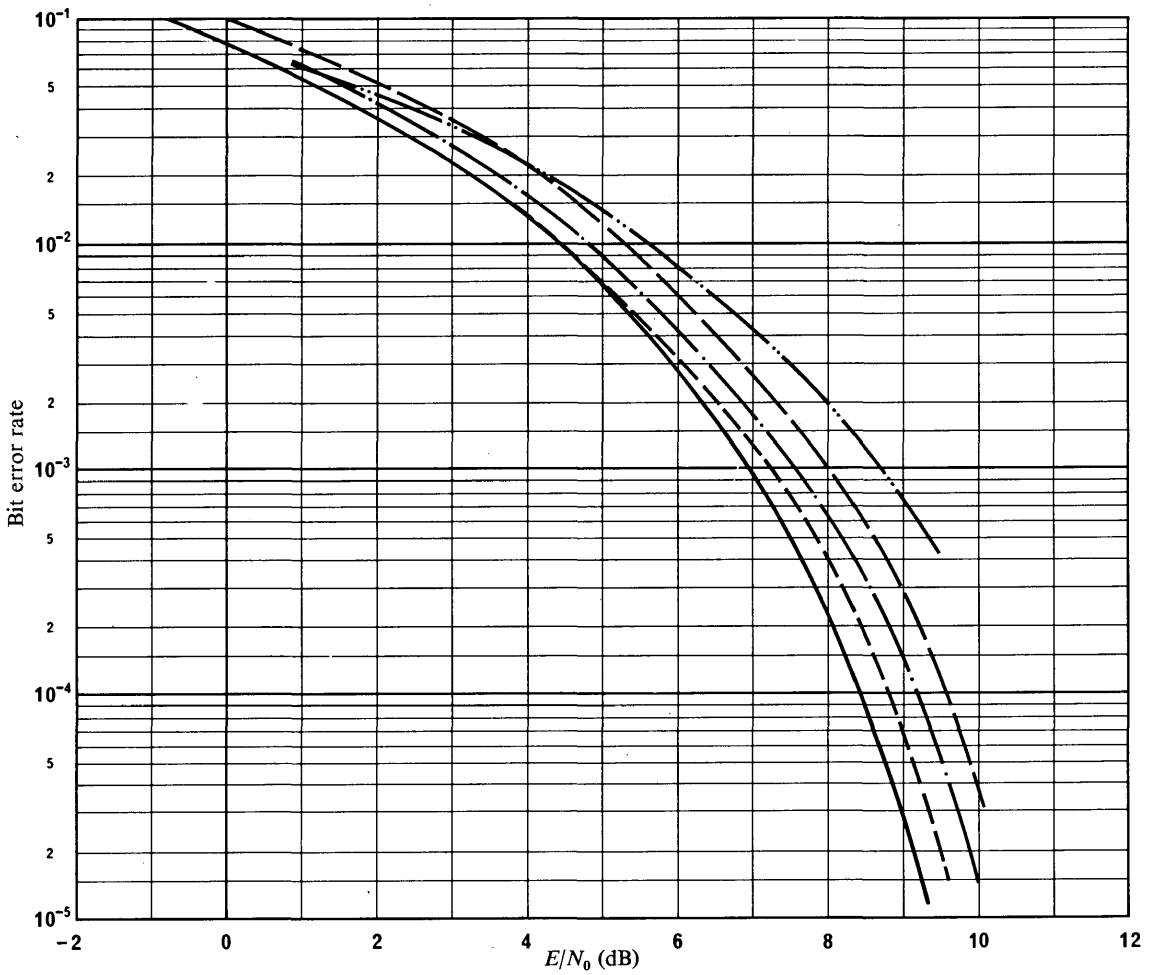


FIGURE 9 — *Effect of the elevation angle on the error / rate*

Test curves
- Theoretical curve
- Elevation angle 5°
- Elevation angle 10°
- Elevation angle 15°
- Elevation angle 20°

3.2.5 *Comparison of experiment and theory*

In order to directly compare the experimental and theoretical results, it is necessary to have a knowledge of m and the direct signal to multipath ratio.

Using the parameters given in the example of 2.1, a theoretical system margin of 11 dB is required, assuming no antenna discrimination. For a satellite elevation of 5°, both the direct and reflected signals will arrive within the main beam of the high gain antenna of the experiment. Extrapolating the 5° curve of Fig. 9, the measured degradation in E/N_0 for a bit error ratio of 10^{-5} is approximately 2.5 dB.

Substantial multipath discrimination in addition to that given by the antenna must have contributed to give this low value. The assumption made above regarding practical values for m and C/M require validation by further experiment.

3.3 *Tests performed by the Federal Republic of Germany with Marisat and with the stored channel method*

3.3.1 *Description of the tests*

Communication to and from ships via geostationary satellites is complicated by both multipath propagation at the sea's surface and antenna tracking requirements. In the case of the relatively large antennas used up to now, very little degradation was caused by fading occurring at elevation angles greater than 5°. Smaller antennas, in view of their broad beamwidth, do not require accurate tracking but lead to greater degradation. Limited information was available on the deterioration of the transmission quality to be expected due to multipath propagation. As it is extremely difficult to reproduce fading under realistic conditions, the stored channel principle was employed. During two field trials which took place in 1979 the signal response of the channel with respect to amplitude and phase was recorded on board ship and evaluated at a laboratory. The channel was modelled as shown in Fig. 10. The correlations between the model's parameters and the various antenna types, sea conditions and elevation angles were also determined at the laboratory. By using the recorded fading to control a channel simulator it is possible to accurately reproduce the signal amplitude and phase response of the fading.

The addition of noise permits a comparison between various modulation and coding methods at a variable signal-to-noise ratio. At the laboratory, the bit error ratios and the required fading margin of various transmission methods were determined for various sea conditions and elevation angles (0°-29°) with four different antennas and tracking mechanisms [Schweikert *et al.*, 1980].

The ship antennas used approximated to the INMARSAT Preparatory Committee standard (see also Report 921).

TABLE III

Ship	Standard	G/T (dB(K^{-1}))	Gain (dB)	Beamwidth (−3 dB)	Size/type	
"Bannock" 1 300 GRT	A	−4	25	9°(±4.5°)	(1.5 m)	reflector with helix switchable
	B	−10	19	16°(±8.1°)	(1.5 m)	
	B	−13	16	25°(±12.5°)	0.6 × 0.6 m	short backfire
	C	−18	11.5	46°(±23°)	0.4 m	short backfire
"Meteor" 2 615 GRT	A	−4	23	10°(±5°)	1.25 m	standard dish with turnstile feed

3.3.2 *Determination of C/M from the amplitude histograms*

It was assumed that the signal received on board ship by multipath propagation is determined by numerous reflection points on the rough sea's surface as well as the additional reception of a direct signal component. In accordance with a simple model as shown in Fig. 10, it is therefore possible to describe the probability distribution of fading amplitude with a Rice-distribution. The distribution density of the momentary normalized power is determined by one variable parameter only, namely the direct signal-to-multipath signal power ratio C/M.

The histogram of the fading amplitude and the normalized power was based on the signals recorded on-board ship. The distribution density was adapted to the histogram in the best possible manner in order to derive C/M. A weighted mean square error was taken as the criterion of adaptation.

Summary of the results [Schweikert *et al.*, 1980]:

- The measured distributions of fading amplitude closely resemble the Rice-distribution.
- Figure 11 shows the correlation between C/M in dB and the elevation for the various antenna types indicated. The wave height in all measurements ranged between 1-3 m.

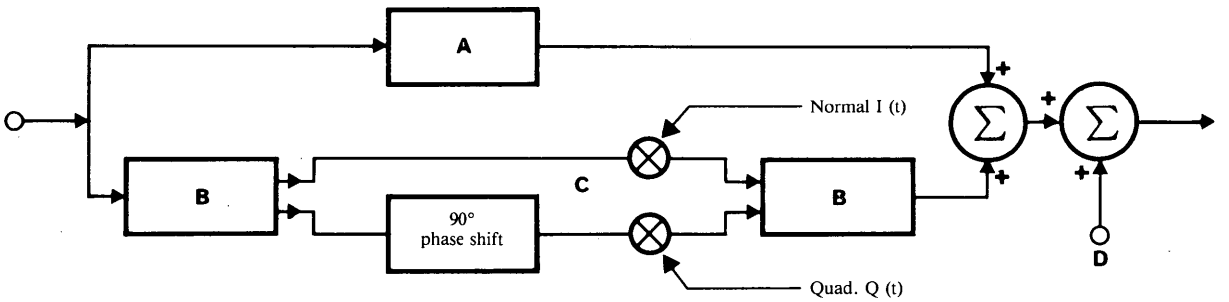


FIGURE 10 – *Channel model representative of a satellite-ship link*

A: direct path (constant complex gain factor)
B: quad hybrid
C: multipath (time varying complex gain factor, normal and quadrature component)
D: $n(t)$ (noise)

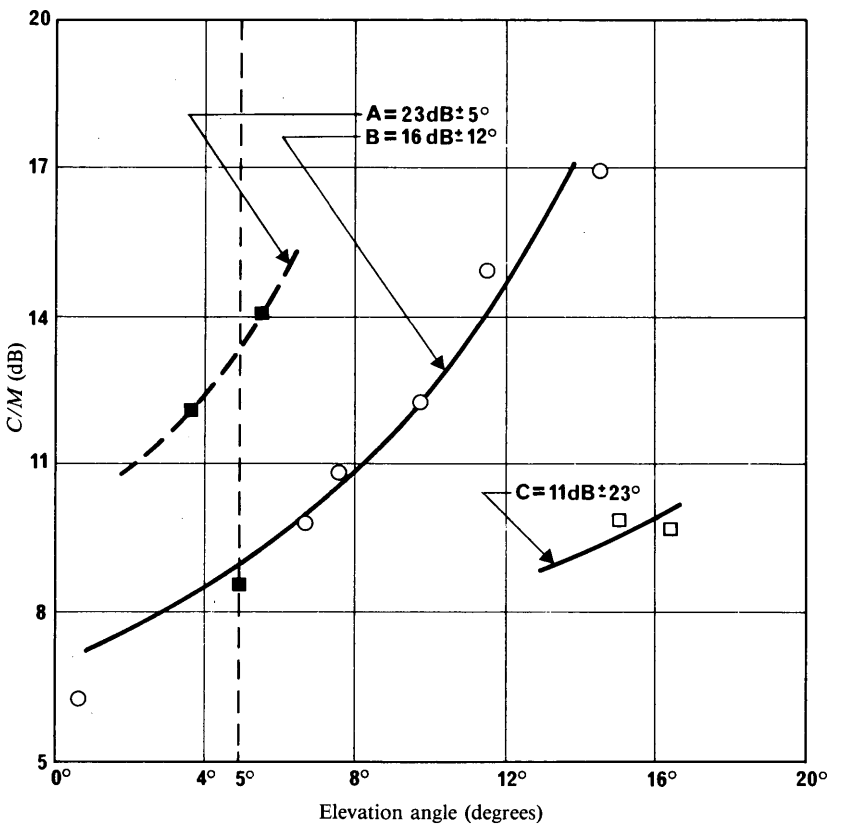


FIGURE 11 – *The direct signal-to-multipath signal power ratio C/M in dB for various antennas and elevation angles*

3.3.3 *Data transmission via the stored channel*

At the laboratory, a complete transmission path was simulated which was used, *inter alia*, for the transmission of a data sequence of 1.2 kbit/s with two-phase PSK. The signal was sent on a 70 MHz IF via a channel simulator controlled by the fading signals recorded on tape. The signal-to-noise ratio was changed by introducing additive noise whilst the fading of the channel remained unchanged due to replaying of the tape. The data sequence was analysed and the mean error rate as well as the error structure (error burst) were determined. In order to prove that the transmission via the stored channel in the laboratory yields the same results as a shore-to-ship transmission, the error structure on both transmission paths was compared. The error structures were found to be very similar, confirming the usability of the stored channel for maritime data transmission, [Schwiekert *et al.*, 1980; Hagenauer and Papke, 1980].

The following aspects of the test results in [Schweikert *et al.*, 1980] are of particular interest:

- The mean bit error probability as a function of E_s/N_0 (mean signal energy per transmitted symbol/one-sided noise density) only gradually decreases at low elevation angles. Fig. 12 shows the values for a standard B antenna at 1.2 kbit/s two-phase PSK transmission via the stored channel.

- It was possible to derive the fading margin for various antennas, elevation angles and bit error ratios from the bit error curves by varying E_s/N_0. Fig. 12 shows the result for 1.2 kbit/s two-phase PSK.

- The additional loss caused by an inaccurately pointed standard B antenna merely amounts to about 1 to 2 dB.

- The fading margin is dependent on sea condition and wave height and may amount to several dB [Schweikert *et al.*, 1980].

- It was possible to compare different modulation methods under identical fading conditions. A transmission over an FM voice channel using a data modem compared with, for example, direct PSK transmission, requires a signal power increase of about 10 dB (standard B antenna, 7° elevation).

- The results of the statistical evaluation both quantitatively and qualitatively closely correspond to those of the data transmission experiments [Schweikert *et al.*, 1980].

- Theoretical calculations have proven [Hagenauer and Papke, 1980] that feasible forward error correction methods (e.g. modified Viterbi-decoding) can after decoding reduce the error rate of the fading channel to that of the channel without fading (Gaussian interference).

The conclusions derived from the tests performed can be summarized as follows:

- The loss caused by multipath propagation is considerably higher in the case of ship terminals equipped with small rather than standard A antennas. The error rate, error structure and amplitude statistics are qualitatively known.

- Small antennas with a broad beamwidth only required approximate pointing by means of simple tracking systems.

- Adapted digital techniques (e.g. coding) can be used to lower the bit error ratio [Hagenauer and Papke, 1980].

4. Conclusions

The effect of the sea-reflected multipath interference on the received bit error ratio characteristics of binary coherent PSK and non-coherent FSK signals was theoretically examined by Japan assuming that the amplitude distribution of sea-reflected signals follows the *m*-distribution. The *m*-distribution can deal with almost all types of fading phenomena caused by specular reflected signals or by Gaussian reflected signals. The methods outlined and the figures shown in § 2.1 are useful in estimating the fading margin, although the value of m and C/M must be determined by experiments.

Theoretical analysis and experimental data obtained by the United States with ATS-6 using a 35° beamwidth shipboard antenna indicate that a margin of 5 dB will make possible a $P_e = 10^{-5}$ when $C/M = 12$ dB under ideal conditions. It is likely that under realistic conditions, a 5 dB margin will allow for $P_e = 10^{-5}$ when C/M is greater than about 14 dB. This multipath level (or less) was typically obtained when the elevation angle to the satellite was equal to one half the antenna beamwidth (or more).

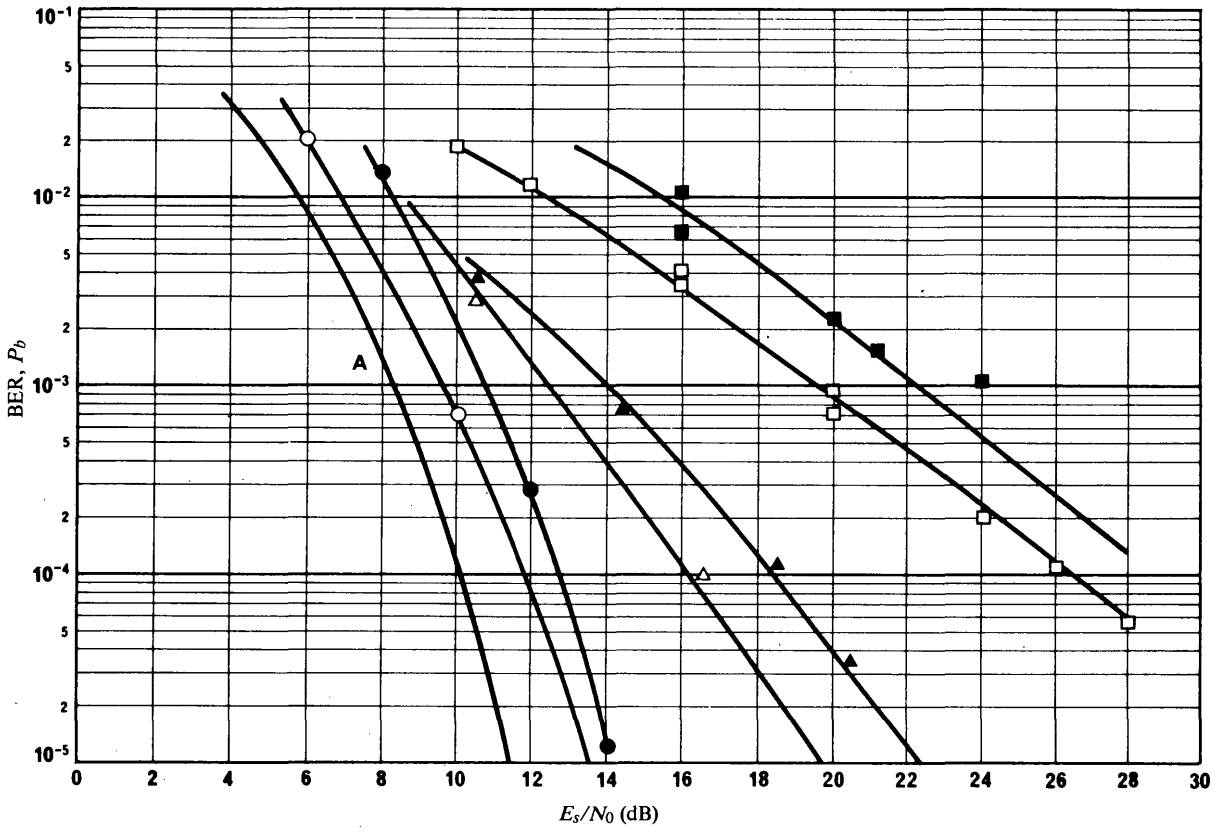


FIGURE 12 – *Bit error ratio dependent on E_s/N_0 for PSK 1.2 kbit/s (INMARSAT Preparatory Committee standard B antenna 16 dB ± 12°)*

A:PSK – Gaussian channel measured without fading

Elevation angle	Sea state (wave height)
○ 12°	1 m
● 10°	2 m
△ 7,7°	4 m
▲ 6°	1 m
□ 3,5°	2 m
■ 1,3°	?

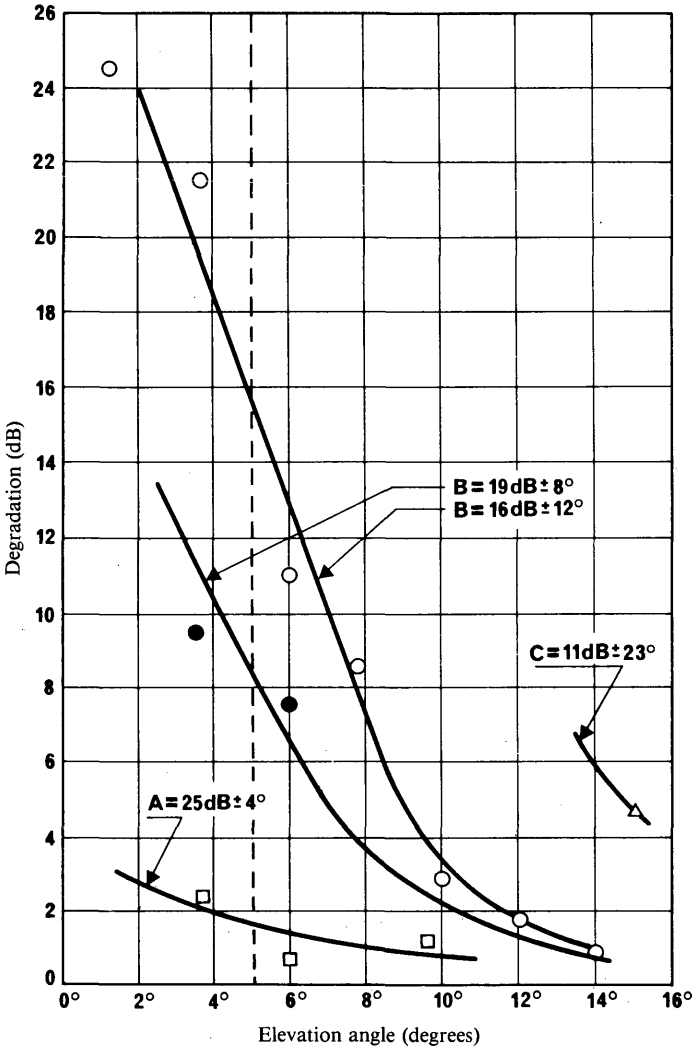


FIGURE 13 – *Power degradation by fading in the case of PSK transmission (Bit error ratio 10^{-5})*

The experimental curves given in Fig. 9 obtained by France with ATS-6, illustrate the effect of multipath upon the bit error ratio with the 20 dB gain antenna used. The test curves deviate from the thermal noise curve by a value (in dB) which increases as the elevation angle decreases, as theory predicts. The average additional power requirements due to multipath over that required for no multipath for an error rate of between 10^{-3} and 10^{-4} are found to be the following:

- elevation angle 5°: 2 dB,
- elevation angle 10°: 1 dB,
- elevation angle 15° or more: 0.5 dB approximately.

The performance of the two-phase PSK digital modulation was significantly aided by the discrimination achieved by the 20 dB stabilized antenna.

The stored channel principle was used in the tests performed by the Federal Republic of Germany with Marisat in 1979. A comparison between the transmission of data via satellite and via the recorded channel at the laboratory as well as an evaluation of the amplitude statistics confirmed the usability of the stored channel and the Rice fading model.

The following values were found to be typical for a standard B antenna at 5° elevation:

- C/M = 9 dB
- a fading margin of 15 dB in the case of PSK-modulated data transmission and a bit error probability $P_b = 10^{-5}$.

REFERENCES

ENGELS, P. *et al.* [February, 1976] Maritime communications experiments and search-and-rescue evaluations with the NASA ATS-6 satellites. Report No. DOT-TSC-USCG-76.

HAGENAUER, J. and PAPKE, W. [December 1980] Data transmissions via the real and stored MARISAT channel using small ship antennas. Proc. IEEE National Telecommunications Conference (NTC '80), Houston, USA, 62.3.1. – 62.3.6

MIZUNO, T., MORINAGA, N., NAMEKAWA, T. and HIRATA, Y. [June, 1975] Effects of multipath interference in aeronautical and maritime satellite communication links. IEEE International Conference on Communications (ICC '75), San Francisco, USA, Conf. Record 10.11 – 10.15.

MODESTINO, J. W. and MUI, S. Y. [June, 1976] Convolutional code performance in the Rician fading channel. *IEEE Trans. Comm.*, Vol. COM-24, **6**, 592-606.

NAKAGAMI, M. [1960] The m-distribution – a general formula of intensity distribution of rapid fading. *Statistical Methods in Radio Wave Propagation*. W.C. Hoffman, Ed., Oxford, UK 3.

SALWEN, H. [9 August, 1972] Multipath effects in the Marsat System. Tech. Memo A100-1. Transportation Systems Center, Dept. of Transportation, Cambridge, Mass., USA.

SALWEN, H. [March, 1975] Differential phase shift keying performance under time selective multipath fading. *IEEE Trans. Comm.*, Vol. COM-23, **3**, 383-385.

SALWEN, H. and DUNCOMBE, C. [July, 1975] Performance evaluation of data modems for the aeronautical satellite channel. *IEEE Trans. Comm.*, Vol. COM-23, **7**, 695-705.

SCHWEIKERT, R., PAPKE W. and HAGENAUER J. [1980] Channel measurement and data transmission via the real and stored maritime satellite channel (Marisat). DFVLR Internal Report NE-NT-T-26/80, 144 pages (in German), available from DFVLR/NT, D-8031 Oberpfaffenhofen, Federal Republic of Germany.

REPORT 763-1

SIGNAL LEVEL VARIATION DUE TO MULTIPATH EFFECT OVER LINKS OF THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The effect of multipath interference caused by sea-reflected signals is one important factor to be considered in establishing maritime satellite communication systems.

The fading characteristics depend on:

- frequency;
- angle of elevation;
- sea surface condition, especially wave height and slope (wind is an important factor);
- the shipborne antenna pattern;
- satellite and shipborne antenna axial ratio;
- the angular orientation of the polarization ellipses for the satellite and shipborne antennas;
- the shipborne antenna pointing error;
- the superstructure of the ship;
- the height of the antenna above the sea.

A theoretical model based on diffuse reflection is given in order to predict values of fading as a function of the satellite elevation angle, sea state and antenna gain.

Results are given of radio-link experiments carried out across the Norwegian fjord, Lysefjorden, in terms of measurement of sea reflection coefficients and spectra.

Results are also given of radio-link experiments carried out in Tago Bay, Japan, in terms of coherent and incoherent reflected waves.

Shipborne experiments were carried out off the Azores by France in 1975 by means of the ATS-6 satellite. From the results of these tests, some suggested values for multipath carrier fade are given; results are also given for observed fluctuations and corresponding spectra. Tests were also carried out by others (see Report 598 (Kyoto, 1978)).

A computer simulation has been made to establish the fading resulting from reflection from a ship's superstructure. Results are given of this simulation.

2. Theoretical model of fade prediction

2.1 *General*

The purpose of a theoretical model is to meet the need for data on fading due to the multipath effect for various parameter values.

The model used is based on the theoretical work of [Beckmann and Spizzichino, 1963] and, more particularly, on the data contained in § 12.4.5, 12.5 and 17.1 of that study.

Further studies are required in order to investigate the effects of specular reflection, particularly at low elevation angles and under smooth sea conditions. Account has not been taken of antenna polarization discrimination. No account has been taken of fluctuations due to the atmosphere; their effect is decisive when the effects due to the sea are negligible, in other words at high elevation angles.

2.2 *Description of method*

2.2.1 *Principle of model*

The model used assumes that reflection is produced under the effect of the various sea facets (shiny points) within a "glistening surface". The area of this surface increases with the agitation of the sea, since a given state of the sea corresponds to a given maximum value of the slope of the facets, a value related to the dimensions of the surface. The reflected signal resulting from it is assumed to be in accordance with the Rayleigh distribution.

2.2.2 *Equivalent reflection coefficient*

This coefficient, ρ^2, corresponds to the mean reflection coefficient of the entire glistening surface, the reflection coefficient for an elementary facet being taken as equal to 1; ρ^2 is given, in the case of an isotropic antenna, by formula (55) of [Beckmann and Spizzichino, 1963]. In the case of a non-isotropic antenna, this formula should be replaced by the following formula in which integration is carried out with respect to all points of the "glistening surface".

$$\rho^2 = \frac{1}{2\pi\beta_0^2} \int_{v_1}^{v_2} \operatorname{cotg} v \left[\int_0^{u(v,\gamma)} g[\theta(u, v)] \, du \right] dv \qquad (1)$$

where:

β_0 : the maximum value of the angle formed by a facet with the horizontal plane;

γ : the elevation angle of the satellite, seen from the ship station;

u : the difference in azimuth between the satellite and a reflecting point, from the ship station;

v : the elevation angle of the ship station, seen from the reflecting point;

$\theta(u, v)$: the angle between the direction of the atellite and the direction of the reflecting point;

$g(\theta)$: the radiation pattern of the ship station antenna, the maximum gain being taken as the origin of gains;

$u(v, \gamma)$: the value of u at the edge of the glistening surface;

v_1 : the larger of values $\gamma - 2\beta_0$ and 0.05°;

v_2 : the smaller of values $\gamma + 2\beta_0$ and 90°.

It will be noted that in the definition of v_1 the value 0.05° has been introduced in place of the value 0° used in formula (54) of § 12.4 of [Beckmann and Spizzichino, 1963].

The value taken corresponds to the limit imposed by the curve of the Earth for an antenna height of about 15 m above sea level.

The parameters $\theta(u, v)$ and $u(v, \gamma)$ are given by the following formulas:

$$\cos \theta(u, v) = \cos \gamma \cos u \cos v - \sin \gamma \sin v \tag{2}$$

$$2 \cos u(v, \gamma) = \frac{\cos v}{\cos \gamma} + \frac{\cos \gamma}{\cos v} - \mathrm{tg}^2 \beta_0 \frac{(\sin \gamma + \sin v)^2}{\cos \gamma \cos v} \tag{3}$$

The radiation pattern of the ship station antenna $g(\theta)$ is taken to be equal to:

$$10 \log g(\theta) = -6 \times 10^{-4} \left[10^{\frac{G}{10}} - 1\right] \theta^2 \tag{4}$$

where G is the value of the maximum gain. This formula represents the main radiation lobe if G is between 0 and 25 dB. It is based on the fact that the antenna beamwidth varies approximately inversely as the square of the maximum gain and it has been adjusted so as to represent closely the main radiation lobe given in Fig. 16 of this Report (for $G = 20$ dB, $10 \log g(\theta) = -0.06\ \theta^2$). It is assumed that the multipath effect of the side lobes may be neglected.

2.2.3 *Determination of fading*

The fading value, A, for p of the time, is obtained by the formula:

$$1 - \frac{p}{100} = \frac{\rho^2}{2 e^{1/\rho^2}} \int_0^{\frac{2 \times 10^{-A/20}}{\rho^2}} \frac{t}{e^{\rho^2 t^2/4}} I_0(t)\ \mathrm{d}t \tag{5}$$

where p, in %, is the percentage of time and $I_0(t)$ designates the modified Bessel function of order zero. This formula is derived directly from formula 56 of [Beckmann and Spizzichino, 1963].

2.2.4 *State of the sea*

The following correspondence between the state of the sea, wave height peak to peak and β_0 ([Beckmann and Spizzichino, 1963], Table 12-1) is assumed:

No.	State of the sea	Wave height (m)	β_0 (°)
0 and 1	calm	< 0.1	1
2	smooth	0.1 -0.5	1 - 5
3	slight	0.5 -1.25	5 -12.5
4	moderate	1.25-2.50	12.5-23.5
5 and 6	rough	2.50-4	23.5-35
7	very rough	4 -6	35 -46.5
8	high	> 6	46.5

The values given for β_0 in this Table assume a linear relationship between tan β_0 and wave height.

2.3 *Results*

2.3.1 *Presentation*

The method described above has been applied to determine fading values obtained 99% of the time for various conditions of the sea, satellite elevation angles (5°, 10°, 15°, 20°, 50°) and of a ship's antenna gain values. Results will be found in Figs. 1-6 for antenna gains of 23, 20, 15, 10, 5 and 0 dB.

2.3.2 *Interpretation*

The results obtained may be interpreted as follows:

2.3.2.1 In general, fading depth increases with decreasing wave height, unless the sea is very calm and the elevation angle is sufficiently high for the main antenna lobe not to meet the sea.

2.3.2.2 For high-gain antennas, the limit of the "service area" should be fixed at 10°, not at 5°, because of the fade differences obtained.

2.3.2.3 For medium-gain antennas (16-20 dB), the gap between the results obtained at 5° and 10° widens and is accompanied by the effect referred to in 2.3.2.1.

2.3.2.4 For medium-gain antennas (10-15 dB), fading increases, even with relatively high elevation angles.

2.3.2.5 For low-gain antennas (0-10 dB), fading is very severe (10-15 dB) irrespective of the elevation angle.

3. Experiments on sea reflection signals

3.1 *Radio-link experiments across a fjord*

3.1.1 *General*

Measurements of sea reflected signals were carried out using an experimental link set up across the Norwegian fjord, Lysefjorden.

The fjord is to a large extent shielded from wind, and no peak-to-peak wave heights greater than 50 cm were observed during the measurement period.

If the height of the antenna above the sea is varied, the received signal (V_{tot}) will pass through positions giving maximum and minimum constructive interference. The corresponding signals are V_t (max) and V_t (min).

From a signal analysis of V_t (max), V_t (min) and V_t^2 (max), the coefficients for coherent (R) and incoherent (D) reflection are determined.

3.1.2 *Measurement set-up*

Figure 7 shows the terrain profile of the transmission path. The equipment consisted on the transmit side of a transmitter with a 1 m parabolic antenna having a directivity of approximately 20 dB with a circular polarization and on the receive side of an 0.75 m antenna with linear polarization and receiving and recording equipment.

The location of the receive equipment was kept fixed while the location of the transmitter was varied in order to obtain different angles of incidence. The measurements were performed for four different elevation angles: 5°, 7.5°, 9.5° and 15°.

The mean height of the receive antenna was approximately 15 m above the sea level. It was mounted on a telescopic mast which permitted a continuously variable height over a range of 1.5 m.

The wave height was determined visually using binoculars and a clearly marked pole approximately 50 m from the shore. No significant difference between the sea structure in the close vicinity of the pole and in the rest of the fjord was observed.

For a given polarization, the antenna was set to the positions of maximum and then minimum constructive interference. For each position, short recordings of the signal were made. The complete measurement cycle lasted 6 to 7 min, a period short enough to ensure negligible influence from the tide and statistically stationary surface conditions. The dipole feed of the antenna was then mechanically rotated 90° and similar records were made for the orthogonal polarization.

A recording was also made of the interference pattern along the mast for each polarization. As the phase centre of the antenna remained unchanged during the rotation, the recordings include the phase difference $\Delta\varphi$ between vertical and horizontal polarization.

A double set of measurements was made. In the first set, the receive antenna pointing direction was kept in the horizontal plane. In this case both the direct and the coherently reflected signals were received with equal gain by the antenna. In the second set, the antenna pointed towards the transmitter and since the antenna radiation pattern was known, it was possible to accurately determine the ratio of the direct to the reflected signal. The coherent reflection coefficients were calculated for both cases.

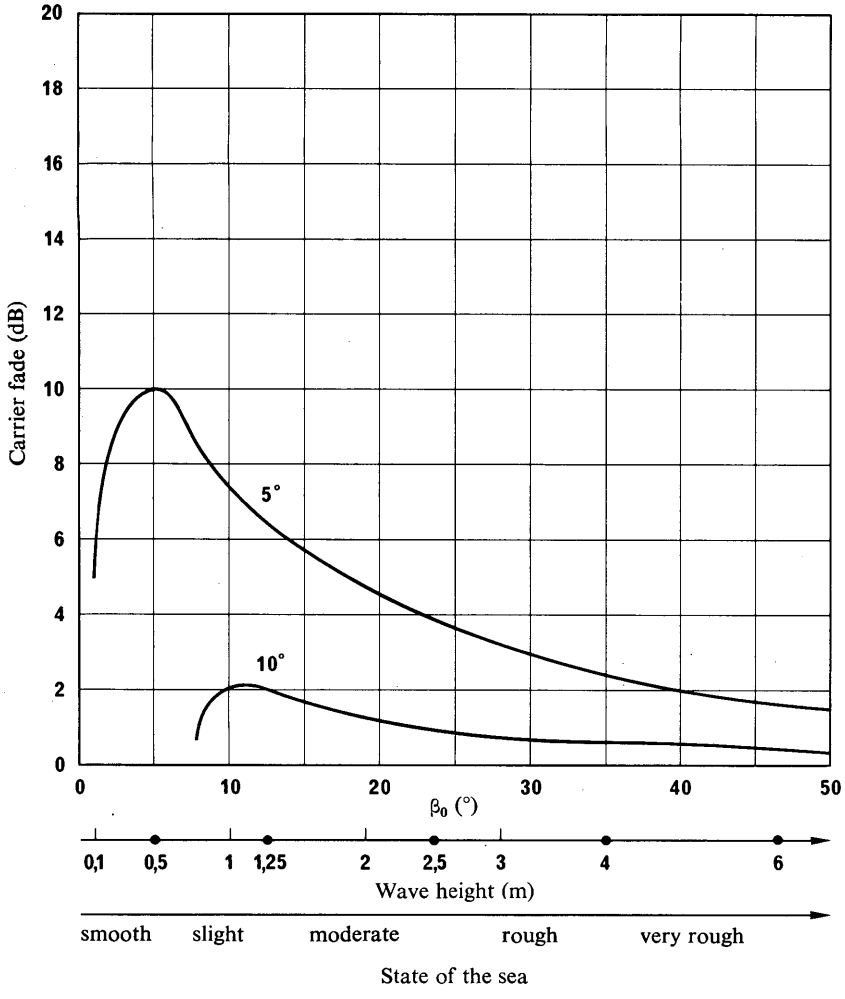


FIGURE 1 — *Carrier multipath fade for 99% of the time (dB)*

G = 23 dB

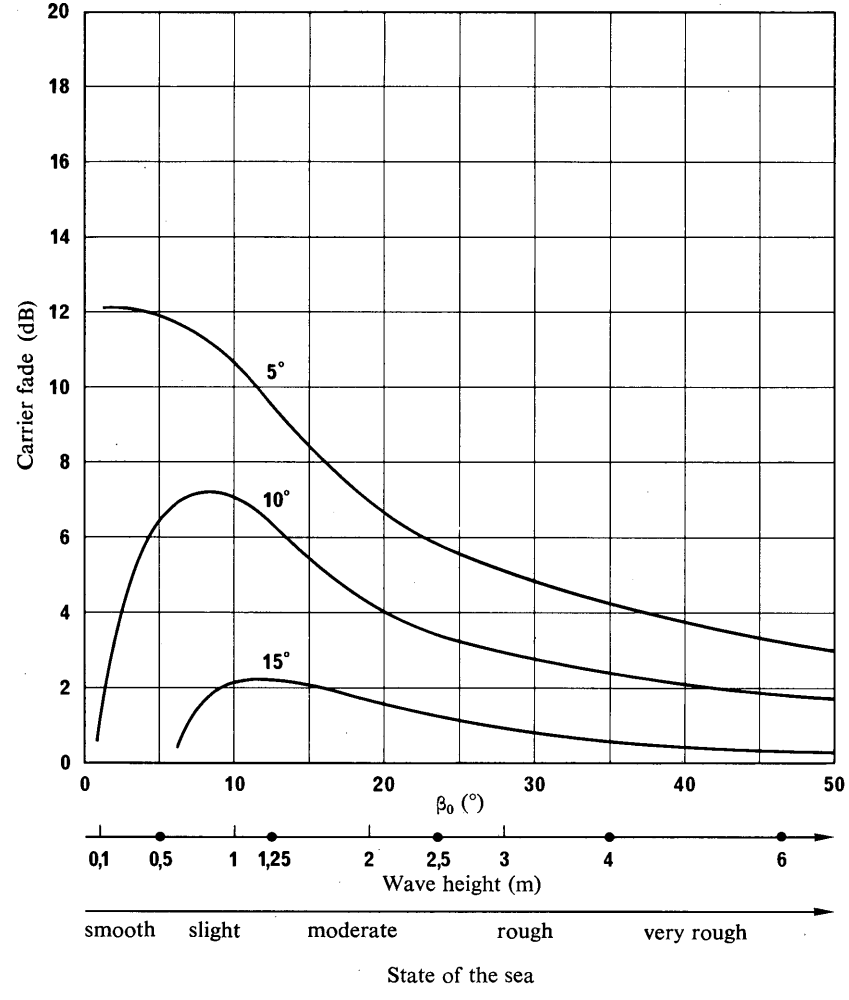


FIGURE 2 — *Carrier multipath fade for 99% of the time (dB)*

G = 20 dB

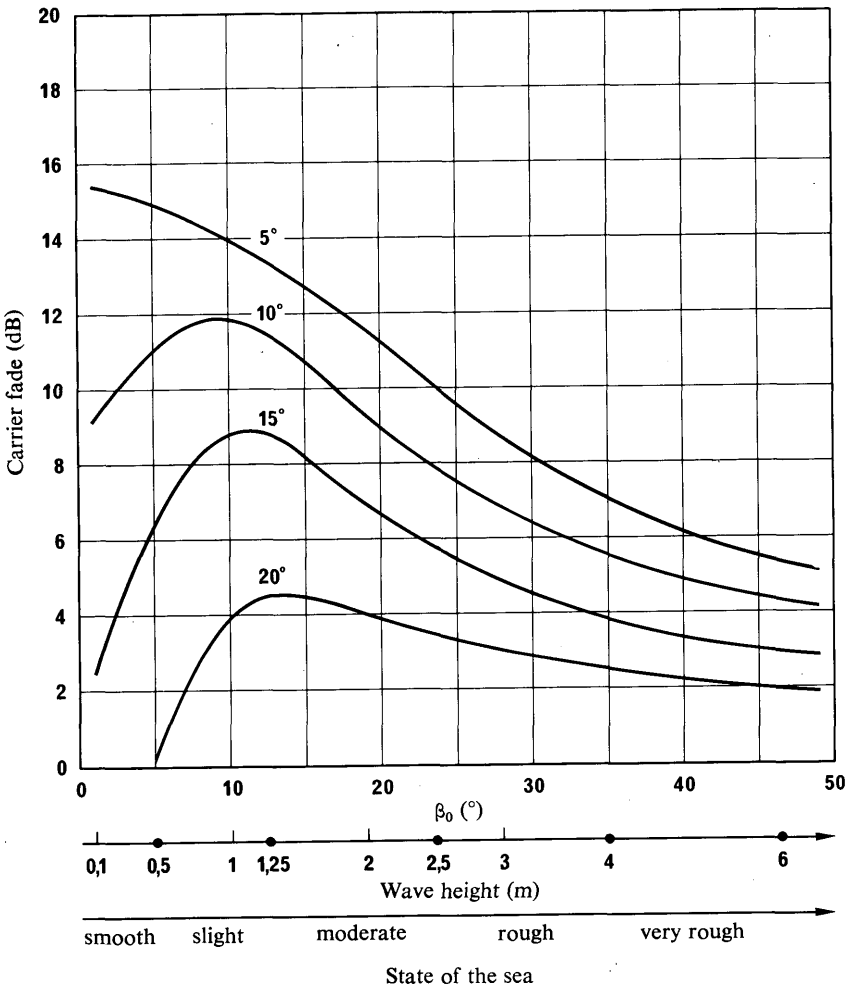


FIGURE 3 — *Carrier multipath fade for 99% of the time (dB)*

G = 15 dB

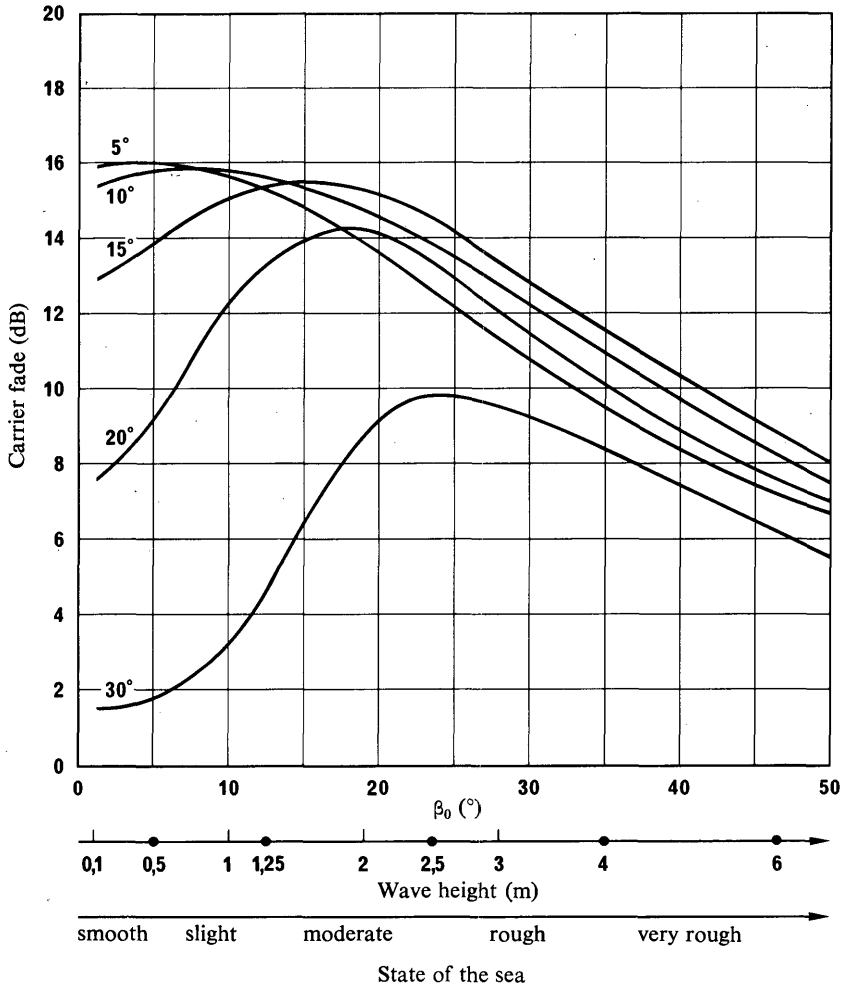


FIGURE 4 — *Carrier multipath fade for 99% of the time (dB)*

G = 10 dB

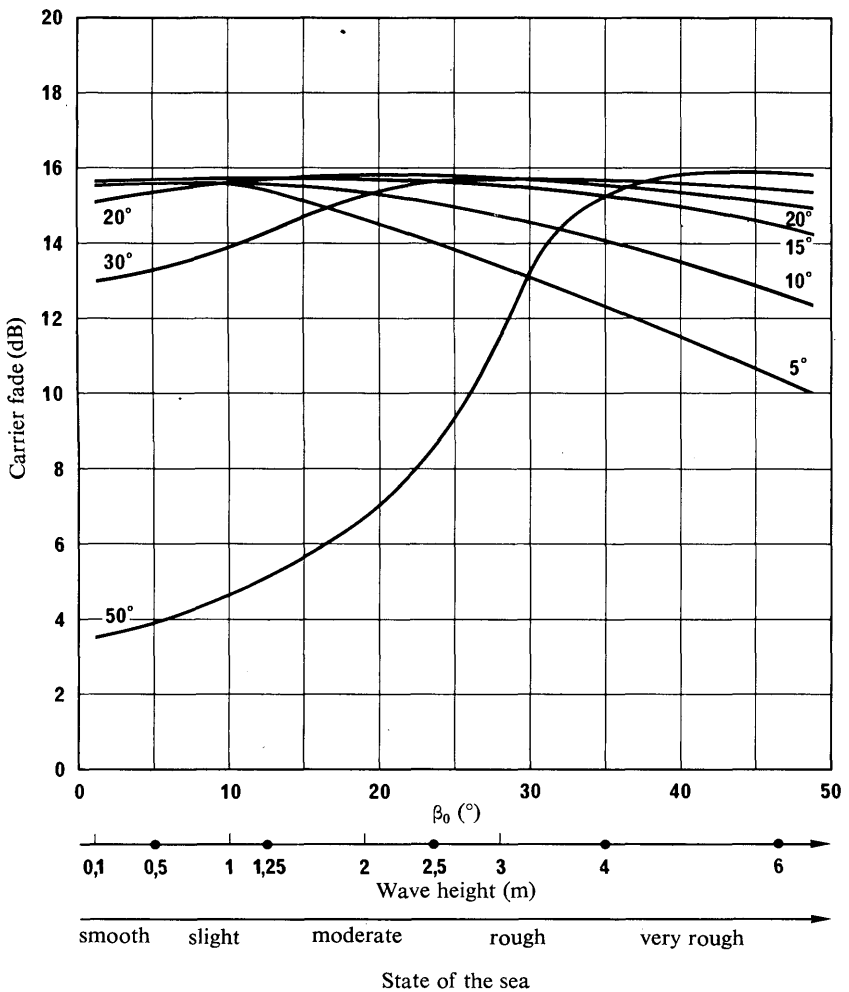


FIGURE 5 — *Carrier multipath fade for 99% of the time (dB)*

G = 5 dB

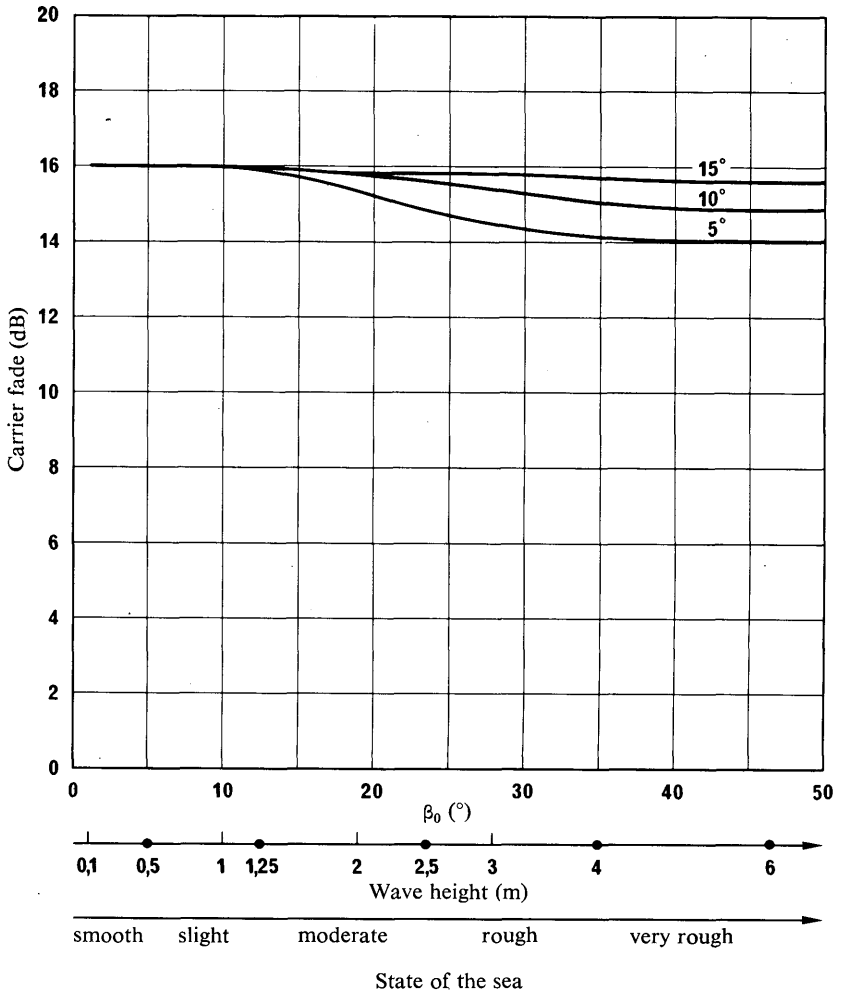


FIGURE 6 — *Carrier multipath fade for 99% of the time (dB)*

G = 0 dB

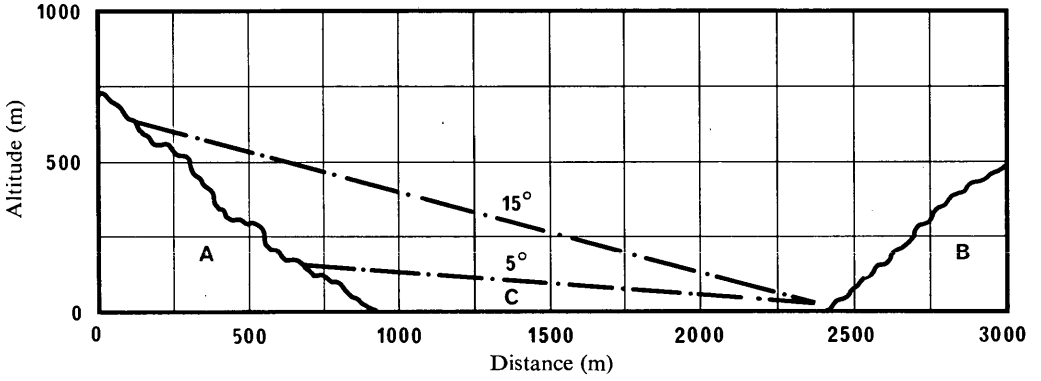


FIGURE 7 — *Terrain profile of measurement path (experiments across a fjord)*

A: Transmit side
B: Receive side
C: Sea level

3.1.3 *Measured results*

Table I A and B show measured coherent reflection coefficients (R) for four different elevation angles and for a number of calm sea states. In general there was good agreement between the two sets of measurements.

Table II A and B list the weighted r.m.s. incoherent reflection contributions (D) relative to the direct signal.

The two pointing directions for the receiving antenna (horizontal and elevated) give different values for D. In order to compare the two cases, the value obtained for the horizontal case is multiplied by $g(\psi)/g(0)$, where $g(\psi)$ is the antenna gain function and ψ the angle between the (elevated) antenna axis and the direction to the point of coherent reflection. This is equivalent to treating the incoherent reflected signal as coherent, with the same fixed angle of incidence. In general the results obtained in this manner are not equal, as would be the case if the coherent reflections were from an infinite surface. However, from the number of measurements made (Table II) the differences are not significant, indicating that the dominant contributions arise from a central area in the vicinity of the specular point of reflection.

For small wave heights a certain regularity of the sea wave structure was present in the fjord and was clearly visible with the unaided eye. In general, care should be taken when selecting a statistical model for incoherent reflections.

The frequency spectrum of the incoherently reflected signal is shown in Fig. 8. The regularity of the wave structure, especially for the case of horizontal polarization, is observable by the peak of the spectrum at 2 Hz.

TABLE I – *Measured coherent reflection coefficients*
(The phase angle of the vertical polarization coefficient shown is relative to the phase angle of the corresponding horizontal polarization coefficients

A. Horizontal polarization coefficients*

Wave height (peak-to-peak) (cm)	Elevation angle / 5°	7.5°	9.5°	15°
0-1		0.95		
1-5	0.92		0.93	0.93
5-10	0.94	0.91	0.89	0.86
10-15	0.89	0.93	0.81	0.92
15-20	0.80	0.90		0.89
20-25			0.80	0.89
40-50	0.82			

B. Vertical polarization coefficients*

Wave-height (peak-to-peak) (cm)	Elevation angle / 5°		7.5°		9.5°		15°	
	Absolute value	Relative phase angle	Absolute value	Relative phase angle	Absolute value	Relative phase angle	Absolute value	Relative phase angle
0-1			0.11	167°			0.39	
1-5	0.10	75°			0.21		0.38	158°
5-10	0.10	67°	0.14	160°	0.17	140°	0.39	
10-15	0.10	51°	0.14		0.19	155°		
15-20	0.11	92°	0.14	120°			0.27	177°
20-25					0.17		0.32	169°
40-50	0.12	68°						

* *Measured coherent reflection coefficients*
The value given in A is the ratio of received coherent field strength of the reflected signal to the received direct signal for horizontal polarization, $R_H = | E_{RC}/E_D |_H$.
A. Horizontal polarization: $P_H = R_H \exp(j \psi_H)$.
B. Vertical polarization: $P_V = R_V \exp(j \psi_V)$, $R_V = | E_{RC}/E_D |_V$.
Absolute value: R_V; relative phase angle $(\psi_H - \psi_V)$.

TABLE II – *Weighted relative r.m.s. incoherent reflection contributions*

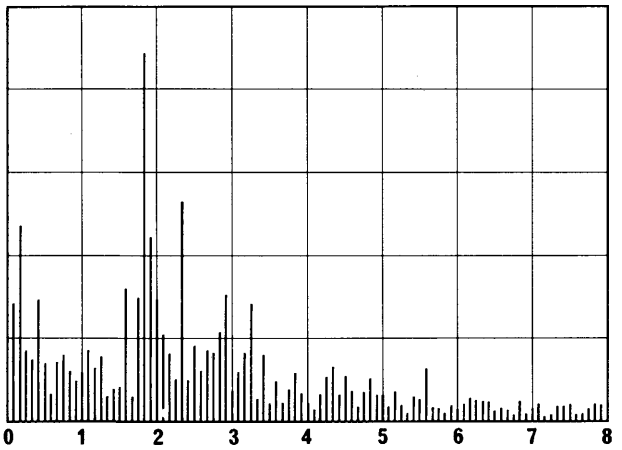
A. Horizontal polarization coefficients*

Wave-height (peak-to peak) (cm)	Elevation angle / 5°		7.5°		9.5°		15°	
	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna
0-1								
1-5	0.04				0.03		0.02	
5-10	0.08	0.07			0.10		0.02	
10-15			0.10		0.12		0.03	
15-20	0.11	0.09	0.18	0.11				0.04
20-25							0.07	0.06
40-50	0.14	0.13						

B. Vertical polarization coefficients*

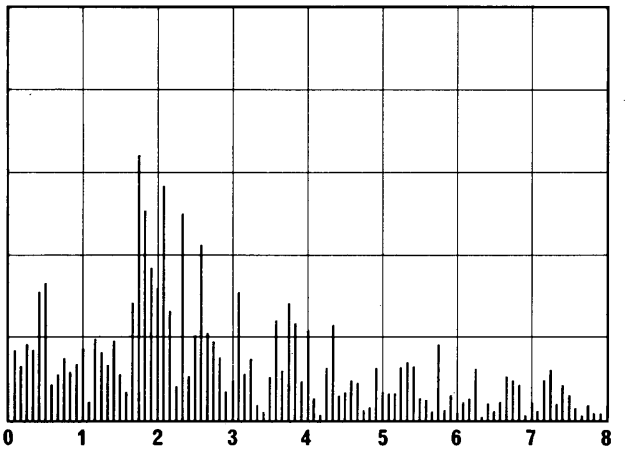
Wave-height (peak-to-peak) (cm)	Elevation angle / 5°		7.5°		9.5°		15°	
	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna
0-1								
1-5	0.02				0.03		0.02	
5-10	0.02	0.02		0.04	0.04		0.03	
10-15			0.05		0.06		0.04	
15-20	0.06	0.05		0.10				0.04
20-25							0.07	0.05
40-50	0.07	0.08						

**Weighted relative r.m.s. incoherent reflection coefficients*
The value given in A and B is the ratio, D of the incoherent field strength r.m.s. level of the reflected signal to the received direct signal for horizontal and vertical polarization respectively. $D = \overline{(E_{RD}^2)}^{1/2} / E_D$.



Frequency spectrum of incoherently reflected signal

Elevation angle: 5°
Wave height: 40-50 cm peak-to-peak
Horizontal polarization



Frequency spectrum of incoherently reflected signal

Elevation angle: 5°
Wave height: 40-50 cm peak-to-peak
Vertical polarization

FIGURE 8 — *Frequency spectrum of incoherently reflected signal (both curves measured in the same linear scale)*

3.2 *Radio link experiments in Japan*

3.2.1 *General*

In these measurements, fading phenomena due to sea reflections are divided into coherent and incoherent components, measured individually through experimental radio circuit across the bay. The data obtained are analysed for each part and the general fading characteristics due to sea reflections are estimated through integration of two kinds of components.

3.2.2 *Experiments*

3.2.2.1 *Technical information*

Date: February 1977

Place: Tago Bay, Nishi-Izu, Shizuoka, Japan

Frequency: 1643.0 MHz

Polarization: Right hand circular

Wave height: 10-20 cm peak-to-peak, measured by pole in the sea.

Antenna	*Gain*	*Beamwidth*
1.2 m∅ dish	23.7 dB	± 5.8°
0.6 m∅ dish	17.6 dB	± 9.1°
0.4 m∅ short backfire	14.0 dB	± 14.4°
0.2 m length helical	10.6 dB	± 22.6°

Two dish antennas of 0.6 m∅ were used, one for transmitting and the other for receiving.

The terrain profile of measurement path is given in Fig. 9. The measuring block diagram is given in Fig. 10.

3.2.2.2 *Experimental procedures*

3.2.2.2.1 *Fading measurements due to coherent reflection:*

Height pattern was measured for each antenna. A 1.2 m∅ dish and one of the other antennas were placed on the same lifting platform for each cycle. The 1.2 m∅ dish was also used for monitoring the link conditions.

3.2.2.2.2 *Fading measurements due to incoherent reflection:*

The two antennas mentioned above were fixed at the points of minimum and maximum field strength (corresponding to heights h_{min} and h_{max}, respectively); then the variation of received level was measured for 10 min switching between each antennas every one minute. Since the complete measuring cycle lasted not more than 25 min, very few influences from tide were observed.

3.2.2.3. *Test results*

The examples of height pattern and level variation are shown in Fig. 11 and Fig. 12, respectively.

3.2.3 *Analysis of the results obtained*

3.2.3.1 *Coherent reflection*

The variation of the reflected coherent component is caused by the vertical antenna movement which corresponds to the height pattern. The measured and calculated fading depth of coherent component are shown in Table III.

The difference between measured and calculated values are in the range of ± 1 dB, except for the helical antenna.

3.2.3.2 *Incoherent reflection*

Fading due to incoherent reflection occurs at random at any place between h_{min} and h_{max} shown in the drawing of Fig. 15. Standard deviation of fading due to incoherent reflection are given in Figs. 13 and 14, for h_{min} and h_{max}, respectively.

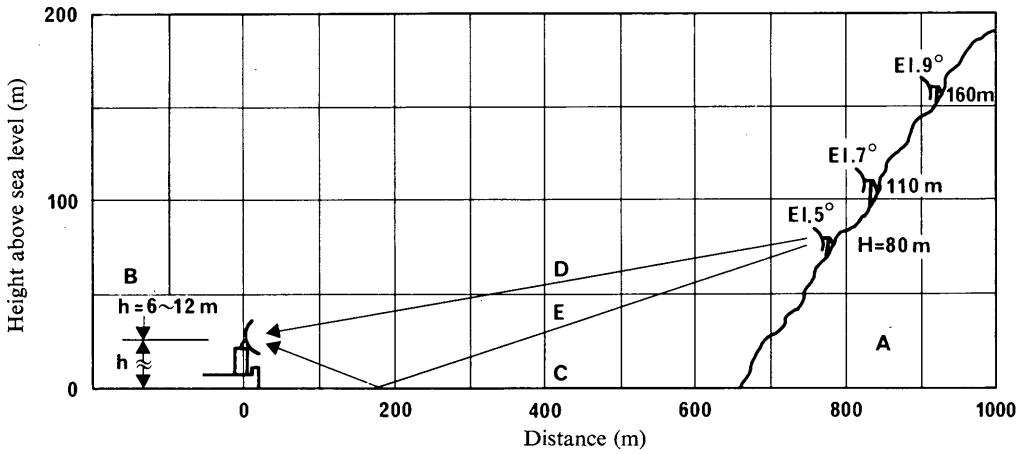


FIGURE 9 — *Terrain profile of measurement path (experiments in Japan)*

A: transmitting side
B: receiving side
C: sea level
D: direct wave
E: reflected wave

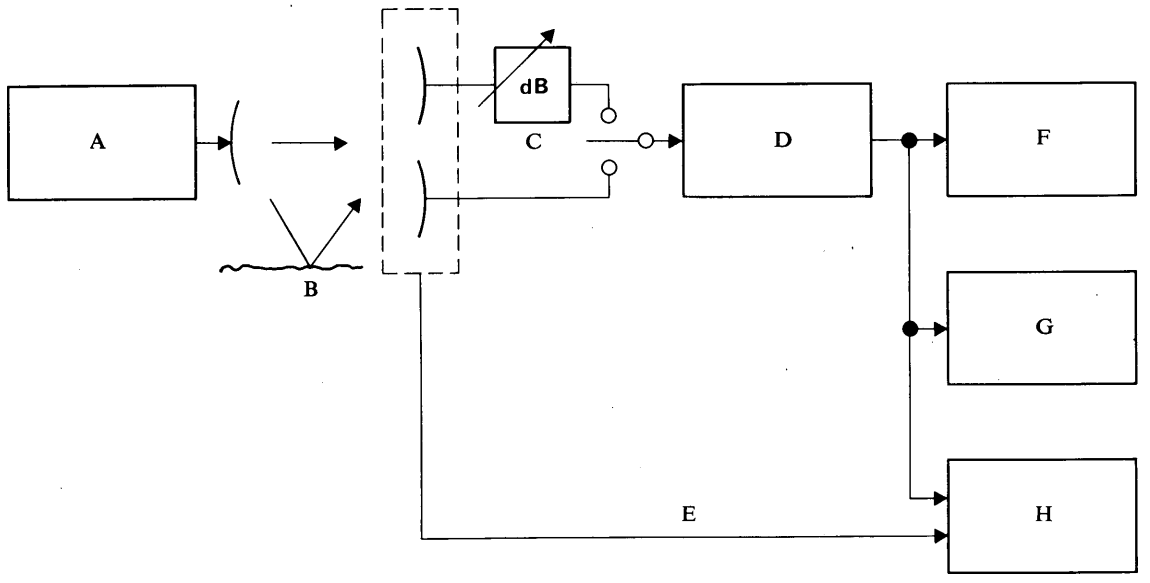


FIGURE 10 — *Measuring block-diagram (experiments in Japan)*

A: transmitter
B: sea
C: attenuator
D: receiver
E: height of receiving antenna
F: data recorder
G: pen recorder
H: X-Y recorder

TABLE III – *Measured and calculated fading depth of reflected coherent component (dB)*

Antenna	Elevation angle					
	5°		7°		9°	
	measured	calculated	measured	calculated	measured	calculated
1.2 m ∅ dish	0.8	1.67	0.6	0.26	0.24	0.08
0.6 m ∅ dish	3.8	3.90	1.8	1.97	1.0	0.57
0.4 m ∅ short backfire	5.5	5.96	4.8	3.89	2.4	2.43
0.2 m length helical	6.5	6.65	7.4	4.86	4.9	3.37

3.2.3.3 *Resulting fading depth*

By adding twice the value shown in Fig. 13 and the fading depth given in Table III above, Fig. 15 is obtained. The value composed of fading depth of coherent component and 2 σ of incoherent component at h_{min} corresponds to nearly 99% of the fade value.

3.3 *Shipborne experiments with ATS-6 off the Azores*

3.3.1 *General*

Tests carried out in 1975 by means of the ATS-6 satellite provided experimental results on the multipath effects in the case of reception on board a ship cruising off the Azores of a pure continuous wave emitted by the satellite. Results given in this section are those obtained by France; those obtained by others with ATS-6 are in Report 598 (Kyoto, 1978).

3.3.2 *Ship antenna*

The ship station antenna used for receiving the signals from the satellite was of the quadrihelix type with a maximum gain of about 20 dB and a half power beamwidth of 14°. The antenna's radiation diagram is shown in Fig. 16. Appropriate design features were incorporated in order to reduce the level of the first side lobe. The height of the antenna above the sea was about 20 m. The antenna was stabilized to about 1°, using a vertical reference and the ship's gyrocompass.

3.3.3 *Sea conditions*

Two different states were observed, "rough sea" and "smooth sea". They corresponded to a mean peak-to-peak wave height of about 3 m and 30 cm respectively.

3.3.4 *Results obtained*

3.3.4.1 *Signal level fluctuation*

3.3.4.1.1 *Classification*

The fluctuations observed can be classified into three categories in increasing order of periods and amplitudes:

– *Noise*

Low amplitude fluctuations, similar to thermal noise, with periods of less than one second;

– *Intermediate fluctuations*

Medium amplitude fluctuations with periods between about 1 and 3.5 s;

– *Interference*

Large-amplitude fluctuations, with very marked maxima and minima, with periods varying between about 3.5 and 10 s.

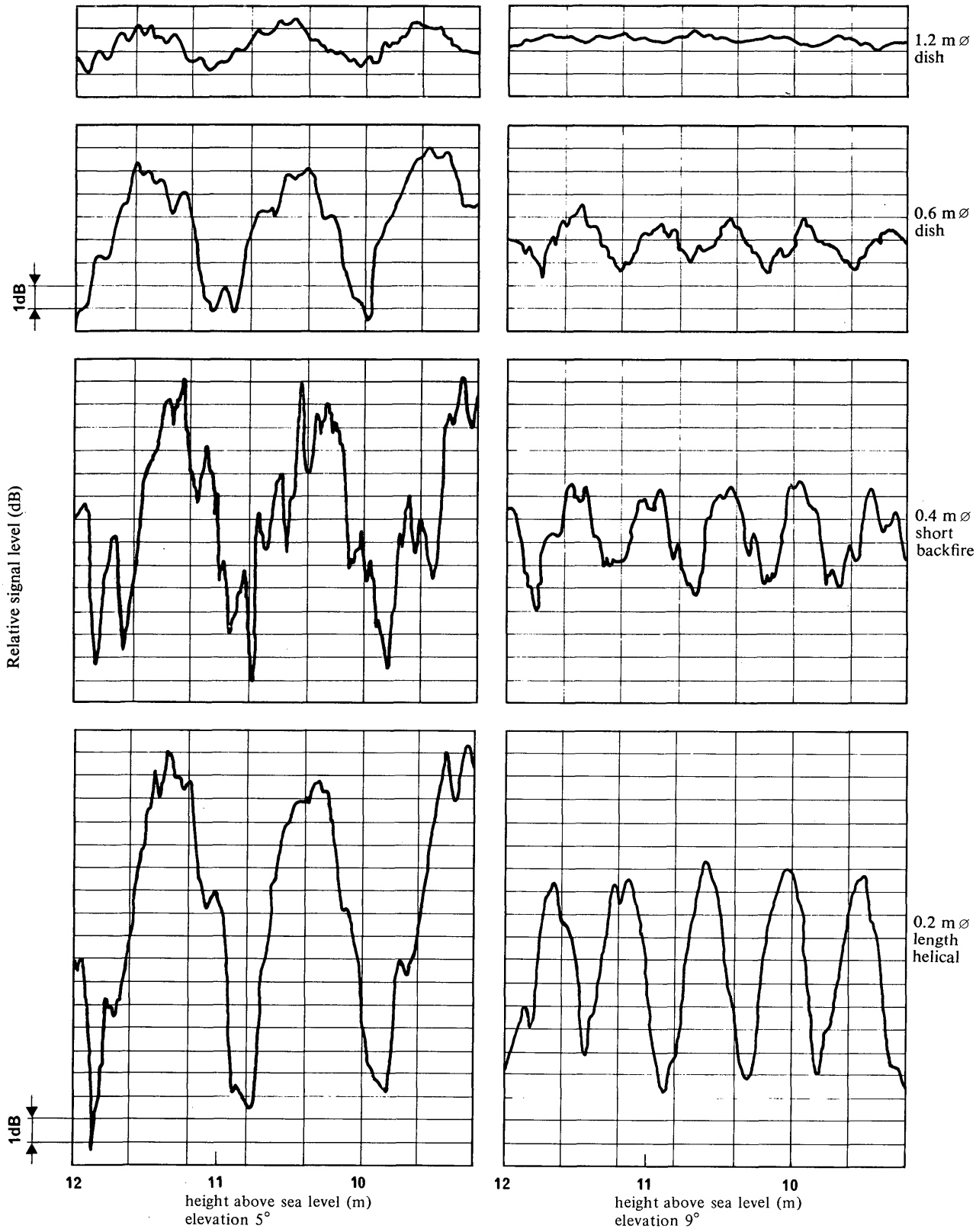


FIGURE 11 — *Examples of height pattern*

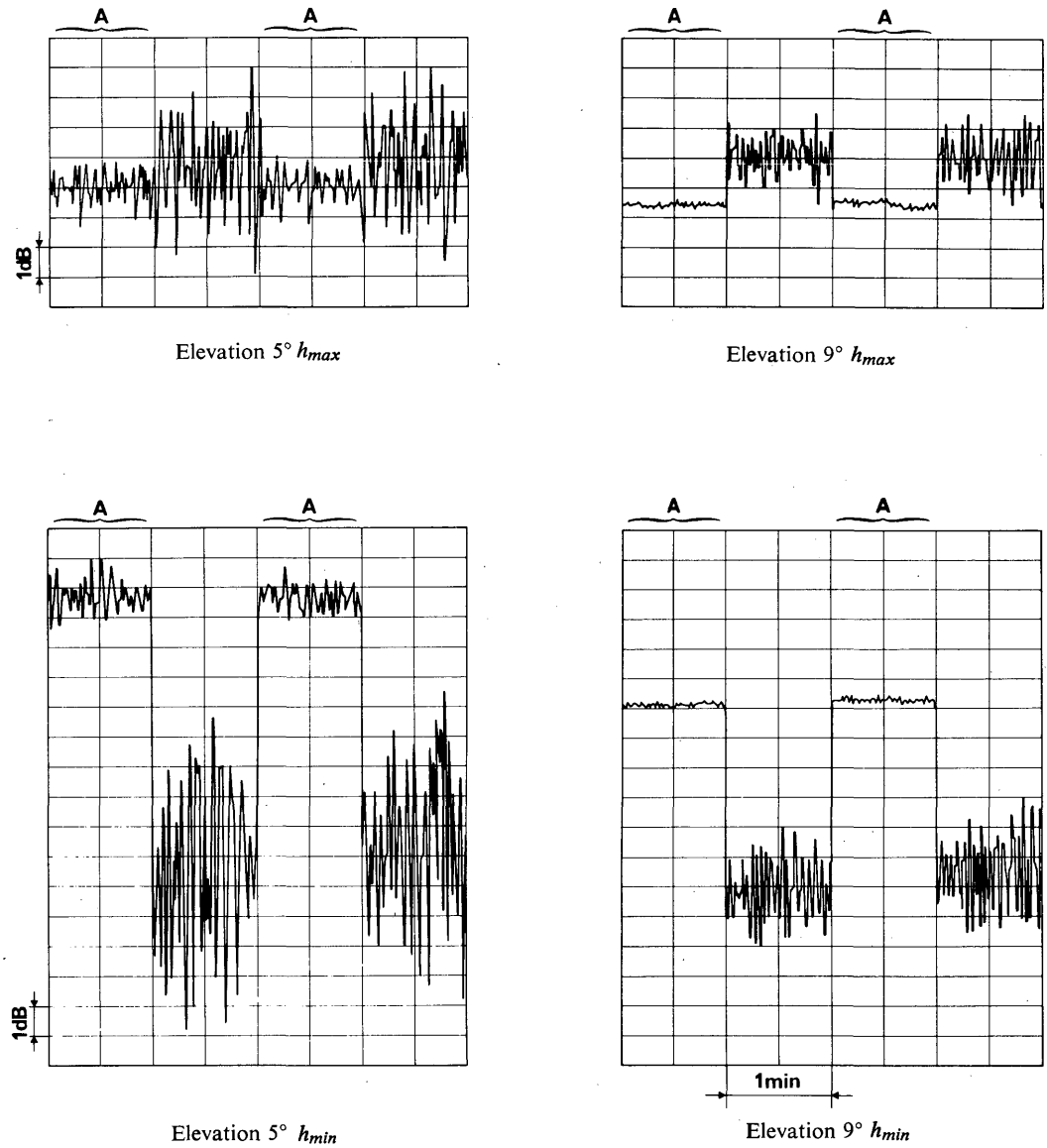


FIGURE 12 – *Examples of received level (helical antenna)*

A: 1.2 m ϕ **dish antenna**. (see § 3.2.2.2)

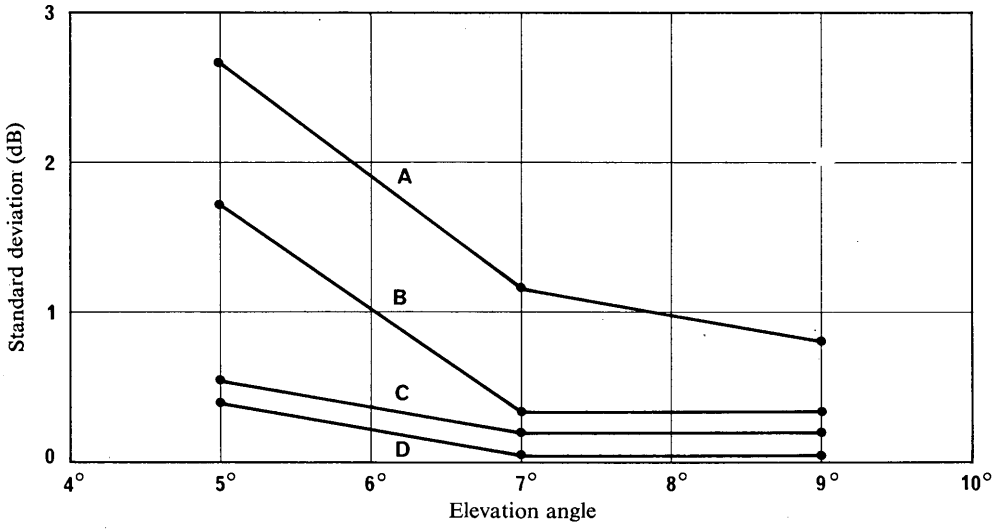


FIGURE 13 — *Standard deviation of fading due to incoherent reflection at h_{min}*

Curves A: Hel
B: SBF
C: 0.6 m ⌀ dish
D: 1.2 m ⌀ dish

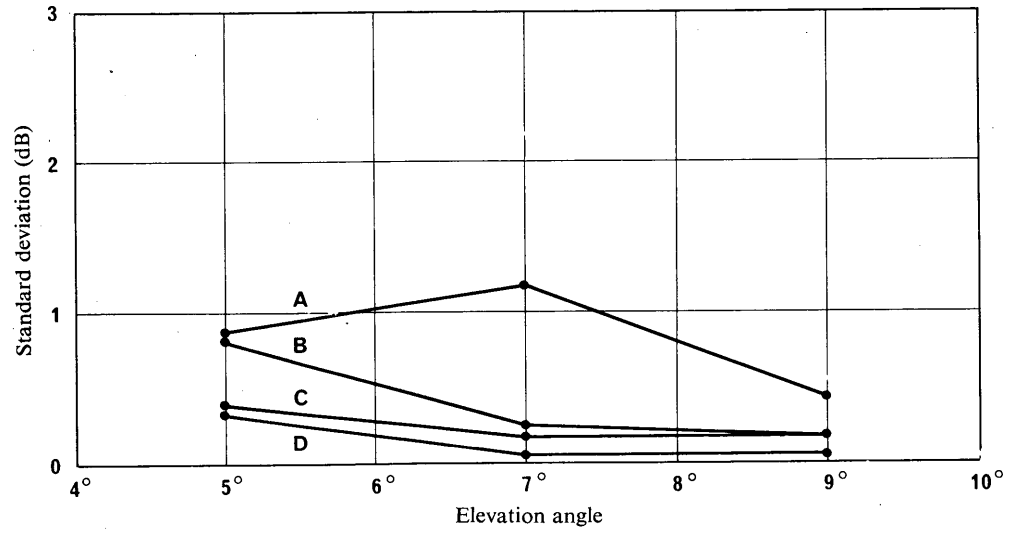
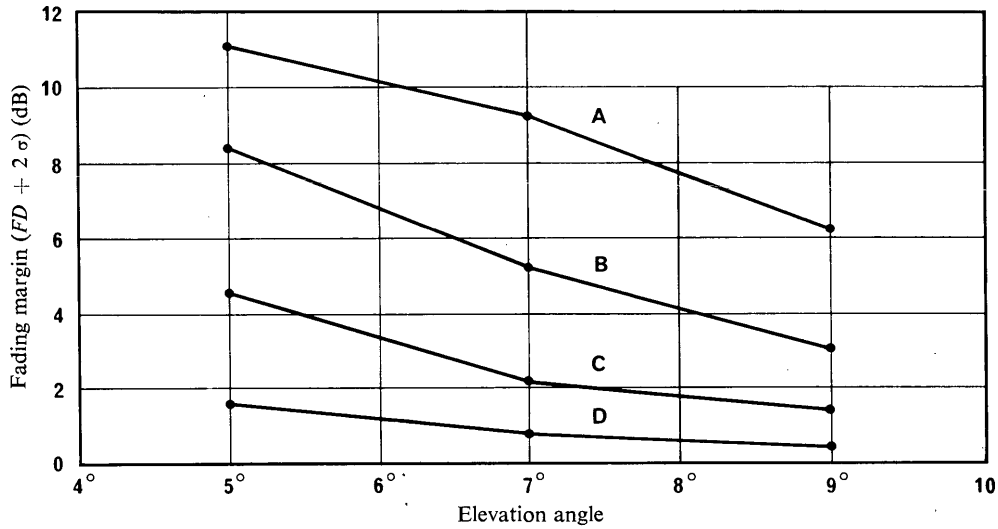


FIGURE 14 — *Standard deviation of fading due to incoherent reflection at h_{max}*

Curves A: Hel
B: SBF
C: 0.6 m ⌀ dish
D: 1.2 m ⌀ dish



Curves A: helical antenna
B: short backfire antenna
C: 0.6 m ⌀ dish
D: 1.2 m ⌀ dish

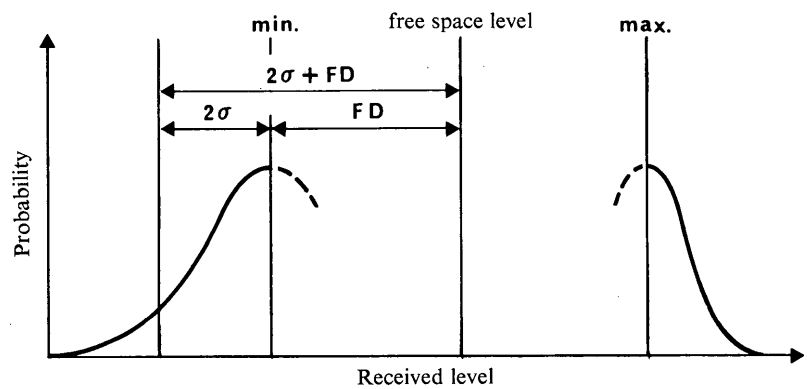


FIGURE 15 — *Fading margin due to multipath effect (experiments in Japan)*

3.3.4.1.2 *Variations in time*

Fig. 17 gives an example of the fluctuations observed for different angles of elevation in the rough sea conditions and Fig. 18 an example of the fluctuations observed for a given angle and elevation (10° in the case considered) and two different sea conditions.

These figures reveal the types of fluctuation indicated in Table IV:

TABLE IV – *Fluctuations observed*

State of the sea	Elevation angle			
	5°	10°	15°	20°
Rough sea	Interference Intermediate fluctuations	Intermediate fluctuations	Noise	Noise
Smooth sea		Interference Intermediate fluctuations		

In general, it can be seen:

- that higher level of interference may be found at low elevation angles;
- that the amplitude of the interference increases as the wave height diminishes for a given elevation angle.

3.3.4.1.3 *Spectral analysis*

Figure 19 shows the spectral analysis of the fluctuations observed in the case of a rough sea for different angles of elevation. It will be noted from this figure that the spectrum undergoes substantial modifications when the elevation angle increases, changing from an interference and intermediate fluctuation spectrum (with high amplitude values for frequencies less than 1 Hz) to a uniform noise spectrum. Fig. 20 gives the spectral analysis of the fluctuations observed with an elevation angle of 10° and two different states of the sea. It will be seen that, when we pass from a rough to a smooth sea, the fluctuations tend to concentrate towards the lower frequencies while the amplitude increases. On Figs. 19 and 20, the abscissae show the scale of frequencies (1 Hz/4 cm).

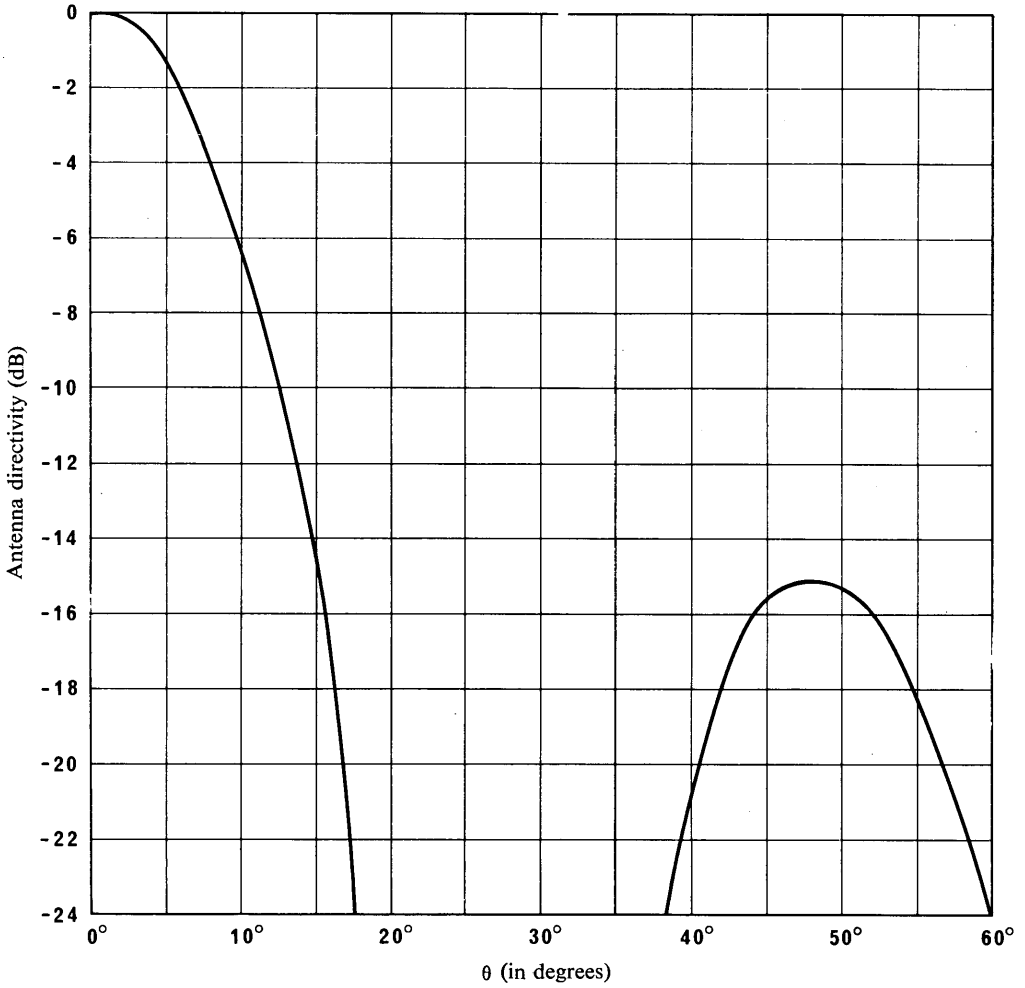


FIGURE 16 — *Ship station antenna diagram*

(G = 20 dB)

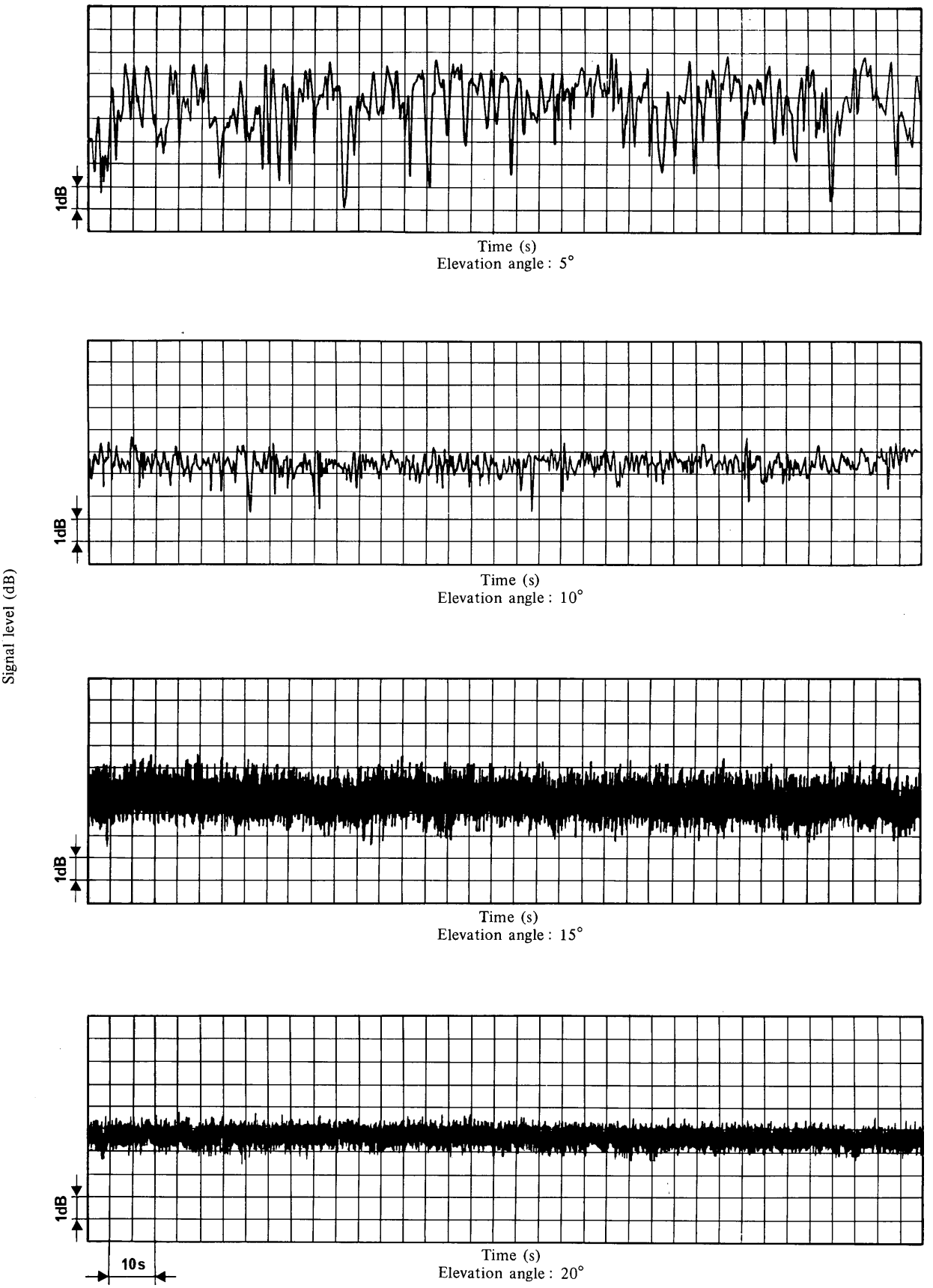


FIGURE 17 — *CW signal level fluctuations observed with a rough sea*

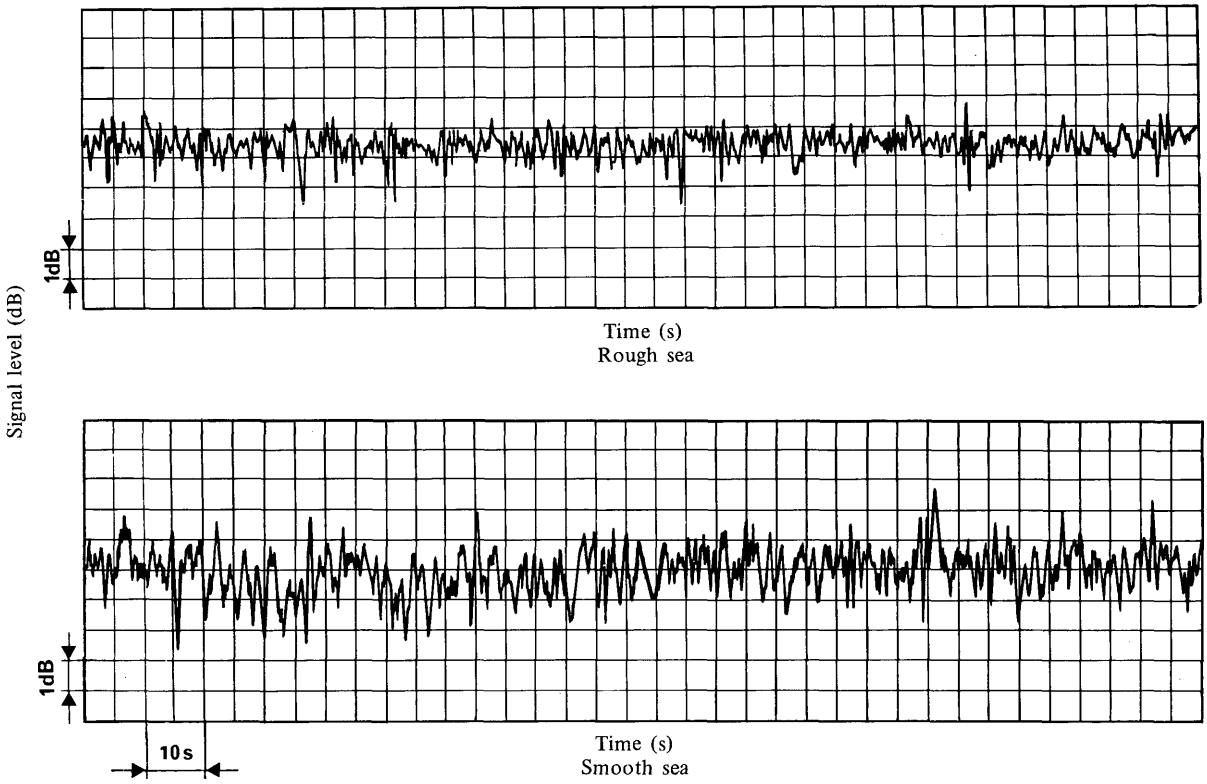


FIGURE 18 — *CW signal level fluctuations observed with two states of sea (elevation angle: 10°)*

Time (1 s/mm)

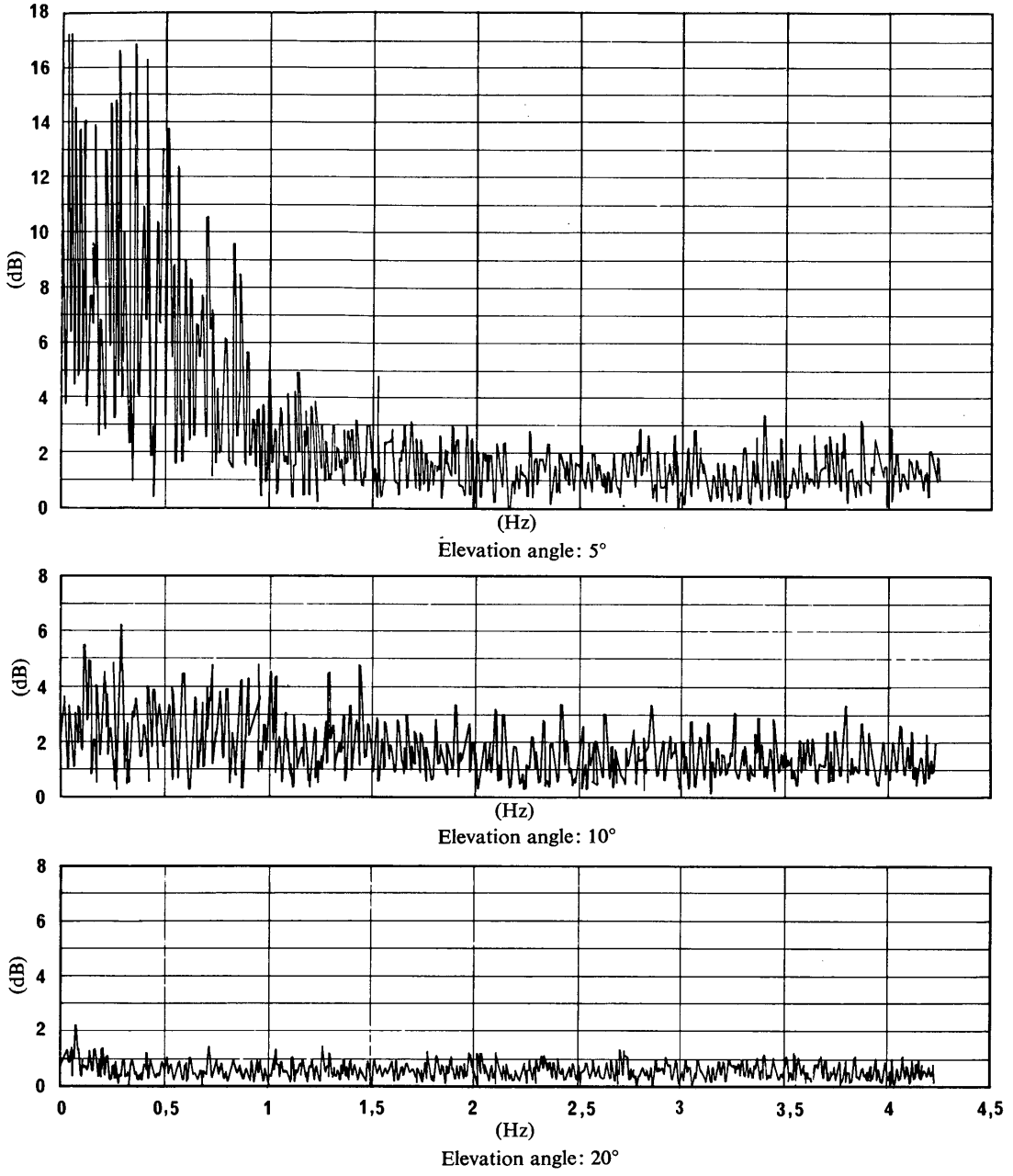


FIGURE 19 — *Spectra of fluctuations observed with a rough sea*

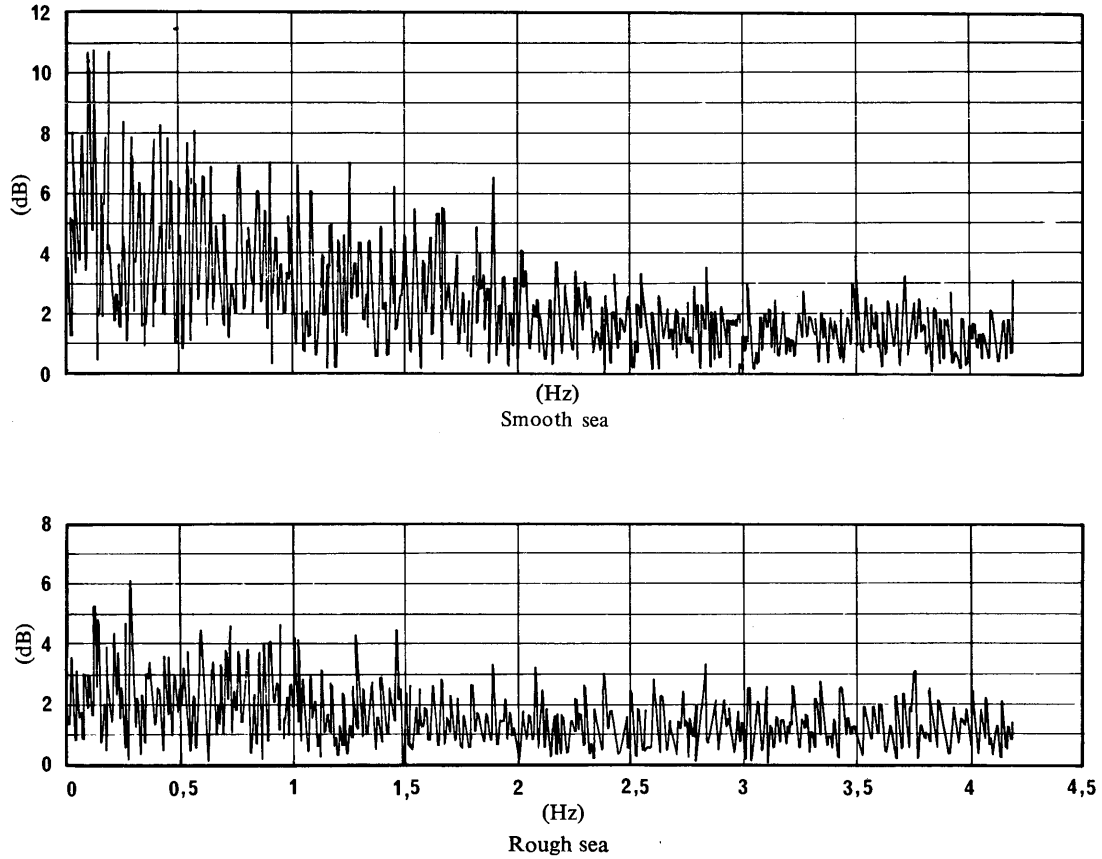


FIGURE 20 — *Spectra of fluctuations observed with two states of sea (elevation angle: 10°)*

Figure 21 gives a schematic representation of the changes in the fluctuation spectrum when the elevation angle or the roughness of the sea diminishes. In this figure, it can be seen how, starting from a uniform spectrum, we arrive at an interference spectrum, passing *via* successive spectra in which the intermediate fluctuations are larger and larger; we find the same types of fluctuation as in Table IV with the frequency bands corresponding to the information given in § 3.3.4.1.1.

3.3.4.2 *Carrier multipath fading*

3.3.4.2.1 *Definition*

A carrier fade at p% is defined as the difference, in dB, between the mean value of the signal received and a value such that the level received is higher during p% of the time.

The fade values corresponding to p equal to 95% and 99% were determined for rough and smooth sea.

3.3.4.2.2 *Values obtained*

Fade level values were obtained by computer processing of measured results. These are shown in Fig. 22. Averages of these figures are shown in Table V.

TABLE V – *Carrier multipath fade (in dB)*
(20 dB antenna gain)

State of the sea	Elevation angle (°)	Multipath carrier fade (dB)	
		at 95%	at 99%
Rough sea	5 10 20	2.7 1.7 0.5	4.8 2.8 0.6
Smooth sea	10	3.2	5.4

3.3.4.2.3 *Comparison with the theoretical values*

The fading values obtained for 99% of the time as given in Table V tally with those of Fig. 2 (corresponding to an antenna gain of 20 dB).

In the case of a rough sea (wave height of 3 m), the values given by that figure for elevation angles of 5, 10 and 20° are 5, 3 and 0 dB. These values are very close to those obtained experimentally, with the exception of that corresponding to the elevation angle of 20°. In this case, the fading observed is due to the atmosphere, an effect which we know has not been taken into account in the theoretical model of § 2.

In the case of a smooth sea (wave height of 30 cm), the value given by Fig. 2 is 5 dB (for 10°). This is sufficiently close to the experimental value.

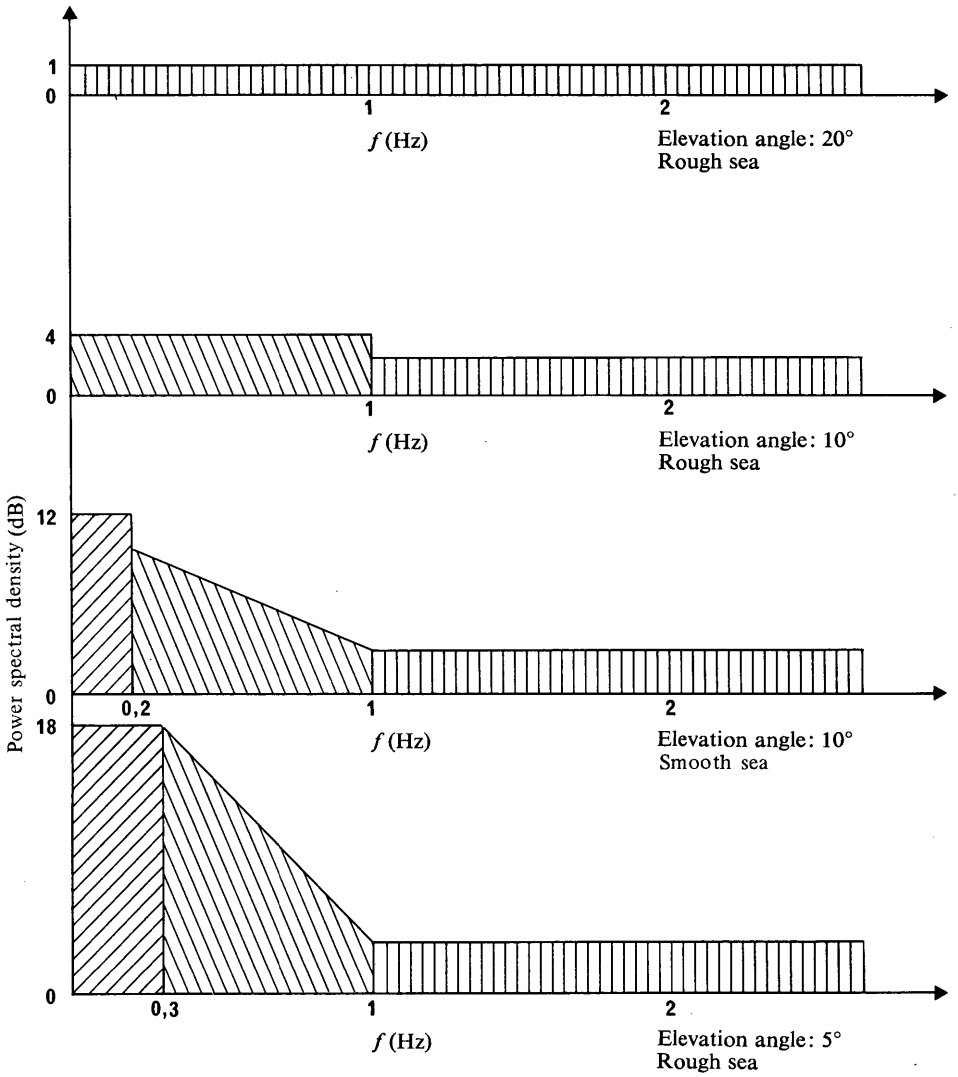


FIGURE 21 — *Changes in the fluctuation spectrum with elevation angle and state of sea*

Interference

Intermediate fluctuations

Noise

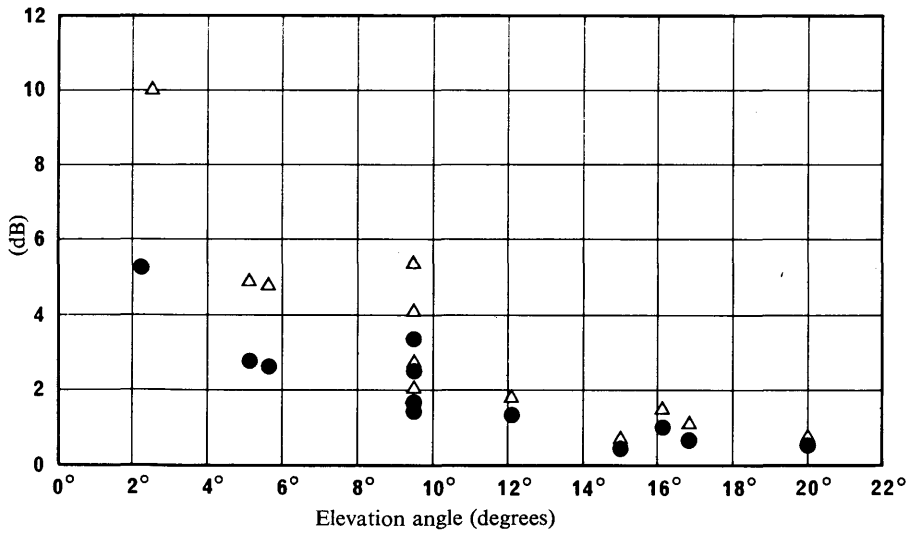


FIGURE 22 — *Carrier multipath fade*
(experimental values obtained with ATS-6)

● Carrier fade at 95%

△ Carrier fade at 99%

4. Computer predictions of reflections from ship superstructure

4.1 *General*

Reflections from the ship's superstructure, which are mainly coherent with the direct signal, will cause fading in the received signal.

The fading depth depends on a number of parameters:

- shape of the ship;
- location of the ship antenna;
- antenna directivity and side lobe level;
- axial ratio and orientation of the polarization ellipse, both for the satellite and the ship antenna;
- elevation and azimuth angle.

An oil tanker of approximately 230 000 tons deadweight (see Fig. 23) was chosen as a sample ship for a computer prediction of ship reflections. This type of ship was expected to give strong reflections because of its large open deck space in front of the antenna. The reflecting surface on the ship deck was modelled as a set of plane surface elements with infinite conductivity. The on-axis axial ratio of the ship antenna was assumed to be 1 dB and that of the satellite antenna to be 2 dB.

4.2 *Results*

In Fig. 24 the signal levels predicted by the computer are presented as a function of the elevation angle for two values of assumed directivity, 20 dB and 24 dB. The effect of antenna pointing error is shown, corresponding to a loss of 1 dB. The corresponding pointing angle errors are $-5.4°$ in elevation for the 20 dB antenna and $-3.4°$ for the 24 dB antenna.

The variations within the elevation angle range 9° to 11° are caused by interference between reflections from the various parts of the deck.

For this particular example, the predicted multipath effect from a ship superstructure:

- decreased to zero when the ship heading was more than 14° off the bearing of the satellite,
- changed less than one dB when the height of the antenna above the deck varied.

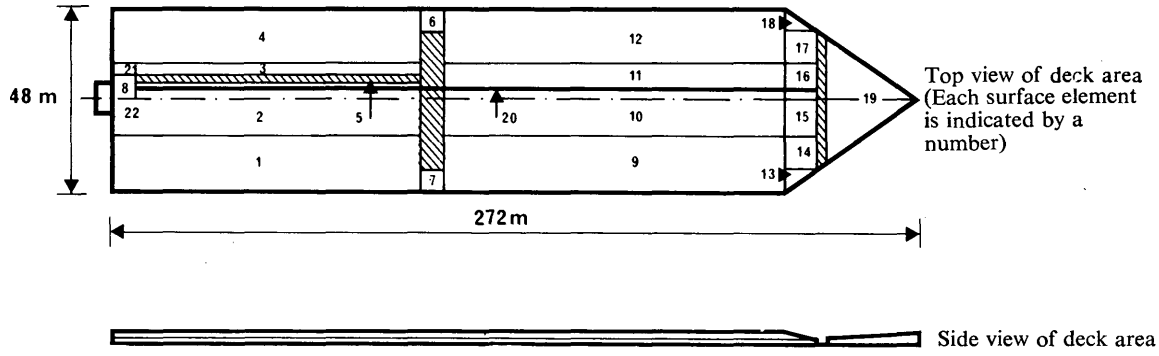


FIGURE 23 — *Diagram of tanker used for simulation of ship's reflectors*

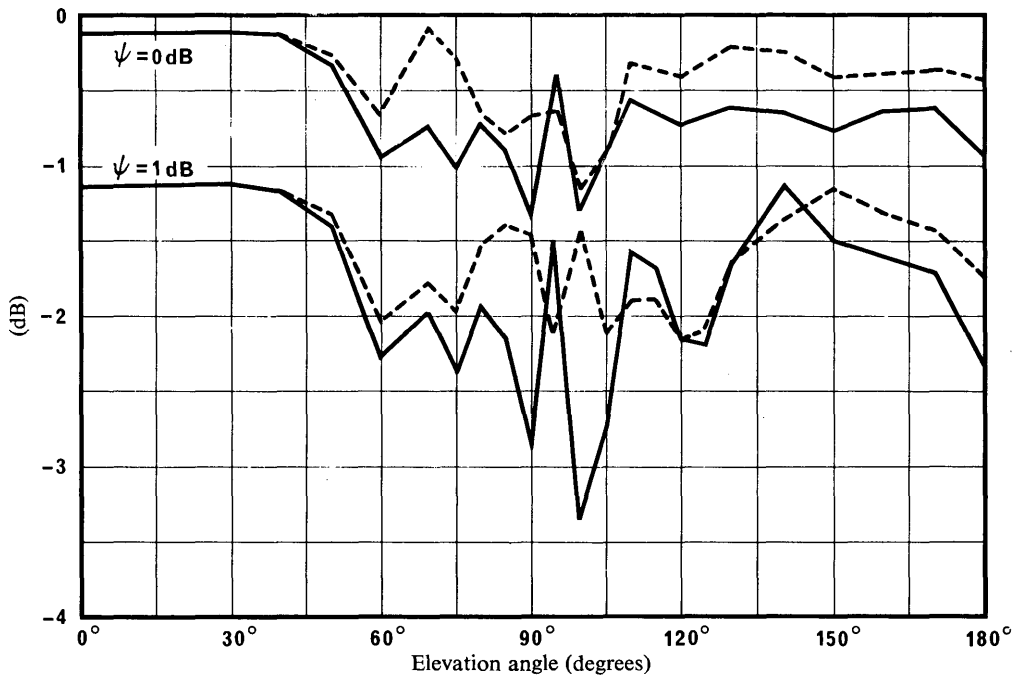


FIGURE 24 — *Computer predicted fading depth versus elevation angle for an oil tanker of 230 000 tons deadweigh*
(ψ = pointing loss)

——— 20 dB directivity

– – – – – 24 dB directivity

5. Conclusions

The results obtained by the theoretical model given in § 2 enable fading due to the multipath effect to be predicted for a wide range of parameter values. It has been shown that fading depth increases with decreasing wave height, with the exception of very calm sea in cases where the main antenna lobe does not meet the sea. The fading depth generally decreases with increasing satellite elevation angle (with, in some cases, the exception of rough sea). The fading depth increases with decreasing antenna gain. The severity of fading predicted for 99% of time may require future consideration of values of fading predicted for 95% of time.

For low elevation angles the coherent (specular) component of the reflection may predominate while the incoherent (diffuse) component dominates for higher elevation angles.

The experimental results described above show that the multipath effect increases with decreasing satellite elevation angles and, generally, with calmer sea conditions. This effect must be taken into account in link budgets by allowing for a margin selected as realistically as possible. From the results obtained during the tests described in § 3.3, the approximate carrier fade levels given in Table V would appear to be realistic for an antenna gain of about 20 dB and for a continuous wave. For antenna gains higher than 20 dB, the results of § 2 show that the carrier fade levels obtained will be lower than those indicated in Table V.

The results of this Report and the results given in Report 744 imply that the most conservative specification for system margin, due to multipath received by a ship terminal, may be obtained from the *CW* carrier fade depth, irrespective of the modulation employed. This must be confirmed by further experimental results.

Reflections from the superstructure of a large oil tanker were studied. The results show that fades of the order of one dB may be expected for antenna directivities in a range of 20 to 24 dB, assuming small pointing errors and for the antenna aligned along the axis of the ship.

REFERENCES

BECKMANN, P. and SPIZZICHINO, A. [1963] *The Scattering of Electromagnetic Waves from Rough Surfaces.* Pergamon Press.

BIBLIOGRAPHY

BEARD, C. I., KATZ, I. and SPETNER, L. M. [April, 1956] Phenomenological vector model of microwave reflection from the ocean. *IRE Trans. Ant. Prop.*, Vol. AP-4, **2**, 162-167.

HOGBEN, N. and LUMB, F. E. *Ocean Wave Statistics etc.* Her Majesty's Stationery Office, United Kingdom.

CCIR Documents

Report 505-2.

REPORT 764-1

INTERFERENCE AND NOISE PROBLEMS FOR MARITIME MOBILE-SATELLITE SYSTEMS USING FREQUENCIES IN THE REGION OF 1.5 AND 1.6 GHz

(Study Programme 17A/8)

(1978-1982)

1. Introduction

Operational maritime mobile-satellite systems will employ at least frequencies in the region of 1.5 and 1.6 GHz for the satellite-to-ship and ship-to-satellite links respectively. This Report gives results of a theoretical investigation of the potential interference to a maritime mobile-satellite system from different sources and of the interference caused to other systems from the maritime mobile-satellite systems at such frequencies [Haakinson and Kimball, 1974; Haakinson, 1974]. Results of practical electromagnetic (EM) noise measurements in harbours and on-board ships at sea are summarized [Clarke *et al.*, 1974]. Finally, consideration is given to other sources of noise at these frequencies such as extra-terrestrial noise and receiver noise temperature.

2. Interference to maritime satellite systems

2.1 *Interference from radar altimeters*

Radar altimeters can interfere with the shipboard satellite receivers when aircraft with operating altimeters are in the shipboard antenna beam. It is understood however that the number of radar altimeters operating in this band is diminishing. Radar altimeter operation may be restricted to the high end of the allocated band to reduce the chances and duration of interference.

2.2 *Interference from aeronautical satellite systems*

An aircraft transmitter of an aeronautical satellite system is not expected to cause interference to a maritime satellite system shipboard terminal, even while radiating into the main beam of the shipboard antenna [Haakinson, 1974].

2.3 *Interference from out of band radar emissions*

The AN/SPS-29 air search radar used by US government ships can be considered a potential radio-frequency interference problem. This EM noise source can be suppressed by the insertion of a simple commercially available RF coaxial filter at the transmitter. Similarly the interference from 10 cm surface search radar can also be suppressed with a simple commercially available waveguide filter located at the transmitter output. There was no evidence of Band 9 noise originating from 3 cm surface search radars used by government and merchant ships.

2.4 *Interference from existing shipborne communications equipment and associated high voltage insulators*

HF ship transmitter emissions may lead to interference in satellite channels of ship earth stations. Results of theoretical and experimental assessment of this effect are published in Annex I of this Report. Further experimental data and study are required.

3. Potential interference from shipboard maritime satellite transmitters

3.1 *Interference to aeronautical satellite systems*

One study has shown that interference from a shipboard transmitter of a maritime satellite system may occur only when the aircraft satellite receiver is within 4 nautical miles of the ship and is within the main beam of the maritime satellite transmitter [Haakinson, 1974].

3.2 *Interference to collision avoidance systems*

Spurious emissions from shipboard transmitters are potentially capable of interference to experimental collision avoidance systems. Limits on spurious emission should be established to eliminate insofar as practicable the source of interference.

3.3 *Out-of-band interference to other radiocommunication services*

Satellite ship terminal transmitters may generate intermodulation, harmonic and other forms of spurious emissions which could cause harmful interference to other services operating above, between and below the 1.5 and 1.6 GHz maritime mobile satellite service bands. Limits on spurious emissions from satellite ship terminals should be determined which would eliminate insofar as practicable such interference. Studies on the values of limits should recognize practical equipment limitations.

3.4 *In-band interference to the fixed service*

In accordance with the provisions of No. 727 and 730 of the Radio Regulations, the band 1540 to 1660 MHz is also allocated to the fixed service to certain Administrations in Regions 1 and 3.

The potential interference from shipborne transmitters to the fixed service is under study.

4. Electromagnetic compatibility

An in-harbour and at-sea electromagnetic compatibility survey was made on board the *American Alliance* for a maritime satellite shipboard terminal operating in the 1500 to 1600 MHz band [RCA, 1974].

4.1 *Field strength*

Measurements of field strength 1 m from the radar transmitter cabinets in the storage room showed that the cabinet radiation was not excessive.

Field strength measurements at the above deck locations showed levels that were either equivalent to or less than the levels measured in the storage room.

Radar interference to the shipboard terminal was influenced by the relative location of the antennas. On the *American Alliance*, the separation between the maritime satellite antenna and the radar Band 9 antenna was 9.2 m, and for the Band 10 antenna it was 7.4 m. Closer spacing might justify the requirement for an additional low pass filter.

4.2 *Interference to radars*

The test for shipboard satellite terminal interference to the Band 9 and Band 10 radars as installed on the *American Alliance* showed that this should not be a problem with 15 W power from the shipboard satellite transmitter. One 1.2 m (4 feet) diameter parabolic dish reflector, containing a right-hand circular polarization feed, was used. The antenna gain was 24 dB at 1559 MHz.

5. Extra-terrestrial noise

Table I summarizes the effects of extra-terrestial radio noise sources on a system at 1500 MHz.

6. Atmospheric noise from absorption

An absorbent medium, such as oxygen and water vapour in the atmosphere, emits thermal noise that can be described in terms of apparent sky temperature. Report 714 gives a summary of available information. At 1600 MHz the temperature varies from 80 K to 2 K between elevation angles from 0° to 90°. At a 10° elevation angle the sky temperature is about 10 K. (See also § 5.2 of Report 714.)

7. Noise of satellite ship terminal receiver

The noise temperature of a satellite ship terminal receiver will depend mainly on the type of pre-amplifier stage and the feeder loss between the antenna and pre-amplifier. Typically the pre-amplifier would be mounted immediately behind the antenna to minimize feeder loss. In such a configuration a transistor pre-amplifier can provide a receiver noise temperature of the order of 225 K and an uncooled parametric amplifier of the order of 55 K.

8. Man-made noise

Data have been recorded in harbour and at sea for approximately ten different classes of ships [Clarke *et al.*, 1974]. All of the significant electromagnetic noise sources of Band 9 (1535 to 1660 MHz) which were measured were determined to be broadband in character relative to the link bandwidths contemplated for future maritime mobile-satellite system design. The broadband noise was intermittent and generally having a duration much shorter than a typical message element envisaged for a maritime satellite system.

TABLE I – *Extra-terrestrial radio source characteristics at 1500 MHz*

Source		Sun	Moon	Jupiter	Casseopeia	Galactic centre
Source size (steradians)		$1{\cdot}35 \times 10^{-4}$	$1{\cdot}07 \times 10^{-4}$	Point source	Point source	$1{\cdot}9 \times 10^{-3}$ ($2{\cdot}6 \times 1{\cdot}4°$)
Power flux-density (W/(m^2·Hz))		$9{\cdot}3 \times 10^{-21}$	–	–	$2{\cdot}2 \times 10^{-23}$	
Apparent temperature (K)		10^5	250	2×10^3	–	162
Antenna temperature (K)	20 dB Antenna gain	107	0·21	< 1	0·24	15
	10 dB Antenna gain	11	$2{\cdot}1 \times 10^{-2}$	$< 10^{-1}$	$2{\cdot}4 \times 10^{-2}$	7
	3 dB Antenna gain	2	$2{\cdot}1 \times 10^{-3}$	$< 2 \times 10^{-2}$	$4{\cdot}8 \times 10^{-3}$	2 (estimated)

The predominant sources of serious Band 9 electromagnetic noise were found to be associated with electrical equipment operating intermittently in ports or in close proximity. This noise is generally broadband in character. A high percentage of these intermittent sources originated as broadband impulsive noise from ignition circuits associated with dockside and shipboard unloading apparatus. The same noise category was frequently evident for automobiles and trucks on highways and bridges adjacent to harbours, ports and canals. Also evident at ports is a component of city ambient noise which varies in amplitude from port to port, and also depends upon the time of the day. This noise varies in magnitude by 20 dB depending on whether it is measured on a normal working day or on weekends and holidays, when it is lower in magnitude. Occasionally evident while near or in port were radio-frequency interference noise power density levels 20 to 30 dB above the ambient receiver noise power density level for a 3 dB noise figure receiver. This increase in apparent ambient noise level may seriously affect link thresholds. Beyond radio line-of-sight of any port, radio-frequency interference should not affect receiver sensitivity especially for new ships.

8.1 *Interference from automobiles on an expressway*

The peak amplitude of the noise emanating from the Brooklyn Expressway with heavy traffic was recorded to be about −150 dB(mW/Hz) within Band 9. For this test, a 20 dB gain horn antenna was used, oriented in the direction of the noise source. Under certain operating conditions, man-made noise from automobile traffic may impair receiver sensitivity level [Clarke *et al.*, 1974].

8.2 *Ship-yard*

Extremely high peak amplitudes of noise of −141 dB(mW/Hz) were recorded from the Boston Navy Yard which was in full operation at the time. This noise is a combination of city ambient noise and of broadband electromagnetic noise from industrial equipment. A 20 dB gain horn antenna was used, oriented in the direction of the noise source. Under certain operating conditions ship-yard noise may impair receiver sensitivity levels in Band 9 [Clarke *et al.*, 1974].

8.3 *Dockside noise*

Broadband impulsive noise, originating from combustion engine ignition circuits used with dockside unloading apparatus, was found to exist at all ports. The recorded peak amplitude of the noise at Narragansett Bay, 5 miles from Portsmouth, Rhode Island (USA), is about −137 dB(mW/Hz) within the maritime mobile-satellite receive band. Noise levels of −150 dB(mW/Hz) have been recorded from ships' cranes. A 20 dB gain horn antenna was used, oriented in the direction of the noise sources.

ANNEX I

EFFECT OF SHIPBORNE HF TRANSMITTER OPERATION ON SHIP EARTH STATION

1. Theoretical aspects

A criterion for identifying the extent to which the HF transmitter emissions can affect the ship earth station operation is the susceptibility threshold of the ship earth station receiver. The threshold of susceptibility is assumed to be receiver sensitivity level calculated for the corresponding frequencies, f_{SR}, which are capable of producing spurious responses and may be represented by the following expression:

$$f_{SR} = \frac{pf_{LO} \pm f_{IF}}{q} \pm \frac{B_R}{2q} \tag{1}$$

where:

f_{LO}: local oscillator frequency, MHz

f_{IF}: first intermediate frequency, MHz

B_R: 3 dB bandwidth at the first intermediate frequency, MHz

p,q: harmonic number of local oscillator and interfering signal, respectively (p,q = 0, 1, 2 ..., etc.).

The receiver spurious response susceptibility threshold at the receiver input, $P_R(f_{SR})$, can be expressed as:

$$P_R(f_{SR}) = P_R(f_{OR}) + I \log \frac{f_{SR}}{f_{OR}} + J \tag{2}$$

where:

$P_R(f_{OR})$: receiver fundamental sensitivity, dBm,

f_{OR}: receiver fundamental frequency, MHz,

I,J: constants for characterizing receiver off-tune rejection, in dB/decade and dB respectively.

The interference signal power produced by HF transmitter emissions at ship earth station receiver input, $P_I(f_{SR})$, is determined for transmitter fundamental harmonics in accordance with the following equation:

$$P_I(f_{SR}) = P_T(f_{OT}) + A \log n + B - L_c \tag{3}$$

where:

$P_T(f_{OT})$: fundamental power, dBm

n: harmonic number of transmitter frequency (f_{OT}) relative to receiver spurious response frequency (f_{SR}), $n = f_{SR}/f_{OT}$,

A,B: constants for characterizing transmitter harmonic emission levels, in dB/decade and dB respectively,

L_c: coupling loss, in dB, including propagation, receiver antenna and transmitter antenna effects.

Equations (1) and (2) were applied to calculate receiver susceptibility threshold for spurious response frequencies most close to HF transmitter operating frequencies. Initial data used in the calculation were as follows:

f_{OR}	= 1538 MHz	f_{LO}	= 1351 MHz
f_{IF}	= 187 MHz	$P_R(f_{OR})$	= −139 dBm
B_R	= 8.5 MHz	I	= −20dB decade
P	= 0	J	= 80 dB.

Results of the calculation are shown in Table II.

TABLE II — *Spurious response susceptibility thresholds*

q	f_{SR} (MHz)	$P_R(f_{SR})$ (dBm)
8	23.37 ± 0.53	−22.6
10	18.70 ± 0.42	−20.7
11	17.00 ± 0.39	−19.9
5	37.40 ± 0.85	−26.7
7	26.71 ± 0.61	−23.8

The spurious response frequencies as given in Table II are the first IF sub-harmonics of ship earth station receive system.

Using equation (3), interference power of spurious response frequencies was calculated and compared with the obtained values of receiver susceptibility threshold. The calculation was performed for those HF transmitter frequencies, f_{OT}, which are capable of producing interference at the receiver spurious response frequencies. It was assumed that $P_T(f_{OT}) = 1500$ W, $A = -70$ dB/decade, $B = -20$ dB, and free space loss over a distance of 10 m was used for L_c.

Results of the calculation are shown in Table III.

TABLE III — *Spurious response interference power*

f_{OT} (MHz)	n	$P_I(f_{SR})$ (dBm)	$P_I(f_{SR})/P_R(f_{SR})$ (dB)
4.670 ± 0.1062	5	−27.0	− 4.4
6.2333 ± 0.1417	3	− 9.5	+11.2
17.00 ± 0.3864	1	+24.7	+44.6
8.50 ± 0.1932	2	+ 3.6	+23.5
12.4666 ± 0.2833	3	−15.5	+11.2
13.3571 ± 0.3035	2	− 0.3	+23.5

The above interference values are for only the first sub-harmonics of the ship earth station IF. It should be noted that equations (2) and (3) do not take into account non-linearities in active receiver or transmitter components that can affect the relative susceptibility or emission levels for different harmonics.

2. Experimental Results

During the experimental period, $(I+N)/N$ levels were measured to identify the effect of HF transmitter emissions. Interference was produced by the HF transmitter emissions at the frequencies selected within the band shown in Table III. Noise levels and interference-plus-noise levels were determined for 20 kHz bandwidth in the first IF channel of the ship earth station.

The ship earth station antenna was directed towards the HF transmit antenna located at 8.6 m distance. The transmitter was operating in A1A emission mode, the emitted power being 1.5 kW.

Shown in Table IV are results of processing of measured $(I+N)/N$ values.

TABLE IV — *Mean $(I+N)/N$ vs HF transmitter operating frequency*

f_{OT} (MHz)	4.68	6.23	8.35	12.51	13.2	16.75
$(I+N)/N$ (dB)	0	20	18	23	17	16

The measured interference in Table IV does not compare directly with the calculated interference in Table III. Any inconsistency is due to a number of factors not taken into account in calculating Table III values, e.g. frequency dependent effects on L_c. Further information on predicting spurious responses can be found in Reports 522 and 524.

The interference in receive channel was narrowband in nature, with its level dependent upon directing the ship earth station antenna towards HF transmit antenna.

Throughout the experiment period, the effect of HF transmitter emissions on the quality of telephone and telex message reception was examined at $f_{OT} = 12.502$ MHz which causes interference at the receive frequency 1537.75 MHz (satellite channel). Values of $(I+N)/(C+N)$ were determined.

No troubles were experienced in reception of reference telex messages with $(I+N)/(C+N) \leqslant 4$ dB. Quality of reception of telex messages with the $(I+N)/(C+N)$ exceeding 4 dB was not examined. It should be noted that the said ratio may reach 15 dB at low elevation angles.

Degradation of reception performance was observed in telephone channels with $(I+N)/(C+N) > 0$. Should the $(I+N)/(C+N)$ value measured in the first IF channel be equal to or exceed 5 dB, the telephone channel was completely blocked due to the interference.

REFERENCES

CLARKE, J. M., CANTOR, S. R., WINCHUS, J. J. and CAPORALE, A. L. [December, 1974] Measurement and analysis of L-band (1535-1660 MHz) electromagnetic (EM) noise on ships. Final Report No. CG-D-50-75. US Department of Transportation, Washington, DC 20590.

HAAKINSON, E. J. [October, 1974] Spectrum resource assessment for the 1535-1660 MHz bands (Addendum). OT Technical Memorandum 74-165-2, US Department of Commerce, Washington, DC.

HAAKINSON, E. J. and KIMBALL, H. G. [March, 1974] Spectrum resource assessment for the 1535-1660 MHz band. Phase II – Analysis. OT Technical Memorandum 74-165, US Department of Commerce, Washington, DC.

RCA [August, 1974] In-harbour and at-sea electromagnetic compatibility survey for maritime satellite L-band shipboard terminal. RCA Service Corp. Contract NAS5-24035. National Aeronautics and Space Administration, Washington, DC.

BIBLIOGRAPHY

DUFF, W. G. and WHITE, D. R. J. [1972] EMI Prediction and Analysis Techniques. A Handbook Series on Electromagnetic Interference and Compatibility, Vol. 5, Germantown, Maryland, USA.

REPORT 765

EFFICIENT UTILIZATION OF THE ALLOCATED FREQUENCY BANDS FOR THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

1. Introduction

The frequency spectrum is a precious resource. The efficiency of frequency spectrum utilization can be enhanced by employing frequency re-use techniques, careful frequency assignment and other methods of maximizing the traffic-carrying capacity of available frequency bands. Once the methods of using the frequency allocation have been decided upon, it may be very difficult to change them later. Since some of the techniques which maximize frequency spectrum utilization have a great effect on both satellite and ship-board terminal design, it is necessary to study this subject at the initial stage of the maritime mobile-satellite service.

2. Channel requirements

The traffic forecast for a world-wide maritime satellite service has been considered by the IMCO Panel of Experts on Maritime Satellites and has been presented in the Report to the Governments [IMCO, 1974].

The analysis has shown that the number of equivalent telephone channels required on a world-wide basis will "most probably" exceed 150 channels after about 13 years of operation, and a further increase in the channel requirements is likely to occur also in the later stages of development. Therefore, the system must be planned in such a way that it can accommodate more than 150 channels in order not to limit the growth of the service. Since a 7.5 MHz allocation divided into 50 kHz channels equates to 150 channels, it is clear that the techniques to improve the efficiency of the frequency band must be considered.

3. Methods for efficient utilization of the allocated frequency bands

The following methods should be considered individually or in combination, in order to obtain an efficient utilization of the frequency band:

- frequency re-use through orthogonal polarization;
- minimization of channel spacing for a given signal bandwidth;
- re-use of frequencies through geographical or angular separations;
- frequency off-set;
- modulation methods resistant to interference.

3.1 *Frequency re-use through orthogonal polarization*

The use of orthogonal polarizations, as conditioned by cross channel interference, is affected by the obtainable cross polarization discrimination of the various antennas in the communications link and by depolarization phenomena encountered along the signal path.

Signal depolarization may be due to various effects, the most important of which are:

- ship motions,
- ship superstructure reflection,
- multipaths,
- satellite rotations.

These problems must be studied carefully and to the extent possible by means of experiments, keeping in mind the different types of ships' antennas (gains going from 0 dB to above 20 dB) which are expected to be used for the various communication services.

More generally, the performances of linear polarized systems, as opposed to circularly polarized systems, should be studied in this respect.

3.2 *Minimization of channel spacing for a given signal bandwidth*

This is limited by:

- the frequency error of individual carriers;
- the allowable inter-channel interference;
- the intermodulation introduced by the satellite transponder;
- the effect of filters on the spectrum of the transmitted signal.

3.2.1 *Frequency errors of individual carriers*

The main sources of frequency errors are due to Doppler shift and instability of the local oscillators in the shore station, in the satellite and in the ship terminal.

Doppler shift in a maritime satellite system is caused by the relative motion of the satellite with respect to a shore station and by the movement of ships relative to the satellite.

In the case of the shore station/satellite component of Doppler, the precise value will be different at each shore station location. However, it is possible, by a suitable adjustment of a particular shore station transmit or receive frequency, to compensate completely for the Doppler component at that shore station arising from satellite motion.

In the case of the ship/satellite component of Doppler, the frequency error is obviously different for each ship. There is no known simple or economic way for this component of Doppler shift to be compensated.

Table I indicates the frequency error resulting from some assumed values of frequency stability for shore station satellite and ship station equipment with an assumed 50 kHz channel separation plan. The values of frequency stability are considered feasible without incurring substantial economic penalty.

Frequency errors can be reduced in several ways, such as:

- the use of higher stability local oscillators,
- the use of spectrum centring pilots.

Higher stability oscillators may have considerable impact on the system cost, particularly as far as satellite transponders are concerned. This solution does not reduce Doppler shift.

Spectrum centring pilots can be used in two ways:

(a) in connection with automatic frequency control (AFC) in the receivers. Only one pilot signal is required to control all receivers. In fact, the whole frequency band comprising both the pilot and the communication channels is shifted in frequency but remains properly spaced. This method could be used in either the ship-to-shore or shore-to-ship direction, but the application of this technique to the latter case is not preferred since it would unduly complicate the ship terminal equipment;

(b) by measuring the frequency of the pilot signal after transmission through the satellite. The information is used to adjust the frequencies of the transmitted carriers at the shore station so that the carriers are received at their nominal frequencies. This method may be used in the shore-to-ship direction.

The advantages of spectrum centring pilots are:

- the stability requirements of the satellite transponder can be reduced without affecting the channel spacing of the received signals;
- where method *(b)* is used in the shore-to-ship direction, individual ship receivers need not be equipped with AFC;
- the component of Doppler shift due to the motion of the satellite relative to the shore station may be compensated; for ships not too distant from the particular shore station which has been specially compensated for Doppler on a 1.6 GHz satellite-to-shore link, there will also be some compensation for Doppler arising from satellite movement relative to the ship. Doppler error arising from movement of the ship itself would, of course, remain uncompensated.

From the figures given in Table I it can be deduced that whatever the choice for the shore-to-satellite and satellite-to-shore frequency bands, the net residual frequency error can be reduced to less than $\pm$ 1.5 kHz by means of spectrum centring pilots, (limited only by residual Doppler error in the 1.6 GHz band and errors from ship oscillator instability).

Further study is required on the ways in which spectrum centring pilots could be implemented.

3.2.2 *Inter-channel interference*

The inter-channel interference depends on the voice processing method, the modulation technique used and the performance objectives chosen. As yet, no general rules have been established concerning the required width of the guardband.

3.2.3 *Intermodulation*

If hard limiting is used in the satellite transponder, the amount of intermodulation distortion may become excessive. In such situations, a channel spacing such as the Babcock spacing must be employed, which leads to inefficient utilization of the frequency band. Therefore, in order to achieve efficient utilization of the frequency spectrum, the best possible carrier-to-intermodulation-noise ratio performance at the satellite transponder is desirable. However, with present technology, satellite power amplifier efficiency reduces with increasing linearity. Techniques such as pre-distortion, constant gain control and feed-forward, which improve linearity without significantly reducing efficiency, are under investigation.

The intermodulation distortion also depends on the modulation technique and on whether voice activation is used. When voice activation is used, the average intermodulation distortion would be reduced by an amount approximately equal to the voice activation advantage. If voice activation is not used, the actual intermodulation will depend on the spectrum of an idle channel. In FM systems, the idle channel will consist of a pure carrier, unless an energy dispersal technique is used, whereas for the Delta M/PSK systems the idle channel will be modulated by the idle pulse pattern of the Delta encoder, thus resulting in energy dispersal of the RF signal.

TABLE I – *Typical frequency errors*

Channel separation	50 kHz			
Guard band	8 kHz			
Frequencies MHz	1500 or 1600/ 4000 or 6000		1500 or 1600/ 11 000 or 14 000	
	Frequency errors (maximum)			
	Shore-to-ship (kHz)	Ship-to-shore (kHz)	Shore-to-ship (kHz)	Ship-to-shore (kHz)
Transmitting oscillator (Note 1)	±0.18	±0.24	±0.435	±0.24
Up-link Doppler shift: Satellite (Note 2)	±0.46	±0.12	±1.1	±0.12
Up-link Doppler shift: Ship (Note 3)	-	±0.07	-	±0.07
Satellite oscillator (Note 4)	±4.5	±2.4	±13.0	±10.1
Down link Doppler shift: Satellite (Note 2)	±0.11	±0.3	±0.11	±0.89
Down link Doppler shift: Ship (Note 3)	±0.07	-	±0.07	-
Receiving oscillator	±0.12	±0.23	±0.225	±0.35
Total error (maximum)	±5.44	±3.36	±14.94	±11.77
Required information bandwidth (depending on modulation method used)	25-35 kHz			

Note 1. – Frequency stabilities quoted for ship terminals and shore stations assume use of quartz crystal oscillators in continuously running ovens requiring periodic correction to offset aging effects. The periodic correction for shore stations is assumed to be monthly and for ship terminals six to twelve months. On this basis a frequency stability of $\pm 3 \times 10^{-8}$ for shore stations and $\pm 1.5 \times 10^{-7}$ for ship stations would seem to be feasible.

Note 2. – Satellite orbital inclination ±3.0 degrees and zero eccentricity or a combination of lower inclination and some eccentricity.

Note 3. – Ship speed 50 km/h.

Note 4. – Satellite frequency stability $\pm 10^{-6}$ over the satellite lifetime.

3.2.4 *The effect of filters on the spectrum of a signal*

In FM systems, the bandwidth of the transmitted spectrum can be approximated to the Carson rule bandwidth. Truncation of higher order sidebands would not add any appreciable distortion as long as the truncating filters are symmetric.

In digital systems, transmit filters can be designed such that the spectrum width is restricted to less than 1.2 times the Nyquist bandwidth.

The filter problems have been treated by several authors [Lavean and Palmer, 1974; Assal, 1974; Lopriore and Lundquist, 1974; Muratani *et al.*, 1974].

3.3 *Re-use of frequencies through geographical or angular separations*

World-wide coverage (excluding polar regions) can be provided by various arrangements of geostationary satellites. The minimum requirement is for three satellites employing global beam antennas (17° beamwidth). Other possibilities exist. Four satellites provide greater possibilities for frequency re-use than using three satellites. A system which provides for radiodetermination would use more than four satellites. With each of the above possibilities, spot beams (i.e. beamwidths less than 17°) may be employed to provide the necessary coverage. However, the use of spot beams leads to operational complexities and, unless adaptive spot beams are used, to loss of flexibility.

3.3.1 *Frequency re-use in different areas*

3.3.1.1 *Three geostationary satellites*

3.3.1.1.1 *Full re-use*

In this case, each radio frequency can be used in all three ocean areas regardless of whether or not the same frequency is being used simultaneously in an adjacent area. The main constraint is the co-channel interference introduced by the second satellite in the overlap areas. An important parameter here is the relative antenna gain of the ship terminal in the direction of the interfering satellite. This gain cannot be reduced below a certain limit determined by the antenna design and the unpredictable reflections from the superstructure of the ship. Moreover, the individual e.i.r.p.-variation of carriers transmitted by different satellites may require large margins to protect against severe degradations. Further study is required on such aspects as antenna performance, satellite transponder design, statistical distribution of interfering signal levels due to variation of earth station e.i.r.p. and statistics on sea states.

3.3.1.1.2 *Limited re-use*

Channels may be assigned for use in overlap areas only. The number of channels so required depends on the expected traffic to and from ships in these areas.

Co-channel interference may have a significant influence on the system performance only when the angle of elevation is low. Therefore, special frequency assignment is essential only in those parts of the overlap area where the satellite is seen under low angles of elevation.

The number of ships in these zones of the overlap area of the Atlantic and the Indian satellites may be about 7% of the total number of ships in the area covered by the Atlantic satellite alone [Thompson, 1970].

In this case, the number of channels obtainable with partial re-use is 93% of that obtained by full re-use.

One disadvantage concerning limited re-use is that the area of operation of the ship must be known.

3.3.1.1.3 *Globally controlled access*

A combination of the above methods may be used to prevent a channel from being used simultaneously by two satellites covering the same overlap area.

The channels must then be assigned on request from each shore station on a world-wide basis. The channel assignment must be done over one or more service channels common to all shore stations.

Such an approach would seem more practical if there was "control by a single routing centre" as described in Report 596 (Kyoto, 1978).

If the traffic peaks are not likely to occur simultaneously in all three ocean areas, this method may be nearly as efficient as full re-use. The technical and operational problems involved, however, need further study.

3.3.1.1.4 *Zone configuration method*

In the zone configuration method the available channels are divided into groups (G_1, G_2 etc.). The surface of the Earth is divided into zones (Z_1, Z_2 etc.).

Figure 1a shows an example of a zone configuration giving an effective world-wide channel capacity of 450 channels which is a frequency re-use factor of 3. It should be noted that in this example of zone configuration, satellite spot beams would need to be employed (see § 3.3.2).

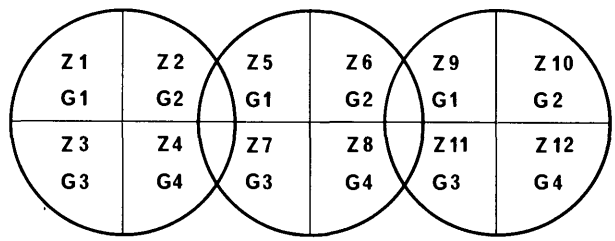
3.3.1.2 *Four geostationary satellites*

The use of four geostationary satellites together with the zone configuration method offers a significant frequency re-use factor. Figs. 1b and 1c show examples which give an effective world-wide channel capacity of 300 and 600 channels respectively, corresponding to a frequency re-use factor of 2 and 4. The example in Fig. 1c requires the use of satellite spot beams (see § 3.3.2). The economic implications of using four satellites instead of three is an important factor that needs to be considered.

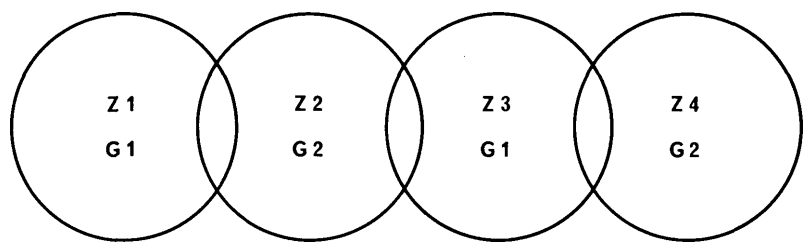
If, in the initial stage of a world-wide maritime satellite service, a three-satellite arrangement is chosen, it would remain possible to extend to a four-satellite arrangement using a zone configuration method at a future time.

3.3.2 *Use of spot beam antennas in the same or in different areas*

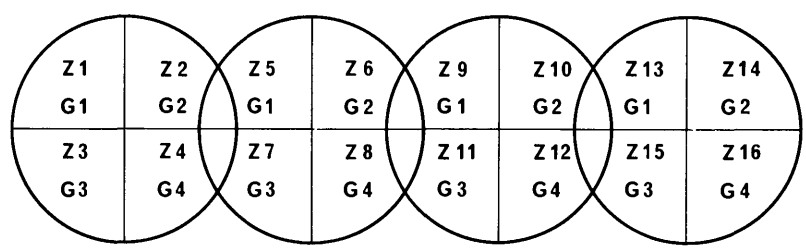
The use of multiple satellite antennae giving spot beam coverage can significantly increase the number of available channels. However, for high channel capacity, unless adaptive spot beams are used, it is desirable to have frequency re-use between spot beams within the same global coverage area. It has been shown [Phillips and Temple, 1975] that the manner in which spot beams are arranged can affect the re-use rate. In Fig. 2a no frequency re-use is possible between any beams within the global coverage area. However, the zone configuration methods as discussed in § 3.3.1.2 can take advantage of such a spot beam arrangement. In Fig. 2b some re-use may be possible between beams 5 and 2, 1 and 4 etc., although isolations may not be sufficient depending on attainable discrimination between beams. The possibility exists of utilizing additional discrimination such as that provided by frequency interleaving in order to obtain sufficient isolation between channels, a possibility which may be worth further study.



(a) Three geostationary satellites each having four spot beams and four groups of frequency channels



(b) Four geostationary satellites each having a global beam and two groups of frequency channels



(c) Four geostationary satellites each having four spot beams and four groups of frequency channels

FIGURE 1 — *Example of zone configuration*

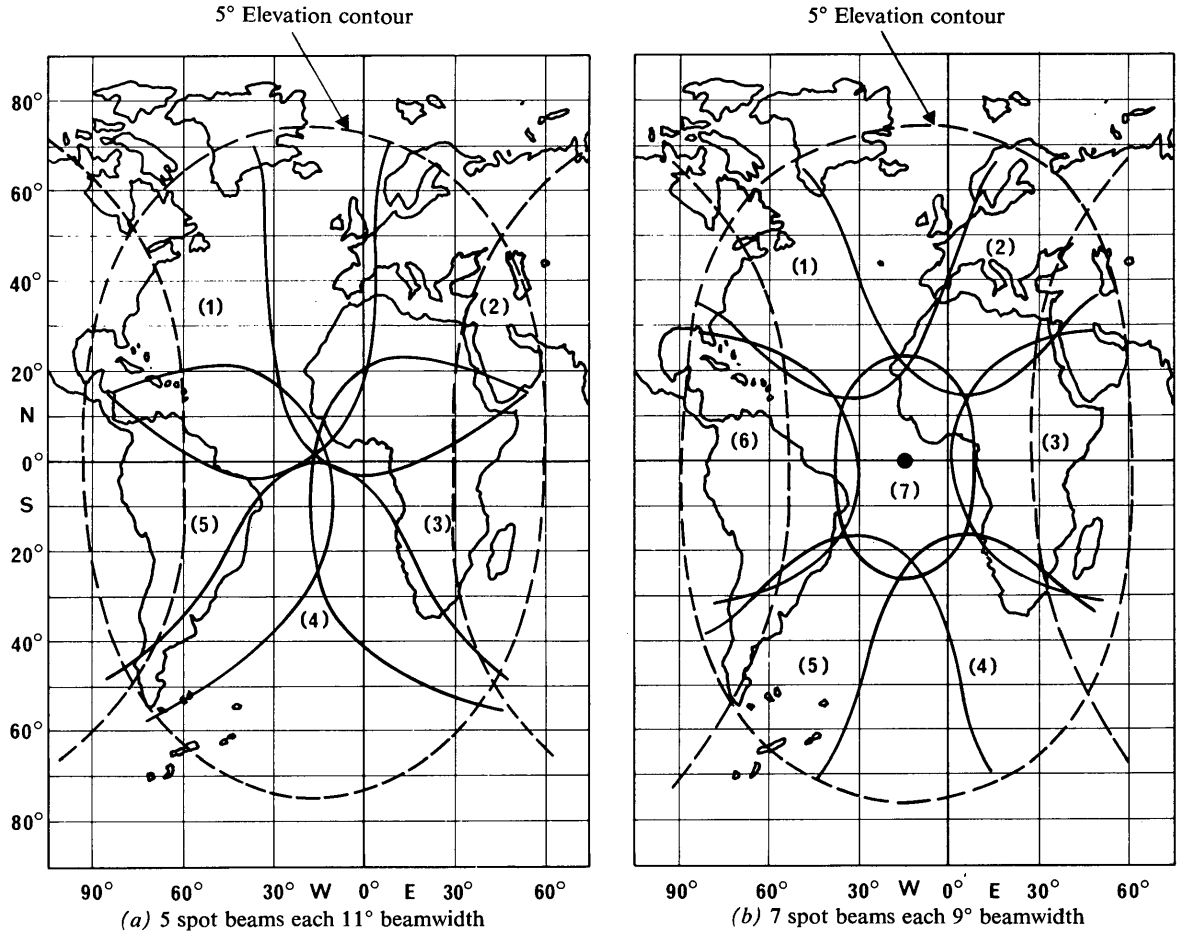


FIGURE 2 — *Some examples of practical spot beam coverage arrangements*

3.4 *Frequency off-set*

It is possible to make more efficient use of the available spectrum by arranging the carriers so that their spacing is some fraction of the actual channel bandwidth. In this way, a large proportion of the energy from one channel will fall into the edge of the adjacent channel. The amount of discrimination that can be achieved needs to be determined experimentally for different frequency off-sets. Frequency interleaving is a particular case of a frequency off-set arrangement where the frequency of a carrier is off-set by one-half of the channel bandwidth from another carrier.

3.5 *Modulation methods resistant to interference*

The immunity of the modulation system to interference is an important factor in efficient spectrum utilization. For example, a four-phase PSK signal has approximately the same resistance to interference as a two-phase PSK signal but needs only slightly more than one-half the bandwidth required for two-phase PSK. A higher than four-phase PSK signal is less resistant to interference than four-phase PSK. Studies on modulation techniques should consider the aspect of resistance to interference.

4. Other considerations

4.1 *Frequency tuning flexibility of the ship earth station*

All techniques of frequency re-use require ships' terminals to tune to specific channels under particular circumstances. Implementation of these techniques is facilitated if ships' terminals are able from the outset to tune to any channel in the allocated 8.5 MHz bandwidth.

4.2 *Antenna radiation patterns*

Some frequency re-use techniques discussed above require good side lobe suppression of the ship terminal antennas. Studies are required on what practical performance is achievable, taking into account the effect to the ship structure. Administrations are urged to submit data on measurements to the CCIR related to the different types of antennas which are expected to be used in the maritime mobile-satellite service.

For a satellite with multi-spot beam antennas, similar considerations apply.

4.3 *Permissible interference levels*

The allowable noise power on the hypothetical telephone reference circuit will include a contribution from inter-channel interference.

The larger the value allowed from this contribution the greater will be the overall frequency re-use factor. This will, however, involve a trade-off between the various noise contributions from the satellite link and the terrestrial network.

4.4 *Sub-synchronous satellites*

The Report of the IMCO Panel of Experts calls for coverage of all ocean areas, including the polar regions, as the long-term objective. A geostationary satellite which radiates channels across all of the allocated band may inhibit sub-synchronous polar orbiting satellites from radiating whilst in the beam of that geostationary satellite. This may have adverse operational consequences in the zone where a ship's angle of elevation to a geostationary satellite is between 0 and 5°, i.e. where it may be preferable to use a sub-synchronous satellite. This requires further study.

4.5 *Assignment of telephony and telegraphy channels to shore and ship stations*

The pre-assignment of telephony channels to shore stations would quickly exhaust the available frequency spectrum. The most efficient use of the frequency spectrum is accomplished when all telephony channels are available for use by all shore stations and ship stations. Public correspondence telephony channels, therefore, should be allocated on an automatic demand assigned basis. Since access channels may be pre-assigned to earth stations there may be an advantage to a limited pre-assignment of telegraphy channels to shore stations, e.g. multiplexed with the access channels (see Report 596 (Kyoto, 1978)).

5. Conclusions

The prospective traffic demand in a maritime mobile satellite system and the available frequency spectrum of only 8.5 MHz in each direction of transmission will make it necessary to consider special techniques to improve the efficiency of use of the frequency band.

This Report indicates a number of areas in which further study is required before any decision on feasibility or the desirability of employing the various techniques available can be taken. However, conclusions can be drawn on some aspects of the studies undertaken so far:

5.1 The use of polarization discrimination or ship antenna side-lobe discrimination in frequency re-use techniques will need to take into account all the antenna sizes that are expected to be used for the various communication services.

5.2 The use of four geostationary satellites instead of three to provide world-wide coverage offers a technically simple solution to increasing the frequency spectrum re-use; however, the extra capital cost and operational complexity may be a disadvantage.

5.3 Ship terminals should be able from the outset to tune to any channel in the allocated 8.5 MHz bandwidth.

5.4 It would assist the introduction of some frequency re-use techniques for provision to be made in the design of ship terminals to enable information on the ship's area of operation to be passed to shore stations.

5.5 The assignment of channels automatically on demand between ship and shore stations is the preferred channel assignment concept. However, for telegraphy a limited pre-assignment of channels to shore stations may be desirable.

5.6 Some form of frequency error reduction technique would appear to be desirable to minimize the effects of the frequency instability of local oscillators in the satellite and shore stations. In particular the use of spectrum centring pilots would appear worth further study.

5.7 A frequency stability of $\pm 1.5 \times 10^{-7}$ for ship stations quartz crystal local oscillators in continuous running ovens would seem feasible providing it is shown to be practicable to re-calibrate the oscillators approximately every 6 to 12 months. Some practical experience would be desirable on this point.

REFERENCES

ASSAL, F. T. [28-30 November, 1972] Optimum bandpass network designs for coherent four-phase PSK-PCM digital communication. Deuxième colloque international sur les télécommunications numériques par satellite. Paris, C2, 164-174.

IMCO [1974] Report of the Panel of Experts on Maritime Satellites, 5th Session.

LAVEAN, G. E. and PALMER [28-30 November, 1972] Efficient utilization of satellite e.r.p. and bandwidth employing TDMA and FDMA. Deuxième colloque international sur les télécommunications numériques par satellite. Paris, B7, 144-153.

LOPRIORE, M. and LUNDQUIST, L. [28-30 November, 1972] Choice of optimum TDMA transmission system. Deuxième colloque international sur les télécommunications numériques par satellite. Paris, C3, 175-182.

MURATANI, T, MATSUSHITA, I., TSUJI, Y and HARA, T. [28-30 November, 1972] Simulation of a PSK transmission system including the non-linear satellite channel. Deuxième colloque international sur les télécommunications numériques par satellite. Paris, C4, 183-192.

PHILLIPS, R. O. and TEMPLE, S. R. [7-10 April, 1975] The impact of multiple spot beam antennas if introduced into a later phase of a world-wide maritime satellite system. IEE Second Conference on Satellite Communication Systems Technology, London.

THOMPSON, R. [15 September, 1970] A study of maritime mobile satellite service requirements, frequency planning, modulation and interference analysis, Vol. I – National and international merchant vessel population and distribution: present and forecast. Automated Marine International, Newport Beach, Calif., USA.

REPORT 766 *

FEASIBILITY OF FREQUENCY SHARING IN BAND 9 BETWEEN THE RADIONAVIGATION SYSTEM NAVSTAR GPS AND TERRESTRIAL RADIOLOCATION AND RADIONAVIGATION SERVICES

(Question 17/8)

(1978)

1. Introduction

This Report refers to Question 17/8, Decides 5. i.e., "Is the sharing of frequencies with other systems feasible, and if so what other systems and under what circumstances?". The Question is addressed for a specific radionavigational satellite system operating in band 9.

This radionavigation satellite system, NAVSTAR Global Positioning System (NAVSTAR GPS), will provide accurate position determination via two satellite-to-Earth transmission channels. A more thorough description of the NAVSTAR GPS system and the rationale behind the selection of frequencies are presented in Annex I.

This Report addresses the feasibility of this system sharing frequencies with the terrestrial stations operating in the 1215 to 1240 MHz portion of band 9.

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* The Director, CCIR, is requested to draw the attention of IMCO and ICAO to this Report.

2. Frequency sharing considerations

The frequency band 1215 to 1240 MHz is presently allocated on a primary basis to the radio location service in all three regions. Thus the feasibility of sharing with these stations has been given primary emphasis. Detailed consideration has also been given to other allocated services, i.e. amateur, fixed, mobile, and radionavigation.

3. NAVSTAR GPS sharing with the radiolocation and radionavigation services

The radiodetermination services presently operating in the 1215 to 1250 MHz radiolocation band are almost exclusively P0N and XXX type emissions with duty cycles between 10^{-2} and 10^{-3}.

3.1 *Interference to the NAVSTAR GPS*

The basic NAVSTAR GPS receiver has been designed to operate in a pulsed environment. From the hardware viewpoint, high-speed, rapid-recovery front-end limiters are used to prevent high-energy pulses from damaging the receiver. In addition, intermediate-frequency clipper circuits essentially maintain the peak pulse voltages at the same level as peak noise bursts.

The modulation structure and system logic are such that the system is essentially invulnerable to normal radar signals. The pseudo-random phase-shift signal with a bit rate in excess of 10 MHz is compressed to an information bandwidth of 50 Hz. This provides an extremely large protection ratio against all types of interference of narrower bandwidth than the GPS emissions. Results of various studies have shown that a system of this type, once synchronized, can function satisfactorily in a pulsed environment which has a duty cycle much higher than any operational environment [USA, 1976].

3.2 *Interference from the NAVSTAR GPS to the radiolocation and radionavigation services*

The signal transmitted from the GPS satellite is of uniform power flux density over the visible portion of the Earth and will appear as a noise-like signal over a band of approximately 20 MHz. The majority of radars operating in the 1215 to 1240 MHz band have IF bandwidths much less than 20 MHz and consequently will receive a noise-like signal with a flat spectral power density over the receiver band pass. The amplitude of this signal will be a function of the radiolocation receiver antenna gain in the direction of the satellite and the impact upon the operation of the radiolocation system will be dependent upon the ratio of this signal amplitude to the receiver noise spectral power density or to the receiver threshold.

The antenna gains and receiver noise figures for the radiolocation equipment operating in the 1215 to 1250 MHz band will vary over a wide range depending upon the system mission. It will be convenient here to utilize the concept of the antenna gain/temperature ratio (G/T) in assessing the impact of the NAVSTAR GPS signal upon the radiolocation systems.

3.3 *Radar sensitivity*

Virtually all radars operate very near their noise level in order to maximize the detectability of the system. There is normally a threshold level established between 5 and 15 dB above the noise level, chosen to optimize the trade-off between suppressing noise peaks and other anomalous responses (false alarms) and detecting the desired signals. Interference power from well below the noise level up to just below the threshold level manifests itself as an increasing number of false alarms. The interference power level at the radar receiver input is given by:

$$(I)_{dB} = (SPFD)_{dB} + (A_e)_{dB} + (B)_{dB} \quad (1)$$

where

$(I)_{dB}$ means 10 log I,

I: interference power in watts,

$SPFD$: GPS satellite spectral power flux-density at earth surface ($W/(m^2 \cdot Hz)$),

A_e: effective antenna aperture of the ground receiving antenna in the direction of the satellite,

B: ground receiver bandwidth in Hz,

$$A_e = \frac{G\lambda^2}{4\pi} \quad (2)$$

where

G: ground receiving antenna power gain,

λ: GPS wavelength = 0.2444 m,

$$(I/N)_{dB} = (I)_{dB} - (kTB)_{dB} \quad (3)$$

where

k: Boltzmann's constant = 1.38×10^{-23} joule K^{-1},

T: receiver noise temperature (K),

B: receiver noise bandwidth (Hz),

I/N: interference to receiver noise ratio that would produce noticeable degradation.

From equations (1), (2) and (3) we have:

$$(G/T)_{dB} = -205.4 + (I/N)_{dB} - (SPFD)_{dB} \quad (4)$$

where:

$(G/T)_{dB}$: maximum ratio of gain of ground antenna to receiver noise temperature for which limiting interference to noise ratio will not be exceeded.

The power flux-density from the satellite L2 signal (see Annex I) in a full capability GPS has been determined to be -200.0 dB(W/(Hz · m^2)). This value includes a margin allowing for satellite aging, signal fading, etc. Substituting this value into equation (5):

$$(G/T)_{dB} = (I/N)_{dB} - 5.4 \quad (5)$$

The value of I/N will vary with the type of radar and some of its basic circuits. For a value $I/N = 0$ dB, the false alarm rate for a simple PPI radar with no clutter, jamming or interference suppression circuits would be degraded from 10^{-n} to $10^{-n/2}$ if the G/T in the direction of the NAVSTAR GPS satellite exceeded -5.4 dB [Barton, 1965]. The range of acceptable values of I/N might extend from -10 dB for very sensitive systems to values exceeding $+20$ dB for systems with automatic clutter suppression and anti-jamming circuits.

For the remainder of this discussion, a value of 0 dB will be assumed for I/N.

3.4 *Variation in G/T*

In the band 1215 to 1250 MHz, the antenna sizes range from 1.8 m (6 feet) to 12 m (40 feet) or 15 m (50 feet) for a range of gains 19 dB to 35 dB. Noise figures range from a few dB to $+15$ dB. The G/T for the main beam illumination of the satellite is given below for three representative systems:

- a small transportable radar with a 3 metre antenna and a 9 dB noise figure would have a G/T of -10 dB,
- a large search radar with a 15 metre antenna and a 5 dB noise figure would exhibit a $+10$ dB G/T,
- space tracking systems with phased-array antennas of 30 metre and noise figures as low as 1.5 dB have a G/T as high as $+26$ dB.

Considering the above examples, it appears that small transportable radars could operate with little or no observable degradation while the larger systems might find compatible co-channel operations difficult.

4. Sharing with the fixed, amateur services and other CW type stations

Presently the Radio Regulations of the ITU permit the amateur service to operate on a secondary basis to the radiolocation service in the 1215 to 1240 MHz band. The allocation in the Radio Regulations is footnoted, indicating that certain countries have allocated the band to fixed and mobile services. Stations in the amateur, fixed and mobile services usually operate via modulating a CW carrier or as a high duty cycle pulsed system (PCM).

4.1 *Interference to the NAVSTAR GPS*

In the previous discussion of interference to the NAVSTAR GPS system it was found that the system was essentially invulnerable to radar type pulsed signals due to their low duty cycle and to the S/I improvement due to the NAVSTAR GPS modulation/demodulation process. This is not so, however, with continuous wave systems.

The NAVSTAR GPS system modulation techniques provide a substantial processing gain to S/N or S/I input levels. However, much of the improvement is required to overcome receiver noise and to allow the use of small omnidirectional antennas and the use of low-cost equipment. The absolute interference power levels which can be tolerated for narrow band or continuous wave signals is not large and has been estimated between -90 and -100 dBm at the NAVSTAR GPS receiver input [USA, 1977].

Meeting these interference limits would place untenable constraints upon these services. For example, a 1-watt transmitter with an omnidirectional antenna could cause interference to a NAVSTAR GPS user out beyond the line-of-sight. For aircraft operations this could be greater than 160 km (100 miles).

4.2 *Interference from the NAVSTAR GPS to the amateur fixed and mobile stations*

Power flux density limitations on the Earth's surface have been specified for space stations operating in the fixed satellite service which share frequencies with the fixed service. These are stated in Recommendation 357 for frequency bands from 1.7 to 23 GHz. Extrapolation of these data to a lower frequency, i.e. 1.2 GHz, would indicate that a power flux density of -156 dB(W/(m^2 · 4 kHz)) would suffice for the case at hand, i.e. NAVSTAR GPS sharing with the fixed and amateur service. The stated NAVSTAR GPS L2 requirement of -164 dB(W/(m^2 · 4 kHz)) should cause no problems. Such services are unlikely to be degraded unless high gain antennas are used, as for tropospheric scatter systems.

5. Conclusion

5.1 *Sharing with radiolocation and radionavigation service*

There are radiolocation systems which can operate on a frequency sharing co-equal basis with the NAVSTAR GPS. However, certain radar equipments with large antenna could suffer interference from NAVSTAR GPS signals.

5.2 *Sharing with the amateur and fixed services*

The power flux-density of the NAVSTAR GPS signal at the Earth's surface appears to be sufficiently low to preclude interference to these services.

Transmissions of the fixed or amateur service stations can cause degradation to the NAVSTAR GPS system over very large areas.

REFERENCES

BARTON, D. K. [1965] *Radar System Analysis.* Prentice Hall, Englewood Cliffs, NJ, USA.

USA Electromagnetic Compatibility Analysis Center [October, 1977] An EMC analysis of the GPS receiver in the domestic and foreign environment. USAF Systems Command Electronic Systems Division Technical Report ESD-TR-77-006.

USA Space and Missile Systems Organization [July, 1976] Operating frequencies for the NAVSTAR/global positioning system, Final Report. USAF Air Force Systems Command Report SAMSO. TR-76-197 (NTIS AD-A030164).

ANNEX I

TECHNICAL CHARACTERISTICS OF THE NAVSTAR GLOBAL POSITIONING SYSTEM

1. NAVSTAR GPS system

1.1 *System description*

The US Government is developing a satellite system for the radiodetermination service. The system as proposed will provide accurate position determination in three dimensions anywhere on or near the surface of the Earth.

The system, in its operational form, known as the NAVSTAR Global Positioning System (NAVSTAR GPS) will consist of 24 satellites in three circular 12 hour orbits inclined 63° to the equator. This configuration will ensure that at least three satellites are visible at all times at any spot on the Earth. Each satellite will transmit the same two frequencies for navigational signals. These navigational signals are modulated with a predetermined bit stream, containing coded ephemeris data and time, and having a sufficient bandwidth to produce the necessary navigation precision without recourse to two-way transmission or Doppler integration.

1.2 *Frequency requirements*

The frequency requirements for the NAVSTAR GPS system are based upon an assessment of user accuracy requirements, space-to-Earth propagation delay resolution, multipath suppression, and equipment cost and configurations. Two channels were selected for NAVSTAR GPS operations: 1575.42 MHz (L1) and 1227.6 MHz (L2) [USA, 1976]. The L1 channel will be used to resolve a user's location to within 150 metres. A second signal transmitted on both L1 and L2 channels, provides the necessary frequency diversity and wider bandwidth for increased range accuracy for Earth-to-space propagation delay resolution and for multipath suppression to increase the total accuracy by an order of magnitude.

Telemetry and maintenance signals from US based control facilities to the satellite and return will be accommodated in the allocated telemetry band in the US.

2. CCIR guidance

The development of such systems has been under careful study of the CCIR for a number of years. There have been four Study Programmes, 25 Reports and two Recommendations generated for the purpose of tracking the progress of development and keeping the community aware of the potential spectral requirements of the final system configurations. Recommendation 361 was formulated and provides the following guidance.

- bands 8, 9, or 10 be used,
- narrowband signals be used where feasible,
- it is preferred that telemetry and control be accomplished on radiodetermination frequencies,
- experimentation be carried out on different bands and using different techniques.

3. Conformance to Recommendation 361

Below is a summary of the various aspects of the NAVSTAR GPS system.

3.1 *Operating frequency*

Primary operation (L1) is in a segment of band 9 allocated to aeronautical radionavigation.

3.2 *Emission bandwidth*

While the emission from any given satellite cannot be labelled narrowband, the fact that the wideband signal serves a large number of users for 24 hour continuous service, provides range accuracy of 15 metres, and provides multipath suppression while generating low power flux densities on the Earth indicates that the system is an efficient user of the RF spectrum. Further study should be carried out to determine the feasibility of reducing the bandwidth.

3.3 *Telemetry functions*

The NAVSTAR GPS is a passive system. There is no need for a navigational up link. Therefore, spectrum is conserved by placing telemetry and housekeeping functions in bands allocated for such use.

3.4 *Development*

The GPS is the result of over 15 years of study and experimentation of a wide variety of competitive systems in an attempt to optimize the configuration of a navigational satellite system.

REFERENCE

USA Space and Missile Systems Organization [July, 1976] Operating frequencies for the NAVSTAR/global positioning system, Final Report. USAF Air Force Systems Command Report SAMSO. TR-76-197, NTIS Accession No. ADA030164. National Technical Information Service, US Dept. of Commerce, Washington, DC, USA.

REPORT 767-1

EFFICIENT DIGITAL SATELLITE COMMUNICATIONS

(Study Programme 17A/8)

(1978-1982)

1. Introduction

Transmission systems carrying voice information generally use analogue processing equipment for companding, echo-suppressing and carrier switching VOX. With analogue processing, initial syllables may be lost because of the low energy content of the first phonemes. This holds in particular when the lower threshold has been raised to reduce the influence of either electrical or room noise.

Digital processing has been found to cope easily with this kind of problem in that it facilitates small delays to be introduced in the stream of digitized voice data, thus providing advanced information to the detectors of the processing equipment which are in turn able to perform more effectively.

A disadvantage of conventional methods of voice digitization is the relatively large bit rate generated: 64 kbit/s for PCM as in SPADE, and 32 kbit/s for Companded Delta Modulation (CDM). These, in turn, require a large bandwidth for transmission.

The disadvantage of the large bandwidth can be alleviated by the use of QPSK which can reduce the frequency occupancy in Delta Modulated Single-Channel-Per-Carrier (SCPC) systems to approximately 22.5 kHz which is slightly less than the bandwidth required by NBFM for the same performance quality.

Comparing the quality of FM to CDM, it appears that CDM is slightly better than FM judging by the articulation tests while on the basis of mean opinion scores FM is preferred over CDM for values of C/N_0 below 52 dBHz. It is concluded on these grounds that the choice between FM and CDM in SCPC mobile services is difficult to make, and that other requirements, should be taken into consideration.

2. Requirements for modulation systems

The modulation methods to be used for the transmission of digital signals in a maritime satellite system, should meet the following requirements:

- efficient bandwidth utilization;
- constant amplitude;
- good bit error ratio (BER) versus E_b/N_0 properties;
- inexpensive and simple implementation.

The following modulation methods can be considered as candidates for the mobile application from the preliminary consideration on necessary bandwidth:

- QPSK;
- filtered QPSK, i.e. hard keyed modulator followed by a spectrum shaping filter;
- phase shaped QPSK in which the digital signal is filtered or shaped and subsequently applied to a linear modulator;
- minimum shift keying (MSK) [de Buda, 1972] often referred to as fast frequency shift keying (FFSK), i.e. FSK with a deviation ratio 0.5;
- tamed frequency modulation (TFM) [de Jaeger and Dekker, 1978; Muilwijk and Noordanus, 1980]; this is a relatively new modulation method, belonging to a class of modulation methods known as "correlative phase shift keying";
- Gaussian filtered MSK (GMSK) [Hirade and Murota, 1979]. This is a modified MSK using a pre-modulation Gaussian low-pass filter and has a narrow bandwidth and out-of-band radiation characteristics. This GMSK can select bandwidths intentionally to conform with the total system characteristics.

The following sub-sections contain a short discussion on these modulation methods in the light of these requirements.

2.1 *Constant amplitude*

If the information is only comprised in the phase of the carrier, hard limiting cannot affect this modulation, so that high efficiency (class C) power amplifiers can be used in the system. Basically the modulation methods considered here have constant envelope signal characteristics. However, the use of post-modulator filters in order to improve the spectrum, results in amplitude modulation of the signal. Transmission of such a signal through a class C amplifier would result in expansion of the spectrum. TFM, GMSK and MSK do not require any post-modulation filtering.

2.2 *Efficient bandwidth utilization*

The most important aspects with respect to bandwidth utilization are the necessary bandwidth and the out-of-band radiation.

The bandwidth properties can be obtained from Fig. 1 in which spectral density curves are shown for the candidates satisfying the constant amplitude requirement and for QPSK.

Figure 1 demonstrates that further away from the carrier, the spectral density distribution of TFM and GMSK is superior to the other modulation methods shown. As shown in this figure, GMSK with $B_bT = \infty$ is a conventional MSK and GMSK with $B_bT = 0.2$ is almost indistinguishable from the TFM from the viewpoint of spectrum compactness. In fact, TFM and GMSK are the only methods that can be compared in this respect with analogue FM where, in the terrestrial services, selectivity requirements of −70 to −80 dB at 25 kHz channel spacing are usual.

Such requirements could not be met by the other digital modulation methods.

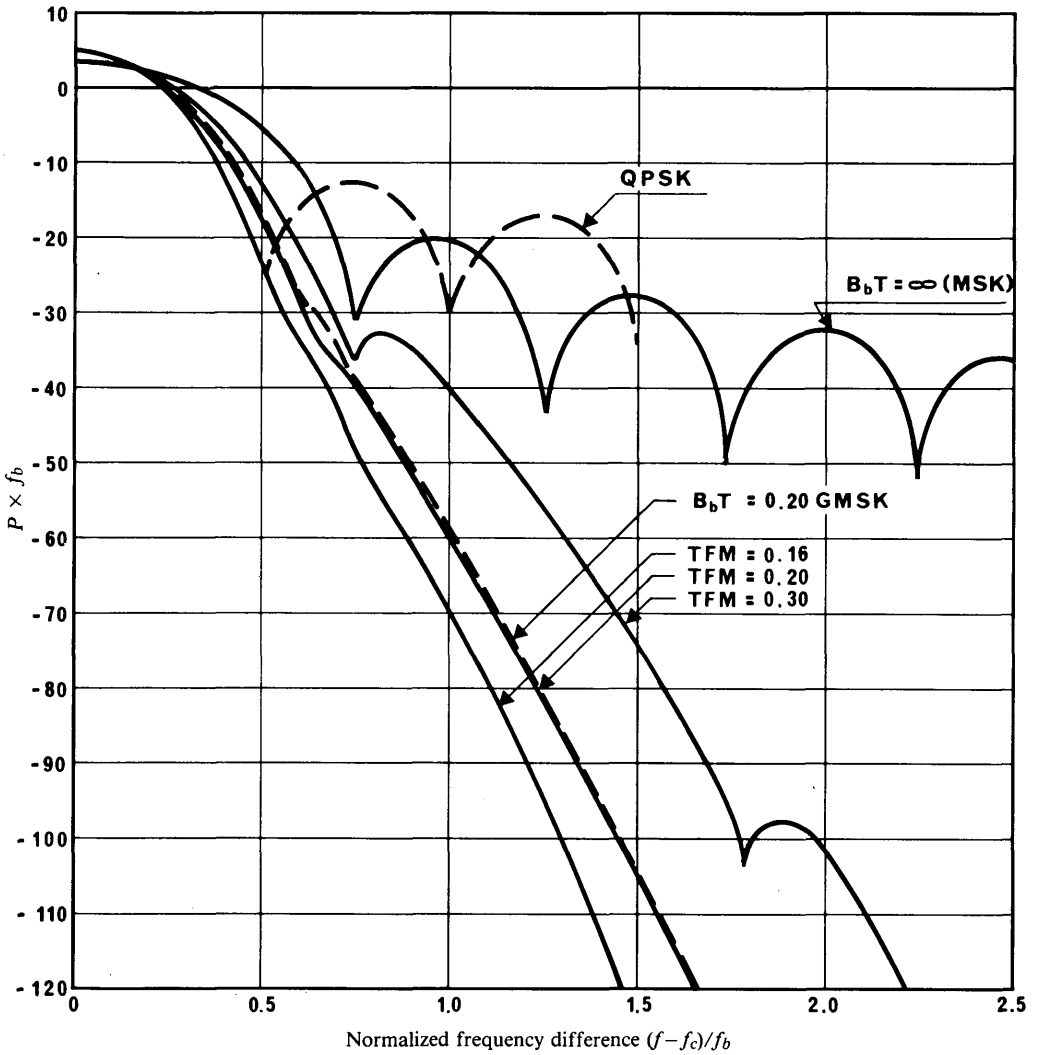


FIGURE 1 – *Power spectral density of GMSK, QPSK, MSK and TFM*

B_bT: normalized bandwidth of premodulation Gaussian bandpass filter (GMSK)
f_c: carrier frequency (Hz)
f_b: bandwidth (Hz)
P: spectral density (W/Hz)

2.3 *Bit error ratio versus* E_b/N_0

BPSK and QPSK have the highest noise resistance, caused by a maximum distance between the signal vectors in the signal space diagram. Therefore BPSK or QPSK can be used as a reference for the judgement of the noise resistance of a modulation method.

Figure 2 shows the following BER versus E_b / N_0 curves:

- theoretical curve for QPSK;
- theoretical curve for TFM with a filter-and-sample detector [de Jaeger and Dekker, 1978];
- a measured curve for TFM including degradations caused by non-ideal filters. IF-limiting and phase jitter in the regenerated carrier and clock signals [Muilwijk, 1979];
- measured curves for GMSK with B_bT = 0.2 and 0.25 respectively, under the condition on predetection Gaussian bandwidth filter normalized bandwidth of 0.63 [Harade and Murota, 1979].

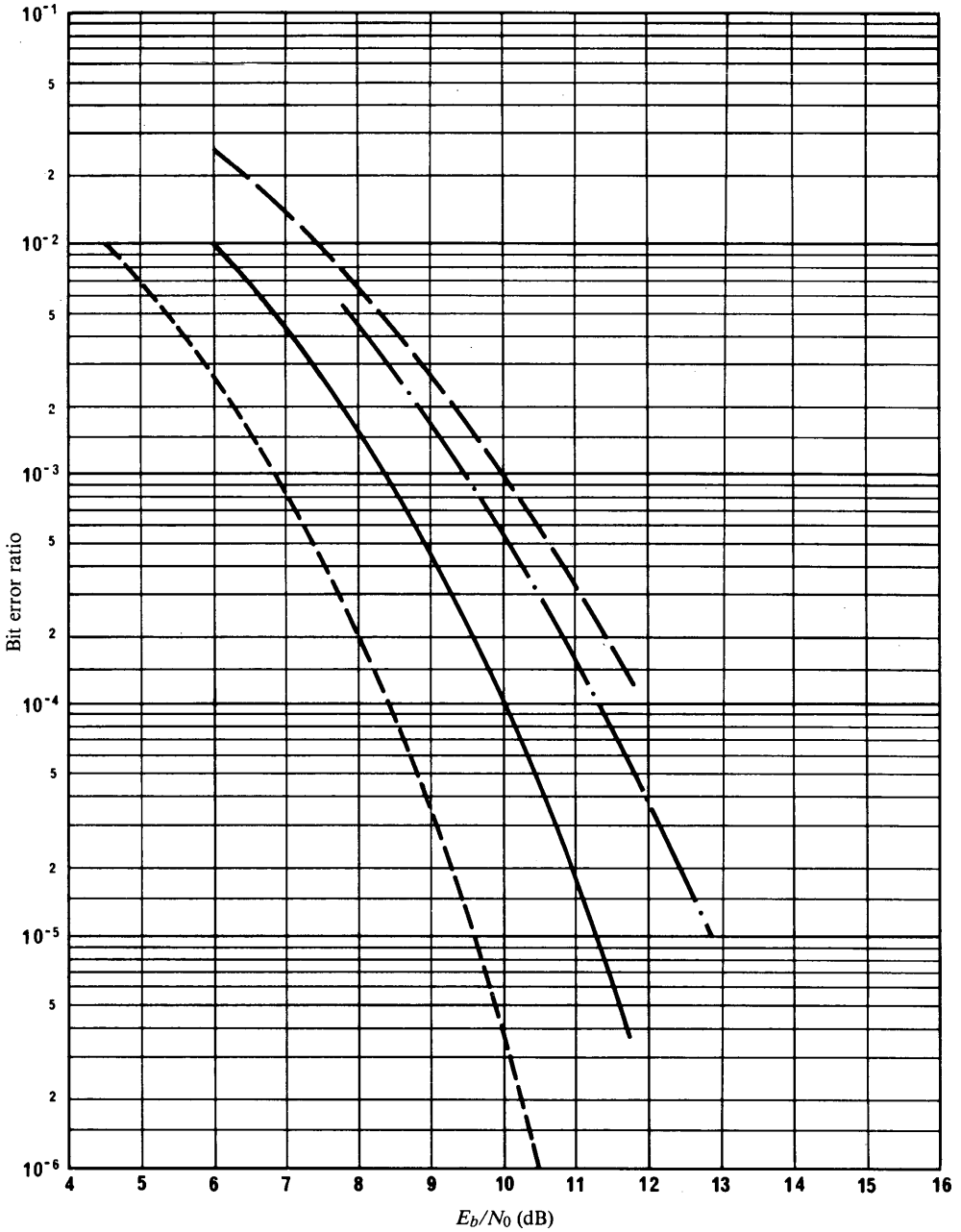


FIGURE 2 – *Bit error ratio vs normalized signal-to-noise ratio*

B_bT: Normalized bandwidth of premodulation Gaussian bandpass filter (GMSK)

— — — : TFM (measured)

• — • — • : GMSK B_bT = 0.20 (measured)

——— : GMSK B_bT = 0.25 (measured) and TFM (theoretical)

— — — — : theoretical BPSK or QPSK

3. Susceptibility to interference

Tests have shown that for a 32 kbit/s data rate the performance degradation at BER of 1×10^{-5} due to the interference from an adjacent channel will be less than 1 dB for BPSK signals separated by 50 kHz, provided the interfering signal power is no greater than 4 dB above the desired signal. With MSK using a channel separation of 25 kHz, 1 dB performance degradation does not occur until the interfering signal power is greater than 14 dB above the desired signal. MSK is clearly superior in a crowded spectral environment.

The low susceptibility to adjacent channel interference can be explained by the shape of the frequency spectrum. With TFM when transmitting 32 kbit/s, spectrum components 16 kHz away from the centre frequency are 23 dB down; at 32 kHz spectral components are 60 dB down.

Another potential area of concern is the receiver's sensitivity to interference from other users of the same channel frequency. It has been demonstrated that both BPSK and MSK have approximately the same sensitivity to co-channel interference and that they are both superior to QPSK. At a BER of 1×10^{-5}, 1 dB of degradation occurs whenever the interference power is within 15 dB of the signal power.

High levels of impulsive noise from engine ignition can cause interference to UHF satellite communications. Tests have demonstrated that the use of a wide band limiter before detection limits the performance degradation to a few tenths of a dB for both BPSK and MSK.

In an efficient UHF satellite system the voice modems would most likely be operated in a "push-to-talk" mode. Thus, it might be necessary for the demodulator to re-acquire synchronization rapidly. The actual carrier synchronization times are usually a function of the particular implementation of the synchronization scheme and not necessarily an inherent trait of the modulation technique. An MSK demodulator can acquire carrier and bit synchronization simultaneously while the BPSK demodulator usually achieves bit synchronization after phase synchronization; thus, the latter technique (BPSK) is generally slower.

4. Conclusions

Tests have shown that voice communication systems employing CDM perform well in satellite systems under noise and interference conditions.

New modulation techniques, such as GMSK and TFM, have been developed for the transmission of digital information in particular, requiring less bandwidth and showing reduced susceptibility to interference as compared to QPSK. These new modulation techniques generate constant envelope signals permitting a better use of non-linear amplifiers without the need for band limiting filters.

REFERENCES

DE BUDA, R. [June, 1972] Coherent demodulation of frequency-shift keying with low deviation ratio. *IEEE Trans. Comm.*, Vol. COM-20, **3**, 429-434.

DE JAEGER, F. and DEKKER, C. B. [May, 1978] Tamed FM, a novel method to achieve spectrum economy in digital transmission. *IEEE Trans. Comm.*, Vol. COM-26, **5**, 534-542.

HIRADE, K. and MUROTA, K. [27 March, 1979] A study of modulation for digital mobile technology. 29th Annual Conference of the IEEE Vehicular Technology Society, 27-30 March, Arlington Heights, Ill., USA, Conf. Record, Session 1A: New communication techniques and technologies – I, 13-19.

MUILWIJK, D. [March, 1979] Tamed frequency modulation – a bandwidth – saving digital modulation method, suited for mobile radio. *Philips Telecomm. Rev.* Vol. 37, **1**, 35-49.

MUILWIJK, D. and NOORDANUS, J. [1980] Digital phase modulation methods giving a band-limited spectrum for satellite communications. To be presented at the 8th AIAA Communications Satellite Systems Conference, Orlando, Florida.

REPORT 768-1

PERFORMANCE MONITORING OF SHIP EARTH STATIONS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The effect of performance variation or malfunction in ship earth station equipment is potentially severe in terms of disruption of a satellite communications network.

In addition such disruption can cause secondary but nonetheless important problems in the international telephone and telex networks to which the system is connected.

It is thus important that adequate monitoring and supervisory arrangements are made for the maritime mobile-satellite service so that the potentially harmful effects of ship earth station malfunction are minimised.

The solution to the problem contains two basic requirements:

(a) the need to ensure that high reliability and consistency of performance is achieved,

(b) the need to ensure that speedy indication of fault conditions is given so that correction or removal of the fault condition can be quickly effected.

Consideration is given here mainly to the ship earth station monitoring aspects covered by item (b), although it is recognized that item (a), which includes maintenance aspects, could also have an effect on monitoring requirements.

2. Call set-up and clear-down

The call set-up procedures usually involve a simple exchange of appropriate signals largely conducted over the out-of-band signalling channel. This does not prove that the communications link is established or that it is of satisfactory quality. Thus the signalling procedures should include arrangements for "in-band" continuity checks by exchange of signals prior to connection of a call. In the event of lack of confirmation of continuity, the call should be cleared prior to notification of call connection. Although it may appear desirable that a check of quality be made prior to the establishment of a call, this is not, in practice, considered to be essential since it is likely to be an unusual occurrence for the quality to be poor, following a continuity check. A good judge of whether or not the quality is acceptable is of course the user.

So that the absence of a clearing signal does not result in a circuit being held open unnecessarily, both shore and ship stations should be designed so that the connection is released if an interruption is noted on the receive side which exceeds a pre-determined short time interval.

3. Effect of malfunction

Ship earth station faults may cause problems of congestion due to faulty signalling protocols and may cause calls to remain connected after they should have been cleared or, interference problems resulting from the presence of unstable radiated carriers. In addition, if the ship earth station misinterprets signalling instructions, it could be caused to transmit on the wrong frequency or to pick up the wrong time slot on the (TDMA) telex carrier. As a result, interference may be caused to one channel or many channels, depending on the actual fault. Since these faults would result in reduced availability of service, all possible precautions should be taken to minimise the risk of them occurring. In addition measures to enable a faulty terminal to be closed down, if necessary, should be built into the system.

4. Supervision and control

If proper arrangements for supervisory indications are made, the effects of faults can be reduced and speedy detection and correction facilitated. To this end supervisory facilities included in the coast earth station (CES) design should be as complete as possible and should enable an indication to be given of failure of a channel to release after the clearing signal has been given. In addition it is desirable that the CES be able to send alarm signals over the signalling channel to alert the ship in the case of an identifiable ship earth station fault.

In the event that normal release does not occur and the ship earth station (SES) is causing serious disturbance, it should be possible to force-release the SES and close its transmitter down. This action should cause an alarm signal to be raised on board ship. It is then necessary to design the SES so that it can be re-activated by the ship staff after the fault condition has been rectified. This demands the establishment of shipboard checking facilities and procedures to enable checkout to be done prior to re-energizing the transmitter.

5. Monitoring functions

In addition to supervisory functions it is desirable that the SES be designed to carry out certain monitoring functions to ensure it does not radiate if fault conditions are present.

Examples of these monitoring functions and the parameters to be measured are as follows:

- transmitted power level;
- revertive check (desirably at RF) that correctly paired transmit and receive frequencies have been selected;
- length of TDMA and Random Access bursts.

It is desirable that "loop back" facilities be available at the ship installation to permit measurement of certain SES parameters at a land based monitoring station. This may facilitate speedy rectification of faulty ship equipment.

It is possible to envisage a system of automatic polling of SESs in order to ensure, on a routine basis, that all SESs are satisfactorily operational. However, care must be taken with such routines since they may interfere with normal communication. This facility would require the provision of fairly complex software at the CES which could not be regarded as normal provision. It could conceivably form part of a communications system monitoring facility.

On board ship it is desirable to incorporate in the SES design self-checking facilities. It is preferable that these self-check arrangements be manually activated otherwise they may interfere with normal communication functions.

RECOMMENDATION 496-1 *

LIMITS OF POWER FLUX-DENSITY OF RADIONAVIGATION TRANSMITTERS TO PROTECT SPACE STATION RECEIVERS IN THE FIXED-SATELLITE SERVICE IN THE 14 GHz BAND

(1974-1982)

The CCIR,

CONSIDERING

(a) that Earth-to-space transmissions of the fixed-satellite service share the band 14-14.3 GHz with the radionavigation service;

(b) that the World Administrative Radio Conference, Geneva 1979, has asked the CCIR to study the criteria for frequency sharing in this band (Recommendation No. 708, § 2.12);

(c) that the Radio Regulations (No. 856) require that the use of this band by the radionavigation service shall be such as to provide sufficient protection to space stations in the fixed-satellite service;

(d) that, in the band 14-14.3 GHz, sufficient protection for geostationary satellites in the fixed-satellite service can be obtained by limiting the power flux-density produced at the geostationary satellite orbit by stations of the radionavigation service;

(e) that some kinds of radionavigation device, such as small ship radars and motor vehicle collision avoidance devices, although generally of comparatively low power, may be used in very large numbers;

(f) Report 560,

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* This Recommendation should be brought to the attention of Study Group 4.

UNANIMOUSLY RECOMMENDS

1. that in order to provide sufficient protection to space station receivers of the fixed-satellite service, the following limits should apply:

1.1 that where there are few simultaneous interference sources, the maximum value of the peak power flux-density produced at any point in the geostationary satellite orbit by any radionavigation transmitter in the band 14-14.3 GHz should not exceed -150 dB(W/m^2) in any 1 MHz band;

1.2 that where the value of D, as defined below, exceeds 2×10^{-4} the maximum value of peak power flux-density produced at the geostationary satellite orbit by any radionavigation transmitter should not exceed

$$-187 - 10 \log D \quad \text{dB(W/m}^2\text{)} \tag{1}$$

where D is the estimated geographical density of radionavigation transmitters per km^2 simultaneously active in any 1 MHz band, taking into account future needs and averaged over the territory of the Administration concerned or over an area of 10^6 km^2, whichever is less.

REPORT 920

MARITIME SATELLITE SYSTEM PERFORMANCE AT LOW ELEVATION ANGLES

(Study Programme 17A/8)

(1982)

1. Introduction

Maritime satellite system performance at low elevation angles is affected by, *inter alia*, a number of propagation factors. The results of tests performed by Japan, the USA and the U.S.S.R. are described in this Report, and a preliminary assessment of the system performance at low elevation angles is given.

2. Japan tests

2.1 *Background*

In June 1976, measurements of 1.5 GHz multipath fading were made by Japan over a period of 2 days using a MARISAT ship earth station on board the Kurama-Maru (51 000 gross tonnage) receiving the signal from the Atlantic Marisat satellite. The received TDM signal (1537.75 MHz) was continuously recorded on a pen-recorder during the course of cruising off Mauritius, the elevation angle being 0° to 10°.

2.2 *Main characteristics of the measuring system*

Main characteristics of the measuring system used are as follows:

– Antenna gain :	24.2 dBi (1.2 m parabolical antenna)
– Beamwidth :	10°
– G/T:	-4 dB(K^{-1})
– Tracking :	step track (0.5°/step; integration time = 30 s)
– Accuracy of roll/pitch compensation :	within ±1°
– Received C/N:	about 16 dB
– Speed of pen-recorder :	5 mm/min

2.3 *Environmental conditions*

Environmental conditions at the time of measurement are summarized as follows:

–	State of sea :	very rough sea	
–	Wind scale :	6-7	
–	Motions of ship :	roll :	13.0° p-p maximum 9.9° p-p average
		pitch :	2.5° p-p maximum
–	Ship speed :	24-26 knots	

2.4 *Measured data*

In Fig. 1, estimated values of fading depth are shown as a function of elevation angle and percent of time. Here, the fading depth is defined as the difference between each reading of the signal level on the pen-recorder paper for specified time percentages and the level that occurred most frequently (C/N of about 16 dB).

2.5 *Experimental results*

The experiment by Japan has indicated that approximately 4 to 5 dB of signal margin would be required to overcome multipath fading for 99% of the time at an elevation angle of 5°.

3. USA tests

3.1 *Background*

In October 1978, an experiment to determine the extent of degradation of satellite-to-ship and ship-to-satellite signals at low elevation angles in the bands 1.5/1.6 GHz was performed by the USA using the Atlantic Marisat satellite. A MARISAT ship earth station having a G/T of -4 dB(K^{-1}) was used on-board the S.S. Mobile AERO, an 18 600-ton oil tanker, while on route from Norfolk, Virginia to Texas City, Texas, with elevation angles changing from 17° to 0°. Baseline measurements were made during the initial portion of the trip. On a straight line sailing from Tampa, Florida to Texas City, Texas on a heading of 274°, the elevation angle from the ship earth station to the satellite decreased steadily from 11° to 0.3° at an average rate of 0.3° per hour. During this 40 h period the experiment was conducted without interruption.

3.2 *Data collection*

The equipment block diagram of the measurement set-up at the ship earth station is shown in Fig. 2. An IDS-1310A data test set was used to generate either 2400 bit/s or the 1200 bit/s data for input to a DPSK modem (ICC-24LSI) or an FSK modem (GDS1200ES), respectively. The input/output point was at the data jack on the ship earth station console (VOICE/DATA). A 600 ohm variable attenuator, not shown in Fig. 2 was inserted at the data jack for the purpose of adjusting the interface level between the console and the modem. The block size for each transmit/receive test could be either 10^6 or 10^7 bit/s, taking either 7 or 70 min to complete for 2400 bit/s tests, and taking twice as long for 1200 bit/s tests. Besides direct readings from the data test set, a printer was also employed to record the bit error ratios [Fang *et al.*, 1981].

3.3 *Test conditions*

Signal degradations on the received TDM carriers due to atmospheric and sea surface anomalies cannot be assessed until the carrier level shifts due to the effect of demand assignment of telephone calls are resolved. To achieve this, the signal levels were measured during the earlier period of the experiment when the elevation angles were above 10°. The distribution of telephone traffic was not uniform over a 24 h period for any given day. The busy time for ship/shore and ship-ship voice communications via the Atlantic Marisat satellite was generally concentrated in early morning hours, between 0330 and 0530 EST (Eastern Standard Time) and in late morning hours, between 0830 to 1130 EST.

Throughout the entire experiment period, the weather was mild. The sky was either clear or cloudy but it never rained. The windspeed was generally under 15 knots (28 km/h).

The highest sea state during the experimental period was 4, corresponding to a wave height of about 1.2 m (4 feet), which was considered relatively calm. The sea surface was, nevertheless, fairly rough from the point of view of the microwave propagation experiment. This is because at L-band, the wavelength is about 0.2 m, which is only 1/6 of the peak amplitude of the sea waves at sea state 4.

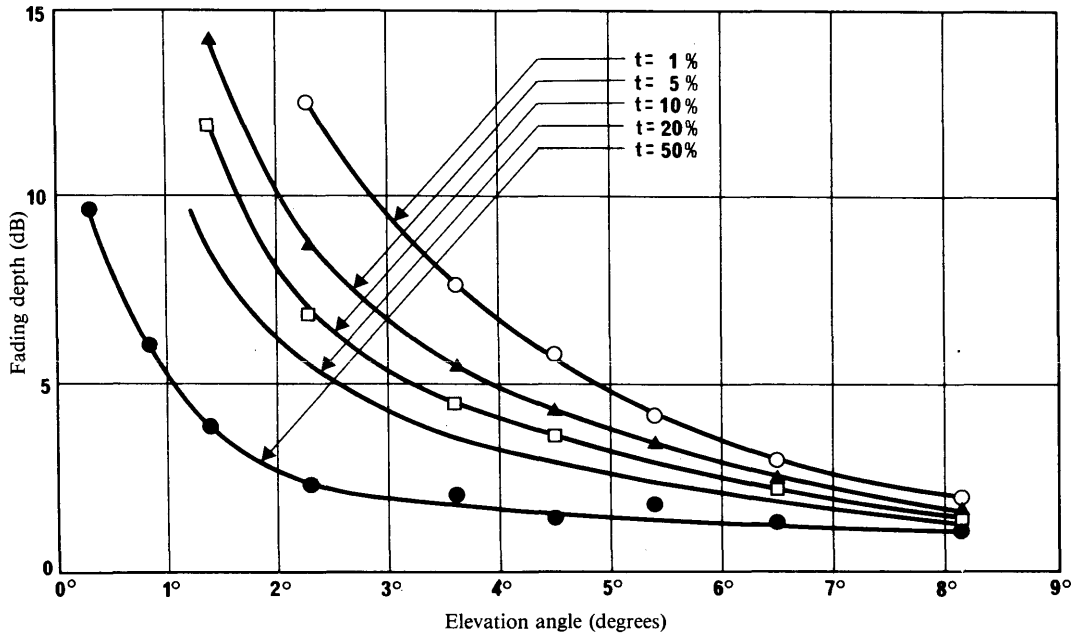


FIGURE 1 – *Estimated values of fading depth as a function of elevation angle*

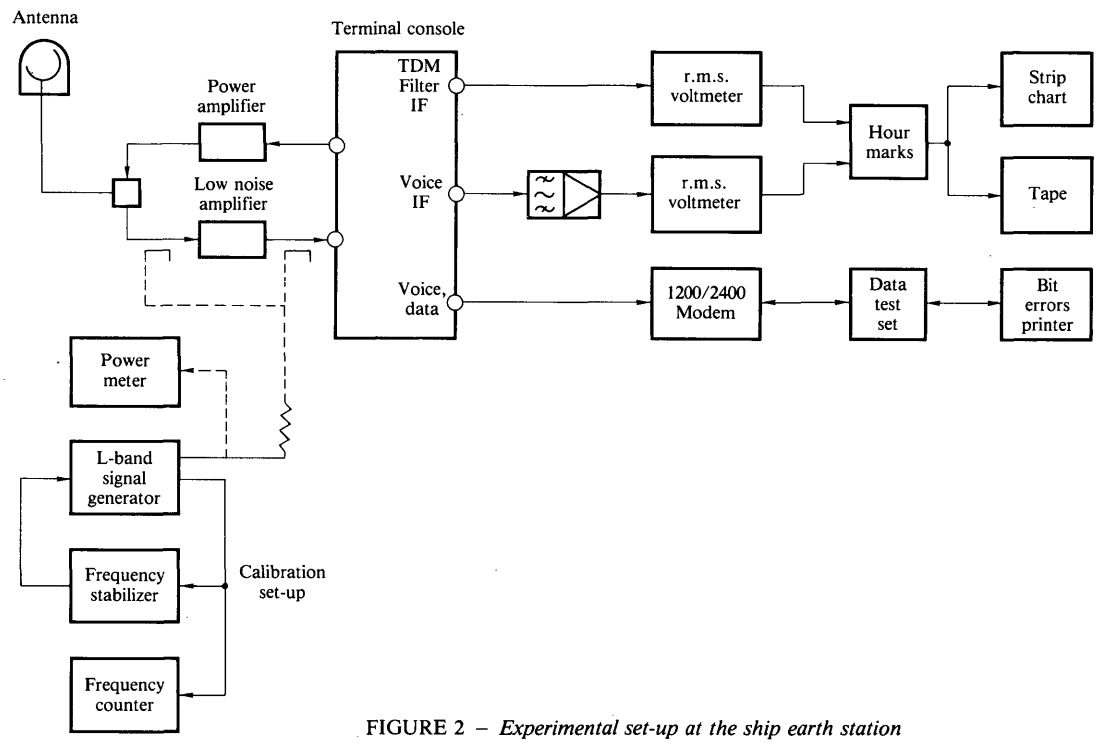


FIGURE 2 – *Experimental set-up at the ship earth station*

3.4 *Experimental results*

3.4.1 *Carrier-to-noise characteristics*

Since the satellite-to-ship TDM and voice carriers are amplified by a common 1.5 GHz TWT, a redistribution of RF powers occurs whenever there is a change in telephone traffic. This is a further cause of the carrier level shifts.

Although such carrier level shifts occur on both TDM and voice carriers, the extent of the shifts is not the same. TDM carrier levels which were continuously available were measured to determine the 1.5/1.6 GHz band C/N variation as a function of elevation angle. (In actuality $(C+N)/N$ was measured in all cases. It is understood that $(C+N)/N$ is implied for measured data where C/N is written.) In addition, the voice carrier levels were measured during times of voice communication or of transmitting and receiving digital data, for the correlation of voice channel C/N and the bit error ratio of the digital signals.

There are two principal differences between the performance at high and low elevation angles:

- mean C/N levels decrease as the elevation angle decreases, and
- peak-to-peak fluctuations of C/N increase with respect to its mean, as the elevation angle decreases.

At extremely low elevation angles, i.e., below 2°, the mean C/N reductions and peak-to-peak C/N fluctuations are so severe that it is impossible to identify the shifts of carrier levels due to the effect of simultaneous telephone traffic.

3.4.2 *BER versus C/N*

For an ideal bit error ratio measurement, the signal C/N should remain at a fixed level, i.e., with little or no variation while the digital data are being transmitted. The BER observed over a block size of 10^6 or 10^7 bits then provides a true measure of probability of errors with a high degree of confidence. Furthermore, if such an ideal measurement can be repeated at different elevations angles, the effect of elevation angle on BER can be readily assessed.

Unfortunately, such an ideal situation never existed during the shipboard tests. First of all, the number of telephone calls changed the C/N level from time to time. Even during a 7 min period, which was the minimum time period required for relaying a block of 10^6 bits at 2400 bit/s rate, the number of simultaneous telephone calls often changed 4 to 5 times. Furthermore, signal fluctuations were severe at low elevation angles. These fluctuations sometimes caused the C/N to fall below the threshold level required to maintain the synchronization of the digital transmission. As a result, an instantaneous drop of C/N below threshold level due to signal fluctuations would generate very large numbers of errors over a prolonged period of time. Even though C/N recovered readily to a respectable level, it took some time for synchronization to be restored.

In order to overcome these difficulties in the data analysis effort, each digital data transmission test was divided into a number of subtests based on the occurrence of sudden shifts of C/N levels. In one 3 min period, the C/N variation about the mean was 2 to 4 dB, which caused a loss of synchronization; while in the following 9 min period, the C/N varied over a 1.0 to 4.0 dB range, giving a BER of 28×10^{-4} with no loss of synchronization. The irregularity is due to the fact that the occurrences of either bit errors and loss of synchronization were random events. Statistical regularities were observable only when an adequate sample size was available, which was not always the case in the subdivisions. Furthermore, the peak-to-peak fluctuations of voice C/N sometimes exceeded 5.0 dB or more. A determination of BER in reference to a fixed value of C/N was not meaningful in such instances. The degradation of BER for elevation angles below 5° was even more serious.

The BER data for elevation angles above 5° were generally much more manageable. This was because the mean C/N was higher and peak-to-peak fluctuations of C/N were less severe, reducing markedly the possibility of synchronization loss. The results of measured BER versus the range of C/N variations during the measurement are presented in Figs. 3 and 4 for the cases of 2400 bit/s DPSK transmission at elevation angles between 5° to 11°, and between 11° and 15°, respectively; and in Fig. 5 for the case of 1200 bit/s FSK transmission at elevation angles between 5° and 11°. Also shown in the figures are curves of BER versus the mean C/N which best fit the data. The gross pattern of the BER fitting curves do follow a general class of error functions, which is consistent with theoretical predictions.

3.4.3 *Multipath measurements*

Measurements of the multipath fading depth were made by observing the level of the time division multiplex signal transmitted from the MARISAT coast earth station located at Southbury, Connecticut. Reduced data for two cases (2.4° and 5.7° elevation angles) are presented in Fig. 6.

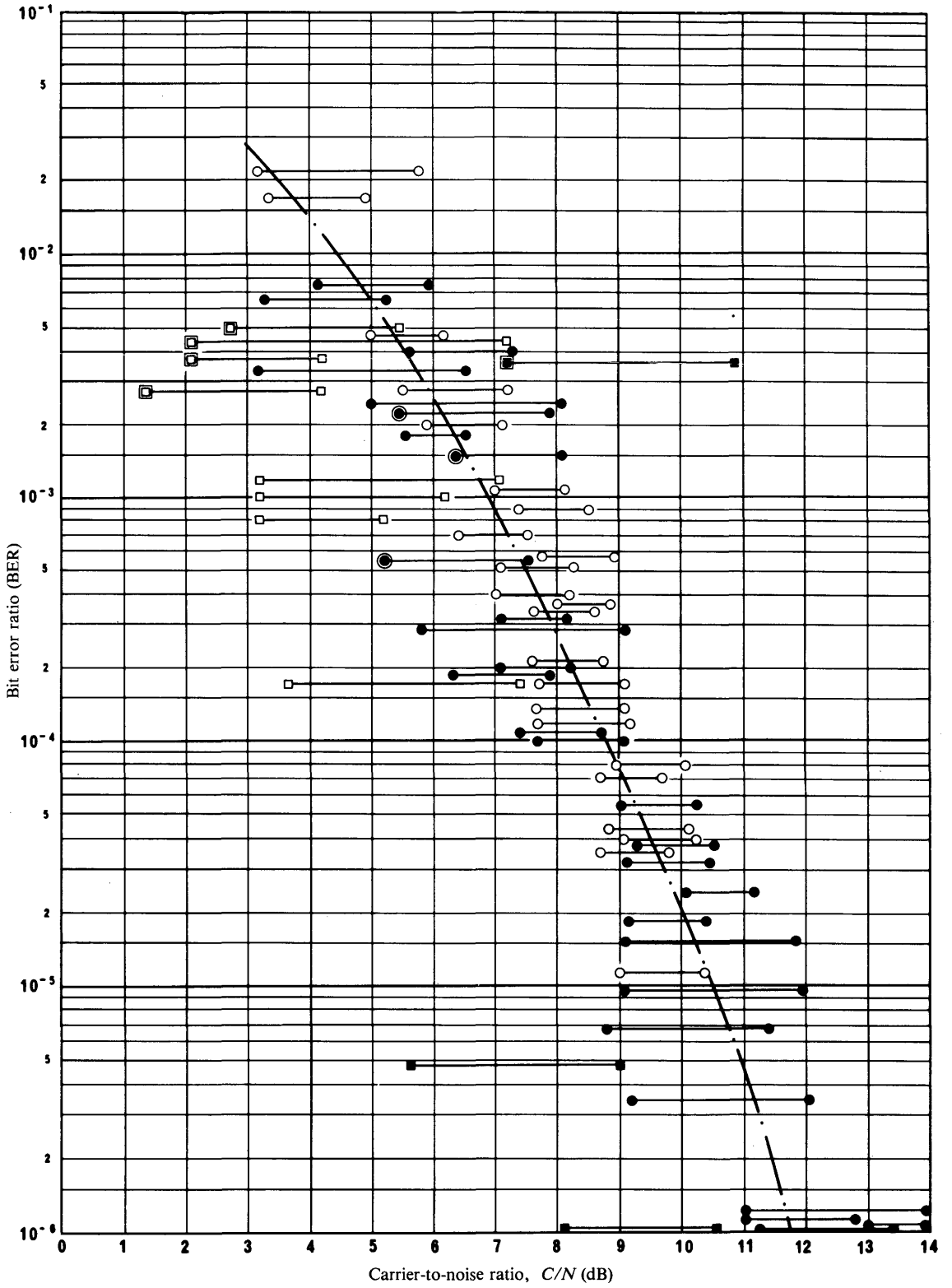


FIGURE 3 – *MARISAT 2400 bit/s DPSK data transmission measurement at elevation angles between 5° and 11°*

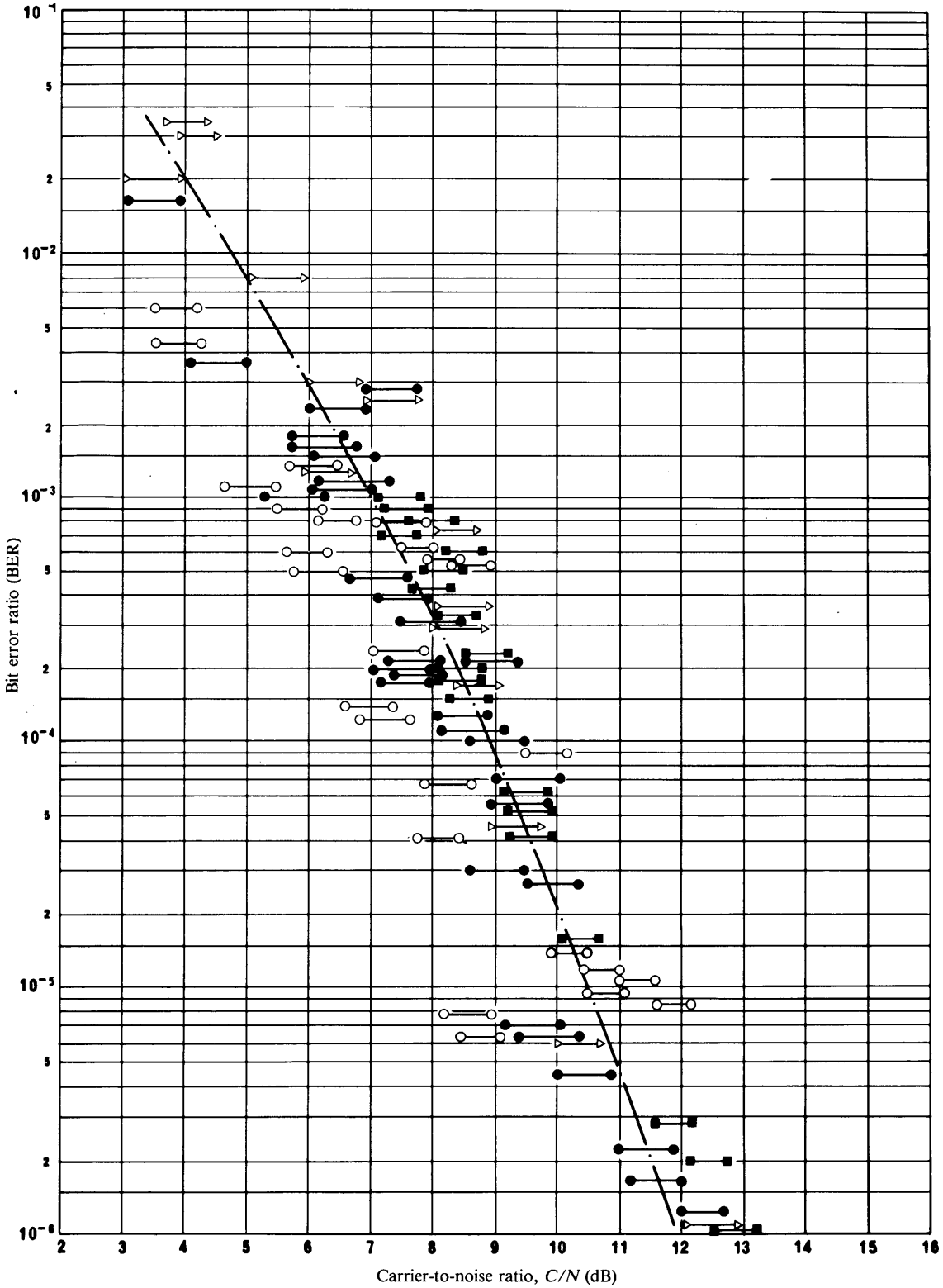


FIGURE 4 – *MARISAT 2400 bit/s DPSK data transmission measurement at elevation angles between 11° and 15°*

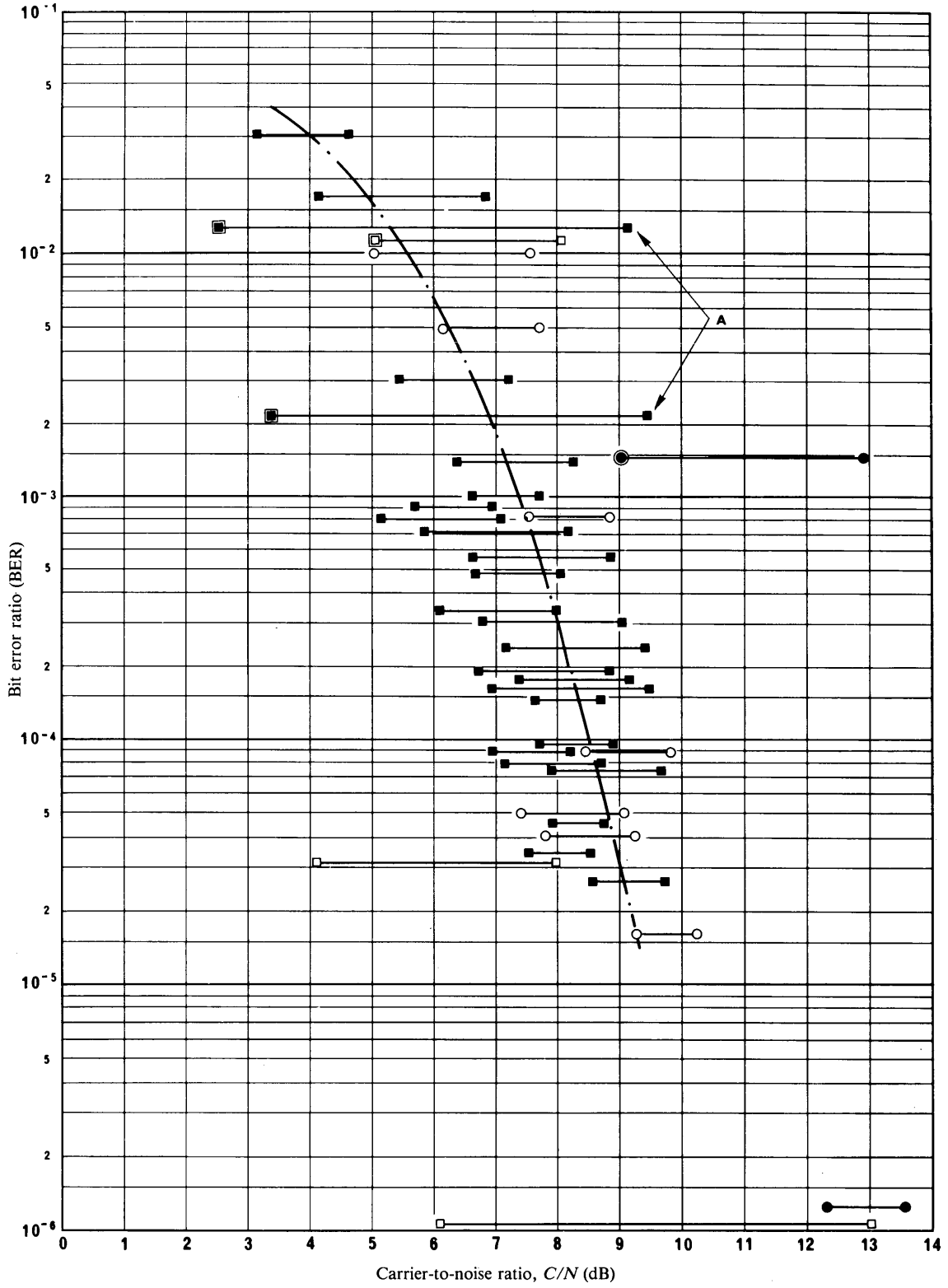


FIGURE 5 – *MARISAT 1200 bit/s FSK data transmission measurements at elevation angles above 5°*

Test	Elevation angle
66	11.2°
67,68	11°
77	8.4°-7.6°
81	6.0°-5.0°
fitting curve	
lost sync	
A	radar mast blockage

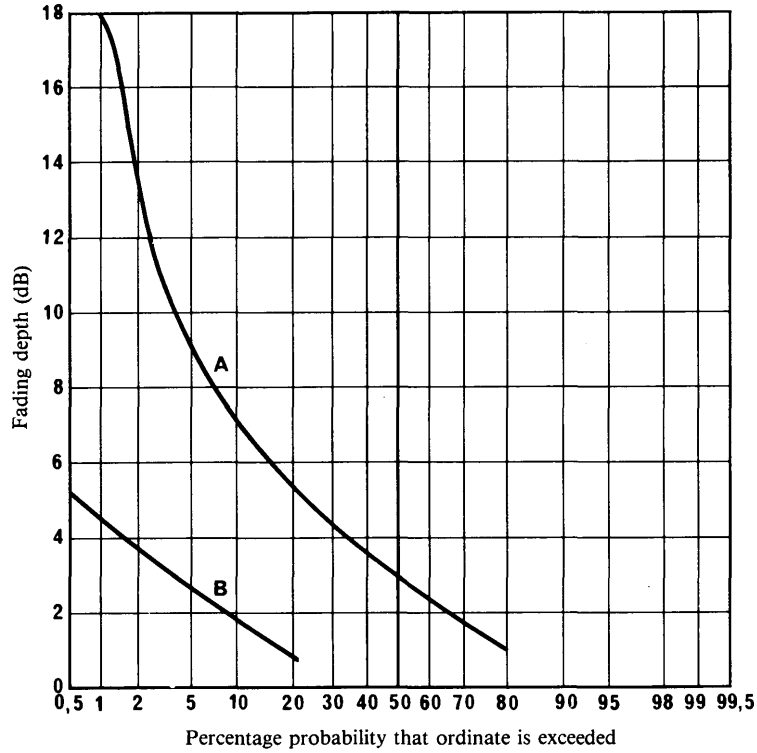


FIGURE 6 – *Measured multipath fading statistics*

Curves A: elevation angle 2.4°
B: elevation angle 5.7°

3.4.4 *Major findings*

Major propagation effects at low elevation angles that have significant system impact include multipath interference, polarization reversal, group time delay, Doppler shift and direction of transmission. Multipath and polarization effects which were identified in the experiment are discussed.

At low elevation angles, multipath interference due to sea surface produces two results: degradation of mean C/N and enhancement of peak-to-peak fluctuations of the C/N with respect to its mean. Although both are complicated effects, they can be evaluated to a first order using a simple two-component specular reflection model, which appears to be adequate for engineering applications for elevation angles of 5° and above. This model predicts a mean C/N drop of about 2.0 dB at an elevation angle of 5° from that at a 10° elevation angle. The maximum fade level due to fluctuations at 5° elevation will be less than -6.5 dB for 99% of the time while at 10° elevation, the fluctuation level is less than -4.5 dB for the same percentage of time. The fading statistics measured during these tests indicate that about 4 to 5 dB of link margin would be required for 99% of the time for a ship earth station having a G/T of -4 dB(K^{-1}) operating at an antenna elevation angle as low as 5°.

There is a polarization reversal effect from the sea surface reflection. To a first order, the cross-polarized wave can be treated as a co-channel interference to the co-polarized signal, and it is a main contributor to C/N degradation at low elevation angles.

Additional signal degradation due to blockage caused by the presence of structures in front of the MARISAT ship earth station antenna may be significant. In one specific instance at 11° elevation angle, an 18 in radar mast was observed to cause a worst case received signal degradation of about 8 dB. For design considerations, the degradation can be estimated by using a simple geometric-optics model based on the Fresnel zone blockage concept.

Due to the degradation of the mean C/N and the severity of peak-to-peak C/N fluctuations with respect to their mean at elevation angles less than 5°, 2400/1200 bit/s digital data transmission through a voice channel is not reliable. Above 5°, however, a relationship between BER and C/N is available as predicted by theoretical studies and it follows a general class of error functions. For example, at 5° elevation angle, a C/N of about 8 dB with the 2400 bit/s test modem was found to produce a BER of 2×10^{-4} or better about 50% of the time. Data transmission measurements over the FM voice channel indicated that BERs of the order of 10^{-4} to 10^{-5} were achieved at 5° elevation, with data rates of up to 2400 bit/s. The relationship itself is independent of elevation angle; however, the confidence level of the relationship decreases as elevation angle decreases.

An ionospheric scintillation event was observed on 10 October, 1978, at a location where the geomagnetic latitude is approximately 35° N. On that occasion, at an elevation angle of about 11°, signal fluctuations of unusual structure were observed to increase from about 2 dB to about 4.5 dB peak-to-peak. Since the probability of occurrence of such events increases drastically during the equinox periods in the regions near the geomagnetic equator, it implies that ionospheric scintillation events will be observed more frequently and will be more pronounced than those reported above. This implies further that ionospheric scintillation is likely to be a significant impairment for ships operated in the tropics.

At extremely low elevation angles, link C/N was observed to vary by more than 15 dB over a very short time period (see Fig. 6).

4. U.S.S.R. tests

4.1 *Background*

Experiments were performed by the U.S.S.R. on board the M/V "Magnitogorsk" (220 m length, 25 000 grt deadweight) over the period November 1979-February 1980. The objective of the tests was the collection and processing of experimental data pertaining to MARISAT system performance at low elevation angles. When the ship was operating near the Bay of Biscay and within the Gulf of Mexico, communication tests were conducted via Marisat satellites over the Indian and Atlantic Oceans respectively.

The M/V "Magnitorgorsk" is equipped with a ship earth station of -4 dB(K^{-1}) G/T which was employed for establishing communication and making tests.

4.2 *Test conditions*

The measurements were conducted under normal operation of shipborne equipment in the absence of failures of satellite or shorebased equipment.

To evaluate the system performance at low elevation angles, the data used was obtained over the periods for which the ship earth station was not affected by operation of other shipborne radio aids. Therefore no allowance is made for the possible effect of these aids in the given results.

Concerning the effect of propagation conditions, variations on a satellite-to-ship link (1.5 GHz) only were estimated. Propagation conditions on a shore-to-satellite link were believed to be stable. The ship-satellite-shore direction was not examined during the tests.

Account was taken of the effect of variations in satellite loading levels (i.e. number of simultaneously operating channels) on C/N values. Variations of C/N at the first IF were then assumed to be due to propagation conditions at low elevation angles.

Measurements were carrried out mainly on telex channels. A limited amount of data was obtained for telephone channels. In evaluating performance of the telephone channels at low elevation angles, the changes in signal levels in the telephone channels were assumed to be proportional to the relevant changes observed at the time in the telex channels. The validity of this assumption was confirmed by a series of measurements taken for the telephone and telex channels at 3° elevation angle.

4.3 *Weather effect*

During the test period, the effects of weather conditions on quality of communications via satellite were studied. The data obtained indicated that, during drizzle and rainstorm conditions, degradations of the mean C/N of about 1.5 dB and 2 dB respectively were observed.

Environmental conditions encountered were mostly favourable, so that the ship rolling and pitching did not exceed 3°-5° and 2°-3°, respectively. Such disturbances are too small to evaluate their effect on quality of satellite communications at low elevation angles.

4.4 *Experimental data*

The total number of readings processed was about 2500. Elevation angles ranged from 3° to 14°.

Experimental data were divided into two groups, each being handled separately.

The first group comprised measured C/N values on telex channels in the absence of operating telephone channels.

The second group comprised measured C/N values with both telex and telephone channels being active.

Graphic presentation of experimental and measured values of C/N ratio in accordance to the first and the second groups mentioned above is given in Figs. 7 and 8 respectively. Because of the limited data for telephone channels, the r.m.s. deviations from mean C/N of telephone channels were assumed to correspond to those of telex channels at the same elevation angles.

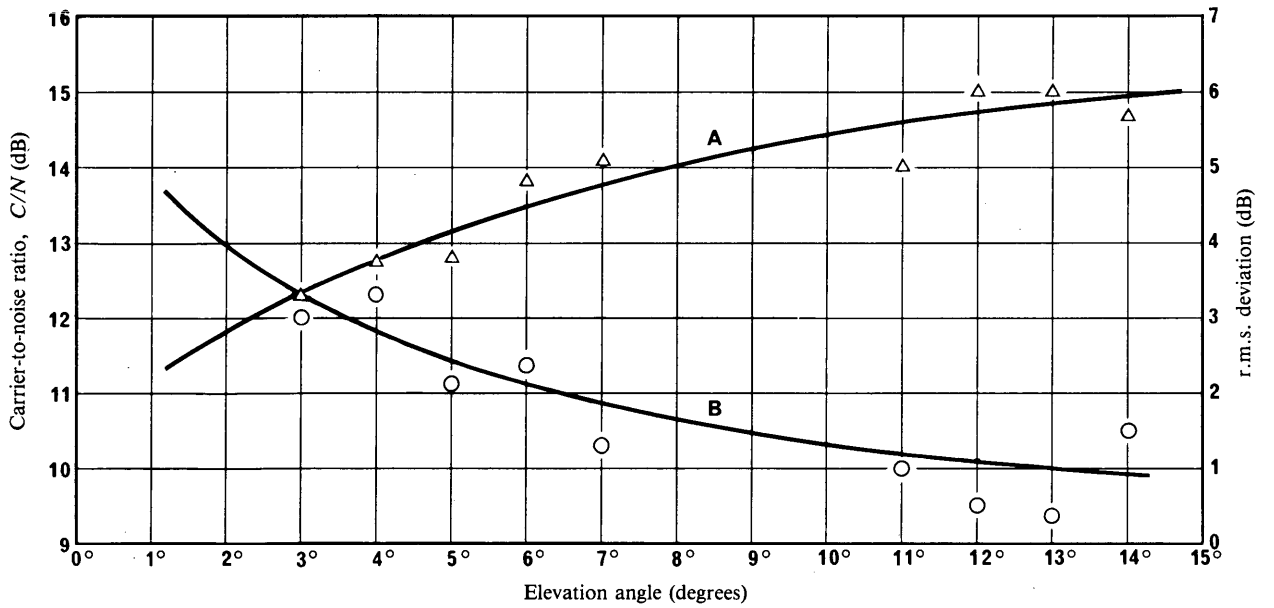


FIGURE 7 – *Received carrier-to-noise ratio (C/N) and root mean square deviation (r.m.s.) from mean C/N of telex channels at different elevation angles (no active telephone channels)*

○, △: experimental data
Curves A: *C/N*
B: r.m.s. deviation

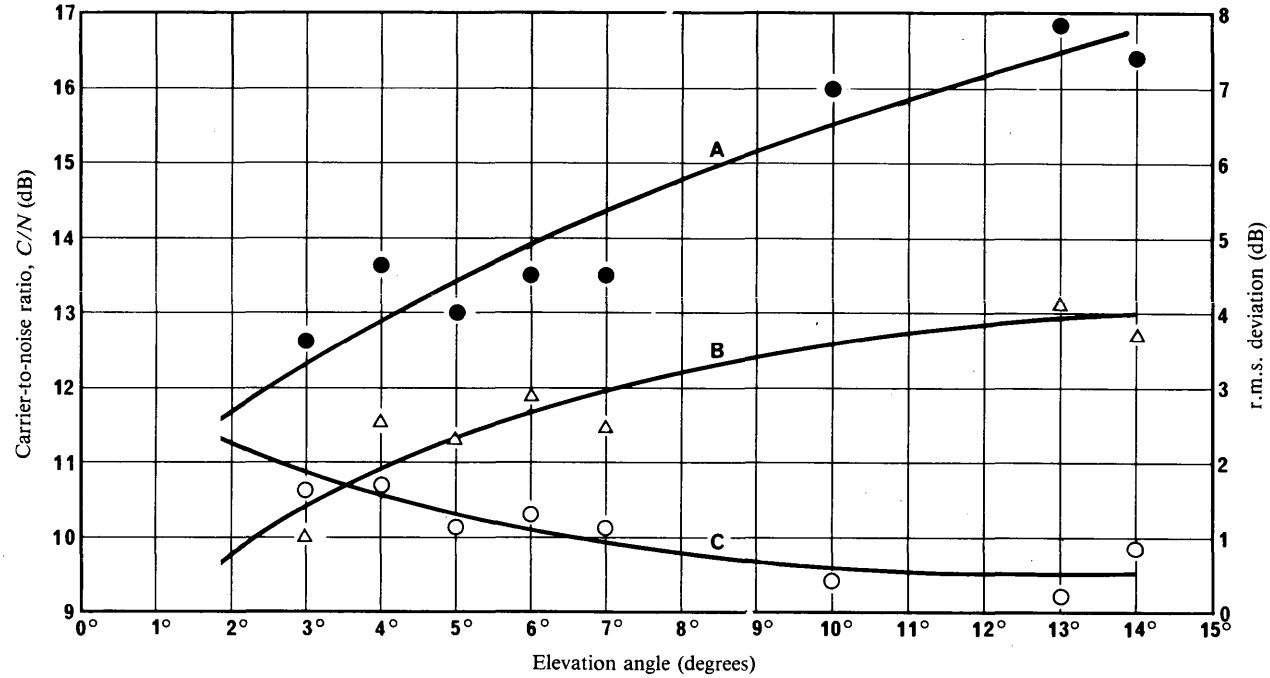


FIGURE 8 – *C/N and r.m.s. deviation from mean C/N in case of simultaneous operation of telex and telephone channels at different elevation angles*

○, ●, △: experimental data
Curves A: *C/N* of telephone channel
B: *C/N* of telex channel
C: r.m.s. deviation

4.5 *Minimal values of elevation angles for telephone and telex services*

In order to determine minimal values of elevation angles, certain threshold values of C/N for telephone and telex channels were assumed. The criterion for telex channel quality was assumed to be a BER of 10^{-5} for 99% of the time. A speech intelligibility of 99% was adopted as the criterion for telephone channels.

The best-fit curves shown in Figs. 7 and 8 were used to determine areas of marginal values of C/N (99% probability) in telex and telephone channels for various levels of satellite loading and different elevation angles.

Shown in Figs. 9, 10 and 11 respectively are the areas of marginal values of C/N for:

- telex channels in the absence of telephone channel loading in the satellite;
- telex channels with telephone channels in operation;
- telephone channels.

The threshold values of C/N are plotted with an allowance being made for possible degradation due to precipitation.

4.6 *Experimental results*

From analysis of Figs. 9 to 11 it can be determined that the required quality of communications of telex channels can be achieved, given certain conditions of external disturbances, if the elevation angle exceeds 4.5°.

A speech intelligibility of 99% for telephone channels can be achieved for at least 99% of the time when the elevation angle exceeds 12.5°. At lower elevation angles, rainstorms may degrade the communication quality, e.g. at 10° elevation angle, intelligibility will be 98% for isolated words and 92% for isolated syllables; at 8° elevation angle the intelligibility drops to 88%.

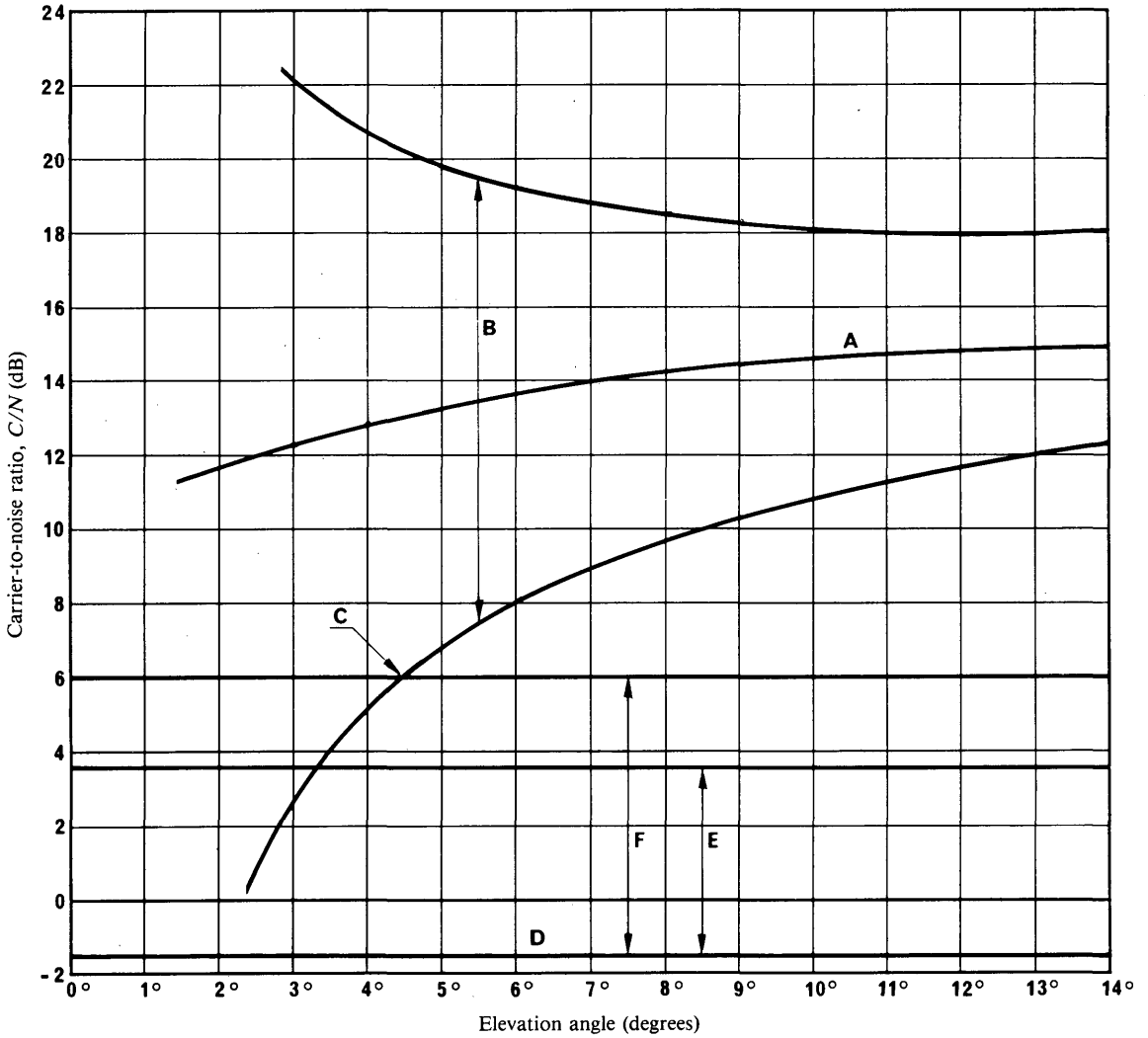


FIGURE 9 – *Area of marginal values of C/N of telex channels at various elevation angles (no telephone loading in the satellite)*

A: mean *C/N*
B: *C/N* marginal value area
C: critical value of elevation angle
D: threshold *C/N* for telex channel (– 1.5 dB)
E: drizzle, 5.25 dB maximum degradation
F: rainstorm, 7.5 dB maximum degradation

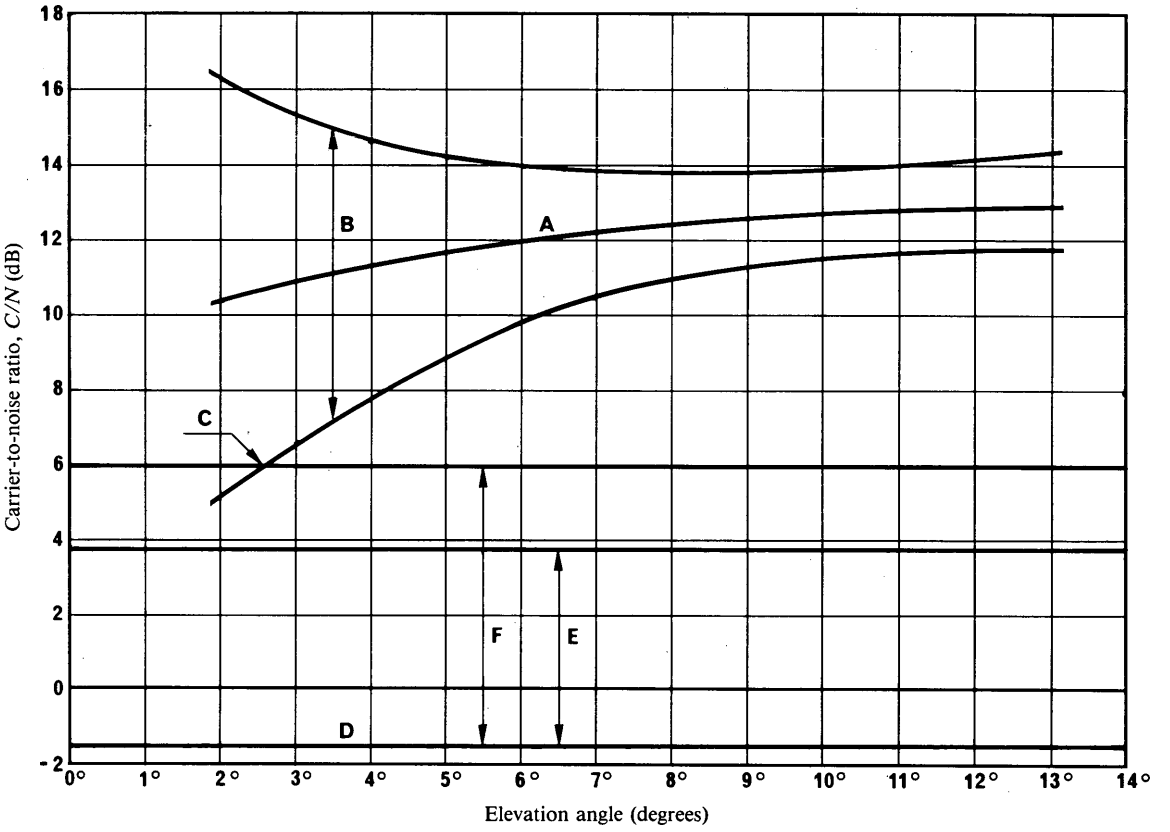


FIGURE 10 – *Area of marginal values of C/N of telex channels at various elevation angles (active telephone channels)*

A: mean *C/N*
B: *C/N* marginal value area
C: critical value of elevation angle
D: threshold *C/N* for telex channel (– 1.5 dB)
E: drizzle, 5.25 dB maximum degradation
F: rainstorm, 7.5 dB maximum degradation

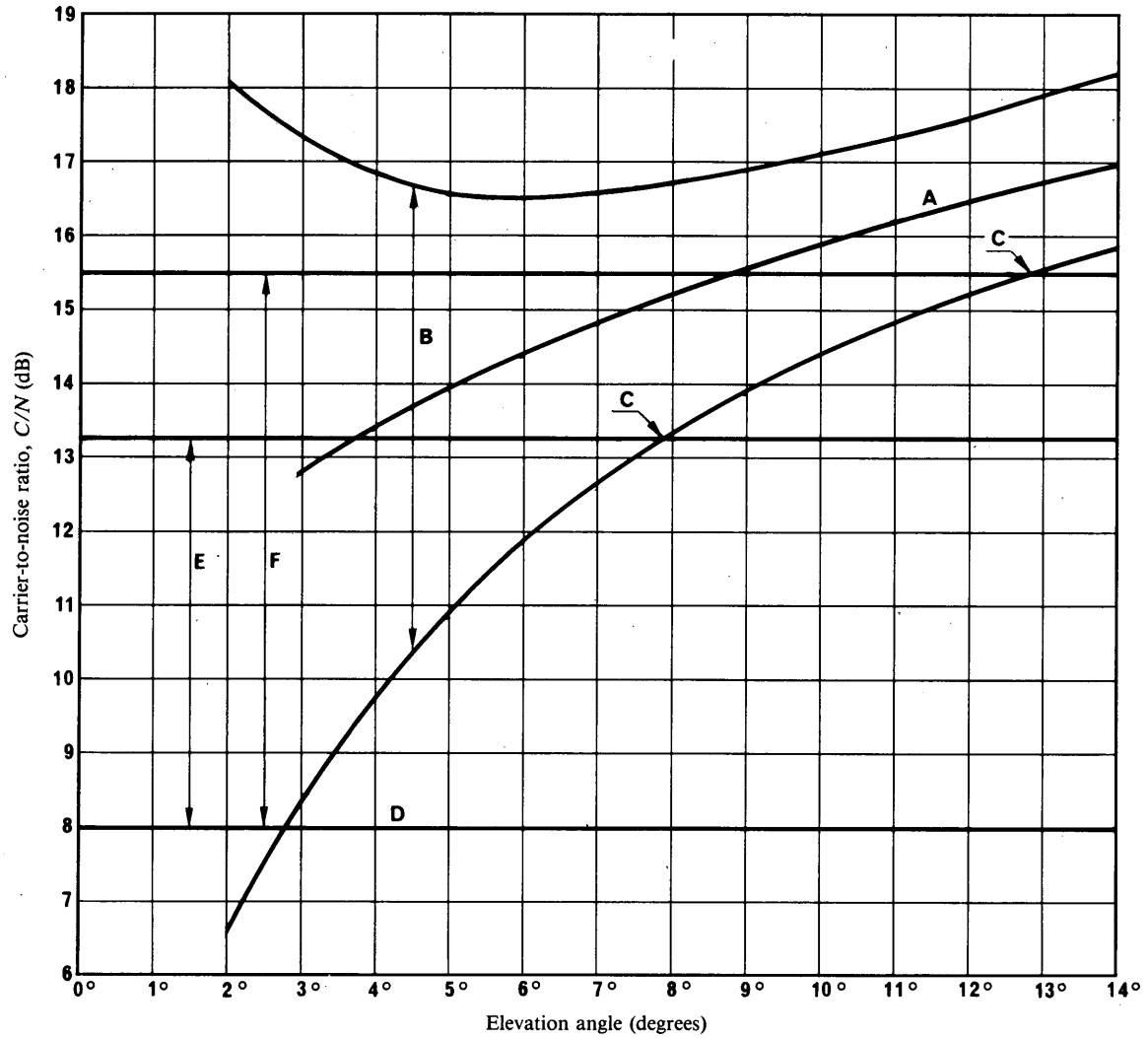


FIGURE 11 – *Area of marginal values of C/N of telephone channels at various elevation angles*

A: mean *C/N*
B: *C/N* marginal value area
C: critical value of elevation angle
D: threshold *C/N* (8 dB)
E: drizzle, 5.25 dB maximal degradation
F: rainstorm, 7.5 dB maximal degradation

5. Conclusion

Minimal elevation angles from ship-to-satellite were determined at which the satellite communication system is still capable of providing the needed quality of communciations. Sufficient communication quality can be achieved at elevation angles of about 5°. It should be recognized, however, that the values obtained are of preliminary nature, since the analysis was limited. Further study of ship earth station performance at low elevation angles is required.

REFERENCES

FANG, D. J., TSENG, F. T. and CALVIT, T. O. [January, 1982] Elevation angle propagation measurement of 1.5 GHz satellite signals in the Gulf of Mexico. *IEEE Trans. Ant. Prop.*, Vol. AP-30, **1**.

REPORT 921

SYSTEM ASPECTS OF LOW G/T SHIP EARTH STATIONS

(Study Programme 17A/8)

(1982)

1. Introduction

The present maritime satellite communication system is designed to operate with ship earth stations with a G/T of -4 dB(K^{-1}). However, it is assumed that smaller and cheaper ship earth stations will be introduced in the future INMARSAT system. The Technical Panel of the INMARSAT Preparatory Committee defined a number of ship earth station standards for a variety of service capabilities [INMARSAT, 1978]. These are summarized in Table I below.

TABLE I — *Summary of ship earth station standards*

Ship earth station standard	(Assumed)		Service capability
	Antenna gain (dB i)	G/T (dB(K^{-1}))	
A	23.5	−4	Full range of public correspondence
B	15	−12	Reduced quality voice and multiplex telegraphy
C	8	−19	Telegraphy only
D	32.5	+5	As standard A, plus high capacity services

In the shore-to-ship direction, it would be possible to provide the same channel quality to a low G/T ship earth station as to a -4 dB(K^{-1}) G/T ship earth station by increasing the satellite e.i.r.p. per channel. However, this approach would reduce the channel capacity of the system, since maritime satellite communication systems are power limited, at least in the foreseeable future.

In the ship-to-shore direction, the same channel quality could be provided by increasing the power from a low G/T ship earth station, but this would result in a radiation hazard and the possibility of increased interference to other maritime satellites.

Therefore, it is necessary to consider efficient techniques which can provide channels at the lower value of carrier-to-noise density ratio (C/N_0).

This Report addresses a number of technical aspects related to the system for low G/T ship earth stations and is based on the philosophy that standard B and C ship earth stations will be used in conjunction with the system designed for standard A ship earth stations. This precludes the possibility of compensating for the low G/T of standards B and C by increasing the satellite e.i.r.p. The low transmit gain of the standard B and C ship earth station antenna can be compensated partly by increasing the transmit power as compared with the standard A ship earth station. However, in this Report it is assumed that the ship earth station transmit power is not increased.

A very low G/T ship earth station ($G/T = -29$ dB(K^{-1})) to be operated in a receive-only mode is discussed in Annex I. Such a relatively simple receive-only ship earth station could be used for reception of distress alerts in the shore-to-ship direction as well as meteorological and navigational warnings through coast earth station facilities. The initial approach has been examined by one administration; other administrations are invited to investigate this concept to provide further information on technical and operational issues.

2. Link power budget for a standard B ship earth station

The satellite-to-ship link is the most power limited link in the satellite system. Therefore, the shore-to-ship link determines the attainable carrier-to-noise density ratio (C/N_0), and consequently, the maximum bit rates for digital signals and the modulation techniques or coding techniques to be used for telephony, telegraphy and signalling.

In this section the satellite-to-ship link power budget is given for an equivalent voice channel. The calculations, shown in Table II, are based on the existing link budgets as given in Report 760. It is assumed that the shore-to-satellite link power budget is the same, irrespective of the ship earth station standard considered. Furthermore, the ship-to-shore link is assumed to result in the same signal quality, i.e. C/N_0 as the shore-to-ship link (Report 760).

TABLE II — *Satellite-to-ship link power budget* (1.54 GHz) at an elevation angle of 10° for a standard B ship earth station*

	Units	99% of the time	80% of the time
Satellite e.i.r.p. per channel	dBW	18.1	
Free space path loss	dB	188.4	
Atmospheric absorption loss	dB	0.2	
Multipath fading loss (1)	dB	[5.0] (5)	[1.8]
Additional losses (2)	dB	[1.3]	[1.0]
Total degradation for random losses (3)	dB	5.8	2.1
Ship terminal G/T (4)	dB(K^{-1})	−11.5	
Boltzmann's constant	dB(J/K)	−228.6	
Down path C/N_0	dBHz	40.8	44.5
Transmitted $C/(N_0+I_0)$	dBHz	62.6	
Resultant $C/(N_0+I_0)$	dBHz	40.8	44.4

* This link budget assumes a fixed multipath fading loss. It should also be noted that the signal level available and processing technique adopted are interdependent.

(1) The results reported from various experiments indicate that the multipath fading loss L_m will be less than 5 dB for at least 99% of the time. In accordance with Report 760 it is assumed that multipath fading statistics are approximately Gaussian with a zero average ($L_m = 0$ dB, $\sigma = 2.15$ dB. Hence, for 99% of the time $L_m = 5$ dB and for 80% of the time $L_m = 1.8$ dB).

(2) Additional losses are taken from Report 760 and comprise wet radome loss, noise temperature degradation, polarization coupling loss and pointing loss ($L_m = 0.8$ dB and $\sigma = 0.2$ dB. Hence, for 99% of the time $L_m = 1.3$ dB and for 80% of the time $L_m = 1.0$ dB).

(3) The total margin has been calculated in accordance with Report 760.

(4) The net value for G/T is -12 dB(K^{-1}). However, a value in which pointing and polarization losses have not been included, is used in the link budget.

(5) Figures in [ ] are not included in the total margins (see Report 760).

3. Telephony

3.1 *Analogue modulation techniques*

Report 509 presents some information on signal quality and analogue voice modulation techniques applicable to ships with low gain antennas.

Articulation index (AI) is used for theoretical comparisons of voice modulation techniques since there is a correlation between AI and intelligibility.

Although not explicitly mentioned, it can be deduced from Report 509 that an AI of 0.6 could be used as a design objective for reduced quality voice modulation techniques. An AI of 0.6 would provide a word intelligibility of 90%.

Figure 2 of Report 509 shows that none of the analogue modulation techniques mentioned there would meet the AI objective under faded conditions (99% of the time, C/N_0 approximately 41 dBHz, see § 2 of this Report). Only SSB (B = 5 kHz) could attain an AI value of 0.6 under unfaded conditions, i.e. for a *mean* carrier power-to-noise density ratio of 45 dBHz.

It may be concluded from the above considerations that the voice channel quality would be inadequate if analogue modulation techniques were used.

3.2 *Digital techniques*

Digital techniques, such as forward error correction (FEC) and voice coding, which can reduce the value of C/N_0 for voice transmission are of prime importance [Satoh *et al.*, 1980]. It is expected that the continuing progress of LSI circuit technology will realize such digital techniques more economically.

3.2.1 *FEC techniques*

The application of FEC to digital channels for voice transmission to and from low G/T ship earth stations seems to be useful, since the value of C/N_0 required to meet the BER criterion derived from the speech quality objective can be reduced significantly, irrespective of the type of voice coding techniques adopted.

Figure 1 shows the BER performance of typical FEC techniques as a function of energy-per-bit-to-noise density ratio (E_b/N_0), assuming that 2-phase CPSK is used as modulation method. Examples of such techniques are convolutional coding/Viterbi decoding and self-orthogonal convolutional coding. The latter technique has been adopted in SCPC channels of the INTELSAT system.

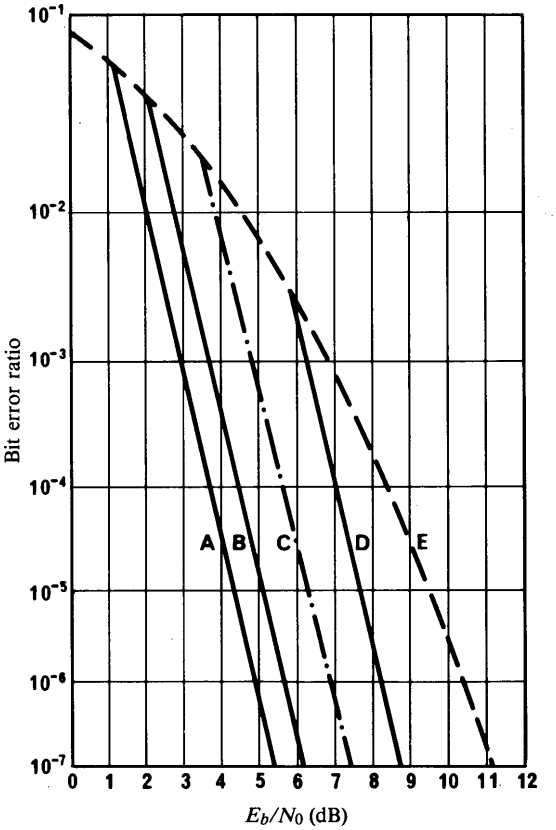


FIGURE 1 – *E_b/N_0 vs. bit error ratio*

Curves A: (2:1)-convolutional coding/8-level soft decision Viterbi decoding
B: (4:3)-convolutional coding/8-level soft decision Viterbi decoding
C: (2:1)-convolutional coding/hard decision Viterbi decoding
D: (8:7)-self-orthogonal convolutional coding
E: without FEC

3.2.2 *Bit rate and required value of C/N_0*

The relation between bit rate (R) and C/N_0 for 2-phase CPSK channels is given as the following equation:

$$C/N_0 = E_b/N_0 + 10 \log \kappa + M \quad \text{dB} \tag{1}$$

where M is the implementation margin.

Figure 2 shows the relations for 2-phase CPSK channels with and without FEC of (2:1)-code/ Viterbi decoding (curve A) in Fig. 1, in which M is assumed to be 0 dB. However, for practical applications, a value of M of 1 to 2 dB should be included. It is obvious from the figure that FEC techniques are very effective in reducing the value of C/N_0 for a given bit rate.

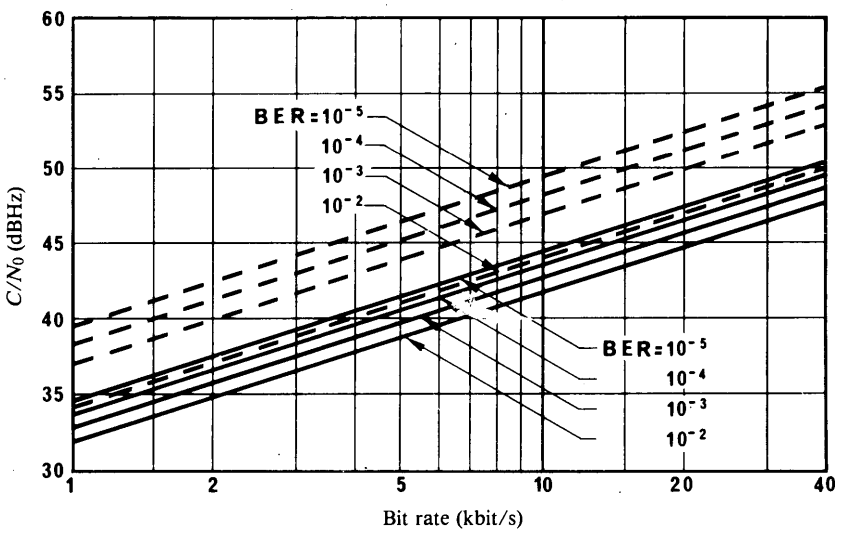


FIGURE 2 – *C/N_0 vs. bit rate*
(Implementation margin, $M = 0$ dB)

——— : without FEC

— — — : with FEC, (2:1)-code convolutional coding/8-level soft decision Viterbi decoding

3.2.3 *Voice coding techniques*

Various kinds of voice coding techniques have been developed for the transmission of voice signals with low transmission bit rates.

In this Report, delta modulation (DM) techniques and vocoding techniques are discussed with particular attention to the possibility of being applied to telephone channels for low G/T ship terminals.

3.2.3.1 *DM techniques*

DM has been considered as a useful voice coding technique for maritime satellite communications (see Report 752), since it has the advantages of circuit simplicity and absence of significant degradation of speech quality due to bit errors as compared with other voice coding techniques. This technique may therefore be applied to voice channels for standard B ship earth stations.

However, considering the available value of C/N_0 for a standard B ship earth station, the sampling frequency (f_s) of DM has to be lower than 32 kHz, the latter being suitable for high quality channels with standard A ship earth stations. Furthermore, the threshold BER, as yet to be specified for the reduced quality channel, may be relaxed considerably, e.g. to 10^{-2}, because a large amount of noise resulting from bit errors provides only a small degradation in the speech intelligibility (see Report 752).

Considering the data shown in Table II and Fig. 2, and assuming that a BER of 10^{-2} for faded conditions gives acceptable speech quality, resultant sampling frequency for the available C/N_0 of 41 dBHz would be 6 kHz. However, this sampling frequency may result in an unacceptable speech quality. For a more realistic sampling frequency of 9.6 kHz, the C/N_0 would need to be around 43 dBHz; likewise, for a sampling frequency of 16 kHz, the C/N_0 would need to be about 45 dBHz.

A laboratory test on the speech quality of 16 kHz DM/PSK channels with FEC for various values of C/N_0 has been carried out. The test results are described in Annex III of Report 752.

3.2.3.2 *Vocoder techniques*

3.2.3.2.1 *Technical considerations*

It follows from Table II and Fig. 2 that a bit rate not greater than about 2.4 kbit/s is available for voice transmission, assuming that a BER between 10^{-2} and 10^{-3} for 99% of the time gives acceptable voice quality for vocoder systems.

One of the approaches that can be considered at such a low bit rate is based on vocoding. Rather than encoding a speech wave-form as accurately as possible, vocoding aims at the extraction and the encoding of the essential speech generating parameters.

In recent years considerable progress has been made with regard to the realization of high-quality vocoders which operate at output bit rates as low as 2.4 kbit/s.

The progress is partly due to the possibilities of advanced signal processing and implementation in LSI-circuitry. For the major part, important breakthroughs in speech parameter extraction have contributed to the achievement of high speech intelligibility and good quality. Vocoders consist of a speech analyzer part, which produces the above-mentioned parameters, and a speech synthesizer which reconstitutes the original speech on the basis of the received parameters. The speech analyzer of a pitch excited vocoder tracks the continuous variation of the speech pitch frequency, indicates the presence of voiced or unvoiced sounds and provides information on the short-term speech spectrum. Depending on the way in which the short-term speech spectrum is determined, vocoders are classified as belonging to various categories, e.g. channel-, formant- or LPC (Linear predictive coding) vocoder [Flanagan *et al.*, 1979]. A channel vocoder uses filter banks to extract rectified-smoothed amplitude information for each band. A formant vocoder also uses filter banks to detect the instantaneous frequency and the average amplitude for each band. An LPC vocoder extracts the so-called vocal tract parameter by minimizing mean square error between the input signal and signal values predicted by a linear weighted summation of past values of the signal.

There is a strong relation between the voice quality of a vocoder and the accuracy of pitch extraction.

The extraction of the pitch frequency from a speech signal is one of the most critical and difficult tasks in speech analysis.

A recent major achievement reported in literature is a new type of pitch extractor which forms the basis of a high-quality type of pitch-excited vocoder at low bit rate [Sluyter, 1980].

Rather than looking at pitch extraction as a pure technical problem, the particular technique is based on the understanding of human pitch perception. The indicated concept includes spectral analysis and harmonic pattern recognition. Using a well-chosen algorithm, the pitch parameter can be calculated in agreement with perception and in real-time.

Regarding the speech quality of LPC vocoders, some intelligibility tests have been carried out with several types of LPC vocoders developed in Japan. For instance, it is reported that one type of 2.4 kbit/s LPC vocoder achieves a syllable articulation score of about 68% in Japanese [Kurematsu *et al.*, 1979] and another type of LPC vocoder PARCOR [Itakura and Saito, 1968] obtains AEN values (see Note 1) (CCITT Recommendation P. 41-45) of 6 dB and 3 dB at 2.4 kbit/s and at 4.8 kbit/s, respectively.

Although remarkable progress has been made in LPC vocoder techniques, it seems quite difficult to recommend any standard at this time, because various types of LPC vocoders have been developed, each of which has a different type of LPC analyzer and pitch extractor.

Regarding the performance of channel vocoders at transmission rates of 2.4 kbit/s, intelligibility tests have been carried out, using phonetically balanced word lists [Lehiste and Peterson, 1959], with the following results as shown in Table III:

TABLE III

Channel BER	Percentage intelligibility	
	Vocoder 2.4 kbit/s no FEC	Vocoder 1.8 kbit/s with FEC 0.6 kbit/s
0%	87.9%	85.4%
2%	83.6%	84.9%
5%	73.7%	78.3%

It is generally accepted that, using the phonetically balanced word lists, the minimum acceptable score is 55-60%. Tests have also been carried out in practical environments and in noise chamber simulations on the suitability of channel vocoders for use in vehicles with very high levels of acoustic noise, considerably worse than would be expected in a ship, and they were found usable with high acoustic noise combined with a BER of 2.5% (with FEC). [Kingsbury and Amos, 1980].

In these tests on channel vocoders the microphones used were of practicle types in common use, but not including carbon microphones. The FEC used was designed specifically for use with the vocoder, and only applies correction to the most significant bits i.e. those that mostly affect the speech.

Note 1. – AEN (Affaiblissements equivalents pour la netteté; Articulation Reference Equivalent) value is the difference between the attenuation level of the reference circuit and that of a circuit under test, each of which is adjusted so that the sound articulation score of 80% is obtained.

3.2.3.2.2 *Further study required with relation to vocoding*

It can be expected that high-quality vocoder systems will be available in the foreseeable future. However, with regard to the applicability of vocoders in the specific situation of the maritime satellite service, further study is required on several aspects, e.g.:

- influence of a limited-quality input speech to the vocoder, as will be experienced especially in the shore-to-ship direction (band-limitation range of talker levels, impulse noise, carbon microphones, etc);
- sensivity to transmission errors (BER-performance);
- influence of ambient noise, especially on board the ship;
- influence of increased intermodulation distortion on NBFM channels with standard A ship earth stations caused by frequency compressed vocoder signals.

Subjective tests will be necessary to evaluate the overall quality of the received speech signals.

4. Telegraphy and signalling

4.1 *Effects of lower G/T of ship earth stations on TDM/TDMA channel performance*

Assuming that the satellite e.i.r.p. is identical for all ship earth station standards, the unfaded C/N_0 of standard B compared with standard A, would be about 8 dB lower (Table I).

The theoretical effect of this lower C/N_0 on the bit error ratio (BER) in the INMARSAT – TDM/TDMA channels used for telegraphy and signalling is illustrated for standard B ship earth stations in Table IV, where the following assumptions are made:

- an implementation margin of 1 dB is included;
- ship satellite elevation angle is 10°.

TABLE IV — *Effects of lower G/T of standard B ship earth stations on TDM/TDMA channels*

Ship earth station standard	Bit rate of TDM/TDMA channels (kbit/s)	80% of the time		99% of the time	
		C/N_0 (dBHz)	BER (1)	C/N_0 (dBHz)	BER (1)
A	1.2 (shore-ship)	50	$<1\times10^{-10}$	48.5	$<1\times10^{-10}$
	4.8 (ship-shore)	53	$<1\times10^{-10}$	51.5	$<1\times10^{-10}$
B	1.2 (shore-ship)	41.4	9.7×10^{-6}	37.8	2.4×10^{-3}
	4.8 (ship-shore)	44.4	1.2×10^{-3}	40.8	2.3×10^{-2}

(1) Assumed characteristics:
— modulation technique: 2-phase CPSK
— implementation margin: 1 dB

The calculated figures of BER in Table IV are unacceptably high; therefore, the use of standard B ship earth stations in the aforementioned TDM/TDMA system would not provide the required signal quality.

The definitions of the ship earth station standards do not foresee the lowering of the quality objectives in telegraphy for standard B ship earth stations. Two solutions seem feasible, namely, use of a low bit rate and extension of redundancy, in order to ensure that the recommended character error rate (Recommendation 552) is not exceeded when such standard B ship earth stations are used.

4.1.1 *Use of a low bit rate*

The BER specified for standard A ship earth stations could be conformed to by reducing the bit rate accordingly, should standard B ship earth stations be used in the aforementioned TDM/TDMA system.

In such an operational mode it would then be necessary to provide separate TDM/TDMA channels for each different bit rate. This would mean, however, that the allocation of these channels would have to be clearly indicated by the subscriber's number or ship earth station identity. In addition, equipment which can receive the request bursts with the various bit rates would have to be provided at the coast earth stations so as to receive the request messages from all the ship earth stations, irrespective of the ship earth station standards adopted. Bit rates significantly lower than 1.2 kbit/s could require more stringent phase-noise specifications.

4.1.2 *Extension of redundancy*

The lower G/T of standard B ship earth stations could be compensated for by extension of redundancy, namely, by using either the technique of repetitive transmission of information bits or forward error correction (FEC) techniques. However, this would require the decrease of the number of information bits per telex channel or the number of telex channels per TDM/TDMA frame.

A decrease of the number of information bits per telex channel would require a buffering memory in both the coast earth station and the ship earth station.

In order to avoid buffering, it may be possible to combine several adjacent telex channels to provide signalling/telegraphy to lower G/T ship earth stations. However, this would reduce to some extent the total number of available telex channels. The feasibility of a corresponding adaptation of the TDM/TDMA channel format would require detailed study.

5. Areas for further study

Further study is required on the following aspects, other than those indicated in § 3:

- speech quality objectives for standard B ship earth stations;
- the interconnection of low G/T systems with the terrestrial networks;
- telegraphy and signalling arrangements, in order to overcome the effects of satellite and ship earth station power limitations;
- further development and subjective assessment of possible telephony modulation methods for standard B ship earth stations;
- effects of increased multipath, due to the use of broader beamwidth ship earth station antennas.

REFERENCES

FLANAGAN, J. L., SCHROEDER, M. R., ATAL, B. S., CHROCHIERE, R. E., JAYANT, N. S. and TRIBOLET, J. M. [April, 1979] Speech coding. *IEEE Trans. Comm.*, Vol. COM-27, **4**, 710-737.

INMARSAT [1978] Final Report of the Technical Panel of the INMARSAT Preparatory Committee, § 4.5 and 8.5 of Annex V.

ITAKURA, F. and SAITO, S. [1968] Analysis synthesis telephony based on the maximum likelihood method. Reports of 6th Int. Cong. Acoust., ed. Y. Kohashi, Tokyo, C-5-5.

KINGSBURY, N. G. and AMOS, W. A. [9 April, 1980], A robust channel vocoder for adverse environments. Proc. IEEE International Conference on Acoustics, Speech and Signal Processing. (ICASSP '80), 9-11 April, Denver, Col., USA, Vol. 1, Session S1: Narrowband Speech, S1.4, 19-22.

KUREMATSU, A., ISHIGAMI, H., KITAYAMA, S., YATO, F. and TAMURA, J. [2 April, 1979] A linear predictive vocoder with new pitch extraction and exciting source. IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP '79), 2-4 April, Washington DC, USA, Conf. Record, Session 2: Narrowband speech communication, 2.8, 69-76.

LEHISTE, I. and PETERSON, G. E. [March, 1959] Linguistic considerations in the study of speech intelligibility. *J. Acous. Soc. of Amer.* Vol. 31, **3**, 280-286.

SATOH, T., OGAWA, A. and HIRATA, Y. [3 December, 1980] A survey on the techniques applicable to the future maritime satellite communications system. IEEE National Telecommunications Conference, Houston. (NTC/80), 30 November-4 December, Houston, Texas, USA, Conf. Record, Vol. 3, Session 62: Recent advances in maritime satellite communications, 62.1.1-62.1.6.

SLUYTER, R. J., KOTMANS, H. J. and LEEUWAARDEN, A. V. [6 March 1980] The harmonic-sieve method for pitch extraction from speech and a hardware model applicable to vocoder systems. Proc. IEEE International Zurich Seminar on Digital Communications, 4-6 March, Zurich, Switzerland, E2.1-E2.6.

ANNEX I

THE SHORE-TO-SHIP DISTRESS ALERTING CHANNEL (SHOSAC) USING RECEIVE-ONLY SHIP EARTH STATIONS

1. Introduction

Today, there exist a number of proposals for maritime distress alerting systems using float free Emergency Position-Indicating Radio Beacons which transmit via satellite (satellite EPIRB). As a necessary complement to these ship-to-shore alerting systems, IMCO requested for its "Future Global Maritime Distress and Safety Systems" that the shore based Rescue Coordination Centre (RCC) should be enabled to quickly and effectively contact ships in the immediate vicinity of the vessel in distress, for which a simple and reliable radio link, a shore-to-ship alert channel, is required.

Therefore, it is being proposed to connect even those vessels which do not possess an INMARSAT communications ship earth station by employing an inexpensive receiver and operating at low bit rates via satellite. Ships could be addressed individually or selectively as a group in a certain area. The link could be used for distress alerting as well as for navigational and meteorological warnings.

2. System definition

The system must be inexpensive to own and operate; therefore, one possible solution, as described here, is to provide an omnidirectional antenna. In order to reduce sea surface multipath effects, the polarization should be circular. Since this service is in the shore-to-ship direction only, the ship terminal is a Receive-Only Ship Earth Station (ROSES). The operational bandwidth of the equipment should include the frequency band 1544 to 1545 MHz which is limited to distress and safety operations by footnote 728. The operational satellites Marisat and first phase INMARSAT space segments INTELSAT V-MCS and MARECS do not include this 1 MHz band. The second generation INMARSAT space segment is expected to use this band.

The small antenna gain of ROSES, in conjunction with an inexpensive (uncooled) receiver and a limited satellite power, allows only a very narrowband SHOSAC-transmission, i.e. a very low bit rate. Assuming that a SHOSAC would be allocated the same effective isotropically radiated satellite power (e.i.r.p.) as the public correspondence voice carrier then this value would be about 18 dBW which corresponds to the present MARECS and INTELSAT V-MCS e.i.r.p.

One predominant problem is the signal acquisition, especially for phase shift keyed (PSK) modulation, as opposed to non-coherent frequency shift keyed modulation (FSK). In this context, the accuracy and stability of the carrier frequency radiated from the spacecraft is of importance. As an example, the frequency inaccuracy value of the INMARSAT system after automatic compensation at the coast earth station is around ± 800 Hz (after the ship earth station demodulator) or 1600 Hz peak-to-peak. In § 5, a frequency inaccuracy of 2 kHz peak-to-peak has been assumed, to take into account residual compensation errors.

3. Suitable modulation and coding techniques

As the ROSES antenna is relatively small, it could therefore be mounted on a high point of the vessel. The link between a ROSES antenna and the satellite should experience reduced multipath effects and little path blockage compared to a link between a buoy and a satellite.

Signal fades can be largely compensated by using forward error correcting codes (FEC). A possible alternative technique would be time diversity but this is considered less suitable for this particular application.

Both PSK and FSK are considered here as possible modulation methods. PSK requires continuous carrier acquisition but this is not required by FSK. However, PSK is around 4 dB more efficient than FSK.

Further information on certain aspects of system design are required; for example, oscillator phase noise, acquisition vs tracking loop bandwidth and effects of multipath.

4. Link budget

The link budget shown in Table V is based on INTELSAT V-MCS and MARECS figures. It is assumed that SHOSAC e.i.r.p. allocation is that of a voice carrier. The multipath fade assumed is 6 dB; the FEC coding gain assumed here amounts also to 6 dB. It is further assumed that degradation on the up-path would have negligible effect on the overall C/N_0.

TABLE V — *SHOSAC link budget calculation*

	Units	MARECS/ INTELSAT V-MCS	
Satellite e.i.r.p. (5° elevation)	dBW		18.0
Free space loss (1 544 MHz; 5° elevation)	dB		188.5
Antenna gain; ship earth station	dBi		1
System noise temperature (1 000 K)	dBK		30
Boltzmann's constant	dB(W/HzK)		−228.6
Multipath fade	dB		6
C/N_0 down path	dBHz		23.1
		PSK	FSK
C/N_0	dBHz	23.1	23.1
Required E_b/N_0 (BER = 10^{-4})	dB	8.3	12.3
FEC improvement approx. (code rate = $^1/_2$)	dB	6	6
Modem losses	dB	2	2
Available bandwidth	dBHz	18.8	14.8
Assumed information bit rate 32 and 16 bit/s		15.1	12.1
Margin	dB	3.7	2.7
Transmitted bit rate	bit/s	64	32
Transmission time for 500 information bits	s	15.6	31.2

The FEC coding gain assumed in the budget is a coarse approximation and needs further refinement. In the study presented here a BCH block code and a Rayleigh-channel are assumed.

5. Acquisition and tracking

Four alternative proposals are discussed which include coherent and non-coherent systems. To avoid mutual intra system interference in the overlapping areas, adjacent satellites transmit the SHOSAC on different carrier frequencies which the ROSES must be equipped to acquire and track. Suitable transmit carrier frequencies offset by, for example 5 kHz, could be achieved at coast earth stations.

A second intermediate frequency (IF) of 200 kHz has been adopted for which cost effective filters and voltage controlled oscillators (VCO's) with bandwidths of a few kilohertz are readily available commercially. Furthermore, it is assumed that, at the beginning of each transmission, the carrier remain unmodulated for between 1 and 10 s, thus allowing the ROSES to acquire lock.

Four different methods of acquisition and demodulation considered to date are as follows and as illustrated in Fig. 3:

(a) BPSK with phase-locked loop (PLL) for acquisition and demodulation (see Fig. 3a);

(b) BPSK with aided PLL for acquisition using a beacon receiver (see Fig. 3b);

(c) BPSK with non-coherent acquisition and coherent demodulation (see Fig. 3c);

(d) BFSK with non-coherent acquisition and non-coherent demodulation (see Fig. 3d).

A preliminary analysis of these system alternatives has been carried out and is summarized in Table VI:

TABLE VI

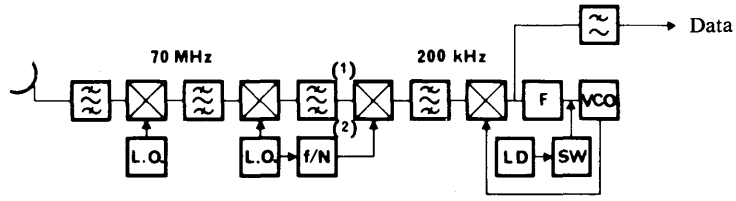
Method	(a)	(b)	(c)	(d)
Modulation	PSK	PSK	PSK	FSK
Acquisition time (s)	10	1	1	1
Information bit rate (bit/s)	32	32	32	16
Transmission time for a message of 500 bits, incl. acquisition time (s)	26	17	17	32

Method (a) requires the least complex implementation, but requires a longer transmission time compared to methods (b) and (c). Methods (b) and (c) appear attractive as far as transmission time is concerned. Method (b) requires a beacon, whereas method (c) requires a more elaborate receiver design. If multipath effects severely degrade the performance of PSK, it could be necessary to use FSK with non-coherent demodulation (method (d)).

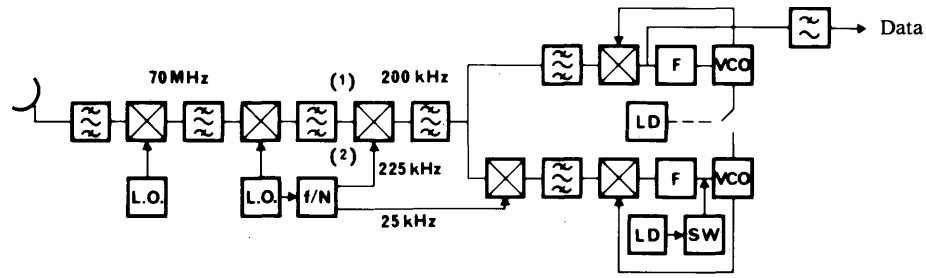
6. Selective broadcast

One of the requirements of the Future Global Maritime Distress and Safety System is selective addressing of shore-to-ship alerts to concise ocean area. IMCO is presently developing such a subdivision (SAR-plan).

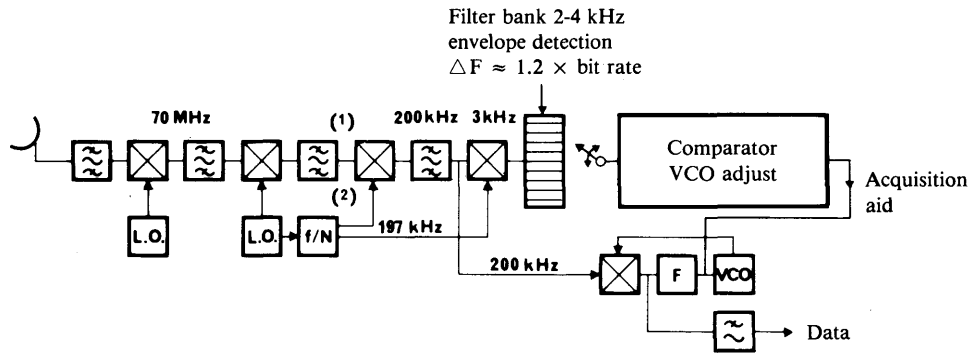
As an example, with the earth subdivided into areas of 120 nautical miles squared, there would be about 3000 sea areas which could be sequentially numbered giving a 12 bit binary area code. Several of these areas may be combined at the expense of another few bits in order to address larger areas for other safety purposes such as navigational and meteorological warnings.



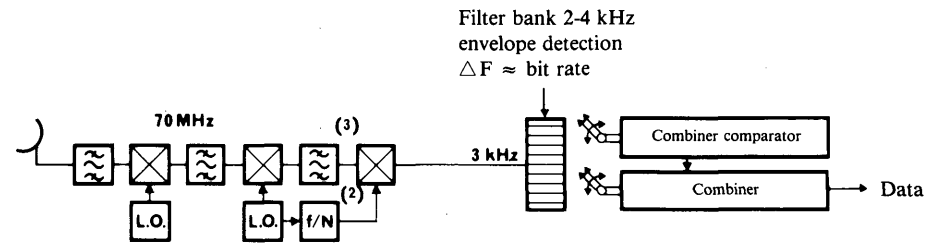
a) Coherent acquisition, coherent demodulation



b) Aided acquisition, coherent demodulation



c) Incoherent acquisition aid, coherent demodulation



d) Incoherent acquisition and demodulation

FIGURE 3 – *Four different methods of acquisition and demodulation*

LD:	Lock detector		(1)	(2)	(3)	
SW:	sweep	AOR	195	5	8	kHz
F:	filter	IOR	190	10	13	kHz
L.O.:	local oscillator	POR	185	15	18	kHz
f/N:	frequency divider					
VCO:	voltage controlled oscillator					

7. Summary

SHOSAC offers the possibility of contacting ships in given areas from a coast earth station via satellite, even if the ships are not equipped with INMARSAT communications ship earth stations.

Both coherent and non-coherent modulation schemes and the respective implications on acquisition and tracking are discussed and typical bit rates and transmission times have been estimated. Multipath effects can be largely compensated by use of FEC.

Additional studies are required on those aspects indicated in § 3 of this Annex.

REPORT 922

REFERENCE RADIATION PATTERN FOR SHIP EARTH STATION ANTENNAS

(Study Programme 17A/8)

(1982)

1. Introduction

Consideration is given in this Report to the reference antenna pattern for ship earth stations to be used in assessing interference between ship earth stations and either terrestrial stations or space stations of different satellite systems sharing the same frequency bands.

The objective of this Report is to present actual measurement of antenna patterns taken on a test range and show that these measured patterns are well below the reference pattern proposed by other Study Groups and defined by the WARC-79.

2. Existing reference radiation patterns

Reference radiation patterns have been developed in various Study Groups of the CCIR; Report 390 and Report 391 in Study Group 4, Report 771 in Study Group 8 and Report 614 in Study Group 9. These Reports give a reference radiation pattern for antennas with diameter less than 100 λ, as stated below.

$$G = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{dB} \quad \text{for } 100 \frac{\lambda}{D} \leq \varphi < \varphi_1$$

$$G = G_1 \quad \text{dB} \quad \text{for } \varphi_1 \leq \varphi$$

where:

D : antenna diameter
λ : wavelength
} expressed in the same unit

φ : angle from beam centre, in degrees

In Report 391, G_1 is taken to be -10 dB. On the other hand, in Report 614, G_1 is taken to be 0 dB. For values of φ less than $100\ \lambda/D$, WARC-79 has defined the following reference radiation pattern for interference calculations:

$$G = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi\right)^2 \quad \text{dB} \quad \text{for } 0 < \varphi < \varphi_m$$

$$G = 2 + 15 \log \frac{D}{\lambda} \quad \text{dB} \quad \text{for } \varphi_m \leq \varphi < 100 \frac{\lambda}{D}$$

$$\text{where, } \varphi_m = \frac{20\lambda}{D} \sqrt{G_{max} - 2 - 15 \log \frac{D}{\lambda}} \quad \text{(degrees)}$$

and G_{max} = maximum gain of the antenna relative to isotropic.

These equations assume the case of a circular paraboloidal reflector antenna, which might not be relevant for some kinds of antennas which could be used in the future for ship earth stations. Therefore, the use of this kind of pattern should clearly be restricted to the case of circular paraboloidal reflector antennas. Moreover, the above Reports have not specifically considered the question of the applicability of these equations to very small values of D/λ; therefore, for antennas of such diameter as small as 4λ, the value of G_1 must be carefully established taking into account measured radiation patterns.

3. Measured antenna patterns

All production designs of ship earth stations manufactured to date for use in the MARISAT system have employed a parabolic reflector antenna having a diameter of between 1.2 and 1.3 m with a G/T of -4 (dBK^{-1}). This value of G/T is the current requirement for INMARSAT Standard-A ship earth stations.

Figures 1 and 2 present measured antenna patterns for 1.3 m antenna for transmit and receive frequencies, respectively. Figs. 3 and 4 present measured antenna patterns for 1.2 m antenna for transmit and receive frequencies, respectively. Fig. 5 presents measured antenna pattern for 0.8 m antenna for receive frequencies.

In submitting information on measured radiation antenna patterns, the following guidelines should be adopted:

- for each antenna diameter, only two Figures should be presented, one for transmit band and one for receive band, which should include all available data for this type of antenna;
- only the peaks of the side lobes measured over the appropriate frequency band and antenna pattern cut should be plotted, for any angle from beam centre;
- the reference radiation pattern as described in § 5 should be included in all Figures;
- the Figures should be one-sided (right-hand) with measured peaks from both sides superimposed;
- the caption of the vertical axis should read "Gain relative to isotropic (dB)" with a scale of 2 dB/cm;
- the caption of the horizontal axis should read "Angle from beam centre (degrees)" with a linear scale of 10°/8 mm;

Figures 1 to 5 in this Report have been prepared using these guidelines.

4. Effect of reflection due to sea and ship's superstructures

Considerations have been given to the concept that the design objectives and the reference radiation pattern for interference studies may be defined separately, because the reference radiation pattern should include the effect of local reflections from the sea and ship's superstruture.

However, it is very difficult to estimate quantitatively such effects, which may be of the order of several dB, because the directions of reflected waves vary in accordance with the ship movement. Moreover, the time probability of the interference caused by such reflected side lobes is very difficult to assess. Further study is needed to clarify the effect of such reflections.

5. Reference radiation pattern for ship earth stations

Based on the above and using a conservative approach, it may be reasonable to adopt the following reference radiation pattern for the antennas of ship earth stations:

$$G = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{dB} \quad \text{for } 0 < \varphi < \varphi_m$$

$$G = 2 + 15 \log \frac{D}{\lambda} \quad \text{dB} \quad \text{for } \varphi_m \leq \varphi < 100 \frac{\lambda}{D}$$

$$G = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{dB} \quad \text{for } 100 \frac{\lambda}{D} \leq \varphi < \varphi_1$$

$$G = 0 \text{ dB} \quad \text{for } \varphi_1 \leq \varphi$$

$$\text{where: } \varphi_m = \frac{20\lambda}{D} \sqrt{G_{max} - 2 - 15 \log \frac{D}{\lambda}} \quad \text{(degrees)}$$

$$\varphi_1 = 120 \left(\frac{\lambda}{D}\right)^{0.4} \quad \text{(degrees)}$$

and where other variables are defined in § 2.

This pattern has been indicated on Figs. 1 to 6.

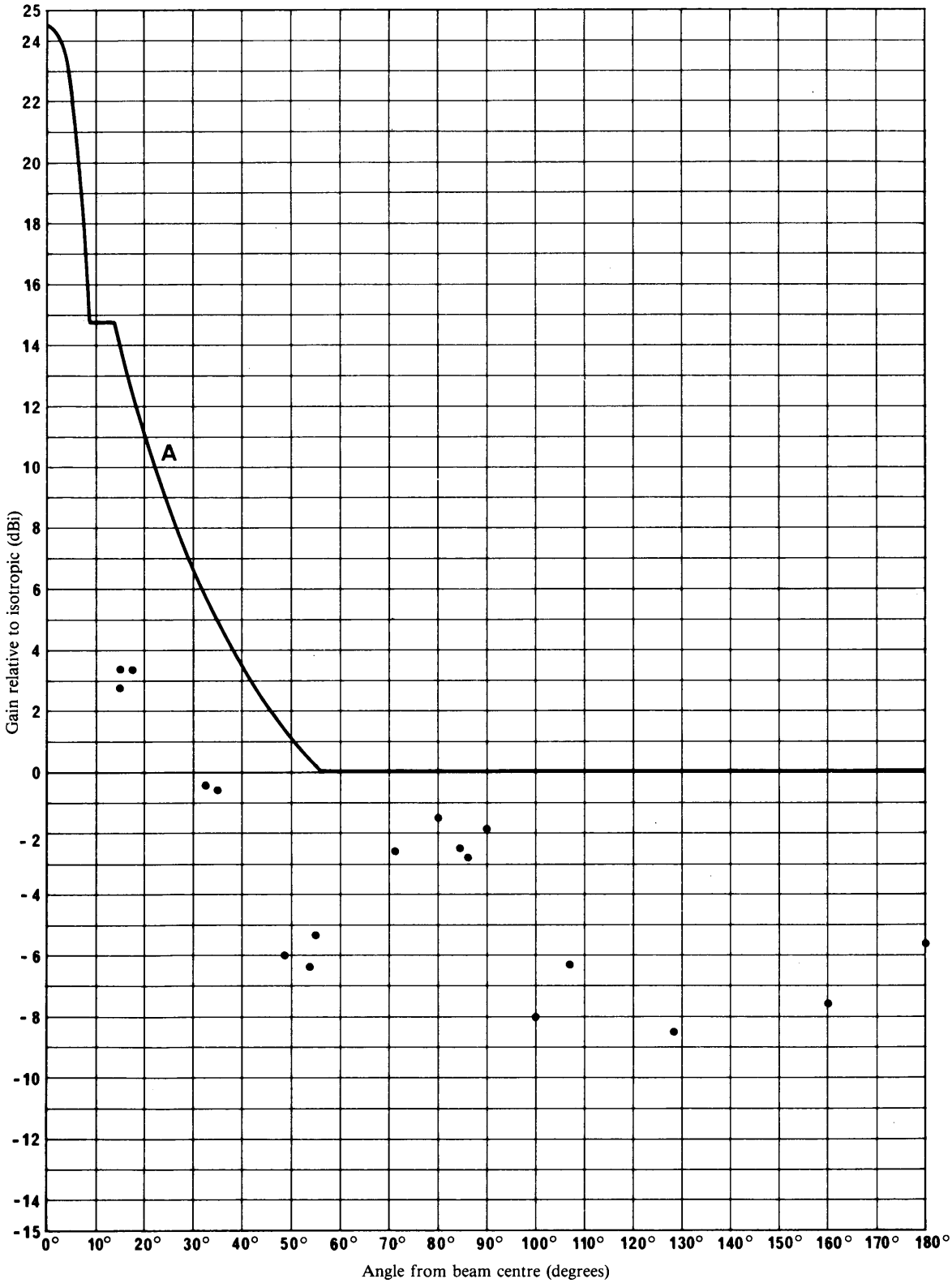


FIGURE 1 – *Measured antenna pattern for a ship earth station antenna*

Type of antenna: circular parabolic
Frequency band: 1636.5-1645 MHz (transmit)
Diameter: 1.3 m

●: maximum gain: 24.6 dBi Polarization: RH circular Manufacturer: UK
A: reference radiation pattern

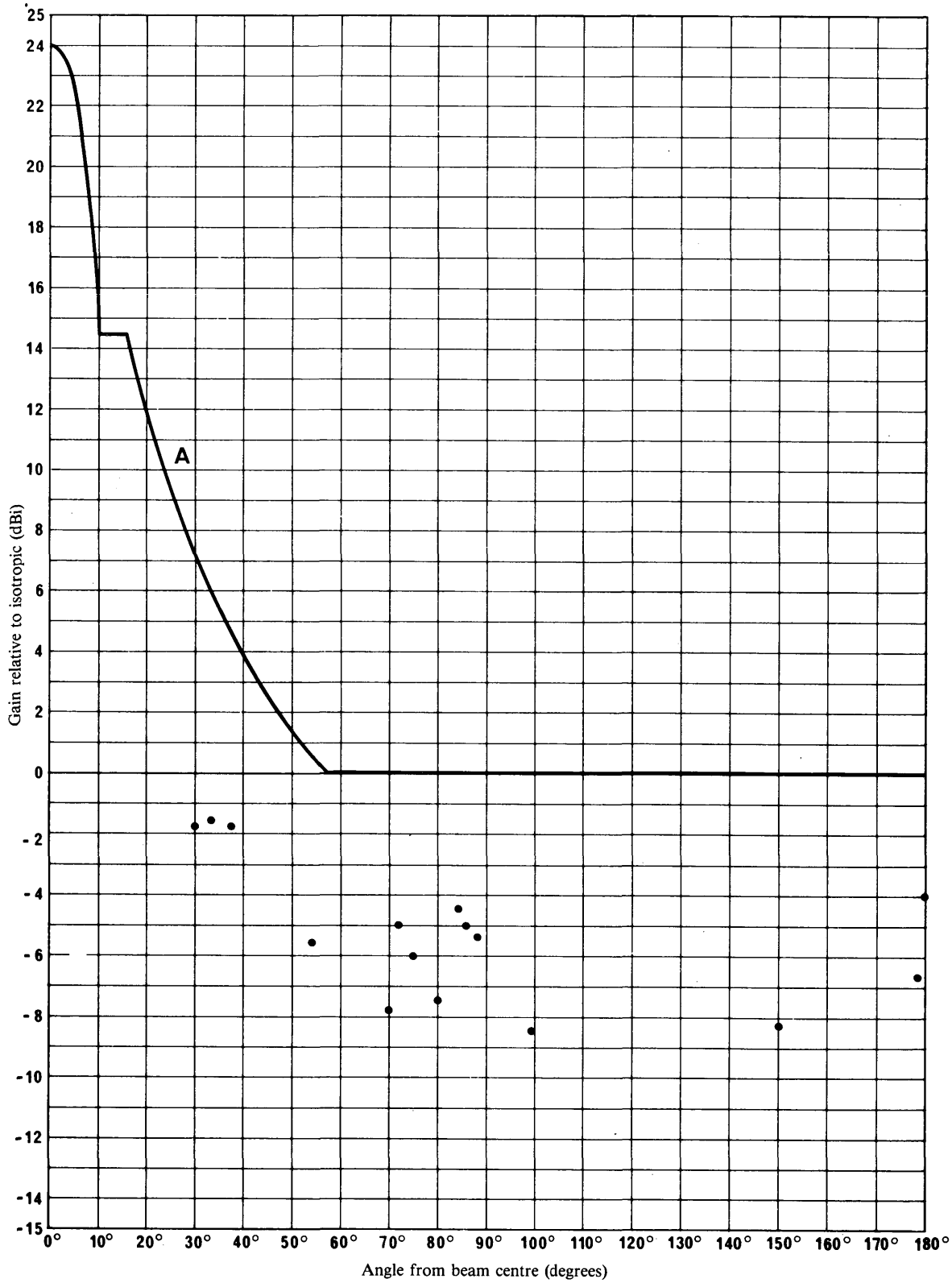


FIGURE 2 – *Measured antenna pattern for a ship earth station antenna*

Type of antenna: circular parabolic
Frequency band: 1535-1543.5 MHz (receive)
Diameter: 1.3 m

●: maximum gain: 24 dBi Polarization: RH circular Manufacturer: UK
A: reference radiation pattern

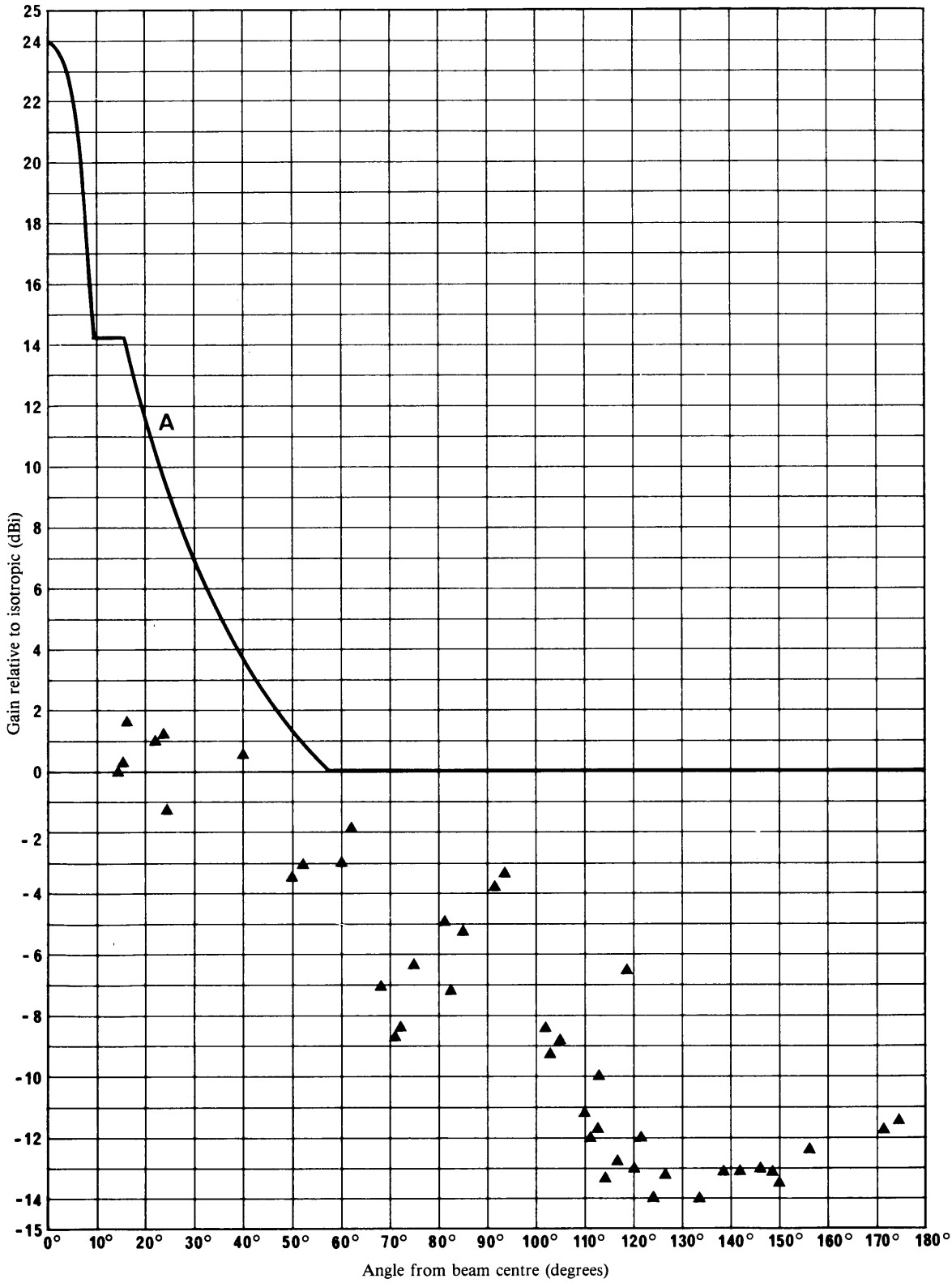


FIGURE 3 – *Measured antenna pattern for a ship earth station antenna*

Type of antenna: circular parabolic
Frequency band: 1636.5-1645 MHz (transmit)
Diameter: 1.2 m

▲: maximum gain: 24 dBi Polarization: RH circular Manufacturer: USA
A: reference radiation pattern

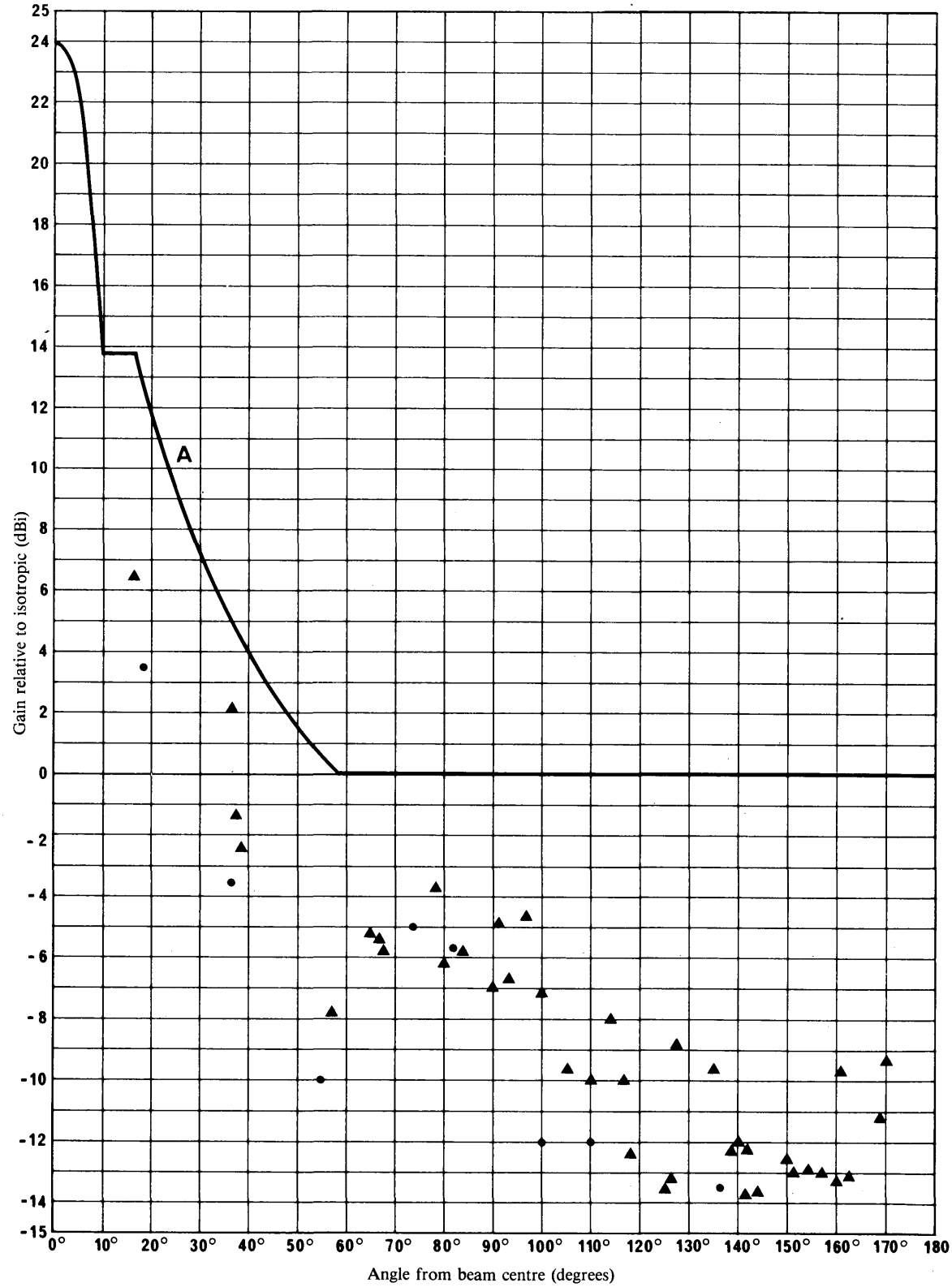


FIGURE 4 – *Measured antenna pattern for a ship earth station antenna*

Type of antenna: circular parabolic
Frequency band: 1535-1543.5 MHz (receive)
Diameter: 1.2 m

●: maximum gain: 23.9 dBi Polarization: RH circular Manufacturer: Japan
▲: maximum gain: 23.5 dBi Polarization: RH circular Manufacturer: USA
A: reference radiation pattern

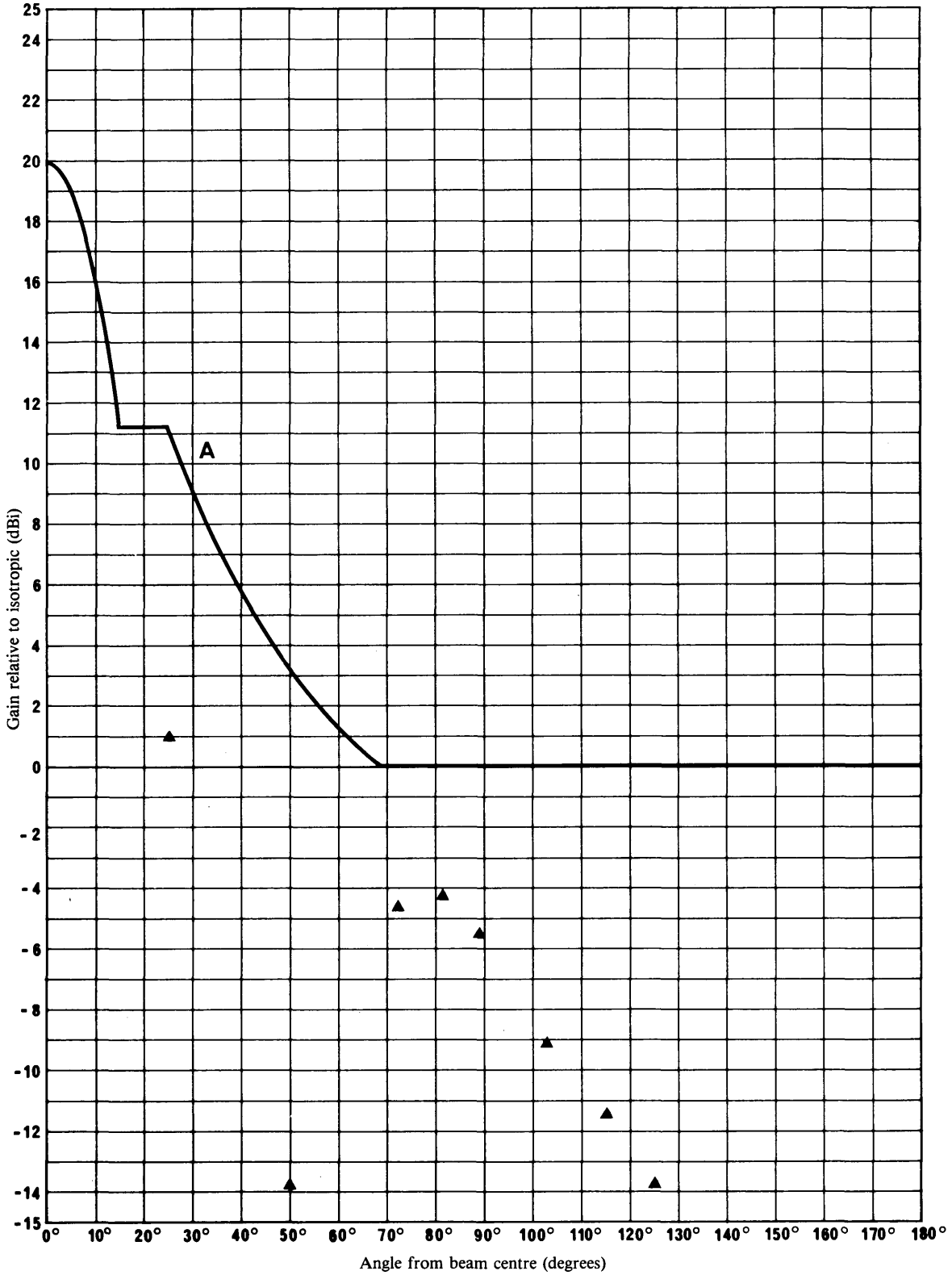


FIGURE 5 – *Measured antenna pattern for a ship earth station antenna*

Type of antenna: circular parabolic
Frequency band: 1535-1543.5 MHz (receive)
Diameter: 0.8 m

▲: maximum gain: 20 dBi Polarization: RH circular Manufacturer: Japan
A: reference radiation pattern

6. INMARSAT side lobe performance requirement

Based on the measured radiation patterns of paraboloidal antenna with diameters between 0.8 m and 1.2 m, the following expression has been determined as the performance requirement for the sidelobe envelope of INMARSAT Standard-A ship earth stations:

$G = 8$	dB	$(16° \leq \varphi \leq 21°)$
$G = 41 - 25 \log \varphi$	dB	$(21° < \varphi \leq 57°)$
$G = -3$	dB	$(\varphi > 57°)$

where G is the antenna gain relative to isotropic at an angle φ from beam centre.

The INMARSAT antenna pattern is illustrated in Fig. 6, together with the reference radiation pattern derived from § 5, for 1.2 m antenna diameter (24 db maximum gain).

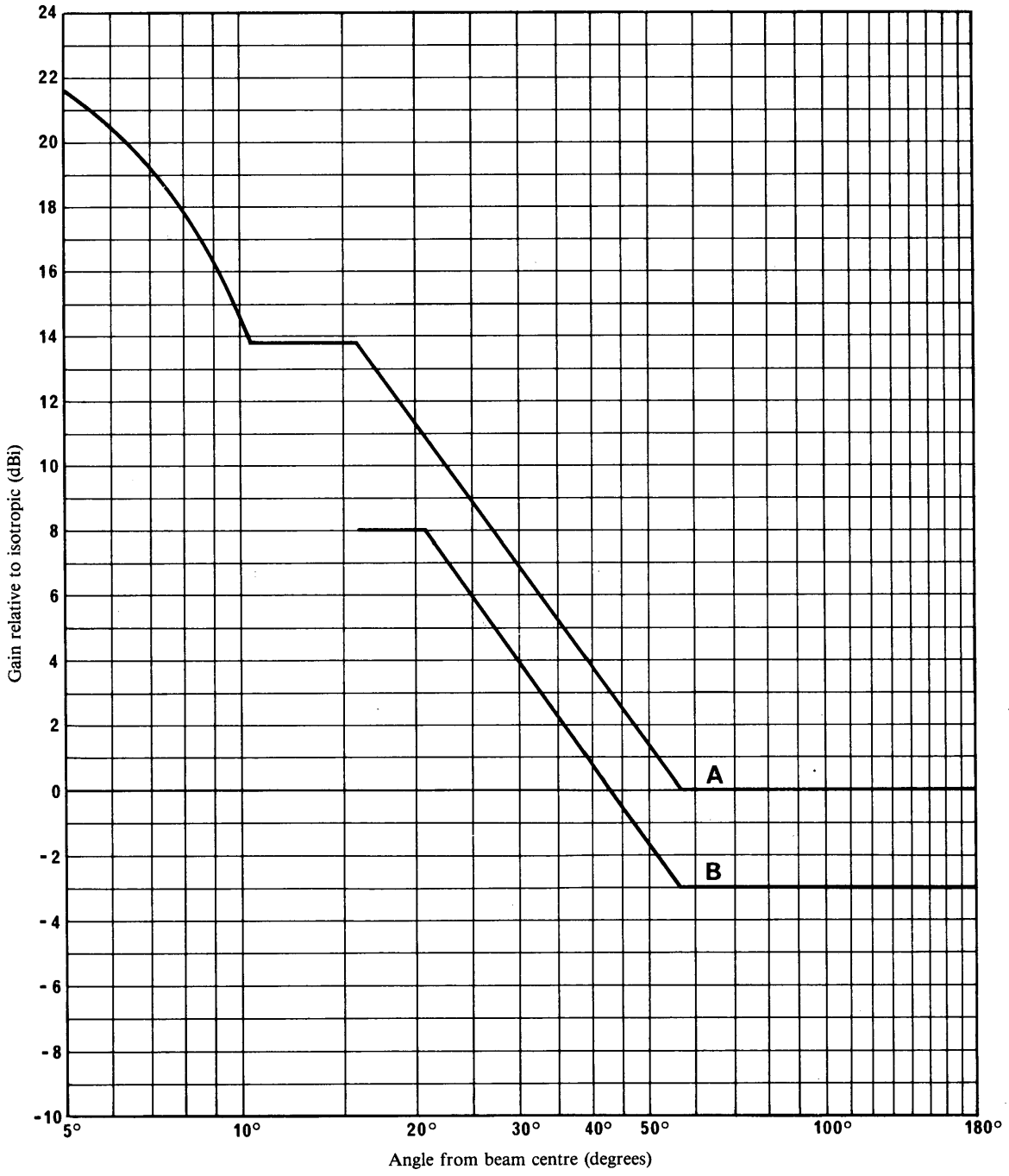


FIGURE 6 – *INMARSAT antenna side lobe envelope for Standard-A ship earth stations*

A: reference radiation pattern (1.2 m antenna diameter, 24 dBi maximum gain)
B: INMARSAT pattern

7. Conclusion

Based on the measured radiation patterns of ship earth stations, it is proposed to adopt provisionally the reference radiation pattern for interference studies as given in this Report, for the circular paraboloidal reflector antennas of D/λ higher than 4 to be used for ship earth stations. In order to assure the suitability of this reference radiation pattern, Administrations are invited to study further and submit measured radiation patterns of ship earth stations of various sizes, using the guidelines delineated in § 3.

To take into account that antennas other than parabolic may be used for ship earth stations, it would be desirable to examine additional measured radiation patterns, and Administrations are invited to submit such information on various antenna types and sizes, using the guidelines delineated in § 3.

REPORT 923

DESIGN OF FREQUENCY PLANS FOR SATELLITE TRANSMISSION OF SCPC CARRIERS USING NON-LINEAR TRANSPONDERS

(Study Programme 17A/8)

(1982)

1. Introduction

In satellite communication systems, a number of SCPC carriers are transmitted via a single satellite transponder. For efficient use of satellite power, the transponder would be operated in the non-linear region, in which case intermodulation noise affects signal quality.

The intermodulation products falling into the frequency slots of occupied signal channels could be reduced by suitably positioning the channels within the available bandwidth. Babcock spacing [Babcock, 1953] is a typical example of this approach where the signal channels are completely free from third-order intermodulation noise. However, such an intermodulation-free frequency plan would not necessarily be desirable because of its inefficient use of available bandwidth, especially where a large number of channels have to be accommodated. For example, in order to accommodate 20 channels, it would be necessary to utilize a bandwidth more than 10 times the width of a plan using adjacent frequency slots. Hence, bandwidth-efficient frequency plans need to be developed, and one approach is to allow some intermodulation products to fall into the signal channels, but only to the extent that the degradation of signal quality can be acceptable.

A reasonable and effective approach to realize such an idea is to minimize the number of the third-order intermodulation products falling into the worst signal channel [Hirata, 1978]. The worst signal channel here means a specific signal channel into which the largest number of the third-order intermodulation products fall. This Report discusses the assignment of frequencies based on this approach, which is referred to hereafter as intermodulation-minimum frequency assignment.

2. Equal level SCPC carriers

2.1 *Relationship between assigned bandwidth and intermodulation products*

It is difficult to determine theoretically intermodulation minimum frequency plans. However, the attainable minimum number of intermodulation products falling into the worst affected signal channel can be estimated by the theoretically derived lower bound. Only products of the type $f_1 + f_2 - f_3$ are considered since $2f_1 - f_2$ products are much less numerous and have 6 dB less power.

Figure 1 shows the theoretically derived lower bound of the number of the $(f_1 + f_2 - f_3)$ type of intermodulation products falling into the worst signal channel as a function of the assigned bandwidth with a parameter of the number of signal channels to be accommodated. In this Figure, the number of intermodulation products is normalized by that falling into the worst signal channel in a plan using adjacent frequency slots. For convenience, the latter plan is referred to hereafter as minimum equal-spacing. The assigned bandwidth is also normalized by that required for the minimum equal-spacing plan. This Figure implies that the number of intermodulation products falling into the worst signal channel could be reduced to about one half compared to the case of minimum equal-spacing when the total frequency bandwidth occupied is 50% wider than that required for minimum equal-spacing.

2.2 *Intermodulation-minimum frequency plan*

Intermodulation-minimum frequency plans have been obtained for practical application by computer calculation. For a small number of signal channels, the optimum solution can be obtained by examining all possible combinations. Table I shows the results obtained where the number of signal channels K is 10.

For a large number of signal channels, the quasi-optimum solution, which may not be optimum but would be considered very close to optimum, can be obtained by an iterative approach [Hirata and Yasuda, 1976]. Table II shows the obtained results where K is 20 in II-A and 40 in II-B, respectively.

Comparing the results of the normalized number of intermodulation products with its lower bound shown in Fig. 1, the difference between them is about 14 to 24% for both $K = 10$ and $K = 20$. In the case of $K = 10$ and normalized bandwidth = 2.0, for example, the normalized number of intermodulation products is 0.286 as shown in Table II-A, while the corresponding value of the lower bound is about 0.23 as shown in Fig. 1, which leads to a difference of 24%. These relatively small differences indicate that the number of intermodulation products falling into the worst signal channel in the intermodulation-minimum frequency assignment can be estimated effectively by using the lower bound curves shown in Fig. 1.

In order to confirm that the quasi-optimum solutions given in Table II could be considered to be near optimum, the intermodulation spectra of frequency plans for $K = 40$ given in Table II-B have been calculated on the assumption that all carriers have the same power level. Fig. 2 shows the calculated results. In the Figure, (a) is the case of minimum equal-spacing, and (b) and (c) are the cases where the available bandwidth is twice and triple that of the minimum equal-spacing plan, respectively. As shown in the Figures, the intermodulation noise level in the frequency slots of signal channels becomes lower than that in unassigned frequency slots around them (see Fig. 2(b) and (c)). In fact, intermodulation noise in the worst signal channel can be decreased by 4.0 dB in case (b) and by 5.5 dB in case (c) compared with case (a), respectively.

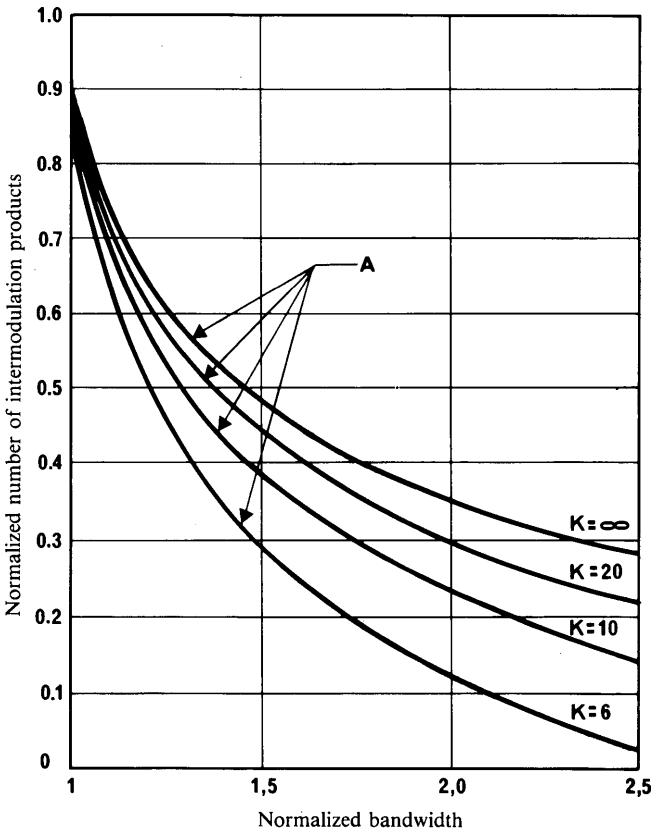


FIGURE 1 – *Lower bound of the number of intermodulation products falling into the worst signal channel as a function of assigned bandwidth*

A: lower bounds
K: number of signal channels

TABLE I — *Optimum intermodulation-minimum frequency plans (number of signal channels, K = 10)*

Number of frequency slots	Normalized bandwidth	Normalized number of IM products	Assigned frequency slots
11	1.1	0.786	1, 2, 3, 4, 5, 7, 8, 9, 10, 11
12	1.2	0.679	1, 2, 3, 4, 6, 7, 9, 10, 11, 12
13	1.3	0.571	1, 2, 3, 4, 6, 7, 10, 11, 12, 13
14	1.4	0.500	1, 2, 3, 4, 6, 7, 10, 12, 13, 14
15	1.5	0.446	1, 2, 3, 4, 7, 8, 11, 13, 14, 15
16	1.6	0.411	1, 2, 3, 4, 7, 10, 12, 14, 15, 16
17	1.7	0.375	1, 2, 3, 4, 7, 10, 12, 14, 16, 17
18	1.8	0.340	1, 2, 3, 5, 7, 10, 13, 16, 17, 18
19	1.9	0.304	1, 2, 3, 5, 9, 12, 14, 17, 18, 19
20	2.0	0.286	1, 2, 3, 6, 8, 12, 15, 18, 19, 20
21	2.1	0.268	1, 2, 3, 5, 10, 14, 15, 18, 20, 21

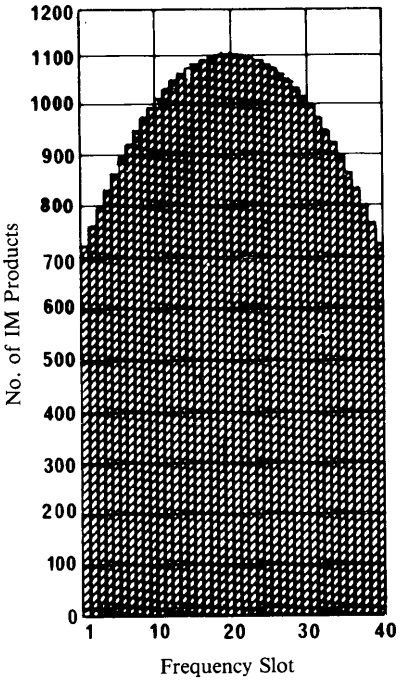
TABLE II — *Quasi-optimum intermodulation-minimum frequency plans*

a) $K = 20$

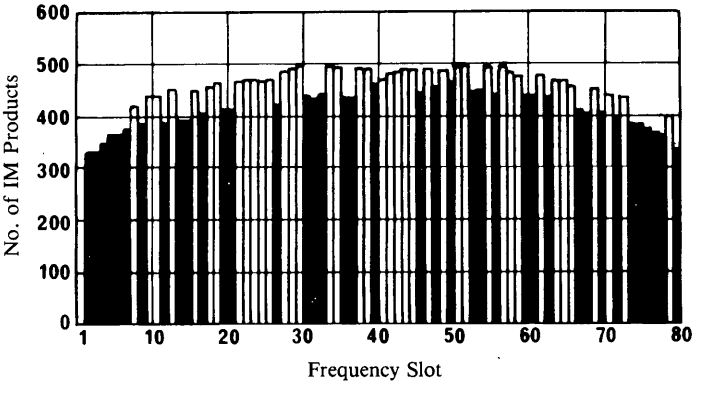
Number of frequency slots	Normalized bandwidth	Normalized number of IM products	Assigned frequency slots
25	1.25	0.663	1, 2, 3, 4, 5, 6, 7, 9, 11, 12, 13, 16, 18, 19, 20, 21, 22, 23, 24, 25
30	1.50	0.521	1, 2, 3, 4, 5, 7, 8, 9, 11, 13, 16, 18, 19, 22, 25, 26, 27, 28, 29, 30
35	1.75	0.433	1, 2, 3, 4, 5, 7, 8, 10, 15, 16, 18, 22, 24, 27, 28, 29, 32, 33, 34, 35
40	2.00	0.364	1, 2, 3, 4, 7, 9, 12, 13, 15, 18, 22, 25, 29, 31, 32, 36, 37, 38, 39, 40

b) $K = 40$

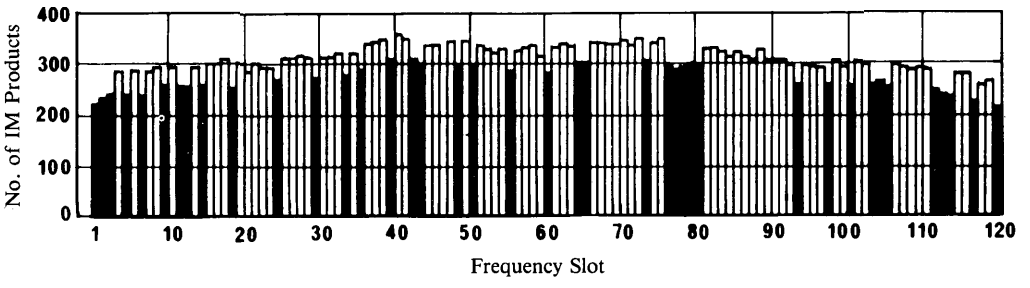
Number of frequency slots	Normalized bandwidth	Normalized number of IM products	Assigned frequency slots
80	2.00	0.419	1, 2, 3, 4, 5, 6, 8, 11, 13, 14, 16, 19, 20, 26, 30, 31, 32, 35, 36, 39, 45, 47, 49, 52, 53, 54, 56, 60, 61, 63, 67, 68, 70, 72, 74, 75, 76, 77, 78, 80
120	3.00	0.283	1, 2, 3, 5, 7, 10, 12, 13, 15, 19, 25, 30, 34, 36, 40, 43, 44, 49, 51, 56, 61, 65, 66, 74, 77, 78, 79, 80, 81, 94, 98, 101, 104, 105, 106, 112, 113, 114, 117, 120



a) Normalized bandwidth = 1.0 (equal-spacing)



b) Normalized bandwidth = 2.0



c) Normalized bandwidth = 3.0

FIGURE 2 – *Intermodulation spectra of the quasi-optimum frequency plans (K = 40) (Signal channels are placed in the hatched frequency slots)*

3. Multi-level SCPC carriers

In future satellite systems it may be desirable to operate with several standards of mobile earth stations having different G/T values. One possibility would be to transmit signals destined to the various mobile earth station standards with different satellite e.i.r.p. levels. Even within systems that operate with a single mobile earth station standard, different satellite carrier power levels may be used for different services.

However, accommodation of large numbers of carriers of mixed power levels in a single non-linear satellite transponder by placing high and low power carriers in arbitrarily selected channel assignments could easily lead to situations where intermodulation noise from certain high power channels would render several low power channels unusable.

A carefully developed frequency plan, resulting in a distribution of intermodulation noise among channels in such a way as to be proportional to the carrier power of the channel could prevent such a situation.

This section briefly describes several frequency plans, and in particular one category in which large and small carriers are placed in even and odd numbered channels respectively.

This carrier placement forces the largest power intermodulation products to fall only on even numbered channels thus protecting the low power carriers on the odd channels.

3.1 *Mixed level frequency plan alternatives*

One type of frequency plan capable of easily accommodating mixed level carriers assigns carriers to channels selected from a set of equally spaced channels using a Babcock spacing [Babcock, 1953; Edwards *et al.*, 1969]. Resultant assigned channels are totally free of third-order intermodulation noise and could consequently be used for carriers of any power level. However, Babcock plans are generally impractical, unless the number of required carrier assignments is small, due to the inefficient use such plans make of the available bandwidth.

Improved efficiency at the expense of third-order intermodulation products falling in assigned channels can be achieved with "double Babcock" plans. Such plans are formed by placing two identical Babcock plans side-by-side in frequency but separated by an amount approximately equal to the bandwidth of one of the identical plans. The penalty paid for the increased carrier density is some third-order intermodulation products falling on assigned channels. It can be shown that, in an "n" carrier plan, precisely $(n/2)-1$ third-order products fall on each of the assigned channels when all carrriers are active. Since such a plan still provides a substantial reduction in the number of third-order products within each assigned channel over that which could be obtained with uniform or random channel spacings, intermodulation performance may be sufficiently good to operate with mixed level carriers.

If required, performance of the "double Babcock" plan can be improved for any selected assigned channel by deleting its "twin" assigned channel in the opposite half of the plan. When this is done, the selected channel becomes totally free of third-order intermodulation products. Consequently these improved channels may be used for carriers either lower or higher in power than other channels of the plan. Although the bandwidth efficiency of this plan is better than that of a Babcock plan, it still utilizes bandwidth inefficiently and is useful only when small numbers of assignable channels are required.

More bandwidth-efficient plans can be achieved at the expense of higher levels of intermodulation noise within assigned channel bandwidths. One method to achieve a significant improvement in bandwidth utilization efficiency while at the same time accommodating dual-level carriers has been suggested [Horstein and LaFlame, 1977]. In this method, high power carriers are placed on even numbered channels and lower power carriers on odd numbered channels. Third-order products created may be classified into one of the eight categories shown in Table III. The Table also shows the approximate relative powers of each product type assuming that the ratio of low power to high power carriers is equal to "r". The advantage gained with this type of plan is that the more powerful intermodulation products of category 1 do not fall in odd numbered channels where the lower power carriers are placed.

Suitable frequency plans that accommodate "m" low power and "n" high power carriers using this approach may be developed by randomly selecting "m" low power and "n" high power channels from within the desired range and then calculating the resultant numbers of intermodulation products of each category that fall on each assigned frequency. The numbers of products in each category, when multiplied by the relative product weight, shown in Table III, and summed, yield a composite weighted intermodulation product count for each channel.

These individual channel weighted intermodulation product counts may also be weighted by the relative power of the carrier placed in the channel to obtain a combined weighted count that is proportional to the carrier-to-intermodulation ratio of each channel. By generating a large number of sets of random channel assignments and computing the weighted numbers of all intermodulation products falling in assigned channels [Hirata, 1978] a near optimum dual-level frequency plan may be derived.

Such plans are best suited for accommodating "*m*" carriers of one level and "*n*" carriers of a second level where m < n. As "*m*" approaches "*n*", the number of products of category 2 increases rapidly and begins to limit channel performance even though they each have less power than products of category 1. In any case, the penalty paid to achieve dual-level performance with an odd-even plan is an increase of about 3 dB in the intermodulation noise falling on each of the "*n*" majority carrier channels as a result of restricting the majority carriers to even channels.

TABLE III — *Categories and relative powers of third-order intermodulation products for a dual-level frequency plan*

Product category	Product type	Channel	Relative power
1	$f_h+f_h-f_h$	Even	1
2	$f_h+f_h-f_l$	Odd	r
	$f_h+f_l-f_h$	Odd	r
3	$f_h+f_l-f_l$	Even	r^2
	$f_l+f_l-f_h$	Even	r^2
4	$f_l+f_l-f_l$	Odd	r^3
5	$2f_h-f_h$	Even	1/4
6	$2f_h-f_l$	Odd	$r/4$
7	$2f_l-f_h$	Even	$r^2/4$
8	$2f_l-f_l$	Odd	$r^3/4$

Note 1. — f_h is used to indicate a high-power carrier and f_l to indicate a low power carrier.
Note 2. — r is the ratio of low power to high power carrier powers.
Note 3. — High power carriers are placed in even channels; low power carriers are placed in odd channels.

3.2 *Typical performance of a dual-level plan*

As an example of the performance of a dual-level plan of this type, a typical frequency plan that places 28 high power carriers on even numbered channels and 8 low power carriers on odd numbered channels was developed using the procedure described in § 3.1. The low power carriers were assumed to have a power ¼ that of a high power carrier (i.e., $r = 0.25$) with a total satellite capacity of 30 high power carriers. Channel assignments were randomly selected from 339 channels and 2000 sets of 35 random assignments examined to obtain the set that resulted in the best worst-channel carrier-to-intermodulation noise ratio.

Table IV summarizes the performance of the plan giving the weighted number of intermodulation products falling in the average and worst assigned channel for both the high power and low power channels. The weighted numbers shown are directly proportional to the intermodulation power in the average or worst case channel. A better indication of channel performance is the normalized carrrier-to-intermodulation ratio which may be computed from the weighted numbers by considering the relative power in each of the carriers. Table IV also shows the average and worst-case carrier-to-intermodulation ratio that would be achieved if a satellite transponder with a non-linear TWTA characteristic similar to that of the Marisat satellite were used.

For comparison purposes, another frequency plan was developed in which the same numbers of high and low power carriers were placed in a selected set of channel assignments taken from 339 available channels but without limiting carrier placement on odd or even channels. As can be seen by comparing the data for both cases the average carrier-to-intermodulation ratio for large carriers is improved by 1.9 dB as would be expected since this second approach doubles the number of channels which may be assigned to large carriers. However, the superiority of the first plan is clearly evident for low power carriers since the intermodulation noise on low-power carrier channels increased on the average by 6 dB over that of the plan without even/odd channel assignments.

4. Conclusions

It has been shown that the number of third-order intermodulation products falling into a channel slot can be substantially reduced by the use of a carrier assignment plan encompassing an assigned bandwidth greater than that for the minimum equal-spacing plan. It was also shown in Fig. 1 that the normalized number of intermodulation products depends on the number of carriers as well as the normalized assigned bandwidth, and that spectrum efficiency decreases with the number of carriers.

In the case where carriers with two power levels must be transmitted, improved carrier-to-intermodulation noise performance for the low power carriers can be achieved by placing high and low power carriers in even and odd numbered channels respectively. With a proper selection of channel assignments using a procedure such as that suggested in this Report, substantial improvements in low power carrier *C/IM* can be achieved with a small sacrifice in high power carrier *C/IM*.

TABLE IV — *Comparison of performance of multi-level frequency plans with and without even/odd channel assignment restrictions*

	Carrier power	
	High	Low
28/8 plan with even/odd channel assignments:		
— weighted average number of *IM* products	62.1	54.2
— weighted worst channel number of *IM* products	70.8	65.0
— average computed *C/IM* (1) (dB)	21.1 dB	21.7 dB
28/8 plan without even/odd channel assignments:		
— weighted average number of *IM* products	40.3	215.8
— weighted worst channel number of *IM* products	55.2	259.6
— averaged computed *C/IM* (1) (dB)	23.0 dB	15.7 dB

(1) 3rd order products only in a 7.5 MHz occupied bandwidth with a typical TWTA at saturation.

REFERENCES

BABCOCK, W. C. [January, 1953] Intermodulation interference in radio systems. *BSTJ*, Vol. XXXII, **1**, 63-73.

EDWARDS, R., DURKIN, J. and GREEN, D. H. [August, 1969] Selection of intermodulation free frequencies for multiple-channel mobile radio systems. *Proc. IEE*, Vol. 116, **8**, 1311-1318.

HIRATA, Y. [Spring, 1978] A bound on the relationship between intermodulation noise and carrier frequency assignment. *COMSAT Tech. Rev.*, Vol. 8, **1**, 141-154.

HIRATA, Y. and YASUDA, Y. [August, 1976] Optimum channel allocation to minimize the intermodulation products. Tech. Rep. on Communication Systems of IECE of Japan, CS76-59.

HORSTEIN, M. and LAFLAME, D. T. [September, 1977] Intermodulation spectra for two SCPC systems. *IEEE Trans. Comm.*, Vol. COM-22, **9**, 990-994.

REPORT 924

FIELD TEST OF DIGITAL FACSIMILE FOR MARITIME MOBILE-SATELLITE SERVICE

(Question 17/8)

(1982)

1. Introduction

Digital facsimile equipment for the maritime mobile-satellite service has been developed, which may be used for the transmission of documents with high quality and high speed. The equipment design is based on CCITT Recommendations T.4 and T.30, with High Level Data Link Control (HDLC) added to provide error control.

A field test was performed with the equipment on board a ship. The test result proved to be satisfactory in picture quality and transmission time.

2. Development of digital facsimile equipment

The equipment is designed for digital facsimile transmission to be used in the maritime environment on board a ship. Specific features are as follows:

(a) It has a mechanical and electrical structure providing protection against severe environmental conditions such as shocks, ship motions and ambient temperature.

(b) Reliable reception is achieved under severe maritime environmental conditions by the use of a thermo-sensitive recording technique.

(c) The smear-desmear filter (S/D filter) protects data signals from impulsive noise.

(d) Re-transmission of erroneous frames by the HDLC procedure guarantees high quality of the received copies.

Specification of the equipment is as follows:

– transmission rate :	4800/2400 bit/s with automatic equalizer and *S/D* filter, or 1200 bit/s;
– transmission mode :	full-duplex or half-duplex;
– error correction :	error correction by retransmission;
– effective line length :	210 mm (at transmitter), 200 mm (at receiver);
– scanning method of transmission :	flat-bed scanner with photo diode array;
– minimum scan line time :	13 ms;
– recording method :	thermo-sensitive recording;
– environmental condition :	ambient temperature : 0 °C-55 °C, ambient humidity : 0%-95%.

3. Field test over the satellite link

The test of digital facsimile equipment was performed between KDD-Maru (4300 grt) cruising on the East China Sea and Tokyo, via the Marisat satellite over the Indian Ocean, in both directions of transmission.

The test circuit configuration is shown in Fig. 1.

The main parameters of the test were as follows:

– elevation angle to the satellite :	8° to 13°;
– received C/N_0 :	51 to 54 dBHz;
– data transmission rate :	4800 bit/s or 2400 bit/s;
– transmission documents for evaluation :	test documents of CCITT Study Group XIV;
– sea state :	rough sea.

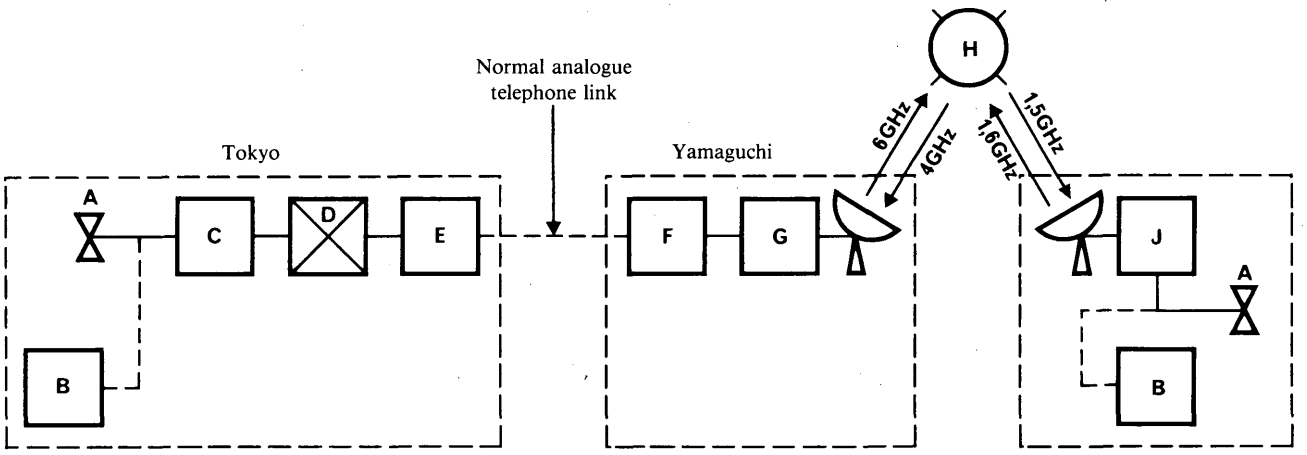


FIGURE 1 – *Test circuit via the Marisat satellite*

A: FAX
B: TIMS (transmission impairment measurement set)
C: Datel adapter
D: Datel exchanger
E: carrier terminal equipment
F: carrier terminal equipment
G: transmitter and receiver
H: Indian Ocean Marisat satellite
J: KDD Maru

The quality of received copies was as good as the originals if the automatic error correcting system was used. The transmission time which was influenced by reduced C/N_0, was measured. The results of these measurements are shown in Fig. 2.

Bit error ratio (BER) of received signal with or without S/D filter was measured. The result revealed the effectiveness of the filter against impulsive noise as shown in Fig. 3.

4. Conclusions

From the field test, the following conclusions may be drawn:

- the performance of the digital facsimile equipment enabled it to be used satisfactorily on a ship operating with the Marisat satellite system,
- the thermo-sensitive recording technique utilized in the equipment was able to reproduce pictures of good quality. The recording speed of this method is fast enough to permit transmission rate up to 4800 bit/s,
- the S/D filter is very effective against impulsive noise, at least for transmission rates of 2400 bit/s and 4800 bit/s.

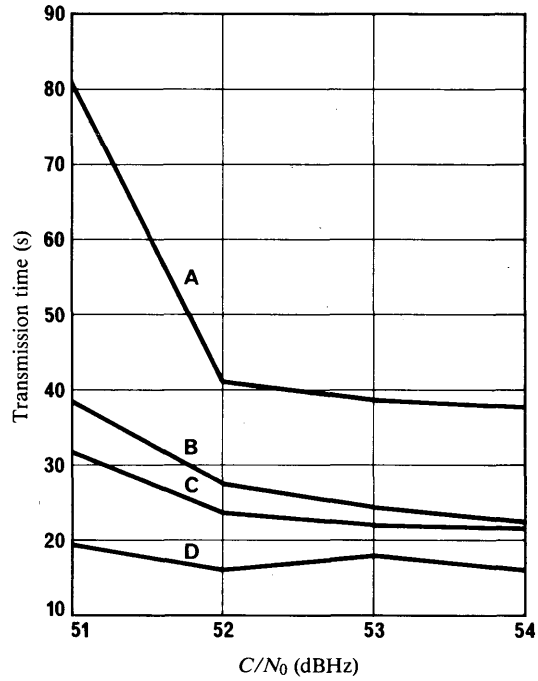


FIGURE 2 – *Examples of transmission times of digital facsimile versus received C/N_0*

A: CCITT SG XIV - No. 5 Test document
B: No. 8 Test document
C: No. 6 Test document
D: No. 2 Test document

Coding scheme:	two-dimensional coding, READ (K* = 4)
Data transmission rate:	4 800 bit/s, with S/D filter
Operation mode:	full duplex, automatic error correcting by retransmission
Picture resolution:	3.85 lines/mm
Document size:	ISO A-4
* Parameter *K*:	in order to limit the disturbed area in the event of transmission errors, a one-dimensionally coded line may be transmitted more frequently than every *K* line

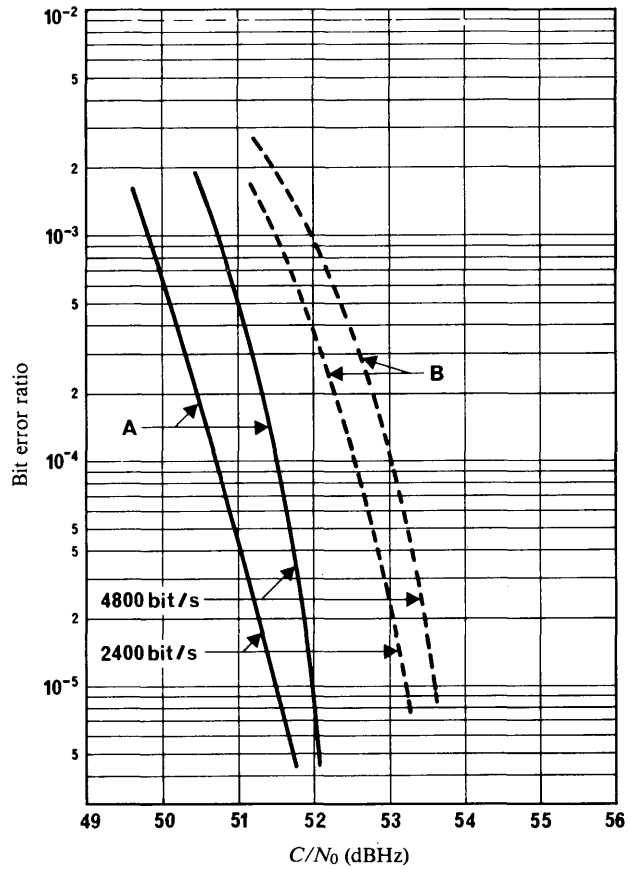


FIGURE 3 – *Bit error ratio with or without S/D filter*

2400/4800 bit/s. (4-phase PSK)
Signal level: —13 dBm0

A: with S/D filter
B: without S/D filter

SECTION 8G: LAND MOBILE-SATELLITE SERVICE AND MOBILE-SATELLITE SERVICE

Reports

REPORT 770-1

TECHNICAL AND OPERATING CONSIDERATIONS FOR A LAND MOBILE-SATELLITE SERVICE OPERATING IN BAND 9

(Question 47/8)

(1978-1982)

1. Introduction

Definitions (Radio Regulations Nos. 27, 29, 31, 35, 73) adopted at the WARC-ST in 1971 anticipated the needs of a mobile-satellite service, separate from the fixed-satellite service, and provided space counterparts of conventional land mobile, maritime mobile, and aeronautical mobile services. Subsequently, considerable progress has been made toward establishing maritime mobile and aeronautical mobile-satellite services in bands allocated for these purposes in 1971. These space services augment and extend the capabilities provided by non-space means, overcoming line-of-sight limitations, and overcoming the uncertainties of ionosphere-dependent propagation.

The purpose of this Report is to explore the operational utility of satellites in the land mobile service, to present information on the probable technical characteristics of certain types of land mobile-satellite systems, and to employ these characteristics in a preliminary assessment of sharing between such a land mobile-satellite service and other services in the vicinity of 1 GHz.

2. Background

In the United States, and in some other countries, frequencies in the vicinity of 900 MHz have been allocated domestically for use by the land mobile service. In the USA in particular, the intent is to develop a nationwide land mobile service which is both a mobile extension of the public telephone services and a substantial augmentation of the Public Safety, Industrial, and Land Transportation Radio Services.

The application of space systems could increase the capacity, capability and versatility of these land mobile systems and services, particularly for covering large geographical areas with a single system, for assuring communications during emergencies and natural disasters, and for extending service to remote and isolated areas.

Because they are intended to be complementary, the technical characteristics of land mobile and land mobile-satellite systems should be compatible. That is, the technical characteristics should allow inter-operability between the systems where appropriate, and they should facilitate frequency sharing under mutually agreed circumstances.

3. Potential applications

Three possible roles for the land mobile-satellite service are experimental, operational, and emergency use. The first of these is a prelude to the others, in that it would permit experimentation in close collaboration with the land mobile service. The purposes of such experiments would be twofold: first, to identify operational services for which satellites may provide a logical and cost-effective alternative, supplement or augmentation for the land mobile service, and second, to establish criteria for possible sharing between the land mobile-satellite service and the land mobile service in rendering these services.

Operationally, the land mobile-satellite service may prove to be the most effective means for dependable coverage into rural and isolated areas. Satellites could either provide geographical extensions of conventional land mobile services (as in the case of aeronautical and maritime satellite services beyond line-of-sight of land masses); or satellites could provide new services not now possible with existing facilities because of line-of-sight limitations of the land mobile service at VHF and UHF.

Another application is a satellite data communication system for vehicles. Preliminary market surveys in Europe have indicated considerable interest in reliable communication for long distance road transports. From these market contacts, it appears that a dispatch system * based on two-way telex and data transmission would satisfy the essential needs. Excluding voice transmission enables a considerable reduction to be made in the system C/N_0. The basic system elements conceived are:

- dispatch centres working through the public telex and data networks;
- a land earth station;
- a satellite transponder; and
- mobile earth stations.

Practical experiments in the concept envisaged in this system would be of great value in finalizing the details. Such a communication system could find wider use, for example finding roaming subscribers in land mobile radio systems. For the time being there is no suitable frequency allocation for the land mobile-satellite service in Region 1. At the WARC-79 an allocation was made for land mobile-satellite communication within the 900 MHz band in Regions 2 and 3. In Region 1, however, only Sweden and Norway have an allocation. Consequently, a Region 1 system will only be possible if a suitable frequency allocation is made at a future competent conference. One possibility could be integration with another system using low G/T earth stations.

Annex IV describes and provides the results of voice communication and position location experiments conducted in the United States using the ATS-6 experimental geostationary satellite.

4. Technical characteristics

The transmission quality objectives for a system in the land mobile-satellite service would be similar to the transmission quality objectives of a land mobile system. For example, for a mobile telephone service, the transmission quality objective would be that there is a 0.90 probability of obtaining a voice circuit which 75% of the subscribers rate as circuit merit 4; and a 0.90 probability of obtaining a voice circuit which 90% of the subscribers rate as circuit merit 3.

A concept definition study [Anderson and Milton, 1979; Anderson, *et al.*, 1981] for a land mobile-satellite system to provide mobile radiotelephone service to about 200,000 subscribers located primarily in rural areas of the contiguous 48 states in the United States has been completed. The satellite consisted of 69 beam multi-beam antenna system featuring a beamwidth of 0.5° between the 3 dB points. There were 111 channels per beam and with a frequency reuse factor of 3, this yielded a total of 333 channels. The total occupied bandwidth was 10 MHz in both the satellite-to-mobile and mobile-to-satellite directions of transmission. For operation in the 800 MHz band, the space station antenna would be about 42 m in diameter and the prime power would be about 12 kW. Operation in the 1550-1650 MHz bands would decrease the antenna diameter to 21 m, but increase the prime power to 48 kW.

Annexes I and II to this Report present the principal technical characteristics of the land mobile and land mobile-satellite services which are pertinent to the feasibility of sharing between these services. The material is drawn largely from these sources:

- Annex I of Report 631 contains summary information on the characteristics of a land mobile service used in Japan.
- Report 358 summarizes information from numerous sources on protection ratios applicable to sharing in the land and maritime mobile services at VHF and UHF. Much of this information is "service-independent" and can be applied, with proper attention to the particular geographical considerations, to analyze sharing between land mobile and land mobile-satellite systems.
- In the United States, experiments are being planned for a nation-wide public radiotelephone system designed on a cellular basis [Addeo, 1976; Fisher, 1976].
- The technical characteristics for a land mobile-satellite service are being developed by the US National Aeronautics and Space Administration, based on an authoritative sampling of the public service community [NASA/GSFC, 1976, 1977].

* For the purpose of this text, "dispatch system" has the meaning: a radio system used to control the operation of a fleet of mobiles, such as aircrafts, taxis, police, etc.

5. Sharing considerations

The technical characteristics given in Annex I and II are employed in Annex III to examine a number of specific aspects of sharing between the land mobile and land mobile-satellite services. In particular, the annexes contain data on minimum values of signals to be protected, protection ratios, power flux-density limitations, and coordination distances. It is emphasized, however, that the coalescence of these parameters into detailed sharing criteria is not possible until the potential for use of satellites becomes more clearly defined, and until further experimentation with proposed land mobile systems provides more data on minimum desired signals and other factors which will influence sharing.

REFERENCES

ADDEO, E. J. [25 March, 1976] An approach to digital signal processing for a high capacity mobile telephone system. 26th Annual Conference of the IEEE Vehicular Technology Group, 24-26 March, 1976, Washington, DC, USA, Conf. Record, 52-57. (Other pertinent papers appear in the Conference Record.)

ANDERSON, R. E. FREY, R. L., LEWIS, J. R. and MILTON, R. T. [May, 1981] Satellite-aided mobile communications: experiments, applications and prospects. *IEEE Trans. Vehic. Tech.* Vol. VT-30, **2**, 54-61.

ANDERSON, R. E. and MILTON, R. T. [June, 1979] Satellite-aided mobile radio concepts study. Final Report on NASA Contract NAS5-25134, General Electric Company.

FISHER, R. E. [14-16 June, 1976] A description of the Bell System 850 MHz high capacity mobile telecommunications system. 1976 International Conference on Communications, Pt. II, Philadelphia, Pa., USA. *IEEE*, NY, USA.

NASA/GSFC [14 January, 1976] Public service communications satellite user requirements workshop, October 17-19, 1976, Final Report.

NASA/GSFC [April, 1977] Public service communications satellite system review and experiment definition workshop, March 27-29, 1977. Draft Report.

BIBLIOGRAPHY

ANDERSON, R. E., FREY, R. L., LEWIS, J. R. and MILTON, R. T. [1980] Satellite-aided mobile communications, experiments, applications and prospects. International Conference on Communications, 8-12 June, 1980, Seattle, Washington, USA.

BRISKEN, A. F., ANDERSON, R. E., FREY, R. L. and LEWIS, J. R. [August 1979] Land mobile communications and position fixing using satellites. *IEEE Trans. Vehic. Tech.*, Vol. VT-28, **3**, 153.

CARDULLO, M. and DORIAN, C. [1969] Mobile communications via satellite. *ITU Telecomm. J.*, **36-IX,** 426-436.

DAWSON, G. [13-15 March, 1973] L-band satellite systems for mobile applications. International Conference on Satellite Systems for Mobile Communications and Surveillance, London, IEE Conf. Publ. 95.

HIRATA, Y., KYOGOKU, M., and ISOMURA, E. [April, 1972] A study on satellite communications for mobiles, Communications Satellite Systems. *Progress in Astronautics and Aeronautics*, Vol. 32, AIAA (ed. P. L. Bargellini).

HULT, J. L. [August, 1969] The promise of UHF satellites for mobile services. Rand Memo. 4170.

HULT, J. L. [September, 1970] Sharing the UHF between space and terrestrial services, Rand Memo. 4436. (See also Proc. of the National Electron. Conf., Chicago, December, 1970.)

LEBOW, I. L., JORDON, K. L. and DROUILHET, P. R. [1971] Satellite communications to mobile platforms. *IEEE*, **59**, 139-159.

ROGER, A. [December, 1976] Coming: the era of telemedicine. *IEEE Spectrum*, 31-36.

WEBER, W. J. III, NADERI, F. and GOLDMAN, A. M. Jr. [1980] Technology considerations for a 1990's operational land mobile-satellite service, Intelcom '80.

ANNEX I

CHARACTERISTICS OF THE LAND MOBILE SERVICE NEEDED TO EXAMINE SHARING POSSIBILITIES

1. General

Technical characteristics from three sources are examined. Maximum allowed interference levels to protect the three systems are found to be nearly identical.

2. Characteristics of Japanese land mobile system to operate at about 800 MHz

In Annex 1 of Report 631, a preliminary evaluation of the feasibility of sharing between the broadcasting-satellite service and the terrestrial mobile service in the 800 MHz band is provided. The permissible limits of power flux density produced on the surface of the Earth are based on worst-case co-channel interference, no account being taken of the advantage of channel interleaving.

The limits of interfering power flux-density produced on the surface of the Earth by a satellite to protect a high grade service are given as:

-133 dB(W/m^2) in a 16 kHz band at the receiving antenna of a mobile station,

-146 dB(W/m^2) in a 16 kHz band at the receiving antenna of a base station which correspond to field strengths of 12.8 and -0.2 dB(μV/m), respectively.

The following base station characteristics were assumed:

Channel spacing	25 kHz
Receiver bandwidth	16 kHz
Receiver noise factor	10 dB
Improvement factor	12 dB
Antenna gain	15 dB
Protection ratio	18 dB
Polarization discrimination	3 dB.

3. Field strength and protection ratios in the mobile service

Report 358, gives the minimum field strength to be protected as:

$$E_{min} = -41 + d + 20 \log f \qquad \text{dB}(\mu\text{V/m}) \qquad (1)$$

where:

d = multipath degradation (dB)

= 10 dB for mobile receiver in motion

= 21 dB for base station receiver (mobile transmitter in motion)

= 0 dB for base station receiver (stationary hand-held portable transmitter)

f = frequency in MHz.

At 860 MHz the minimum field strength and corresponding power flux densities to be protected are:

27.7 dB(μV/m) or -118.1 dB(W/m^2)	for mobile receiver in motion
38.7 dB(μV/m) or -107.1 dB(W/m^2)	for base station receiver (mobile transmitter in motion)
17.7 dB(μV/m) or -128.1 dB(W/m^2)	for base station receiver (stationary hand-held portable transmitter).

According to Table 1 in Report 358, the RF protection ratio is a function of the modulation parameters and difference in frequency between the desired and interfering carriers. However, the RF protection ratio is bounded by 8 and 17 dB. Taking into account a 3 dB polarization isolation and a conservative value of 17 dB for the RF protection ratio (assumes co-channel interference), the permissible interfering field strength and corresponding power flux-density is:

13.7 dB(μV/m) or -132.1 dB(W/m^2)	for mobile receiver in motion
24.7 dB(μV/m) or -121.1 dB(W/m^2)	for base station receiver (mobile transmitter in motion)
3.7 dB(μV/m) or -142.1 dB(W/m^2)	for base station receiver (stationary hand-held portable transmitter).

4. Characteristics of a cellular public radiotelephone system planned for use in the United States of America

Channel spacing		30 kHz
Receiver bandwidth		30 kHz
Modulation	(FM voice)	12 kHz deviation
	(FM 10 kbit data)	8 kHz deviation
Transmitting antenna gain		
	(base station)	10 dBi (or 7.9 dBd)
	(mobile station)	3 dBi (or 0.9 dBd)
e.i.r.p.	(base station)	20 dBW (erp = 17.9 dB)
	(mobile station)	13.8 dBW (erp = 11.7 dB)
Receiving antenna gain		
	(base station) (60° sector)	17 dBi (14.9 dB)
	(mobile station)	4.1 dBi (2.0 dB)

Typical base station height 150 m

Receiver sensitivity (12 dB, SINAD)
(base station) – 146 dBW (0.71 μV (e.m.f.))
(mobile station) – 143 dBW (1.0 μV (e.m.f.))

The minimum desired power flux density may be determined from:

$$\rho = \frac{4\pi P}{\lambda^2 G_r} \qquad W/m^2$$

where:

P: minimum desired signal power (watts)

λ: wavelength (metres)

G_r: receive antenna gain relative to isotropic

Based on the 12 dB SINAD receiver sensitivity, the minimum desired power flux density and corresponding field strength at 860 MHz is:

– 142.9 dB(W/m^2) or 2.9 dB(μV/m) for the base station,

– 127.0 dB(W/m^2) or 18.8 dB(μV/m) for the mobile station.

Taking into account a 3 dB polarization isolation and an assumed 8 dB RF protection ratio, the permissible interfering power flux density and corresponding field strength is:

– 147.9 dB(W/m^2) or – 2.1 dB(μV/m) for the base station,

– 132.0 dB(W/m^2) or 13.8 dB(μV/m) for the mobile station.

5. Summary

Values of permissible interfering power flux density and corresponding field strength are summarized in Table I.

TABLE I – *Summary of permissible interfering power flux-density and corresponding field-strengths*

Interfered with station	Report 631-1		Report 358-3		Cellular	
	dB (W/m^2)	dB (μV/m)	dB (W/m^2)	dB (μV/m)	dB (W/m^2)	dB (μV/m)
Base station	–146.0	–0.20	–142.1	+3.7	–147.9	–2.1
Mobile station	–133.0	+12.8	–132.1	+13.7	–132.0	+13.8

ANNEX II

CHARACTERISTICS OF THE PROPOSED LAND MOBILE-SATELLITE SERVICE NEEDED TO EXAMINE SHARING POSSIBILITIES

1. General

Services offered by the proposed land mobile-satellite service will include voice and data. In order to reduce experimental and development costs, for an initial system, transmitting and receiving equipments are assumed similar to those planned for the land mobile cellular system described in § 4 of Annex I, with the addition of:

– a low-noise receiving pre-amplifier (4 dB, NF) to provide – 152 dBW receiver sensitivity (12 dB, SINAD), *

– a transmitting power amplifier (100 W maximum).

* SINAD is an abbreviation for the ratio between signal-plus-noise-plus distortion to noise-plus-distortion.

Three earth station types are contemplated:

- mobile, roof-mounted, approximately 0.3 m square to allow mobile operation without antenna tracking for satellite elevations above 25°,
- transportable, * approximately 1 m diameter, pointed toward satellite with ± 8° accuracy,
- base station, approximately 2 m diameter, pointed toward satellite with ± 4° accuracy.

2. Earth station characteristics

Antenna gain	(mobile)	3.5 dBi
	(transportable)	16.5 dBi
	(base)	22.5 dBi
E.i.r.p.	(mobile)	17.8 dBW
	(transportable)	17.8 dBW
	(base)	17.8 dBW
Antenna discrimination in the horizontal plane (25° minimum elevation angle)		
	(mobile)	0.6 dB
	(transportable)	12.4 dB
	(base)	22.5 dB
Receiver sensitivity (12 dB SINAD)		−152 dBW
Protection ratio		8-17 dB

The minimum required power flux densities at the edge of the service area are determined by:

$$\rho = \frac{C}{N_T} \cdot \frac{4\pi\, kTB}{\lambda^2 G_r} \qquad \text{W/m}^2$$

where:

$\frac{C}{N_T}$: nominal operating received carrier-to-thermal noise ratio (10 dB assumed),

k: Boltzmann's constant (J/K),

T: operating noise temperature (438 K corresponding to 4 dB noise figure),

B: noise bandwidth (28 kHz),

λ: wavelength (0.35 metres ≈ 860 MHz),

G_r: receiver antenna gain.

Because of the propagation uncertainties associated with the use of low gain mobile antennas, a margin of 8 dB has been assumed.

Substituting the appropriate values in the above equation yields median pfd values of:

−123.1 dB(W/m^2) for the mobile station,

−136.1 dB(W/m^2) for the transportable station,

−142.1 dB(W/m^2) for the base station.

3. Tentative space station characteristics

Antenna gain (7 m diameter) **	33 dBi
Receiving system noise temperature	1200 K
Transmitter power per channel (mobile)	9.9 dBW
Transmitter power per channel (transportable)	−3.1 dBW
Transmitter power per channel (base)	−9.1 dBW

* In this Annex, a transportable station is an earth station in the land mobile-satellite service which may be moved from location to location for temporary use at each location.

** Spot-beam space station antenna gains as high as 50 to 60 dB may be practical within the time frame of WARC-1979 allocations.

ANNEX III

SHARING POSSIBILITIES

1. General

This Annex is provisional and presents a parametric analysis of worst-case sharing possibilities between the land mobile service and the proposed land mobile-satellite service (desired and interfering signals are frequency-modulated and co-channel). No account has been taken of the potential of channel interleaving and spread spectrum or other modulation techniques to reduce mutual interference.

The analysis examines the use of spot-beam satellite antennas as a means of providing coverage to a specific geographical area and to protect terrestrial systems. The geographical separation required between terrestrial stations of the land mobile service and those of the proposed land mobile-satellite service (LMSS) are plotted as a function of the satellite system characteristics.

From the material presented, it is concluded that *co-channel* sharing in the same service area would present formidable design constraints upon the proposed land mobile-satellite service. It is recognized, however, that the development of high-gain, spot-beam satellite antennas along with the use of channel interleaving offers the possibility of reducing these constraints to manageable proportions in the foreseeable future, but a further evaluation of these possibilities is required.

2. Use of spot beams to protect receiving stations in the land mobile service from satellite emissions

A comparison of the power flux density limits listed in Table I of Annex I with those required by a land mobile-satellite service (see Annex II) indicates the following values of additional isolation needed for co-channel operation:

To protect	*Land Mobile-Satellite Station*		
	Mobile	*Transportable* *	*Base*
Land mobile base station	24.8 dB	11.8 dB	5.8 dB
Land mobile mobile station	9.9 dB	−3.1 dB	−9.1 dB

Co-channel operation in a common geographical area is, in general, not feasible, although the use of spot-beam satellite antennas will allow adjacent area operation.

In order to determine the limits of this adjacent area, Figs. 1-3 show the required off-axis angle from the satellite main beam needed to reduce the interfering pfd to a range of specified values, plotted as a function of satellite antenna gain (see Report 810).

Figure 4 depicts a typical coverage area and interference zone as seen from a satellite in geostationary orbit. This example assumes a main beam pfd of -123 dB(W/m^2) to serve a mobile station. From Fig. 1, an off-axis angle of 0.9° would reduce the interfering pfd to -133 dB(W/m^2), the permissible interfering level into a land mobile service mobile station, given a satellite antenna gain of 45 dBi. The 0.9° radius defining the interference area is shown by the dashed circle on Fig. 4. The coverage area of the satellite is shown as the solid circle of 1° diameter (3 dB satellite antenna beamwidth from the top of Fig. 1).

3. Protection of receiving base stations in the land mobile service from proposed land mobile-satellite service earth station emissions

The required geographical separation needed between transmitting stations in the proposed land mobile-satellite service and a receiving base station in the land mobile service is shown on Fig. 5 (derived from curves in CCIR Recommendation 370) as a function of LMSS station e.i.r.p.

The relation between required LMSS station e.i.r.p. and the gain of the satellite receiving antenna is given in Fig. 6.

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* In this Annex, a transportable station is an earth station in the land mobile-satellite service which may be moved from location to location for temporary use at each location.

4. Protection of terrestrial receiving stations in the proposed land mobile-satellite service from land mobile service base station emissions

Fig. 7 (derived from curves in CCIR Recommendation 370) shows the required geographical separation required between a land mobile service base station transmitter and a receiving station in the proposed land mobile-satellite service as a function of LMSS station receiving antenna gain for two conditions:

- for $(I/N) = 0$ dB; assumes that the satellite e.i.r.p. is adjusted to provide an 18 dB (C/N) for each earth station gain value, and
- for $(C/I) = 18$ dB (desired signal pfd $= -123$ dB(W/m^2)); assumes that satellite e.i.r.p. is fixed at the value required to serve a mobile receiver of 3.5 dBi gain.

5. Protection of space station receivers in the proposed land mobile-satellite service from emissions in the land mobile service

Further study is required of the technical and operating constraints to protect space station receivers from emissions of stations in the land mobile service.

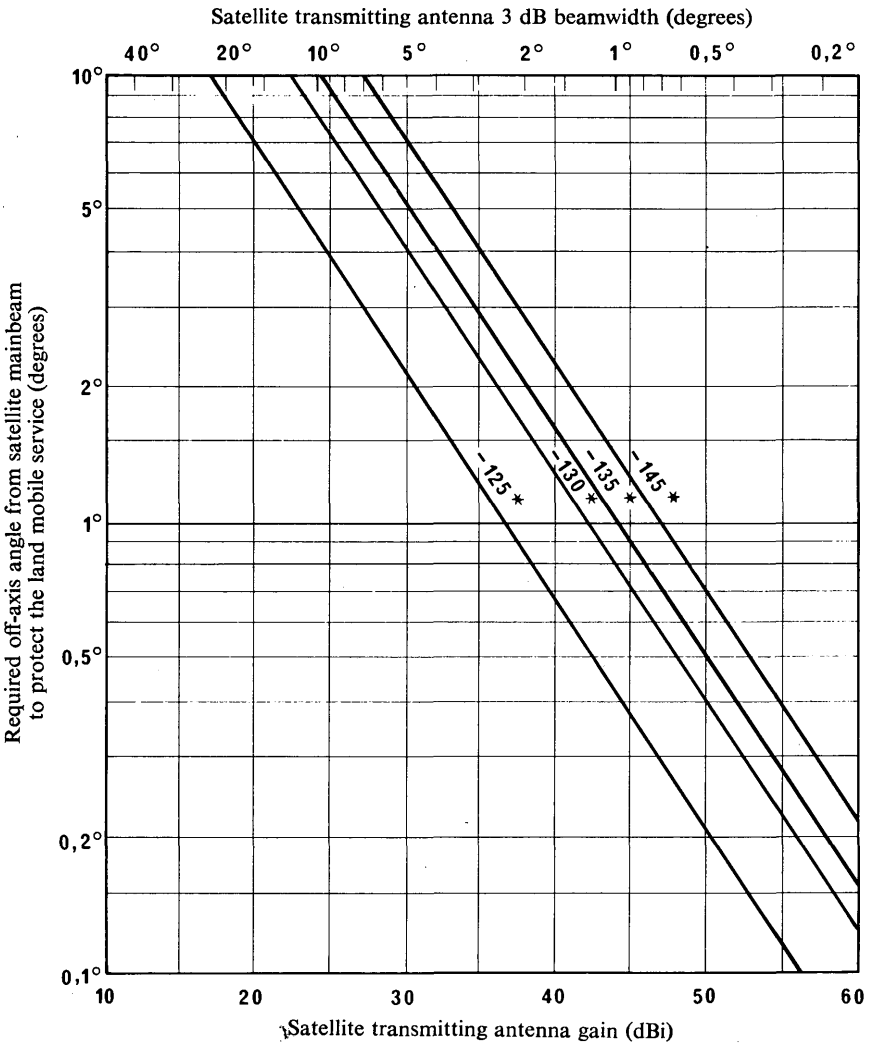


FIGURE 1 — *Off-axis angle to protect the land mobile service from satellite transmissions to land mobile satellite service mobile stations*

Note. — For pfd at Earth in the mainbeam = −123 dB(W/m^2)
(yields 18 dB (C/N) at LMSS mobile station)
where: $G = 3.5$ dBi, noise factor = 4 dB, $b = 28$ kHz.

* Permissible incident pfd (dB(W/m^2)).

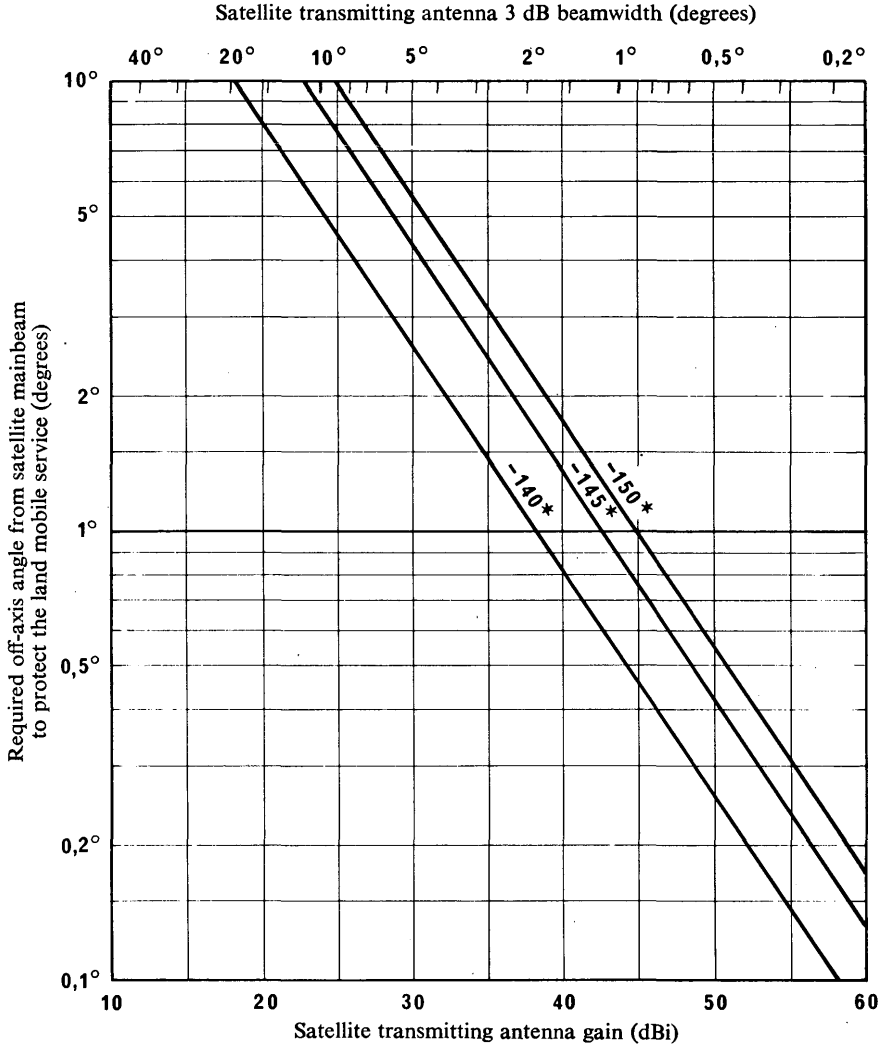


FIGURE 2 — *Off-axis angle to protect the land mobile service from satellite transmissions to land mobile satellite service transportable stations*

Note. — For pfd at Earth in the mainbeam = –136 dB(W/m²)
(yields 18 dB (C/N) at LMSS transportable station)
where: G = 16.5 dBi, noise factor = 4 dB, b = 28 kHz.

* Permissible interference pfd (dB(W/m²)).

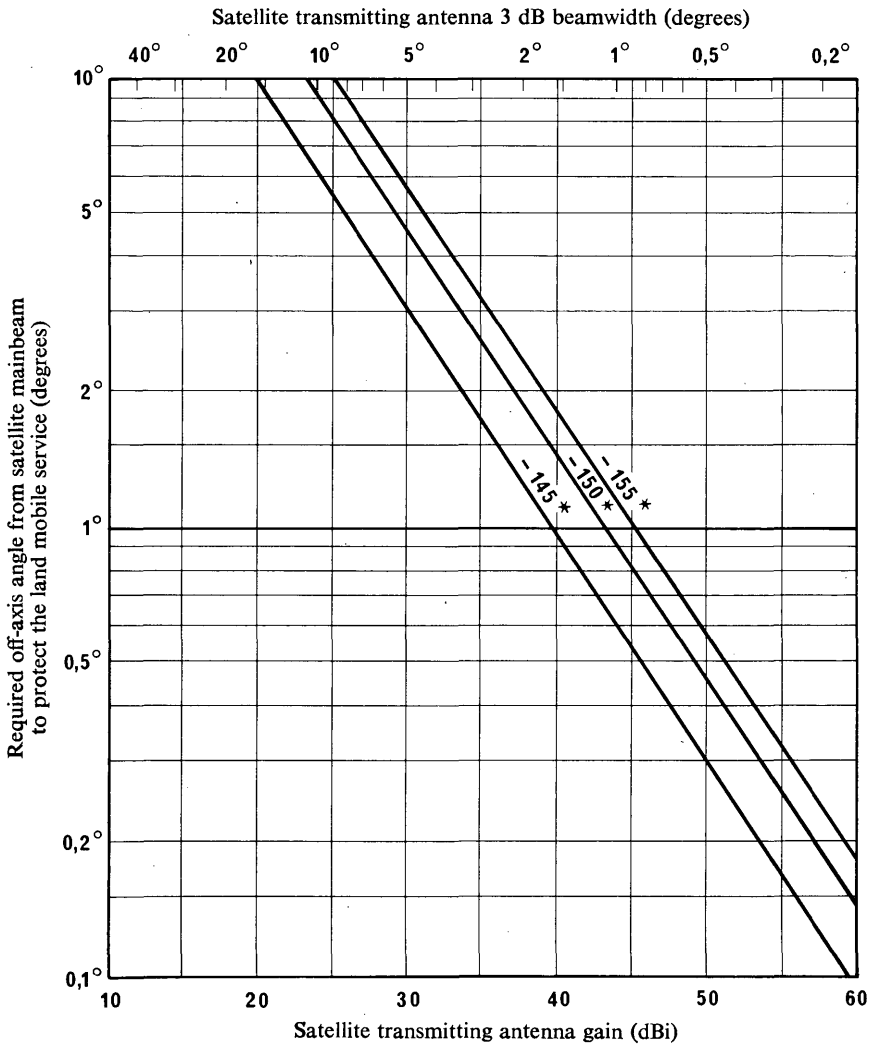


FIGURE 3 — *Off-axis angle to protect the land mobile service from satellite transmissions to land mobile satellite service base stations*

Note. — For pfd at Earth in the mainbeam = −142 dB(W/m²)
(yields 18 dB (*C*/*N*) at LMSS base station)
where: G = 22.5 dBi, noise factor = 4 dB, b = 28 kHz.

* Permissible incident pfd (dB(W/m²)).

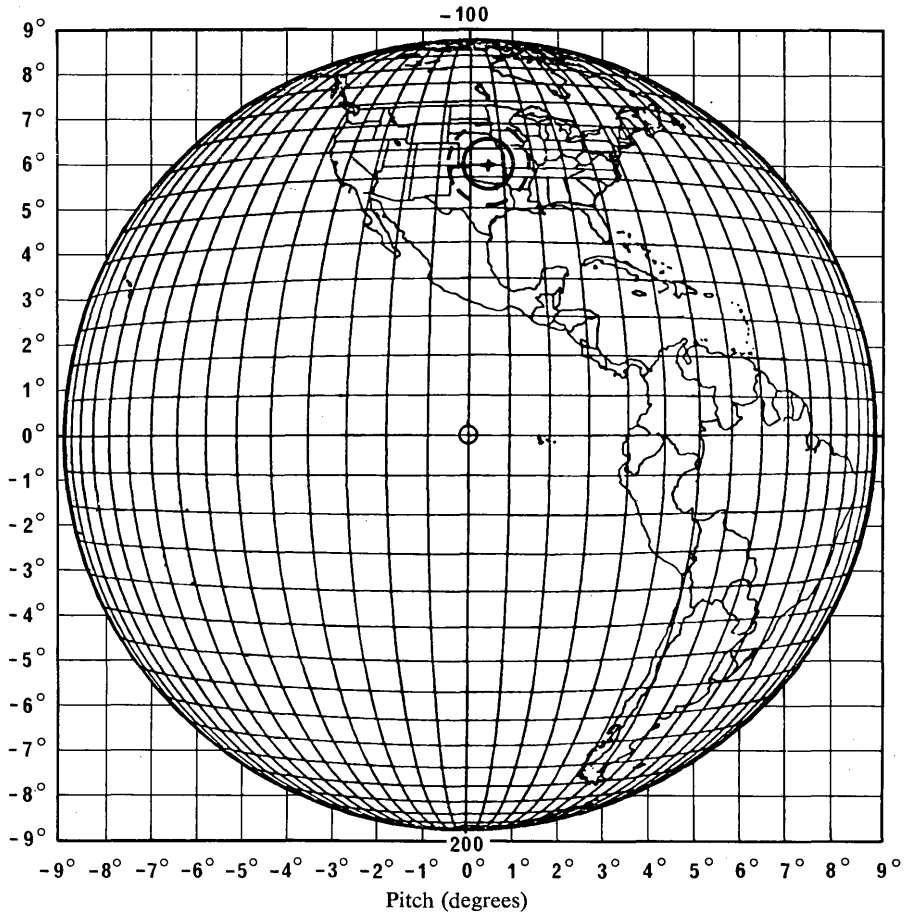


FIGURE 4 — *Land mobile satellite service coverage area and co-channel interference area (45 dBi satellite antenna gain)*

——— Coverage area

— — — — Interference area

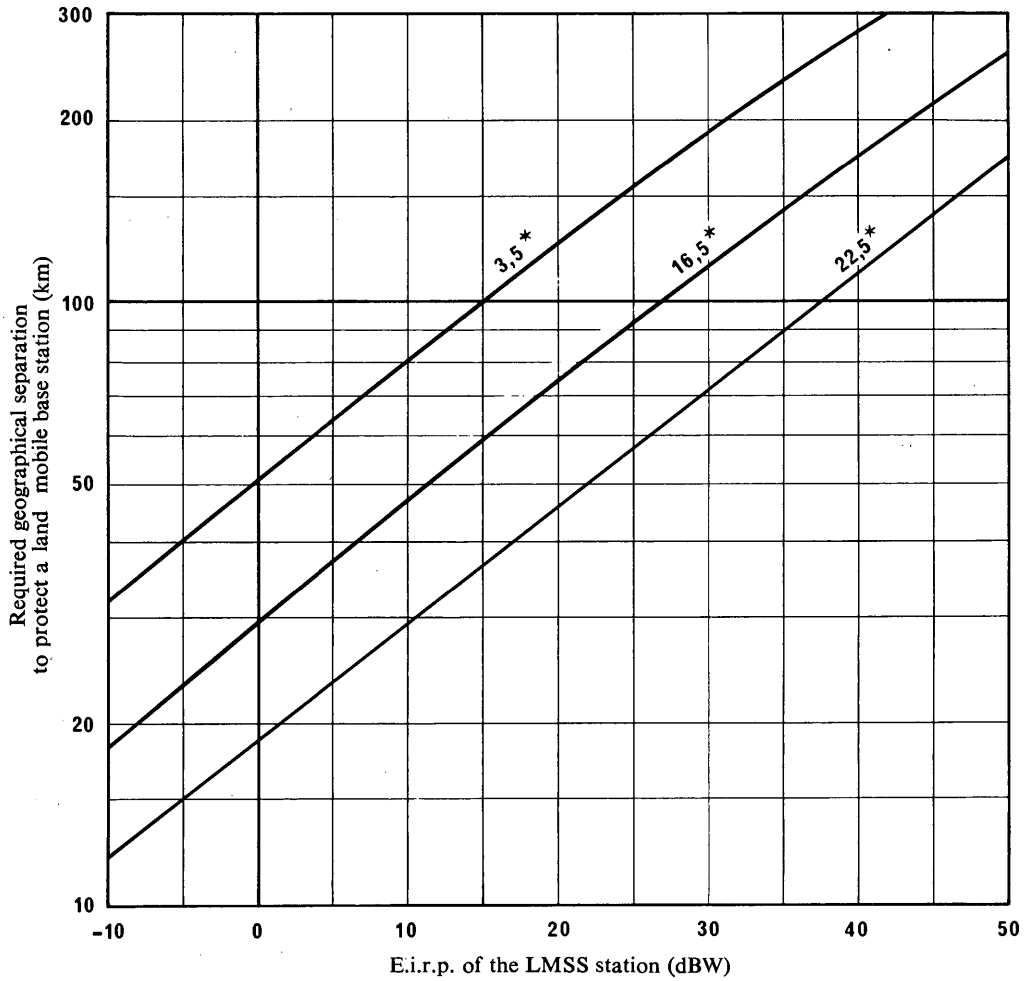


FIGURE 5 — *Geographical separation needed to protect a base station in the land mobile service from land mobile satellite service station emissions*

Note. — For an interference pfd = -146 dB(W/m^2) at the land mobile base station, 10% of the time, 50% of the locations, $h_1 = 150$ m, $h_2 = 3$ m, $\Delta h = 50$ m, suburban propagation path.

* LMSS transmitting antenna gain (dBi).

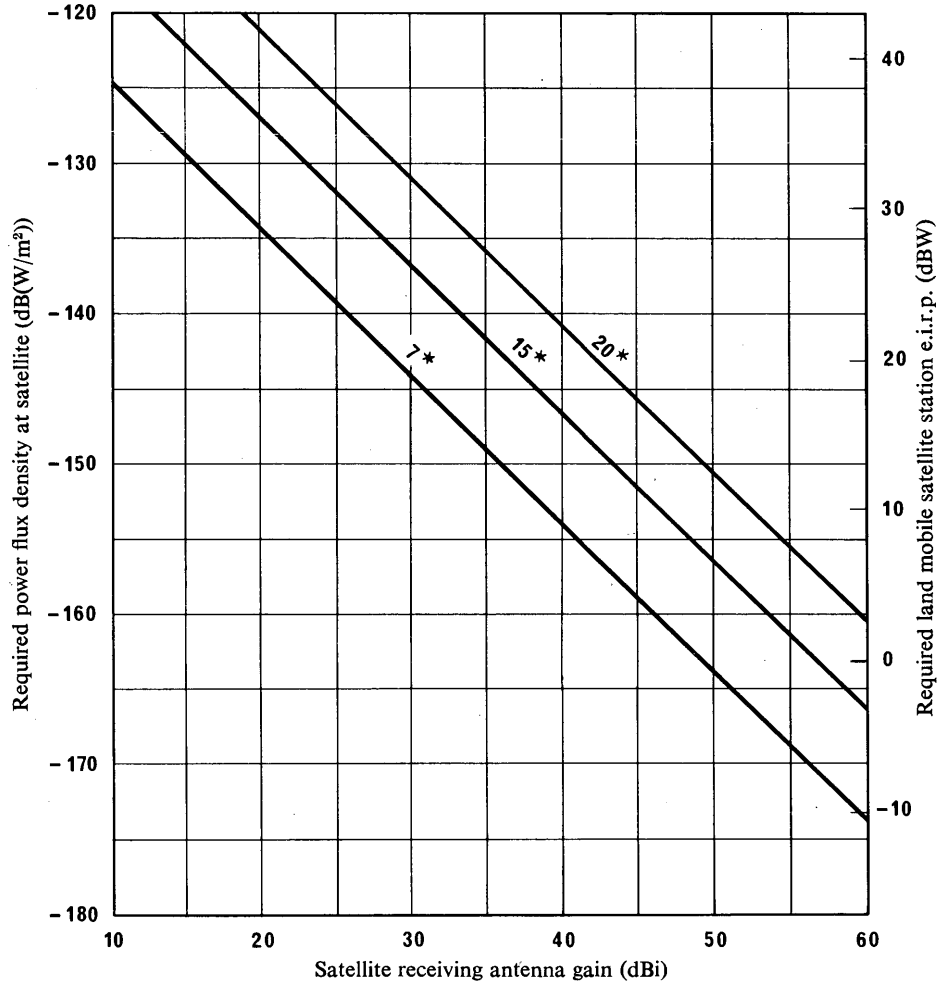


FIGURE 6 — *Relation between required land mobile satellite service station e.i.r.p. and satellite receiving antenna gain*

Note — For $(C/N) = -18$ dB at satellite receiver in a 28 kHz bandwidth.

* Satellite noise factor (dB).

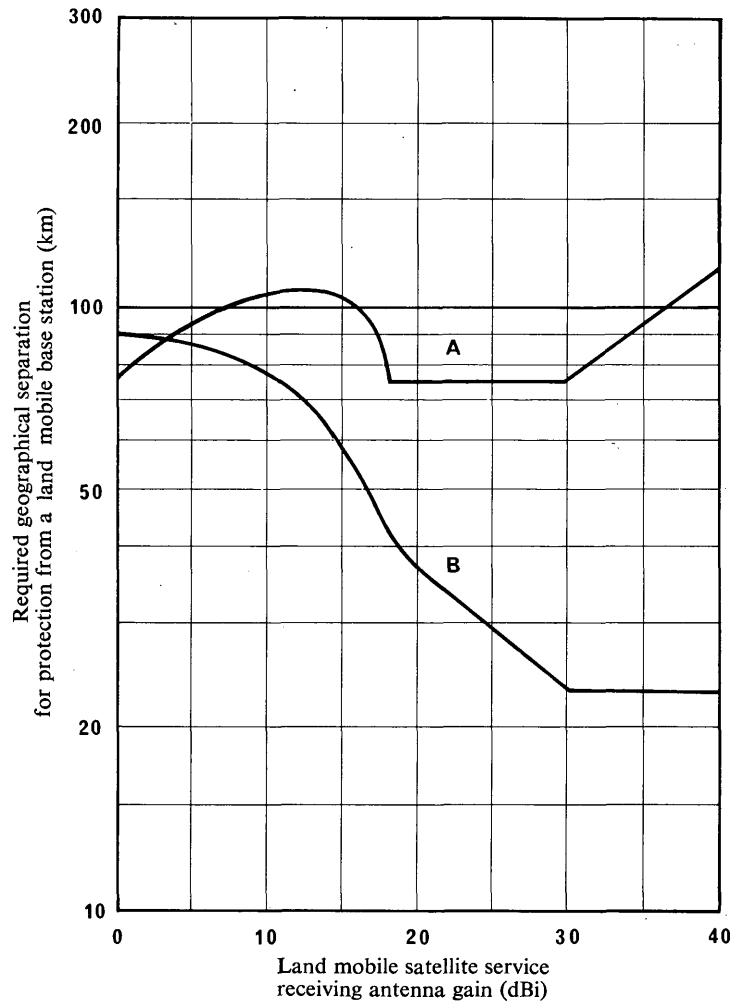


FIGURE 7 — *Geographical separation required to protect receiving land mobile satellite service stations from land mobile service base station emissions*

Curves A: For I/N = 0 dB at LMSS receiver (noise factor = 4 dB)
B: For C/I = 18 dB at LMSS receiver (desired signal pfd = -123 dB(W/m^2))

ANNEX IV

MOBILE VOICE COMMUNICATION AND POSITION LOCATION EXPERIMENTS

1. Introduction

This Annex describes the results of two experiments to demonstrate the feasibility of and obtain data on the reliability of land mobile-satellite systems to provide voice communications and automatic vehicle position location services. These experiments were conducted in the United States using the experimental geostationary satellite ATS-6 positioned at 140° W longitude. In both experiments, signals in the 1650 MHz band were received by ATS-6 using the on-board 9.1 m diameter antenna, processed, and transmitted to Earth in the 1550 MHz band. Transmission parameters adopted for both experiments were the same as those in common use by terrestrial mobile systems, i.e., narrow-band frequency modulation with 2.5 kHz baseband, 5 kHz peak deviation of 15 kHz radio frequency bandwidth [Anderson, *et al.*, 1981].

2. Voice communications experiment [General Electric, 1980a]

Five trucks of a long distance trucking company were equipped with commercial radios built for operation in the 806-890 MHz mobile band. Each radio transmitter drove a varactor frequency doubler that delivered 12 W to the antenna at the L-band frequency of ATS-6 (1550-1650 MHz). The antennas for satellite communications were specially built. They were 75 cm in height, 2 cm in diameter, and were mounted on the truck cab roof. The antennas were of the Wheeler type, with eight half-wave sections in a vertical line phased to produce a pattern that is omnidirectional in azimuth with directivity in the vertical plane from 4° to 19° elevation for reception and from 11° to 28° for transmission between the −3 dB points. The linearly polarized antennas had a maximum gain of 7.3 dB, a net gain of 4.3 dB when used with the circularly polarized satellite.

A base station was installed at the Staunton, Virginia offices of the trucking company. The base station radio was supplemented with a frequency doubler and signal down converter like those used in the trucks. The antenna was a 1.2 m diameter paraboloid mounted on the roof of the one storey building. Its gain was 20 dB. The trucks and base station were equipped with touchtone signalling and sub-audible squelch control to provide selective calling to the individual trucks and automatic identification with digital display of the origin of each received signal.

Communications between the trucks and base station were relayed through an earth station laboratory near Schenectady, New York, where all signals were recorded for later analysis of their quality and reliability. The procedure involved a two-hop mode through the satellite, hence a one-half second propagation time between truck and base station. The delay was not noticeable in the simplex mode of operation.

Signal relay through the laboratory assured strong signals to the trucks and base station because the laboratory received the signals from the satellite on a 9.1 m diameter antenna and retransmitted them through a 1.8 m diameter antenna with a power of 13 W. The satellite power was shared between the simultaneous laboratory and truck or base station signals. Transmission frequencies and received signal-to-noise ratios are shown in Table II.

The satellite beam (1.5° pencil) was centered at 35° N. latitude, 87° W. longitude, near Nashville, Tennessee, during the test periods. The trucks moved through the area extending from New Jersey westward to Nebraska, and Georgia northward to Michigan.

The signal levels of Table II were achieved when there was a clear path between the trucks and the satellite. Trees, buildings, overpasses, and terrain features between the trucks and the satellites interrupted the communications. Most interruptions were very short so they did not affect the understanding of the messages. The drivers were quick to recognize when their communications would be cut out by intervening objects. Table III indicates the reliability of the communications as a function of the goegraphical characteristics of the service area. Elevation angles from the trucks to the satellite were between 9° and 23°, with the lower angles in the mountainous and forested areas of the eastern states.

TABLE II — *Transmission frequencies and received signal-to-noise ratios*

	Transmit frequency MHz	Receive frequency MHz	IF S/N	Audio output S/N
Trucks and Base Station	1655.050	1552.000	26 dB	> 30 dB
Earth Station Laboratory	1652.010	1550.050	18 dB	24 dB

TABLE III — *Truck signals received at earth station laboratory (poorest link, signals better in truck, see Table II)*

Truck location	Approxi-mate elevation	Total time on (s)	Q4 (s)	Q5 %	Q3-Q1 (s)			
					Overpass	Hills, mountains	Trees	Other
Open Plains	19°	2481	2407	(97)	35	8	2	29
Appalachian Western Foothills	15°	344	313	(91)	0	31	0	0
Appalachian Mountains	14°	1037	881	(85)	9	88	59	0
Eastern Piedmont	13°	1219	1107	(91)	9	51	39	13
Southern Piedmont(1)	18°	279	153	(55)	2	0	124	0

(1) Near beam edge

Signal Quality Definitions

Q5: clearly understood, no perceptible noise
Q4: clearly understood, perceptible noise
Q3: mostly understood, noisy
Q2: poorly understood, much noise
Q1: signal present, not understood

Propagation characteristics are very different for satellite links as compared with terrestrial links. The differences enable communications via the satellite to be conducted with the same transmitted power and receiver sensitivity as the terrestrial communications. The vehicle antenna for the satellite link can be approximately the same size as the vehicle antenna for terrestrial links, although the antenna used with the satellites should be circularly polarized and have an elevated pattern that discriminates against ground reflections (Report 925).

The truck experiment confirmed that there was virtually no multipath fading with an antenna having the recommended pattern. One or two dB multipath fading was observed briefly as a truck approached or receded from an obstruction such as an overpass.

Obstructions, including trees, in the direct path between vehicle and satellite caused a complete drop out of the signal. Table III presents results typical of the truck experiment. The shadowing due to hills, trees and building would be less for a satellite at higher angles of elevation. Outside urban areas, the shadowed regions are usually small, fixed in location, and readily anticipated by the user.

3. Position location experiment [General Electric, 1980b]

One of the truck mobile units and the base station unit were modified for a position location experiment with a towboat on the Mississippi River. A mobile unit was installed on a towboat and a base station was installed at the Davenport, Iowa, office of the towing company.

The earth station laborartory near Schenectady tracked the towboat as it proceeded along the Mississippi. One line-of-position for a position fix was made by active tone-code ranging through the ATS-6 satellite. The other line-of-position was derived from passive reception of timing signals from the GOES satellite of the National Oceanic and Atmospheric Administration. Tone-code ranging interrogations were transmitted from the laboratory every 3 s, alternately to the towboat and fixed base station, resulting in a position fix for the towboat every 6 s during a tracking exercise. The position fixes of the fixed base were compared in the computer with its true position to derive corrections for errors in the independent predictions of satellite positions.

An experimental tone-code and data responder was connected between the transmitter and receiver on the towboat and the base station communication equipments. A satellite-controlled clock was added to each unit to receive time signals from GOES at one second intervals. Time "tick" outputs of the clocks were connected to the responders. The laboratory also was equipped with a satellite-controlled clock.

The tone-code ranging signals that produced the ATS-6 lines-of-position consisted of 1024 cycles of a 2.4414 kHz tone frequency modulated on the 1650 MHz band carrier with a deviation of 5 kHz so that the signal was limited to a 15 kHz bandwidth. The tone frequency and deviation were selected for compatibility with narrowband frequency modulation used for commercial mobile radio. The tone was followed by a 30 bit digital address in which a binary "zero" was transmitted as a suppressed audio cycle and a binary "1" was transmitted as an audio cycle. The responder units matched locally generated 2.4414 kHz tones to the received-tone phase, averaging over 256 cycles of the received tone to determine its phase. When the received code matched the code wired into the responder's correlator, it recognized that it was the interrogated unit and produced an output signifying the time-of-arrival of the signal. It then stopped the counter that was counting time since the last GOES tick, turned on its transmitter, transmitted the tone burst, its address code, its internal time delay measurement, and the count in the GOES interval counter.

Figure 8 presents results that are typical of all the results during the two 5 h test periods. The data was taken when the towboat was stopped in Lock 19 at Keokuck, IA; an accurately known location. The position fixes shown in Fig. 8 were recomputed after equipment recalibration. The recomputation was from the punched tape records of data made during the test. The real time results were displaced 3.7 miles toward GOES and 0.25 miles away from ATS-6 because there was not sufficient time to calibrate the equipment time delays accurately before deployment of the equipment. All of the fixes in Fig. 8 are clustered within $\pm$ 0.1 nautical mile of the true ATS-6 line-of-position, but are scattered over $\pm$ 1.5 and $\pm$ 2.2 nautical miles of the true GOES line-of-position. The difference in precision is due to the difference in bandwidths and signal-to-noise ratios of the ATS-6 and GOES ranging singals. If the GOES signals had the same bandwidth and the signal strength as the ATS-6 signals, the GOES precision would approximate that of ATS-6 and the fixes would be in a small cluster.

4. Conclusions

The experiments demonstrated that good quality voice bandwidth communications can be relayed through geostationary satellites with mobile radio equipments that are similar in cost and construction to present-day commercial mobile radios. A circuit added to the voice communication equipment can enable a fixed earth station to determine a line-of-position of the vehicle. If the vehicle carries a receiver that can measure the time-of-arrival of a signal from a second satellite, the fixed earth station can determine a second line-of-position, and hence position locate the vehicle.

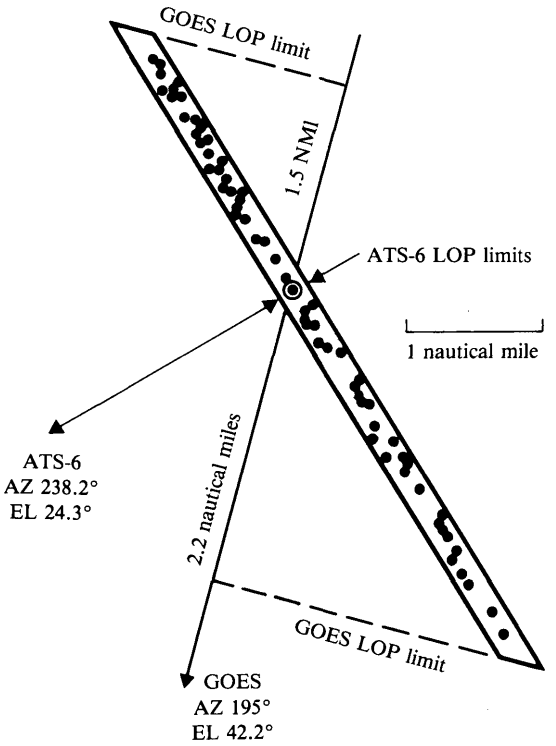


FIGURE 8 – *Geometry of fix determination*

LOP: line-of-position

REFERENCES

ANDERSON, R. E., FREY, R. L., LEWIS, J. R. and MILTON, R. T. [May, 1981] Satellite-aided mobile communications: experiments, applications and prospects. *IEEE Trans. Vehic. Tech.*, Vol. VT-30, **2**, 54-61.

General Electric [July, 1980a] Satellite-aided mobile communications limited operational test in the trucking industry. Final Report, NASA Contract NAS5-24365, General Electric Company.

General Electric [January, 1980b] Position surveillance using one active ranging satellite and time-of-arrival of a signal from an independent satellite. Final Report, NASA Contract NAS5-25135, General Electric Company.

REPORT 925

FACTORS AFFECTING THE CHOICE OF ANTENNAS FOR MOBILE STATIONS OF THE LAND MOBILE-SATELLITE SERVICE

(Question 47/8)

(1982)

1. Introduction

Report 770 describes the applications and technical characteristics of a potential land mobile-satellite system intended to extend the availability of mobile radiocommunication services routinely obtainable in urban areas into rural and remote areas. The mobile-satellite system would be compatible with the terrestrial mobile system in order to minimize user equipment costs. From this viewpoint it is desirable to use the same mobile station antenna and transceiver. Terrestrial mobile systems operating in the 800 MHz band (the band allocated by the World Administrative Radio Conference, 1979) are designed to operate with low cost, low gain omni-directional antennas on the mobile station. The use of such simple mobile station antennas, while desirable from cost and compatibility considerations, may impact on the land mobile-satellite space segment cost and on sharing with other services.

Omnidirectional antennas are susceptible to multipath, which in turn results in the carrier power received by the mobile station being a random variable. For a given grade of service, sufficient margins must be designed into the link to overcome the multipath fading. The resultant increase in the space station e.i.r.p. has a direct effect not only on the cost of the space station but also on the potential for interference to other terrestrial services. Similar multipath considerations also apply to the up link from the mobile station and result in a larger e.i.r.p. from the mobile station.

Interference between mobile stations in the land mobile-satellite service and stations (either base or mobile) in the mobile service is also a function of the gain characteristics of the mobile station antenna. The directivity of the land mobile-satellite earth station antenna will also have a direct influence on the efficient utilization of the geostationary orbit.

This Report summarizes a preliminary analysis of how the system link margins and interference to terrestrial mobile systems are affected by the gain characteristics of the mobile station antenna.

2. System link margins

This analysis focuses on the space-to-Earth path. A simple low cost omnidirectional antenna is assumed to be mounted on the roof of the mobile station.

2.1 *Propagation modelling*

The carrier power received by an antenna whose characteristics approximate those of an isotropic antenna is a function of the total electromagntic field in which it is located. The total field is the vector sum of three major components. The direct line-of-sight component (when there are no obstructions), a specular multipath component (or components), and a diffuse multipath component. The multipath components result from the geometry and reflection characteristics of the environment. Their amplitude and phases will tend to be random variables yielding a received carrier power which is itself a random variable.

The conditions for both specular reflection and diffuse scattering in a rural environment may be determined from the scattering coefficient, ρ_s, for surfaces exhibiting random height variations with a Gaussian probability density function [Beckmann and Spizzichino, 1963]:

$$\rho_s = \exp\left[-\frac{1}{2}\left(\frac{4\,\pi\,\sigma_h \sin\delta}{\lambda}\right)^2\right] \tag{1}$$

where, σ_h is the r.m.s. height of the irregularities of the earth's surface (metres) δ the elevation angle, and λ the wavelength (metres).

The scattering coefficient is one term in the equation for the specular reflection coefficient, R_s:

$$R_s = \rho_s\, D\, R_0 \tag{2}$$

where D is the divergence factor, and R_0 the reflection coefficient of a plane smooth earth.

For antenna heights less than 3 m and an elevation angle greater than about 1.3°, the divergence factor will be greater than 0.77 and will rapidly approach unity with increasing elevation angle.

Similarly, the magnitude of the reflection coefficient for a plane smooth earth is close to unity except for vertically polarized waves at elevation angles in the vicinity of Brewster's angle [Beckmann and Spizzichino, 1963]. Consequently, the value of the scattering coefficient is a simple first order approximation of the magnitude of the specular reflection coefficient.

Equation (1) has been evaluated at 860 MHz for terrain irregularities corresponding to a Δh between 5 m and 50 m (Δh is defined in Report 239 as the difference between the 10% and 90% terrain contours. The corresponding r.m.s. height, σ_h, is given by $\Delta h/(1.82\sqrt{2})$). For Δh = 5 m, the scattering coefficient is .0013 for an elevation angle of 3°, and rapidly decreasing. For Δh = 50 m, the scattering coefficient is .0013 for an elevation angle of only 0.3°. It may therefore be concluded on theoretical grounds that in rural areas, where the elevation angle is greater than 3°, the reflected energy is contained primarily in the diffusely scattered waves with a negligible amount of energy in the specularly reflected component.

The amplitude of the envelope of the diffusely scattered wave has been shown to be Rayleigh-distributed, whereas the phase is uniformly distributed over the interval $-\pi$ to $+\pi$ [Beckmann and Spizzichino, 1963]. The probability density function of the envelope of the vector sum of the diffusely scattered component and the line-of-sight component is given by the familiar Rice-Nakagami density function (Report 415 (Kyoto, 1978)):

$$p(r) = \frac{r}{\sigma^2} I_0 \left(\frac{E_0 r}{\sigma^2} \right) e^{-\frac{(r^2 + E_0^2)}{2\sigma^2}} \tag{3}$$

where, r is the instantaneous peak envelope voltage (a random variable), σ the root mean square envelope voltage of the multipath, I_0 the modified Bessel function of order zero, and E_0 is the peak envelope voltage of the line-of-sight component.

The probability that the envelope of the received signal exceeds a prescribed value, R_0, is given by:

$$P(r \geq R_0) = \int_{R_0}^{\infty} p(r)\, dr \tag{4}$$

Substituting (3) into (4) yields an integral which cannot be evaluated analytically. However, it can be expressed in terms of a function commonly called the Marcum Q function:

$$P(r \geq R_0) = Q(\alpha, \beta) \tag{5}$$

where, $\alpha = E_0/\sigma$, and $\beta = R_0/\sigma$. The Marcum Q function has been tabulated (Report 415), [Marcum, 1950], computed by a simple algorithm [Brennan and Reed, 1965].

The value of the parameter α is a measure of the direct line-of-sight signal relative to the multipath signal at the input to the receiver. The amplitude of the multipath signal is a function first of the environment which produces it and secondly the gain of the antenna for the elevation and azimuth angles at which it arrives.

In urban areas where there are tall buildings with heights much greater than the antenna height, the multipath elevation angles could range up to 90°. However, in rural areas where diffuse scattering by rough ground will predominate, multipath elevation angles will tend to be less than 0° (Report 763), [Beckmann and Spizzichino, 1963]. By controlling the gain of the antenna in and below the horizontal plane, the effects of multipath, at least in rural areas, may be controlled.

The link margins required for specific values of diffuse scattering and shadowing (attenuation of the line-of-sight component due to foliage, an occasional building, etc.) may be obtained from equation (5). The ratio of the peak envelope voltage of the line-of-sight signal to the r.m.s. envelope voltage of the diffuse scattering component (α) has been varied over the range from 4 to 23 dB. In addition, line-of-sight signal fading due to shadowing up to 30 dB has been considered. The results are shown in Figs. 1 to 6.

The figures clearly demonstrate the deleterious effect of diffuse scattering in the absence of line-of-sight attenuation. As shown in Fig. 1 for $\alpha = 4$ dB, a 6 dB margin is required to ensure the received envelope being above a minimum value for 90% of the time, increasing to about 15 dB for 99% of the time. In contrast, as shown in Fig. 6, rejecting the diffuse scattering by 19 dB ($\alpha = 23$ dB) reduces the required margin to less than 2 dB to meet the minimum value for 99% of the time.

The figures also show that diffuse scattering may be used as the primary propagation mechanism in the presence of severe line-of-sight attenuation. Referring again to Fig. 1, it is seen that for an attenuation of the line-of-sight signal by up to 20 dB, the corresponding increase in the 90 percentile margin is about 4 dB, and about 5 dB for the 99 percentile margin.

Figures 2 to 6 illustrate that for a given attenuation of the line-of-sight signal the required margin increases with increasing rejection of the diffuse scattering component.

These figures indicate that there are substantial link margin trade-offs to be made on the basis of the amount of mobile antenna discrimination in the horizontal plan. These trade-offs depend on the link performance objective: 90 percentile, 95 percentile or 99 percentile; the percentage of locations which will experience line-of-sight attenuation; and the spatial attenuation probability density function.

Propagation measurements are needed in order to complete the mobile antenna design trade-offs which critically affect link design margins and potential interference to other services sharing the same frequency band.

2.2 *Propagation measurements*

Some very preliminary propagation measurements have been made in the United States. An experimental measurements program was conducted from 1977 to 1978 to characterize the space-to-Earth path to mobile earth stations which used low gain antennas approximating to an isotropic antenna [Hess, 1978; Hess, 1979].

Circularly polarized signals transmitted at 860 MHz and 1550 MHz from the NASA Applications Technology Satellite 6 (ATS-6) were received by a specially equipped mobile test van. Conventional, linearly polarized quarter-wave antennas were mounted on the van roof about 2.5 m above the ground. The amplitude of the received signal was encoded digitally and stored for later analysis.

The measurements were taken in urban, semi-urban, suburban and rural areas at elevation angles that varied between 19° and 43°. Direction of travel and side of the street relative to the direction to ATS-6 were also noted. A total of approximately 36 h of data were taken.

Analysis of the data showed there was a similarity between the major propagation characteristics exhibited by terrestrial paths and by Earth-space paths; namely, over small distances, of the order of several hundred wavelengths, the statistical variation of the received carrier power exhibits a rather constant local mean value: whereas, over large distances, of the order of kilometres, there is a statistical variation in the local mean value. No attempt was made to separate the effects of line-of-sight attenuation, specular reflection or diffuse scattering. The margin required to ensure that the received carrier power will be above a specified value for 90% of the time for an urban area may be estimated by:

$$M = 17.8 + 1.93f - 0.052\,\delta + K(7.6 + 0.053f + 0.040\,\delta) \tag{6}$$

and for a suburban/rural area by:

$$M = 12.5 + 0.17f - 0.17\,\delta + K(6.4 - 1.19f - 0.05\,\delta) \tag{7}$$

where, M is the margin (dB), f the operating frequency (GHz), δ the elevation angle (degrees) and K is the factor which relates the percentage of the locations for which the specified carrier power will be exceeded. Values for K are:

$$\begin{aligned} K\,(50\%) &= 0 \\ K\,(90\%) &= 1.3 \\ K\,(95\%) &= 1.65 \\ K\,(99\%) &= 2.35 \end{aligned} \tag{8}$$

These equations have been derived from a regression analysis of measured data taken at 860 MHz and 1550 MHz over a limited range of elevation angles (19° to 43°). Care must be taken in applying them to other frequencies and, in particular, to elevation angles greater than 43° and less than 19°.

From equation (6), margins between 18 dB (50% of the locations) and 39 dB (99% of the locations) are necessary in urban areas to ensure that the received carried power is above a specified value relative to the line-of-sight value for 90% of the time. These values apply to an operating frequency of 860 MHz and are almost independent (within 1 dB) of elevation angles between 20° and 40°. These margins indicate that the predominate propagation mode in urban areas will be diffuse scattering: the line-of-sight path will experience large attenuation in most of the locations. Because of this large margin, plus other factors such as cost, which is consequential to the margin, and efficient spectrum utilization, the feasibility of serving urban areas using space techniques is questionable.

The corresponding margins for 90% of the time in a suburban/rural environment at 860 MHz have been calculated using equation (7). The results are shown in Table I. According to [Hess, 1978], for the suburban/rural environment the 90 percentile temporal margins may be extrapolated to other percentages of time in the 50 to 95 percentile range. Within this range the data exhibited a sensitivity of about 0.1 dB/%. The 50% temporal margin shown in Table I is therefore 4 dB less than the 90% temporal margin.

It may be deduced from the values given in equation (8) and the form of equation (7) that the probability density function for the spatial margin, i.e., percentage of locations, is given by the normal density function:

$$p\,(m) = \frac{1}{\sqrt{2\,\pi}\;\sigma_m}\,\varepsilon - \frac{[m - U_0]^2}{2\,\sigma_m^2} \tag{9}$$

where, m is the margin (dB), U_0 the margin for 50% of the locations, and σ_m^2 the variance of the distribution. Values for U_0 and σ_m are obtained from equation (7) noting that the 50% temporal margin is 4 dB less than that given by equation (7). Consequently:

$$U_0 = 8.5 + 0.17f - 0.17\,\delta \quad (10)$$

$$\sigma_m = 6.4 - 1.19f - 0.05\,\delta \quad (11)$$

where the variables are the same as previously defined.

To test the hypothesis that the 0.1 dB/% temporal sensitivity observed by [Hess, 1978] is consistent with the model for a line-of-sight plus diffuse scattering channel, a fifth curve E has been added to Figs. 3, 4 and 5. This curve is given by:

$$X = -0.1\,(P-50) + b \qquad \text{dB} \qquad \text{for } 50\% \leqslant P \leqslant 95\% \quad (12)$$

where P is the probability expressed as a percentage, and b is a constant picked so that the curve will closely approximate curve A of the figures. The closeness of fit appears to be best in Fig. 4 where the maximum difference for a given probability is less than 1 dB.

It appears reasonable then to assume, based on the above analysis of empirical data, that the ratio of the peak envelope voltage of the line-of-sight signal to the r.m.s. envelope voltage of the diffusely scattered signal is of the order of 13 dB. Stated differently, the ratio of the line-of-sight signal power to the diffusely scattered signal power is on the order of 10 dB.

TABLE I — *Link margins, 860 MHz suburban/rural environment*

Elevation angle (degrees)	Percentage of locations (%)	50% temporal margin (dB)	90% temporal margin (dB)
20	50	5.2	9.2
	90	10.9	14.9
	95	12.5	16.5
	99	15.5	19.5
30	50	3.5	7.5
	90	8.6	12.6
	95	9.9	13.9
	99	12.7	16.7
40	50	1.8	5.8
	90	6.2	10.2
	95	7.4	11.4
	99	9.8	13.8

2.3 *Summary*

To a first order approximation, the space-to-Earth land mobile-satellite path for a suburban/rural environment may be modelled as a line-of-sight plus diffuse scattering channel. The statistics of the spatial variation of the received power of the line-of-sight component, expressed in dB, approximates the Gaussian density function. The mean is given by equation (10) and the square root of the variance, in dB, by equation (11).

The statistics of the temporal variation (movement by the mobile over a distance of several hundred wavelengths) closely approximate the Rice-Nakagami density function when the parameter α is 4.47 (13 dB).

This model applies primarily to a roof top mounted linearly polarized quarter-wave whip receiving a circularly polarized signal in the 800 MHz band.

3. Coordination considerations

The allocation to the mobile-satellite service in the 800 MHz band is shared with allocations to the mobile, broadcasting and fixed services. Coordination is to be carried out under the provisions of Article 14 of the Radio Regulations. The e.i.r.p. of the space station and the mobile station operating in the mobile-satellite service is a key parameter effecting the coordination. As shown in § 2, the link margins and therefore the e.i.r.p. of both the space station and the mobile station may be reduced by minimizing the gain of the mobile station antenna in and below the horizontal plane. Each dB reduction in the space-to-Earth link margin will facilitate coordination with the terrestrial services.

The e.i.r.p. in the horizontal plane of the mobile station antenna will govern the coordination distance between mobile stations and stations operating in the terrestrial services. Two advantages are gained here through the control of the antenna gain characteristics. First, the e.i.r.p. in the horizontal plane will be decreased as a result of the reduced antenna gain, and secondly, the transmitter power will be decreased because of the higher antenna gain for elevation angles above 20°, for example, and the smaller link margin.

The relative significance of controlling the gain in the horizontal plane may be shown by the following example. Assume that the space-to-Earth and the Earth-to-space paths are reciprocal so that identical space-to-Earth and Earth-to-space link margins are required. Assume further that the paths exhibit Rice-Nakagami fading with $\alpha = 13$ dB and that the margins are chosen such that the received signal is above a threshold value for 95% of the time. For an isotropic antenna, the required margin will be about 3 dB as shown in Fig. 4. For an antenna with 3 dBi gain in the upper hemisphere coupled with -10 dBi gain in and below the horizontal plane, the margin is reduced to less than 1.5 dB as shown in Fig. 6. (The figure for $\alpha = 23$ dB has been used rather than including another figure for $\alpha = 26$ dB for this specific example.)

It may be readily shown that the e.i.r.p. in and below the horizontal plane is 14.5 dB less for the case of hemispherical antenna compared to the case of the isotropic antenna.

A first order estimate of the relative coordination distance may be made using equation (1) from Report 567, viz:

$$E = 69 \sqrt{P} \frac{h_t \, h_r}{\lambda \, d^2} \tag{13}$$

where E is the median field strength (μV/m), P the effective radiated power of the transmitter in the horizontal plane (watts), d the distance between antennas (m), h_t the effective height of the transmitting antenna (m), h_r the effective height of the receiving antenna (m), and λ the wavelength (m). This equation is valid within the region where the field strength decreases monotonically with distances up to the radio horizon.

Assuming the protection criteria is given in terms of a permissible field strength, the relative separation distance for a hemispherical antenna compared to an isotropic antenna may be derived from equation (13) to be:

$$\frac{d_2}{d_1} = \left(\frac{P_2}{P_1} \right)^{1/4} \tag{14}$$

For P_2/P_1 equal to 1/28.2 (-14.5 dB), the separation distance is reduced by a factor of 2.3 when using a hemispherical antenna compared to an isotropic antenna.

4. Conclusion

It has been shown that the mobile station antenna gain characteristics play a key role in determining the link margins required in mobile-satellite systems, and have a significant effect on the coordination distance to protect terrestrial systems from harmful interference from mobile stations in the mobile-satellite service.

Preliminary urban propagation measurements taken in the United States indicate that link margins of the order of 18 to 39 dB are required for 90% of the time in 50% and 99% of the locations, respectively. These margins are based on the use of a roof mounted, linearly polarized quarter-wave antenna.

In suburban/rural areas the measurements indicate that the space-to-Earth path may be modelled as a line-of-sight plus diffuse scattering channel. The spatial statistics, expressed in dB, approximates the Gaussian density function, whereas the temporal statistics are approximated by the Rice-Nakagami density function. These conclusions also apply primarily to a roof mounted, linearly polarized quarter-wave antenna.

It has also been shown that the mobile station antenna characteristics play a key role in determining the coordination distance to stations operating in the terrestrial services. In the example given, it was shown that the coordination distance could be reduced by a factor of 2.3 by the use of a mobile station antenna with -10 dBi gain in and below the horizontal plane.

The land mobile-satellite earth station antenna directivity also affects the geostationary satellite orbit utilization efficiency. Additional study is required in order to quantify this specific aspect of the land mobile-satellite service.

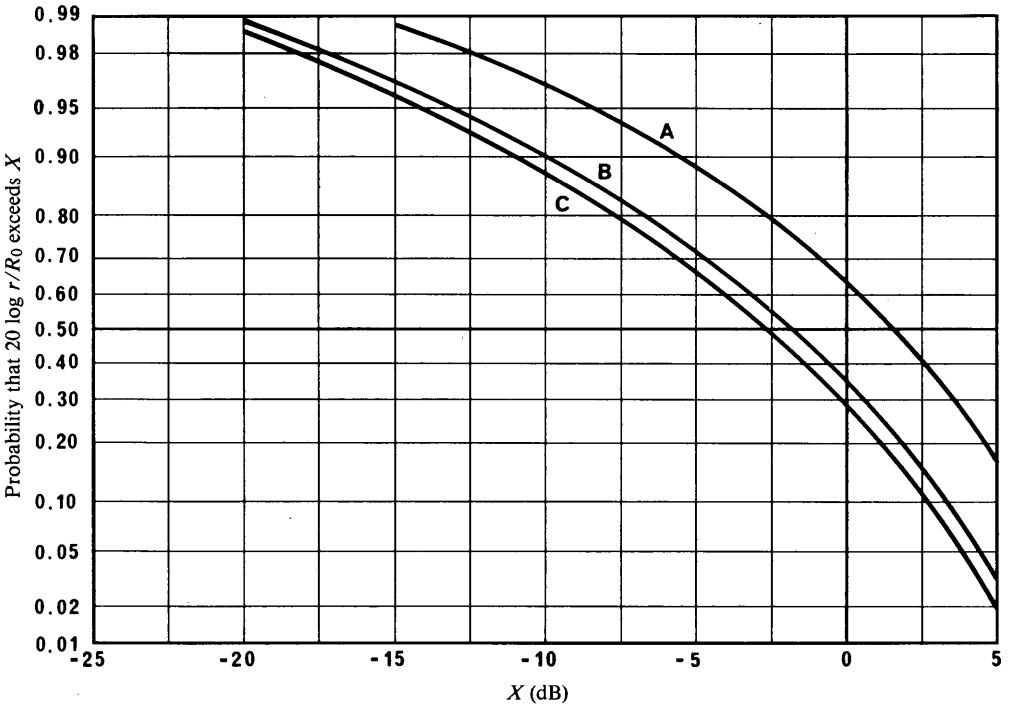


FIGURE 1 – *Received carrier envelope*
Distribution function: α = 4 dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss

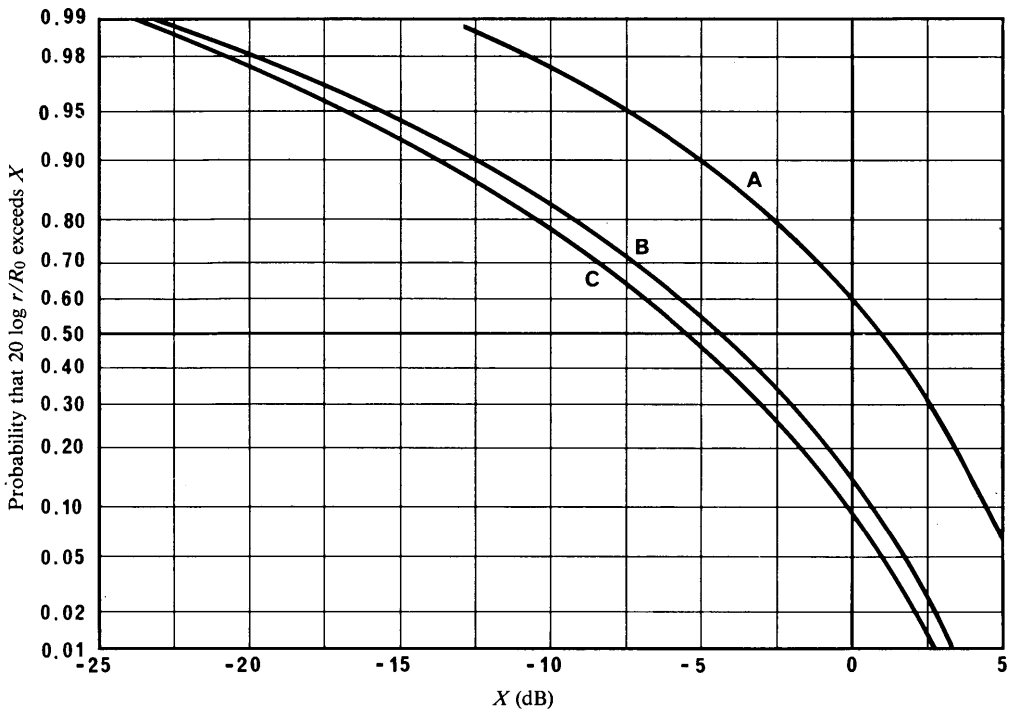


FIGURE 2 – *Received carrier envelope*
Distribution function: α = 7 dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 to 30 dB shadow loss

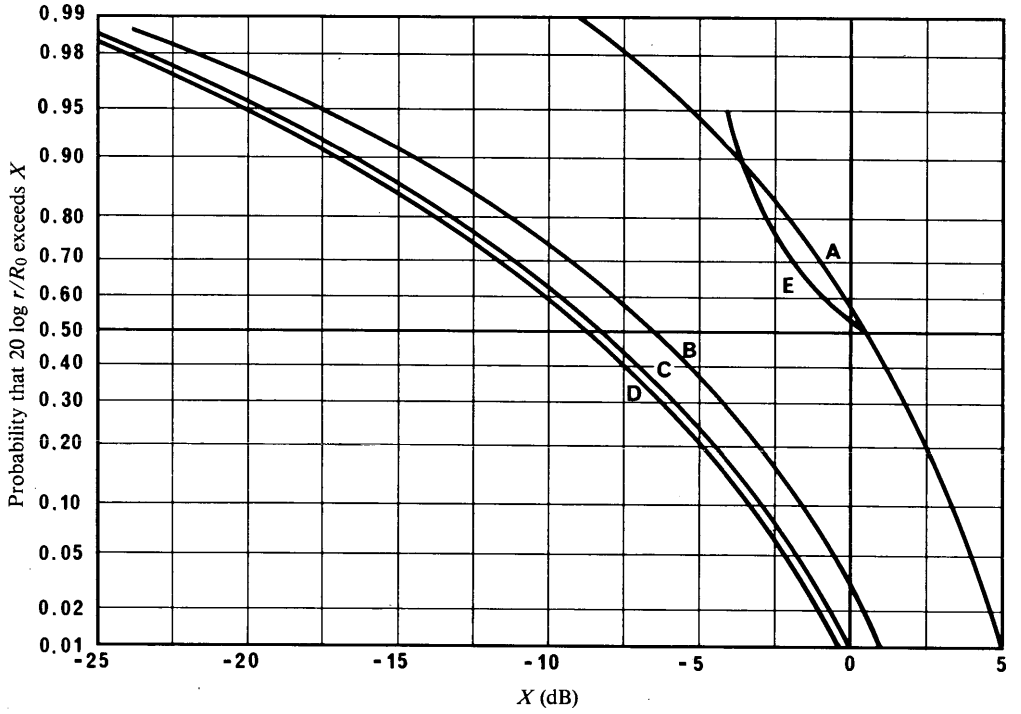


FIGURE 3 – *Received carrier envelope*
Distribution function: α = 10 dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss
D: 30 dB shadow loss
E: 0.1 dB/% temporal sensitivity

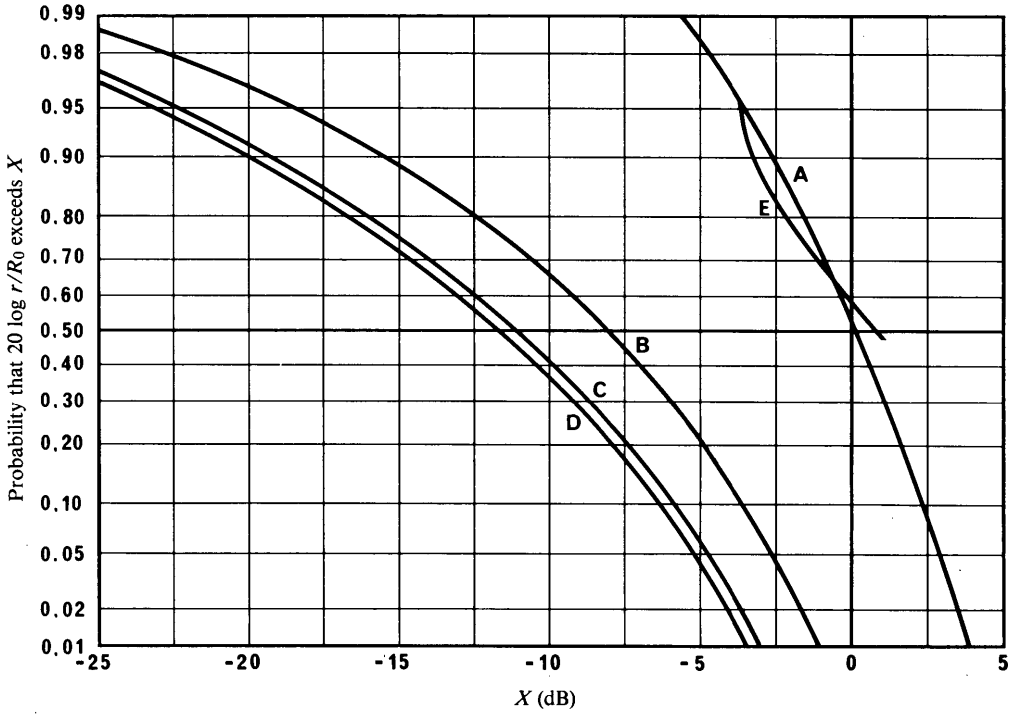


FIGURE 4 – *Received carrier envelope*
Distribution function: α = 13 dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss
D: 30 dB shadow loss
E: 0.1 dB/% temporal sensitivity

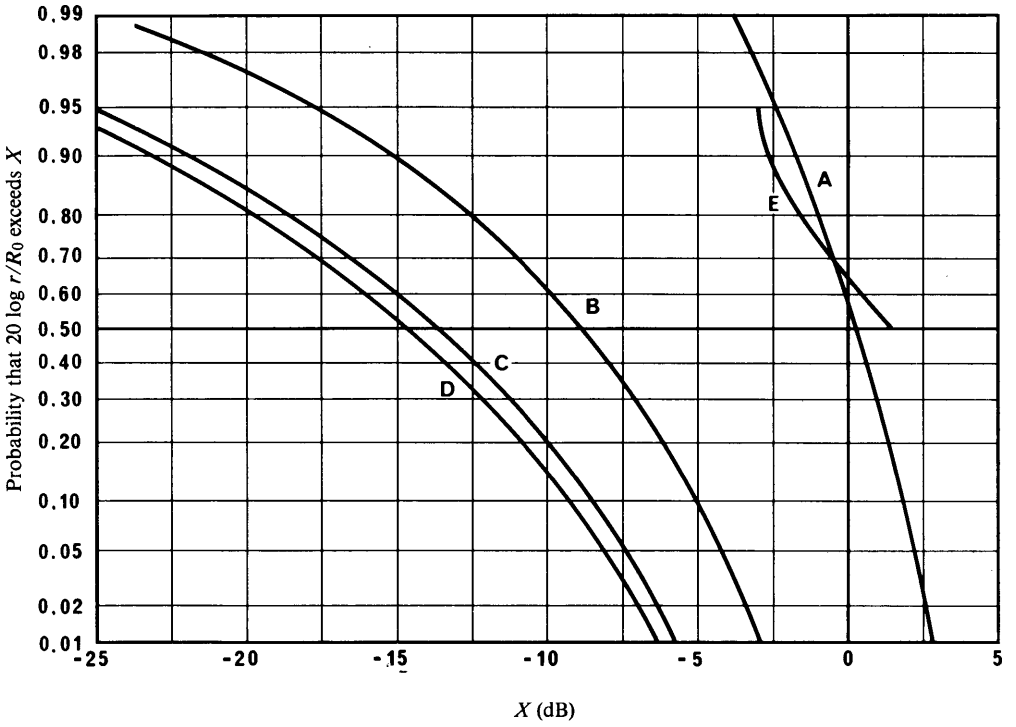


FIGURE 5 – *Received carrier envelope*
Distribution function: α = 16 dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss
D: 30 dB shadow loss
E: 0.1 dB/% temporal sensitivity

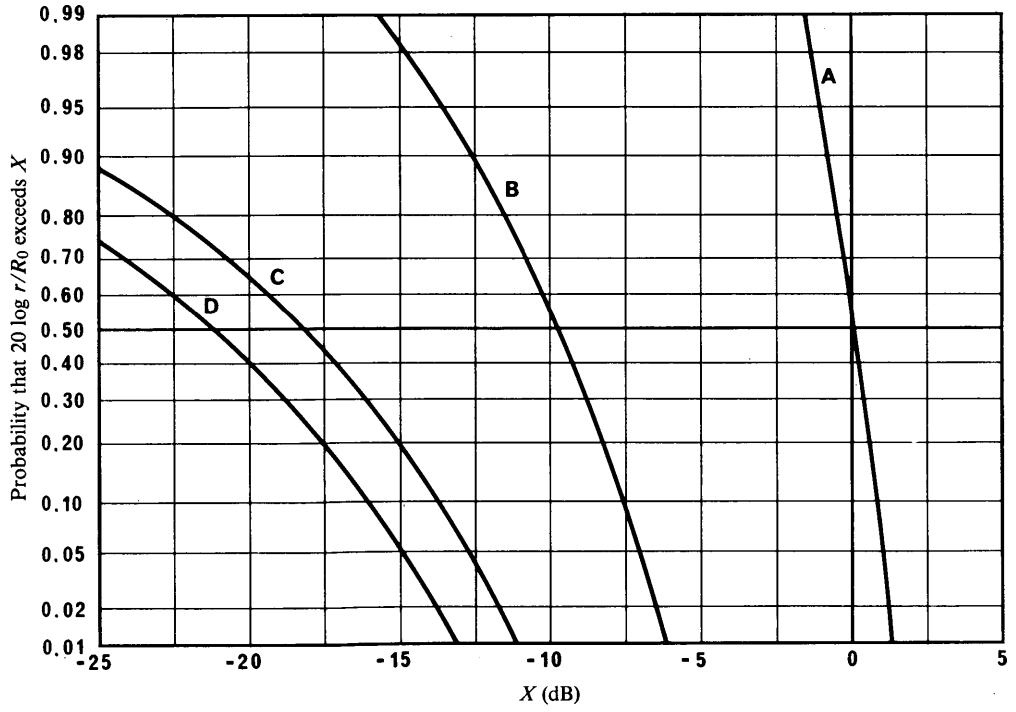


FIGURE 6 – *Received carrier envelope*
Distribution function: α = 23 dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss
D: 30 dB shadow loss

REFERENCES

BECKMANN, P. and SPIZZICHINO, A. [1963] *The Scattering of Electromagnetic Waves from Rough Surfaces.* Pergamon Press.

BRENNAN, L. E. and REED, I. S. [April, 1965] A recursive method of computing the Q function. *IEEE Trans. Inform. Theory*, 312-313.

HESS, G. C. [1978] Land mobile satellite path loss measurements. Final Report Third Year ATS-6 Experiment, prepared by G. C. Hess, Motorola, Inc.

HESS, G. C. [March, 1979] Land mobile satellite excess path loss measurements. 29th IEEE Vehicular Technology Conference, Arlington Heights, Ill., USA.

MARCUM, J. I. [1950] Table of Q functions. RM-339, Rand Corp., Santa Monica, Ca., USA. ASTIA Document No. AD 116551.

REPORT 771-1

CONSIDERATIONS FOR A MOBILE-SATELLITE SERVICE

(Question 32/8)

(1978-1982)

1. Introduction

The purpose of this Report is to discuss factors relating to the performance characteristics for a mobile-satellite service.

A mobile-satellite service is a service which might have earth stations on ships, on land, and on aircraft, all operating within the same system.

2. General system considerations

A mobile-satellite system is one with many small, relatively inexpensive earth stations, having low to intermediate values of figure of merit (G/T), and with satellites having relatively high values of e.i.r.p. and transponder gain (the input to output gain between the receive and transmit antenna terminals of the satellite).

2.1 *Preferred ranges of frequencies for the mobile-satellite service*

The practical lower bound on the frequency range is determined by the antenna gain achievable with the small apertures that are suitable for mobile applications. Assuming that at least 3 dB antenna gain (above isotropic) is required for a hemispheric radiation pattern, then the lower limit on frequency for a 1 m effective aperture is about 200 MHz.

The practical upper limit on operating frequency is affected by a number of factors. Above about 10 GHz, attenuation due to precipitation and molecular absorption generally increases with frequency; however, transmission windows exist between approximately 10 and 50 GHz, 80 and 110 GHz, 125 and 150 GHz and between 210 and 280 GHz (Report 205). Availability objectives are a major factor in the use of frequency bands above about 10 GHz.

For a mobile-satellite system with high availability requirements, the optimum range of frequencies would be 200 MHz to 10 GHz. However, in identifying a preferred band, several factors in addition to propagation should be considered; for example, the maturity of the state-of-the-art, availability requirements, and operational constraints due to frequency sharing. For some applications, airborne earth stations could employ the millimetre wave bands to advantage, since present-day aircraft typically fly at altitudes above much of the attenuating atmosphere.

2.2 *Performance characteristics for an earth station*

An earth station in the mobile-satellite service has the requirement for simplicity, ease of maintenance, limited size, and limited weight. Where transportable equipment is employed, it should also have the capability for rapid and simple assembly and dismantling and be able to be compactly packaged.

The antenna type and dimensions are determined primarily by the operational factors appropriate to the type of mobile platform to be used. The required antenna pointing accuracy of mobile earth stations will generally increase with antenna gain. The difficulty of achieving this pointing accuracy increases with antenna mass. The desirability of smaller (lower gain) mobile earth station antennas due to the above mechanical factors is dampened by other factors, including spectrum/orbit sharing considerations and link performance. Signal multipath problems, which are particularly severe for shipborne mobile earth stations, might be alleviated through the use of antennas with high main beam gain and/or low sidelobe gains.

At frequencies of the order of 7 GHz, an earth station in the mobile-satellite service might typically employ an air-cooled Klystron or TWT having an output power in the range of 100 to 1000 W and an uncooled parametric amplifier having a noise temperature in the range of 100 to 200 K. Solid-state devices have also been evolving rapidly in the microwave frequency range. Low-noise field effect transistor (FET) amplifiers are becoming competitive with the uncooled parametric amplifiers in terms of noise temperature and are less expensive. High-power transistor amplifiers offer a promising alternative to the Klystron for applications where the bandwidth requirement is not too large.

2.3 *Performance characteristics of a space station*

The implementation of a mobile-satellite system, which would serve the various classes of mobile users simultaneously, necessarily involves a very flexible space segment – particularly if some degree of interconnection is desired between the different user communities. The large disparity between the size and type of earth stations (for example, differences in G/T, etc.), and possibly different modulation and multiple access techniques employed by shipborne, airborne and land mobile users also requires a compromise system design. As a result the high performance and efficiency attainable in a specialized mobile-satellite system would be exchanged in some degree for the flexibility and ruggedness of a general purpose mobile-satellite system.

3. System considerations

Several operational and technical factors affect the choice of modulation and access schemes (Report 708). Modulation and multiple access techniques requiring time synchronization are more difficult to implement in mobile-satellite systems than for fixed-satellite systems, particularly for earth stations on aircraft. Systems intended for a wide variety of applications might best be designed to permit several modulation types and multiple access schemes in order to optimize the utilization of the available satellite capacity.

Table I gives an example of three major system characteristics for a hypothetical mobile-satellite system compared with a typical fixed-satellite system. An example of a specific system which has been used extensively for mobile-satellite experimental applications is given in Annex I. The mobile-satellite system is assumed in this example to be operating with earth stations having a 15 dB(K^{-1}) range of G/T (this might correspond to $G/T \approx 10$ dB(K^{-1}) for airborne stations; $G/T \approx 15$ dB(K^{-1}) for land stations). All values given are illustrative.

TABLE I – *Major system factors*

Service	Earth station G/T range (dB(K^{-1}))	Satellite e.i.r.p. density range dB(W/Hz)	Resulting pfd dB(W/(m^2·4 kHz))
Fixed-satellite (4/6 GHz)	20 to 40	−30 to −50	−157 to −177
Mobile-satellite (5/10 GHz)	10 to 25	−20 to −35	−147 to −162

The reduction of side-lobe and back-lobe radiation is of major importance in a mobile-satellite earth and space station. Low side-lobe radiation levels promote frequency sharing with other services and frequency re-use within the mobile-satellite service.

Representative circular antenna side-lobe gains for small earth station antennas (D/λ less than 100) can be calculated from Report 391:

$$G = 52 - 10 \log (D/\lambda) - 25 \log \alpha \qquad \text{dBi} \qquad (1)$$

where

G: gain relative to an isotropic antenna (dBi);

D: antenna diameter (m);

λ: wavelength at operating frequency (m);

α: angle off main-beam axis (°).

It should be noted that this formula should be assumed to apply only to the region beyond the first side-lobe peak, that is, at and beyond α (degrees) $\approx 100\ \lambda/D$. In addition, it should never be assumed that the reference antenna gain falls below -10 dB relative to isotropic.

Work is progressing on specially designed small earth stations with improved side-lobe characteristics. Side lobes suppressed further than those in the above formula have been measured for an antenna with offset feed and D/λ of 66, (Report 391). The offset feed is one current solution to the problem of feed and feed support aperture blockage which contributes to the high side-lobe problems. There are other techniques which may be used to reduce the side-lobe levels of satellite system antennas such as tapering the primary illumination across the antenna aperture.

4. Applications of systems in the mobile-satellite service

The wide variety of earth stations which can be accommodated in a mobile-satellite system makes it particularly suitable for use in situations of natural disaster and relief operations. Besides providing telephony and radioteletype services, the system could embrace wideband transmissions in support of scientific endeavours and exploration missions. Temporary communications for news and special events is another example of the type of beneficial service a mobile-satellite system could provide.

ANNEX I

CHARACTERISTICS OF THE UNITED STATES GOVERNMENT COMMUNICATION SATELLITE SYSTEM, PHASE II

1. Introduction

This Annex describes the characteristics of the United States Government Communications Satellite System (USGCSS). The USGCSS employs geostationary satellites, operating in the 7/8 GHz frequency bands.

The USGCSS Phase II satellites are spin-stabilized, with two steerable narrow beam antennas, one narrow coverage (NC) and the other with area coverage (AC) footprints and two earth coverage (EC) antennas all on a de-spun platform. The antennas are cross-strapped to permit any antenna to receive and transmit via any other. The various transponders and cross-straps have different bandwidths selected on the basis of expected needs. The overall frequency range covers 500 MHz including guard bands: 7900 to 8400 MHz up-link and 7250 to 7750 MHz down-link. The Phase II satellites have tunnel diode inputs and travelling wave tube (TWT) output amplifiers.

2. Phase II system development

The Phase II system has an evolutionary operation communications concept comprising three distinct stages.

Stage 1a operated in the frequency division multiple access (FDMA) and pseudo-noise orthogonal multiple access and provided a point-to-point (single destination) operational capability. Both frequency-modulated carriers (FM-FDMA) and pseudo-noise (PN) modulated carriers were employed during this period. This stage is now superseded.

Stage 1b operates principally in the FM-FDMA and phase-shift keying (PSK) – frequency division multiple access (FDMA) modes to provide a multi-destination communications capability and the pseudo-noise (PN) mode to provide selected point-to-point communications. This stage employs multiple receive and transmit carriers at selected locations (nodes) to support links in a multi-point network operating via a single satellite. Traffic at present ranges from 3 to 72 voice channels, depending upon the size of the earth station. A few links are also used to provide wideband (megabit) digital data traffic between selected area and digitized voice (50 kbit/s).

Stage 1c will be phased in with the installation and operation of digital equipment (PCM, PSK, Quaternary Phase Shift Keying (QPSK) and later, coding equipment) into the system. FDMA will remain the principal mode of access. Time division multiple access (TDMA) may be introduced with a follow-on satellite design.

The introduction of digital operation will result in increased system capacity through a more efficient combination of different types of traffic (voice, teletype, data, and wideband data) than is possible in an analogue system, and through the use of coding, which allows more efficient use of satellite power. As the PCM and other analogue-to-digital conversion equipment becomes available, the system will phase from an analogue system to a hybrid, and finally into an all digital system. Some traffic will continue to be provided using PN equipment.

The introduction of digital communications into the Phase II system will signal the beginning of new families of PSK/QPSK modems for transmitting and receiving high-speed PCM data. The modulation/coding technique chosen for the system consists of differential-encoded phase shift keying in conjunction with convolutional coding and Viterbi decoding. This approach provides an earth station which yields a high communication performance in terms of link bit error ratio (BER). A full complement of existing earth stations, suitably modified, and newly procured earth stations will be available for use during this final stage. Requirement analyses have indicated that the USGCSS in this time frame can serve a broad spectrum of earth stations. For example, in feasibility studies using experimental shipborne mobile-satellite terminals, satisfactory communications were obtained using antennas with apertures of a few metres and with gain-to-noise temperature ratios (G/T) of the order of 18 dB(K^{-1}). On the other hand, the USGCSS has been used with large earth station antennas having apertures of 18.3 m (60 feet) and a G/T ratio of 39 dB(K^{-1}). Further, to satisfy various classes of users, it will be necessary to employ several modes of access, including a demand access capability for low duty-cycle users and FDMA for high capacity networks.

3. Space segment

The USGCSS Phase II satellite transponder consists of a multi-channel repeater with cross-linked channels, a receive and a transmit EC antenna and two steerable NC/AC antennas, each capable of receiving and transmitting simultaneously. This arrangement provides four modes of operation:

- earth coverage to earth coverage (EC-EC),
- earth coverage to narrow beam (EC-NC/AC),
- narrow beam to earth coverage (NC/AC-EC),
- narrow beam to narrow beam (NC/AC-NC/AC).

The basic interconnection for these four modes is shown in Fig. 1.

The up-link frequency transmitted by a Phase II earth station determines which of the four modes will be used. The signal received at the satellite in the 7900 to 8400 MHz band is amplified and re-transmitted in the 7250 to 7750 MHz band. A simplified frequency diagram presented in Fig. 2 relates the various channel modes, together with their related frequency translations and satellite antennas. Mixers provide the necessary 725 MHz down-conversion from the receive frequency to the transmit frequency, except for Channel 4, which is translated only 200 MHz. Both Channel 1 and 2 share the output power of the high level 20 W TWT amplifier, using the EC antenna. Likewise, Channel 3 and Channel 4 are combined and transmitted via a second 20 W TWTA using either one or both of the narrow beam antennas. A commandable mechanical waveguide shuttle switch at the output of the narrow beam transmitter serves to direct the total power to either NC or AC antenna, or to function as a power splitter delivering half the power to each. The antenna pointing directions for each of four satellites are indicated in Table II and the modes of operation for each satellite are indicated in Table III.

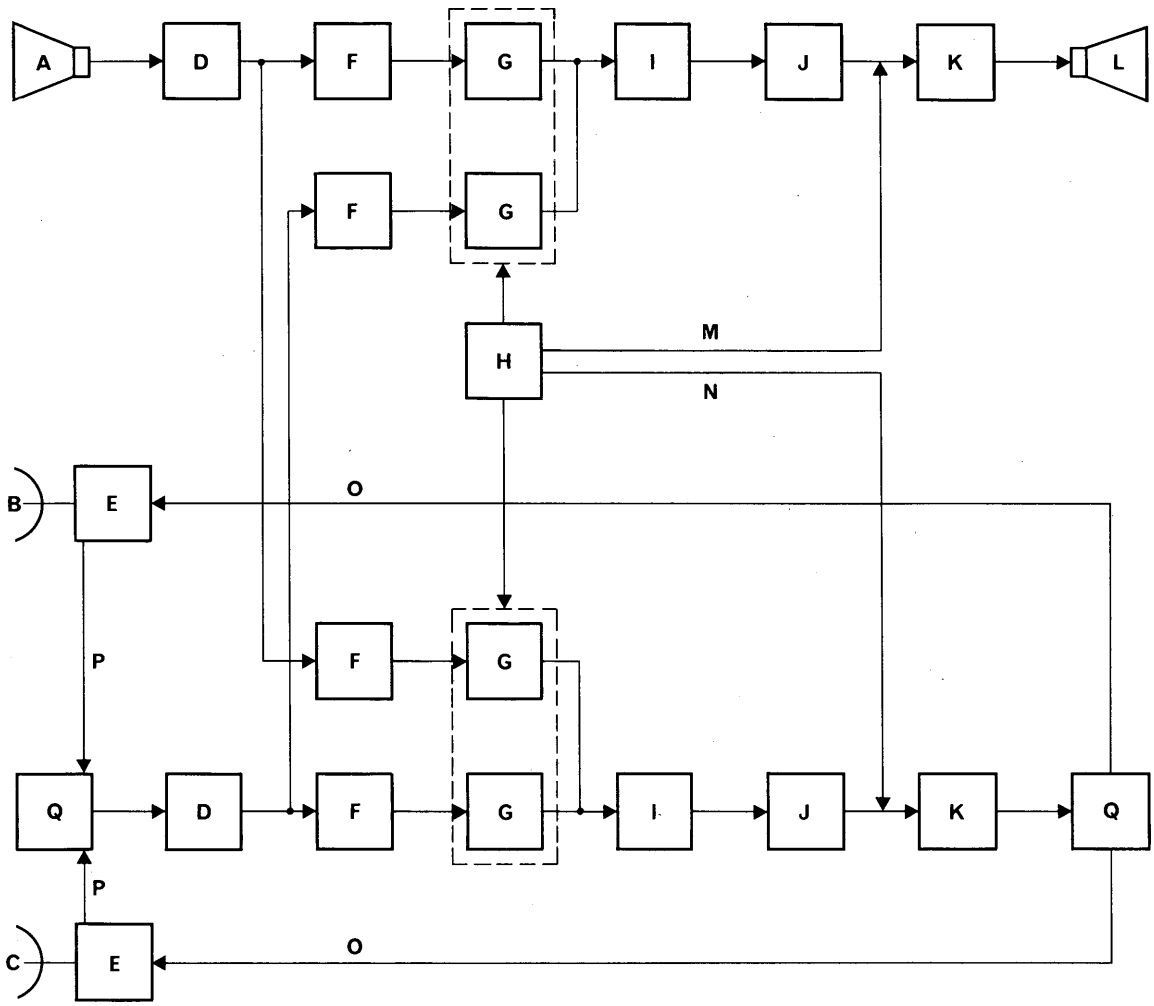


FIGURE 1 — *USGCSS Phase II transponder block diagram*

A: earth coverage receive antenna
B: area coverage antenna
C: narrow coverage antenna
D: pre-amplifier
E: diplexer
F: limiter
G: converter
H: frequency generator
I: summing amplifier
J: exciter low level TWT
K: power amplifier high level TWT
L: earth coverage transmit antenna
M: beacon 1
N: beacon 2
O: transmit
P: receive
Q: antenna selector

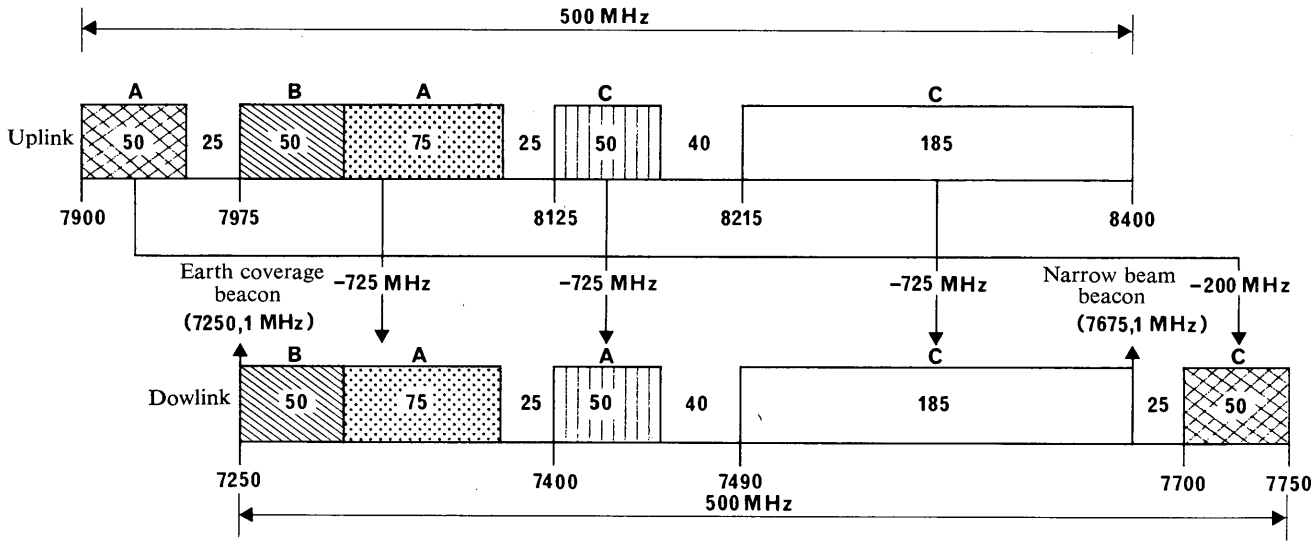


FIGURE 2 — *Frequency plan (Frequency translation (in MHz) from the uplink frequency to the downlink frequency)*

A: earth coverage
B: exclusive band
C: narrow coverage/area coverage

TABLE II – *Antenna pointing direction*

Satellite	EC	NC	AC
West Pacific Ocean	0° N/175° W	37° N/122° W	27° N/128° E
East Pacific Ocean	0° N/135° W	Stand-by use	33.5° N/106.2° W
Atlantic Ocean	0° N/ 12° W	38° N/ 77° W	40.85° N/14.25° E
Indian Ocean	0° N/ 60° E	49° N/ 11° E	Stand-by use

TABLE III – *Modes of operation*

Channel and bandwidth (MHz)	Transmit frequency (MHz)	Transmit antenna	Receive frequency (MHz)	Receive antenna
1 (125)	7250-7375	EC	7975-8100	EC
2 (50)	7400-7450	EC	8125-8175	NC/AC
3 (185)	7490-7675	NC/AC	8215-8400	NC/AC
4 (50)	7700-7750	NC/AC	7900-7950	EC

Prior to frequency conversion, input signals in each channel pass through an amplifier/limiter stage. This unit consists of a five-stage tunnel diode amplifier/limiter (TDAL). Each TDAL is gain variable over a 24 dB range in approximately 4 dB steps selected by ground command. This feature allows each channel's gain to be optimized for a particular class or mix of earth stations working the satellite.

The bandwidth of each channel is shown in Table III and represents 410 MHz of usable bandwidth. The high level 20 W TWTA is of special design in order to enhance its intermodulation and AM/PM conversion performance. A 40 W version of the TWTA will be incorporated on designated replenishment satellites.

The Phase II satellites have on-board thrusters which are capable of maintaining longitudinal position of the spacecraft in geostationary orbit to within ± 1° of their designated positions. In addition, they can be repositioned at least once during their operational life to any other equatorial point at a rate of 15° per day. North-south stationkeeping to compensate for the inclination angle of the orbit is not provided. However, a "nodding programmer" is included in the spacecraft which compensates the NC/AC antennas for the diurnal movement due to the residual inclination. Thus, when the satellites move south, the elevation gimbals of the NC/AC antennas are nodded north, and vice-versa, by an amount just sufficient to compensate for the satellite movement. The same thing is done for the azimuth gimbals to correct for the diurnal east/west motion of the satellite.

All the transmitting antennas are lefthand circularly polarized (LHC), whereas the receiving antennas are right-hand circularly polarized (RHC). The NC/AC antennas are separately gimbaled and are capable of being independently steered ± 10° from each of two orthogonal directions. Separate horn antennas, of the square pyramidal design, are employed for earth coverage receive and earth coverage transmit. The transmit horn is designed to maximize the gain at the beam edge angle – nominally 8.5° off-axis. The receive horn has a slightly different roll-off characteristic; both earth coverage antennas yield a peak gain of approximately 20 dBi. The nominal NC antenna peak gain is approximately 35 dBi for both the receive, transmit and the AC peak gain is 3 dB lower, i.e. 32 dBi.

All the active components within the USGCSS Phase II are backed up with redundant units. The selection of the active or stand-by units and NB antenna switching and steering is done by ground command. To achieve the maximum in-orbit usage of the Phase II satellite, all housekeeping systems have been sized to provide for five year operational life. The mean-time-to-failure (MTTF) for the Phase II satellite within the five year wear-out life has been computed as 3.2 years. Electrical power is supplied by on-board batteries for eclipse operation and full communication capability.

4. Earth segment

The USGCSS operates with many different types of earth stations. A summary of the characteristics of existing and planned earth stations is given in Table IV. Most of these stations fall into the RF tunable class (frequency selection accomplished at RF) with a standard 70 MHz IF frequency. The newer model Phase II terminals, the large (18.3 m) and the medium (12.2 m), have incorporated many special reliability and control features. The large earth station is the standard for fixed-station service. It can be equipped with up to 9 transmit and 12 receive frequency converters. The antenna reflector consists of a solid-surface, 18.3 m (60 ft.) diameter high efficiency main reflector and a sub-reflector, with a G/T of 39 dB(K^{-1}). This earth station interfaces with the communication sub-system at IF frequencies of 70 or 700 MHz. Tuning of transmit and receive carriers in increments of 1 kHz over the full 500 MHz up link and down link frequency bands is provided. An automatic carrier balance capability provides automatic level of each transmitted carrier with an accuracy of ± 0.2 dB.

Despite the sophistication represented by the large and medium sized earth stations, there has been increasing emphasis on the use of small, low-cost earth stations, especially those that can be transported to different areas in times of an emergency or natural disaster. The latter are typified by rapidly deployable stations with antennas of 6.1 m. Further, experimental stations aboard ships, employing satellite antennas with a diameter of 2.44 m are now undergoing feasibility tests, while an experimental station with a 0.84 m terminal intended for operation aboard aircraft is being tested.

TABLE IV – *Characteristics of existing and planned USGCSS earth terminals*

Terminal type or application	Antenna diameter (m)/(ft.)	Transmit gain (dB)	Receive gain (dB)	System noise temperature (K)	G/T (dB(K^{-1}))
Large (1)	18.29 (60)	61.0	60.2	132	39
Medium (1)	12.19 (40)	57.4	56.6	180	34
Small (2)	6.1 (20)	51.4	50.6	290	26
Small (2, 3)	2.44 (8)	43.5	42.5	300	18
Shipborne (3)	2.44 (8) 1.22 (4)	42.8 36.8	42.0 36.0	250 320	18 11
Airborne (4)	0.84 (2.75)	34.3	33.2	465	6.5

(1) In this example fixed-satellite earth stations are also included in the system.
(2) This type antenna is relocatable.
(3) This type antenna is being operated on an experimental basis, worldwide.
(4) This type antenna is being operated on an experimental basis, in USA only.

An example of the flexibility provided by small earth stations can be seen from the features of the station with the 6.1 m diameter (20 feet) antenna:

- load and transport on 2.5 ton truck or transport aircraft;
- 12-to-24 h erection on rough terrain (slopes up to 10°);
- group feed assembly including horn, filters, polarizer, and orthomode transducer is integrally electro-formed for intermodulation free performance;
- $G/T = 26$ dB(K^{-1});
- safe antenna erection in 32 km/h winds;
- tracking error: 0.5 dB in 16 km/h winds;
- tracking error: 2.0 dB in 120 km/h winds.

REPORT 772-1

ORBITAL SPACING CONSIDERATIONS FOR A MOBILE-SATELLITE SERVICE *

(Question 32/8)

(1978-1982)

1. Introduction

Question 32/8 addresses the technical and operating aspects of the mobile-satellite service, including the feasibility of sharing with other satellite services. Of particular interest is the spacing required between adjacent satellites.

The interference between adjacent satellite systems is a function of the earth station antennas sizes and the modulation schemes and other characteristics of these services rather than the location or motion of the earth stations. Physical size, weight and primary power are intrinsic constraints placed on earth stations intended for operation in the mobile-satellite service. These constraints result in physically small earth station antennas (as compared to those which may be used in the fixed-satellite service).

* The material contained in this Report is preliminary and has been drawn up by Study Group 8 only, without the benefit of consultation with Study Group 4. This Report should be brought to the attention of Study Group 4.

In this Report, inter-satellite spacing is calculated for geostationary satellites operating in the 8 and 7 GHz band. The spacing is determined parametrically as a function of allowable interference, mobile earth station antenna diameter and modulation type. The more general problem of inter-satellite spacing in any frequency band is treated in Annex I, wherein a method for determining required orbital spacing of geostationary space stations is developed.

2. Factors affecting orbital sharing

There are numerous factors affecting the general problem of optimum utilization of the geostationary orbit. These are discussed in Report 453. The factors bearing most heavily upon the problem of a general mobile-satellite service sharing the orbit with the fixed-satellite service are as follows:

- permissible interference levels;
- earth station antenna gain characteristics;
- earth station antenna pointing accuracy;
- satellite system inhomogeneity.

2.1 *Permissible interference levels*

The maximum permissible levels of interference in a geostationary satellite network in the fixed-satellite service caused by other networks of this service are specified in Recommendations 466 and 483 for frequency modulated FDM telephone and television. No criteria have been developed for adjacent satellite networks in a mobile-satellite service.

2.2 *Antenna gain characteristics*

Equipment operating in a general mobile-satellite service will utilize a wide range of antenna diameters. It can be expected that the antenna size will be determined by the system application. There are limiting factors on antenna size. In bands shared with terrestrial services, the power flux density (pfd) limitations will usually limit the minimum antenna size and data rate. In bands not shared with the terrestrial services, there is no limit to down link e.i.r.p. other than the state-of-the-art in spaceborne transmitter design and one might envision general mobile-satellite service requirements calling for extremely small antennas and correspondingly high transmitter power.

The amount of energy in the side lobes of the antenna must be controlled in order to use the geostationary orbit efficiently. These levels can be controlled by careful antenna design and selection of proper illumination functions. However, this sidelobe suppression is commonly achieved at the expense of reduced main beam gain and beam broadening. The limiting factor will then be a combination of beamwidth and pointing accuracy.

2.3 *Antenna pointing accuracy*

As the antenna diameter is decreased, the beam broadens. It becomes increasingly difficult to accurately centre the beam on the desired satellite. This fact coupled with the present limit on satellite station keeping places a limit on minimum antenna size (Recommendation 484). Thus, the minimum antenna size is a function of orbital spacing between satellites and the pointing accuracy of the earth-station antenna.

2.4 *Satellite system inhomogeneities*

Any large disparity in antenna sizes of earth stations utilizing the same satellite transponder will require the users of the smaller antennas to increase their transmitter power in order to maintain the desired down link signal strength. This, in turn, increases the e.i.r.p. in the side lobe region and therefore the potential for interference to both terrestrial systems and other space systems.

3. Equations for calculating inter-satellite spacing requirements

Equation 1, which is used to calculate the required satellite separations in the geostationary orbit, derive from Appendix 29 to the Radio Regulations. Figure 1 is a diagram of a given satellite system and an adjacent interfering satellite system. The parameter notation is similar to Appendix 29 with the parameters of the interfered-with system being unprimed and those of the interfering system being primed.

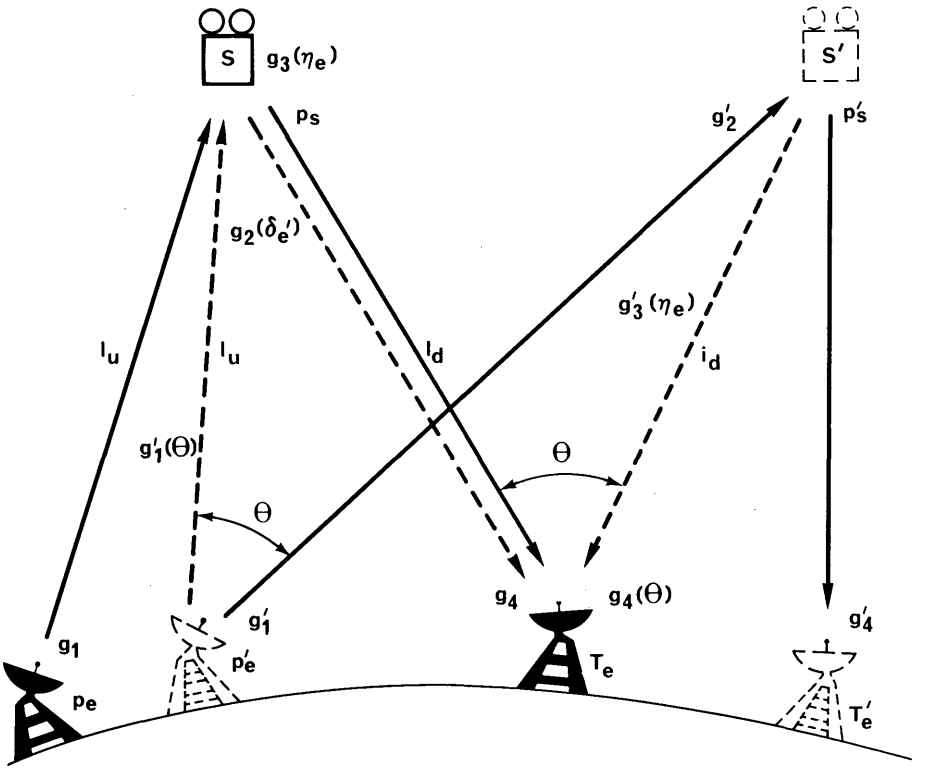


FIGURE 1 — *Link diagram of desired and interfering systems*

Note. — The symbols used in Fig. 1 are the same as those defined in Report 454 " Method of calculation to determine whether two geostationary-satellite systems require coordination ".

The equation taking into account earth station, satellite, link and modulation parameters developed in [CCIR, 1974-78] and evaluated specifically for the 7 and 8 GHz band is:

$$\theta = \left\{ \frac{2}{\Delta T/T_e} \left(\frac{c/kT\,|_{req.}}{SF} \right) \left[\frac{(D'_{4L})^2}{(D'_4)^2\,(D'_1)^3} + \frac{3}{D'_4} \right] \right\}^{0.4} \qquad (1)$$

where

θ : is the resulting off-axis angle subtended by the interfering satellite on the earth station antenna; θ is approximately the inter-satellite separation for geostationary satellites (degrees);

$\Delta T/T_e$: is the acceptable ratio of an equivalent interference noise temperature to the receive earth station thermal noise temperature. (This is not identical to the Appendix 29 definition);

$c/kT|_{req}$: the required carrier-to-noise density ratio;

SF: total signal power divided by maximum signal power density; SF is a spectrum spreading factor;

$D'_{1,4}$: are the diameters of the earth station transmit, receive antennas in the interfering system (metres);

$\left(\frac{D'_{4L}}{D'_4}\right)$: inhomogeneity factor where D'_{4L} is the largest receive earth station antenna diameter in the interfering system (metres).

The assumptions embodied in equations 1 are:

- The adjacent satellites have earth coverage antenna patterns and the same receive noise temperatures. However, for a spot beam satellite antenna, the general results also apply when the antenna gains and coverage areas of the adjacent satellite are identical.
- The earth station side lobe reference patterns are as in Report 391.
- The ratio of up-path to down-path carrier-to-noise density is equal to or greater than 4, for both the mobile and fixed-satellite systems.
- The earth station noise temperatures are 300 K for mobile earth stations and 100 to 200 K for fixed earth stations.
- Satellite station-keeping errors are not taken into account.

The factor $\left(\frac{c/kT|_{req.}}{SF}\right)$ depends on the modulation type.

For FDM-FM, a threshold extension demodulator and 4 dB link margin are assumed. For phase shift keyed modulations, 4 dB link margin and 2 dB implementation loss are assumed. The values for $\left(\frac{c/kT|_{req.}}{SF}\right)$ are shown in Table I:

TABLE I

Modulation type	$\left(\frac{c/kT\|_{req}}{SF}\right)$
QPSK	19.4 dB
QPSK coded rate ½	11.4 dB
FDM-FM	15 dB

It should be noted here that, in actual practice, this parameter will not be the same for both the fixed-satellite and mobile-satellite services. In this analysis, the same value is applied to both services in order to consider what would be the worst case.

Another important parameter is $\left(\frac{D'_{4L}}{D'_4}\right)^2$. This represents the degree of inhomogeneity within the interfering satellite system. In this analysis, it was assumed that a mobile earth station with a four metre antenna is always part of the interfering mobile network. This important parameter should be given careful consideration in planning any mobile network or the use of any one transponder in a satellite for any service.

An important feature of equation (1) is that the inter-satellite separation angle depends almost entirely on the characteristics of the interfering network, T_e being the only parameter of the interfered with network that is involved.

4. Inter-satellite spacing requirements of the general mobile-satellite service

For purposes of analysis herein, the fixed-satellite service (FSS) at 7 and 8 GHz is considered as containing earth stations whose antenna diameters are greater than 4 metres; 4 metres is a diameter equal to 100 λ. Below this value, the earth station is considered as being "small". The mobile-satellite service (MSS) at 8 and 7 GHz is assumed to have earth station antenna diameters of 4 metres or less.

The ratio of equivalent interference noise to down link thermal noise, $\Delta T/T_e$, is an important parameter. T_e (earth station noise temperature) as used herein differs from the Appendix 29 definition which refers to the total link equivalent noise temperature. The value of T in the ratio $\Delta T/T$ of Appendix 29 is highly dependent upon individual link characteristics. The factor T_e was chosen for this analysis in order to provide a constant frame of reference. The $\Delta T/T_e$ parameter is arbitrarily assigned the following values: 2%, 8%, and 20% in order to cover a range of inter-satellite interference allowances.

Since the separation angles calculated for FSS interference into MSS are always smaller than those of equation (1), the latter will be used to calculate the separation angles between the satellites of the two services. These angles are plotted as a function of the interfering antenna diameter in Fig. 2. The effect of different modulations are shown in Fig. 3 for this case.

Antenna pointing accuracy is not taken into account in these analyses.

5. Analysis of results

It should be emphasized that the examples presented here are for a limited set of parameter values and are given as an aid for efforts to plan future general mobile-satellite systems.

The inter-satellite spacing between fixed and mobile-satellite systems can be determined from Figs. 2 and 3. The characteristics of a general mobile service system are taken to correspond to a mobile to mobile inter-satellite separation of 10°. For 2 m antennas and FDM/FM modulation in the mobile system an inter-satellite spacing of about 13.5° for an interference allocation of $\Delta T/T_e = 8\%$ in the fixed system. A 1.5 m mobile earth station antenna and coded QPSK modulation would imply a spacing of 16°. These spacings are representative of the mobile earth stations accessing the same frequency as the fixed stations on the adjacent satellite.

The spacing requirements could be as much as 2 to 3 times as large as those shown in Figs. 2 and 3 if the mobile-satellite up link shared the same satellite transponder with a system using large antenna (> 10 m).

Modulation inhomogeneities have an effect on satellite space requirements as shown in Fig. 3. Modulation inhomogeneities of 7 dB affect the satellite spacing by a factor of about two. Considerably higher inhomogeneities than this currently exist in the satellite networks of the FSS in the case of FM-TV interference on single-channel-per carrier systems.

6. Summary

Equation (1) has been presented here for calculation of separation angle requirements between satellites in the mobile and fixed-satellite services for the 7/8 GHz band. Examples are provided which demonstrate the variability of these requirements over certain parametric ranges: antenna dimensions, interference criteria and modulation types.

Two parameters in equation (1) should be examined further to determine their effect on satellite spacing: the degree of inhomogeneity and the required carrier-to-noise ratios of the mobile-satellite system. In addition, the effect of earth station antenna pointing accuracy should be investigated.

Other aspects of system design will affect satellite spacing requirements and a set of favourable system trade-offs such as separated antenna spot beams, polarization diversity, one-way transmission links or relatively interference free signal/modulation combinations would tend to increase orbit utilization and lessen spacing requirements.

Equation (10) in Annex I can be used to determine required orbital spacing between geostationary space stations in any frequency band. This equation is more generally applicable than equation (1) since it embodies less restrictive assumptions.

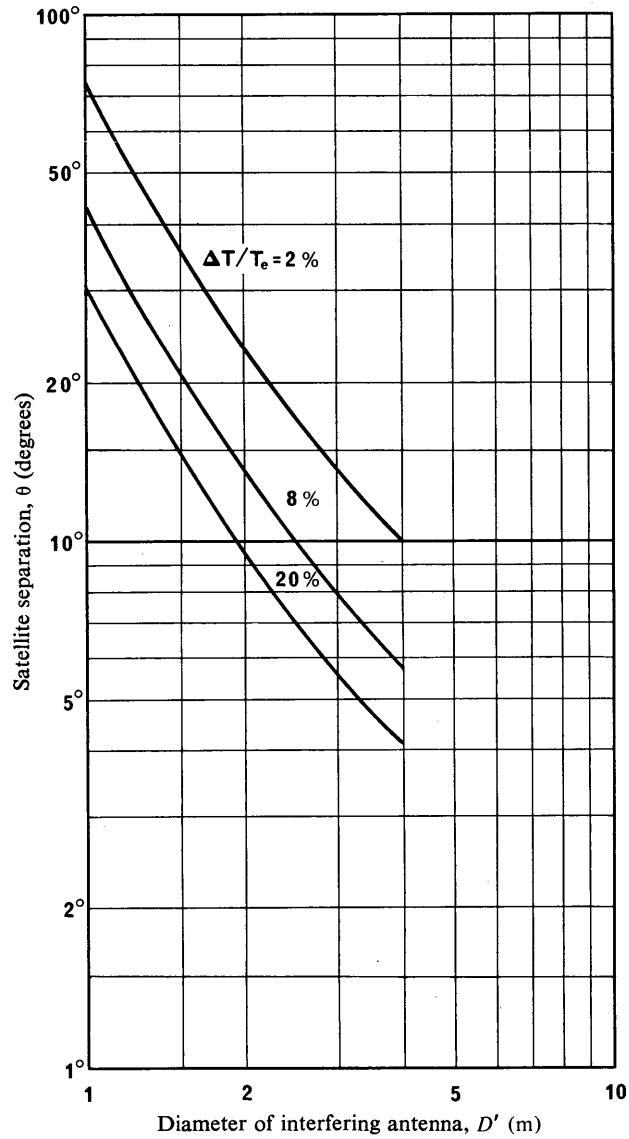


FIGURE 2 — *Satellite spacing requirements based upon interference from the Mobile-Satellite Service to the Fixed-Satellite Service*

(FDM-FM)

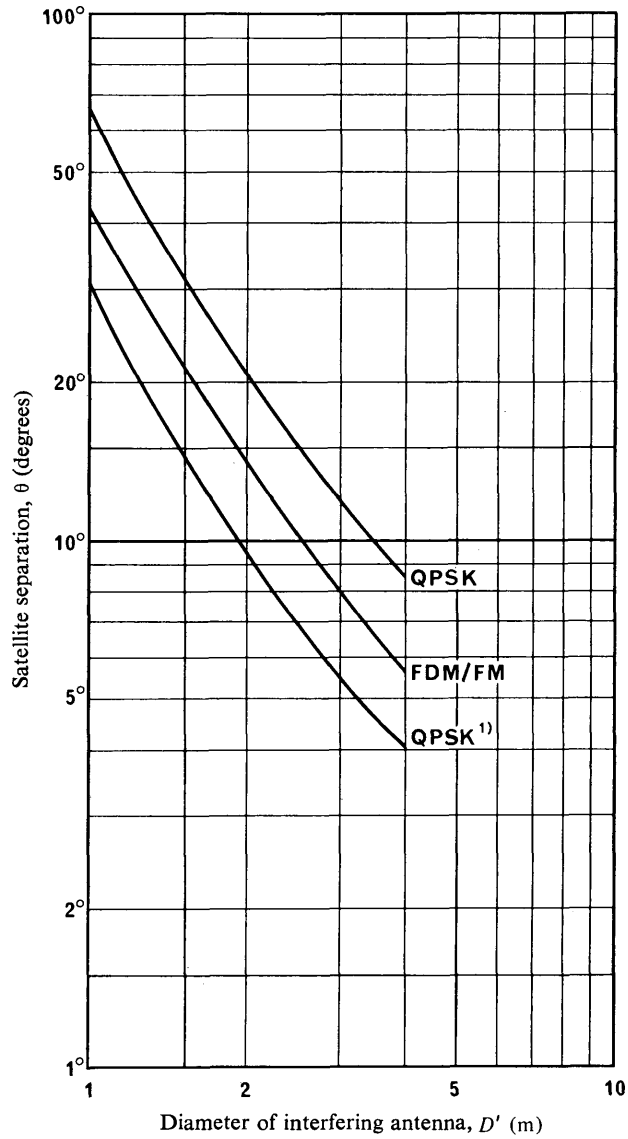


FIGURE 3 — *Effect of modulation type on satellite spacing requirements based on interference from the Mobile-Satellite Service to the Fixed-Satellite Service*

$\Delta T/T_e = 8\%$

[1]) Coded rate ½

REFERENCE

CCIR Documents

[1974-78]: 8/347 (USA).

ANNEX I

METHOD OF CALCULATION TO EVALUATE THE REQUIRED ANGULAR SEPARATION BETWEEN INDEPENDENT GEOSTATIONARY SATELLITE NETWORKS SHARING THE SAME FREQUENCY BANDS

Equation (1) in the body of the Report defines a method for calculating separation between satellite systems whose satellite antenna gains and coverage areas are identical. This Annex considers a more general situation, wherein adjacent satellites may be independent and therefore have different characteristics, including antenna gain and coverage area. The method of calculating required angular separation is based on the concept that a maximum permissible interference-to-thermal noise ratio may be specified in the system receiving interference. It can, therefore, be applied irrespective of the modulation characteristics of the satellite networks, and of the precise frequencies used.

In the method described in this Annex, the power level of each interference entry is determined parametrically at the earth station receiver of the system receiving interference. The summation of the interference entries is then compared with the equivalent link thermal noise power. From the resulting equation, the effect of each system parameter upon the interference-to-thermal noise ratio may be determined. For most cases, the equation may be solved directly for the required angular spacing, and used for evaluation or for a parametric analysis as a function of the satellite network parameters.

The geometry involved in the two systems is shown in Fig. 4. The symbols are defined in Table II. Referring to Fig. 4, the interfered with system up-path e.i.r.p. is given by the product of the earth station transmitter power (p_{et}) and earth station transmitting antenna gain (g_{et}):

$$e.i.r.p. = p_{et}\, g_{et} \qquad \text{W}$$

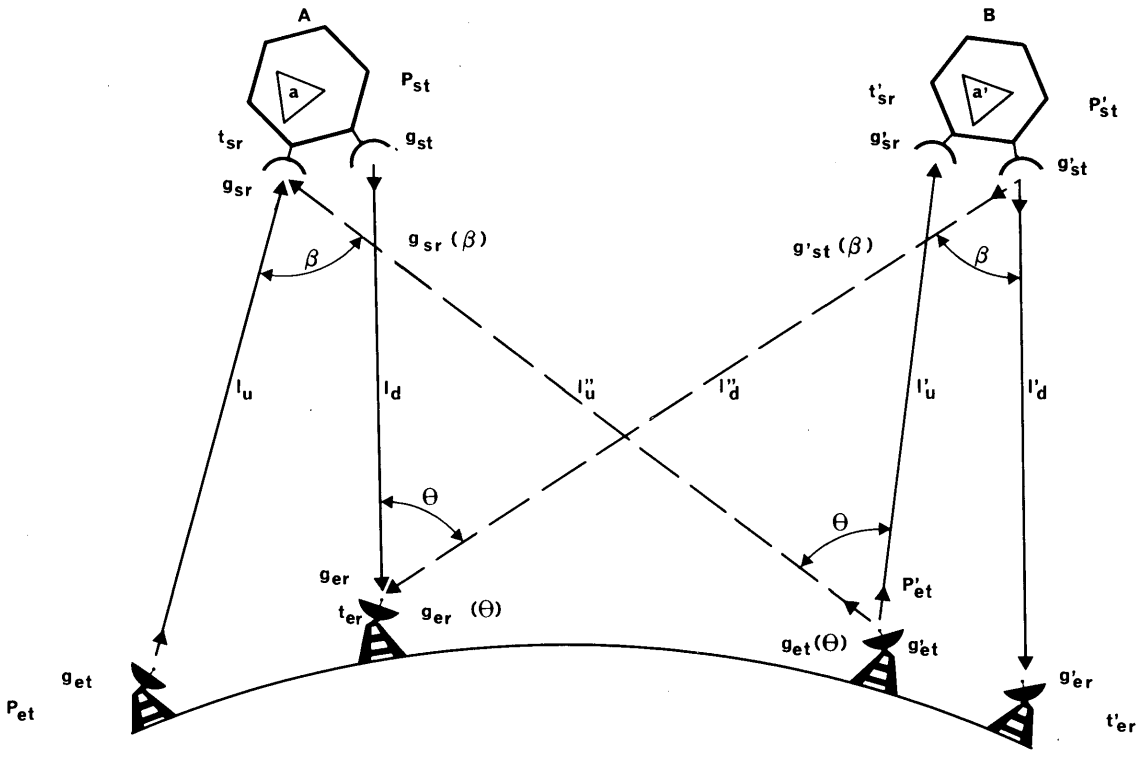


FIGURE 4 – *Geometry to determine interference between satellite systems*

——— : desired path

— — — : potential interference path

A: interfered with satellite system
B: interfering satellite system

Note. – All symbols are defined in Table I

TABLE II — *Definition of parameters used in Fig. 4*

Note. — Primed (′) or (″) parameters refer to the interfering system.

p_{et}: power delivered to the earth station transmitting antenna in the reference bandwidth, b; W.
g_{et}: power gain of the earth station transmitting antenna*.
g_{er}: power gain of the earth station receiving antenna*.
p_{st}: power delivered to the space station transmitting antenna in the reference bandwidth, b; W.
g_{st}: power gain of the space station transmitting antenna*.
g_{sr}: power gain of the space station receiving antenna*.
t_{er}: effective noise temperature of the earth station receiver (K).
t_{sr}: effective noise temperature of the space station receiver (K).
a: the ratio of power delivered to the space station transmitting antenna to the power available to the space station receiver.
b: reference bandwidth (Hz).
θ: off-axis angle from earth station antenna main beam (degrees).
β: off-axis angle from space station antenna main beam (degrees).
l_u: up-path basic transmission loss, power ratio.
l_d: down-path basic transmission loss, power ratio.
$g_{er}(\theta)$: power gain of earth station receiving antenna in the direction of the interfering space station*.
$g'_{et}(\theta)$: power gain of the interfering earth station transmitting antenna in the direction of the interfered with space station*.
$g_{sr}(\beta)$: power gain of space station receiving antenna in the direction of the interfering earth station*.
$g'_{st}(\beta)$: power gain of the interfering space station transmitting antenna in the direction of the interfered with earth station*.

* Relative to an isotropic antenna.

Given the up-path basic transmission loss (l_u), the received signal level at the space station receiver is given by:

$$p_{sr} = p_{et}\, g_{et}\, g_{sr} / l_u \qquad \text{W}$$

and the carrier-to-thermal noise ratio at the space station receiver is then:

$$c/n = p_{sr} / k\, t_{sr}\, b$$

The received signal power (p_{sr}) increased by the gain of the space station transponder *(a)* is then the power delivered to the space station transmitting antenna:

$$p_{st} = p_{sr}\, a \qquad \text{W}$$

In this manner, the following levels may be determined at the *interfered with earth station receiver:*

– The desired carrier power:

$$c = \frac{p_{et}\, g_{et}\, g_{sr}\, a\, g_{st}\, g_{er}}{l_u\, l_d} \tag{2}$$

– The up-path interference power:

$$i'_u = \frac{p'_{et}\, g'_{et}(\theta)\, g_{sr}(\beta)\, a\, g_{st}\, g_{er}}{l''_u\, l_d} \qquad \text{W} \tag{3}$$

– The down-path interference power (from an interfering satellite to the interfered with earth station receiver):

$$i'_d = \frac{p'_{et}\, g'_{et}\, g'_{sr}\, a'\, g'_{st}(\beta)\, g_{er}(\theta)}{l'_u\, l''_d} \qquad \text{W} \tag{4}$$

– Rebroadcast noise from the interfering space station:

$$n'_{ss} = \frac{k\, t'_{sr}\, b\, a'\, g'_{st}(\beta)\, g_{er}(\theta)}{l''_d} \quad \text{W} \tag{5}$$

– The earth station receiver noise:

$$n_{er} = k\, t_{er}\, b \quad \text{W} \tag{6}$$

– Re-broadcast noise from the interfered with system space station receiver:

$$n_{ss} = \frac{k\, t_{sr}\, b\, a\, g_{st}\, g_{er}}{l_d} \quad \text{W} \tag{7}$$

Where both satellite system space stations are in geostationary orbit, the above equations provide useful working relations, with negligible error, for most cases by assuming:

– All up-path and down-path transmission losses in a frequency band are equal:

$$l_u = l_d = l'_u = l'_d = l''_u = l''_d = l$$

– Off-axis angles from space station antenna mainbeams are sufficiently small to be neglected, so that:

$$g(\beta) = g$$

– The topocentric angular separation between two satellites (θ) as seen from any earth station is equivalent to the geocentric angular separation between the two satellites.

With these assumptions, the total interference-to-link noise ratio may be written using equations (3) through (7):

$$\frac{i_{total}}{n_{link}} = \frac{i''_u + i'_d + n'_{ss}}{n_{er} + n_{ss}} \tag{8}$$

and substituting equations (3) through (7):

$$\frac{i}{n} = \frac{\overbrace{p'_{et}\, g'_{et}(\theta)\, l^{-1}\, g_{sr}\, a\, g_{st}\, l^{-1}\, g_{er}}^{\text{Up-path interference}} + \overbrace{p'_{et}\, g'_{et}\, l^{-1}\, g'_{sr}\, a'\, g'_{st}\, l^{-1}\, g_{er}(\theta)}^{\text{Down-path interference e.i.r.p.}} + \overbrace{k\, t'_{sr}\, b\, a'\, g'_{st}\, l^{-1}\, g_{er}(\theta)}^{\text{Rebroadcast noise from interfering satellite}}}{\underbrace{k\, t_{er}\, b}_{\text{Earth station noise}} + \underbrace{k\, t_{sr}\, b\, a\, g_{st}\, l^{-1}\, g_{er}}_{\text{Satellite rebroadcast noise}}} \tag{9}$$

Down-path interference

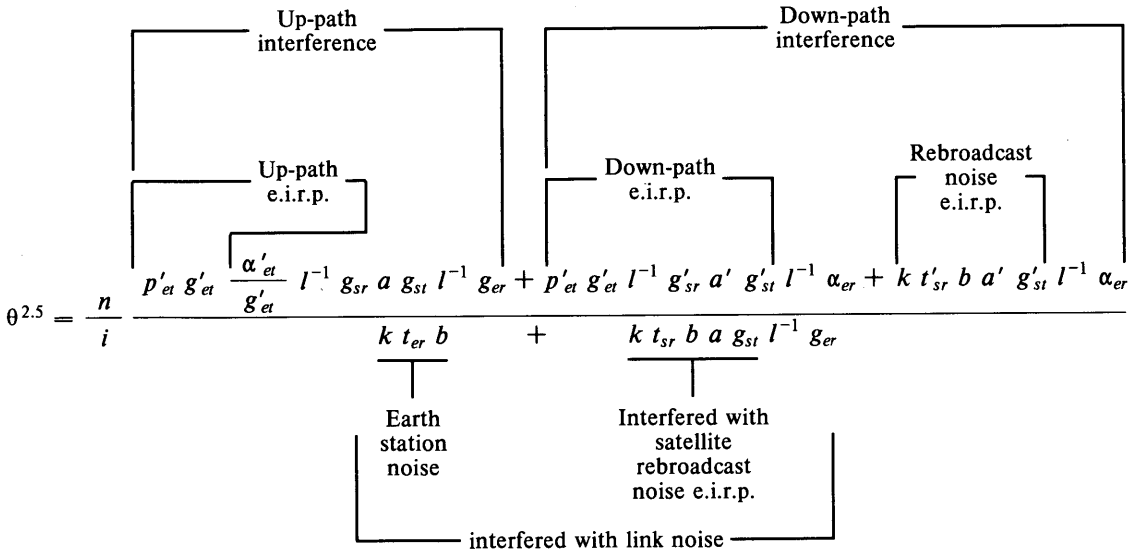
Since, for most cases of interest, the earth station antenna gain function may be written (for example, when $G(\theta) = 32 - 25 \log \theta$, $g(\theta) = 1585\, \theta^{-2.5}$):

$$g(\theta) = \alpha\, \theta^{-2.5}$$

the equation (9) may be arranged as follows for convenient computation:

$$\frac{i}{n} = \frac{p'_{et}\, g'_{et} \left| \frac{\alpha'_{et}\, \theta^{-2.5}}{g'_{et}}\, l^{-1}\, g_{sr}\, a\, g_{st}\, l^{-1}\, g_{er} + l^{-1}\, g'_{sr}\, a'\, g'_{st}\, l^{-1}\, \alpha_{er}\, \theta^{-2.5} \right| + k\, t'_{sr}\, b\, a'\, g'_{sr}\, l^{-1}\, \alpha_{er}\, \theta^{-2.5}}{k\, t_{er}\, b + k\, t_{sr}\, b\, a\, g_{st}\, l^{-1}\, g_{er}}$$

This equation may be used to calculate the interference-to-equivalent link noise ratio between any two satellite networks, where the parameters included in Table II are known. When the permissible i/n ratio is given, it is convenient to solve this equation for the satellite separation angle (θ), as follows:



$$\theta^{2.5} = \frac{n}{i} \cdot \frac{p'_{et}\, g'_{et} \dfrac{\alpha'_{et}}{g'_{et}}\, l^{-1}\, g_{sr}\, a\, g_{st}\, l^{-1}\, g_{er} + p'_{et}\, g'_{et}\, l^{-1}\, g'_{sr}\, a'\, g'_{st}\, l^{-1}\, \alpha_{er} + k\, t'_{sr}\, b\, a'\, g'_{st}\, l^{-1}\, \alpha_{er}}{\underbrace{k\, t_{er}\, b}_{\text{Earth station noise}} + \underbrace{k\, t_{sr}\, b\, a\, g_{st}\, l^{-1}\, g_{er}}_{\text{Interfered with satellite rebroadcast noise e.i.r.p.}}} \qquad (10)$$

Using this equation, the required satellite separation can be calculated given the values of parameters in Table II. For the case where the c/n ratio of the interfering system is specified:

$$(c/n)' = \frac{p'_{et}\, g'_{et}\, l^{-1}\, g'_{sr}\, a'\, g'_{st}\, l^{-1}\, g'_{er}}{k\, t'_{er}\, b + k\, t'_{sr}\, b\, a'\, g'_{st}\, l^{-1}\, g'_{er}}$$

the separation becomes:

$$\theta^{2.5} = \frac{n}{i} \cdot \frac{\left(\dfrac{c}{n}\right)' \dfrac{k\, t'_{er}\, b + k\, t'_{sr}\, b\, a'\, g'_{st}\, l^{-1}\, g'_{er}}{l^{-1}\, g'_{sr}\, a'\, g'_{st}\, l^{-1}\, g'_{er}} \left| \dfrac{\alpha'_{et}}{g'_{et}}\, l^{-1}\, g_{sr}\, a\, g_{st}\, l^{-1}\, g_{er} + l^{-1}\, g'_{sr}\, a'\, g'_{st}\, l^{-1}\, \alpha_{er} \right| + k\, t'_{sr}\, b\, a'\, g'_{st}\, l^{-1}\, \alpha_{er}}{k\, t_{er}\, b + k\, t_{sr}\, b\, a\, g_{st}\, l^{-1}\, g_{er}} \qquad (11)$$

and after re-arranging terms to simplify:

$$\theta^{2.5} = \frac{n}{i} \cdot \frac{\left(\dfrac{c}{n}\right)' (t'_{er} + t'_{sr}\, a'\, g'_{st}\, l^{-1}\, g'_{er}) \left(\dfrac{\alpha'_{et}}{g'_{et}} \dfrac{g_{sr}}{g'_{sr}} \dfrac{a\, g_{st}\, l^{-1}\, g_{er}}{a'\, g'_{st}\, l^{-1}\, g'_{er}} + \dfrac{\alpha_{er}}{g'_{er}} \right) + t'_{sr}\, a'\, g'_{st}\, l^{-1}\, \alpha_{er}}{t_{er} + t_{sr}\, a\, g_{st}\, l^{-1}\, g_{er}} \qquad (12)$$

Using this equation, the impact on separation of each system parameter is easily determined.

REPORT 773

A CONCEPT OF COORDINATION AND PROTECTION CONTOURS FOR USE IN THE COORDINATION OF MOBILE EARTH STATIONS *

(Question 32/8)

(1978)

1. Introduction

Reports 382 and 448 provide analytical methods for use in the coordination of fixed-satellite service earth stations and fixed service (terrestrial) stations. The use of these methods allow the fixed-satellite and fixed services to operate in the same frequency band without mutual interference. The concepts and interference calculations in Reports 382 and 448 can be used to determine whether stations in the mobile-satellite and fixed services can operate in the same frequency band without mutual interference.

This Report discusses the concept of the use of coordination contours in identifying potential mutual interference situations between mobile earth stations and terrestrial stations. If it is desired to operate both the mobile earth station and a terrestrial station within the coordination contour, detailed interference calculations are required in order to assess the probability of mutual interference.

The detailed interference calculations result in distances, referred to as protection distances, which indicate where the mobile earth station can operate without risking mutual interference. A technique is presented for graphically illustrating the protection distances.

2. Coordination contours

Coordination contours are calculated for worst case conditions, (i.e., those leading to the largest, most conservative contour). This requires careful consideration of the mobile earth station antenna radiation pattern, interference criteria, other sources of interference, and propagation mechanisms. The calculation of the maximum permissible levels of interference, minimum permissible basic transmission losses, and coordination distances may be performed in a manner similar to that of Reports 382 and 448 **.

2.1 *Coordination contour construction*

Figure 1 shows an example of a coordination contour constructed around a mobile earth station service area. The coordination distances, the locus of which forms the coordination contour, are calculated in an incremental fashion around the perimeter of the mobile earth station service area. The coordination contour which results will be equivalent to a union of contours constructed for a mobile earth station located at any specific point within the service area.

The coordination contour calculations are performed for a mobile earth station intended to access a particular geostationary satellite; thus, the mobile earth station antenna main beam direction is uniquely determined for any possible mobile earth station location. If access to another satellite is desired, a new coordination contour must be calculated using the associated antenna gain-azimuthal relationship. The main beam path through Zone "A" of Fig. 1 will be approximately parallel, if the area of desired mobile earth station operation is suitably small. Furthermore, it can be observed that Zone "C" will grow larger, and Zone "B" will grow smaller, as the required mobile earth station elevation angle increases.

The propagation mechanisms involved in the operation of an airborne mobile earth station differ from those considered in Reports 382 and 448. Reports 715, 238 and Recommendation 528 provide the necessary propagation data for airborne considerations.

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* The material contained in this Report is preliminary and has been drawn up by Study Group 8 only, without the benefit of consultation with Study Groups 4 and 9. The attention of Study Groups 4 and 9 should be drawn to this Report.

** These calculations must be performed for both cases of (1) receiving terrestrial stations (mobile earth station transmitting) and (2) the receiving mobile earth station (transmitting terrestrial stations) to afford protection from interference to either service.

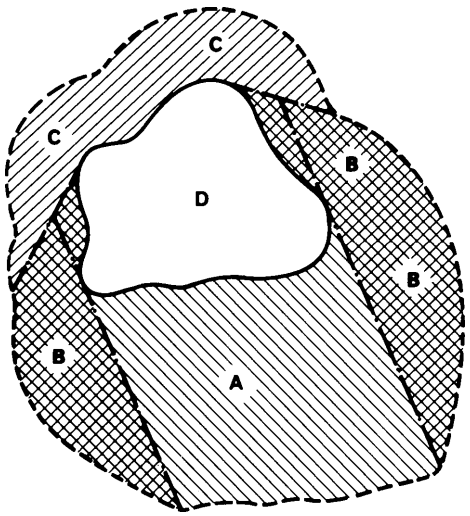


FIGURE 1 — *Coordination contour around a mobile earth station service area*

Zone A: area transversed by earth station main beam paths in azimuths towards the satellite

Zone B: area where the mobile earth station antenna gains will be less than the main beam gain and greater than the backlobe gain

Zone C: area where backlobe earth station antenna gain (commonly −10 dBi) will be used

Zone D: mobile earth station service area

– – – – –: coordination contour

3. Protection contours

Protection contours may be constructed around the terrestrial station(s) located within the coordination contour of a mobile earth station as shown in Fig. 2. A protection contour is the locus of the protection distances, which are the distances from a terrestrial station beyond which a mobile earth station can operate without causing or experiencing more than a permissible level of interference. Equations for calculating protection distances should account for frequency dependent rejection, propagation considerations, other transmitters which may contribute to the interference environment, and other factors which could affect the protection distances.

The protection contours are only applicable for access to the particular geostationary satellite considered for the coordination contour. Since frequency dependent rejection is incorporated in the calculations, a set of protection contours will normally only apply to a certain mobile earth station carrier frequency. However, the protection contours within a certain coordination contour may apply to several mobile earth station carrier frequencies if all carrier frequencies are considered and the protection distances of each terrestrial station reflect the worst case condition (e.g., the mobile earth station carrier frequency closest to that of the terrestrial station is used for the individual protection contours).

It can be seen that in many cases the protection contours will be small even though the mobile earth station and terrestrial station share the same frequency band. Figure 2 shows that the protection contour need not necessarily be calculated for all azimuths, (i.e., open contour) since only azimuths directed towards the desired area of mobile earth station operation are of concern. However, all azimuths from a terrestrial station located within the desired area of mobile earth station operation must be considered.

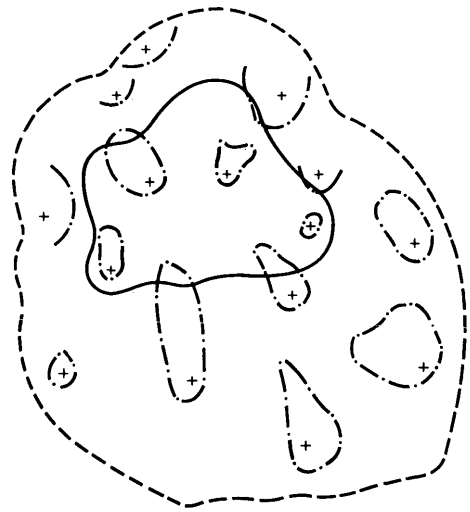


FIGURE 2 — *Protection contours around terrestrial (fixed) stations*

_ _ _ _ _ Coordination contour

—·—·—·— Protection contour

\+ Terrestrial (fixed) station

——— Service area boundary

4. Conclusions

The calculation of protection contours and coordination contours could be extremely complex, particularly where the density of terrestrial stations is high, and would require the use of computer techniques.

The establishment of coordination contours provides a method for identifying potential interference situations. It should be noted that the methods in this Report are applicable to the frequency bands from 1 GHz to 40 GHz as in Reports 382 and 448. The calculation of coordination contours associated with airborne mobile earth station operation requires special consideration. Some consideration of this problem is set out in Annex I.

When a terrestrial station lies within the coordination contour of a mobile earth station, the protection contours specify the protection distances to be observed. Additionally, frequency planning for the mobile earth station may take place prior to calculating protection contours, in order to select the optimum mobile earth station operating frequencies, which in turn will yield the smallest protection contours.

The methods described herein will not preclude the expansion of the fixed service, since the contours can be recalculated to afford protection to new fixed stations. Clearly, the burden of calculation and coordination lies with the mobile-satellite service.

BIBLIOGRAPHY

MORAN, W. M., WINKLER, C. and GAMBLE, W. [1976] An automated procedure for predicting potential electromagnetic interference between space and terrestrial systems within the coordination areas in the bands between 7.25 and 8.4 GHz. Office of Telecommunications Report 76-100, United States Department of Commerce (NTIS PB-261229).

NG, H. J. [1977] Technical considerations of small fixed, mobile, and transportable satellite systems. Office of Telecommunications Report 77-115, United States Department of Commerce. (NTIS PB-266600).

CCIR Documents

[1974-78]: 8/344, 8/346, 8/349, 8/351 (USA).

ANNEX I

AIRBORNE MOBILE EARTH STATION COORDINATION AND PROTECTION CONTOURS

1. The airborne mobile earth station is capable of operation on the ground as well as throughout its flight path. While on the ground, the coordination and protection contours can be calculated as described in the text of this Report.

The concepts of coordination distance and interference calculations as described in Reports 382 and 448 need not be greatly altered for application to airborne earth station operation. The basic transmission loss model in Report 238 must be used. The coordination distances can be computed for the aircraft at a specific location and altitude. These distances are then used to define an area on either side of the proposed flight path, within which coordination is required. The distances on either side of the aircraft flight path must be recalculated periodically along the path to account for the change in earth station antenna pointing angle. In order to account for potential interference situations during take off and landing, a series of contours will have to be generated for a sequence of altitudes in the vicinity of airports.

Two other areas require special treatment:

- the earth station antenna pattern will not necessarily be described by the reference radiation patterns of Report 391, and

- the rain scatter mode of propagation may not be applicable to the high altitude aircraft.

All terrestrial stations identified as being located within the coordination contour must be considered, using more detailed calculations. If the detailed calculations (protection contours) require that the aircraft alter its flight path, the coordination contour around the new flight path must be constructed.

In order to determine the extent of the potential interference problems, an extensive test programme was conducted in the United States. One of the objectives of this programme was to determine the dynamic characteristics of the received interference level due in part to aircraft motion through the multi-lobed pattern of the terrestrial radio-relay system antenna.

2. Measurements

An airborne mobile earth station was flown for a total of 80 hours over pre-planned flight paths in the vicinity of five different point-to-point microwave systems (Table I). Interference power was measured continuously at the antenna output terminals of the microwave stations. The distribution of interference power versus time is plotted in Fig. 3. The abscissa is expressed as 1 minute mean power levels (dBW) at the antenna terminals of the terrestrial system. The ordinate is the amount of time during a flight that a given level on the abscissa was exceeded. Given allowances for variations in flight path configurations, i.e., not all worst case, and allowing an arbitrary rate of encounter (number of flights over a site), the interference power distribution over a longer period can be determined. Curve A of Fig. 4 presents the interference power density distribution over a 1 month period for three flights per day over a site with an airborne mobile earth station power of 1 kW.

Also plotted on Fig. 4 (Curve B) are the permissible interference power density levels of Report 382. This level is based upon the interference levels of Recommendation 357 as well as the equipment characteristics given in Report 382. Curve C on Fig. 4 is also based on Recommendation 357; however, the equipment characteristics are those of current FDM-FM radio-relay stations. Curve D is also based on Recommendation 357. This curve represents systems whose interference criteria and/or critical mission requirements are such that additional protection is required. The particular equipment characteristics used to generate Curve D are those of a wideband FM system transmitting radar video signals.

TABLE I – *Test site characteristics*

Site	Terrain	Transmission type	Fixed or mobile	Fade margin (dB)	Antenna
Site 1	Desert	Television	F	20 to 50	Dish (beam horizontal)
		High speed data	M		Dish (beam elevated)
Site 2	Average	FDM-FM (600 ch CCIR)	F	40	Dish
Site 3	Coastal	Radar RML-4	F	20	Periscope
		FDM-FM data RML-6	F	40	Midpath reflector

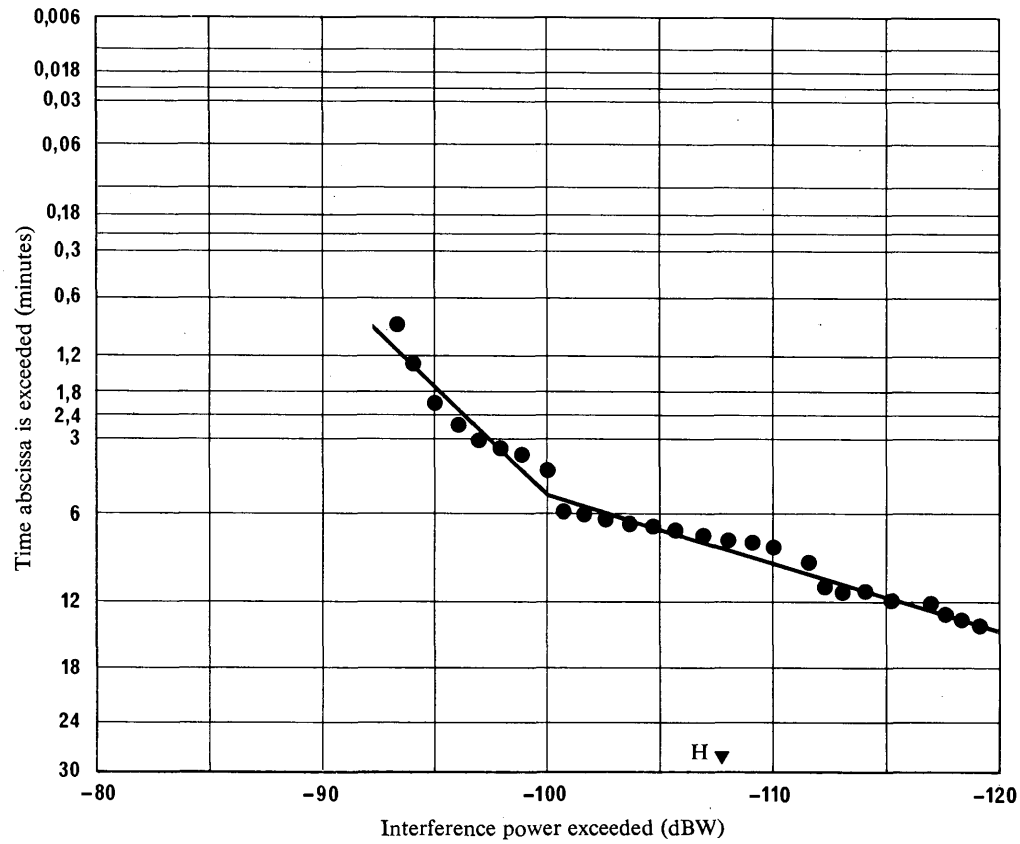


FIGURE 3 — *Distribution of measured interference power (Worst-case 1 minute mean) for an airborne mobile earth station with radiated power of 1 kW*

H: 1 hour mean

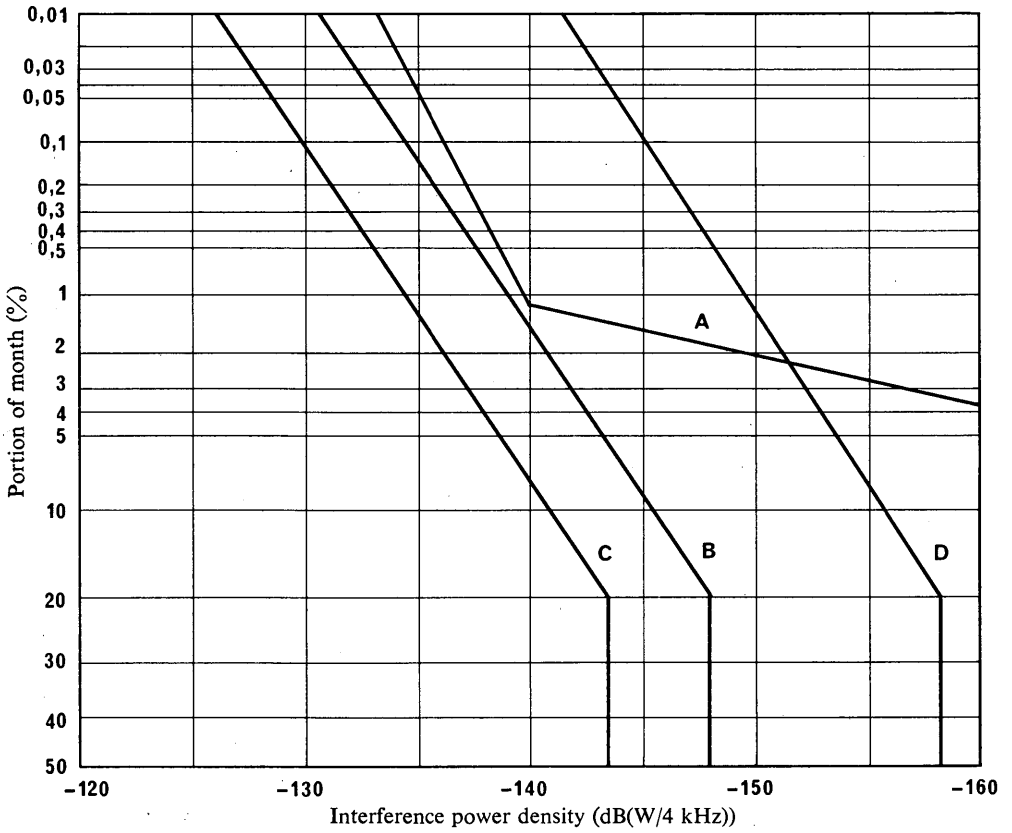


FIGURE 4 — *Comparison of expected interference power density distribution (1 minute mean) with permissible interference power density levels for three different criteria*

Curves A: expected interference power density distribution (1 minute mean)

B: permissible interference power density levels using equipment characteristics specified in Report 382

C: permissible interference power density levels using current equipment characteristics

D: permissible interference power density levels for broadband analogue terrestrial systems

3. Summary

Figure 4 shows that the extent to which airborne mobile earth stations and systems of the fixed service may share frequencies is dependent upon the operational requirements, quality, and type of service provided by the terrestrial systems.

In many cases, coordination between the airborne earth stations and terrestrial stations could be accomplished through an examination of the system performance characteristics of systems of the fixed service.

Figure 4 shows that there are systems requiring additional protection which must be provided by additional coordination through the generation of protection contours as described in the body of this Report. For such systems, these protection contours might cover a large area and thus the use of airborne earth stations could be difficult if not impossible in such areas.

SECTION 8H: AERONAUTICAL MOBILE SERVICE, AERONAUTICAL MOBILE-SATELLITE SERVICE AND RELATED SUBJECTS

Recommendations and Reports

RECOMMENDATION 441-1

SIGNAL-TO-INTERFERENCE RATIOS AND MINIMUM FIELD STRENGTHS REQUIRED IN THE AERONAUTICAL MOBILE (R) SERVICE ABOVE 30 MHz

(Question 1/8)

(1966-1982)

The CCIR,

CONSIDERING

(a) that the World Administrative Radio Conference, Geneva, 1979, in Recommendation No. 64, invited the CCIR to continue its study of signal-to-noise ratios and minimum field strengths;

(b) that there are partial data relating to interference protection ratios and minimum field strengths required in certain documents of the ITU;

(c) that the International Civil Aviation Organization (ICAO) has adopted standards and recommended practices for the best use of VHF frequencies and the aeronautical service and the avoidance of harmful interference,

UNANIMOUSLY RECOMMENDS

that the provisions made by the ICAO should be considered as adequate for the planning and protection of Aeronautical Mobile (R) Service frequencies above 30 MHz; the provisions are contained in Annex 10, Volume 1, Part II, § 4.1.5, to the Convention on International Civil Aviation.

REPORT 926 *

FACTORS THAT SHOULD BE CONSIDERED WHEN ESTABLISHING PROTECTION CRITERIA FOR AERONAUTICAL SAFETY SERVICES

(Question 62/8 and Study Programme 21A/8)

(1982)

1. Introduction

For the purposes of this Report, "electromagnetic noise" or "noise" is defined as all electromagnetic energy from both intentional and unintentional radiators, except from a desired signal for a specific system of interest.

Existing and proposed protection criteria, sometimes referred to as "maximum permissible interfering signals", "maximum permitted interfering field strengths", or "noise limits", are often stated in the following manner:

N μV/m at 30 m for the frequency band 108 to 112 MHz

This type of statement may be insufficient in itself as it fails to consider a number of pertinent factors, some of which will be identified in § 2.

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* The Director, CCIR, is requested to bring this Report to the attention of the International Civil Aviation Organization (ICAO) and the International Electrotechnical Commission (IEC), and Study Group 1.

2. Specific factors

2.1 The conditions for the field strength measurement of the interfering signal should be stated. Failure to specify the conditions for field strength measurements, such as the receiver bandwidth (e.g., 10 kHz, 100 kHz or 1 MHz, 3 dB, 6 dB, or effective impulse bandwidth), receiver detector characteristics, calibration techniques, type of antenna used, polarization and antenna height above ground, leaves the method of measurement open to interpretation; this could then result in erroneous conclusions and inability to compare with data obtained by other experts. Dissimilar characteristics of the many different types and makes of field strength meters widely used also prevent a direct comparison of data obtained by different experts. A recent survey of field strength meters used for the measurement of noise produced by power lines has shown a less than satisfactory correlation in some frequency bands.

2.2 Systematic and random measurement errors result from errors in instruments and their calibrating sources and from errors in test set-up and measurement procedures. Error problems also exist because electromagnetic interference problems are often probabilistic, rather than deterministic, in nature. The method of error analysis in the development of parameter limits becomes important where regulatory aspects must be considered.

2.3 Interference prediction techniques, noise models and communication system models are currently under development or refinement by a number of administrations, educational institutes, and industrial research organizations. A non-exhaustive list of noise measurement parameters and techniques used includes:

- average voltage (V_{avg}),
- root-mean-square voltage (V_{rms}),
- quasi-peak voltage (V_{qp}) (both CISPR and ANSI),
- peak voltage (V_p),
- impulsiveness ratio $V_d = 20 \log (V_{rms}/V_{avg})$,
- effective antenna noise factor (F_a),
- mean noise power (P_n),
- amplitude probability distribution (APD),
- noise amplitude distribution (NAD),
- average crossing rate (ACR).

Some of these parameters are useful principally as means of detecting the presence or absence of unwanted emissions from some area or object. Ideally, the emission or radiation parameter or measurement technique selected should correlate directly to how the noise is degrading the performance of a radio communication or navigation system.

2.4 A single protection ratio covering all noise sources within a fixed frequency band may not be realistic. Such a protection ratio may fail to take into account the characteristics of the noise (that is, whether the noise is continuous wave, Gaussian, random or impulsive). Noise sources may have to be broken down into groups such as power lines, industrial-scientific-medical apparatus and ignition systems, with protection ratios defined for each of these groups.

2.5 The time characteristic of the noise is an important consideration. Depending on the grade of service required, a noise source that exceeds the protection criterion only 0.5% of the time may have to be treated differently from a noise source that exceeds this criterion 95% of the time.

2.6 Protection criteria may be required to take into account variations in radio communication and navigation equipment performance. One approach may include the determination of susceptibility of radio communication and navigation systems to man-made noise and the establishment of parameters and levels that describe the noise that these systems can withstand without intolerable degradation in performance.

2.7 Where the sources of noise are manufactured in quantity, control of their radio frequency emission limits may be effected by statistical sampling tests (e.g. CISPR test method). Such tests may only give guarantees that a certain proportion of the manufactured items conform to a stated limit. A detailed examination of the statistical sampling test may therefore be necessary to establish whether the statistical guarantees are compatible with the particular protection required. Annex I gives such an examination of the CISPR statistical method.

2.8 For the protection of aeronautical safety services it may not be realistic to formulate protection ratios based on field strength measurements made at or near ground level when, in the real world, aircraft fly over noise sources. An examination of available literature has shown that in some cases, noise levels at a given distance measured laterally from a noise source are lower than those measured at the same distance above the noise source. In addition, aircraft in flight could be subjected to noise from many possible sources; although the noise produced by one source may be of little consequence, the effect of many such sources could be significant. It should be noted that aircraft in flight regularly experience unwanted signals that are not detected by ground monitoring.

Considering the mobility of aircraft and the large viewing area to which aircraft are exposed, together with the variability and uncertainty of assessing and controlling harmful interference to safety of life services, the impracticability becomes obvious of accurately accounting for all of the signal characteristics of the unwanted signal sources that aircraft may encounter. Nevertheless, these factors must be accommodated if the high reliability of civil air transport is to be maintained. One method of accommodating these factors is by including a compensation in the form of a margin added to the protection ratios.

2.9 The protection of radio communication and navigation systems might be better achieved by a combination of protection criteria in a prescribed critical area around a site. This would assist in land-use planning around airports and around off-airport radio communication and navigation facilities. In regard to protection of aeronautical radiocommunication and/or navigation facilities at airports, attention is drawn to the coordination procedure presented in Report 929.

3. Conclusion

In order to safeguard aeronautical safety of life services, it is essential to establish adequate protection criteria from unwanted signals. However, the formal derivation of such protection criteria is considerably complicated by factors which introduce significant uncertainties. Some of these factors have been presented in this Report.

ANNEX I

AN EXAMINATION OF THE CISPR (INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE) STATISTICAL TEST PROCEDURES FROM THE VIEWPOINT OF INTERFERENCE PROTECTION TO THE AERONAUTICAL SERVICES

1. Introduction

1.1 The CISPR has published much valuable work on the methods of measurement of radio frequency energy and corresponding recommended limits of radiation from various types of equipment which may cause interference [CISPR, 1975a and b; 1976 and 1977]. Some of these equipments are manufactured in quantity, and in these cases the CISPR recommends a statistical sampling method for checking compliance with corresponding RF radiation limits. This Annex is a first assessment, in statistical terms, of the potential interference to aeronautical services from equipments whose RF radiation limits are measured by the CISPR statistical method.

2. The CISPR statistical testing method

2.1 Full details of the method recommended and a comprehensive exposition of its mathematical derivation are available in CISPR publication 13 [CISPR, 1975b]. In essence two choices are offered: either taking measurements from a relatively small sample of the production run or from one item only.

In the latter case the value measured must be at least 2 dB more stringent than the CISPR recommended limit for the particular equipment type. Only if the item does not meet this more stringent limit is the sampling method obligatory.

In the sampling method, compliance with the CISPR limits is judged by measuring the variable interference attribute (e.g. field strength radiated in a particular band) in accordance with the test procedure and measuring instrument characteristics laid down (e.g. typically using a quasi-peak detector on a test site).

Depending on the sample size, and with the set of results to hand, (typically 5 to 12 values of field strength expressed in dB relative to 1 μV/m), the mean and the standard deviation of these values is calculated. These values are, in turn, substituted in the formula:

$$\overline{X} + KS \leq L$$

where

$\overline{X}$: arithmetic mean of measured levels from the items;

S : standard deviation of the same measured levels;

L: appropriate CISPR permissible limit; and

K: factor depending on the sample size (n);

K: given in Table I:

TABLE I

Sample size (n)	3	4	5	6	7	8	9	10	11	12
K	2.04	1.69	1.52	1.42	1.35	1.30	1.27	1.24	1.21	1.20

2.2 If the sample results satisfy the relationship given above then the whole production of the item is classified as "meeting the CISPR limit".

2.3 Clearly, the factor K is very important and the CISPR references show that K is based on the assumption that the production output exhibits a normal distribution and that the "consumer's risk" is that there shall be an 80% confidence that 80% of all the production items shall be below the CISPR limit.

From the viewpoint of the degree of protection offered to an interfered with service it is important to note that the consumer risk, in turn, means that 20% of the items must be assumed to radiate RF energy greater than the CISPR limit – how many and how much greater will depend on the parameters of the particular distribution in practice, which depends on the manufacturer's design decisions. For example purposes two hypothetical cases are given below in Table II:

TABLE II

CISPR limit = L dB	Case a)	Case b)
Production line mean value (manufacturer's choice) (dB)	$(L-5)$	$(L-1)$
Corresponding standard deviation required to meet CISPR "80%/80%" consumers's risk exactly (dB)	5.95	1.2
Resulting approximate radiation level exceeded by 5% of items (dB)	$(L+5)$	$(L+1)$
Resulting approximate radiation level exceeded by 0.5% of items (dB)	$(L+10)$	$(L+2)$

Thus, in both of these hypothetical cases the production line would "meet the CISPR limit" and yet a wide variation of higher radiation levels would exist.

2.4 Further examination also shows that the factor K is very sensitive to changes in the percentage values chosen for the consumer's risk. Table III gives examples of the variation of K for more stringent risk values. It is evident that such changes might have important economic repercussions for the manufacturers of the items being tested.

TABLE III — *CISPR statistical sampling method*

(Source: Biometrika Tables for Statisticians)

K (80%/80%)	2.04	1.69	1.52	1.42	1.35	1.30	1.27	1.24	1.21	1.20
K (95%/95%)	—	5.13	4.19	3.70	3.39	3.18	3.02	2.83	—	—
K (99.5%/99.5%)	—	17.25	11.77	9.37	8.01	7.15	6.56	6.12	—	—

3. Statistical requirements of the aeronautical services

It is clearly difficult to assess the probability of actual harmful interference occurring in practice from a knowledge of the statistical probabilities of certain manufactured items exceeding certain radiation limits.

However it is pertinent to note that some aeronautical services are designed to meet statistical targets which are extremely stringent and several orders higher than the values implied by a consumer's risk of "80%/80%" (see Report 927). There is therefore some justifiable doubt whether the current CISPR consumer's risk is acceptable in these cases and further study is required on this matter.

4. Specific areas of concern

To assist in further study some particular points of concern have been identified, as follows:

4.1 The use of a statistical test method based on a small number of samples and a simple statement of "consumer's risk" does not provide strong practical control over the range of actual radiation limits likely to be met in practice, possibly in significant quantities. As § 2 shows, a significant proportion of equipments manufactured to meet a CISPR limit could exceed the actual limit value by quite a high margin.

In practice, commercial pressures may lead a manufacturer to adopt a tighter specification than the CISPR consumers' risk indicates, in order to give the manufacturer better assurance that his products will be accepted when tested by sampling. However this possible factor cannot easily be taken into account by the aeronautical community.

4.2 The ability, as an alternative within the CISPR test method, to assess compliance with the CISPR limit by testing only one item from a production series – albeit to a 2 dB more stringent level – offers statistically no guarantee of protection to any consumer at any level of consumer's risk. There would therefore seem to be a strong need for the justification of this alternative to be re-examined.

4.3 There would appear to be a basic need for justified aviation protection requirements to be stated as precisely and fully as possible, including statistical criteria where applicable.

4.4 The most difficult area of investigation would seem to be the *practical* conversion of limits established by § 4.3 above into corresponding limits for the testing of production items by the CISPR sampling test method.

4.5 Following on from § 4.1 above it would seem to be important to examine if it would be possible to limit the actual use of equipment which emits radiation above certain levels (higher than the relevant CISPR limit). It should be noted here that in view of the stringent statistical requirements referred to in § 3 the prime aim may need to be to prevent interference from occurring rather than to seek to identify and remove the interference after it has occurred.

5. Conclusions

This Annex indicates some specific areas of concern in relation to the use of the CISPR statistical test method in cases where very high protection from interference is required, e.g. aeronautical radionavigation.

REFERENCES

CISPR [1975a and 1976] Publications 11 and 11A. Limits and methods of measurement of radio interference characteristics of industrial, scientific and medical radio-frequency equipment (excluding surgical diathermy apparatus).

CISPR [1975b] Publication 13. Limits and methods of measurement of radio interference characteristics of sound and television receivers.

CISPR [1977] Publication 16. CISPR specification for radio interference measuring apparatus and measurement methods.

REPORT 927 *

GENERAL CONSIDERATIONS RELATIVE TO HARMFUL INTERFERENCE FROM THE VIEWPOINT OF THE AERONAUTICAL MOBILE SERVICES

(Questions 1/8 and 62/8 and
Study Programme 21A/8)

(1982)

1. Background

The ITU definition of "harmful interference" is contained in Radio Regulation No. 163 as follows:

"Harmful Interference: interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with these Regulations."

The term "harmful interference" is not generally definable in a precise quantitative manner and therefore an assessment of harmful interference must be construed in the light of the nature of the operations and the safety environment. This leads directly to the conclusion that the determination of quantitative threshold levels of harmful interference for the various aeronautical mobile radiocommunication services requires the examination of the appropriate safety criteria.

2. Aviation safety criteria

A prime basis of aviation safety is the *statistical* assessment of performance criteria and failure rates. The following statistical "failure rates" may have been used as criteria by some civil aviation administrations in the international aeronautical community:

- the air traffic systems which ensure separation between aircraft flying *en route* are designed to reduce the chances of mid-air collisions to a level no greater than 2 in 10^8; and
- the certification of aircraft automatic landing equipment by many civil aviation administrations requires that the control system in each aircraft be demonstrated statistically to have a failure rate no greater than 1 in 10^7 landings.

In light of the above, it is evident that for aeronautical mobile radiocommunication services, the required interference protection ratios will be very much influenced by the statistical characteristics of the particular service. For instance, a radionavigation aid providing the sole guidance to an aircraft during automatic landing requires very high protection from harmful interference. Indeed, it would follow that the statistical probability of harmful interference in such cases needs to be more stringent than 1 in 10^7. In comparison it may be possible to identify other aeronautical systems which do not require this same degree of protection. § 5 of this Report examines this aspect further for the various aeronautical systems.

The above points lead directly to the thought that whilst it may be possible to quantify a signal level for unwanted harmful interference which would permit safe operation of a particular type of radio service, the promulgation of such a level without an associated description of its assumed nature and statistical variation could be of little value and could have serious implications. This would apply particularly to those environments where there are a multitude of potential interfering sources, possibly of more than one type, and where the aggregate harmful interferences at any particular point, therefore, could be expected to vary with time.

3. Aeronautical and non-aeronautical sources of harmful interference

An important aspect of the study of harmful interference is the determination of whether or not the criteria for harmful interference from non-aeronautical sources has, or should have, any relationship with the technical planning criteria established in the aeronautical services for co-channel and adjacent channel assignments. Frequency assignment planning criteria adopted internationally within the aeronautical services are based on practical considerations which take into account the operational usage of the particular service. In addition, the planning criteria are based, reasonably enough, on the premise that mutual cooperation and internationally agreed aviation standards and procedures are used by everyone involved. It is a point of fact that the 146 Contracting States of ICAO are under certain obligations relative to the adoption of aeronautical standards, recommended practices, and procedures, as set forth in Article 38 of the Convention on International Civil Aviation (Chicago, 1944). Pursuant to these obligations, there is a highly developed international information and

* The Director, CCIR, is requested to bring this Report to the attention of ICAO and IEC, and Study Groups 10 and 11.

registration service which ensures that all aviation facilities and their "frequency protected" service volumes are formally promulgated and available on charts in accordance with Annex 15 to the Convention on International Civil Aviation; and appropriate information from this service becomes part of aircraft flight deck documentation. Thus, in respect of all technical protection criteria adopted in the international civil aviation community against "aeronautical-to-aeronautical" harmful interference, there is comprehensive and significant additional protection provided through the organizational structure of international civil aviation, with ICAO at its focal point.

The additional protection indicated in the above paragraph is largely non-existent for non-aeronautical sources of harmful interference to aviation, some of which are only partially regulated by the ITU. Consequently, there is not necessarily an inherent relationship between aeronautical protection criteria and those criteria which may be appropriate to safety services for application to non-aeronautical sources of harmful interference. Each potential non-aeronautical source of harmful interference requires individual consideration in this respect.

The following external sources of man-made emissions and radiations are known to have caused harmful interference to aeronautical services:

- broadcasting, LF/MF AM and VHF FM;
- cable distribution systems;
- power line distribution systems;
- industrial, medical, and scientific equipment;
- local oscillator emission from domestic electronic equipment.

It should be observed that some of the above are not under the direct purview of the ITU, and therefore, it will be necessary to effect coordination between ITU, ICAO, and other concerned organizations. However, this need not influence CCIR involvement in the investigation of adequate protection criteria.

4. Shared and exclusive allocations

Regardless of the original intentions of radio spectrum planners, there can be no doubt that the pressure on the radio spectrum for additional allocations to the various radiocommunication services can result in aeronautical protection criteria being effectively regarded as non-aeronautical sharing criteria. As a consequence, a safety service must take considerable precautions to ensure that any radio service sharing the same radio band is constrained sufficiently to leave an adequate margin under all likely circumstances so that the aggregate harmful interference never exceeds the required protection criteria.

The constraints of weight, size, and power consumption placed upon airborne equipment have resulted in relatively low powered transmitters and sensitive receivers, which is consistent with general ITU guidance for efficient and effective use of the radio spectrum. Nonetheless, the above set of conditions does cause difficulties for the aeronautical community when interference problems arise. For instance, the wanted signal at the edge of a VHF radiotelephony service volume must be no less than 70 μV/m to meet ICAO standards and recommended practices. For an aircraft flying at, say, 300 m above the ground, such a wanted field strength could be equalled by an unwanted signal source on the ground with an e.i.r.p. of only 16 μW. Many interfering sources can easily produce more than 16 μW. Article 8 of the Radio Regulations, the Table of Frequency allocations, contains examples of sharing arrangements between aeronautical and other radiocommunication services, some of which have resulted in harmful interference problems. In such cases, the need to maintain the necessary aeronautical protection criteria has led to a less efficient use of the radio spectrum for aeronautical purposes than could be achievable with separate exclusive allocations. Thus caution should be exercised before considering any sharing involving the aeronautical radiocommunication services.

Annex II details some of the items to be evaluated when considering the specific problem of sharing with the aeronautical flight test telemetry stations. In this regard Annex II responds to WARC-79 Resolution No. 505.

5. Aeronautical radiocommunication systems

Precise details of aeronautical radiocommunication systems are contained in Annex 10 to the Convention on International Civil Aviation. However brief synopses are given below:

5.1 *HF and VHF digital data interchange and radiotelephony*

Air/ground digital data interchange or radiotelephony constitute a direct link between an aircraft in flight and aeronautical stations on the ground. The number of aircraft flying simultaneously in any given airspace and the multiplicity of air routes flown, result in a complex set of rules and procedures to ensure the safety of air operations. While it is true that interference to air/ground radiotelephony communications is relatively easier to detect, in as much as the pilot can hear it and is normally less likely to be misled, than in the case of interference

to digital data interchange or to a radionavigation aid, such interference may nonetheless have serious consequences, particularly for aircraft contacting approach control of an airport while flying at positions where the ground clearance is of the order of a few hundred feet. Thus, regardless of adherence to precise phraseology and to other standard operational procedures, cases have arisen where even a slight interference to a single phrase has resulted in catastrophic consequences.

The conversion of the above factors into quantitative protection ratio criteria is a difficult task. On the one hand there is general acceptance of the view that some minimum interference to voice communications could normally be accepted, but on the other hand, it needs to be recognized that under difficult operational circumstances, errors that would normally be accepted can assume great significance, and under these circumstances an interference-free service can be vital. Therefore, a general protection ratio for HF and VHF radiotelephony should be developed such that the aggregate interference on any channel should not significantly add to the basic noise level of the safety service receivers used for air-ground communications. Following the same general idea, a protection ratio should be developed for HF and VHF digital data interchange.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.2 *Instrument landing system (ILS) – (VHF and UHF)*

The ILS consists of a "localizer" (VHF) providing lateral guidance for aircraft to the airport runway, a "glide-path" (UHF) providing the line of descent in the vertical plane, and one, two, or three "marker beacons" providing the aircraft with height and distance checks at known points from the runway threshold. One or more "locators" or other supplementary approach aids such as VOR may be used in conjunction with the ILS to assist in guiding aircraft to the "on-course" radio beams. Each of the above components of the ILS performs a different function and hence it can be seen that these components do not provide any form of redundancy for each other.

In the approach and landing phase of flight, when the aircraft is manœuvring in close proximity to the ground, it is essential that harmful interference to any of the radio aids in use during this phase of flight be kept at an extremely low level of probability of occurrence. It is particularly relevant to note in this regard that the use of automatic landing systems which utilize ILS guidance signals, is the normal operating procedure for modern large aircraft, regardless of weather conditions. It should be noted that the very high level of protection against harmful interference required to support such operations is only needed within fairly constrained volumes of airspace around the ILS installations, e.g., around aerodromes. This factor may be helpful when considering the practical issues involved in protection against harmful interference.

Because of its critical nature considerable investigation of interference to ILS has occurred and Annex I gives more detailed information and derives protection ratios required under specified circumstances.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.3 *VHF omnidirectional radio range (VOR)*

The VOR system consists of a ground-based beacon radiating an omnidirectional signal providing directional guidance in the horizontal plane in such a manner that the airborne system provides an accurate indication of the compass bearing from the aircraft to the beacon. The system also provides identification signals and allows for voice transmission. The beacon transmits modulated CW signals continuously and can serve simultaneously any number of suitably fitted aircraft. The service volume of some *en route* facilities can extend beyond 300 km.

Most VOR installations provide *en route* service, often in association with DME equipment (see § 5.4). In addition, certain low-power VOR installations are used as holding or approach aids in the vicinity of aerodromes. With respect to the bearing function, interference to VOR can manifest itself as false bearing information to the aircrew and/or automatic flight control system, and this interference would directly impinge on the safety of the flight. The degree of the effect of the interference would depend on its type, strength and duration. In the low-powered VOR cases, even lower levels of interference could be critical to the operation of the aircraft, but fortunately, the service volumes concerned are relatively small.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.4 *Distance measuring equipment (DME) – (UHF)*

The DME system utilizes coded digital transmissions providing the aircraft with accurate slant-range distance measurements to ground-based beacon positions. The beacon transmits in response to an interrogation from an aircraft, and although the coded interrogation and reply offers a measure of interference protection, the system can become saturated when many aircraft are within range of a beacon. Under these circumstances, interference could be detrimental to safety.

DMEs are most often used in conjunction with VORs to provide international short-range navigational facilities. However, some DMEs are used in association with ILS, and consequently these circumstances may require special provisions to ensure adequate protection against harmful interference.

It is also important to recognize that DME frequency assignments are always "paired" by international agreement with either a VOR or ILS frequency. Consequently, frequency protection considerations need to be satisfied simultaneously on both of the paired frequencies.

5.5 *Radars*

Radar for aeronautical purposes can take many forms with widely varying characteristics and operational usages, e.g., long-range air traffic surveillance, radar altimeters, secondary surveillance radar, very short-range aerodrome surface surveillance, airborne weather detection and navigational assistance.

It is not possible to provide a universal interference assessment to cover these variations, and therefore, each case needs to be considered separately. However, it is worthy of note that regardless of the transmission characteristics employed, it is quite normal for the reception requirements of a radar system to be, necessarily, highly sensitive and thus capable of detecting low levels of unwanted signals.

Sophisticated processing techniques can sometimes be used to alleviate some types of interference, but these techniques are not practicable universally, and under some operational conditions are not acceptable.

5.6 *Non-directional beacons (NDB) – (LF/MF)*

Although at first sight NDBs may appear similar to VORs in concept, there are significant practical differences in their usage. NDBs are more widely implemented than VORs and are frequently used by smaller aircraft, which are, in some cases, not equipped to utilize VORs. NDBs are also frequently used to guide and establish aircraft on flight paths that enable them to acquire more accurate VHF aids (VOR, ILS, etc.) as part of the approach procedure. In addition, the airborne equipment used in association with NDBs is simpler in concept and is less able to cope with interference than more sophisticated airborne equipment. The basic simplicity of the system makes it less able to distinguish between true NDB signals and unwanted emissions near or within the channel passband. In particular, an "overhead beacon" indication on the aircraft flight deck can be falsely provided under certain conditions by interfering signals.

Interference to NDBs is an important issue in the aviation world, because many NDBs are in radio bands which are shared with other users in some parts of the world, and in addition, these bands are sometimes highly congested. Protection criteria against harmful interference must take these facts into consideration.

6. Conclusions

The design of an aeronautical radiocommunication system takes into consideration appropriate levels of integrity and reliability in order to achieve, in a statistical sense, the overall objectives of the total operational system. Criteria to protect aeronautical systems from non-aeronautical sources of interference must be adequate to meet these objectives.

ANNEX I

SOME INTERFERENCE MECHANISMS RELATED TO THE INSTRUMENT LANDING SYSTEM

1. Introduction

Detailed examination of some of the interference mechanisms that could cause harmful interference to the ILS localizer signals has taken place in several aeronautical administrations, and this Annex summarizes some aspects of these examinations. The examinations have encompassed both theoretical studies and laboratory tests, and the degree of correlation has been extremely high.

2. Harmful interference threshold

The criteria establishing the threshold of harmful interference for ILS have been taken from Annex 10 of the Convention on International Civil Aviation (Chicago, 1944).

From the aircraft localizer receiver point of view, interference to a localizer signal will appear as an aberration of the localizer course line (in ICAO terminology, an aberration of the localizer course line is called a "bend"), and will contribute to the total allowable receiver output error. The allowable receiver output error ultimately is a function of the permissible lateral displacement of the aircraft from the localizer course line, and this displacement is dependent on the operational category of the ILS to be fulfilled and the approach speed of the aircraft. Annex 10 contains standards, recommended practices, and guidance material which are necessary for the attainment of the objectives of the instrument landing system, and this material indicates that in order to restrict aircraft deviations to less than 5 m lateral displacement from the localizer course line for Categories II and III, the aberration of the localizer course line must not be greater than 5 μA. Attention is drawn to the fact that there are other contributors to course aberrations which need to be considered in the attainment of the objectives of the instrument landing system, but these will not be discussed in this Annex. However, these other criteria must be taken into account in order to define satisfactorily protection ratio(s) for ILS. This matter also is addressed in § 4 of Report 929 in light of compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz.

For the purpose of this Annex, interference mechanisms producing an aberration of the localizer course line of 5 μA or greater have been defined to be harmful interference; however, in view of the factors mentioned above this value is subject to amendment.

3. Interference mechanisms

Several modes of interference were established by mathematical analysis and confirmed by laboratory tests using several airborne equipments conforming to ICAO standards.

3.1 *Interference from an unmodulated carrier signal*

Type I – If an unwanted signal is within the ILS localizer receiver RF passband and beats with the localizer carrier signal to produce a difference frequency within about 0.5 Hz of the 90 Hz or 150 Hz ILS sideband signals, the unwanted RF signal field strength must be as low as 46 dB below the localizer carrier level in order not to exceed the 5 μA limit.

Type II – If an unwanted signal is within the ILS localizer receiver RF passband and beats with the localizer carrier signal to produce a difference frequency within about 10 Hz of the 90 Hz and 150 Hz ILS sideband signals, but not within the Type I tolerance, above, the unwanted RF signal field strength must be as low as 26 dB below the localizer carrier level in order not to exceed the 5 μA limit.

Type III – If any unwanted signal is within the ILS localizer receiver RF passband with sufficient strength, there will be a progressive "capturing" of the receiver. In this case the unwanted RF signal field strength must be as low as 7 dB below the localizer carrier level in order not to exceed the 5 μA limit. Very strong signals, in the order of 10 mV or stronger, will cause receiver blocking and cross-modulation.

3.2 *Interference from a modulated carrier signal*

Type IV – If an unwanted signal contains a carrier with 20% amplitude modulation by a 90 Hz or 150 Hz component, the unwanted RF signal field strength must be as low as 13 dB below the localizer carrier level in order not to exceed the 5 μA limit. Such an unwanted signal, for example, can arise from the use of 3-phase rectification of a 50 Hz alternating current power supply.

4. Conversion to absolute signal-in-space field strength

Annex 10 to the Convention on International Civil Aviation specifies several signal conditions within the service volume of an ILS, and one of the relevant conditions near the runway threshold is that for facility performance category III localizers, the minimum field strength along the localizer course line shall not be less than 200 μV/m. Using this value of minimum field strength, the maximum absolute signal-in-space field strength of an unwanted signal near the runway threshold can be determined as shown in Table I:

TABLE I

Type of interference	Unwanted/wanted ratio (dB)	Field strength of unwanted signal near the runway threshold (μV/m)
I	−46	1
II	−26	10
III	− 7	90
IV	−13	45

5. Other factors

The preceding paragraphs have developed unwanted/wanted ratios with respect to harmful interference to the ILS localizer, but it is noted that certain operational and statistical factors could affect the practical application of these ratios. For instance, the effects caused by the Doppler shift of frequencies due to the speed of an aircraft, or the probability that an unwanted signal will meet the precise characteristics necessary to cause the particular interference mechanism, have not been taken into consideration, and attention is drawn to the fact that these, as well as other, factors need further study. However, it is relevant to note that the field strengths of unwanted signals shown in § 4, above, in the worst case could imply very severe emission limits on potential interfering sources near aerodrome aircraft approach paths. For example, an emission causing the Type I mechanism would need to be limited to a maximum e.i.r.p. of −95 dBW (3.3 μV/m, measured 30 m from the source), in order not to cause harmful interference to an aircraft flying at an altitude of 100 m above the source.

6. Summary and conclusion

The ILS localizer system is susceptible to certain types of interference. Further study is required to determine whether the practical effect of the described mechanisms are in any way alleviated by operational and probabilistic factors.

It is important to note that this Annex examines only those interference mechanisms where the unwanted signal appears within the RF passband of the ILS localizer receiver. There are other known mechanisms, such as intermodulation in ILS localizer receivers, which do not fall within this category. Studies relative to these mechanisms are continuing.

ANNEX II

CONSIDERATIONS FOR SHARING BETWEEN
AERONAUTICAL FLIGHT TEST TELEMETRY STATIONS
AND SPACE AND EARTH STATIONS IN THE
FREQUENCY BANDS 1435 TO 1535 MHz AND 2310 TO 2390 MHz

1. Introduction

Frequencies for aeronautical flight test telemetry are considered in the mobile service.

Flight test telemetry is important to its users because:

- it frequently is necessary for the safety of the pilot and the aircraft;
- it provides the only good record of the nature of a failure that may have caused an accident, thus, it contributes to the safety of future flights;
- it is a daily tool in evaluating the progress of each flight and the performance of the vehicle being tested. The costs of each flight hour may be measured in tens of thousands of dollars. Telemetry significantly reduces the number of hours required to develop the aircraft, or a sub-system of the aircraft.

Because flight test telemetry is vital to its users, telemetry flights should operate without harmful interference. To achieve this end, all telemetry operations are scheduled. The formality of the scheduling varies from area to area of the country, based upon the number of licensees and the number of aircraft each licensee operates. Each geographical area has its own scheduling procedure. For example, in southern California where several telemetry systems share the band on a co-channel and adjacent-channel basis, the scheduling procedure is highly formalized and hour-by-hour schedules are developed to preclude interference. In other areas where a single licensee is isolated either geographically or by frequency separation, the scheduling becomes an informal procedure within the licensee's own organization. However, even under these ideal conditions there are more test vehicles than frequencies and the scheduling must be done.

Technically important aspects about a flight test telemetry station are:

- The bandwidth requirements of each flight and each aircraft installation often vary widely from one another. Emissions from 500KF9 to 3M00F9 are typical. Occasionally emissions of 10M0F9 are authorized.
- Typically, most aircraft or small missiles will have only one telemetry transmitter, however, some aircraft and many spacecraft will be equiped with two or more transmitters that typically have independent transmissions.
- Power output from each transmitter typically ranges between 1 and 65 W into antenna systems that are intended to be omnidirectional, but which in reality contain deep nulls.
- Communication paths frequently require that reliable signals from minimums in the aircraft antenna pattern be received at 150 to 200 km. Frequently, the antenna on aircraft and spacecraft will be well engineered to provide good null-free operation in the most optimum directions for normal flight profiles; however, installations in one-of-a-kind test programs may not be so engineered. In either case, abnormal attitudes encountered in roll, pitch, and yaw manœuvres may present the nulls in the antenna patterns of the aircraft or spacecraft to the ground antenna. In the event of aircraft or spacecraft failure, this abnormal condition may occur at the most important period of the flight for those engineers and technicians who must analyse the data from the test.

Thus, the signal strength analysis that is considered in this paper will necessarily be the worst-case situation. Interference from any other source during this worst-case situation could cause the data to be totally lost or useless.

Telemetry ground antenna installations vary widely. Simple installations in geographically isolated areas may use some stacked vertical omnidirectional arrays for reception of signals from aircraft flying near the receiver site. Usually they will employ some directive antenna arrays which may be simple horns with about 30° beam-widths, but more often become sophisticated parabolic or helical arrays with automatic tracking. A substantial portion of these sites employ two-axes tracking systems and parabolic reflectors from 2.5 to 10 m in diameter. Larger parabolas become excessively massive for the tracking systems to maintain the test aircraft in the beam under manœuvring conditions, and beam distortion because of the excessive gravitational forces on the dishes becomes a problem. The use of low-noise receivers is not uncommon. Frequently, the systems are located on mountain tops and track below the local horizon as well as above it, with capabilities of tracking through the

zenith if necessary. Typically, such antennas are calibrated by using quiet space as a reference. The atmospheric noise floor of -204 dB (W/Hz) measured at 290 K, a 4 kHz bandwidth (commonly used as a CCIR reference bandwidth for such purposes), a zero dB signal-to-noise ratio in the receiver IF section, a receiver noise figure of 4 dB referred to the input, and a (9.144 m) (30 foot) diameter antenna (such an antenna has a measured gain of 38 dBi) and an effective aperture correction of 25 dB (corresponding to an approximate frequency of 1.5 GHz) combine to give an atmospheric noise flux level of -177 dB (W/(m^2 · 1 kHz)). The system can be expected to operate with an FM capture ratio of 16 dB to 19 dB. Therefore, the system will be designed to operate at flux densities of -161 dB (W/(m^2 · 4 kHz)). Extraneous co-channel signals, such as from a satellite must be at lower levels than -177 dB (W/(m^2 · 4 kHz)) at the Earth's surface assuming the satellite can be in the field of view of the receiving telemetry ground station.

Telemetry standards commonly specify that spurious emissions from telemetry transmitters must be at levels lower in amplitude than -55 dB (W/3 kHz). These are conducted or equivalent radiated standards. Converting them to the basis of CCIR practice, this becomes approximately -54 dB (W/(m^2 · 4 kHz)) if an isotropic radiator is assumed. Although this value exceeds the receiver noise floor for the receiving system, above, by 123 dB, usually the geographic separation of the transmitter from the receiver will be sufficient to guarantee that the receiver will not be adversely effected. The tracking antenna will provide about 33 dB of the required protection, and, since the interfering source can be expected to be on a flight ramp or runway that may be screened by a hill or removed from the runway by more than 5 km, the required protection will be supplied. This spurious emission standard cannot be used as a level of signal that would assure non-interference to the telemetry system.

Table II shows the range of parameters that can reasonably be used by a transmitter for flight test telemetry:

TABLE II

	Range of values to be expected in telemetry systems	
	Low values	High values
Gain, transmitting antenna (airborne) (dBi)	1.7	6
e.i.r.p. (dBW)	-3	18
Gain, receiving antenna (dBi)	2	41
Aircraft transmitter. Beamwidth (1)	360° × 30°	30° × 30°
Ground station. Beamwidth (2)	360° × 30°	1.4° × 1.4°

(1) The beamwidth for airborne antenna is referenced to the aircraft vertical axis.
(2) The beamwidth of the ground station is referenced to a tracking antenna (high gain) direction of maximum gain. It is usually a receiving antenna, but may be a transmitting antenna.

The current state of the development of aircraft and spacecraft continues to require frequencies for flight testing of both manned and unmanned vehicles. The altitudes of flights for such vehicles vary from a few metres to several hundred kilometres. The range varies from a few hundred metres to earth orbit. The primary distinction between the mobile service used for flight test and the other services where aeronautical or space telemetry equipment is used is the purpose of the transmission. The mobile service is used when the testing of the vehicle is the primary purpose of the flight. Other services are indicated when the primary purpose of the flight is research (atmospheric or space exploration, earth exploration) or operation of the vehicle. The equipment used for telemetering in the different services is often similar or even the same equipment. In cases where continuous data collection is required for an extended period of time, the use is generally not considered to be flight test and therefore, the frequency assignment is made in a band reserved for operational use and frequencies subject to daily or hourly scheduling are not authorized.

2. Interference from a satellite to telemetry ground stations

In Section 1 above, the flux density at the receiver site that will generate harmful interference has been considered. The figure, -177 dB (W/(m^2 · 1 kHz)), will cause the telemetry system to lose range and receiving margin required when the aircraft is at the edge of a test range, which may be at some great distance or some high altitude. The position of the tracking antenna, whether looking at satellite or looking away from it, could introduce a 33 dB or greater signal variation, based upon whether the main lobe or the minor lobes of the antenna encounter a satellite signal.

2.1 *Geostationary satellites:* Geostationary satellites may be out of view of any particular telemetry receiving site. However, depending upon their longitudinal position, the satellites can appear at local elevation angles up to 39° above the horizon at 48° latitude or up to 55° at 30° latitude. Such angles are clearly possible for telemetry currently in heavy use. It can be shown that even a 30° horn connected to a low noise receiver could suffer interference problems from satellites that have been proposed to operate in these bands. Thus, the -177 dB (W/(m^2 · 4 kHz)) can be assumed to be the level of co-channel receiver-site flux that could be allowed for non-interference of unscheduled satellite transmissions. Since this level is that of quiet space, it is not likely that it would be satisfactory to the satellite system designer.

2.2 *Satellites with near-earth orbits:* Satellites that are in non-geostationary orbit will progressively traverse the view of every telemetry ground receiving facility. The only way to achieve protection from co-channel operations for the telemetry ground station is by scheduling all transmissions from the aircraft and from the satellite. This requirement would make some data memory systems (for example, tape recorders and computer memories) and some control or command systems for the control of the transmitter on board the satellite necessary. Scheduling would have to be controlled through the same mechanisms/organizations that are used by the mobile service (aeronautical flight test telemetry), with the added complication that the satellite may be seen from several scheduling areas simultaneously. This added requirement could require significant and costly changes to the scheduling organizations and the equipment used for communication between the present areas. Earth exploration satellites authorized in current regulations in the 1525-1535 MHz band, if implemented, would present this kind of scheduling problem in Region 2, although both the mobile service and earth exploration services are secondary to space operations (telemetry) allocations.

2.3 *Satellites with near-earth equatorial orbits:* Such satellites would present the same problem as geostationary satellites, in that telemetry ground receiving sites would be likely to have their primary antenna lobe intercept the satellite position. This would occur several times a day. Their low altitude compared to the geostationary satellite may hide them from some high latitude receiving sites, but it would also provide less free-space attenuation of their signal. They would, therefore, interfere with telemetry at low latitudes and scheduling and a control system would also be required for co-channel sharing.

3. Interference to satellite receivers due to transmissions from airborne telemetry stations

Generally, the characteristics of satellite-borne receivers and the satellite orbits are not defined well enough to specify in this document the expected degradation in the presence of telemetry signals. Abnormal attitudes of aircraft during stalls, spin tests, or other specific manœuvres will require consideration at the receiving satellite of the primary beam of the aircraft antenna pattern. Therefore, the e.i.r.p. of the signal from the aircraft could be as great as 24 dBW. The signal could be concentrated at a discrete frequency for short periods of time, but would more usually be spread as an FM signal with modulation index between 1 and 5 and a bandwidth of between 650 kHz and 9 MHz. The altitude of the telemetry transmitter could be from the Earth's surface up to orbital altitudes. The combination of transmitter, antenna, and modulation scheme may be designed for one-time usage and depend heavily on equipment availability. It may not be the optimum design from a communications engineer's viewpoint. It can be seen that unless coordination and scheduling are accepted by all licensees of the band, interference is highly probable.

4. Interference to satellite receivers due to transmission from telemetry ground stations

Telemetry ground station antennas are usually considered to be for receiving purposes only. There is no regulation to this effect, and up link telemetry signals have limited use. The limited bandwidth of the available spectrum, in addition to causing crowding and the demand for more spectrum, is causing innovative systems to be placed upon the aircraft. These systems require data up links to control the data collection process or telemetry up links to combine data on the ground with data collected on-board the airborne vehicle. These systems provide significantly higher field strengths at the satellite than the airborne telemetry systems discussed above. There are not presently enough such systems to give typical power outputs, but the signal strength that is required will be

larger for the aircraft receiving station than the ground receiving station. This is because the airborne receiver will not contain the cryogenic elements required for low-noise receivers, and temperature variation, vibration aboard the aircraft, etc., will rule out many techniques used to produce low-noise receivers.

5. Conclusions

In the 2.3 GHz band, the allocated terrestrial services can share by using the different frequency management techniques already discussed, i.e. scheduling, different frequency assignments, terrain shielding, etc. On the other hand, satellite operations in the same bands with the mobile service will encounter mutual interference with co-channel telemetry users unless all licensees accept a requirement for scheduling. The introduction of continuously transmitting satellites into this scheduling environment would place a severe hardship on telemetry licensees by enlarging the interference areas. The operating organization and communications systems required to establish a single scheduling organization would be costly to all licensees. Practical considerations suggest that such a scheduling procedure would be very difficult to achieve.

Co-channel frequency assignments for the satellite and mobile services are only practical when satellites do not transmit in the space viewed by telemetry receiving sites or when a single scheduling organization can be employed to prevent harmful simultaneous use of a frequency.

Consequential to the frequency allocations of the WARC-79, it is recognized that the maritime mobile-satellite service will require the band 1530-1535 MHz by 1990 and that the space operation service may require the band 1525-1530 MHz after January 1, 1982.

REPORT 769

AIR/GROUND DIGITAL SELECTIVE-CALLING SYSTEMS FOR AERONAUTICAL MOBILE SERVICES

(Question 46/8)

(1978)

1. Introduction

1.1 Question 46/8 seeks to study the optimum methods of coding and modulation for air-ground-air data transmission for all purposes. Selective calling can be considered as a sub-set of such data transmission usage.

1.2 There is a stated requirement for selective calling on the voice communications channels served by the aeronautical mobile service. The reason for this requirement is that under conditions imposed by the International Civil Aviation Organization (ICAO) aircraft are required to maintain a permanent watch with the aeronautical stations responsible for their control.

1.3 The ICAO Standards for this ground/air alerting are contained in Annex 10 to the Chicago Convention on Civil Aviation, Part 1, Chapter 4.8 and Attachment D, Chapter 3.

1.4 In order to exercise control over their aircraft, aircraft operating agencies are permitted to conduct communications with aircraft in the aeronautical mobile service bands in addition to those communications exercised by Air Traffic Control (ATC) authorities. The categories of communications permitted to the aircraft operating agencies are defined in § 5.1.8.6 of Volume II of Annex 10 to the Chicago Convention and are in general classed as flight regularity messages. However, other types of messages permitted by Annex 10 may also be carried, as necessary, on channels reserved for what is now commonly termed "operational control".

1.5 There is a requirement to exercise operational control in all bands allocated to the aeronautical mobile service.

1.6 Since the early 1960s, some aircraft operating agencies have been conducting operational control on frequencies licensed to them by their respective State authorities within the aeronautical mobile (R) service between 2 and 22 MHz. These operators use the ICAO Selcal Standards (as in § 1.3 above) for alerting aircraft from the ground; however, a number of operational factors have led to the design of other selective calling systems for the ground-to-air direction.

2. Operational requirements for air/ground selective calling

2.1 Aeronautical stations serving the operational control function in the HF band have to mount guard on several different frequencies and have experienced significant traffic growth since their implementation.

2.2 Further, due to the lack of frequencies currently available for this type of service, numerous separate operations are conducted on common frequencies so that any single aeronautical station has to identify if each and every call occurring on the channel is directed to it or some other aeronautical station.

2.3 Due to the random access nature of this form of communication, an operator may be handling a call on one frequency or taking action on a call when further calls appear on that or other frequencies from other aircraft. There is thus a requirement to queue calls from aircraft for subsequent attention.

2.4 Some of the developed stations serve more than one airline and more than one function within an airline. Hence, the operation has developed a requirement for selective addressing not only of the aeronautical station but also of the individual aircraft operator and a specified function (flight operations/engineering/commercial, etc.) within the designated aircraft operator organization.

2.5 Some of the developed stations have automated their antenna management; special coding in the aircraft interrogation is used to indicate the sector/direction from which the call is being made in order to direct high gain antennas in the required direction.

2.6 Logging of messages/contacts is also a mandatory requirement for the operation of some stations.

2.7 Thus, watchkeeping as well as technical and administrative services are served by the implementation of air-to-ground selective calling. In addition, such a facility serves to ease the strain on operators at both the aeronautical station and in the aircraft, thus providing a more efficient service which enables better use to be made of the RF spectrum.

3. Types of air/ground selective calling

3.1 A number of different types of air/ground selective calling have been developed to meet specific operational requirements.

3.2 Technical descriptions of a system are given in Annex I to this Report.

3.3 Attention is also drawn to Recommendation 493.

4. Technical aspects of air/ground selective calling systems

These will need to be developed by CCIR to complete the Report.

ANNEX I

AN AIR-TO-GROUND SELECTIVE CALLING SYSTEM: AEROCALL

1. Introduction

The Aerocall System is an air-to-ground selective calling system whose purpose is to automatically warn a given ground station that a radio contact is requested by a distant aircraft. One feature of the system is that it still permits the establishment of a radio link when marginal propagation conditions prevail and prevents the detection of a voice call from taking place.

2. Summary of constraints

2.1 *Transmission channel characteristics*

Speech channel of commercial HF link.

2.2 *Transmission equipment characteristics*

Airborne, SSB/HF transmitter.

2.3 *Constraints*

2.3.1 Channel constraints: the transmission channel is an HF radio link where slow (Raleigh) and fast selective fading is encountered, as well as multipath propagation and noise.

2.3.2 Equipment constraints: the transmitter is an airborne type, which can only radiate a limited amount of HF power through an inefficient antenna, and which creates a frequency shift (because of synthetizer precision and Doppler shift).

3. Principle of the chosen solution

3.1 *Noise reduction technique*

To reduce the effect of noise, the required bandwidth has been chosen to be as small as possible according to minimum requirements.

3.2 *Fading effect reduction technique*

To reduce the effect of fading, frequency shift of a subcarrier is used. This technique was chosen according to the good results obtained with an earlier HF calling system.

3.3 *Frequency shift reduction technique*

To reduce the frequency shift induced by transmission, a pilot tone of sufficient stability is used.

3.4 *Selected transmission and coding technique*

The transmission scheme selected consists of the simultaneous transmission of a pilot tone and of a frequency shift keyed sub-carrier.

The coded message which keys the frequency shifts consists of a very simple acquisition code (tone encoded) followed by a telegraph type message whose constitution permits time diversity decoding.

4. Described technique implementation

4.1 *Voice frequency signal characteristics*

- pilot tone 550 Hz
- FSK carrier frequency 2030 Hz
- frequency shift ± 90 Hz.

4.2 *Call message format*

The call sequence is composed of two different periods: acquisition and validation. These two periods are transmitted, successively, three times.

Acquisition is realized by shifting the carrier frequency of the 2030 Hz sub-carrier, at a 55 Hz rate, during 600 ms. Validation is realized by setting the sub-carrier frequency at its higher value during 500 ms.

4.3 *Telegraph message format*

The telegraph message of variable length, consists of the transmission of four identical frames. Each frame consists of:

- a sync character (1 START, 7 ZEROS, 1 STOP),
- between 1 and 10 alphanumerical characters (1 START, 6 USEFUL BITS, 1 STOP).

Transmission is isochronous and at a speed of 75 bauds.

4.4 *Received signal processing*

4.4.1 *Induced frequency shift removal; demodulation*

The received signal is routed through two separate band-pass filters. These filters, centred at 550 and 2030 Hz restitute separately the pilot and the FSK tone. The bandwidth associated with both filters allows an induced frequency shift of ± 100 Hz to be correctly taken into account. The pilot and the FSK tone intermodulate in a non-linear device, generating sum and difference frequencies.

The difference frequency, which is always centred on 1480 Hz, carries the significant modulation. This difference frequency is band-pass filtered, amplified, and squared. A classical discriminator type demodulator restitutes the original modulation.

4.4.2 *Acquisition recognition*

The demodulated signal is filtered by a very sharp, 55 Hz central frequency, band-pass filter. When a 55 Hz frequency is applied to the input of this filter, a 300 ms delay is necessary for the output amplitude to build up and reach a given threshold, which is considered as a probability of acquisition.

The equivalent noise bandwidth has an approximate value of 3 Hz.

Acquisition will be decoded and taken into account only if, 700 ms later, a correct fixed polarity replaces the 55 Hz modulation.

4.4.3 *Telegraph message decoding*

When acquisition is recognized, the telegraph decoder is activated.

Analysis of the various received frames is displayed for later or immediate use of the most probable received message.

4.5 *Operation*

The electrical nature of the acquisition and alphanumeric signals is well adapted to the use of those signals to trigger a buzzer, light a bulb, display figures and letter in order to inform a human operator that his station is being called. Moreover, when the data contain an antenna code number, an appropriate antenna can be switched into use which, while not improving the actual signal-to-noise ratio, does reduce the effects of garbling picked up by an omnidirectional antenna.

5. Final results

"Aerocall" has enabled the French Administration to offer a better service to its national airline.

The system has improved the efficiency of ground services: in fact, the rate of successfully decoded calls increased when good propagation conditions prevailed, but it is evident too that the number of decoded calls greatly increases during bad propagation conditions (e.g. for a 30% link probability, 50% of the calls are properly decoded).

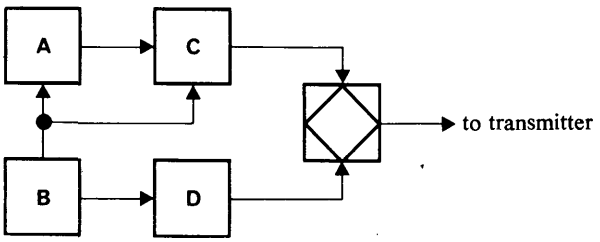


FIGURE 1 — *Encoder*

A: digital encoder
B: time base
C: frequency modulator
D: pilot tone generator

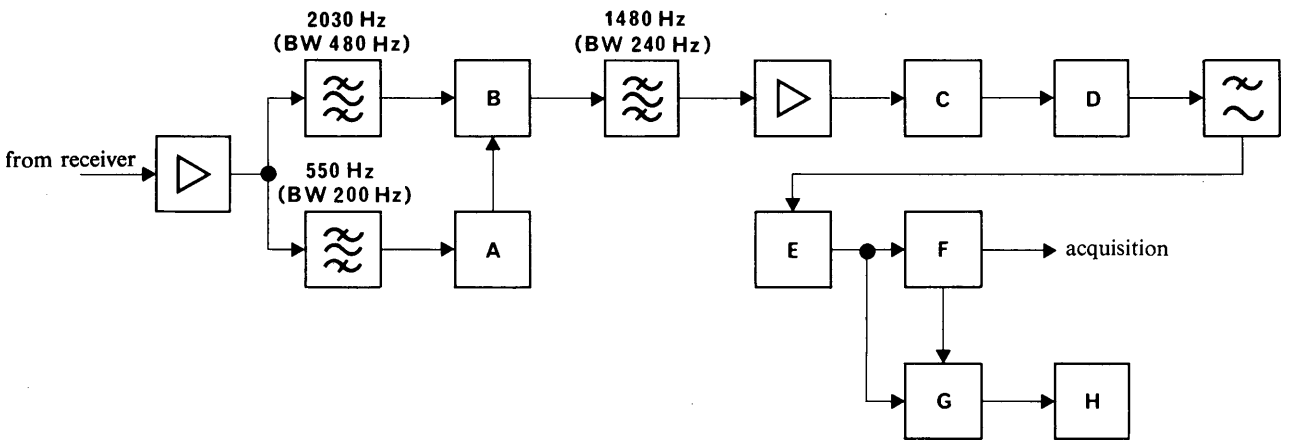


FIGURE 2 — *Decoder*

A: limiter
B: product modulator
C: limiter
D: discriminator
E: shaper
F: acquisition decoder
G: time diversity decoder
H: display
BW: bandwidth at 3 dB

REPORT 928

OPTIMUM CODING AND MODULATION METHOD(S) FOR THE TRANSMISSION OF DIGITAL DATA BETWEEN TERRESTRIAL STATIONS AND AIRCRAFT STATIONS OPERATING IN THE AERONAUTICAL MOBILE (R) SERVICE

(Question 46/8)

(1982)

1. Introduction

This Report describes the principal features of a bi-directional digital signalling and data communication system which may be employed in the aeronautical mobile (R) service high frequency (HF) bands allocated to that service.

2. Discussion

For many years the unique requirements of aviation have been partially satisfied by the International Civil Aviation Organization (ICAO) selective calling (SELCAL) system. SELCAL, however, provides signalling only in the ground-to-air direction and does not offer the capability for digital data transfer. The recent introduction within several States of more effective and economical management of aircraft movements dictate transition to a modern, standardized bi-directional system. Hence, the international aviation community has conducted experiments to define an improved system to fulfil the requirements of this new operating philosophy. The experiments and experience have indicated more effective use of the available radio frequency spectrum and enhanced integrity of the vital aeronautical safety service can be achieved.

3. Operational requirements

New operational requirements are evolving in many countries to conserve energy and human resources. A system designed to fulfil these needs must satisfy the following basic requirements:

- provide bi-directional signalling for the management of voice communications;
- support more timely and reliable communications and data processing for the automatic exchange of aircraft operating information;
- ensure continued capability to use SELCAL during introduction of the new system.

4. System functions

The specific functions required in a system to meet the foregoing operational requirements include the following:

- signalling for air-to-ground voice communications management;
- signalling for ground-to-air voice communications management;
- identification and location of aircraft initiating air-to-ground signalling;
- identification of the ground station the aircrew wishes to contact;
- identification by the ground station of the SELCAL code or digital address of the aircraft;
- identification of a specific party on the ground with which the crew member desires to converse;
- ground system establishment of a voice communication channel for transmitting safety and regularity of flight communications between the aircrew and desired party on the ground without operator intervention. This capability also may be used for ground-to-air originated voice requests;
- acquire and transmit data from the aircraft on-board system, or sub-system, using digital data transmission without aircrew intervention;
- rapidly transmit information and data related to aircraft safety or other emergency information, without continuous aircrew interaction;
- process digital data transmitted from aircraft for expeditious resolution of action required (if any) by the ground system or personnel;
- notify aircraft, as required, of unusual circumstances which may affect the aircraft safety well in advance of the impending condition(s).

5. System description

Fundamental characteristics of this digital system are as follows:

- voice and calling signals share a common frequency;
- asynchronous data transmission; and,
- two possible methods of modulation and encoding are described in § 7 below.

6. Message elements

6.1 *Signalling messages*

Signalling messages typically include combinations of the following elements:

- identity of the ground station processing the call;
- identity of the called party;
- SELCAL code of the calling aircraft (air-to-ground only);
- flight number, airframe registration mark or other prescribed identification of the called or calling aircraft;
- geographical position of the calling aircraft (air-to-ground only).

6.2 *Digital data messages*

Digital data messages typically include the following elements:

- flight number, airframe registration mark or other prescribed identification of the aircraft originating or receiving the message;
- a technical acknowledgement of the last message received by the transmitting terminal indicating whether or not the message was received free of errors;
- coded identification of content and/or desired handling of the text of the message being transmitted;
- message text.

7. Modulation and encoding

Two possible methods of modulating and encoding digital data for transmission in the aeronautical mobile (R) service have reached various stages of development; however, further study of this subject is needed. The two candidate methods of modulating and encoding digital data are as follows:

7.1 One system uses audio frequency shift keying signals to modulate the RF carrier. The tones are interleaved. Theoretical studies conducted by the Radio Technical Commission for Aeronautics, with participation of other international experts, have shown a four-tone system as described below in Table I to be an appropriate method of modulation for HF signalling and data.

TABLE I

	Mark		Space	
f_1	935 × × × × × × × × × × × ×			
f_2			1375 × × × × × × × × × × × ×	
f_3		1815 × × × × × × × × × × × ×		
f_4				2255 × × × × × × × × × × × ×

7.2 Another method of modulating and encoding digital data employs the four-signature coding system.

To meet both the requirements of a separate signature for the "1", "0" and to differentiate between successive bit positions, four separate signatures can be deployed as in Table II:

TABLE II

	Bit order	1	2	3	4	5	6
	Message	1	0	0	0	1	1
Signature 1	Even "1"						×
Signature 2	Odd "1"	×				×	
Signature 3	Even "0"		×		×		
Signature 4	Odd "0"			×			

It can be seen that alternate bits are separately coded and that each bit can be separately identified. If separate detectors for each of the four signatures are used some distinct advantages emerge. The advantages are as follows:

- each "1" and "0" is transmitted and detected as a signal in its own right, thus a "1" corrupted by noise will not be mistaken as an "0" because of its absence, as in the case of a single detector, which must assume an "0" unless a "1" signal is received;
- the break-up of a signal due to noise will not be mistaken as a number of separate bits of information;
- redundancy of signal can be employed, giving a higher probability of communication. Any resulting time variation due to the detection of the signature can be accommodated in the receiving equipment;
- an effective error detection facility is a feature of the coding procedure;
- simple and foolproof receiving equipment can be built, using the properties of the code to permit three-state statistical processing.

7.2.1 *Interaction of encoding and hardware*

Binary information is usually received and stored in two-state registers e.g., in core storage. A problem arises of how to deal with the residue of the previous message, either both the "1s" and the "0s" must be presented to the bi-stable or the register must be cleared to the "1" or the "0" state. In both cases, the register is biased before receiving the incoming information. Should information fail to be detected or there be a malfunction in the input equipment to the register, an error may be produced. It can be seen that the receiving register is an extension of the detecting apparatus and the argument for having separate detectors for each of the four signatures must be extended into the register itself.

By careful design of a three-state register, many of the problems of bit allocation and error detection disappear. The three-state register that is being referred to should not be confused with a tri-stable having three voltage levels. It is a three-wire system, each wire carrying a two-state signal which is either on or off.

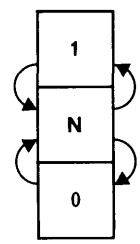


FIGURE 1

N = Nothing

The normal conditions of the bi-stable, i.e. "1" and "0", are still present but there is a third state of "nothing" or no information. The logic conditions are chosen such that the three-state can change from "nothing" to the "1" or "0" state, or it can form the "0" or "1" to the "nothing" state but there is no way in which it can change from a "1" to an "0" or from an "0" to a "1" (see Fig. 1). Input signals from the detectors are connected to those three-state devices.

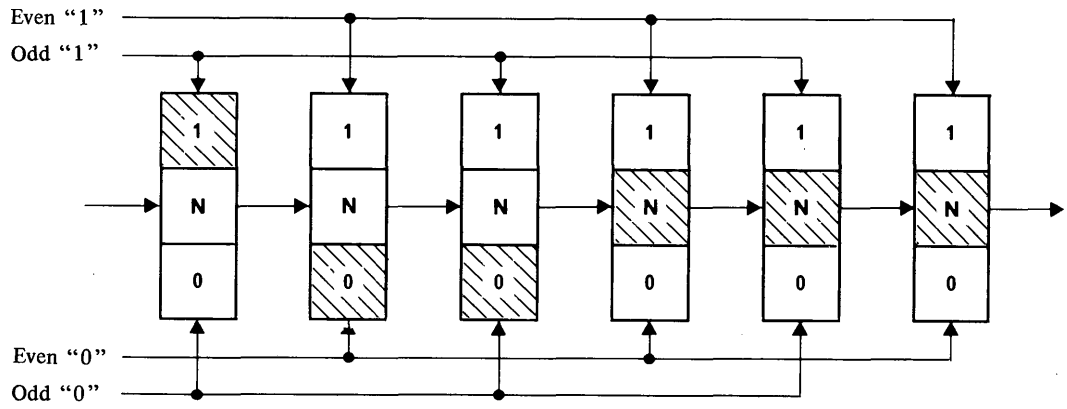


FIGURE 2

N = Nothing

It should be noted that the detector outputs are connected directly to the three-states. Each stage is connected to its predecessor so that any stage in the "nothing" condition forces the succeeding stage also into the "nothing" condition and hence cannot carry information, i.e. a "1" or an "0". Thus to clear the register of any residual information a pulse is applied to the "nothing" input of the first stage, which forces the second stage to the "nothing" condition. This signal will now propagate through the register, turning each stage to the "nothing" condition. To check that the register is cleared it is only necessary to look at the last stage to see that it is in the "nothing" state. Had there been a malfunction of any of the three-states due to component or connection failure, then "nothing" would not have propagated to the last stage and would not be detected, (see Fig. 2).

Having cleared out the previous data, the register is now ready for the reception of new data. On receiving the first bit of the message shown in Table II which is an odd "1", the first stage would be turned from the "nothing" to a "1" condition. This odd "1" signal will also try to change each of the other odd stages to the "1" condition but as the previous even stages are in the "nothing" condition no other three-state can support information. Should there be a number of separate pulses on the off "1" input line which might be caused by break-up of the signal, or two odd "1s" in succession with the even bit missing due to the detector being unable to make a decision through the noise, only one bit will be registered. Later a decision will be taken on which of these two cases applied.

Following Table II, the second piece of information to be received will be an even "0". This will be registered in the second three-state as an "0". The second three-state can support information as its predecessor is no longer in the "nothing" condition. Note, no other succeeding even three-state is able to support the incoming "0" signal.

The third piece of information to be received will be the odd "0". This will operate on the third three-state only. The signal trying to force the first three-state into the "0" state will not succeed because of the logic condition that the three-state cannot change from a "1" or an "0" or an "0" to a "1".

The even "0", which is the fourth bit of information, will act both on the second and fourth stages. As the second stage is already at "0" the input of another signal is of no concern.

7.2.2 *Error detection*

Knowing the number of bits that are being transmitted, missing bits of information can be detected by looking at the condition of the last three-state which should have been filled. Should this be in the "nothing" condition, then obviously data must be missing.

Should an odd and even signal be detected at the same time, overflow will occur. Such errors can be detected by seeing that there are n and not $n + 1$ bits (or more) in the message. In addition, if an odd "1" or an odd "0" (or an even "1" and and even "0") are detected simultaneously, the error may be detected by a gate and a bi-stable. In practice this system has been found to give a very high order of integrity.

The remaining problem to be solved is how to detect the end of the message. Since each bit is received non-synchronously, the receiving equipment would be waiting for further information when the message ends. One possible solution would be to use an over-ride timer which is reset as each incoming piece of information is detected. When the timer has run down, the input signals to the register could be gated out and the error detecting criteria applied. Such a method of detecting the end of the message would in fact restrict the use of the system. A better solution to the problem is presented later.

7.2.3 *Message characteristics*

Messages to be transmitted by such a system fall into the two following categories: messages of dependent data, and messages made up of independent components. A good example of dependent data is an air traffic control position report. This may take the form of an address (aircraft registration), latitude, longitude and height [Parker, 1967; Russell-Smith and Parker, 1969]. It is most important that the whole of this message be received correctly as an error in any part may invalidate its usefulness. For security, error detection should be applied over the entire contents of the message.

Messages consisting of independent components are typical in a teletype system where a long message can occur. When receiving such information, it is undesirable to apply error detection over the entire message as a single error would necessitate retransmission. Each character of the message must be treated individually and reliance placed on the error correction and/or redundancy existing within the printed word and sentence. It is therefore desirable that the encoding system under discussion be capable of handling the short blocks of binary information forming the characters.

7.2.4 *Reception of clear text*

Clear text is received in two separate registers, each having the same number of stages as the bits in a character, plus an overflow stage for error detection. The four information lines, odd "0", even "0" and odd "1" and even "1" are connected to both registers as in the previous discussion (see Fig. 3). Two control lines, B1 and B2 determine the register which will operate at any time and these are fed from detectors which detect two additional "inter-block" signatures.

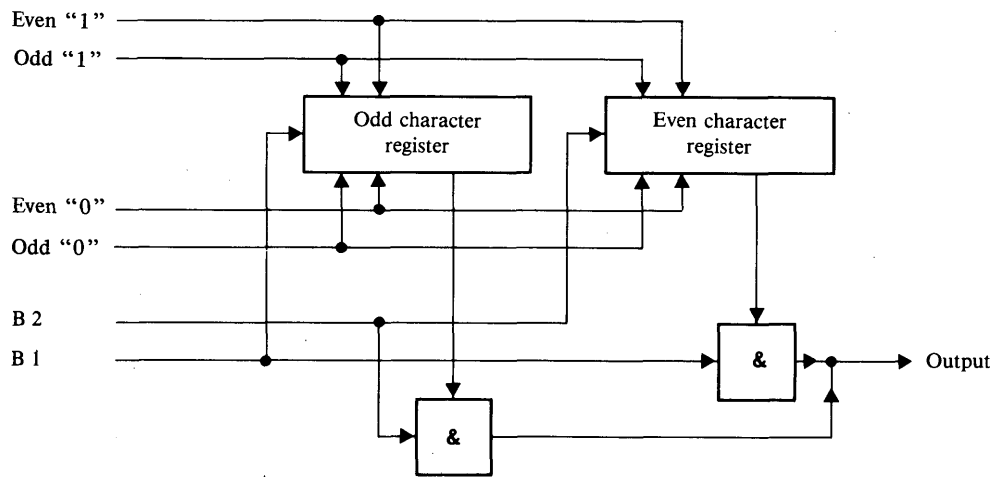


FIGURE 3

One register handles the even characters and the other the odd characters. There are now six input signals instead of four. At the beginning of the message a signal will clear the odd register to its "nothing" condition, after which, the odd and even bit information will be entered into the register. When all the data forming the first block has been completed, a signal on B2 sets the even character register to the "nothing" condition and releases the contents of the first register for error detection. When the second register (even character register) is filled, a signal applied to B1 will clear the odd register ready for further data and release the contents of the second register for error detection.

7.2.5 *Inter-block markers*

Unfortunately, the process described in § 7.2.4 increases the number of signatures required from four to six at the expense of time, and bandwidth or reliability.

There are four invalid combinations of information signatures which could generate errors. They are:

- an odd "0" immediately followed by an odd "1";
- an odd "1" immediately followed by an odd "0";
- an even "0" immediately followed by an even "1";
- an even "1" immediately followed by an even "0".

To avoid an increase in bandwidth whilst retaining the same reliability as with the four-signature system these combinations of signature can be used in place of the inter-block markers, B1 and B2, in Fig. 4. The hardware is simplified but some increase in message transmission time is incurred.

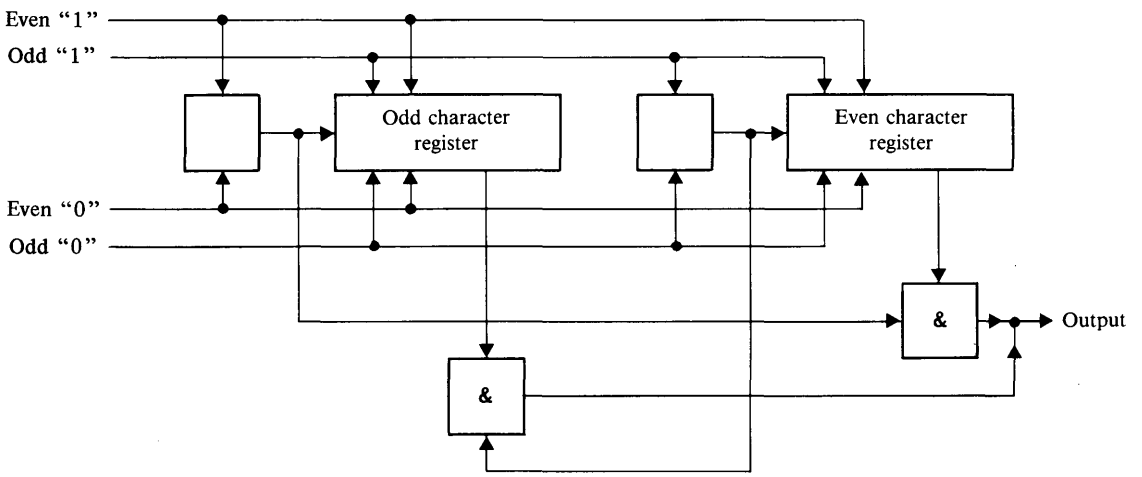


FIGURE 4

The use of four signatures for inter-block markers in this way is completely compatible with the rest of the data-encoding system. If the inter-block markers appeared within a character the error-detecting circuits would reject the character. Should information appear during the inter-block period no inter-block marker would be detected. These inter-block markers can also be used to determine the end of a message making the use of a timer unnecessary.

Using these techniques a building-block approach to digital communications is possible, each data block having an independent integrity check. A message may start with an address and format control, technical acknowledgement etc. This may be followed by a message such as a position report or clear text with error detection over the whole. Alternatively, a combination of address and dependent data blocks or clear-text with individual error-checking may be transmitted and received.

7.2.6 *Modulation methods*

For this method of coding and when using current airborne HF SSB equipment, it would be advantageous to use frequency-shift keying of a subcarrier which would then amplitude modulate the RF carrier – thus ensuring compatibility with the conventional DSB system. However, there could be advantages in the use of two-frequency "chirp" modulation (i.e. two frequencies "up" and two frequencies "down" for the four signatures) in any future developments.

8. Character encoding

Message characters may be encoded in accordance with the International Standards Organization (ISO) Alphabet No. 5, including the use of odd parity.

9. Message formats

The basic signalling message format may consist of the following elements: Prefix, Mode, Ground Address, Party Address, Airline Identification, and Suffix. The Prefix consists of the ISO Alphabet No. 5 "SOH" (Start of Header) character. The mode character contains the numeric character one, "1", which identifies the HF signalling format for ground processing. This character is used as a discriminant in voice/data signal path switching within the ground station. The ground address field contains a three-character alpha identifier of the ground station through which communications is desired. The party address field contains the two-character numeric which identifies the station with whom voice communications is desired. The ground address and party address characters are entered by air control panel action. The airline identification is derived automatically from the aircraft installation. The Prefix, Mode and Suffix characters are permanently stored in the avionics equipment. The Suffix character consists of the ISO Alphabet No. 5 control character "ETX" (End of Text). The foregoing basic message format may be summarized in Table III.

TABLE III

Element	Number of characters	Example
Prekey	1	8 bits
Prefix	2	SOH
Mode	1	1
Ground address	3	NYC
Party address	2	12
Airline identification	2	TW
Suffix	1	ETX

The foregoing basic signalling message format may be expanded by means of additional alpha/numeric character sequences. The format expansion will necessitate appropriate changes to the data entry facilities of the aircrew's control unit. The basic format and typical example of format expansion are as follows:

Basic format:

SOH	MODE	NYC Address	12 Ground Party	TW Airline Identifier	ETX

Format expanded to include provision for a ten-digit telephone number:

SOH	MODE	NYC	12	212 456 7890 Telephone Number	TW	ETX

Note. — The telephone number may be entered without the first three characters (area code); however, the field should then be filled with leading zeros.

Format expanded to include Flight Identification:

SOH	MODE	NYC	12	TW	0403 Flight Identification	ETX

Format expanded to include SELCAL Code:

SOH	MODE	NYC	12	TW	0403	EFCD SELCAL Code	ETX

Format expanded to include Flight Sector:

SOH	MODE	NYC	12	TW	0403 (Note)	EFCD	.... 6 or 12345 Sector	ETX

Note. — This numeric field must be present since it delimits and separates the two alpha fields... Contents may be zeros.

The expanded message format may be configured to individual user requirements by the use of alternating alpha/numeric data element fields. The data message format consists of the following elements: Prefix, Mode, Aircraft Address, Technical Acknowledgement, Label, Uplink Block Identifier (ground-to-air only), Start of Text, and Suffix. The Prefix consists of Prekey and the ISO Alphabet No. 5 "SOH" characters. The Mode Field contains the numeric character "2". The Aircraft Address field contains the registration mark or flight number of the aircraft (up to 7 alpha/numeric characters). The Technical Acknowledgement Field contains the ISO Alphabet No. 5 "ACK" (Acknowledgement) and "NAK" (Negative Acknowledgement) character depending upon whether or not the message being technically acknowledged was received error-free. The Label Field contains two alpha/numeric characters which are used to define the content and/or the desired handling of the information contained in the text field of the message. The Up link Block Identifier Field contains coded information which enables the aircraft sub-system to identify duplicates of messages. The start of Text Field contains the ISO Alphabet No. 5 "STX" character. The Text Field contains up to 220 characters of alpha/numeric data (the text of the message). The Suffix Field contains the ISO Alphabet No. 5 "ETX" (End of Text) character.

Note. – Conditions pertaining to patent matters in § 7.2 of this Report are on file with the CCIR (see Doc. 8/561, 1978-82).

REFERENCES

PARKER, B. D. [March, 1967] The design of an air-to-ground asynchronous digital communication system for ATC. IEE Conf. Publ. 28.

RUSSELL-SMITH, H. P. and PARKER, B. D. [May, 1969] Interaction of communications with cockpit workload and safety. AGARD/ASMP Symposium, Texas, USA.

BIBLIOGRAPHY

PARKER, B. D. [September, 1973] High integrity ATC data links. IEE International Specialist Seminar on Component Performance and System Applications of Surface Acoustic Wave Devices.

REPORT 599-1

AERONAUTICAL SATELLITE TESTS IN BAND 9 (UHF)

(Study Programme 17A/8)

(1974-1978)

1. Introduction

A portion of the 1535-1660 MHz band has been allocated to the aeronautical mobile satellite service. This band has been and is being investigated to determine the technical feasibility of system components and techniques and to characterize the radio-frequency link under various conditions. The ATS-5 and ATS-6 satellites have been utilized as signal sources during the investigations. The ATS-6 satellite, launched in the spring of 1974, has not only provided data in support of oceanic aeronautical satellite system design, but the power output and wide bandwidths made available with this satellite allowed work to be performed in support of high-capacity satellite air traffic control system design for possible use in the Continental United States.

2. Satellite test programme

2.1 *Introduction*

The USA experimental programme using the ATS-5 satellite began in April, 1971 and was completed in May, 1973. Experiments at 1550 MHz were performed to obtain data on narrow-band CW multipath, tone ranging and digital data transfer during approximately fifty flights. No voice tests were performed since the signal was not continuous because of an inadvertent satellite spin. A detailed description of the experiments is contained in [FAA, 1973; FAA, 1975]. The ATS-5 experiments were performed at elevation angles to the satellite of 9° to 34°. A one-way radio-frequency link to the aircraft, using a 6 GHz link from ground-to-satellite and a 1550 MHz link from satellite-to-aircraft, was utilized during the programme. The United States Naval Research Laboratory (NRL) was engaged to obtain sea-state information for the purpose of correlating the multipath and tone ranging data with the ocean surfaces encountered. A description of the sea photo analysis techniques utilized by NRL, the sea-state information obtained, and comparisons of the NRL data with hindcast data are contained in Pilon [1972].

The test-bed aircraft used for the ATS-5 and ATS-6 experiments was a KC-135 (Boeing 707 type aircraft). The aircraft was specially equipped with various antennas that received the direct path and multipath signals independently of each other. For the ATS-5 experiments a slot-dipole prototype antenna system was also installed on the aircraft. Although the slot dipole system was used successfully in the programme to perform ranging experiments and digital data transfer demonstration tests, the power limited (26 dBW at pulse peak with full power) ATS-5 satellite did not provide sufficient signal to fully demonstrate the antenna system capability. Since accurate antenna gain and ellipticity information was required in the data analysis process, this information was obtained for all the antennas by utilizing a scale model of the KC-135 aircraft and correspondingly scaled antenna models.

The direct/multipath antenna system used in the ATS-5 and ATS-6 experiments provided the flexibility of receiving the signals independently or mixed, and allowed various amounts of attenuation to be introduced into either of the signal paths independently (Type II tests). Parametric direct-to-multipath signal ratios were established by varying the attenuation in the multipath channel relative to the direct path channel on board the aircraft. Data gathered in this manner can be utilized to evaluate avionic systems.

The aircraft for the ATS-6 experiments was equipped with other antennas in addition to those used with ATS-5. A 60° beamwidth directional antenna was mounted in the nose of the KC-135 to facilitate detailed multipath characterization tests. A stripline phased array antenna was skin mounted to the fuselage and tested. Comparisons were made with other experimental antennas considered as candidates for satellite communication avionics (see Report 594 (Kyoto, 1978)). Various modem tests were conducted with these antennas (Type I tests) under conditions approximating those for aircraft participating in future oceanic satellite communication experiments.

The ATS-6 experiments were performed at elevation angles to the satellite of 3° to 32°, at altitudes from ground level to 30 000 ft (9145 m) and at various headings and speeds. Radio frequency channels to the aircraft consisted of a 3950 MHz ground-to-satellite link and a 1550 MHz satellite-to-aircraft link; in the return direction, a 1650 MHz aircraft-to-satellite link and a 6350 MHz satellite-to-ground link were used. The ATS-6 satellite had a bandwidth of 40 MHz and ample e.i.r.p. to allow the testing of each modem with a C/N_0 at the aircraft as high as 50 dBHz. Approximately 135 hours of flight testing were performed over a seven month period from September, 1974 to April, 1975. Tests included Satellite Aeronautical Channel Prober (SACP) multipath characterization, evaluation of voice, digital data and ranging modems, and evaluation of various aircraft Band 9 antennas. Results provide data for the evaluation of advanced system concepts and hardware applicable to the design of future satellite-based air traffic control systems. In addition, Air Traffic Control (ATC) demonstration tests were conducted to gain experience with satellite systems as a prelude to the International Aeronautical Satellite (AEROSAT) Programme. This summary represents results of the technology tests only [FAA, 1975].

2.2 *Multipath experiments* *

2.2.1 *ATS-5 tests*

The multipath experiments were performed over various combinations of elevation angles, and sea and land states. The experiments were performed to characterize the multipath, and combined multipath and direct signal properties. The polarization of the multipath antenna could be changed to various modes. This capability was utilized to determine the ellipticity of the multipath signal by receiving the horizontal and vertical components separately, and to determine the phase reversal properties of the multipath signal, by alternately utilizing the left-hand circular and right-hand circular polarization modes of the antenna.

The following significant conclusions concerning sea-reflected multipath were determined from the programme:

- the ratio of mean scattered power to the direct path power is approximately equal to the product of the divergence factor and the smooth-sea reflection coefficient;
- a significant sense reversal effect is present when the signal incident on the ocean surface is circularly-polarized;
- the multipath signal was found to be predominantly diffuse for r.m.s. wave heights greater than approximately 20 cm.

The Canadian Communication Research Centre also participated in the experimental programme by performing multipath probing experiments using a sinusoidal carrier, bi-phase modulated by pseudo-random two-length codes transmitted to the KC 135 aircraft via the satellite.

The correlation of a locally generated code with the received signal allowed the time domain (delayed spread) characteristics of the multipath signal to be determined. The experiments were performed at elevation angles between 11.5° and 22.5° over various sea states. Since the FAA/Boeing multipath experiments yielded frequency domain characterization data, the Canadian and FAA/Boeing data complement each other. A preliminary report has been written that describes the Canadian experiments [Chinnick and Matt, 1971].

* See also Report 505 (Kyoto, 1978).

2.2.2 *ATS-6 tests*

2.2.2.1 *Oceanic test results*

Probes of the oceanic multipath phenomena were conducted in the North Atlantic on eighteen separate occasions covering a range of grazing angles from 3° to 30° and a variety of sea conditions. A limited amount of sea surface data was also acquired using a sea-state buoy. Reduced buoy data is not available for inclusion in this paper. Experimental data was obtained to illustrate the scatter function ($S(\tau, \omega)$), the values of the delay spreads, Doppler spectra and the associated autocorrelation functions and coherence bandwidths. Most of the data given are for simultaneous probing transmissions which have vertical and horizontal linear polarizations. A limited amount of data for circularly polarized transmissions from the forward multipath antenna were obtained [FAA, 1975].

For mid-grazing angles (about 19°), results were compared with predictions based upon surface integration of the physical optics vector-scatter model as applied to a very-rough surface possessing an isotropic slope distribution of the Gaussian form with assumed mean square value. ("Very-rough" is defined as the surface height variations being significantly greater than the electromagnetic wavelength.) Measured values were also compared with theoretical predictions.

For oceanic scatter at Band 9 frequencies, there are compelling reasons to assume that the multipath channel is described as a zero-mean complex Gaussian random scatter process. The experimental test conditions were processed in time segments on the order of 6 s and therefore the effective scatter region traverses a surface area over the ocean in which its significant electrical and physical parameters remain relatively isotropic and stationary. Under these conditions, the scatter function completely characterizes the statistics of the channel. The results were presented in the context of the scatter function from which all detailed parameters were extracted [FAA, 1975].

Several fundamental characteristics have been obtained of the energy distribution dependencies of $S(\tau, \omega)$ upon grazing angle, flight direction, and polarization. Typically, these dependencies are most easily discussed when $S(\tau, \omega)$ is reduced to fundamental relationships such as the channel's Doppler spectra, delay spreads, etc. Observations relative to quantities derived from $S(\tau,\omega)$ are also available [FAA, 1975].

In comparing theoretical model predictions with the ATS-6 experimental measurements, very close similarity was in evidence. Table I presents a summary of results based on computations derived from the Gaussian channel model. The test conditions on the left of the Table, refer to various test conditions of the experiment (or boundary conditions of the model). Both vertical and horizontal polarization measurements were made for the in-plane (radial) or cross plane (tangential) flight headings of the aircraft relative to the satellite.

2.2.2.2 *Overland test results*

A rather extensive data base of overland forward scatter multipath has been obtained. This collection covers a range of grazing angles from 20° to 45° and a variety of terrain electrical characteristics (snow covered to salt flats), surface roughness (flat plains to mountainous), and vegetation coverages (heavily forested to barren). In addition, several hours of data pertaining to multipath reflections in the approach, landing, and taxi phases in large airport environments were obtained. Probing rates of 5 MHz were used with the SACP instrument for these tests.

Due to the non-isotropic nature of the overland scatter surface, the analysis and modelling of the overland multipath channel is not nearly as straigthforward as the oceanic case and necessitates that each return signal structure be treated as a separate entity. Sample scatter function time histories are available which dramatically illustrate the non-stationary statistical behaviour of the multipath return. Data was also obtained for the scatter function signatures [FAA, 1975].

With respect to the airport landing/taxi scatter data, several sample delay spectra are presented in [FAA, 1975] which are representative of the data obtained for the majority of the airport manoeuvres taken during the ATS-6 tests.

Several scatter function plots illustrating the non-stationary overland phenomena have been obtained [FAA, 1975]. These data are roughly categorized as being representative of the following scatter properties:

TABLE I – *Oceanic scatter channel spread and r.m.s. energy values*

Test condition	3 dB Spread parameter				Scatter coefficient (dB)
	Doppler bandwidth (Hz)	Correlation time (ms)	Delay spread (μs)	Coherence bandwidth (kHz)	
Vertical polarization in-plane	105	3.9	0.58	270	−5.7
Horizontal polarization in-plane	86	4.5	0.58	255	−0.6
Horizontal polarization cross-plane	105	3.8	0.58	255	−0.6
Horizontal polarization 45° Heading offset	105	3.9	0.58	255	−0.5

(a) near-zero spread in both Doppler and delay parameters – vertical polarization, in-plane geometry, grazing angle roughly 33°;

(b) modest spread for both Doppler and delay parameters – horizontal polarization, cross-plane geometry, grazing angle roughly 27°;

(c) asymmetrical return from reflection region with predominant energy received from area close to aircraft – vertical polarization, in-plane geometry, grazing angle roughly 33°;

(d) multi-mode signature with large specular return superimposed upon an underlying low energy broadly spread signal – horizontal polarization, in-plane geometry, grazing angle roughly 29°;

(e) broadly spread return with persistence in scatter function tails and highly irregular Doppler spectra-horizontal polarization, in-plane geometry, grazing angle roughly 29°.

The 3 dB spread values associated with the channel parameters of the above data sets are given in Table II. (Test references correspond to the properties defined above.)

TABLE II – *Example spread values for overland multipath*

Test Reference	Doppler spectrum bandwidth (Hz)	Time autocorrelation spread (ms)	Delay spread (μs)	Frequency autocorrelation bandwidth (kHz)
a	24	13	< 0.2	> 2500
b	50	6	≈ 0.2	1500
c	51	5.5	≈ 0.2	1020
d	20	8.5	≈ 0.2	720
e	165	2.4	≈ 0.5	160

2.2.2.3 *Summary of test results*

The multipath experiments using ATS-6 confirmed the ATS-5 test results and additionally provided the detailed statistical parameters associated with the oceanic and overland cases described in Report 505 (Kyoto, 1978).

In the oceanic tests, 3 dB spread values were presented as a function of grazing angle. Doppler bandwidth spreads from a low of 25 Hz to a high of 215 Hz were observed and display a marked tendency to increase with an increase in grazing angle. No appreciable grazing angle dependence was apparent for the delay spread data which varied over a range from 0.35 μs to 1.5 μs. The time autocorrelation function spread displayed, as expected, an inverse grazing angle dependence to that of the Doppler data; it was characterized by a low of 1.5 μs and a high of 9 μs. Coherence bandwidths ranging from 100 kHz up to 380 kHz were measured with the higher values typically being associated (very weakly) with high grazing angles and vice versa.

A dominant characteristic of the overland scatter data is the non-stationary statistical behaviour of the data. The overland channel, compared with the oceanic channel, varied more rapidly in time. This was readily confirmed through a visual observation of a fifteen minute scatter function time history segment. Similarly, the channel's scatter function varies markedly with the nature of the reflecting surface. The observed signature was used to isolate periods of very low spreading, modest spreading, biased positional scatter, large irregular Doppler spectra return, and mixed scatter process return.

2.3 *Tone-ranging experiments*

2.3.1 *ATS-5 tests*

The tone-ranging experiments consisted of measurements on analogue ranging modulation using 8 and 10 kHz tones for various signal levels and in the presence of controlled levels of multipath (Type II tests). The ranging experiments were also performed over a variety of elevation angle and sea-state combinations. Conclusions drawn from the ranging portion of the programme are:

- the r.m.s. ranging accuracy for a modulation comprised of individual sinusoidal tones of 8 and 10 kHz is about 250 m for a signal-to-noise density of 48.5 dBHz, confirming ranging theory and allowing a theoretical extrapolation for other channel characteristics;
- the effect of the multipath interference on the accuracy of a tone ranging system appears to result in a distribution of range error which is zero-mean Gaussian with variance proportional to the reciprocal of the S/I value.

2.3.2 *ATS-6 tests*

Two ranging modems were tested with ATS-6, one using analogue tones and the other digital techniques (a derivative of BINOR, see Report 509) with two clock rates, 156 kHz and 19 kHz.

The two-way r.m.s. error for the analogue tone ranging modem, with a maximum tone frequency of 8.6 kHz was typically between 250 and 350 metres for the limited data available. This ranging system did not perform consistently below a forward link C/N_0 of 43 dBHz. Performance limitations were due to the hardware and not because of any theoretical reasons. Performance of the modem should extend down to about 37 dBHz while still achieving the above r.m.s. values.

The digital tone ranging modem results showed improving performance with increasing C/N_0 and better performance for the mode where the clock rate was 156 kHz rather than 19 kHz. The one-way r.m.s. error relative to the reference flight path was then in the order of 30 metres for a clock rate of 156 kHz, and 100 metres for a clock rate of 19 kHz at 45 dBHz.

2.4 *Data transfer experiments*

2.4.1 *ATS-5 tests*

The digital data transfer experiments consisted of measurements on CPSK and (non-coherent) DPSK demodulators over a direct path link at various signal levels and in the presence of a multipath environment at various signal-to-interference ratio values. Demonstration tests were also performed by using the slot-dipole prototype antenna system. During all the experiments, consisting of eleven flights and a number of ground-to-ground experiments, both units were utilized simultaneously to demodulate the same received signal.

2.4.2 *ATS-6 tests*

2.4.2.1 *Introduction*

Five digital data modems, all utilizing derivatives of phase-shift keyed (PSK) signalling, were tested.

- Hybrid No. 1 – Differentially encoded phase shift keying.
- Hybrid No. 2 – Differentially encoded phase shift keying.
- Coherent phase shift keying (CPSK).
- Differentially encoded coherent phase shift keying (DECPSK).
- Differential phase shift keying (DPSK).

The first four are essentially similar in concept, employing Costas structure coherent reference loops with integrate-and-dump detection followed by differential decoding to eliminate loop lock ambiguity. The fifth is an implementation of DPSK wherein the bit-to-bit relative phase, rather than absolute channel phase, is used to perform decisions.

Both hybrid modems are capable of simultaneous transmission of voice and data signals on a single constant-envelope carrier using quadrature modulation techniques. Hybrid No. 1 differs from Hybrid No. 2 only in the voice channel.

The results and discussions contained below are for operation in the data mode. The actual tests included simultaneous performance for both voice and data modulations; a limited number of these tests have been analysed [FAA, 1975].

2.4.2.2 *Test description*

All five digital data modems were installed aboard the KC-135 aircraft. The test signal consisted of a 2047 bit pseudo-random sequence which was PSK modulated onto a carrier and transmitted to the aircraft via the ATS-6 satellite. All five digital data demodulators operated on the same PSK test signal, thus eliminating any uncertainty regarding unequal signal power or modulation quality. Demodulated outputs were recorded and error statistics were analyzed off-line in a general purpose computer. The tests were divided into two general categories.

2.4.2.2.1 *Type I tests*

These tests acquired performance data for over-ocean flight with operational aircraft antennas (slot-dipoles) at satellite elevation angles ranging from about 10° to 30°. Aircraft heading angles relative to ATS-6 were approximately 45°, 135°, 225° and 315°. Type I tests evaluated data modem performance over a range of signal-to-noise power density ratios (C/N_0) and with the signal-to-multipath interference (S/I) ratios inherent for the slot-dipole antennas at the aircraft/satellite geometries tested. Maximum rejection of ocean reflected multipath was achieved by installing the slot-dipoles in the upper wing/body fairing area, thus taking advantage of wing shielding effects.

2.4.2.2.2 *Type II tests*

These employed a high-gain (15 dB) steerable antenna for reception of the direct path signal and a downward looking antenna for reception of the sea-reflected multipath signal. After preamplification, the two signals were combined at RF in the desired power ratio to obtain various ratios of S/I. Type II tests spanned C/N_0 values between 38 and 52 dBHz in combination with S/I values ranging from heavy multipath fading (S/I = 3 dB) to essentially non-fading conditions (S/I > 20 dB). All Type II test flights were over ocean, approximately broadside to the satellite, at an elevation angle of 15°.

2.4.2.3 *Test results*

Type I test results for the Hybrid No. 1 modem, operating in the data mode, and for the DPSK modem are given in Figs. 1 and 2. The solid lines correspond to ideal theoretical performance for DECPSK and DPSK. Although some performance differences were observed for the four DECPSK modems, the Hybrid No. 1 results are representative of the currently attainable performance for this class of modem [FAA, 1975].

Type II experimental data points for DECPSK and DPSK are plotted in Figs 3 and 4. These figures include reference curves representing the expected performance for various ratios of S/I. The reference curves for the Hybrid No. 1 DECPSK performance were measured using a multipath simulator [Salwen and Duncombe, 1975]. The 1200 bit/s data rate and the Doppler spread bandwidth of 100 Hz used during multipath simulator measurements are consistent with the experimental Type II test conditions. The reference curves of predicted performance for DPSK are based on the slow-fading model wherein the fading bandwidth due to multipath is small compared with the data symbol rate, as is the case of Type II experimental test conditions [Frasco and Goldfein, 1973; Jones, 1968].

2.4.2.4 *Analysis of test results*

A typical performance criterion applied to aeronautical satellite links is a bit error rate (BER) of 10^{-5} at $C/N_0 = 43$ dBHz. Analysis of results contained in Figs. 1 to 4 yielded the following observations and conclusions:

During Type I tests, the DECPSK and DPSK modems achieved BERs of 10^{-5} at C/N_0 values of 41.5 and 42.5 dBHz respectively. The S/I values were measured concurrently during these tests and were found to be usually in excess of 15 dB and frequently greater than 20 dB. Consistent with these high S/I values, the BER values of both modems approximated those determined from the thermal noise model. The modems did not show appreciable degradation due to multipath for these tests.

For the Type II tests, both DECPSK and DPSK demonstrated performance degradation due to multipath in general agreement with the reference curves. The BER performance of DPSK was superior to DECPSK at lower S/I values but this advantage in absolute BER performance disappeared when S/I was greater than about 10 dB.

Experimental data indicates that unless error correction is used, then S/I values must be greater than about 15 dB if BERs of 10^{-5} at $C/N_0 = 43$ dBHz are to be achieved for either DECPSK and DPSK. Either multipath discrimination by the aircraft antenna to provide an S/I of 15 dB is necessary, or error correction coding must be employed to enable operation at lower S/I values, or a combination of both.

Although the high values of S/I needed to meet the performance criterion cited were achieved with the rather unique slot-dipole antenna installation used for the Type I tests, these S/I ratios may not be readily obtainable for all future combinations of operational aircraft antenna designs and aircraft/satellite geometries of interest. Studies on Band 9 operational aircraft antennas have shown that S/I values of 10 dB are achievable over about 95% of the solid angle of interest while providing an antenna gain greater than 2 dB [FAA, 1973]. Investigation of techniques for operation, without BER degradation, at S/I values of less than 15 dB therefore appears desirable.

Extrapolation of the data in Figs. 3 and 4 shows that BERs of 10^{-5} at $S/I = 10$ dB can be achieved for either DECPSK or DPSK if the C/N_0 is increased to roughly 53 dBHz. This amplies that an increase in satellite transmitter power of more than 10 dB would be required as compared with the non-fading (no-multipath) case. Error correction coding designed to improve performance in the presence of multipath fading offers an attractive alternative to increases in satellite output power or complex aircraft antenna configurations and should be given further consideration [Bello *et al.*, 1975; Chase, 1973; Wilson *et al.*, 1976].

2.5 *Voice communication experiments*

2.5.1 *Introduction*

A variety of voice and data modems were tested with the NASA ATS-6 satellite. The modems were installed in a fixed earth station at Rosman, North Carolina and in a specially equipped KC-135 aircraft.

Testing commenced in September, 1974. The tests were conducted to evaluate voice in parallel with data and ranging tests along with other tests of antennas, multipath, and air traffic control demonstrations.

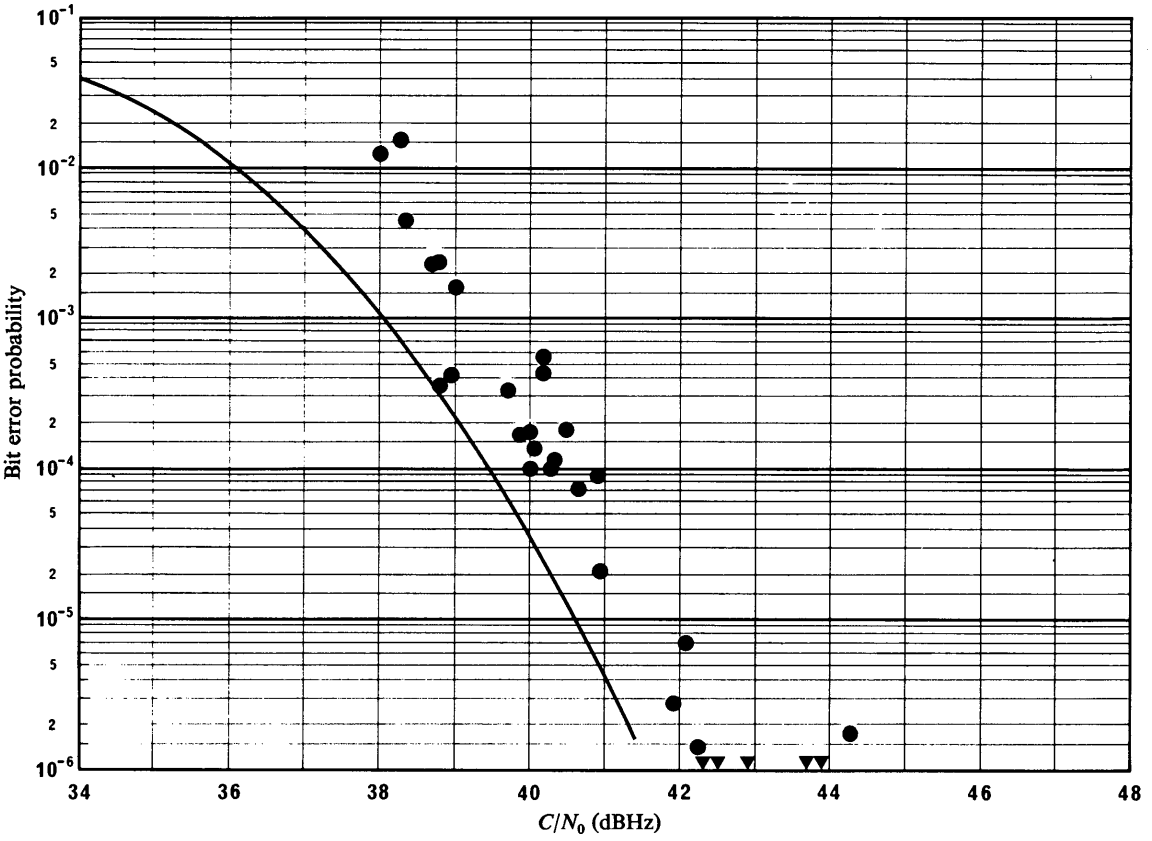


FIGURE 1 — *Bit error performance of DECPSK modem, 1200 bit/s, Hybrid No. 1 demodulator, Type I tests*

——— Theoretical DECPSK

▼ Zero errors (at least 670 kbits processed)

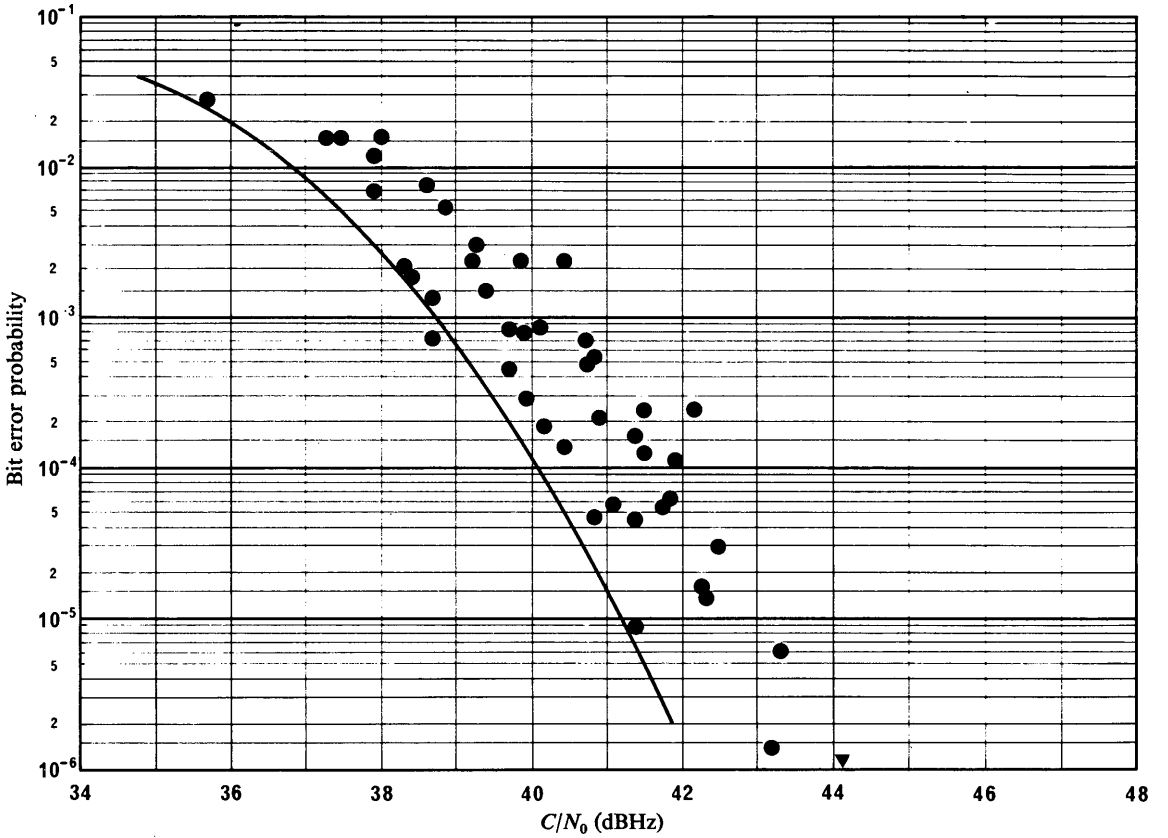


FIGURE 2 — *Bit error rate performance of DPSK modem, 1200 bit/s, FAA DPSK demodulator, Type I tests*

——— Theoretical DPSK

▼ Zero errors

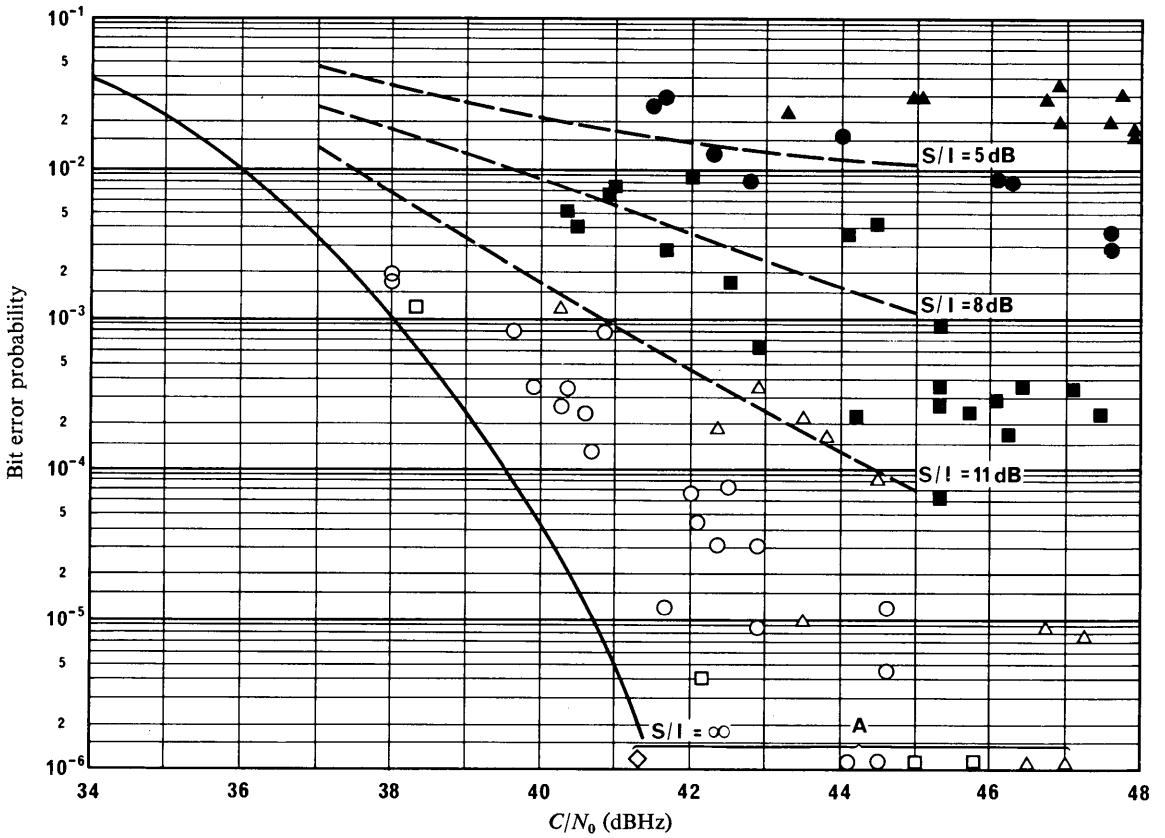


FIGURE 3 — *Bit error rate performance of DECPSK modem, 1200 bit/s, Hybrid No. 1 demodulator, Type II tests*

◇ S/I > 20 dB
□ S/I = 18
○ S/I = 15
△ S/I = 12
■ S/I = 9
● S/I = 6
▲ S/I = 3
} ± 1.5 dB

——— Theoretical DECPSK

— — — — Simulator measurements

A Zero errors

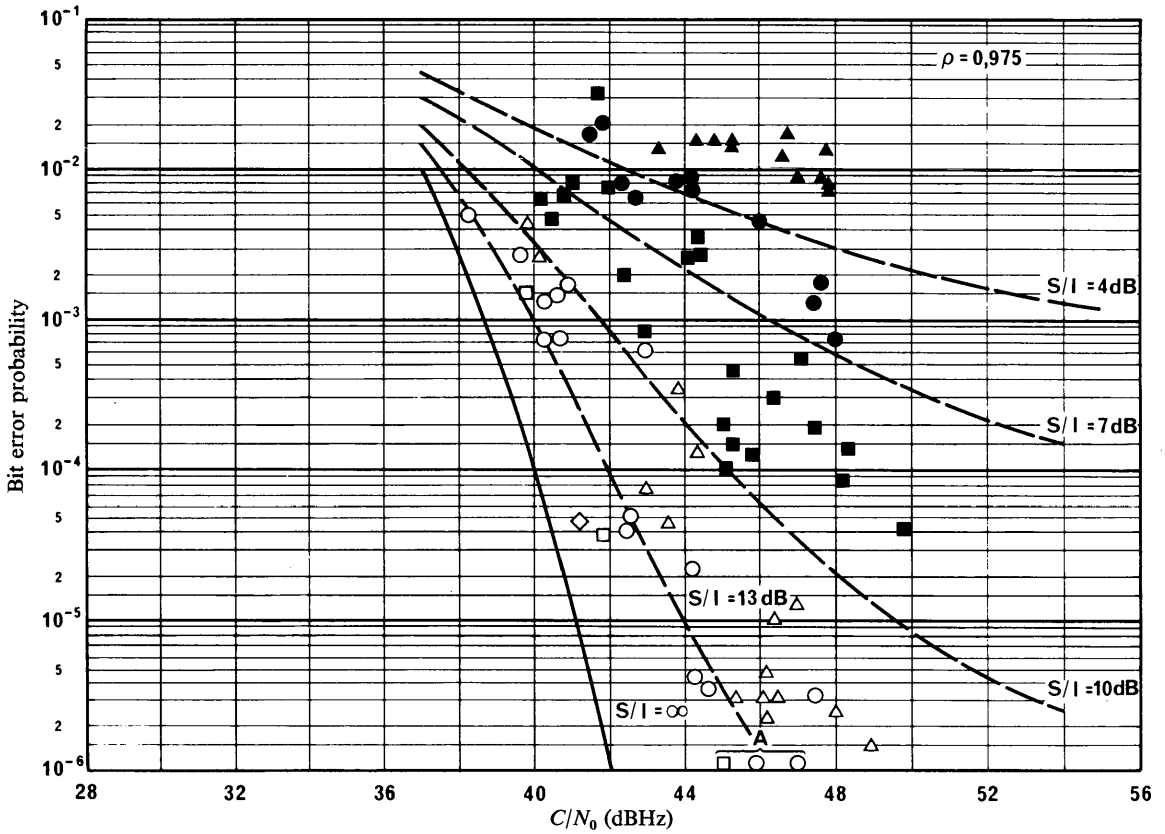


FIGURE 4 — *Bit error rate performance of DPSK modem, 1200 bit/s, FAA DPSK demodulator, Type II tests*

◇ $S/I > 20$ dB

□ $S/I = 18$

○ $S/I = 15$

△ $S/I = 12$

■ $S/I = 9$

● $S/I = 6$

▲ $S/I = 3$

} ± 1.5 dB

——— Theoretical DPSK

— — — — Simulator measurements

A Zero errors

2.5.2 *Voice modems tested*

Four different types of voice modems were tested. Their technical characteristics are summarized in Table III.

The modems are as follows:

2.5.2.1 *Hybrid I modem*

This modem can transmit and receive analogue voice and digital data at 1200 or 2400 bit/s and in the simultaneous mode, voice plus data. Voice is transmitted by low deviation phase modulation of the carrier while data is differentially encoded and phase-shift key modulated onto a quadrature carrier component. Either or both modulations are transmitted on a common carrier occupying the same spectral zone. The demodulator consists of a phase-locked loop to extract the carrier reference for the voice and data demodulations. For simultaneous transmission of voice and data, the two signals are combined in phase quadrature and separated in the demodulator by quadrature product detection of the two orthogonal signals.

2.5.2.2 *Delta voice modem*

An adaptive (variable slope) delta modulation voice modem (ADVM) was tested. This modem operated at a bit rate of 19.2 kbit/s. It was implemented utilizing circuits and components common to the Hybrid I modem. This modem provides both digital matched filtering detection of the received bit stream and analogue bit detection comprised of a simple envelope detector of the baseband bit stream.

2.5.2.3 *Hybrid II modem*

This modem first transforms the input voice signal to a pulse duration modulated signal (PDM) having a suppressed clock of 9.6 kHz. The PDM pulses then phase-shift modulated a carrier. For the digital data channel, the data bit stream at 1200 or 2400 bit/s is differentially encoded and phase-shift key modulates a quadrature carrier similar to the technique used in Hybrid I for simultaneous transmission of voice and data, the voice and data bi-phase modulated carriers are combined in phase quadrature as in Hybrid I. Demodulation uses a phase-locked loop to coherently detect the modulation on each quadrature carrier followed by the respective voice and data detectors.

2.5.2.4 *Adaptive narrow-band FM modem (ANBFM)*

This is a conventional narrow-band FM voice modem. The modulator output has a peak deviation of 1.5 kHz. To improve threshold performance, this demodulator utilizes modulation-tracking phase-locked loop having a variable closed loop bandwidth which adapts proportionately to the input signal/noise ratio.

2.5.3 *Test description*

Tests were conducted, over the Atlantic Ocean from the autumn of 1974 to the spring of 1975 [FAA, 1975]. Approximately 28 hours of voice transmissions were conducted from the fixed earth station at Rosman, North Carolina, through the ATS-6 satellite, to the instrumented KC-135 test aircraft. A summary of the test conditions is as follows:

- Test areas for the KC-135 were selected to provide elevation angles of from 9° to 32°.
- Slot-dipole antennas mounted in the right and left upper wing roots of the KC-135 were used for most voice tests.
- The voice test tapes used for all tests were composed of uniquely scrambled Phonetically Balanced (PB) word lists for evaluation of monosyllabic word intelligibility, in accordance with a modified PB-50 procedure (see Annex I).
- Generally, three modems were tested simultaneously, with each modem receiving the same PB words under the same controlled conditions for C/N_0 multipath and other conditions.
- All voice modem intelligibility evaluations were conducted by the same trained listener panel consisting of ten members.

The data presented herein was derived from a series of winter tests. The data derived during these tests are plotted in Fig. 5. These results are an average of a wide range of conditions representative of a much broader data base. The test results of Fig. 5 represent approximately five hours of reduced data acquired at elevation angles to the ATS-6 satellite in the range 9° to 32°, and at an aircraft altitude of ~ 9150 m (30 000 feet), an aircraft velocity of 965 km/h (600 miles per hour) with a heading relative to

TABLE III – *Technical characteristics of voice modems*

Modem/manufacturer	Modulation type	Demodulation type	Voice processing (1)	RF bandwidth (kHz)	Voice bandwidth (Hz)	C/N_0 threshold (dBHz)
Q-M/PSK (Hybrid I) Bell Aerospace	Quadrature (suppressed carrier A.M., added to quadrature carrier and hard limited)	Quadrature, (PLL (2) for carrier and quadrature demodulation for voice signal)	Pre and deemphasis and compression at modulation (1)	Less than 10	300 to 3500	Down to 38
PDM/PSK (Hybrid II) Magnavox Research Labs.	PDM with suppressed carrier, 9600 samples per second PSK carrier	PSK with Costas loop for carrier and PDM for voice signal demodulation	Pre and de-emphasis and compression at modulation	Approx. 20	300 to 3500	Down to 38
ADVM Bell Aerospace	Adaptive Δ modulation PSK with pilot tone reference, 19.2 kbit/s rate	Digital - PSK with adaptive Δ analogue - PLL for carrier and quadrature modulation with integrator	Some pre-emphasis	40 minimum	300 to 3500	Analogue - down to 38 Digital - down to 41
ANBFM Bell Aerospace	Low deviation index FM (± 1.5 kHz)	PLL demodulation with adaptive closed loop BW vs. C/N_0	Same as Hybrid I	Less than 10	300 to 3500	Down to 39

(1) Companding not used; voice modulation compression ratio peak/r.m.s. = 12 dB.

(2) PLL : phase-locked loop.

the satellite of 0° and 90°. Most test results were obtained using a slot-dipole antenna mounted in the upper wing root fairing of the KC-135 aircraft. In independent measurement under similar test conditions, the signal-to-multipath ratio as received at the modem terminals was known to exceed 15 dB.

2.5.4 *Analysis of voice test results*

The following conclusions can be drawn from Fig. 5.

All modems exceeded a performance level of a word score intelligibility of at least 60% at a C/N_0 of 43 dBHz. The ANBFM modem just meets this performance level.

The Q-M/PSK modem consistently demonstrated superior performance relative to the others tested. Word score intelligibility was 95% at C/N_0 of 43 dBHz and 70% at C/N_0 of 40 dBHz. The design of the voice portion of the Q-M/PSK modem is comparable in simplicity with that of an ANBFM modem.

Adaptive delta modulation performance characteristically decreased rapidly with small decrease in C/N_0 below 42 dBHz. Analogue detection of adaptive delta modulation performed better than for digital detection by about 2 dB below a C/N_0 of 42 dBHz but digital detection was slightly better for C/N_0 greater than about 45 dBHz.

Because of the high signal-to-multipath ratio resulting from the wing shielded slot-dipole antenna, all voice modem performances were essentially thermal-noise limited rather than multipath limited. In other tests of voice modems (data not yet published) where the signal-to-multipath ratio was of the order of 3 dB, the analogue voice modem results correspond closely to those presented here. The corresponding data from the ATS-6 tests for the delta modems with very low values of S/I are still being analysed.

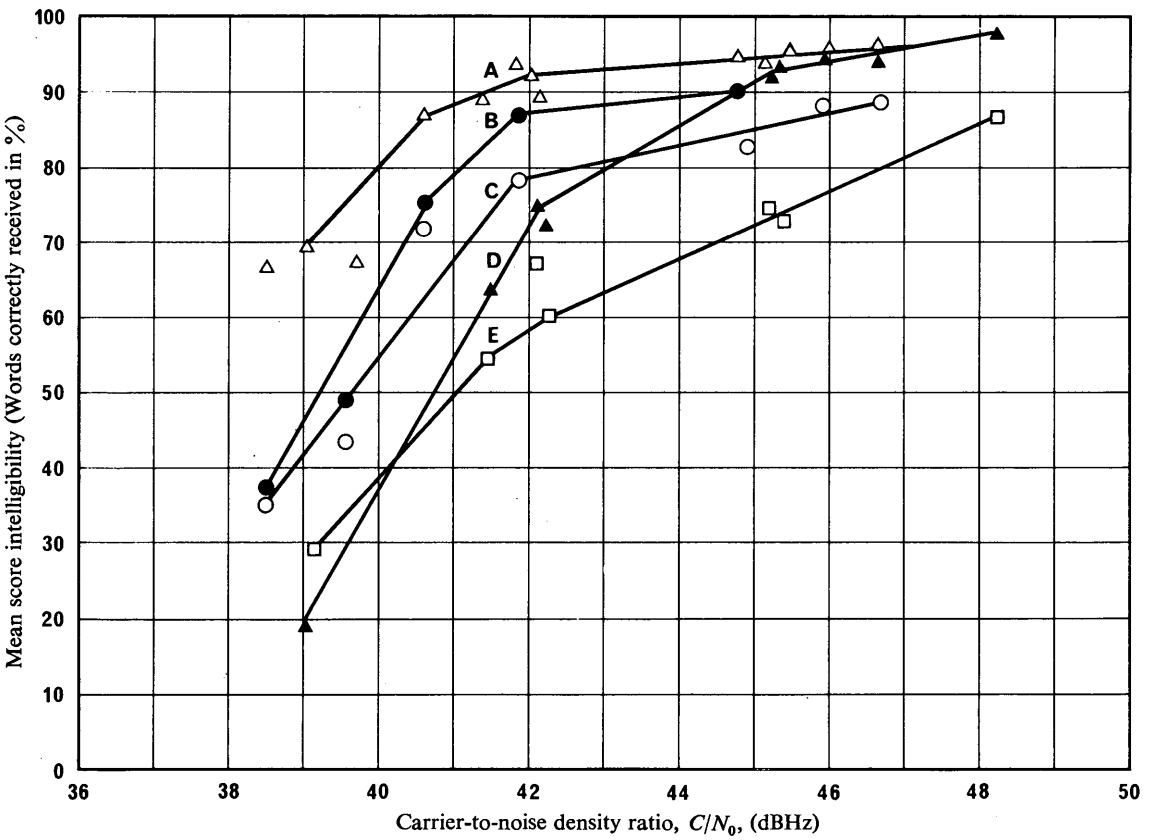


FIGURE 5 — *Intelligibility performance of voice modems flight tested with ATS-6*

Curves
A: quadrature modulated/phase shift keyed
B: adaptive delta modulated (analogue)
C: pulse duration modulated/phase shift keyed
D: adaptive delta modulated (digital)
E: adaptive narrow band — FM

3. Summary

The ATS-5 and ATS-6 satellites have been used to obtain multipath, tone ranging, digital data transfer and voice transmission data using special purpose antennas and antennas representative of those which could be used in an aeronautical satellite system.

These data, which are summarized in the appropriate sections of this Report, were obtained using instrumented aircraft flying at a range of altitudes and speeds.

These data are given in detail in the various documents listed in the References and Bibliography.

REFERENCES

BELLO, P. *et al.* [January, 1975] Impact of aeronautical channel on modem specifications. Report FAA-RD-74-215. Federal Aviation Administration, US Department of Transportation, USA.

CHASE, D. [9-11 October 1973] The applications of codem concepts for communication over the aeronautical channel. International Telemetering Conference, Washington, DC, USA, 419.

CHINNICK, J. and MATT, E. [December, 1971] Spread spectrum measurements of multipath channel characterization in a satellite mobile communication system. Canadian Communication Research Centre.

FAA [April, 1973] Federal Aviation Administration; ATS-5 multipath/ranging/digital data L-band experimental program. Report FAA-RD-73-57, US Department of Transportation, USA.

FAA [June, 1975] Federal Aviation Administration; US aeronautical L-band satellite test program: Interim test results. Report FAA-RD-75-111, US Department of Transportation, USA.

FRASCO, L. A. and GOLDFEIN, H. D. [May, 1973] Signal design for aeronautical channels. *IEEE Trans. Comm.*, Vol. COM-21, **5**, 534-547.

JONES, J. J. [December, 1968] Multichannel FSK and DPSK reception with three-component multipath. *IEEE Trans. Comm. Tech.*, Vol. COM-16, **6**, 808-821.

PILON, R. O. [October, 1972] Determination of oceanic surface descriptors using sea photo analysis techniques, Phase I. Report FAA-RD-72-110, Federal Aviation Administration, US Department of Transportation, USA.

SALWEN, H. C. and DUNCOMBE, C. B. [July, 1975] Performance evaluation of data modems for the aeronautical satellite channel. *IEEE Trans. Comm.*, Vol. COM-23, **7**, 695-705.

WILSON, S. G., SUTTON, R. W. and SCHROEDER, E. H. [March, 1976] DPSK performance on L-Band aeronautical satellite channels: Test results and a coding evaluation. *IEEE Trans. Comm.*, Vol. COM-24, **3**, 374-380.

BIBLIOGRAPHY

BOEING CORP. [December, 1971] ATS-5 multipath/ranging experimental program, Interim Results, Report DG-60149.

MILNER, P. and GOLAB, J. S. [April, 1975] Intelligibility of voice transmission through a satellite relay system. 89th Meeting of the Acoustical Society of America. University of Texas, USA.

ANNEX I

METHOD OF INTELLIGIBILITY EVALUATION OF SATELLITE RELAY VOICE TRANSMISSION SYSTEM

1. Introduction

Using the Applications Technology Satellite (ATS-6), a variety of modem configurations have been evaluated. The modems are installed in a fixed earth station at Rosman, North Carolina, and in a specially equipped KC-135 aircraft. The ranging and data transmission evaluations were relatively straightforward; however, the voice test procedures required special modifications to the American National Standard Phonetically Balanced Word Tests (PB-50) as described in this Annex.

2. Voice intelligibility tests

Voice intelligibility measurement is often performed using the PB-50 word lists of American National Standard S3.2-1960, Method for the Measurement of Monosyllabic Word Intelligibility [ANSI, 1960]. The flight tests presented many problems which made the use of the procedures recommended in this standard impractical. First was the large quantity of testing to be performed in a relatively short period of time. Some 500 to 600 tests were expected to be run. Second, during a flight test, the aircraft was to follow a specified flight pattern with several legs of about 23 minutes duration during which all tests related to that flight path were to be completed. Third, as many as six simultaneous recordings of a given voice transmission would be recorded, three aboard the aircraft and three aboard a ship, for presentation to the listening panel. Finally, there should be a high correlation to PB-50 word tests run under similar conditions using the standard method.

Based on previous experiments, it was determined that the PB-50 word tests could be modified from the standard procedures without significantly affecting measurement reliability and accuracy [Milner, 1973; Milner and Golab, 1975].

Therefore, to meet the requirements of the flight tests, the following modifications of the standard PB-50 tests were made:

- reading rate was increased to one word per 2.5 s;
- the carrier phrase was eliminated;
- 400 PB words were used for each test instead of 1000;
- 68 scrambled orders of the word lists were created.

3. Reading rate and carrier phrase test

Recordings of the PB-50 lists were prepared with a male and female talker at reading rates of one word per 3.5 s with the carrier phrase and rates of one word per 3.5, 3.0, 2.5 and 2.0 s respectively without the carrier phrase. White noise was mixed with the speech at signal-to-noise (S/N) ratios of 4 and 6 dB and intelligibility measured. Table IV indicates that neither increasing the reading rate (up to the point where the task becomes difficult for the listener) nor removing the carrier phrase affects perceived intelligibility. The experiment is really a measure of the performance of the listeners since, in reality, intelligibility does not change for constant S/N.

TABLE IV – *Intelligibility of PB-50 words mixed with white noise as a function of reading rate with and without carrier phrase*

Reading rate	Intelligibility (%)	
	S/N = 6 dB	S/N = 4 dB
One word per 3.5 seconds with carrier	67.5	56.2
One word per 3.5 seconds without carrier	69.1	60.5
One word per 3.0 seconds without carrier	66.3	–
One word per 2.5 seconds without carrier	69.9	60.8
One word per 2.0 seconds without carrier	58.5	–

The responses of the listeners themselves indicated that the reading rate of one word per 2.0 s was too rapid to hear the words and write them down. Although at first they felt that the reading rate of one word per 2.5 s was too fast also, their performance scores do not indicate this, and this rate was decided as the optimum rate for the flight tests. During the course of the test programme, the listeners accommodated well to the increased rate and tended to prefer it to slower rates.

4. Limited word test

The condition imposed of limited transmission time per flight test (23 minutes) not only demanded increasing the reading rate, but also reducing the number of words in the list. Given the time limits, it was decided to construct tests of 400 words, with 100 read by each of four talkers, two male and two female.

To reduce the effects of reduced vocabulary size and memorization of the words, 68 different scrambled orders of the 1000 PB-50 words were generated. A computer was used to create the random orders and print out the scrambled lists. Each of the four professional talkers recorded seventeen complete scramblings of the 1000 word set. The recordings were made in an anechoic chamber.

Test tapes were made from the master recordings in the form that would be actually transmitted during the flight tests. Each tape, therefore, contained two 400 word tests, one on each track of a two-track tape. The lists on the test tapes were arranged so that each test tape contains two unique tests. No test contains the same words read in the same order by the same talker, and no talker read a scrambling order read by any other. In addition, the talkers were rotated at the beginning of each test recording.

These extensive scramblings and randomizing procedures were carried out to ensure that no memorization of word orders could occur, particularly since many tests would be repeated due to multiple recording of simultaneous modem tests.

5. Summary

In order to fulfil the requirement for conducting a large-scale intelligibility test programme and to minimize the use of satellite and aircraft flight time, a number of major modifications of standard test procedures using the PB-50 words of ANSI Standard S3.2-1960 were implemented. Reading rate was increased to one word per 2.5 s, the carrier phrase was dropped, the tests were limited to 400 words per test and a large number of scramblings of the word lists were generated.

Increasing the reading rate to one word per 2.5 s and eliminating the carrier phrase produced no change in the listeners' performance. Concern for memorization of the word lists was eliminated by creating 68 different scramblings and having four talkers read seventeen different scramblings each.

REFERENCES

ANSI [1960] American National Standards Institute. Method for measurement of monosyllabic word intelligibility. Report No. S3.2-1960. Washington, DC, USA.

MILNER, P. [June, 1973] Advantages of experienced listeners in intelligibility testing. *IEEE Trans. Audio and Electroacoustics*, Vol. AU-21, 161-165.

MILNER, P. and GOLAB, J. [April, 1975] Intelligibility of voice transmission through a satellite relay system. *J. Acous. Soc. of Amer.*, Vol. 57-Supp.1, 23.

For information, see Reports 766 and 510 (Kyoto, 1978), Section 8F.

RECOMMENDATION 591 *

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-136 MHz

(Question 61/8)

(1982)

The CCIR,

CONSIDERING

(a) that high-powered FM broadcasting service operations in close geographic proximity to aerodrome facilities are at times incompatible with airborne ILS, VOR and VHF communications equipment utilizing those facilities, and that this is a widely recognized problem among many users of aviation facilities in the Northern Hemisphere of ITU Region 2 and parts of Region 1;

(b) that in accordance with RR No. 44, the aeronautical radionavigation service is "A radionavigation service intended for the benefit and for the safe operation of aircraft";

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* The Director, CCIR, is requested to bring this Recommendation to the attention of the International Civil Aviation Organization (ICAO), to the FM Broadcasting Conference (Region 1) and Study Groups 1 and 10.

(c) that FM broadcasting transmitters employ power levels which are relatively much higher than aeronautical services transmitters;

(d) that aeronautical radionavigation and communication receivers have varying degrees of signal sensitivity and susceptibility to interference;

(e) that high power broadcasting transmissions may cause interference to airborne receivers, depending upon relative distance between the transmitter and receiver;

(f) Recommendation No. 704 of the World Administrative Radio Conference (Geneva, 1979) (WARC-79) which addresses potential interference problems between the FM broadcasting service and the aeronautical radionavigation service;

(g) Resolution No. 510 of the WARC-79 relating to a Planning Conference for Sound Broadcasting in the Band 87.5-108 MHz for Region 1 and certain countries in Region 3,

UNANIMOUSLY RECOMMENDS

1. that administrations be invited to advise the broadcasting and aviation communities of the potential FM broadcasting and aeronautical systems incompatibility problem;

2. that administrations develop or, where applicable, strengthen coordination procedures between the aviation and broadcasting communities to minimize future problems;

3. that Report 929 be used as the best available guidance to date on the above matters.

REPORT 929 *

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-136 MHz

(Question 61/8)

(1982)

1. Background and introduction

Frequency modulation (FM) broadcasting service interference to airborne instrument landing systems (ILS) localizer, VHF omnidirectional radio range (VOR) and VHF communications equipment ** is a widely recognized problem among users of aviation facilities in the Northern Hemisphere of Region 2. In this region, the FM broadcasting service operates in the 88-108 MHz band and has caused interference problems in the adjacent VHF aeronautical services band 108-136 MHZ. In Region 1 the FM broadcasting band will be expanding up to 108 MHz, and therefore administrations in that region may experience interference problems in the future.

In air/ground communication receivers, this interference problem ranges from nuisance background FM broadcasting audio to distorted and garbled reception. In airborne ILS localizer and VOR receivers, the interference problem ranges from nuisance background FM broadcasting audio to errors in course deviation and flag operation. The interference to these navigation receivers is thought to be the more serious problem, as an error in course deviation, especially during the critical approach and landing phase, is not as readily evident to the pilot as the disruption of communications.

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* The Director, CCIR, is requested to bring this Report to the attention of Study Group 10 and to the International Civil Aviation Organization (ICAO).

** For a description of the ILS, VOR and VHF communications systems, attention is drawn to Report 927.

The level of interference to aircraft receivers is usually most severe at airports having major FM broadcasting facilities nearby, and the interference varies with the type of aircraft and associated navigation and communication (NAV/COM) equipment. The problems experienced are the result of factors such as:

- FM broadcasting stations operate in Region 2 with high-power levels of up to 100 kW e.r.p., whereas aeronautical facilities such as air/ground communication transmitters and ILS localizers operate at low-power levels, in the order of 0.02 kW e.r.p.
- Spurious emissions from FM broadcasting stations.
- The susceptibility of existing airborne receivers to this form of interference. (The minimum performance standards of airborne receivers have not, to date, addressed the problem of high-powered, adjacent FM broadcasting.)
- Lack of a guard-band between the highest assignable frequency for FM broadcasting and the lowest assignable radionavigation frequency.

There is an increasing probability of harmful interference due to the growing need for additional aeronautical frequency assignments and the growing number of FM broadcasting applications for new frequencies, power increases and relocation.

2. Types of interference mechanisms

2.1 There are several mechanisms by which interference from FM broadcasting can occur and these can be divided into two types:

Type A : due to radiation in the aeronautical band.

Type B : due to radiation relatively near to, but outside, the aeronautical band.

2.2 Type A mechanisms comprise those cases where the components or results of broadcasting transmissions fall within the aeronautical bands.

In all these cases the undesired radiation lies within the operational channel of the wanted signal and hence no rejection of the unwanted signal is possible at the airborne receiving system. Suppression at source and/or distance separation are the only effective cures. In the case where the broadcasting frequency and the radionavigation frequency are both close to the common band edge the separation distance required may be substantial.

2.3 *Type B mechanisms include:*

2.3.1 Intermodulation generated in an airborne receiver as a result of the receiver being driven into non-linearity by a high-powered broadcasting signal near to, but outside, the aeronautical band. In this case at least two broadcasting signals need to be present and they must have a frequency relationship which, in non-linear combination, can produce an intermodulation product within the wanted RF channel in use by the airborne receiver. One of the broadcasting signals must be powerful enough to drive the receiver into regions of severe non-linearity but interference may then be produced even though the other signal(s) may be significantly less powerful.

2.3.2 "Front end overload"/"desensitization" which occurs when an airborne receiver RF section is overloaded by a single (or multiple) broadcasting transmission outside the aeronautical band. The effect arises because the RF selectivity of airborne receivers is relatively wide-band and it is difficult to provide sharp RF "cut-off" immediately below 108 MHz.

3. Current experience and tests

3.1 *The United States of America*

3.1.1 In Region 2, where the band of 88-108 MHz has been in use for FM broadcasting for some time, there have been numerous proven cases of interference to aviation services in the band 108-136 MHz as a result of these adjacent broadcasting services [Sawtelle and Dong, 1978]. This has led to an extensive study in the United States. These studies, which included flight tests at low altitude and laboratory measurements, identified FM broadcasting interference at many locations which were investigated. The interference was particularly noticeable and more dominant in or near cities where several high-power FM broadcasting stations were operational. Situations were identified in which the FM signals interfered with both airborne communication and navigation receivers. The tests also indicated that the sensitivity of the airborne receivers is significantly reduced by high-power FM signals.

3.1.2 In the United States, a coordination procedure has been developed to evaluate the effect of high-power FM broadcasting stations on airborne VHF communication and navigation systems. Tests of airborne receivers indicated that at least one strong FM signal (prime signal) was required to force the receiver RF into non-linear operation. Once the receiver was operating in the non-linear mode, the prime signal could mix with other signals 10 to 20 dB lower in level (secondary signals) to produce harmful intermodulation products. Testing of receivers indicated that the minimum prime signal at the input to the receiver was approximately −10 dBm for airborne communication receivers and −20 dBm for airborne navigation receivers. The minimum secondary signal level for both types of airborne systems was approximately −30 dBm. By assuming a lossless isotropic receiver antenna, no line loss, and free space propagation loss, * contour distances corresponding to received power levels of −10, −20, and −30 dBm can be calculated using the following formula:

$$d = \frac{\log^{-1}(e.i.r.p. - P - C - L_R)/20}{f}$$

where:

d: contour radius in nautical miles;

C: 37.8 for d in nautical miles, or 32.4 for d in kilometres;

e.i.r.p.: equivalent isotropic radiated power of the FM broadcasting station in dBm (e.i.r.p. = e.r.p. + 2.15 dB);

f: FM centre frequency in MHz;

P: contour power level desired, either −10, −20, or −30 dBm;

L_R: avionics antenna out-of-band rejection.

Out-of-band avionic antenna rejection (L_R) can be found as follows:

For a navigation antenna:

L_R = 3 dB plus 1 dB/MHz below 108 MHz.

For a communication antenna:

L_R = 10 dB for FM signals from 100-108 MHz;

or:

L_R = 10 dB plus 2 dB/MHz below 100 MHz for FM signals from 88-100 MHz.

The out-of-band antenna rejection value (L_R) is subject to wide variations which are a function of airborne antennas and installation differences.

Figures 1 and 2 give a pictorial presentation of the interference prediction method of the coordination procedure.

3.1.3 *Communication example* (Type B)

In this example, FM station No. 1 is presently operating on 96.5 MHz with 100 kW e.r.p. and is located approximately 30 nautical miles (55.5 km) from the airport. FM station No. 2 is being proposed to operate on 107.9 MHz with 100 kW e.r.p. at a location approximately 3 nautical miles (5.6 km) from the airport. An interfering intermodulation signal is predicted on the airport tower frequency 119.3 MHz ($2 \times 107.9 - 96.5 = 119.3$). The solid circle indicates the −30 and −10 dBm contours for FM stations No. 1 and No. 2, respectively. The cross-hatched area indicates the area where intermodulation interference in avionic receivers is likely within the service volume of the control tower frequency. If the antenna rejection of the airborne communication antenna is considered, the respective interference contours would recede to those shown by the broken circles. In this case intermodulation interference is significant only when the airborne communication antenna provides no rejection of the FM band. Even if FM station No. 1 was not involved, interference could result from the assignment of FM station No. 2 within the service volume of the tower frequency due to receiver front end overload or spurious interference. The method used to predict spurious interference and front end overload is described in § 3.1.5 and 3.1.6 below.

* Free space loss closely approximates median transmission loss curves when transmitter and receiver are within line-of-sight (LOS). LOS for an aircraft about 1500 m (5000 feet) would be a minimum of 87 nautical miles regardless of FM station antenna height.

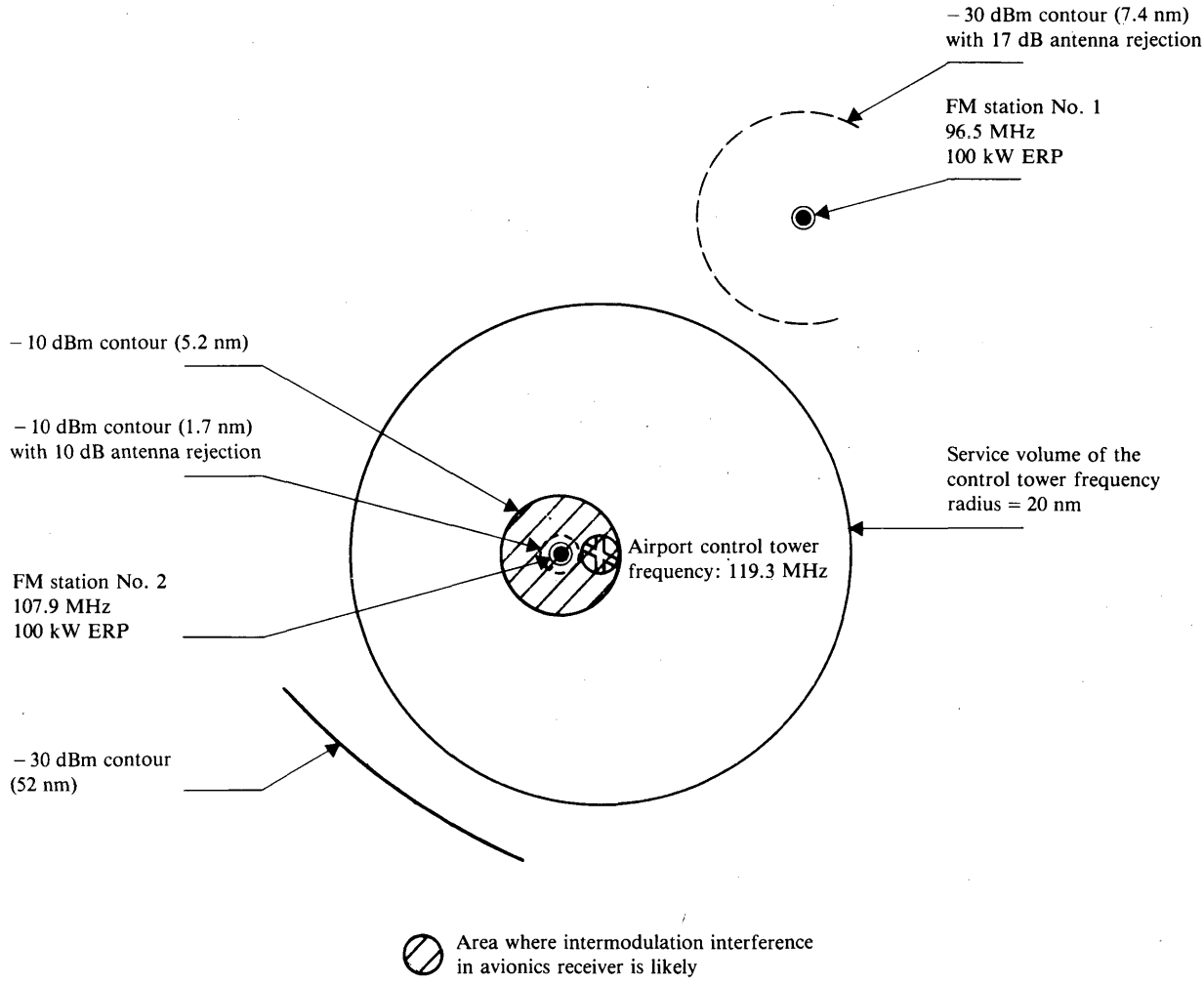


FIGURE 1 – *Example of method used to predict interference to communications receivers*

nm: nautical miles

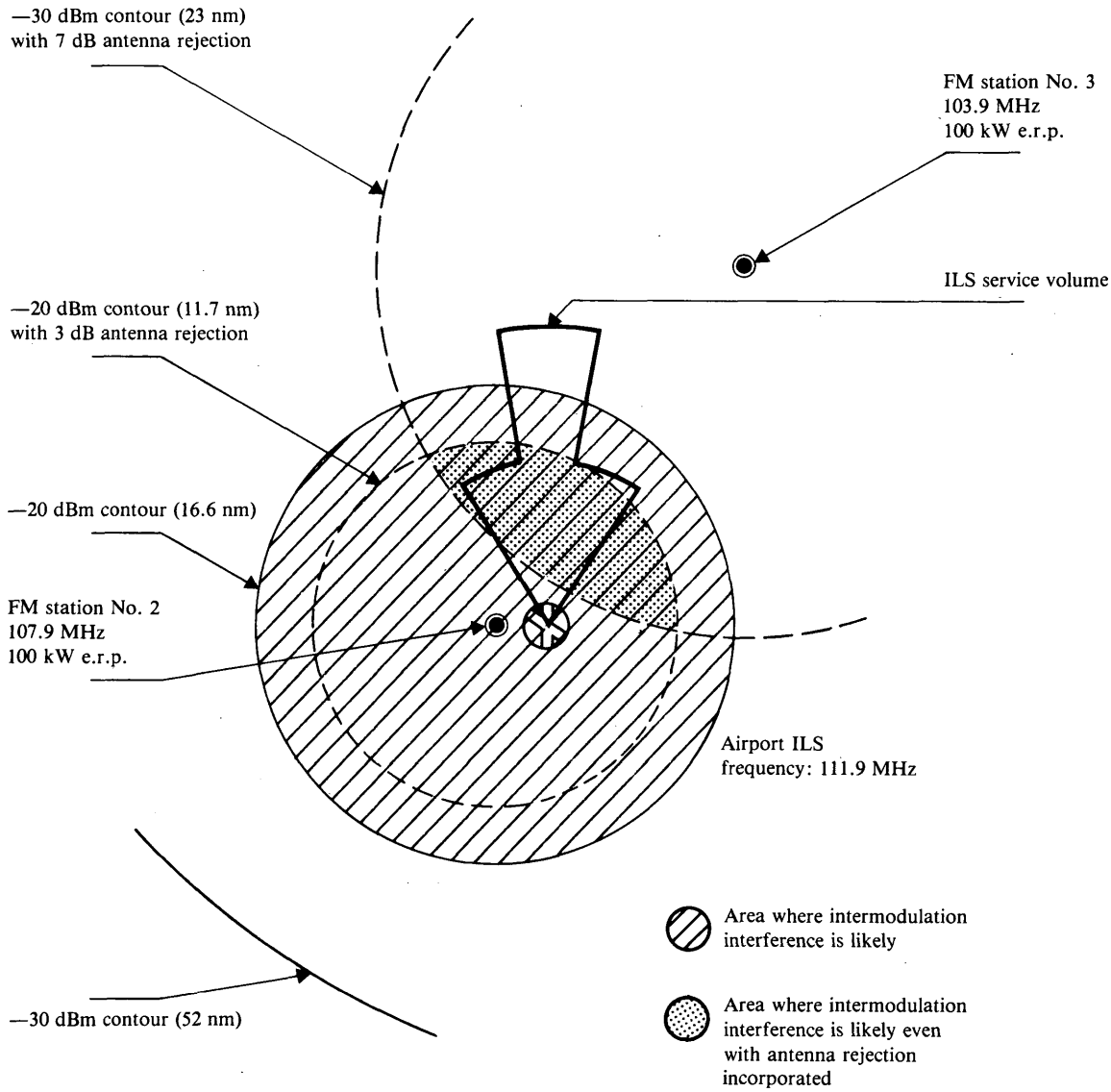


FIGURE 2 – *Example of method used to predict interference to navigation receivers*

nm: nautical miles

3.1.4 *Navigation example* (Type B)

In this example, the existing FM station operates on 103.9 MHz with 100 kW e.r.p. at a location approximately 25 nautical miles (46 km) from the airport. The affected navigation facility is an ILS localizer operating on 111.9 MHz (2 × 107.9 − 103.9 = 111.9). The service volume of the ILS is indicated by the "keyhole" pattern in Fig. 2. A −20 dBm contour was used as the prime signal level. The intersection of the −30 dBm contour from FM station No. 3 with the −20 dBm contour from FM station No. 3 indicates a wide area of potential intermodulation interference covering most of the localizer service volume (cross-hatched area). Even the application of aircraft antenna rejection would still result in an area of potential intermodulation interference along a critical portion of the ILS approach path (shaded area).

3.1.5 *Interference from spurious emissions* (Type A)

The spurious interference occurs when the receiver responds to components of the FM signal which are introduced into the aeronautical frequency bands, and, thus, within the receiver (IF) response. The major factors involved in calculating interference of this form are the receiver sensitivity, the FM spurious emission limits, and the power (e.i.r.p.) of the FM station. The antenna, filter, and receiver selectivity of the aeronautical systems under these conditions have no effect as the FM spurious emission is an on-frequency interfering signal. Thus, spurious interference to VHF aeronautical systems can occur when: e.i.r.p. $- L_D - S_R \geqslant R_S$ and,

where:

e.i.r.p. : equivalent isotropic radiated power of the FM station in dBm (e.i.r.p. = + 2.15 dB);

L_D : free space transmission loss in dB;

S_R : spurious emission limit in dB below the FM station power;

R_S : receiver sensitivity in dBm.

For FM station No. 2 provided in the Fig. 1 and 2 examples:

e.i.r.p. = 164 kW or 82.15 dBm (for e.r.p. = 100 kW);

L_D = 37.8 + 20 log (119.3) + 20 log (3) = 88.88 dB;

S_R = 80 dB (This would represent the worst-case spurious emission level which could be encountered in the United States if the spurious emission limitation is 80 dB below the station power on frequencies separated more than 600 kHz from the carrier.)

R_S = −97 dBm (typical for most airborne receivers).

Therefore: 82.15 dBm −88.88 dB, −80 dB = −86.73 dBm which is approximately 10 dB greater than the typical aeronautical receiver sensitivity, therefore, spurious interference is possible under these conditions. If FM station No. 2 in Fig. 1 was moved to a location approximately 9.8 nautical miles (18.2 km) from the airport, or if the power of the FM station was reduced 8 dB, or if the maximum spurious radiation was limited to 88 dB below the fundamental frequency, aircraft receivers and aeronautical ground facilities at the airport would be protected from FM broadcasting spurious interference. Little can be done to protect aircraft flying in the immediate vicinity of a radiating high-power FM broadcasting station antenna as current state of the art aeronautical receivers were not designed to operate in a high-power environment.

3.1.6 *Aeronautical receiver overload* (mainly Type B)

Front end overload or desensitization of an aeronautical receiver occurs when the receiver RF section is driven into non-linear operation by the high-power FM signal. Intermediate frequency selectivity will not provide any protection as the overload occurs in the broadband RF section which will usually respond to most signals in the FM broadcasting frequency band. Tests have shown that an FM signal level of from 0 to −10 dBm at the input of the aeronautical receiver is sufficient to overload the receiver. The example, of FM station No. 2 in Fig. 1 and 2 portrays the area of potential interference and illustrates how moving the broadcasting station one mile further away from the aerodrome would protect the airport ILS and control tower frequencies from FM broadcasting interference [Sawtelle and Dong, 1978].

3.1.7 *Conversion to field strength*

In order to provide more meaningful results the airborne receiver input levels used in the above procedure need to be converted into field strength values. In practice such a conversion is known to exhibit considerable variation in values. However, bearing in mind the guidance nature of the coordination procedure presented above, the simple assumption of an isotropic antenna and a loss-less feeder cable has proved adequate in the context.

3.2 *France*

3.2.1 Tests are also being carried out in France in a joint exercise between the aeronautical and broadcasting authorities. These tests have so far concentrated on ILS airborne equipment and three ILS receivers belonging to different quality categories were selected: receiver A was a bench-measurement receiver, receivers B and C were typical of general-aviation type and light aircraft type respectively.

3.2.2 The interference criterion chosen for the first tests concerned the desensitization effect on the guidance current output of the ILS receiver. The normal full scale deflection current is represented by 150 microamperes and a desensitization reduction of 20 microamperes from this maximum value was chosen. (This criterion is different from that used in other tests described in this Report, and the question of a "standard" criterion is discussed in § 4.1 later.)

3.2.3 In these tests pairs of "unwanted" signals (F_1 and F_2) were selected to produce an intermodulation relationship of $2F_1 - F_2 = F_3$, where F_3 is the ILS frequency. F_1 and F_2 were varied and the results are shown graphically in Fig. 3.

3.2.4 Despite the different interference threshold criterion used, the results show a good measure of consistency with the -20 dBm concept adopted by the United States (see § 3.1.2). In particular it should be noted in Fig. 3 that the curves intercept the $-20/-20$ point to a close degree.

3.3 *Finland*

3.3.1 A limited number of laboratory tests on ILS-localizer receivers were performed in Finland using most unfavourably likely combinations of unwated signals and relatively stringent criteria for the interference threshold (a maximum fluctuation in the ILS-localizer centering current of $\pm$ 1 μA for equipment designed for Category III operations and ± 4 μA for Category I operations). Preliminary results of these studies suggest that intermodulation problems may arise in some receivers when two unwated signals at a level of $\geqslant -45$ dBm on frequencies 600 kHz and 1200 kHz below that of the wanted ILS-signal are fed into the receiver. Desensitization with one unwanted signal might correspondingly take place at about -20 dBm. There was a great variation in intermodulation response rejection and desensitization performance amongst the receiver types tested.

3.3.2 These tests suggest further that, depending on receiver design (including the audio signal processing units), a protection ratio of the order of 20-30 dB against a co-channel wideband frequency modulated unwanted signal would be required.

3.3.3 The above comments represent a preliminary assessment and studies are continuing.

3.4 *Future tests*

The tests and investigations detailed above are continuing and will include further examination of ILS, VOR and VHF R/T equipments. Tests are also underway within other administrations.

4. Discussion of specific aspects of the problem

4.1 *The definition of a harmful interference threshold*

4.1.1 Although there has been considerable discussion and examination of the matter no universally acceptable quantitative definitions of the harmful interference threshold for ILS, VOR or VHF R/T have yet been determined. Concentrating on ILS, for instance, the following different approaches have been used, advocated or discusssed and each has its merits:

- an aberration of the course guidance current of 5 microamperes or greater (Report 927);
- an aberration of the course guidance current of 1 microampere (Category III ILS) or 4 microamperes (Category I ILS) (see § 3.3 of this Report);
- a 20 microampere reduction in the full-scale deflection of the course guidance current, due to desensitization (see § 3.2 of this Report);
- a reduction (of an amount yet to be determined) of the "flag" current, separately from or in addition to a guidance current criterion.

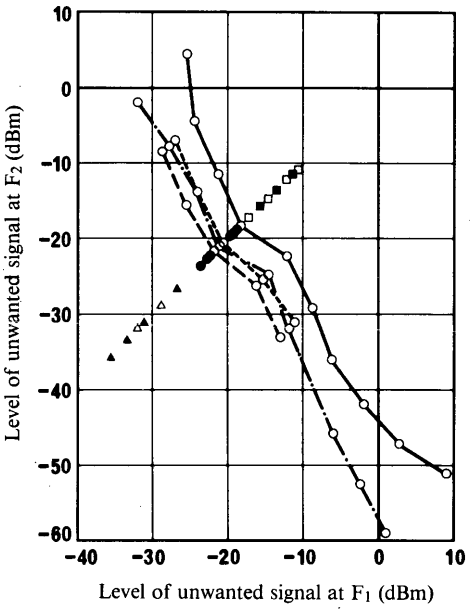


FIGURE 3 – *Levels of interference to ILS reception (F_3) by two broadcast emissions (F_1 and F_2)*

Receiver	104,1 99,1	107 104,9
A	△	▲
B	○	●
C	□	■

1. $F_1 = 104.1$ MHz, $F_2 = 99.1$ MHz

——— : "Wanted" ILS signal level = —66 dBm
·— — — : "Wanted" ILS signal level = —72 dBm
—·—·— : "Wanted" ILS signal level = —79 dBm
— — — : "Wanted" ILS signal level = —86 dBm

} Receiver B in all cases

△ Single points for above "wanted" ILS signal conditions but with Receiver A
□ Single points for above "wanted" ILS signal conditions but with Receiver C

2. $F_1 = 107.0$ MHz, $F_2 = 104.9$ MHz

● Single points for above "wanted" ILS signal conditions but with Receiver B
▲ Single points for above "wanted" ILS signal conditions but with Receiver A
■ Single points for above "wanted" ILS signal conditions but with Receiver C

Notes – a) $2F_1 - F_2 = F_3 = 109.1$ MHz in all cases
b) F_3 = ILS channel
c) Interference criterion = 20 μA reduction in full-scale deflection of ILS guidance current due to desensitization.

4.1.2 The main difficulties preventing the selection of a commonly acceptable ILS harmful interference criterion are:

- There are several ways in which interference to ILS has been known to manifest itself – involving either (or both) guidance current and flag current and also the audio identification channel.
- A very wide range of airborne equipment types and installation variations exist, and the degree to which each can be affected by FM broadcasting transmissions varies considerably.

4.1.3 Theses difficulties have, in fact, led one administration to adopt an approach which addresses the problem by identifying an ILS airborne receiver unwanted signal input level above which practical experience has led that administration to expect harmful interference to occur by one or other means. This is the "prime signal" concept of −20 dBm (for ILS/VOR) or −10 dBm (for VHF R/T) described in § 3.1 of this Report. The administration concerned uses these signal levels (coupled with a simple assumption about the conversion factor from receiver input level to received field strength) as a basis leading to a more detailed coordination process, under which the aeronautical and broadcasting authorities examine the individual cases in detail. This is thus a pragmatic approach, well suited to the circumstances where the allocation of the band up to 108 MHz for FM broadcasting has existed for some time and the problems have been discovered by experience as they have occurred.

4.1.4 With this valuable experience it is clearly important that in regions where frequencies up to 108 MHz are not yet available for the broadcasting service, serious consideration needs to be given to means of *preventing* the problems from occurring. In this respect sufficient information is not yet available to define a protection criterion (e.g. in terms of maximum acceptable unwanted field strength or protection ratio) with complete confidence. Nonetheless the values used in the coordination method described in § 3.1 (which have the important benefit of being based on actual experience) are regarded as good practical guidance at this time.

4.1.5 For the future, particularly where airborne equipment measurements are concerned, it is important to note that *all* of the following parameters appear to be relevant in determining a harmful interference threshold for ILS:

- centering errors;
- changes in course width;
- alterations in flag operation;
- audio channel effects.

Accordingly, further study of these parameters is important with a view to the future establishment of appropriate quantified values for international acceptance. This would in turn lead to a better knowledge of the corresponding unwanted field strengths and/or protection ratios and hence a refinement of the coordination procedures.

4.1.6 As far as VOR is concerned the interference mechanisms are of a similar nature to ILS but far larger coverage volumes are involved. For VHF R/T where interference effects will range from a nuisance background noise to distorted and garbled speech – perhaps during a critical aircraft operation – the assessment is very subjective and will also vary with operational circumstances. Therefore the quantification of a suitable protection criterion will be particularly difficult.

Considering the above VOR and VHF R/T points, a pragmatic approach as described in § 3.1 based on experience has considerable merit and again is regarded as the best guidance at this time.

4.2 *Airborne equipment*

4.2.1 *Current international standardization principles*

Airborne equipment is subject to a very high degree of national and international standardization. However this has always been directed towards those aspects which ensure:

- an adequate performance under ICAO-specified conditions of wanted signal-in-space;
- interchangeability of equipment between manufacturers;
- safety when carried onboard aircraft (e.g. fire risk, etc.); and
- specified minimum performance over a specified range of temperature, pressure, etc.

As far as electromagnetic compatibility is concerned the international standardization has also had to ensure that adequate adjacent channel rejection characteristics are specified – and in turn this becomes a key factor in the extensive national and international coordination of frequency assignment activity within the aviation community. In addiion very stringent conditions are laid down to ensure that airborne equipment does not adversely affect, and is not adversely affected by, other airborne equipment installed in close proximity on the aircraft.

The scope of the standardization of airborne equipment has, however, necessarily had to take cognizance of the vital fact that the airborne system is not capable of standardization on those aspects which are affected by differences between airframe types. The antenna and feeder characteristics are the main areas of difficulty here, because the airframe exerts considerable influence over the antenna and feeder characteristics and very wide variations exist. In consequence, ICAO traditionally tends to specify "signal-in-space" characteristics to ensure minimum acceptable performances and airborne equipment design has sought to ensure that the "black boxes" will be adequate to process the wanted signals under adverse antenna/feeder circumstances.

4.2.2 *Current equipment and expected improvements*

Tests so far carried out on airborne receivers, including those described in § 3 of this Report, have shown wide variations in those characteristics and susceptibilities relevant to the rejection of very high-level unwanted signals. The poorer performance receivers are usually associated with general aviation aircraft, which form the majority of aircraft flying today. Improvements in the minimum acceptable performance standards in respect of high-powered unwanted signals are, however, already in the process of being introduced by the appropriate regulatory authorities; although this is necessarily a long-term exercise which will result in a phased practical improvement over a fairly large number of years. Short-term improvements may be possible on a case-by-case basis (for example, in the form of add-on RF rejection filters) but these methods are not considered as feasible general solutions.

It is, however, very important to note that there are practical limits to the technical improvements that can be realized in both the short- and long-terms, and therefore airborne equipment improvements cannot reasonably be expected to resolve all compatibility problems with the FM broadcasting service. Accordingly, close coordination between aeronautical and broadcasting authorities will continue to be required in the long-term.

4.2.3 *A future standard airborne system characteristic*

From the viewpoint of providing long-term stability in the planning of aeronautical and broadcasting services in their respective bands each side of 108 MHz, in a situation where complete compatibility is clearly most unlikely, the development of a standard airborne equipment characteristic (i.e. against which broadcast planning can proceed with confidence) is an important aim. The setting of such a standard would provide the aeronautical community with a high degree of confidence that airborne systems meeting the standard would have an acceptably low risk of suffering from harmful interference from FM broadcasting in most cases. Similarly the broadcasting community could then proceed and develop in the knowledge that any restrictions then remaining would be reflecting a reasonable consequence of the basic problem of the incompatibility of adjacent "high" and "low"-powered services.

It would seem that the simplest (and probably the best) way in which such a standard could be defined would be in the form of a maximum permitted field strength at the airborne antenna due to the FM broadcasting transmission. This value would probably be a function of the frequency difference from 108 MHz.

5. Summary of study

The study of potential interference between the FM broadcasting service and the aeronautical radionavigation services in the band 108-118 MHz, has received considerable attention in a number of Administrations as reported above. These studies take on a special importance in regions where the band up to 108 MHz will shortly become available to FM broadcasting and where, therefore, broadcast planning is imminent.

It has not been possible at this stage to establish simple protection ratio values or other criteria which could readily and with confidence be applied in a general assignment planning for the FM broadcasting service in order to prevent harmful interference from occurring to the existing and planned aeronautical radionavigation and aeronautical mobile (R) services.

It is evident that no simple technical solutions to the incompatibility problem are immediately available. The interference potential from high-powered FM broadcasting stations (singly or otherwise) to ILS, VOR and/or VHF R/T will depend on many factors. Apart from airborne equipment performance itself, the most important factors as shown in § 3 with embrace combinations of:

- broadcasting transmitter power (e.r.p.) and antenna characteristics (height, directivity, etc.);
- separation distances;
- frequency separation;

– frequency relationships;

– geographical and topographical aspects.

In this Report § 2 explains, how all the interference mechanisms can be divided into two main categories, Type A and Type B.

Some examples of each type of interference to VHF-radionavigation and R/T receivers are shown in detail in § 3 and some conclusions arrived at in terms of theoretical geographical areas where interference is likely to appear, taking into account the different combinations and values of the above parameters.

Taking this framework into account, it will be possible for the administrations to consider throughout the process of planning, case by case, all the potential conflicts e.g. along the guidelines presented in this report.

At the implementation stage of the FM-broadcasting plan it will be necessary for the relevant broadcasting and civil aviation authorities to consider, in close cooperation, possible solutions to eliminate any potential interference problems between the two services.

6. Conclusions

6.1 The problem is complex and not capable of complete resolution by adoption of a single set of protection criteria. The complication is introduced mainly by the wide variability of aircraft equipment characteristics which need to be accommodated, particularly antenna/feeder characteristic variations between different airframe types.

6.2 The interference potential from Type A and Type B mechanisms both need to be addressed in practice. ILS and VOR in the sub-band 108-118 MHz have the greatest potential for serious difficulties (and at the same time are operationally the most critical from a safety viewpoint).

6.3 The volume of critical airspace to be protected in ILS cases is relatively small, but in the VOR and VHF R/T cases it may be very large.

6.4 Airborne equipment improvements to reduce the interference potential are already in the process of being progressed through the national legislations of several aviation administrations. These improvements will not solve the problems completely, and will take many years to be incorporated widely.

6.5 The calculations given in this Report show that the current requirements of the Radio Regulations (in respect of spurious emisssion limits for FM sound broadcasting transmitters above one kW) would possibly require large distance separations in order to avoid Type A interference problems. Suppression levels of better than 85 dB are known to have been achieved in practice in seeking solutions to specific cases of difficulty.

6.6 The guideline procedures in this Report strongly indicate that frequency assignment coordination and siting and suppression coordination will need to supplement any general criteria in order to reduce the interference potential. Because of the large line-of-sight distances involved this interference potential may exist across, as well as within, national boundaries.

6.7 For at least the Type A mechanisms, it is evident that adequate reduction of the levels of unwanted signals at the aviation receiver will involve the broadcasting power, the separation distance and the frequency separation. In this respect any ability to avoid the use of the highest powers at the broadcasting channels closest to 108 MHz will assist considerably in difficult cases in the vicinity of aerodromes.

6.8 Both the aeronautical and broadcasting services need to cooperate closely in order to minimise restrictions on their freedom to deploy their respective facilities.

7. General recommendations

7.1 Close and continuing assignment coordination between aeronautical and broadcasting authorities appears to be the only practical way to reduce the probability of harmful interference to the aeronautical services to generally acceptable levels.

7.2 Further study is required in order to develop standard harmful interference threshold criteria for the measurement of airborne ILS, VOR and VHF R/T system performance in the presence of high-powered FM broadcasting signals.

7.3 It is a highly desirable aim that standard airborne ILS, VOR and VHF R/T system characteristics be developed with respect to the rejection of unwanted signals outside the aeronautical band.

7.4 The coordination procedure described in § 3.1 of this Report is the best guidance available at this time.

7.5 This Report should be brought to the attention of administrations and other interested parties. This should be done urgently in the case of administrations involved in imminent FM broadcasting planning.

REFERENCE

SAWTELLE, E. M. and DONG, J. G. [July, 1978] Interference in communications and navigation avionics from commercial FM stations. FAA-RD-78-35, National Technical Information Service (NTIS) US Dept. of Commerce, Washington DC, USA.

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SECTION 8J: AMATEUR SERVICE: AMATEUR SATELLITE-SERVICE

Reports

REPORT 905

TECHNICAL INVESTIGATIONS IN THE AMATEUR SERVICE

(Question 48/8)

(1982)

1. Introduction

This Report describes examples of technical investigations undertaken by the amateur service. These investigations may result in new or improved spectrum conservation techniques and additional knowledge concerning spectrum sharing among telecommunications services. One motivation is a desire to develop reliable low cost communications systems and techniques.

2. Technical investigations

2.1 *Improved reliability of long-distance communications*

Amateurs are investigating long-distance relay communications in the 1260 to 1300, 2300 to 2450, 3300 to 3400, 5650 to 5925 MHz and other microwave frequency bands allocated to them. The knowledge gained about reliability, propagation, modulation, antennas interference and equipment design and costs is available to help in planning systems.

2.2 *Bandwidth compression*

A bandwidth compression technique called NBVM (narrow-band voice modulation) [Harris and Cleveland, 1978a and 1978b] has been developed. The second and third formants of speech, which do not occur simultaneously with vowel sounds, are inverted by down-conversion at the transmitter and restored at the receiver. This technique can reduce the bandwidth to about 1500 Hz and investigations at 1200 and 1000 Hz are being conducted.

Further investigations are proceeding, particularly as to performance in the presence of interference.

2.3 *Signal processing techniques*

Stations in the amateur service use several different voice processing techniques and are continuing to improve them, possibly leading to the development of entirely new systems to improve the effectiveness of communications.

2.4 *Voice-frequency telegraphy (VFT)*

VFT systems, often associated with microprocessor techniques, are in widespread use in the amateur service and further investigation and development of them may lead to improvements including more efficient error correcting codes and decoding algorithms.

2.5 *Computer communications*

The advent of personal microcomputers has resulted in extensive experimentation with computers by private individuals, including some in the amateur service. There is a trend towards merging these two experimental areas. One example is a type of packet radio technology that employs a host computer with multiple users. Amateur technical investigations of packet radio are underway in Canada [Hodgson, 1979]. Useful information can be expected to emerge, for example, about frequency sharing between packet radio systems and between packet radio users and others employing more conventional methods.

2.6 *Development of low-cost communications equipment*

Investigation in the amateur service has great influence on the design of equipment for minimum cost. This influence affects, for example, the design of J3E receivers, microwave equipment and equipment employing digital techniques.

2.7 *Selective filtering technique – aural selective devices*

Although the trained operator's brain is an effective interference-rejecting filter, many types of selective device are used within or following the audio section of the receiver to enhance that capability. For example:

2.7.1 *The stereocode filter (for Morse code reception)*

This filter makes use of the ability of the brain to focus upon a signal coming from given directions despite the presence of random interference (the "cocktail party effect") [Charman, 1975]. The filter splits the input into two channels, one for each ear, and between the two outputs produces delay and amplitude dispersion matched to those of normal hearing (see Figure 1). Thus over a given audio passband it produces an identical signal output at the mid-frequency but time dispersion of ± 500 μs and amplitude dispersion of $\pm$ 6 dB at the respective edges. With 700 Hz as the desired tone to be in phase at the two ears, this signal appears subjectively to be centered; signals above and below 700 Hz appear to originate from the left or the right. The brain is able to focus more intently on 700 Hz while being able to deflect attention to other signals as required.

2.7.1.1 Another filter based on the stereo concept uses highpass and lowpass audio filters with a common crossover frequency of 750 Hz or so. Signals in the upper part of the audio band appear in one ear, those in the lower part in the other; only the 750 Hz signal appears in both (Fig. 2).

2.7.1.2 With both these filters it is necessary to keep the audio level in each ear relatively low if the ability of the brain to direct attention to the "right" or the "left" is to be maintained. Under these conditions the two hemispheres of the brain are able to operate independently in a more efficient manner.

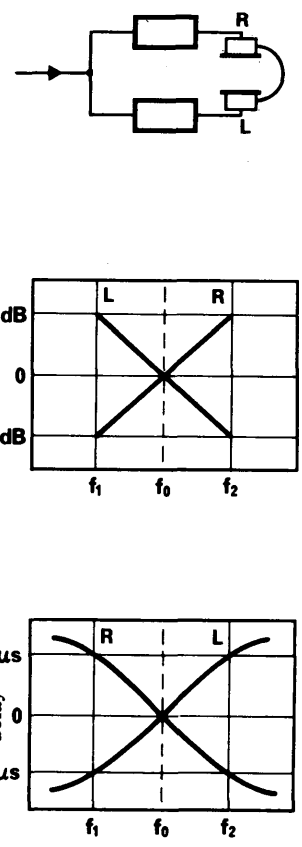


FIGURE 1 – *Stereocode filter. Gain and delay dispersion.*

R: right
L: left

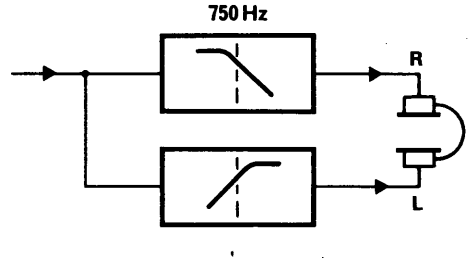


FIGURE 2 – *Stereocode using highpass-lowpass filtering.*

R: right
L: left

2.7.2 *The wideband-narrowband filter*

Many skilled operators use split headsets, with a traffic channel fed to one side and a secondary or guard channel fed to the other, usually having the traffic in the right ear as this ear is associated mainly with the left hemisphere of the brain, the side which in most people is most efficient in pattern recognition.

The filter shown in Fig. 3 enhances this capability by feeding a selected signal to one ear through a narrowband filter, and the full audio bandwidth to the other unfiltered but with controllable attenuation. The intrusive effect of the "off to the side" signals is then under control and can be eliminated completely if necessary. For the same reason explained in § 2.7.1.2 the audio level in both outputs must be kept relatively low.

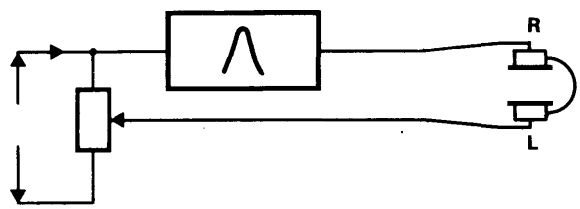


FIGURE 3 – *Wideband-narrowband selective filter.*

R: right
L: left

2.7.3 *The coherent audio filter*

This filter is designed to enhance a selected audio tone in the presence of intelligible interference and random noise (even from the "hash" radiated from power distribution lines). It works on the principle of the diversity combiner, but processes a single audio tone.

A delay line several cycles long provides samples at every half-cycle of the wanted frequency, which are then added in phase to enhance the signal at the expense of the incoherent noise [Charman, 1980]. Since the phase varies with frequency, coherence degenerates as the frequency moves away from the half-cycle value, and the effect is that of a narrowband filter with no ringing. Fig. 4 shows the basic principle and Fig. 5 the typical frequency response. This filter is especially useful where power line noise, statistically one of the most troublesome forms of local interference to communications below 8 MHz, is a problem. With most types of conventional narrowband filter, this kind of noise tends to be "bunched" into the narrow passband, completely obscuring a weak signal.

This filter technique should not be confused with "coherent CW" (CCW) [Terman, 1930; ARRL 1981] which is a systems technique involving the synchronization of transmitted and received signal; although the amplitude-vs-frequency response curves of the audio signal resulting from each system bear a marked resemblance in form, the bandwidth of the coherent audio filter is measured typically in hundreds of Hz whereas the bandwidth of the CCW system is measured in tens of Hz.

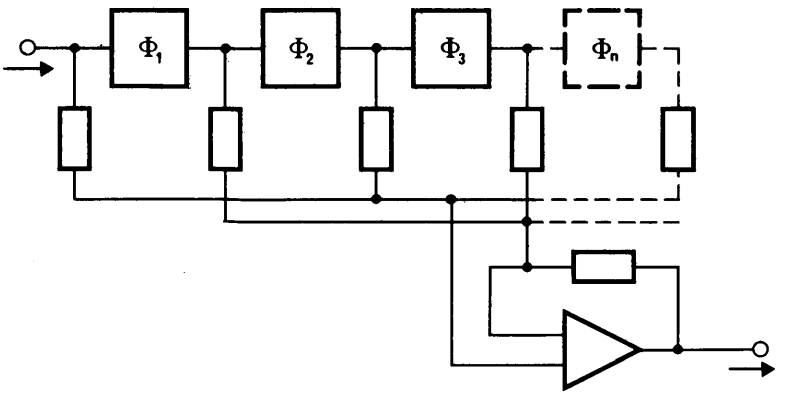


FIGURE 4 – *Coherent audio filter – basic concept.*

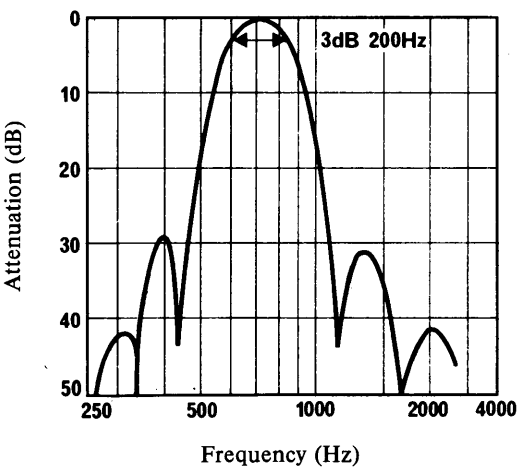


FIGURE 5 – *Coherent audio filter – frequency response.*

2.7.4 *Variable bandwidth filter*

Active filters with a variable bandwidth (typically 50-2000 Hz) and variable frequency (250-2500 Hz) are used in a peak-resonance and/or highpass or lowpass configuration. The bandwidth is normally selected to be as wide as possible consistent with adequate rejection of interference and noise; variation of the centre frequency lessens fatigue and allows the operator to shift troublesome interference into a "zero-beat" position.

The same filters can be switched into a frequency-rejection mode, with notches up to 60 dB deep and bandwidth ranging from 20 Hz upwards.

2.7.5 *The frequency-agile filter*

This filter [Tong, 1978] combines all the functions described in § 2.7.4 and has the added capability of locking on to a tone being peaked or rejected and tracking it automatically if its frequency changes. It can also be set to scan continuously "looking" for an interfering signal, lock on to it in the "reject" mode and track it. The automatic search facility is very useful when using a very narrow notch; when using a rejection filter to eliminate an interfering tone from a single-sideband signal it is difficult for an operator to concentrate both on understanding the voice and tuning for elimination of the interfering tone.

2.7.6 *Automatic gain control techniques*

When using automatic gain control in a receiver designed for morse code reception, it is usual to have a selection of time constants for the automatic gain control function. Even so, there are problems when the amplitude of the desired signal "pumps" in sympathy with AGC developed by a nearby stronger signal. In some receivers this is now overcome by deriving AGC from the demodulated audio and placing the audio filters in series between the detector and the AGC loop, thus gaining immunity from nearby signals while taking advantage of the protection afforded by automatic gain control.

REFERENCES

ARRL [1981] Coherent CW. *The 1981 Radio Amateur's Handbook*, 14-34. AARL, Newington, Conn., 06111, USA.

CHARMAN, F. [November, 1980] Coherent audio filters for CW reception. *Wireless World*, Vol. 86, **1538**, 67-71.

CHARMAN, F. and HARRIS, R. [September, 1975] Subjective selectivity and stereocode. *Radio Comm.*, 674-681.

HARRIS, R. W. and CLEVELAND, J. F. [November, 1978a] A baseband communications system (Part 1). *QST*, Vol. LXII, **11**, ARRL, Newington, Conn., 06111, USA.

HARRIS, R. W. and CLEVELAND, J. F. [December, 1978b] A baseband communications system (Part 2). *QST*, Vol. LXII, **12**, ARRL, Newington, Conn., 06111, USA.

HODGSON, I. [June, 1979] An introduction to packet radio. *Ham Radio*, Vol. 12, **6**. Communications Technology Inc., Greenville, New Hampshire, 03048, USA.

TERMAN, F. E. [January, 1930] Some possibilities of intelligence transmission when using a limited band of frequencies. *IRE Proc.*, Vol. 18, **1**, 167-177.

TONG, D. A. [February, 1978] Audio filters as an aid to reception. *Radio Comm.*, 114-118.

REPORT 906 *

FREQUENCY USAGE IN THE AMATEUR SERVICE

(Question 48/8)

(1982)

1. Modes of emission to be accommodated

In considering the ways in which the various frequency bands allocated to the service are employed by stations and groups, it is convenient to consider the information transfer mode as composed of families, one grouping being:

1.1 *Narrow-bandwidth systems*, including Morse code, teleprinter and very slow speed data and control. In addition, narrow-bandwidth voice modulation systems are coming into increasing use.

1.1.1 *Morse telegraphy (A1A class of emission)* owes its popularity to the relative simplicity of equipment; its effectiveness under conditions of low power, weak signals, or high noise; its inherent capability to bridge the language barrier between operators who do not speak the same language; and its narrow-bandwidth characteristics, which permit a very high density of stations in a heavily occupied band.

1.2 *Voice-bandwidth systems*, including single sideband, narrow-band frequency modulation and data systems using essentially the bandwidth of a voice signal.

1.3 *Television* activities fall in two major categories – conventional television using a bandwidth of approximately 4 MHz which is limited to UHF, and slow-scan television with a bandwidth of less than 1500 Hz, which is used primarily for the transmission of still pictures on HF. Recently, much attention has been devoted to spectrum-efficient techniques such as slow-scan. UHF television repeaters have been constructed by some groups to facilitate the exchange of picture transmissions.

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* This Report should be brought to the attention of Study Group 6.

1.4 *Extended-bandwidth systems*, including high deviation voice frequency FM, and data and control systems operating at low multiples of voice-bandwidths.

1.5 *Wide-bandwidth systems*, including high definition television, data systems of equivalent bandwidth, and pulse systems. The Amateur Service does not normally utilize the extremely broadband signals formed by ensembles of other signals.

2. Frequency usage in the HF band (1.7 to 30 MHz)

2.1 Because of the relatively low-power levels typically used by amateurs, absorption can be a significant barrier to communication if suitable orders of frequency bands are not available. The essential consideration in determining the bands for the amateur service was that there be allocations at increments of approximately 3 to 4 MHz throughout the HF spectrum. Such increments take into account the rapid variations of the MUF.

2.2 A band around 2000 kHz provides frequencies the propagation characteristics of which allow short range communications during the daytime hours and medium and long range communications during the night-time hours. This band is particularly useful during sunspot minima, when the MUF is below most of the amateur allocations in band 7 (3 to 30 MHz).

2.3 The amateur service is presently allocated spectrum in the 3.5, 7, 10, 14, 18, 21, 25 and 28 MHz bands. In addition to providing optimum bands for the international exchange of technical comments and ideas, these allocations also provide bands in which propagation phenomena are readily observable, including the effects in the auroral zones and the variation of ionization of the atmosphere due to changing solar activity. Because of the hourly, seasonal, and solar cyclic changes that affect the ionosphere and the MUF, the fact that bands are at increments of 3 to 4 MHz throughout the HF spectrum permits working close to the MUF at all times.

2.4 *Frequency bands 24 to 30 MHz*

The factors which cause propagation variability limit the usefulness of these bands for wideband data, and make them unsuitable for very wideband data. Narrow-bandwidth systems are usable for all propagation modes, and voice-bandwidth for all but some extremely variable scatter modes. Extended-bandwidth systems are usable for the dominant modes.

3. Frequency usage in the VHF bands (where allocated to the amateur service)

3.1 *Bands around 50 MHz*

The relatively low variability makes the band technically suitable for all information transfer modes used in the amateur service. The relative infrequency of sky-wave propagation, and the relatively low coupling of the scatter modes indicate that sharing on a regional basis is feasible. Frequencies around 50 MHz are used for local amateur communication, and for new technical investigation.

3.2 *144 to 148 MHz*

Transequatorial (TE) paths have been found useful over long distances. The discovery of TE propagation can be attributed in part to the increased activity in this band, arising from its use to provide regional coverage.

The relatively low variability makes this band technically suitable for all information transfer modes in the amateur service. The balance between natural and equipment noise makes this band suitable for Earth-moon-Earth communications using narrow-bandwidth techniques. It is very useful for local, regional and international communication, experimentation and self-training.

3.3 *220 MHz*

Technical factors regarding propagation and variability are essentially the same as for frequencies around 144 MHz. Factors relating to limits imposed by sharing, and by characteristics of services in adjacent bands, have reduced opportunities for amateur utilization of this band, but it is nevertheless used for technical investigation, and for local intercommunication.

4. Frequency usage in UHF and higher bands (where allocated to the amateur service)

4.1 *Bands around 430 MHz*

Factors relating to equipment limitations and to "percentage of available bandwidth" make these the lowest available bands for local wideband communication and experiment. The small propagation variability makes these bands operationally suitable for local functions requiring communication reliability (e.g. data transmission and repeater control and on-scene communications in emergencies). The lack of ionospheric effects makes the bands technically suitable for Earth-Moon-Earth regional and international communication and technical investigation using narrow to extended voice-bandwidths.

4.2 *Bands around 915 MHz*

Frequency bands around 915 MHz are ideal for local communication and technical investigation including wideband techniques, and for local functions involving communication reliability. The bands may be useful for amateur Earth-Moon-Earth communication and investigation.

4.3 *Bands around 1240 MHz and above*

Many serious investigations are proceeding in these bands. Access on a secondary basis to bands allocated to the radiolocation service permits operation and investigation in these bands. Interference to the radiolocation service is avoided by operational practices in the amateur service as well as by geographical and frequency separation. There is very significant technical investigation at microwave frequencies, especially around 10.5 GHz.

5. Frequency usage in the event of natural disasters

This aspect of the amateur service is recognized in Resolution No. 640 of WARC-79, and in footnote No. 510 in Article 8 of the Radio Regulations.

Emergency communication was provided after the earthquakes in Nicaragua (1972), Guatemala (1976), Italy (1976 and 1980), Romania (1977), Algeria (1980), after a dam disaster in India (1979), after the floods in Honduras (1974) and the United States (1977), as well as the hurricanes in the Caribbean (1980).

Implementation of the new allocations at 10, 18 and 24 MHz will greatly improve the emergency use of the amateur service bands. The improvement in efficiency resulting from the allocation of bands by WARC-79 is demonstrated in Annex I.

ANNEX I

INFORMATION RELATIVE TO THE AMATEUR SERVICE IN THE HF BAND

Table II shows the improvement in reliability of communication on three East-West paths, when frequencies of the order of 10 MHz are used. The following typical parameters were used:

Antennas:	horizontal half-wave dipoles 15.2 m above poor ground. Conductivity 0.001 S/m, dielectric constant 4 (paths 1 and 2).
	3-element Yagi, 19.8 m above poor ground (path 3).
Transmitter peak power:	1 kW.
Spectral noise density:	"suburban" man-made noise – 146 dB(W/Hz) at 3 MHz.
Mean S/N_0 ratio:	49 dBHz (15 dB in 2500 Hz).

Calculations were made at 3-hour intervals for the months of June, September and December with sunspot numbers of 10, 70 and 130. For each complement of frequencies, the highest reliability of each hour was used to obtain the average.

TABLE I – *Increase in communication capability resulting from the addition of the 10, 18 and 24 MHz bands*

Circuit	Sun-spot number	Month	Total daily hours in the 3.5, 7, 14, 21 and 28 MHz bands	Increase of communication capability using new bands							
				10 MHz		18 MHz		24 MHz		Total	
				Hours	%	Hours	%	Hours	%	Hours	%
Melbourne to Tokyo	10	III	27	06	22	07	26	–	–	13	48
		VII	27	02	07	–	–	–	–	02	07
		IX	23	03	13	–	–	–	–	03	13
		XII	28	02	07	02	07	–	–	04	14
	100	III	64	12	18	16	25	10	16	38	59
		VII	40	10	25	10	25	–	–	20	50
		IX	57	12	21	14	25	05	09	31	54
		XII	44	10	23	16	36	01	02	27	61
Melbourne to San Francisco	10	III	16	03	19	–	–	–	–	03	19
		VII	20	03	15	–	–	–	–	03	15
		IX	17	01	06	–	–	–	–	01	06
		XII	21	–	–	–	–	–	–	–	–
	100	III	33	10	30	04	12	04	12	18	54
		VII	20	05	25	05	25	–	–	10	50
		IX	29	08	28	03	10	06	20	17	53
		XII	19	–	–	03	13	01	04	04	17
Sydney to Perth	10	III	23	09	39	–	–	–	–	09	19
		VII	28	10	36	–	–	–	–	10	36
		IX	20	09	45	–	–	–	–	09	45
		XII	24	09	38	–	–	–	–	09	48
	100	III	40	16	40	01	03	–	–	17	43
		VII	36	13	36	01	03	–	–	14	39
		IX	39	12	30	–	–	–	–	12	30
		XII	26	14	54	–	–	–	–	14	54

All figures derived from computer studies based on ESSA Technical Report ERI 110-ITS. [ESSA, 1978]

Reliability of 90%, field strength greater than 1 μV/m for power1 kW.

Antenna: 3.5 to 10 MHz half-wave dipole, 13 m above ground;
14 to 30 MHz 3 element Yagi – spacing 0.2 λ, 13 m above ground.

TABLE II

Path	Bands (MHz)	Reliability during the month (%)								
		June			September			December		
		Sunspot number, R_{12}								
		10	70	130	10	70	130	10	70	130
Vancouver-Toronto (3367 km) path 1	7, 14, 21	56	60	59	55	61	64	73	76	76
	7, 10, 14, 21	62	67	65	64	69	69	74	77	83
Vancouver-St. Johns (5013 km) path 2	7, 14, 21	29	30	32	17	36	36	25	47	53
	7, 10, 14, 21	38	41	39	29	44	43	33	48	56
Toronto-Tokyo (10352 km) path 3	7, 14, 21	11	24	16	16	19	33	23	27	31
	7, 10, 14, 21	16	24	16	24	32	34	32	40	43

REFERENCE

ESSA [1978] Technical Report ERI 110, Institute for Telecommunications Sciences, Boulder, Colo., USA.

REPORT 542-1 *

TECHNICAL FEASIBILITY OF FREQUENCY SHARING BY THE AMATEUR SATELLITE SERVICE

Interference potential of amateur satellites in shared bands

(Question 50/8)

(1974-1978)

1. Introduction

It was shortly after the first demonstration of the practicability of electromagnetic wave communication without wires that radio amateurs began to experiment with radio transmission. Over the years since 1896 radio amateurs around the world have contributed significantly to the development of radio communication. Today they are involved in a wide range of communication activities which include some of the most modern techniques [CCIR, 1974-78]. In particular they are communicating via satellites.

In recent years several amateur radio organizations, with the active support of the International Amateur Radio Union and its member societies, have made contributions to the development of space techniques and experience. Project Oscar, Inc. (Orbiting Satellites Carrying Amateur Radio), an organization formed in 1960 by amateurs on the west coast of the United States, developed and arranged launches for four amateur radio satellites of the Oscar series. A fifth Oscar satellite was constructed by Project Australis, an amateur group in Melbourne, Australia, and the flight qualification tests and launch were arranged by the Radio Amateur Satellite Corporation of Washington, D.C., with the co-operation of the National Aeronautics and Space Administration.

A sixth Oscar satellite (AMSAT-Oscar-6) was launched in October 1972, after assembly in the United States, using systems built by amateurs in Australia, the Federal Republic of Germany and the United States AMSAT-Oscar-7 was launched in November 1974 into an orbit very similar to that of AMSAT-Oscar-6.

This Report treats questions concerning the administrative control of satellites in the amateur service and the interference potential of amateur satellites operating in shared bands.

Annex I summarizes the characteristics of Oscar-6 and Oscar-7.

Annex II is a report on the results of AMSAT-Oscar-6 and AMSAT-Oscar-7 experiments as of October 1975.

2. Administrative control of satellites in the amateur service

No. 2741 of the Radio Regulations requires that, in the case of amateur satellites to be operated in shared bands, the authorizing administration should ensure that a sufficient number of capable, reliable and responsible amateur command stations are established before launching is effected, so as to be able to guarantee that any harmful interference that might be reported can be terminated by group command. (It may be noted that the possibility of harmful interference being received from a non-geostationary satellite will last no more than a few minutes, on any one occasion and will not reappear for several hours, if not days, depending upon the location at which the interference occurs.)

3. Effects of amateur satellites on other services in shared bands

Annex III contains an approach to the analysis of the interference potential of amateur satellites in the bands shared with television broadcasting, radiolocation, and fixed and mobile services. The problem of sharing with the radiolocation service, in particular, requires further study.

General information on protection ratios and sharing criteria for the use of space techniques in the amateur radio service is presented in [CCIR, 1970-74]. Among other things, it provides data on earth receiver signal-to-noise ratios produced by satellites in the amateur satellite service, and tabulates the technical characteristics of all Oscar satellites.

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* This Report has been drawn up by Study Group 2 is brought to the attention of Study Group 1.

BIBLIOGRAPHY

BELLAIR, D. T. and HOWARD, S. E. [1969] Australis-OSCAR. *QST*, **53**, 58.

BELLAIR, D. T. and HOWARD, S. E. [1969] Obtaining data from Australis-OSCAR-5. *QST*, **53**, 70.

GABRIELSON, H. [1962] The OSCAR satellite. *QST*, **46**, 21.

GABRIELSON, H. [1964] Experiments with OSCAR-III, *QST*, **48**, 39.

JACOBS, G. [1964] OSCAR-III – an active communication satellite for radio amateurs. *CQ*, Part 1, **54**.

JACOBS, G. [1965] OSCAR-III – an active communication satellite for radio amateurs. *CQ*, Part 2, **38**.

JACOBS, G. [1966] OSCAR-IV in orbit. *CQ*, **22**, 24.

KASSER, J. and KING, J. A. [1974] OSCAR-7 and its capabilities. *QST*, **58**.

KING, J. A. [1969] Proposed experiments with Australis-OSCAR-5. *QST*, **53**, 54.

KING, J. A. [1970] Australis-OSCAR-5 spacecraft performance. *QST*, **54**.

KING, J. A. [1973] The sixth amateur satellite – a technical report, *QST*, **57**.

KLEIN, P. I. and KING, J. A. [1972] The AMSAT-OSCAR-B series of radio amateur satellites. Paper 72-521, AIAA 4th Communication Satellite Systems Conference, Washington, DC.

ORR, W. I. [1962] OSCAR-I: a summary of the world's first radio amateur satellite. *QST*, **46**, 46.

ORR, W. I. [1963] The OSCAR-III VHF translator satellite. *QST*, **47**, 42.

ORR, W. I. [1963] OSCAR-II: a summation. *QST*, **47**, 53.

ORR, W. I. [1965] OSCAR-III orbits the Earth. *QST*, **49**, 56.

SOIFER, R. [1970] Australis-OSCAR-5 ionospheric propagation. *QST*, **54**.

STONER, D. S. [1961] Project OSCAR. *QST*, **45**, 56.

CCIR Documents

[1970-74] 2/32 (USA).

[1974-78] 2/219 (Canada).

ANNEX I

TECHNICAL CHARACTERISTICS OF THE AMSAT-OSCAR-6 AND AMSAT-OSCAR-7 SPACECRAFT

AMSAT-Oscar-6

Launch:	October 15, 1972 from the Western Test Range, Lompoc, Calif., by NASA with the NOAA-2 meteorological satellite on a two-stage Thor-Delta launch vehicle.
Orbit:	1460 km circular, polar orbit, 101.6° inclination, 114.9945 minute period; sun-synchronous orbit, with passes repeating on a two-day cycle around 9 AM and 9 PM local time.
Transponder characteristics:	145.9 to 146.0 MHz input passband, 29.45 to 29.55 MHz output passband, 1 to 1.3 watts output; linear transponder, input signal of −100 dBm produces 1 watt output.
Beacons:	29.45 MHz at 100 to 200 milliwatts. 435.10 MHz at 300 milliwatts (this beacon is no longer operative).
Antennas:	Ten metre half-wave dipole made of standard carpenter's rule. Two metre quarter-wave monopole made from piano wire. 70 cm quarter-wave monopole made from piano wire.
Telemetry:	24 channels, transmitted sequentially in Morse code at 20 or 10 words per minute. Battery and regulator voltages, solar array and experiment currents, RF outputs and temperatures are telemetered approximately every 90 or 180 seconds, depending upon code speed.
Codestore:	896-bit digital shift-register message storage unit capable of storing and playing back 18 word Morse code and 22 word teletype messages loaded by selected ground stations.
Telecommand:	21 function telecommand system capable of turning on and off the transponder, 435 MHz beacon, selecting between telemetry and Codestore, and between 20 and 10 word per minute Morse code telemetry rate.

Power:	n-on-p silicon solar cells and rechargeable 6 ampere hour nickel-cadmium battery (24 volt system). Approximately two watts of average prime power available at beginning of life.
Stabilization:	Passive magnetic attitude stabilization along the longest axis, achieved by means of a 20.3 cm long 50 000 pole-cm aluminium-nickel-cobalt (Alnico 5) magnet. Spin is dampened by twelve 0.32 cm diameter permalloy rods.
Size:	16.3 × 30.5 × 44.0 cm rectangular solid, 50 per cent covered with solar cells.
Weight:	18.2 kg.
Lifetime objective:	one year.

AMSAT-Oscar-7

Launch:	November 15, 1974 from the Western Test Range, Lompoc, Calif; by NASA with the NOAA-4 meteorological satellite on a two-stage Thor-Delta launch vehicle.
Orbit:	1450 km near-circular, polar orbit, 101.7° inclination, 114.9448 minute period; sun-synchronous orbit, with passes repeating on a two-day cycle around 8 to 9 AM and 8 to 9 PM local time.
"Mode A" transponder characteristics:	145.85 to 145.95 MHz input passband, 29.40 to 29.50 MHz output passband, 1 to 2 watts output; linear transponder, input signal of −100 dBm produces 1 watt output.
"Mode B" transponder characteristics:	432.125 to 432.175 MHz input passband, 145.975 to 145.925 MHz inverted output passband, 6 to 8 watts or 3 to 4 watts output; linear transponder, input signal of −106 dBm produces 2.5 watts output.
Beacons:	29.502 MHz at 100 to 200 milliwatts (associated with Mode A transponder). 145.972 MHz at 100 to 200 milliwatts (associated with Mode B transponder). 435.103 MHz at 300 milliwatts. 2304.091 MHz at 40 milliwatts.
Antennas:	Ten-metre deployable "STACER" half-wave dipole. Two-metre quarter-wave circularly polarized canted turnstile made of standard carpenter's rule (used also as three-quarter wave canted turnstile at 432 and 435 MHz). 2304 MHz circularly polarized quadrifilar helix.
Telemetry (Morse code encoder):	24 channels, transmitted sequentially in Morse code at 20 or 10 words per minute. Battery and regulator voltages, clock count, solar array and experiment currents, RF outputs and temperatures are telemetered approximately every 90 or 180 seconds, depending upon code speed.
Telemetry (teletype encoder):	60 channels, transmitted sequentially in five-level (Baudot) code at the rate of approximately one parameter per second. Two lines of digital status data are also encoded, including readings of the spacecraft clock and the contents of the command storage registers. The encoder can be commanded to dwell on any desired channel.
Codestore:	896-bit digital shift-register message storage unit capable of storing and playing back 18 word Morse code and 22 word teletype messages loaded by selected ground stations.
Telecommand:	35 function redundant telecommand decoders capable of turning on and off the two transponders, 435 and 2304 MHz beacons, selecting between high and low speed Morse code telemetry, teletype telemetry (in either "commutate" or "dwell" modes), Codestore, and other functions.
Power:	n-on-p silicon solar cells and rechargeable 6 ampere hour nickel-cadmium battery (14 volt system). Approximately 14 watts of average prime power available at beginning of life.

Stabilization:	Passive magnetic attitude stabilization, achieved by means of four 15.2 cm long, cast aluminium-nickel-cobalt (Alnico 5) magnets. Spin is dampened by permalloy rods. Slow spin maintained by effect of solar pressure on white/black paint patterns on canted turnstile antenna elements.
Size:	Octahedral in shape, 36 cm high, 42.4 cm diameter.
Weight:	28.9 kg.
Lifetime objective:	three years.

ANNEX II

RESULTS OF THE AMSAT-OSCAR-6 AND AMSAT-OSCAR-7 AMATEUR SATELLITE EXPERIMENTS

1. Introduction

The principal objectives of the AMSAT-Oscar 6 and 7 satellites (A-O-6 and A-O-7) are:

- to experiment with multiple-access communications operating techniques, using large numbers of small terminals operating simultaneously in the amateur service.
- to conduct store-and-forward communications tests using an on-board digital message storage unit.
- to study radio propagation from the satellites at their operating frequencies of 29.5, 146, 432 and 435 MHz.
- to demonstrate the operation of small, deployable amateur earth terminals with the AMSAT-Oscar 6 and 7 satellites, suitable for use in the event of natural disasters, epidemics, famines and similar emergencies.
- to experiment with satellite signals as an instructional tool in the classroom in order to directly involve and motivate youngsters towards seeking careers in engineering and the sciences.
- to experiment with voice bulletin and other special transmission techniques, such as slow-scan television, ranging, and radio-control.
- to investigate the feasibility of operating Earth-to-satellite and satellite-to-Earth links at frequencies shared with the Radiolocation Service.

2. Multiple-access communication experiments

Well over 3000 amateur radio operators in at least 100 different countries have demonstrated their communication capabilities with the AMSAT-Oscar 6 and 7 satellites, with often as many as 50 signals heard through the transponder simultaneously. The linear transponders aboard A-O-6 and A-O-7 permit mixed-mode, random access operation. Approximately 75% of the communications has been by Morse code telegraphy (A1A emission), 20% by single-sideband voice (J3E) and the remainder by AM voice (A3E), direct printing radiotelegraphy (F1B), slow-scan television and various experimental transmission modes.

One objective of the transponder experiments has been to determine the effectiveness of linear, frequency-translating transponders in random, multiple-access applications, and to establish user power-sharing criteria for various types of amplitude-modulated user signals. It was found that much of the signal variations occuring on the Earth-to-satellite and satellite-to-Earth links can be compensated for by the user during transmissions. This is facilitated by the nearly universal adoption of an operating procedure whereby each satellite user monitors his or her own downlink signal to correct for Doppler shift and varying signal levels as a function of satellite position, orientation, and transponder loading. The fact that as many as 50 users have been observed operating through the transponder at the same time tends to verify the hypothesis that random variations in the amplitude-modulated user signals, when averaged over the passband, provide each user with a larger percentage of the transponded power than might be predicted if one were to divide the power proportionately among the users. This characteristic is best exhibited by single-sideband (J3E) users, since single-sideband transmissions have lower average power characteristics than do on-off Morse code (A1A), or constant-power techniques such as narrow-band FM (F3E) [Klein and King, 1974].

3. Message-store and forward experiments

Both AMSAT-Oscar 6 and 7 have digital message storage units capable of storing messages in Morse code up to 18 words in length. This system, called "Codestore" can be loaded by telecommand stations in Australia, Canada and the United States. A message typical of those stored in the Codestore system is:

"DUE TO LOW BATTERY VOLTAGE OSCAR 6 WILL BE OUT OF SERVICE UNTIL JUNE 28".

The operation of Codestore has also been demonstrated in a real-time regenerative mode in which Morse code characters transmitted via the spacecraft telecommand system are reconstituted and retransmitted character-by-character over the spacecraft telemetry beacon transmitter.

4. Inter-satellite propagation experiments

The frequency plans of the communications transponders aboard A-O-6 and A-O-7 are such that output signals from A-O-7 can be retransmitted through A-O-6 when the two spacecraft are within range of one another. This makes possible inter-satellite propagation tests involving stations in the amateur service. The two spacecraft are in nearly identical orbits and have a difference in period of 0.05 minutes per orbit. As a result, the two satellites pass close together for several weeks each six months [Klein and Soifer, 1975]. The sensitivity of the A-O-6 transponder is such that it should be capable of repeating signals from the A-O-7 transponder out to separation distances of the order of 5000 km.

The possibility of inter-satellite propagation was realized two months after the launch of A-O-7 as observations of successful A-O-6/A-O-7 linked communications began to be received. Two-way inter-satellite communication reports were received from 15 radio amateurs who successfully used both telegraphy (A1A) and single-sideband (J3E) transmission modes. Fifty-five amateur stations in 12 countries were involved in these contacts, which occurred out to satellite separation distances of up to 2000 km. Successful two-way communication was accomplished between stations transmitting through different satellites at the same time, i.e., one station transmitting through A-O-7 and the other transmitting through A-O-6, and also between stations where both operators were transmitting through A-O-7 and listening to their signals retransmitted through A-O-6.

5. Small terminal and emergency communication experiments

The 1400 to 1500 km orbital altitudes of AMSAT-Oscar 6 and 7, and the 29.5, 146 and 432 MHz frequencies used for the transponder links permit small portable or mobile terminals to be used for two-way, Earth-satellite-Earth communication. Transmitting equipment costing under 100 US dollars has been available, as have high-frequency receivers and very high-frequency receiving converters. Complete satellite earth terminals can be obtained for under 1000 US dollars made up of completely "off-the-shelf" equipment manufactured in several countries. The wide availability of solid-state transmitting and receiving equipment for the frequency bands employed makes battery operated suitcase size terminals feasible, and these terminals can be hand carried and easily transported. Several such terminals have been constructed and are in use.

Mobile terminals installed in automobiles, aircraft and boats by amateur radio operators in the United States, Japan, France and the Philippines have been quite successful in providing two-way communication with AMSAT-Oscar 6 and 7.

The potential application of Oscar spacecraft to assist in communication in the event of natural disasters, epidemics, famines and similar emergencies was demonstrated in September 1974, in an emergency test conducted to simulate an earthquake in the state of Alaska. During this test, several messages were passed between Alaska and other areas of the United States via AMSAT-Oscar 6.

Besides the factors of availability, reliability, portability, ease of operation and the low cost of OSCAR portable user terminals, the amateur radio community in many countries represents a resource of radio operators experienced and trained in emergency communication procedures [ITU, 1979].

6. Instructional applications

Experimental curriculum material has been prepared by educators and distributed to teachers in a number of countries. These guides contain lesson units describing how AMSAT-Oscar 6 and 7 can be received in schools on shortwave receivers, and used to teach concepts of orbital mechanics, Doppler shift, fading, communications range, telemetry and the physics of the environment. Telemetry signals are transmitted as a series of numbers in Morse code, so that only pencil, paper, a telemetry decoding sheet, and a knowledge of the ten Morse code digits are needed for receiving and decoding the data [Dunkerley, 1974]. On several mornings each week during the school year, volunteer amateur radio operators serving as bulletin stations transmit condensed lessons intended for use by teachers and students in classrooms.

7. Multiple-address bulletin experiments

Bulletins have been transmitted through the Oscar transponders on a regularly scheduled basis, generally under single-access conditions in which the bulletin stations employ the full power output of the spacecraft transponder. Bulletins in this "broadcast" mode generally include orbit ephemeris information, the current operating schedule, and announcements of planned experiments and demonstrations. Additional bulletin stations have regularly transmitted hurricane watch information during the hurricane season.

8. Other communications-related experiments

AMSAT-Oscar 6 and 7 have been used with a number of different satellite range and range-rate measurement techniques involving tones, pulses, measured delays in speech, slow-scan television line synchronization time delays, feed-back tones, and Doppler shifts [Meinzer, 1973]. Radio control of model aircraft via Oscar satellite links has also been demonstrated; as has the successful transmission of electro-cardiograms, facsimile data and slow-scan television pictures.

One of the two transponders in AMSAT-Oscar 7 employs a novel, high efficiency technique called "Envelope Elimination and Restoration" to achieve linear operation. The successful demonstration of this technique in space, along with the successful demonstration of low cost techniques for fabricating spacecraft hardware, is of importance for a number of non-amateur applications.

9. Shared band experiments

AMSAT-Oscar 7 contains a transponder which relays Earth-to-satellite signals in the frequency range 432.125 to 432.175 Mhz (see Annex I). As this band is shared between the amateur and radiolocation services, special pulse-limiting circuitry was incorporated in the transponder design to suppress the effects of interference from radiolocation transmitters. In spite of the high sensitivity of the receiver portion of this transponder (-106 dBm input produces 2.5 watts output, and signals 20 dB weaker can still be received), no reports of significant interference from the radiolocation service have been received from the users of this transponder, although weak signals attributable to radiolocation have been observed occasionally.

The 435.1 MHz telemetry beacon in AMSAT-Oscar 6 produced approximately 300 mW e.i.r.p. during the several months period in which it functioned. The AMSAT-Oscar 7 435.1 MHz beacon produces approximately 300 mW for one orbit on command. 300 mW e.i.r.p. corresponds to a maximum power flux density at the Earth of -140 dB(W/m^2) at the subsatellite point. There have been no known reports of interference to the radiolocation service due to the operation of these beacons or any other system in the two spacecraft. On occasion, interference to amateur receiving stations has been reported due to radiolocation transmitters situated within several hundred kilometres of an amateur receiving station, but these incidents have generally been of a localized, relatively minor nature.

10. Telecommand station automation

Because a large number of commands is required to maintain AMSAT-Oscar 6's operation, several amateur telecommand stations in Australia, Canada, Germany and the United States have been equipped with automated equipment capable of sending sequences of preprogrammed commands. The command signals are transmitted at regular intervals, as controlled by timers and punched paper tape. More sophisticated automated telecommand equipment has also been developed in which microcomputers are employed to send programmed commands, point antennae and log transmitted commands, permitting fully unattended telecommand station operation.

11. Conclusion

11.1 *Interference to other services*

In-orbit experience with the AMSAT-Oscar 6 spacecraft since October 1972, and AMSAT-Oscar 7 since november 1974 in a number of experimental applications, has resulted in no known reports of interference to other services, including the radiolocation service which shares the 430 to 440 MHz amateur band.

11.2 *Interference from other services*

Interference to amateur receiving stations from transmitters in the radiolocation service has been reported, but these generally have been local problems limited to regions near amateur receiving stations.

11.3 *Interference between amateur and amateur satellite operations*

There have been some cases of interference to amateurs from stations transmitting to amateur satellites, and from amateurs to stations receiving satellite transmissions. Generally, these cases have been solved by informal band-planning and agreements not requiring action by government telecommunication authorities.

11.4 *General*

The results of operations with AMSAT-Oscar 6 and AMSAT-Oscar 7 indicate that sharing between the amateur satellite and radiolocation services is feasible for Oscar spacecraft operating in the 430-440 MHz band.

REFERENCES

DUNKERLEY, W. I., Jr. [March 26-29, 1974] Using an active satellite for space science education, IEEE International Convention Record, New York City, USA.

ITU [1979] Relating to the use of space radiocommunication systems in the event of natural disasters, epidemics, famines and similar emergencies, Recommendation No. 1, Final Acts of the World Administrative Radio Conference (Geneva, 1979).

KLEIN, P. I. and KING, J. A. [March 26-29, 1974] Results of the AMSAT-OSCAR 6 communications satellite experiment, IEEE International Convention Record, New York City, USA.

KLEIN, P. I. and SOIFER, R. [October 1975] Intersatellite communication using the AMSAT-OSCAR 6 and AMSAT-OSCAR 7 radio amateur satellites, *Proc. of the IEEE Letters.*

MEINZER, K. [May 1973] Range measurements with OSCAR 6, *QST*, Vol. 57, 36-37.

ANNEX III

INTERFERENCE POTENTIAL OF AMATEUR SATELLITES IN SHARED BANDS

1. General

To date, amateur satellites have been in low, i.e. non-geostationary, orbits. While some use of the geostationary orbit can be expected, it is anticipated that the lower orbits will be the more common for the following reasons:

- amateurs must usually use simple techniques, to keep the cost and scale of effort to attainable bounds;
- amateurs must arrange launching on the basis of "as available" capacity; since a given size rocket has a greater payload capability when used to attain low orbits, there are more opportunities for spare capacity to be available;
- amateurs generally prefer low orbits, since the resulting motion makes world-wide use of a single satellite possible, giving more opportunity for experiment and communication.

However, the following comments take account of both moving and geostationary orbits.

2. Review of low orbit characteristics

A satellite in a low orbit appears to rise and set. The presence or absence of visibility, the visible duration and the interval between passes are functions of orbital height, inclination and location of the observing point. For a point on the equator, the following data are obtained for a direct equatorial satellite.

Height (km)	True period (min)	Apparent period (min)	Half arc of visibility (degrees)	Max. slant range (km)	Visibility time (min)	Probability of being visible P_v (%)	Surface visibility (%)
1 853	126	143	39	5 190	30	21	17·2
3 706	162	183	51	8 150	52	28	18·2
7 412	264	324	62·5	11 300	112	34	26·8
12 971	444	640	71·5	17 975	254	40	32·8
18 330	606	1 280	75	24 090	532	40	37·1
35 792	24 hr.	00	81·5	41 320	Continuous	100 or 0	42·3

If the observation point is not on the equator, the probability of the satellite being visible decreases, becoming zero if the latitude of the point is greater than the half arc of visibility angle.

With inclined orbits, the maximum duration of visibility is the same as the visibility time in the table. However, on some passes, the time will be shorter, and on other passes a low satellite will not be visible at all.

For a number of satellites in orbits of various inclinations and a number of points at various latitudes, the probability of visibility, P_v, is approximately equal to the "% surface visibility" column in the above table.

3. Probability of signal arrival

Let θ_H and θ_v be the horizontal and vertical beamwidths of a terrestrial antenna, i.e. the main-lobe angles. The probability that an amateur satellite is in the main lobe is given by:

$$P_m = P_v \frac{\theta_H}{360} \cdot \frac{\theta_v}{90} \tag{1}$$

where the angles are measured in degrees, and where P_v may be determined by exact or approximate methods.

Let Φ_H and Φ_v be the horizontal and vertical angles at which the antenna pattern is some number of decibels below the on-axis gain; in interference studies, this number is often taken as equal to the on-axis gain; i.e. the interference is received by an isotropic antenna. The probability that an amateur satellite is received "off main lobe" or not at all, is then:.

$$P_b = 1 - \left(P_v \frac{\Phi_H}{360} \cdot \frac{\Phi_v}{90} \right) \tag{2}$$

For the special case of equal horizontal and vertical angles, these probabilities are:

Angle (degrees)	P_m	P_b
1	$3{\cdot}1 \times 10^{-5} P_v$	1·0
3	$2{\cdot}78 \times 10^{-4} P_v$	1·0
10	$0{\cdot}0031 P_v$	$1 - 0{\cdot}0031 P_v$
30	$0{\cdot}0278 P_v$	$1 - 0{\cdot}111 P_v$
90	$0{\cdot}25 P_v$	$1 - 0{\cdot}25 P_v$

As a specific example, assume that P_v is 0.25, that $\theta_H = \theta_v = 25°$ and $\Phi_H = \Phi_v = 60°$ (values for Band III television from Recommendation 419). Then the probability of reception of an amateur satellite via the main lobe is less than 0.5%, and the probability that reception is either at or below the level of an isotropic antenna exceeds 97%.

4. Amateur satellites and television broadcasting

The present frequency bands for which amateur service and television broadcasting are authorized but not necessarily in the same regions are:

50 to 54 MHz:
- amateur service in Region 2;
- broadcasting service (television, Band I) in Region 1;
- amateur service in Region 3, subject to the provisions of Nos. 244, 245, 246 and 247 of the Radio Regulations.

220 to 225 MHz:
- amateur service in Region 2;
- broadcasting service (television, Band III) in Region 1 up to 223 MHz, plus limited amateur use under No. 301 of the Radio Regulations;
- amateur service, 220 to 225 MHz.

Recommendation 417 gives the following as values to be protected 90 to 99% of the time:

Band	dB (μV/m)
I	+48
III	+55

Recommendation 419 gives the antenna directivity as:

Band	Off-axis angle (degrees)	Discrimination (dB)
I	50 to 70	0 to 6
III	25 to 60	0 to 12

From the above relations, the probability of the occurrence of interference for a typical moving satellite (P_v = 25%) is:

Band	Main lobe (%)	Back lobes (%)
I	1·9	96
III	0·5	97

Given that the interference is not steady, and assuming that the frequencies will not be specially selected, the protection ratio deduced from Recommendation 418 for either CW or sound signal interference has the value of 50 dB. Since the sound signals may be amplitude or frequency modulated, this value also is probably satisfactory for such types of amateur signal. No data are available for single-sideband emissions and a common assumption is to assume that the interference is related to the average signal power.

The allowable power flux-density, W_a is given by:

$$W_a = U - P_r + G_D - 146 \qquad \text{dB(W/m}^2\text{)} \tag{3}$$

where

U is the signal level to be protected (dB(μV/m)),

P_r is the protection ratio (dB),

G_D is the antenna discrimination (dB).

Using the values developed above, the allowable amateur satellite signal to protect a television service becomes, for the strength outside an allocated region:

Band	Frequency (MHz)	Max. allowable power flux-density (dB (W/m²))	Field strength equivalent (dB (μV/m))
I	50 to 54	− 142	+ 4
III	220 to 223	− 129	+ 17

Since for a radio amateur satellite in the geostationary satellite orbit, the signal would be steady, the signal strength outside an allocated region should be 10 dB lower, i.e. −152 and −139 dB(W/m²) for Bands I and III.

These values correspond to:

Band	Allowable e.i.r.p.	
	Stationary orbit (dBW)	Synchronous orbit (not stationary) (dBW)
I	10	20
III	23	33

or to about 0 dBW for Band I and +13 dBW for Band III; these values being established for the worst case values and for an orbit of 2000 nautical miles.

Formerly, amateur satellites operated at an average value of e.i.r.p. of about −10 dBW, with some future units planned for an average value of e.i.r.p. of approximately 4 dBW. In view of the fact that these are all non-geostationary satellites it appears that the probability of harmful interference is negligible, and that the probability of detectable interference at any time is small.

5. Sharing between amateur satellites and the radiodetermination service

Sharing with the radiodetermination service has not hitherto been studied by the CCIR. The following study combines data from several sources to determine the allowable sharing criteria.

For a pulse system, the minimum detectable, or threshold, signal at the receiver input is related to the receiver noise by:

$$P_D = kTB + NF + L_{BT} \qquad \text{dB} \tag{4}$$

where

P_d is the threshold signal (dBW),

kTB is the theoretical noise over the receiver bandwidth B (dBW),

NF is the receiver noise figure,

L_{BT} is the threshold power factor, to allow for the effect of the receiver passband on the pulse shape.

For square pulses and a double-tuned intermediate-frequency amplifier, L_{BT} is [Reference Data for Radio Engineers, 1968]:

BT	L_{BT} (dB)
0·01	20
0·1	10
0·8	3
1·0	4
10·0	13

where the bandwidth, B, is in MHz and the pulse width, T, is in μs. If the equipment is of a normal design, $BT = 1.0$. In this case, for an interfering signal, B can be taken as the bandwidth of the interfering signal, and T as the design pulse width.

The threshold signal power flux-density W_0 for a fixed antenna and a fixed signal source is related to the receiver input by:

$$W_0 = P_D + L_L + L_D - A \qquad \text{dB(W/m}^2\text{)} \tag{5}$$

where

L_L is the line loss (dB),

L_D is the duplexer loss (dB),

$A =$ 10 log S where S is the effective antenna area (m^2).

A is related to the antenna gain, G, by the equation:

$$A = \frac{\lambda^2}{4\pi} G \tag{6}$$

and as an approximation is often taken to be 50% of the physical area.

If the antenna is scanning, there is an additional loss, L_S, introduced by the fact that the indicator integration time period is reduced. This loss is approximately:

Percentage of maximum integration time, t (%)	Loss, L_s (dB)
100	4
30	7
10	10
3	12
1	14
0·3	17
0·1	20

The percentage integration time, t, is given by:

$$t = \frac{F\theta_H}{6000\,\omega} \qquad \% \tag{7}$$

where

F: pulse rate per second,

θ_H: half-power beamwidth in horizontal plane,

ω : scan rate per minute.

Note that the loss, L_S, includes an allowance for the variation of antenna gain with angle, and that it is essentially based on a 100% probability of visibility; the values for a 50% probability are approximately 3 dB less.

If vertical scanning is also used, the time percentage should be multiplied by the ratio of the vertical beamwidth to the vertical scan angle; the result being used to determine L_S.

In addition, there is a loss, L_p, if a long-persistence indicator is used, as in a pulse position indicator, and a further loss, L_i, if the target is moving.

The interfering power flux-density W_i for a moving signal source which is just detectable on a scanning radar is therefore:

$$W_i = kTB + NF + L_{BT} + L_L + L_D + L_s + L_p + L_i - A \qquad \text{dB(W/m}^2\text{)} \tag{8}$$

As an example, assume a typical airport surveillance radar, with:

B = 1 MHz (T = 1μs)

NF = 9 dB,

Antenna = 3 × 6 m,

θ_H = 1.2°,

Scan = 360° horizontal,

Pulse rate = 1000/s,

Scan rate = 3 r.p.m.

Typical values for the other losses would be:

L_L = 1 dB

L_D = 2 dB

L_p = 3 dB

L_i = 5 dB

The scan percentage is 1000 × 1.2/6000 × 3 or 7%, giving L_s equal to 13 dB. S is approximately 9 m^2, or A = 10 log S is approximately 10 dB.

For an interfering frequency-modulated signal occupying a bandwidth of 25 kHz, BT is 25 × 10^{-3}, giving a value of L_{BT} of approximately 16 dB. The power flux-density to produce a just detectable response is:

$$W_0 = (-204 + 60) + 9 + 16 + 1 + 2 + 13 + 3 + 5 - 10 = -154 + 49 = -105 \text{ dB(W/m}^2\text{)}$$

An amateur signal of the above characteristics and strength would appear as a just visible brightening of the trace at the azimuth of the satellite. If modulated, small intensity changes might be observed. The signal would not appear often, the probability of its appearance being approximately $2P_v \cdot \theta_v/90$, or less than 2% of the time in the above example. The signal could not be confused with a target.

Anti-clutter circuits would reduce detectability. One that is effective against narrow-band signals is a fast time-constant circuit; with this, only rapidly changing portions of the signal, as for keyed CW, would be visible. The interference reduction provided by such circuits is approximately the same as their effectiveness in the reduction of clutter.

The presence of the interference would reduce maximum range by a small amount over an azimuth of 3° for about 2% of the total time. With a moving satellite, this reduction would occur at any azimuth for only a short period; typically, for one or two scans.

Other types of radar exist. However, the general principles of bandwidth and scanning loss apply in a similar manner, with, of course, different numerical values.

The probability of amateur satellite interference to radar systems appears to be very small. For the above example, the allowable signal would be 5 dB less if the satellite were stationary, or -100 dB(W/m^2). This corresponds to an e.i.r.p. of $+52$ dBW from the synchronous orbit. Former amateur satellites operated at about -10 dBW, with some units planned for an average e.i.r.p. of approximately $+4$ dBW. Thus, the margin against interference is such that detectability could not be achieved unless transmitter power were increased by at least 23 dBW and about 25 dB of the satellite antenna gain employed. Since this corresponds to a beamwidth of about half the visible Earth, or less for lower orbits, the probability of interference is small.

6. Sharing with fixed and mobile services

Report 358-1 (New Delhi, 1970) gave the following values as median field-strengths to be protected (mobile service) *:

Frequency Band (MHz)	Urban noise only (dB (μV/m))	Receiver noise only (dB (μV/m))
30 to 50	24	8
50 to 100	24	14
100 to 200	19	20
200 to 400	14	26
400 to 500	11	29

The bulk of land mobile operation is in urban or traffic-generated noise, and some fixed services in these bands are among or near noise sources, and it may be reasonable in some instances to use the larger of the two values in the table.

Report 358, also gives protection ratios, typical values being 8 dB for the protection of frequency modulation services, and 17 dB for the protection of amplitude modulation services.

Combining these values, and converting them into values of power flux-density gives the following signal levels:

Frequency band (MHz)	Max. signal for the protection of mobile services in urban areas	
	Frequency-modulation services (dB (W/m^2))	Amplitude-modulation services (dB (W/m^2))
30 to 50	− 130	− 139
50 to 100	− 130	− 139
100 to 200	− 134	− 143
200 to 400	− 128	− 137
400 to 500	− 125	− 134

* These figures should be used with caution pending the result of further studies by Study Group 8.

Under rural noise conditions, the allowable signal would be less in some bands, by 12 dB in the band 30 to 50 MHz, and by 6 dB in the band 50 to 100 MHz.

These values are for co-channel operation.

For an amateur satellite in a synchronous orbit, the band 100 to 200 MHz would allow an e.i.r.p. of +28 dBW or +19 dBW when sharing with frequency or amplitude modulation services respectively.

It may be noted that the probability of reception with full antenna gain is higher in the mobile services than in others. This is due to extensive use of simple antennae, $\theta_H = 360°$ and $\theta_v = 50°$ being typical. However, the antennae rarely have gain, and may show a loss compared to an isotropic antenna.

Formerly, amateur satellites operated with an e.i.r.p of about −10 dBW with some future units planned for an e.i.r.p. of approximately +4 dBW (a power flux-density of about −135 to −145 dB(W/m^2) depending on orbit). In view of the fact that these are moving satellites, it appears that the probability of harmful interference is not great.

7. Conclusions regarding the proposals emanating from the CCIR Special Joint Meeting (Geneva, 1971)

The amateur proposals of § 5.4 of the Report of the Special Joint Meeting endorse positive shut-off as the interference control measure (see No. 2741 of the Radio Regulations), noting that further additional developments are expected to provide for change in frequency, power and/or mode of emission.

In view of the margin between signal levels which cause interference and the present and projected power levels of amateur satellites, and considering further, that the low-orbit satellites which seem to be desired in the amateur service have low or very low probabilities of causing interference; it appears that provisions for change in frequency, power and emission mode should be developed, since these would allow a choice of the most favourable conditions of operation.

If this step were taken, and considering the proposals made by the amateurs for the provision of means to change frequency, power, and mode of emission, and further considering that such steps as channel interleaving or frequency offset can be used to reduced effects of interference, it would appear satisfactory to:

- establish a limitation of the power flux-density (band by band) which would give a low risk of detectable interference and negligible risk of harmful interference;
- allow, as an alternative to power flux-density limits, operation under No. 342 of the Radio Regulations in the regionally allocated bands.

Since most, if not all, countries place a power limit on amateur transmission which is equivalent to a limit on the power flux-density in the practical sense; on the basis of available data, special limits for the power flux-density do not appear to be required in bands above 450 MHz.

REFERENCE

REFERENCE DATA FOR RADIO ENGINEERS [1968] 5th Edition, Howard Sams, Co.

QUESTIONS AND STUDY PROGRAMMES, RESOLUTIONS, OPINIONS AND DECISIONS

QUESTION 1/8

SIGNAL-TO-INTERFERENCE PROTECTION RATIOS AND MINIMUM FIELD STRENGTHS REQUIRED IN THE MOBILE SERVICES

(1963)

The CCIR,

CONSIDERING

(a) that full effect should be given to the studies which the World Administrative Radio Conference, Geneva, 1979, in its Recommendation No. 64, invited the CCIR to continue for all services;

(b) that for certain kinds of mobile services, partial data relating to interference protection ratios and minimum field strengths required, exist in documents of some Conferences of the ITU, for example, in the Final Acts of the International Administrative Aeronautical Radio Conference, Geneva, 1948-1949 and of the Special Regional Conference, Geneva, 1960;

(c) that such documents, however, do not constitute a complete and consistent set of data relating to all kinds of mobile services operating in all frequency ranges, particularly with respect to VHF-UHF mobile services,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the signal-to-interference protection ratios which define the threshold of harmful interference for the several mobile services;

2. what are the signal-to-noise ratios and the minimum field strengths required for satisfactory reception of the different classes of emission in the several mobile services;

3. what are the appropriate fading allowances in the several mobile services?

Note 1. – The above studies should be continued simultaneously and with the same urgency.

Note 2. – Particular attention should be given to those studies which will assist the further refinement of the technical standards used by the International Frequency Registration Board.

Note 3. – The above-mentioned studies should be carried on permanently and recommendations and possible revisions be published as soon as practicable.

Note 4. – See Reports 358, 914, 924 and Recommendation 441.

QUESTION 5-3/8 *

THE INTRODUCTION OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(1965-1966-1970-1978-1982)

The CCIR,

CONSIDERING

(a) that there is a requirement for communication in the maritime mobile service by means of direct-printing telegraph techniques;

(b) that Recommendation 476 recommends a direct-printing telegraph system which uses error-detecting and error-correcting methods;

(c) that this system has proved to provide a satisfactory technical solution and is in actual operation, in accordance with Appendix 38 to the Radio Regulations (Geneva, 1979);

(d) that, nevertheless, the increased use of direct-printing telegraph equipment has emphasized the importance of the unambiguous identification of both stations when a both-way narrowband direct printing circuit is established or re-established;

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* The Director, CCIR, is requested to bring this Question to the attention of Inter-Governmental Maritime Consultative Organization (IMCO) and the CCITT.

(e) that unambiguous identification could be accomplished by the exchange of self-identification signals between the ARQ equipments at the 7-unit level, or by functionally equivalent means;

(f) that Appendix 43 of the Radio Regulations, CCIR Recommendation 585 and CCITT Recommendation E.210/F.120 provide for a comprehensive system of assigning maritime mobile service identities;

(g) that operational procedures should be agreed upon,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what operational procedures should be recommended for direct-printing telegraph systems in the maritime mobile service;

2. whether master, slave or both master and slave identifications should be transmitted during initial establishment, re-establishment or both establishment and re-establishment of the circuit;

3. what are the preferred methods to provide unambiguous identification taking into account compatibility with older equipments;

4. whether the address capability of the call signal system should be expanded, taking into account the future assignment of maritime mobile service identities? If so, what would be the preferred method to provide such an expanded address capability, taking into account compatibility with existing equipments and the need to keep the time required for establishing the radio circuit as short as practicable?

Note. – See Reports 585, 907 and Recommendations 476, 490, 491, 492, 540.

QUESTION 7-2/8

CHARACTERISTICS OF EQUIPMENT AND PRINCIPLES GOVERNING THE ALLOCATION OF FREQUENCY CHANNELS IN THE LAND MOBILE SERVICES BETWEEN 25 AND 1000 MHz

(1956-1966-1970-1974)

The CCIR,

CONSIDERING

(a) that an interchange of information on the requirements of administrations concerning the technical characteristics of equipment used in land mobile services between 25 and 1000 MHz, would be advantageous in the development of those services;

(b) that an exchange of information among different countries concerning the practices applied to the assignment of channels and the experience gained in the operation of land mobile services between 25 and 1000 MHz is of value in general;

(c) that a certain measure of agreement may be desirable on the characteristics of the land mobile equipment that are used in the border areas of neighbouring countries to minimize mutual interference;

(d) that a certain measure of agreement may also be desirable on the practices governing the allocation and use of channels in land mobile services between 25 and 1000 MHz in border areas,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the technical requirements of administrations concerning equipment used in land mobile services between 25 and 1000 MHz that are of international importance in the development of such services, e.g. transmitter power, antenna characteristics, emission characteristics, frequency tolerance;

2. to what extent would it be desirable to standardize the performance characteristics of land mobile equipment between 25 and 1000 MHz internationally;

3. what are the broad practices adopted by administrations in the allocation of channels to the various kinds of user in the land mobile service between 25 and 1000 MHz, e.g. channel separation, geographical spacing of stations in the same adjacent channels, frequency separation for duplex operation, degree of frequency sharing in a particular service area;

4. to what extent is it desirable to reach international agreement on the practices for the allocation of channels in the land mobile service between 25 and 1000 MHz?

Note. – See Reports 319, 740, 898 Recommendation 478 and Resolution 20.

STUDY PROGRAMME 7A-2/8 *

TECHNICAL CHARACTERISTICS OF LAND MOBILE EQUIPMENT BETWEEN 25 AND 1000 MHz

(1966-1974-1981)

The CCIR,

CONSIDERING

(a) that Report 319 gives a partial answer to Question 7/8;

(b) that information contained in this Report will facilitate cooperation between administrations in the technical operation of their services;

(c) that a degree of standardization is desirable, since the land mobile service connected to the national network may form part of an international connection, as stated in Recommendation 77-3 (Kyoto, 1978);

(d) that it is desirable to determine equipment technical characteristics, to facilitate the planning of channel allocation in the land mobile bands;

(e) that it would therefore be desirable to reach agreement upon which are the essential technical characteristics for VHF and UHF radiotelephone equipment for use in the land mobile service, in order to expedite the international interchange of data on such equipment;

(f) that it is also desirable to investigate the relationship between subjective measurement techniques and objective measurement techniques for the various systems operating in the land mobile service,

UNANIMOUSLY DECIDES that the following studies should be carried out:

determination of equipment characteristics (and/or methods of measurement) for the various land mobile services between 25 and 1000 MHz which may be adopted by administrations, in particular:

1. for frequency-modulation systems:

1.1 the maximum frequency deviation for various channel-frequency spacings;

1.2 pre-emphasis and de-emphasis characteristics;

2. for amplitude and frequency-modulation systems:

2.1 the maximum audio-frequency bandwidth;

2.2 frequency tolerances of transmitters;

2.3 typical and maximum output powers of base and mobile station transmitters;

2.4 mean power limits of harmonic and other spurious emissions:

2.4.1 falling in any other land mobile channel,

2.4.2 falling within the bands of other radio services;

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* The Director of the CCIR is requested to bring this Study Programme (in particular, § 3) to the attention of International Electrotechnical Commission (IEC) and the CCITT.

2.5 receiver characteristics, particularly:

- frequency stability;
- selectivity;
- radiation;
- intermodulation;
- choice of intermediate frequency;
- sensitivity;
- audio-frequency response.

3. appropriate methods of:

- measuring subjective voice quality with particular attention to voice recognizability and intelligibility;
- relating objective and subjective measurements;
- comparing either the peak or average RF powers;
- comparing the interference caused by co-channel and/or adjacent channel emissions modulated by voice and/or data.

Note. – Study Programmes 7B/8, 7C/8, 7E/8 and Question 37/8 should be borne in mind.

STUDY PROGRAMME 7B-1/8

MINIMUM CHANNEL SEPARATION AND OPTIMUM SYSTEMS OF MODULATION FOR LAND MOBILE SERVICES BETWEEN 25 AND 1000 MHz

(1966-1974)

The CCIR,

CONSIDERING

(a) that Report 319 partly answers Question 7/8;

(b) that congestion in the VHF and UHF bands is a serious problem in many countries;

(c) that this is due to the rapid growth of the land mobile services;

(d) that in a number of countries many base stations are operated from within a limited geographical area;

(e) that the frequency tolerances given in Table I (Column 3) of Report 181 are now readily achievable with equipment used in the land mobile service;

(f) that in a number of countries impulse noise is at such a level as to cause serious degradation to communications range,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the minimum bandwidth necessary for various known modulation techniques, in particular for double-sideband amplitude-modulation, frequency-modulation and single-sideband emissions;

2. determination of the relative advantages and disadvantages of various types of modulation system as the occupied bandwidth approaches the minimum necessary for the transmission of intelligence, taking into account the necessary signal-to-noise ratio at the receiver input;

3. determination of the minimum channel separation achievable between base station transmitters located within a limited geographical area or at a common site;

4. determination of the minimum frequency separation between transmitters and receivers under conditions of duplex operation at the same site;

5. determination of the technical characteristics, criteria and techniques to achieve, in practice, the channel and frequency separations in §§ 3 and 4.

Note. – See Report 899.

STUDY PROGRAMME 7C-1/8

INTERFERENCE DUE TO INTERMODULATION PRODUCTS IN THE LAND MOBILE SERVICES BETWEEN 25 AND 1000 MHz

(1966-1974)

The CCIR,

CONSIDERING

(a) that Report 319 only partly answers Question 7/8;

(b) that large numbers of base station transmitters and receivers may be operated within the same limited geographical area;

(c) that such transmitters may produce high-level intermodulation emissions, the odd orders of which fall within and on either side of a land mobile band, and these may fall on receive frequencies of land mobile stations;

(d) that channelling plans can be devised so as to minimize the effects of intermodulation products;

(e) that receivers may have spurious intermodulation responses as a result of two or more strong input signals;

(f) that external non-linearly conducting elements may produce intermodulation products from two or more signals,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the various causes of intermodulation products arising within transmitters, receivers and external non-linear elements, and the various techniques which may be used to minimize their production and reduce their effects, the method used being stated in each case;

2. determination of the maximum permissible mean power of intermodulation emissions for satisfactory operation in the land mobile services;

3. determination of the precautions that are required against the formation of intermodulation products in receivers and which are compatible with satisfactory operation of the land mobile services.

Note. – See Report 739.

STUDY PROGRAMME 7E/8

FREQUENCY PLANNING METHODS FOR THE LAND MOBILE SERVICE

(1980)

The CCIR,

CONSIDERING

(a) that there is a necessity for efficient use of the frequency bands allocated to the land mobile service;

(b) that the exchange of information on frequency planning methods for the land mobile service would be advantageous in the coordinated introduction and development of that service (see also Resolution 20);

(c) that a certain measure of agreement is desirable on frequency planning criteria that are used in border areas of neighbouring countries to minimize interference,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. elaboration of methods and criteria for the choice of frequencies to be assigned to stations in the land mobile service, taking into account spectrum efficiency, the technical characteristics of equipment, propagation characteristics and also administrative procedures;

2. which methods and criteria are of particular use in the coordination of stations in the land mobile service in border areas of neighbouring countries.

QUESTION 9-4/8 *

DIGITAL SELECTIVE-CALLING SYSTEM FOR FUTURE OPERATIONAL REQUIREMENTS OF THE MARITIME MOBILE SERVICE **

(1967-1970-1974-1978-1982)

The CCIR,

CONSIDERING

(a) Resolution No. 311 and Recommendation No. 312 of the World Administrative Radio Conference, Geneva, 1979;

(b) that the decisions were taken by the World Maritime Administrative Radio Conference, Geneva, 1974 concerning the allocation of frequencies exclusively for digital selective-calling for future operational requirements of the maritime mobile service;

(c) that Recommendation 493 recommends the operational characteristics and the technical characteristics of the digital selective-calling system for use in the maritime mobile service;

(d) that Recommendation 541 recommends the operational procedures for the use of digital selective-calling equipment in the maritime mobile service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what information, in conjunction with the selective call, may be required for the operation of future maritime communication systems;

2. what operational procedures should be added to Recommendation 541 as operational experience is gained with the digital selective-calling system by administrations?

Note. – See Reports 501, 908 and Recommendations 493 and 541.

QUESTION 11-1/8

IMPROVEMENTS IN THE PERFORMANCE OF RADIOTELEPHONE CIRCUITS IN THE MF AND HF MARITIME BANDS

(1968-1978)

The CCIR,

CONSIDERING

(a) that there is a need to improve the quality of transmission of MF and HF maritime radiotelephone circuits;

(b) that the adoption of new compandor principles offers the prospect of such an improvement,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the methods by which compandor techniques can be applied to maritime radiotelephone circuits in the MF and HF bands;

2. what improvement in performance is to be expected with these techniques;

3. what characteristics would need to be agreed if such a technique were adopted;

4. what changes, if any, would need to be made to the tolerances of existing equipment, etc. to satisfactorily apply such techniques;

5. what measures should be taken to provide compatible operations between stations utilizing compandor principles and those fitted with conventional equipment only?

Note. – See Recommendation 475.

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* The Director, CCIR, is requested to draw the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) to this Question and invite it to cooperate in the study.

** Selective calling in the maritime mobile satellite service is considered under Question 17/8.

QUESTION 12-1/8

RADIO-PAGING SYSTEMS *

(1968-1974)

The CCIR,

CONSIDERING

(a) that systems for paging by means of radio are in operation in a number of countries and that their use is extending;

(b) that as the areas of coverage are increased, the possibility of interference between different radio-paging systems, and between radio-paging systems on the one hand and other radiocommunication systems on the other hand is increased;

(c) that the various systems already in use, or proposed, are not necessarily compatible one with another;

(d) that system compatibility is necessary in the case of international operation;

(e) that for international operation it is desirable to agree on the parameters of the system;

(f) that it is essential to make the most efficient use of the available radio-frequency spectrum,

UNANIMOUSLY DECIDES that the following question should be studied:

1. based on service area considerations, what types of radio-paging systems may be identified and of these, which are of international importance;

2. from a technical point of view, what frequency bands are most suitable for radio-paging systems;

3. what overall quality of transmission (capacity, degree of immunity from false calls, successful call ratio, etc.) should be provided by radio-paging systems;

4. what are the technical characteristics of radio-paging systems on which international agreement is desirable;

5. what operational facilities need to be specified to permit international operation of radio-paging systems, and in what circumstances could they share frequencies with other radiocommunication systems?

Note. – See Reports 499, 900 and Recommendation 539.

STUDY PROGRAMME 12A/8

RADIO-PAGING SYSTEMS

Standardization of code and format

(1980)

The CCIR,

CONSIDERING

(a) that Report 499 indicates the need for a standardized signalling format with the choice of the appropriate coding technique taking account of the capacity of code combinations, the speed of transmission and the reliability of call reception;

(b) that Recommendation 539 recommends that the transmission of alternative messages should be possible to any paging receiver in an international service;

(c) that a standardized code and format are desirable to permit receivers to operate freely in radio-paging systems providing an international service;

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* Radio-paging – a one-way calling system without speech.

(d) that the alternative of code conversion is uneconomic of equipment and results in a significant reduction of the paging rate achievable;

(e) that an acceptable standard would lead to compatibility of equipment and systems;

(f) that large scale production of decoders is beneficial to operators and users alike;

(g) that national systems are being established which require codes providing up to 2 million discrete combinations;

(h) that international systems will require many more combinations;

(j) that each code combination has to be associated with a unique dialling code used in the public telephone network with which the radio-paging service operates;

(k) that for international use the code should be applicable to both large and small national systems without creating problems for either,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. to determine a code and format suitable for use in international radio-paging systems, taking account of:

1.1 the frequency bands likely to be used;

1.2 the error rates likely to be encountered, particularly in urban areas;

1.3 the possible range of system sizes;

1.4 the code capacity necessary;

1.5 the rate of code transmission required;

2. to determine the most appropriate means of transmission of such codes over the radio system;

3. to determine a format for codewords and combinations of codewords which would fully exploit the advantages of the chosen code whilst allowing to the maximum extent future modification and expansion.

Note. – See Recommendation 584 and Report 900.

QUESTION 14-1/8

DIRECT-PRINTING AND OTHER DATA SIGNALS USING VOICE-FREQUENCY TECHNIQUES ON VHF RADIOTELEPHONY CHANNELS IN THE MARITIME MOBILE SERVICE

(1970-1978)

The CCIR,

CONSIDERING

(a) that provision is made in Appendix 18 of the Radio Regulations for radiotelephony in the maritime mobile service in the frequency band 156 to 174 MHz;

(b) that provision is also made for high-speed data and facsimile transmissions as well as narrowband direct-printing telegraphy and data transmissions, subject to special arrangement between interested and affected administrations;

(c) that the application of VHF radio techniques enables communication services to be made available to ships on coastal and inland waters with predictable reliability and coverage area;

(d) that in many such areas, the use of digital and analogue voice-frequency techniques now utilized over land circuits can be extended to ships by VHF radio using existing radio equipment;

(e) that there are developing requirements for reliable facilities enabling the exchange of direct-printed information, and of data and facsimile traffic between ships and subscribers ashore;

(f) that a number of administrations have already introduced direct-printing techniques in the maritime mobile service;

(g) that the required shipborne equipment should not be unduly complex;

(h) that a VHF maritime radiotelephone channel may be suitable for direct-printing and other data signals or that such a channel may be suitable for simultaneous transmission of radiotelephony and direct-printing or similar data signals;

(j) that preferably the radiotelephone traffic-handling capacity, and the service quality, of the available channels should not be unduly reduced by the introduction of direct-printing or other kinds of traffic,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what technical standards should be adopted in the use of voice-frequency techniques for direct-printing, data and facsimile transmissions in the VHF maritime mobile service;

2. what are the comparative advantages of using the same or different channels for radiotelephony and the other kinds of traffic referred to in § 1 above;

3. what procedures, including choice of frequency channels, should be adopted for types of communication other than radiotelephony with duplex and simplex radio equipment?

Note. – See Report 584.

QUESTION 17-2/8 *

TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS PROVIDING COMMUNICATION AND/OR RADIODETERMINATION USING SATELLITE TECHNIQUES FOR AIRCRAFT AND/OR SHIPS

(1968-1970-1974-1982)

The CCIR,

CONSIDERING

(a) Recommendations Nos. 405, 312 and 604 of the World Administrative Radio Conference (Geneva, 1979);

(b) that the International Maritime Satellite Organization (INMARSAT) has been established,

UNANIMOUSLY DECIDES that the following question should be studied with respect to aircraft and/or ships:

1. what are the preferred types and technical and operating characteristics of the following systems:

1.1 mobile-satellite system;

1.2 radiodetermination-satellite system;

2. what are the preferred frequency bands for such systems;

3. are combined systems for radiocommunication and radiodetermination purposes feasible and advantageous;

4. is the sharing of frequencies with other systems feasible, and if so, with what other systems and under what conditions;

5. what are the various technical and operating problems concerning communication and/or radiodetermination systems using satellite mtechniques for aircraft and/or ships, when relevant factors, such as traffic distribution, system complexity, economic efficiency, interfacing with terrestrial telecommunication networks, and new types of services, are taken into account?

Note. – See Reports 912 and 924.

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* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO), the Inter-Governmental Maritime Consultative Organization (IMCO) and INMARSAT.

STUDY PROGRAMME 17A-1/8 *

TECHNICAL CHARACTERISTICS OF SYSTEMS PROVIDING COMMUNICATION AND/OR RADIODETERMINATION USING SATELLITE TECHNIQUES FOR AIRCRAFT AND/OR SHIPS

(1968-1970-1980)

The CCIR,

CONSIDERING

(a) that there is a need for more reliable long-distance communication between land stations and:

– aircraft,

– ships;

(b) that systems employing space communication techniques could be employed to ensure a service of sufficient reliability;

(c) that communication with aircraft and ships will be needed for the transmission of telephony and telegraphy (including data transmission, direct printing, facsimile) or both;

(d) that in the interest of conservation of the radio-frequency spectrum and to minimize the equipment which aircraft and ships carry, there might be overall merit in establishing a joint and/or adjacent aeronautical mobile/maritime mobile communication band;

(e) that the use of common satellites for the mobile services – aeronautical and maritime – might be advantageous, especially if the same order of frequency were used;

(f) that important advantages, including those of frequency economy, might arise from combined systems for communication and radiodetermination,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the preferred types of orbit to provide:

1.1 communication via satellite between aeronautical earth stations in the aeronautical mobile-satellite service and aircraft and between coast earth stations in the maritime mobile-satellite service and ships;

1.2 a radiodetermination satellite service for aircraft and for ships;

2. the preferred frequencies and technical characteristics for:

2.1 satellite-aircraft links;

2.2 satellite-ship links;

2.3 satellite-feeder links;

3. the technical feasibility of developing and operating satellite systems for both the aeronautical mobile-satellite service and the maritime mobile-satellite service;

3.1 in the same frequency bands;

3.2 in the same frequency bands as other space and/or terrestrial services;

4. the technical feasibility of developing and operating systems employing space communication techniques jointly for communication and radiodetermination purposes for aircraft and/or for ships.

Note. – See Recommendations 546, 549, Reports 509, 599, 751, 752, 754, 758, 760, 762 to 768, 917 and 920 to 923.

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* The Director, CCIR, is requested to bring this Study Programme to the attention of the International Civil Aviation Organization (ICAO), the Inter-Governmental Maritime Consultative Organization (IMCO), the International Maritime Satellite Organization (INMARSAT) and through the Secretary-General of the ITU, the United Nations Committee on the Peaceful Uses of Outer Space, and, in particular, to invite the cooperation of ICAO, INMARSAT and IMCO in this study. This Study Programme should also be brought to the attention of Study Group 4.

STUDY PROGRAMME 17B-2/8 *

TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS PROVIDING RADIOCOMMUNICATION AND/OR RADIODETERMINATION USING SATELLITE TECHNIQUES FOR DISTRESS AND SAFETY OPERATIONS

(1972-1974-1980)

The CCIR,

CONSIDERING

(a) Recommendations No. 201, and No. 604 of the World Administrative Radio Conference, Geneva, 1979;

(b) that the bands 121.45 to 121.55 MHz and 242.95 to 243.05 MHz have been also allocated to the mobile-satellite service for the reception on-board satellites of emissions from emergency position indicating radio beacons (EPIRB) transmitting at 121.5 and 243 MHz;

(c) that the band 406.0 to 406.1 MHz has been allocated to the mobile-satellite service and reserved solely for the use and development of low power emergency position-indicating radio beacon (EPIRB) system using space techniques;

(d) that the bands 1544 to 1545 MHz (space-to-Earth) and 1645.5 to 1646.5 MHz (Earth-to-space) have been allocated to the mobile-satellite service and are limited to distress and safety operations,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the feasibility of using the frequencies allocated to the mobile-satellite service, especially for ships and survival craft, in particular with regard to distress, search and rescue and safety operations;

2. the operating, technical and economic consequences of employing a single frequency band or multiple frequency bands for shipboard equipment, satellite EPIRBs, and other satellite facilities;

3. determination of the role of maritime mobile-satellite in a coordinated distress system, as well as in safety operations.

Note. – See Reports 761 and 919.

STUDY PROGRAMME 17F-2/8

AVAILABILITY OF CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(1978-1980-1981)

The CCIR,

CONSIDERING

(a) that continuity of traffic on established links in the maritime mobile-satellite service may be interrupted by equipment failure or by natural phenomena (solar interference, attenuation due to multipath or atmospheric effects);

(b) that the interruptions may be divided into self-restoring interruptions (protection switching, natural phenomena) and interruptions which include repair time;

(c) that site diversity of earth stations and protection switching, to increase availability when required, convert long interruptions to very brief ones;

(d) that traffic may be interrupted by sudden variations of signal level at baseband, by the complete disappearance of the wanted signal or by a high level of noise or, in the case of digital transmission systems, by bursts of errors;

(e) that in planning a satellite link, decisions must be taken on receive signal margins, protection switching, etc. which have a major impact on the link availability and the cost of its provision;

(f) that availability requirements may be different for different types of transmission (telephony, telegraphy, data transmission);

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* The Director, CCIR, is requested to bring this Study Programme to the attention of the International Civil Aviation Organization (ICAO), the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Maritime Satellite Organization (INMARSAT) and invite them to cooperate in the study.

(g) that the duration of some interruptions may depend on the configuration of the satellite network: they may also depend on whether earth stations are always attended or unattended at the onset of an interruption and on whether or not the earth station antennas are readily steerable to point from one satellite to another;

(h) that the shore-to-ship and ship-to-shore hypothetical telephone reference channels are dissimilar;

(j) that, since the shore-satellite link is fixed and the ship-satellite link is mobile, they may need to be considered independently;

(k) that ship earth stations will be subject to environmental conditions that vary not only with time but also with the location of the ship within the satellite coverage area;

(l) that a reliable communication system will have a positive impact on ship, crew and passenger safety;

(m) that reliable communications are desirable even under adverse conditions;

(n) that terms and definitions that are required in connection with these studies should, as far as possible, be based on internationally accepted expressions,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. rate of incidence and the duration of self-restoring and other interruptions to be expected in modern satellite systems between points defined by the hypothetical reference circuit;

2. for satellite links with and without site diversity protection, the proportion (in frequency and in duration) of interruptions due to propagation effects;

3. preferred characteristics (e.g. switching time) for equipment protection arrangements;

4. proportion of interruptions due to maintenance, including human error;

5. preferred characteristics of devices that would prevent malfunctioning of other systems connected in tandem at baseband;

6. ship earth station availability, taking account of such factors as redundancy, tracking capability, etc.;

7. compilation of a list of terms and definitions currently used in the documents of various international bodies dealing with terminology which are applicable to these studies, and a list of additional terms and definitions which may be required.

Note. – See Report 918.

STUDY PROGRAMME 17G/8 *

FREQUENCY SHARING BETWEEN THE MARITIME MOBILE-SATELLITE SERVICE AND THE SPACE OPERATION SERVICE IN THE 1530-1535 MHz BAND

(1981)

The CCIR,

CONSIDERING

(a) Recommendation No. 708 of the World Administrative Radio Conference, Geneva, 1979;

(b) that the frequency band 1530 to 1535 MHz has been allocated on a shared basis to the maritime mobile-satellite service (space-to-Earth) and to the space operation service (space-to-Earth);

(c) that the allocation to the maritime mobile-satellite service of the band 1530 to 1535 MHz shall be effective from 1 January 1990,

UNANIMOUSLY DECIDES that the following study should be carried out:

the criteria for frequency sharing between the maritime mobile-satellite service (space-to-Earth) and the space operation service (space-to-Earth) in the frequency band 1530 to 1535 MHz.

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* The Director, CCIR, is requested to bring this Study Programme to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO), the International Maritime Satellite Organization (INMARSAT) and Study Group 2.

QUESTION 18-3/8 *

ON-BOARD COMMUNICATIONS BY MEANS OF PORTABLE RADIOTELEPHONE EQUIPMENT

(1971-1972-1978-1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 305 of the World Administrative Radio Conference, Geneva, 1979;

(b) that use of channels 15 and 17 for on-board communication with a maximum effective radiated power of 1 W is permitted (Appendix 18, Note *l)*, to the Radio Regulations);

(c) that the frequency 156.8 MHz (channel 16) is the international distress safety and calling frequency for VHF radiotelephony;

(d) that decisions were taken by the World Maritime Administrative Radio Conference, Geneva, 1974 concerning UHF on-board communication stations and in particular Appendix 20 to the Radio Regulations;

(e) that the Inter-Governmental Maritime Consultative Organization (IMCO) has indicated an operational requirement, particularly for safety purposes, for VHF and UHF frequencies to be made available for world-wide use on board ships on the high seas, in territorial waters and in harbours;

(f) that the use of channels 15 and 17 may be restricted by national regulations (Appendix 18, Note *l)* of the Radio Regulations);

(g) that there is considerable variation in the factors relating the output power to the effective radiated power of small portable radio equipment and that more information is required;

(h) that systems employing radiating cables have a low interference potential and are in use in other services;

(j) that there might be some saving of spectrum if radiating cables were used,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what frequency bands are most suitable for portable radio equipment for on-board communication and what powers are required for effective communication;

2. how many channels should be provided;

3. what is the maximum effective radiated power in the respective frequency bands which will not cause harmful interference to other users, taking into account the environmental conditions on board the ship and the average characteristics of the portable equipment used;

4. what precautions must be taken to ensure that no interference is caused to the fixed radio installation on the ship;

5. could radiating cable systems meet the technical and operational requirements of on-board communications;

6. what frequency bands would be preferred for maritime mobile applications of radiating cables;

7. what are the preferred characteristics of radiating cable systems intended for maritime mobile applications?

Note. – See Report 589 and Recommendation 542.

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* The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO).

QUESTION 20-1/8

BLACK AND WHITE FACSIMILE TRANSMISSIONS OVER COMBINED METALLIC AND RADIO CIRCUITS IN THE MARITIME MOBILE SERVICE

(1972-1974)

The CCIR,

CONSIDERING

(a) the growing interest in the use of black and white facsimile transmissions over radio circuits in the maritime mobile service;

(b) that great advantages can be obtained by standardization of the technical characteristics of the transmissions,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the preferred characteristics for black and white facsimile transmissions to and from ships where combinations of metallic circuits and maritime radio circuits are involved;

2. what operational procedures should be recommended for such transmissions?

Note 1. – The Director, CCIR, is requested to bring this Question to the attention of the CCITT and the World Meteorological Organization (WMO).

Note 2. – See Report 588.

STUDY PROGRAMME 21A-2/8 *

DEFINITION OF INTERFERENCE AND UNITS AND METHODS OF MEASUREMENT

(1972-1974-1982)

The CCIR,

CONSIDERING

(a) that Recommendation No. 708 of the World Administrative Radio Conference, Geneva, 1979, asks the CCIR to study as a matter of priority the various technical sharing criteria between space radiocommunications and terrestrial radiocommunication services;

(b) that the above-mentioned Conference has adopted definitions for the certain terms of interference;

(c) that the above-mentioned definitions are essential for the development of proper criteria for the sharing of radio frequencies between stations of the aeronautical mobile, maritime mobile, land mobile and radiodetermination services (terrestrial and satellite) on the one hand and stations of other services on the other hand,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. investigation of the meaning of the terms "acceptable (or unacceptable) interference" and "harmful interference" with respect to the aeronautical mobile, maritime mobile, land mobile and radiodetermination services (terrestrial and satellite);

2. investigation of the appropriate units in which such types of interference may be expressed, whether in terms of signal level, of percentages of time, and/or by other means as the case may be;

3. investigation of the appropriate methods to be used for measurement of interference to various types of mobile services caused by other radio emissions.

Note 1. – The Director, CCIR, is requested to draw the attention of ICAO and IMCO to this Study Programme and invite them to cooperate in the study.

Note 2. – See Reports 926 and 927.

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* This Study Programme is based on Question 45/1 of Study Group 1.

QUESTION 22/8 *

MOBILE RADIOCOMMUNICATION EQUIPMENT FOR RELIEF OPERATIONS

(1972)

The CCIR,

CONSIDERING

(a) Recommendation No. 1 of the World Administrative Radio Conference, Geneva, 1979;

(b) that rapid and reliable telecommunications are essential for relief operations in the event of natural disasters, epidemics, famines and similar emergencies;

(c) that, through damage or from other causes, the normal telecommunications facilities in disaster areas are often inadequate for relief operations and cannot be restored or supplemented quickly through local resources;

(d) that CCIR Study Group 4 is carrying out studies concerning standard specifications and preferred frequencies for transportable earth stations for relief operations,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred characteristics and frequency bands for radiocommunication equipment in the mobile service to establish telecommunications for relief operations, taking into account that this equipment may be connected to a transportable earth station in the fixed-satellite service?

QUESTION 23-3/8 **

AUTOMATED VHF/UHF MARITIME MOBILE TELEPHONE SYSTEMS

(1974-1978-1982)

The CCIR,

CONSIDERING

(a) that the VHF maritime mobile telephone service is of utmost importance for communication in coastal waters where the traffic load is heavy;

(b) that the traffic growth in the manual systems operating today is substantial;

(c) that the operating cost of manual handling tends to limit the quality of service;

(d) that advantage should be taken of the possibilities offered by the development of new techniques and the possibility of the use of the UHF band;

(e) that automated VHF communications systems are being developed to provide radiotelephone, radiotelegraph, facsimile, data and safety services;

(f) that international standardization is of great importance in the maritime mobile service;

(g) that a delay in this standardization might necessitate national solutions;

(h) Resolution No. 311 and Recommendation No. 312 of the World Administrative Radio Conference (Geneva, 1979),

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* See also Questions 22/3, 22/4 and 20/9.

** The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and the CCITT.

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the operational requirements of a VHF/UHF maritime mobile automated telephone service;

2. what restraints should be imposed on an automated system in order to assure compatibility with manual services;

3. what should be the technical and operational characteristics of the system, including the signalling methods to be used on the radio path and the interface with the public switched telephone network;

4. what characteristics of an automated radio telephone service should be considered to provide for the inclusion of other communications services?

Note. – See Recommendations 586, 587, Report 587 and Decision 30.

STUDY PROGRAMME 23A/8 *

PREFERRED FREQUENCY BANDS FOR AN AUTOMATED UHF MARITIME MOBILE RADIOCOMMUNICATION SYSTEM

(1980)

The CCIR,

CONSIDERING

(a) Recommendation No. 310 of the World Administrative Radio Conference (Geneva, 1979);

(b) that Study Group 8 has approved at its Interim Meeting Question 52/8 on the integration of public mobile radiocommunication services in the VHF/UHF frequency bands,

UNANIMOUSLY DECIDES that the following studies should be carried out:

to determine the preferred frequency bands from operating and sharing aspects for an automated UHF maritime mobile radiocommunication system.

QUESTION 26-2/8 **

USE OF CLASS J3E EMISSIONS FOR DISTRESS AND SAFETY PURPOSES

(1974-1978-1982)

The CCIR,

CONSIDERING

Resolution No. 200 and 305 of the World Administrative Radio Conference, (Geneva, 1979),

UNANIMOUSLY DECIDES that the following question should be studied:

1. what recommendations should be made on the use of class J3E emissions for distress and safety purposes in the MF telephony bands;

2. what special provisions should be made for radio direction finding and homing in connection with the use of J3E emissions for distress and safety purposes?

Note. – See Report 744 and Recommendations 543 and 544.

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* The Director, CCIR, is requested to bring this Study Programme to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO).

** The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO).

QUESTION 27-1/8 *

TECHNICAL PARAMETERS OF RADAR BEACONS (RACONS)

(1982)

The CCIR,

CONSIDERING

(a) Resolution No. 600 and Recommendation No. 600 of the World Administrative Radio Conference (Geneva, 1979);

(b) that shipborne radars operate in the bands 2920-3100 MHz and 9320-9500 MHz;

(c) that aeronautical mobile radars operate in the band 9320-9500 MHz;

(d) that there are various types of maritime radar beacons (maritime racons) which operate in the frequency bands 2920-3100 MHz and 9320-9500 MHz;

(e) that the use of fixed frequency racons is not permitted in the bands 2920-3100 MHz and 9320-9500 MHz;

(f) that in the bands 2900-2920 MHz and 9300-9320 MHz the use of shipborne radars is no longer permitted with a view to facilitating development of fixed frequency racons in this band;

(g) that the use of shipborne transponder systems is confined to the bands 2930-2950 MHz and 9280-9300 MHz;

(h) that the use of the band 2900-3100 MHz by the aeronautical radionavigation service is limited to ground-based radars;

(j) that the use of the band 9300-9500 MHz by the aeronautical radionavigation service is limited to airborne weather radars and ground-based radars. In addition, ground-based radar beacons in the aeronautical radionavigation service are permitted in the band 9300-9320 MHz on condition that harmful interference is not caused to the maritime radionavigation service. In the band 9300-9500 MHz, ground-based radars used for meteorological purposes have priority over other radiolocation devices,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what general technical parameters should be recommended for radar beacons (racons) taking into account electromagnetic compatibility with other services having allocations in the same frequency bands;

2. what specific technical parameters should be recommended for fixed frequency racons;

3. what specific technical parameters should be recommended for the various types of racons which could operate in the same frequency bands as shipborne radars?

Note. – See Report 774 and Recommendation 554.

QUESTION 28-1/8 **

FREQUENCY REQUIREMENTS FOR SHIPBORNE TRANSPONDERS ***

(1974–1982)

The CCIR,

CONSIDERING

Resolution No. 600 and Recommendation No. 605 of the World Administrative Radio Conference (Geneva, 1979),

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* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO), Inter-Governmental Maritime Consultative Organization (IMCO), World Meteorological Organization (WMO) and the International Association of Lighthouse Authorities (IALA).

** The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and to the International Association of Lighthouse Authorities (IALA).

*** A receiver-transmitter which emits a signal automatically when it receives the proper interrogation.

UNANIMOUSLY DECIDES that the following question should be studied:

what is the most suitable order of frequencies and bandwidth required for shipborne transponders and the technical parameters to be met by such devices, taking into account electromagnetic compatibility with other services having allocations in the same frequency band?

Note. – See Report 775.

QUESTION 29-1/8 *

THE CHOICE OF A FREQUENCY OR FREQUENCIES IN THE MARITIME MOBILE BANDS BETWEEN ABOUT 1605 kHz AND 3800 kHz TO BE RESERVED FOR VOICE OR SELECTIVE-CALLING FOR ROUTINE TRAFFIC

(1974-1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 307 of the World Administrative Radio Conference (Geneva, 1979);

(b) that the Inter-Governmental Maritime Consultative Organization (IMCO) recommends that the frequency 2182 kHz be a dedicated international frequency in the Future Global Maritime Distress and Safety System on which only distress and safety communications are permitted;

(c) the studies carried out under Question 44/8,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the technical and operating aspects that should be taken into account when choosing a frequency or frequencies different from 2182 kHz, in the maritime mobile bands between about 1605 and 3800 kHz for voice or selective-calling for routine traffic?

Note. – See Report 745.

QUESTION 30-2/8

IMPROVED USE OF THE HF RADIOTELEPHONE CHANNELS FOR COAST STATIONS IN THE BANDS ALLOCATED EXCLUSIVELY TO THE MARITIME MOBILE SERVICE

(1974-1978-1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 302 of the World Administrative Radio Conference (Geneva, 1979);

(b) that the above-mentioned Conference requested the CCIR to complete this study before the next competent World Administrative Radio Conference;

(c) that the level of man-made noise on board ships may affect the efficient use of radiotelephone channels (see Recommendation 218);

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* The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO).

(d) the limited number of channels available for HF radiotelephony in the maritime mobile service;

(e) the increasing demands for radiotelephony in the maritime mobile service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the technical and operational sharing criteria relating to the use of HF coast radiotelephone channels in the bands allocated exclusively to the maritime mobile service, which should be recommended including the use of electronic or other means to facilitate multiple access to the channels;

2. what improved operational procedures should be adopted for setting up calls to obtain a more efficient channel utilization;

3. what new methods of determining sharing patterns are feasible;

4. in the case of man-made noise on board ships:

4.1 what is the preferred method of measurement;

4.2 what are the sources and levels, and

4.3 what further measures other than those indicated in Recommendation 218 are possible for effectively reducing these noise levels?

Note. – See Report 748.

QUESTION 31-2/8 *

FUTURE USE AND CHARACTERISTICS OF EMERGENCY POSITION-INDICATING RADIO BEACONS IN THE MOBILE SERVICE AND THE MOBILE-SATELLITE SERVICE

(1974-1978-1982)

The CCIR,

CONSIDERING

(a) Resolution No. 601 and Recommendation No. 604 of the World Administrative Radio Conference (Geneva, 1979);

(b) the development of automated watch-keeping facilities for use on board ships;

(c) that the Future Global Maritime Distress and Safety System shall provide for the receipt of distress alerts and the location of units situated in all maritime areas;

(d) that administrations may find it necessary to develop EPIRBs to satisfy unique national requirements;

(e) the possible need for an extension of the homing range which can be achieved by EPIRBs using the frequency of 2182 kHz and the limited value of such EPIRBs to ships operating in areas of high noise conditions,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the preferred technical and operating characteristics of EPIRBs and satellite EPIRBs to meet the requirements of IMCO and ICAO and what is the preferred order of frequencies, with particular reference to the prime requirement for homing and the desirability for unification?

Note. – See Report 749 and Recommendation 439.

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* The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Civil Aviation Organization (ICAO) and to invite these organizations to make their requirements known to the CCIR.

QUESTION 32-2/8 *

PREFERRED TECHNICAL AND OPERATING CHARACTERISTICS FOR A MOBILE-SATELLITE SYSTEM

(1976-1978-1982)

The CCIR,

CONSIDERING

(a) that there may be a need for a mobile-satellite service; which could have earth stations on ships, land and/or aircraft all operating within the same system;

(b) that the operating and technical characteristics of such a mobile-satellite service may differ from those limited to an exclusive aeronautical mobile, land mobile or maritime mobile-satellite service;

(c) that Question 22/4 deals with the use of transportable earth stations in connection with natural disasters and other similar emergencies;

(d) that Question 23/4 deals with the use of low capacity earth stations, implying the use of small antennas;

(e) that there are other potential uses which may require mobile earth stations and which may necessitate rapid deployment and operation of earth stations which are not consistent with the coordination requirements of the earth stations of the fixed-satellite service;

(f) that the characteristics envisaged for earth stations mentioned in *(b)* and *(c)* may be similar and involve small antennas,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the preferred technical and operating characteristics for a mobile-satellite system which would have earth stations on ships, land and/or aircraft all operating within the same system;

2. what are the technically preferred range of frequencies and modulation methods for such a system;

3. what are the preferred performance characteristics of earth stations and space stations for such a system;

4. to what extent may such a system be shared with other services and what sharing criteria are applicable?

Note. – See Reports 771, 772 and 773.

STUDY PROGRAMME 32A/8 **

A GLOBAL LOW-ORBIT SATELLITE SYSTEM FOR DETECTION AND POSITIONING OF LOW-POWER TRANSMITTERS

(1980)

The CCIR,

CONSIDERING

(a) that many of the current available terrestrial systems for alerting and radiodetermination services suffer from technical shortcomings which cannot be overcome without unreasonably high costs;

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* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO), the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Maritime Satellite Organization (INMARSAT).

** The Director, CCIR, is requested to bring this Study Programme to the attention of the International Civil Aviation Organization (ICAO), the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Maritime Satellite Organization (INMARSAT).

(b) that the technique for systems based on satellites for these needs is developing rapidly;

(c) that different system concepts for search and rescue in maritime and partly also in the aeronautical field employing geostationary satellites and low altitude polar orbiting satellites will be tested and evaluated in the near future;

(d) that strong requirements exist today, and will probably grow stronger with time, for systems for detection and positioning in remote areas;

(e) that these requirements could be obtained by utilizing a satellite system employing low-orbit satellites, with active ranging facilities;

(f) that the total costs for establishing a highly reliable low-orbit satellite system will be high and may require the participation of many countries;

(g) that the requirement for keeping the terminal costs reasonable is internationally agreed;

(h) that the availability of frequency spectrum for such applications is limited,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the preferred technical and operating characteristics of a future global low-orbit satellite system for detection and positioning of low-power transmitters;

2. the possibilities of incorporating such a system as part of an existing or planned low-orbit satellite system.

QUESTION 33-1/8

INTERFERENCE TO RADIONAVIGATION SERVICES FROM OTHER SERVICES IN THE BANDS BETWEEN 70 kHz AND 130 kHz

(1976-1978)

The CCIR,

CONSIDERING

(a) that the Radio Regulations authorize radionavigation, fixed and maritime mobile services in various combinations in the bands between 70 and 130 kHz depending on region;

(b) that radionavigation systems are either operational or being implemented to provide coverage in all regions;

(c) that since radionavigation is a safety service, it is essential that there be no harmful interference to any system of the service;

(d) that both pulse and continuous wave radionavigation systems are used in the separately allocated bands between 70 kHz and 130 kHz;

(e) that separation in time domain of radionavigation signals of one system enables several stations of that system to overlap the same geographic area,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what system parameters must be defined to assure compatibility and to avoid harmful interference between the different systems of the radionavigation service and/or other services authorized in the bands between 70 and 130 kHz;

2. what system factors may cause interference between the same and different types of radionavigation systems where the former operate in the same band and the latter operate in one or more of the other bands between 70 and 130 kHz;

3. what operational characteristics should be recommended to avoid mutual interference between stations providing the same type of radionavigation service?

Note. – See Recommendation 589 and Report 915.

QUESTION 35-1/8 *

EFFICIENT USE OF THE RADIO SPECTRUM BY RADAR STATIONS IN THE RADIODETERMINATION SERVICE

(1977-1978)

The CCIR,

CONSIDERING

(a) that the radio spectrum available for use by the radiodetermination service is limited;

(b) that the necessary bandwidths of emissions from radar stations in the radiodetermination service are large compared with emissions from stations in many other services;

(c) that wherever possible, it is desirable for different radar stations to use the same frequencies;

(d) that various techniques, including Pulse Recurrence Frequency Discrimination (PRFD) have been used successfully in a number of countries to reduce mutual interference and enable radar stations in close proximity to use the same frequencies;

(e) that maritime radar stations should be compatible with radar beacons in the maritime radionavigation service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what economy in spectrum utilization, and improvement in operational performance can be achieved by the use of interference suppression techniques for radar stations;

2. what technical characteristics of radar stations should be recommended for international application;

3. what radiodetermination services could utilize interference suppression techniques effectively;

4. what are the limitations on the use of interference suppression techniques;

5. what other factors could improve the efficiency of utilization of the frequency spectrum?

Note. – See Report 914.

QUESTION 36/8

RADIATING CABLE SYSTEMS IN THE LAND MOBILE SERVICES

(1978)

The CCIR,

CONSIDERING

(a) that the number of radio stations in the land mobile service is increasing very rapidly;

(b) that new stations can sometimes only be introduced at the expense of degrading the performance of existing systems by interference;

(c) that systems employing radiating cables having a low interfering potential are in use;

(d) that radiating cable systems could be used with advantage to meet certain operational needs, for example: coverage of motorways, railways and tunnels,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what frequency bands are to be preferred for the applications in which it is advantageous to use radiating cables;

2. whether frequency bands allocated to other radio services could be used additionally for land mobile services using radiating cables and, if so, under what conditions;

3. what are the preferred technical and operating characteristics for use in radiating cable systems?

Note. – See Report 902.

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* The Director, CCIR, is requested to bring this Question to the attention of the International Association of Lighthouse Authorities (IALA), the International Civil Aviation Organization (ICAO) and the Inter-Governmental Maritime Consultative Organization (IMCO).

QUESTION 37-1/8

SYSTEMS WITH IMPROVED SPECTRUM EFFICIENCY FOR THE LAND MOBILE SERVICE

(1978-1982)

The CCIR,

CONSIDERING

(a) that the number of radio stations in the land mobile service is increasing very rapidly;

(b) that in several geographical areas the growing demand for radio channels in the land mobile service has resulted in a serious congestion in the frequency bands allocated to this service;

(c) that in order to alleviate these bands as well as those to be allocated in the future, it might be desirable for the land mobile service to employ spectrum saving techniques;

(d) that Question 7/8 deals with the spectrum efficiency to be achieved by modulation techniques;

(e) that improved spectrum efficiency might be achieved:

- by employing automatic frequency sharing techniques for radio channels;
- by optimizing the size of base station coverage areas, particularly for stations operating in the higher frequency bands, e.g., in the 900 MHz region, where the coverage areas may be small;
- by combining these two techniques;

(f) that, particularly for systems operating in border areas of neighbouring countries, it is desirable to reach international agreement on certain system parameters and technical equipment characteristics,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what techniques are appropriate to improve spectrum efficiency of public and private land mobile systems covering one or more radio zones, taking the following aspects into consideration:

- frequency bands and propagation conditions;
- switching of radio channels for calls-in-progress, when mobile stations move from one coverage area to a neighbouring area (hand-off);
- the initiation and receiving of calls through a control centre other than the control centre to which the mobile station is assumed to be assigned (roaming);

2. in which way and to what extent is it possible to achieve improved spectrum efficiency by employing automatic sharing techniques for radio channels, for example by means of trunking systems covering one or more radio zones, taking into account essential system characteristics like traffic density, grade of service, etc., and costs;

3. what are the optimum sizes of base station coverage areas from the point of view of frequency spectrum efficiency and complexity of equipment;

4. what are the preferred frequency assignment methods;

5. can spectrum efficiency be improved by integration of public and private networks and if so, in what way and to what extent;

6. how can the improvement in spectrum efficiency be measured;

Note. – See also Question 47/1: Definition of efficiency and utility of spectrum use, and relevant Reports of Study Group 1.

7. what are the system parameters and technical characteristics of equipment on which international agreement is desirable?

Note. – See Reports 740, 741 and 901.

QUESTION 38-1/8

USE OF FREQUENCIES IN THE BANDS BETWEEN ABOUT 1606 AND 4000 kHz ALLOCATED TO THE MARITIME MOBILE SERVICE

(1978-1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 301 of the World Administrative Radio Conference (Geneva, 1979);

(b) the fact that the frequency bands shared between the mobile and the fixed services between about 1606 and 4000 kHz are very useful to the land mobile service and to the fixed service for certain types of circuits;

(c) that during the time of day when the traffic of the maritime mobile service is highest only the surface wave is usable in practice in these bands,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the technical and operational aspects to be considered in the use of frequencies in the bands between about 1606 and 4000 kHz allocated to the maritime mobile service;

2. what are the criteria for geographical and time sharing of the frequency bands between about 1606 and 4000 kHz between the maritime mobile service and the fixed and land mobile services, in view of the different conditions under which these frequencies are used by these various services?

QUESTION 39-1/8 *

PUBLIC LAND MOBILE TELEPHONE SYSTEMS

(1978-1982)

The CCIR,

CONSIDERING

(a) that public mobile telephone services, i.e. services for public correspondence via radio stations connected to the switched public telephone network, are in operation in a number of countries and that their use is extending;

(b) that the various technical systems already in use or proposed for such services, are not necessarily compatible one with another;

(c) that system compatibility is necessary in the case of international operation;

(d) that for international operation it is desirable to agree on the parameters of the system;

(e) Recommendation No. 310 of the WARC-79;

(f) Question 52/8 on the integration of public radiocommunication services in the VHF/UHF frequency bands,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the system parameters and technical characteristics of equipment used in public mobile telephone systems on which international agreement is desirable;

2. what operational facilities and technical characteristics need to be specified to permit international operation of public mobile telephone services;

3. from a technical point of view, what frequency bands are most suitable for public land mobile telephone systems?

Note. – See Report 742.

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* The Director, CCIR, is requested to bring this Question to the attention of the CCITT.

QUESTION 40-1/8

DIGITAL TRANSMISSION IN THE LAND MOBILE SERVICE

(1978-1982)

The CCIR,

CONSIDERING

(a) that digital signals in various formats are being used to improve the communications efficiency of the land mobile service;

(b) that there may be advantages in adopting digital transmission standards that are compatible with the characteristics of the speech channel of existing land mobile systems;

(c) that there may also be advantages in adopting for the land mobile service standards that are compatible with the CCITT Recommendations relevant to the fixed services;

(d) that the transmission characteristics of land mobile systems may differ from those of the fixed services, due to the particular characteristics of the service, its radio frequency propagation path and noise environment;

(e) that digital transmission systems which are not compatible with existing land mobile systems should also be considered, including the transmission of digitally encoded speech signals,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what data speeds are suitable and how should the data be formed (e.g. word and block length) *;

2. what improvements in performance can be achieved by the use of, for example, various diversity techniques, various error detection/correction codes or other techniques *;

3. what bit error ratios and block error rates can be achieved at the median signal strength and with the propagation variations currently acceptable for analogue speech communication;

4. what are the requirements for digital modulation methods which could directly modulate the radio frequency carrier of the transmitting equipment of future land mobile systems;

5. what are the possibilities of conveying digitally encoded speech signals in the systems referred to in § 4;

6. what characteristics of data modems * should be specified to ensure compatibility with existing mobile equipment, taking into account the particular characteristics of the radio path and available information from the CCITT?

Note. – See Report 903.

STUDY PROGRAMME 40A/8

DIGITIZED SPEECH TRANSMISSION IN THE LAND MOBILE SERVICE

(1982)

The CCIR,

CONSIDERING

(a) that there is a rapid development in methods for digitization of speech and digital modulation techniques;

(b) that this development gives new possibilities to obtain higher system flexibility and improved frequency economy;

(c) that there is a growing demand for data communication with higher speed and better reliability;

(d) that future mobile telephone systems might be integrated in the digital telephone system under development in several countries;

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* See V and X Series Recommendations of the CCITT.

(e) that a digitized speech system based on a wider channel separation may have more spectrum efficiency than a corresponding analogue system;

(f) that there is a growing demand for more privacy in speech communication;

(g) that international agreement may be necessary for some characteristics of digital mobile radio;

(h) that analogue and digitized speech transmissions may have to co-exist in the same frequency band and that interference between these systems must be minimized,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. possible improvement, if any, in spectrum efficiency compared with analogue systems;

2. definition of quality of digitized speech for different land mobile applications;

3. the proper choice of bit rate for digitized speech taking into account speech quality, required amount of channel coding, efficient frequency usage, and cost;

4. design of a digital modulation system to take account of the characteristics of the radio channel;

5. sharing principles that should be applied between analogue and digital systems;

6. the proper choice of channel spacing taking into account the bit rate required for digitized speech in the various land mobile services;

7. the technical characteristics on which international agreement is desirable to ensure compatibility of equipment between systems and/or operation of differing systems in neighbouring coverage areas.

QUESTION 41/8

WIRE ANTENNAS FOR USE ON BOARD SHIPS

Performance at 500 kHz

(1978)

The CCIR,

CONSIDERING

(a) that, in its Report on its 13th Session to the Maritime Safety Committee, the Sub-Committee on Radiocommunications of the Inter-Governmental Maritime Consultative Organization (IMCO) expressed doubts concerning the value of the existing metre-ampere table for wire antennas, especially for ships of modern design, and proposed that interested member Governments should be invited to request the CCIR also to study the question of wire antennas;

(b) that the methods which are used for self-supporting antennas in Report 502 (Kyoto, 1978), and on which the metre-ampere table in that Report is based, could be extended without difficulty to wire antennas installed on board ships,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what advice should be offered to the Inter-Governmental Maritime Consultative Organization (IMCO) by the CCIR on changes to be introduced into the metre-ampere table appearing in § (h) of Regulation 10 in Chapter IV of the International Convention for the Safety of Life at Sea, 1974, in order to take into account the conditions for installing wire antennas, particularly on modern ships;

2. to what extent could the dimensions of the antenna and its height above the maximum-load water-line be used to determine whether the requirements laid down in the above-mentioned Convention are complied with;

3. what improved methods of assessing the performance of the wire-antenna system might be employed?

Note. – The Director, CCIR, is requested to transmit this Question to the Inter-Governmental Maritime Consultative Organization (IMCO).

QUESTION 42/8

CHARACTERISTICS OF DIGITAL CHANNELS IN THE MARITIME MOBILE SERVICE

(1978)

The CCIR,

CONSIDERING

(a) that the administrations of many countries are developing equipment designed for the transmission of digital information by radio channels in the maritime mobile service;

(b) that the adoption of technical recommendations should be based on a comparison of the quality of the equipment proposed by various administrations;

(c) that it is difficult to arrange for joint comparative tests of different types of equipment;

(d) that the operational characteristics of digital information transmission equipment depend to a large extent on the radio-channel conditions;

(e) that, in view of the variable nature of radio propagation in the maritime mobile service, the test results obtained on the equipment by the administrations may differ;

(f) that it is essential to develop a standard method for assessing test conditions in radio channels in the maritime mobile service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what parameters should be considered in assessing the quality of digital radio channels, for example, the (bit, symbol, word) error probability in a specified time interval, the error grouping rate for blocks of various lengths, strength of signal and interference, etc.;

2. on what scope should tests be conducted;

3. what test signals should be used for evaluating the quality of channels;

4. what method should be used to assess the quality of radio channels when Administrations carry out full-scale tests of digital information transmission equipment;

5. in what range of variation of channel quality should tests be carried out on digital information transmission equipment?

Note. – See Report 743 and Decision 31.

QUESTION 44-1/8 *

THE CHOICE OF FREQUENCIES, IN THE MARITIME MOBILE BANDS ABOVE 1605 kHz TO BE RESERVED FOR DISTRESS AND SAFETY PURPOSES

(1978-1982)

The CCIR,

CONSIDERING

(a) that because of different propagation conditions over certain areas, the present MF distress frequencies do not provide adequate communication for distress, urgency and safety purposes in such areas;

(b) that many Administrations are using the radiotelephone frequencies of 4125 kHz and/or 6215.5 kHz to supplement the distress frequency of 2182 kHz for distress and safety purposes;

(c) that in respect of the 2182 kHz radiotelephone frequency, the significant advantages of using J3E class of emission will be realizable on implementation of the Future Global Maritime Distress and Safety System;

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* The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Civil Aviation Organization (ICAO).

(d) that in the radiotelegraph bands above 4000 kHz, the frequency of 8364 kHz is designated for use by survival craft for safety purposes,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the technical and operational aspects that should be taken into account when choosing frequencies, in the maritime mobile bands above 1605 kHz for distress calls and messages, urgency signals and messages and certain safety messages?

Note. – See Report 746 and Recommendation 545.

QUESTION 45-1/8 *

TECHNICAL AND OPERATING CONSIDERATIONS FOR A FUTURE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM

(1978-1982)

The CCIR,

CONSIDERING

(a) the need to provide communications for distress alerting, locating, coordination and rescue of persons and property, in distress, at sea;

(b) the shortcomings of the present distress systems;

(c) IMCO Resolution No. A.420(XI) and the continuing study of this matter by that organization;

(d) the number of frequencies and classes of emission authorized by the Radio Regulations for distress, urgency and safety;

(e) Recommendation No. 201 of the WARC (Geneva, 1979);

(f) that IMCO is developing the Future Global Maritime Distress and Safety System,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the technical and operating factors involved in a future global distress and safety system at sea;

2. what are the most suitable arrangements for such a system;

3. what special measures, if any, need to be taken to assist the implementation by IMCO of the Future Global Maritime Distress and Safety System?

Note. – See Report 747.

QUESTION 46/8

OPTIMUM CODING AND MODULATION METHOD(S) FOR THE TRANSMISSION OF DIGITAL DATA BETWEEN TERRESTRIAL STATIONS AND AIRCRAFT STATIONS OPERATING IN THE AERONAUTICAL MOBILE (R) SERVICE

(1978)

The CCIR,

CONSIDERING

(a) the importance of using the radio frequency spectrum as efficiently as possible;

(b) the continuing development of airborne electronic equipment using digital techniques;

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* The Director, CCIR, is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) and the International Civil Aviation Organization (ICAO).

QUESTION 45-2/8*

TECHNICAL AND OPERATING CONSIDERATIONS FOR A FUTURE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM

(1978-1982-1983)

The CCIR,

CONSIDERING

(a) the need to provide communications for distress alerting, locating, coordination and rescue of persons and property, in distress, at sea;

(b) the shortcomings of the present distress systems;

(c) IMO Resolution No. A.420(XI) and the continuing study of this matter by that Organization;

(d) the number of frequencies and classes of emission authorized by the Radio Regulations for distress, urgency and safety;

(e) Recommendation No. 201 (MOB-83) and Resolution No. 321 (MOB-83) of the WARC-M (Geneva, 1983);

(f) that IMO is developing the Future Global Maritime Distress and Safety System (FGMDSS);

(g) Recommendation No. 773 (MOB-83) of the WARC-M-83 relating to Radar Transponders for Search and Rescue operations at sea;

(h) Resolution No. 203 (MOB-83) of the WARC-M-83 relating to the use of frequencies of the FGMDSS by the land mobile service in uninhabited and remote areas,

DECIDES that the following question should be studied:

1. what are the technical and operating factors involved in a future global distress and safety system at sea;

2. what are the most suitable arrangements for such a system;

3. what special measures, if any, need to be taken to assist the implementation by IMO of the Future Global Maritime Distress and Safety System;

and in the framework of the FGMDSS:

4. what are the technical and operating characteristics of radar transponders for facilitating search and rescue operations at sea;

5. what are the technical and operational characteristics and procedures for the use of frequencies of the FGMDSS by the land mobile service in uninhabited and remote areas?

Note. – See Report 747.

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* The Director, CCIR, is requested to bring this Question to the attention of the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO) and invite these Organizations to make their requirements known to the CCIR.

(c) a considerable proportion of aeronautical air-ground-air communications is of a routine or semi-routine nature;

(d) the future need for exchange of digital data between aircraft and the ground to exploit the potential of automated processing systems now being introduced on the ground for air traffic control, for airline control of operations and for utilizing instrumental outputs on-board the aircraft;

(e) the need to detect and correct errors in the two-way information exchange between aircraft and ground stations sufficiently to ensure meeting the overall communication integrity and flight safety requirements;

(f) the effects on the transmission characteristics of screening and multipath reflections in the air-ground radio propagation path and the effects of interference on communications in the aeronautical (R) bands;

(g) the characteristics of aircraft radio systems, particularly the limited radiated power, the antenna directional properties and the high radio noise levels,

UNANIMOUSLY DECIDES that the following question should be studied:

in the bands allocated for the aeronautical mobile (R) service:

1. what is the optimum coding method for information which is to be transferred in air-ground-air digital data communications;

2. what are the optimum methods of providing the degree of error protection required;

3. what are the optimum methods of modulation for the air-ground and ground-air digitized data transmissions?

Note 1. – The Director, CCIR, is requested to bring this Question to the notice of ICAO and to invite that Organization to make its requirements known to the CCIR.

Note 2. – See Reports 769 and 928.

QUESTION 47-1/8

PREFERRED TECHNICAL AND OPERATIONAL CHARACTERISTICS FOR THE LAND MOBILE-SATELLITE SERVICE

(1978–1982)

The CCIR,

CONSIDERING

(a) that there may be a need for the land mobile-satellite service;

(b) that there is an increasing need for land mobile systems to extend the benefits of radiocommunications to the largest possible number of users;

(c) that the assumed need for a land mobile-satellite service must be analysed and, in particular, the desirable operational requirements;

(d) that the World Administrative Radio Conference (Geneva, 1979) has adopted Recommendation No. 1 relating to the use of space radiocommunication systems in the event of natural disasters, epidemics, famines and similar emergencies;

(e) that the scope for development and future application of land mobile-satellite systems may depend to a great extent upon the feasibility of sharing frequency bands used by other services, without mutual interference;

(f) that it may not in all cases be possible for such systems to share frequency bands with other services, because of mutual interference;

(g) that the operational requirements will have a decisive influence upon the capacity requirements of future systems and in consequence the requisite frequency bandwidth;

(h) that the efficiency of orbit-spectrum utilization in land mobile-satellite systems will be determined in part by the technical characteristics employed, such as modulation methods and parameters, frequency re-use techniques or the arrangement of radio frequency carriers;

(j) that the establishment of land mobile-satellite systems may require international agreement on the technical characteristics to be employed, including baseband, modulation and radio frequency characteristics;

(k) that satellite communications with land mobile earth stations have been successfully demonstrated,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what requirements are foreseen for systems in the land mobile-satellite service;

2. for these requirements:

2.1 what are the technically preferred range of frequencies and modulation methods for the land mobile-satellite service and the associated penalties for each;

2.2 what are the preferred performance characteristics of earth stations and space stations in systems of this service;

2.3 to what extent frequencies may be shared between this service and other services and what sharing criteria are applicable;

2.4 what system characteristics must be defined to ensure compatibility with other systems and to ensure making most effective use of frequency bands which may be allocated?

Note. – See Reports 770 and 925.

QUESTION 48-1/8

TECHNIQUES AND FREQUENCY USAGE IN THE AMATEUR SERVICE

(1978-1982)

The CCIR,

CONSIDERING

(a) that the amateur service provides benefits of self-training, inter-communication, and technical investigation carried on by amateurs, that is, by duly qualified and authorized persons throughout the world interested in radio technique solely with a personal aim and without pecuniary interest;

(b) that, incidental to its basic purposes, the amateur service has pioneered in new and novel techniques for radio reception and transmission;

(c) that frequency dependent factors determine to a large extent the effectiveness of radiocommunications in the amateur service;

(d) that amateur station operators contribute to the development and demonstration of spectrum conservation techniques throughout the radio frequency spectrum;

(e) that the amateur service is able to provide a service of communications during natural disasters and other catastrophic events when normal communications may be temporarily interrupted or inadequate for the needs of human relief operations in the period pending restoration of facilities,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what technical and operating factors influence the usage by the amateur service of the frequency bands allocated to it throughout the radio spectrum;

2. what techniques being applied or investigated in the amateur service may be of interest to other services;

3. what are the appropriate criteria for frequency sharing between the amateur service and other radiocommunication services?

Note. – See Reports 905 and 906.

QUESTION 49/8

RADIOCOMMUNICATION FOR SHORT-RANGE HEARING AIDS

(1978)

The CCIR,

CONSIDERING

(a) that in certain conditions, e.g. in noisy environments or for persons with impaired hearing it is desirable to operate appropriate radiocommunication hearing aids;

(b) that a significant number of persons have impaired hearing;

(c) that in such conditions acoustically linked hearing aids do not allow speech to be presented at an optimum level and without environmental noise;

(d) that radio emission is a practical means of transferring a signal with a favourable signal-to-noise ratio from a microphone located near the lips of the person whose speech is being auditioned to a hearing aid;

(e) that such a radiocommunication hearing aid could be designed to assist persons with a hearing loss to communicate over distances as are ordinarily spanned by unaided speech;

(f) that a range of transmission of about 10 metres would be adequate;

(g) that such a short range transmission can be obtained in an induction field having an approximately inverse cubic decay characteristic;

(h) that certain countries are carrying out research and development into such systems;

(j) that such a communication system may have wider application;

(k) that persons with hearing impairments would benefit from using radiocommunication hearing aids when travelling;

(l) that international agreement to the use of these devices is desirable,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the most suitable technical characteristics of a short-range radiocommunication hearing aid system;

2. what interference is likely to be caused to other services by the widespread use of low power radiocommunication hearing aids;

3. what protection is required from other services to permit satisfactory operation of radiocommunication hearing aids using an internationally common radio frequency channel;

4. what is the preferred frequency band and mode of operation for a short-range hearing aid system?

Note. – See Report 778.

QUESTION 50/8 *

TECHNICAL FEASIBILITY OF FREQUENCY SHARING BY THE AMATEUR SATELLITE SERVICE

(1972-1974)

The CCIR,

CONSIDERING

(a) that the World Administrative Radio Conference for Space Telecommunications, Geneva, 1971, established an Amateur Satellite Service, allocated frequencies to it in bands already allocated to the Amateur Service on an exclusive or shared basis, and adopted No. 2741 of the Radio Regulations concerning cessation of emissions from amateur satellites;

(b) that the Amateur Service, and particularly the Amateur Satellite Service, has made significant contributions to the observation and understanding of propagation phenomena especially in bands 7, 8 and 9;

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* This Question replaces Question 13-1/2 which had been drawn up by Study Group 2.

(c) that amateur stations generally, including those used for satellite communication, are typified by simple terminals with small antennae;

(d) that the desire for widespread use and experimentation has led to extensive use of low, non-geostationary orbits, for which any given area of the Earth is exposed to the transmissions of the satellite for relatively short periods,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the techniques and operating modes of the Amateur Satellite Service in frequency bands shared with other Services, and what are the preferred frequency bands for this Service;

2. what is the potential interference from and to the Amateur Satellite Service in frequency bands shared with other Services; what sharing criteria should be applied in these bands; and what are the differences in these criteria that should be applied with satellites in geostationary and non-geostationary orbits?

Note. – See Report 542.

QUESTION 51/8

AUTOMATIC DETERMINATION OF LOCATION IN THE LAND MOBILE SERVICE

(1982)

The CCIR,

CONSIDERING

(a) that within the land mobile service there is a great and growing demand for automatic vehicle location (AVL), including portables;

(b) that in advanced land mobile systems which use computer-controlled dispatch this requirement is often essential;

(c) that radio location systems are in operation for other services which can give accurate position data;

(d) that the operational requirements for AVL systems can vary considerably e.g. between urban and rural areas and between various types of operations in the land mobile service;

(e) that the introduction of AVL in international land mobile services may be required;

(f) that in some circumstances AVL systems may be shared by a number of land mobile radio systems;

(g) that minimizing the number of types of AVL systems could improve spectrum efficiency;

(h) that a considerable part of the voice communications on radio dispatch channel is location and other routine messages;

(j) that the costs of running land mobile dispatch operations are sharply increasing;

(k) that an AVL system integrated in a land mobile radio dispatch system can potentially reduce the cost of running land mobile dispatch operation,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what type of AVL systems are suitable for use in the land mobile service; for what type of operations and which of these types are suitable for international use;

2. what are the operational requirements for AVL systems e.g. procedures, accuracy and coverage;

3. what ~~are the~~ technical characteristics for AVL systems which need to be standardized, including those required when an AVL system is shared by a number of land mobile systems and when it is used in international services;

4. can existing radio location systems in other services be used to meet the needs of the land mobile service;

5. how can existing land mobile installations and frequency assignments be used to provide AVL;

6. what data traffic levels are expected and what are the requirements as concerns acceptable transmission delay, frequency of up-date and error rate when the determination of location is made within a mobile unit;

7. what are the costs/benefits of AVL to land mobile dispatch operations;

8. what is the impact of AVL on spectrum efficiency as a result of the reduction in voice communications?

Note. – See Report 904.

QUESTION 52/8 *

INTEGRATION OF PUBLIC MOBILE RADIOCOMMUNICATION SERVICES IN THE VHF/UHF FREQUENCY BANDS

(1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 310 of the World Administrative Radio Conference (Geneva, 1979);

(b) Question 23/8 on automated VHF/UHF maritime mobile telephone systems;

(c) Study Programme 23A/8 on preferred frequency bands;

(d) Recommendations 586 and 587 related to an automated VHF/UHF maritime mobile telephone system;

(e) Question 39/8 on public land mobile telephone systems;

(f) that advantages should be obtained from integration of the mobile services, for example, improved spectrum efficiency, economy in the production, use and operation of equipment, standard operating procedures and subscriber convenience;

(g) that various levels of integration are possible, for example, use of common frequency spectrum, switching equipment, and signalling and access procedures on the radio path;

(h) that the degree of integration might be influenced by operational constraints;

(j) that there is an urgent need to identify suitable frequency bands;

(k) Recommendation 478, especially in regard to the separation of transmit and receive frequencies;

(l) that some propagation characteristics differ for the respective mobile services;

(m) Questions 11/II and 6/XI of the CCITT,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what operating and technical characteristics need to be specified for the integration of public mobile radiocommunication services;

2. what levels of integration are practicable, and in what time frame;

3. what are the constraints associated with the different levels of integration and how can they be alleviated;

4. from a technical point of view what frequency bands are most suitable for integrated public mobile radiocommunication services?

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* The Director, CCIR, is requested to bring this Question to the attention of ICAO, IMCO and the CCITT.

QUESTION 53/8 *

USE OF FREQUENCIES BY THE MARITIME MOBILE SERVICE IN THE BAND 435-526.5 kHz

(1982)

The CCIR,

CONSIDERING

Recommendation 300 of the World Administrative Radio Conference (Geneva, 1979),

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the technical and operational aspects to be considered in the use of frequencies by the maritime mobile service in the band 435-526.5 kHz in Region 1;

2. what are the sharing criteria with other services?

Note. – See Report 910.

QUESTION 54/8

TECHNICAL CHARACTERISTICS FOR MARITIME RADIO EQUIPMENT USING NARROWBAND PHASE-SHIFT KEYING (NBPSK) TELEGRAPHY

(1982)

The CCIR,

CONSIDERING

(a) that digital communication modes are currently being widely introduced in the maritime mobile service;

(b) that the frequency stability of ship radio receivers and transmitters has considerably improved;

(c) that synchronous 7-unit codes with error detection are widely used in direct-printing links, using FSK modulation techniques;

(d) that the adoption of NBPSK telegraphy could increase the number of channels available for digital communications;

(e) that the adoption of NBPSK in the maritime service could replace the present use of FSK,

UNANIMOUSLY DECIDES that the following question should be studied:

1. with a view to determining the desirability of adopting narrowband PSK telegraphy what are:

1.1 the occupied bandwidths and out-of-band spectra of NBPSK emissions;

1.2 the required frequency stability of radio links using NBPSK;

1.3 the permissible deviations of the bit duration from the nominal value in systems using NBPSK;

1.4 the comparative performance in the presence of noise fading and interference of maritime mobile service channels using NBPSK and FSK;

1.5 the recommended characteristics of NBPSK signal-shaping filters;

1.6 methods of using NBPSK with transmitters, receivers and terminal equipment, and additional requirements for such equipment;

2. whether the NBPSK modulation method is suitable for use with the codes being used in the maritime mobile service;

3. the operational and economic factors to be taken into account if NBPSK were to be introduced into the maritime mobile service?

Note. – See Report 909.

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* The Director, CCIR, is requested to bring this Question to the attention of IMCO and ICAO.

QUESTION 53-1/8*

USE OF FREQUENCIES BY THE MARITIME MOBILE SERVICE IN THE BAND 435-526.5 kHz

(1982-1983)

The CCIR,

CONSIDERING

(a) Recommendation No. 300 of the World Administrative Radio Conference (Geneva, 1979);

(b) Resolution No. 318 (MOB-83) and Recommendation No. 315 (MOB-83) of the World Administrative Radio Conference for Mobile Services (Geneva, 1983),

DECIDES that the following question should be studied:

1. what are the technical and operational aspects to be considered in the use of frequencies by the maritime mobile service in the band 435-526.5 kHz in Region 1;

2. what are the sharing criteria with other services, and in particular in the band 510-526.5 kHz (510-525 kHz in Region 2) with special emphasis in the vicinity of the frequency 518 kHz;

3. what are the conditions for the effective use of the band around 500 kHz for shore-ship digital selective calls for public correspondence and distress alerting?

Note. – See Report 910.

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* The Director, CCIR, is requested to bring this Question to the attention of the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO) and invite these Organizations to make their requirements known to the CCIR.

QUESTION 55/8 *

DEVELOPMENT AND FUTURE IMPLEMENTATION OF SHIP MOVEMENT TELEMETRY, TELECOMMAND AND DATA EXCHANGE SYSTEMS

(1982)

The CCIR,

CONSIDERING

(a) Resolution No. 310 of the World Administrative Radio Conference (Geneva, 1979);

(b) that frequencies in the region of 10 GHz appear satisfactory for short-range automated systems of this nature,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the bandwidths and the data formats required for ship movement telemetry, telecommand and data exchange systems?

QUESTION 56/8 **

FREQUENCY SHARING BETWEEN SERVICES IN THE BAND 4 - 30 MHz

(1982)

The CCIR,

CONSIDERING

(a) that the World Administrative Radio Conference (Geneva, 1979) allocated several bands between 4 to 30 MHz on a shared basis to various services including the mobile services;

(b) that preliminary theoretical studies have indicated that satisfactory sharing can be carried out with high confidence under certain circumstances;

(c) that the frequencies in the 4-30 MHz band are typically used for propagating radio frequency energy over large distances using the sky-wave mode;

(d) that frequency sharing between the mobile services and other services requires a complete understanding of the technical parameters and operational procedures used in these services;

(e) that there is ever increasing need to improve the efficient use of the existing high frequency bands to satisfy the expanding world-wide communication requirement,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the technical parameters and operational considerations which must be taken into account to permit satisfactory frequency sharing between the mobile and other services in the frequency bands between 4 to 30 MHz?

Note. – See Report 911.

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* The Director, CCIR, is requested to bring this Question to the attention of IMCO.

** The Director of the CCIR is requested to bring this Question to the attention of the IFRB and Study Groups 1, 3 and 10.

QUESTION 57/8

SHARING CRITERIA FOR THE INTER-SATELLITE SERVICE AND THE RADIONAVIGATION SERVICE IN THE BAND 32-33 GHz

(1982)

The CCIR

CONSIDERING

Recommendation No. 707 of the World Administrative Radio Conference (Geneva, 1979),

UNANIMOUSLY DECIDES that the following question should be studied:

what are the sharing criteria for the inter-satellite service and the radionavigation service in the band 32-33 GHz?

QUESTION 58/8 *

TECHNICAL CHARACTERISTICS OF MARITIME RADIO BEACONS

(1982)

The CCIR,

CONSIDERING

Recommendation No. 602 of the World Administrative Radio Conference (Geneva, 1979),

UNANIMOUSLY DECIDES that the following question should be studied:

what are the technical characteristics for maritime radio beacons, including field-strength values for the service ranges and the adjacent channel separation?

Note. – See Recommendation 588 and Report 913.

QUESTION 59/8

SHARING POSSIBILITIES BETWEEN THE RADIONAVIGATION-SATELLITE SERVICE AND THE FIXED AND MOBILE SERVICES IN THE BANDS 149.9-150.05 MHz AND 399.9-400.05 MHz

(1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 703 of the World Administrative Radio Conference (Geneva, 1979), and in particular:

(b) that the frequency bands 149.9-150.05 MHz and 399.9-400.05 MHz have been allocated to the radionavigation-satellite service on an exclusive worldwide basis;

(c) that many administrations require an extended period of time to re-accommodate existing fixed and mobile operations in other appropriately allocated bands;

(d) that early implementation of the radionavigation-satellite service will be of benefit to all administrations, particularly in its application to marine navigation;

(e) that interference to users of the radionavigation-satellite service could constitute a hazard to the safety of life and property;

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* The Director, CCIR, is requested to bring this Question to the attention of IMCO and IALA.

(f) that, pending an affirmative determination by the CCIR that sharing is possible and practicable between stations of the radionavigation-satellite service and the fixed and mobile services, administrations have to take all possible steps to protect from harmful interference the operations of mobile earth stations using the radionavigation-satellite service,

UNANIMOUSLY DECIDES that the following question should be studied:

is sharing possible and practicable between stations of the radionavigation-satellite service and the fixed and mobile services in the bands 149.9-150.05 MHz and 399.9-400.05 MHz?

Note. – See Recommendation 590 and Report 916.

QUESTION 60/8 *

BROADCASTING AND AERONAUTICAL RADIONAVIGATION SERVICES IN THE LF BANDS

Interference between Regions

(1982)

The CCIR,

CONSIDERING

(a) that the use, in Region I, of the LF bands by high power broadcasting stations could cause harmful interference to aeronautical radionavigation service non-directional beacons (NDB) operating in the same bands in Regions 2 and 3;

(b) that non-directional beacons are used world-wide as a prime source of basic navigational data in the aeronautical radionavigation service;

(c) that the aeronautical radionavigation service is a safety service;

(d) that No. 2854 of the Radio Regulations states that the assignment of frequencies to aeronautical radio beacons in the bands 160 to 435 kHz shall be based on a protection ratio against interference of at least 15 dB for each beacon throughout its service area;

(e) that No. 346 of the Radio Regulations states the basic principle of the equality of right to operate and accordingly, the stations of each service on one Region must operate so as not to cause harmful interference to services in other Regions;

(f) that the Plan contained in Annex I to the Final Acts of the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3), Geneva, 1975, includes a number of new broadcasting transmitters and increases in power of transmitters already in use, thereby changing the probability of harmful interference to the safety services;

(g) that Resolution No. 500 of the WARC (Geneva, 1979) provides for a downward shift in the carrier frequencies of broadcasting transmitters in the LF band in Region 1, to take effect progressively from 1 February, 1986,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the criteria for compatible operation which ensure that no harmful interference occurs between the broadcasting service in Region 1 and the aeronautical radionavigation service (non-direction beacons) in Regions 2 and 3, both operating as primary services in the same LF band in their respective Regions, taking into account:

- the agreed protection criteria for each services;
- the LF radio propagation characteristics;
- the characteristics of beacon receivers;
- the nominal usable field strengths;
- possible limitations which might result from mutual interference between transmitters within each service?

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* The Director of the CCIR is requested to bring this Question to the attention of ICAO. This Question should also be brought to the attention of Study Groups 5, 6 and 10.

QUESTION 61/8 *

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-136 MHz

(1982)

The CCIR,

CONSIDERING

(a) Recommendation No. 704 and Resolution No. 510 of the World Administrative Radio Conference (Geneva, 1979);

(b) that two distinct and different aeronautical radionavigation systems operate in the band 108-118 MHz; namely:

- Instrument Landing System (ILS) localizer (108-112 MHz);
- VHF Omnidirectional Range (VOR) (108-118 MHz);

(c) that the aeronautical mobile (R) service operates in the band 118-136 MHz;

(d) that interference to these aeronautical services has been experienced by several mechanisms due to high-powered FM broadcast transmissions operating in the band 88-108 MHz in Region 2 and in the band 88-100 MHz in Region 1;

(e) that high-powered FM broadcast transmitters and VHF aeronautical receivers are sometimes operated in close geographic proximity of aerodrome facilities;

(f) that the WARC-79 allocated the band 100-108 MHz in Region 1 to FM broadcasting;

(g) that high-powered FM broadcast signals are a potential source of interference to aeronautical receivers;

(h) that the performance characteristics of airborne receiver installations may also cause incompatibility between the high-powered FM broadcasting and these VHF aeronautical services;

(j) that transmissions from aeronautical transmitters may cause interference to the broadcasting service;

(k) that it would be desirable to study possible methods of achieving compatibility between the aeronautical VHF services and the FM broadcasting service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the interference problems arising from the operation of the broadcasting service in the band of about 87-108 MHz and the different VHF aeronautical services in the band 108-136 MHz;

2. what is the susceptibility of existing and future aircraft receivers to the following types of interference arising from the operation of high-powered FM broadcasting stations at various power levels, frequency separations from the aeronautical frequency and relative distances between the broadcasting, aeronautical and aircraft stations:

- desensitization (front-end overloading) of the receiver;
- intermodulation generated in the receiver;
- spurious emissions from FM broadcast stations and radiation produced by non-linear interaction between FM broadcast emissions;

3. what are the variations in the susceptibilities of existing airborne receivers to such interference and, in particular, in what measure is this variation due to differences in avionic equipment installation practices, e.g. antenna feeder cable lengths, antenna position on airframe, type of antenna;

4. what are the protection criteria applicable to the services involved;

5. what technical methods can be used to achieve compatibility between the FM broadcast service and the VHF aeronautical services; and, in particular, are additional methods potentially available for Region 1 as a result of the fact that FM broadcast assignment plans above 100 MHz have not yet been made for that Region?

Note. – See Recommendation 591 and Report 929.

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* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO), to the FM Broadcasting Conference (Region 1) and Study Groups 1 and 10.

QUESTION 62/8 *

INTERFERENCE TO THE AERONAUTICAL RADIONAVIGATION SERVICE

(1982)

The CCIR,

CONSIDERING

(a) that the aeronautical radionavigation service is a safety service;

(b) the increasing concern being expressed over the degree of control of harmful interference to this safety service;

(c) that the types of radiation which can cause harmful interference to this service can differ widely, depending on the particular technical and operational characteristics involved;

(d) that it may be possible in some cases to identify in detail the characteristics of the interfering radiation;

(e) that the radiations from many of the potential sources of harmful interference are the subject of standards and measurement methods developed by the International Electrotechnical Commission (IEC);

(f) that the practical control of harmful interference often needs to be effected by the national legislation of individual Administrations and it is common for the above-mentioned IEC standards and measurement methods to be adopted in this context;

(g) that there would be considerable practical advantages if there were a better understanding of the relationships between these IEC test and measurement standards and the protection criteria for the aeronautical radionavigation service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. are the IEC/CISPR recommended limits and measurement methods adequate for the protection of the aeronautical radionavigation service;

2. what methods can be recommended for stating detailed protection criteria?

Note. – See Reports 926 and 927.

QUESTION 63/8 **

USE FOR THE RADIONAVIGATION SERVICE OF THE FREQUENCY BANDS 2900-3100 MHz, 5470-5650 MHz, 9200-9300 MHz, 9300-9500 MHz AND 9500-9800 MHz

(1982)

The CCIR,

CONSIDERING

(a) that the bands 2900-3100 MHz and 9300-9500 MHz are allocated world-wide to the radionavigation service on a primary basis and to the radiolocation service on a secondary basis;

(b) that the band 5470-5650 MHz is allocated world-wide to the maritime radionavigation service on a primary basis and to the radiolocation service on a secondary basis;

(c) that at the WARC-79 the band 9200-9300 MHz was allocated world-wide to the maritime radionavigation service on an equal primary basis with the radiolocation service;

(d) that at the WARC-79 the band 9500-9800 MHz was allocated worldwide to the radionavigation service on an equal primary basis with the radiolocation service;

(e) that the band 9320-9500 MHz is heavily used by mobile radars of both the maritime and aeronautical radionavigation services;

---

* The Director, CCIR, is invited to draw the attention of the ICAO, IEC and the CISPR to this Question.

** The Director of the CCIR is requested to bring this Question to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO), the International Civil Aviation Organization (ICAO), the World Meteorological Organization (WMO) and the International Association of Lighthouse Authorities (IALA).

(f) that even greater use of mobile radars of the radionavigation service is expected;

(g) that through Resolution No. 600 of WARC-79, attention has been drawn to the increase in harmful interference occurring in the 9300-9500 MHz band due to the increasing number of shipborne radars, the increasing need for navigational aids and transponders working with primary radars and the increasing numbers of stations of the aeronautical radionavigation service;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what is the present and expected future use of the band 9320-9500 MHz by mobile radars of the radionavigation service;

2. depending upon the results of the studies arising from DECIDES (1):

2.1 what technical measures can be recommended to ensure that the increasing needs of the maritime radionavigation service and the aeronautical radionavigation service can be accommodated without harmful interference being caused to mobile radars of either service; and

2.2 what technical matters need to be taken into consideration by the next competent WARC to decide the most effective frequency utilization for the radionavigation service;

3. what is the most effective utilization for the radionavigation service and what should be the corresponding technical characteristics for the bands 2900-3100 MHz and 5470-5650 MHz?

RESOLUTION 20-4

CHARACTERISTICS OF EQUIPMENT AND PRINCIPLES GOVERNING THE ALLOCATION OF FREQUENCY CHANNELS BETWEEN 25 AND 1000 MHz IN THE LAND MOBILE SERVICE

(Question 7/8)

(1959-1963-1966-1970-1974-1978)

The CCIR,

CONSIDERING

(a) that land mobile services of various kinds are developing rapidly;

(b) that, in border areas, difficulties may arise between the services of different administrations;

(c) that it would be advantageous if there were a sufficient measure of agreement, where necessary, between administrations on the characteristics of equipment and on the principles adopted in the planning for land mobile services,

UNANIMOUSLY DECIDES

1. that administrations should consult together as necessary to resolve any difficulties concerning their land mobile services and for the purpose of improving such services;

2. that those administrations which are interested in the provision of common land mobile services should consult together and should advise the CCIR of any technical and operational problems that require international study;

3. that administrations should continue to submit new data regarding the measuring methods used in their respective countries to the Chairman, Study Group 8 and to the Director, CCIR, for circulation. The attention of administrations is drawn to the methods of measurement currently being standardized by the International Electrotechnical Commission (IEC) (see Opinion 42);

4. that administrations should submit information on practices adopted for the allocation of channels between 25 and 1000 MHz for land mobile services to the Chairman, Study Group 8 and the Director, CCIR, for circulation;

5. that administrations should submit details of the blocks of frequencies between 25 and 1000 MHz allocated:

5.1 for transmissions from base stations, and

5.2 for reception at base stations;

QUESTION 64/8*

HF BANDS ALLOCATED ON AN EXCLUSIVE OR SHARED BASIS TO THE MARITIME MOBILE SERVICE

(1983)

The CCIR,

CONSIDERING

Resolution No. 319 (MOB-83) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1983);

DECIDES that the following question should be studied:

what are the technical issues involved in a revision of the sub-allocations and channelling plans in the HF maritime mobile service, including the following issues:

- the establishment of sharing criteria between the maritime mobile and fixed services in the 4000-4063 kHz and 8100-8195 kHz frequency bands;
- radiotelegraph channel spacing based on existing and future requirements and technological advances in equipment;
- the most effective arrangement and channelling scheme for radiotelephone channels based on 3.0 kHz channel spacing?

---

* The Director, CCIR, is requested to bring this Question to the attention of the International Maritime Organization (IMO) and invite this Organization to make its requirements known to the CCIR.

QUESTION 65/8*

PROTECTION OF THE BAND 406-406.1 MHz ALLOCATED TO THE MOBILE-SATELLITE SERVICE

(1983)

The CCIR,

CONSIDERING

(a) Resolution No. 205 (MOB-83) of the World Administrative Radio Conference for Mobile Services (Geneva, 1983);

(b) that in accordance with RR MOD 649, the use of the band 406-406.1 MHz by the mobile-satellite service is limited to low power satellite emergency position indicating radio beacons,

DECIDES that the following question should be studied:

what are the conditions of compatibility between satellite EPIRBs in the band 406-406.1 MHz and services using adjacent bands?

QUESTION 66/8*

RELATING TO THE FUTURE USE OF THE BAND 2170-2194 kHz

(1983)

The CCIR,

CONSIDERING

(a) Recommendation No. 203 of the World Administrative Radio Conference (Geneva, 1979);

(b) Resolution No. 204 (MOB-83) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1983);

(c) Questions 29-1/8 and 44-1/8,

DECIDES that the following question should be studied:

what are the implications of placing a digital selective calling (DSC) channel in the band 2188-2190.5 kHz with regard to the protection of the DSC channel for distress alerting at 2187.5 kHz?

---

* The Director, CCIR, is requested to bring this Question to the attention of the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO) and invite these Organizations to make their requirements known to the CCIR.

6. that administrations which have reached agreement with adjacent countries on the operation of land mobile services in border areas, should submit to the CCIR technical and operational details of the agreement to assist other administrations with similar problems.

OPINION 42-1

METHODS OF MEASUREMENT OF TECHNICAL CHARACTERISTICS OF EQUIPMENT FOR THE LAND MOBILE SERVICE BETWEEN 25 AND 1000 MHz

(1970-1974)

The CCIR,

CONSIDERING

(a) that it is desirable to interchange information of the requirements of administrations concerning the technical characteristics of equipment used in land mobile services between 25 and 1000 MHz;

(b) that to facilitate the exchange of such information it is desirable to reach agreement on the methods to be adopted for the measurement of the technical characteristics;

(c) that it is understood that the International Electrotechnical Commission (IEC) is studying methods of measurement,

IS UNANIMOUSLY OF THE OPINION

1. that the IEC should be invited to advise the CCIR of any proposals they have made (or have under consideration) for the methods of measurement of the technical characteristics of transmitters and receivers which could be applied to radio equipment used in land mobile services;

2. that the Director, CCIR, should be invited to transmit this Opinion to the IEC.

Note. – Recommendation 478 indicates the technical characteristics considered of international importance.

OPINION 43-2

SELF-SUPPORTING ANTENNAS FOR USE ON BOARD SHIPS

Performance at 500 kHz

(1970-1974-1978)

The CCIR,

CONSIDERING

(a) that an increasing number of ships are equipped with self-supporting antennas;

(b) that the CCIR has studied the problems concerning self-supporting antennas and has collected data from measurements carried out by administrations (see Report 502 (Kyoto, 1978));

(c) that development work is taking place in several countries with the aim of improving the performance of such antennas;

(d) that further study is necessary,

IS UNANIMOUSLY OF THE OPINION

1. that the information given in Report 502 (Kyoto, 1978) demonstrates that the values in the table of metre-amperes in Chapter IV, Regulation 10 (*g*) of the International Convention for the Safety of Life at Sea, London, 1974, are not applicable to self-supporting antennas;

2. that a single metre-ampere table may not be sufficiently accurate for all types of self-supporting antennas and corrections should be made according to results obtained from series of field strength measurements on various ship installations, including each particular type of self-supporting antenna;

3. that from the results of tests available, the following additions to the above-mentioned table of metre-amperes could be made to include self-supporting antennas:

TABLE I

Normal range in nautical miles	Metre-amperes (1)
200	305
175	215
150	150
125	110
100	85
75	55

(1) The product of the distance (in metres) from the highest part of the antenna to the deepest load water-line and the current (in amperes) measured at the base of the radiating portion of the antenna.

4. that for certain types of antennas such as the whip type shown in Fig. 18 of Report 502 (Kyoto, 1978), the metre-amperes values in the table shown in § 3 might be considerably higher;

5. that this Opinion, together with Report 502 (Kyoto, 1978), should be brought to the attention of the Inter-Governmental Maritime Consultative Organization (IMCO) by the Director, CCIR.

OPINION 49-1

METHOD OF MEASUREMENT OF MAN-MADE NOISE IN THE VARIOUS MOBILE SERVICES

(1974-1978)

The CCIR,

CONSIDERING

(a) that the CCIR has under study the signal-to-noise ratios and the minimum usable field strengths required for satisfactory reception of the different classes of emission in the various mobile services;

(b) that the minimum usable field strengths required are influenced by levels of ambient man-made noise;

(c) that information on ambient man-made noise levels is necessary to further the present studies;

(d) that the levels of man-made noise will vary with the distance from the source of that noise;

(e) that the units in which man-made noise is measured should be the same as the units used in the determination of the degradation of performance of mobile radio receiving equipment;

(f) that the degradation of performance of mobile radio receiving equipment appears to be dependent not only on the amplitude of such noise but also on the pulse repetition rate;

(g) that the IEC have under consideration methods of measurement of degradation of performance of mobile radio receiving equipment due to man-made noise; and

(h) that a uniform method of measurement and presentation of results is desirable to permit comparison of measurements made independently,

IS UNANIMOUSLY OF THE OPINION

1. that the International Electrotechnical Commission (IEC) and the International Special Committee on Radio Interference (CISPR) should be invited to advise the CCIR of suitable methods of measuring the parameters of man-made noise;

2. that the methods proposed should include the definition of a reference antenna and a reference distance from noise sources;

3. that the IEC and the CISPR should advise the CCIR on the preferred units to be used in the measurement of noise parameters and degradation of performance by man-made noise.

Note 1. – The Director, CCIR, is invited to draw the attention of the IEC and the CISPR to this Opinion.

Note 2. – The Director, CCIR, is also invited to draw the attention of the Interim Working Party 6/2 to this Opinion.

OPINION 73

INTERFERENCE DUE TO MAN-MADE NOISE IN THE VARIOUS MOBILE SERVICES

(1982)

The CCIR,

CONSIDERING

(a) that the CCIR has under study the signal-to-noise ratios and the minimum usable field strengths required for satisfactory reception of the different classes of emission in the various mobile services;

(b) that the minimum usable field strengths required are influenced by levels of ambient man-made noise;

(c) that information on ambient man-made noise levels is necessary to further the present studies;

(d) that the International Electrotechnical Commission (IEC) has elaborated methods of measurement of degradation of performance of mobile radio receiving equipment due to man-made noise;

(e) that the IEC has elaborated methods of measurement of man-made noise which are expressed in the same units as used in Considering *(d)*;

(f) that the International Special Committee on Radio Interference (CISPR) limits provides for measurements of ignition systems of motor vehicles in the frequency range 40-250 MHz,

IS UNANIMOUSLY OF THE OPINION

1. that the IEC and the CISPR should be invited to advise the CCIR as to the man-made radiation levels of motor vehicles complying with the CISPR limits when received by a base or mobile station antenna:

1.1 mounted on a vehicle radiating the noise,

1.2 mounted on a vehicle operated in traffic of from 100 to 10 000 vehicles per hour,

1.3 mounted at a base station in an area of traffic density of 10, 100, 1000 vehicles per km^2,

1.4 mounted on an aircraft operating at altitudes of 1 km, 4 km and 10 km for traffic densities of 100 and 1000 vehicles per km^2 in an area below the aircraft;

2. that the IEC and the CISPR should be invited to advise the CCIR as to the degree of degradation to both analogue and digital communication systems caused by these noise levels.

DECISION 32-2 *

TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Question 17/8)

(1978-1980-1981)

CCIR Study Group 8, at its Final Meeting (Geneva, 1981)

CONSIDERING

(a) the provisions of CCIR Resolution 24;

(b) that the maritime mobile-satellite service will need agreement on the technical and operating characteristics of systems used;

(c) Recommendations Nos. 201 and 312 and Resolution No. 3 of the World Maritime Administrative Radio Conference, (Geneva, 1979);

(d) Decision 2 of CCIR Study Group 4;

(e) that IMCO has requested the CCIR to coordinate trials of satellite EPIRB systems;

(f) that the INMARSAT Organization is willing to make space segment capacity available free of charge for CCIR coordinated trials of low-power distress transmitter designs,

DECIDES:

1. that Interim Working Party 8/7 should be maintained;

2. that this Interim Working Party shall determine for the maritime mobile-satellite service:

2.1 the characteristics of systems employing high gain, medium gain and low gain antennas and associated link power budgets;

2.2 technical and operating characteristics of systems for safety and distress;

2.3 technical and operating characteristics of new services – e.g. data, facsimile, video and computer-to-computer;

2.4 technical and operating characteristics of systems providing radiodetermination through maritime mobile communication satellites;

3. that the Interim Working Party shall:

- prepare a coordinated trials programme for low power distress transmitter designs using the INMARSAT space segment;
- evaluate the test data;
- prepare a report on the final test results.

The actual trials would need to be financed and carried out by the individual administrations in accordance with the programme;

4. that the Interim Working Party shall study and evaluate all available test information on low power distress transmitter designs using geostationary and low orbiting satellites and prepare a draft Recommendation;

5. that the Interim Working Party shall prepare contributions on all mobile satellite services necessary for the first session of the World Administrative Radio Conference (1985) on the use of the geostationary satellite orbit and the planning of space services utilizing it;

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* The Director, CCIR, is requested to bring this Decision to the attention of the CCITT.

6. that the Interim Working Party should also carry out any additional studies referred to CCIR by IMCO or the INMARSAT Organization and agreed by the Chairman of Study Group 8 in consultation with the Director, CCIR. The additional studies would be circulated to all administrations participating in the work of Study Group 8.

7. that the Chairman and the composition of Interim Working Party 8/7 shall be as shown in Annex I;

8. that the Interim Working Party should attempt as far as practicable to carry out its work by correspondence. However, to ensure that basic studies are to be completed within an acceptable time scale, meetings may be called as necessary.

ANNEX I

The following Administrations, International Organizations and Recognized Private Operating Agencies have indicated that they wished to participate in the work of Interim Working Party 8/7:

Administrations:

Germany (Federal Republic of)
Argentina
Australia
Brazil
Canada
China
Denmark
United States of America
France
India
Italy
Japan
Norway
New Zealand
Netherlands
Poland (People's Republic of)
United Kingdom
Sweden
U.S.S.R.

International Organizations and Recognized Private Operating Agencies:

ESA
CIRM
CTNE (Spain)
INMARSAT Organization
IMCO

International Telecommunication Union:

IFRB

Chairman of Interim Working Party 8/7:

Mr. J. T. Gilsenan
Federal Communications Commission
Common Carrier Bureau
1919 M Street, NW
Washington, DC 20554
USA

Telephone: 202-632-3214
Telex: TWX 7108220160
Answerback: FED COM COM

DECISION 47

PUBLIC LAND MOBILE TELEPHONE SYSTEMS

Location Registration

(Question 39/8)

(1980)

CCIR Study Group 8,

CONSIDERING

(a) the provisions of CCIR Resolution 24;

(b) that the connection of roaming * mobile radiotelephone subscribers to the public switched telephone network requires that operational procedures be internationally agreed;

(c) that standardized procedures would benefit subscribers, particularly when they were operating abroad;

(d) that the CCITT Study Groups II and XI are already studying the interconnection of the different mobile services with the public switched telephone network (Questions 11/II and 6/XI respectively);

(e) that interconnection of a roaming mobile subscriber with the telephone network involves a knowledge of the location of the mobile subscriber, together with the means of registering the information, so that appropriate routing and charging can be applied;

(f) that fully automatic procedures are desirable;

(g) that Interim Working Party 8/5 has considered location registration procedures for the maritime mobile VHF/UHF service (Recommendations 586 and 587 and Report 587),

DECIDES:

1. that an Interim Working Party 8/9 should be established;

1.1 that the Interim Working Party should aim to complete its work in time for consideration by Study Group 8 at its Interim Meeting in 1983,

1.2 that the Interim Working Party should attempt as far as practicable to carry out its work by correspondence;

2. that this Interim Working Party shall determine:

2.1 basic rules for allocating numerical identities to base station service areas;

2.2 general procedures for providing location information from mobile units to the location register(s);

2.3 methods by which a mobile unit may determine when its location needs to be up-dated;

3. that the Interim Working Party should consider whether the solution proposed by Interim Working Party 8/5 for the maritime mobile VHF/UHF service could be employed in land mobile systems;

4. that the Chairman and composition of Interim Working Party 8/9 shall be as shown in Annex I.

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* Each subscriber is assumed to be assigned, to one radio control centre. When the subscriber leaves the radio coverage area controlled by this centre, he enters the roaming state and can only initiate and receive calls via another radio control centre.

ANNEX I

At the end of the Interim Meeting of Study Group 8 (Geneva, 1980) the following Administrations, International Organizations and Recognized Private Operating Agencies indicated that they wished to participate in the work of Interim Working Party 8/9:

Administrations:

Germany (Federal Republic of)
United States of America
Finland
France
Italy
Japan
Norway
Netherlands
United Kingdom
Sweden

International Organizations and Recognized Private Operating Agencies:

CIRM
CTNE (Spain)

Chairman of Interim Working Party 8/9:

Mr. B. Løken
Norwegian Telecommunications Administration
P.O. Box 83
N-2007 Kjeller
Telephone: +47 2 73 91 00
Telex: 71203 gentl n

DECISION 48

DIGITAL SELECTIVE-CALLING

Coordination of trials

(1981)

CCIR Study Group 8, at its Final Meeting (Geneva, 1981),

CONSIDERING

(a) the provisions of CCIR Resolution 24;

(b) the intention of IMCO to include digital selective-calling as one of the important methods of distress alerting in the Future Global Maritime Distress and Safety System;

(c) the need to establish the number of channels necessary for satisfactory operation of digital selective-calling for distress and safety and for improving maritime communications generally;

(d) the need for operational trials to be carried out on the digital selective-calling system described in Recommendation 493 and on the procedures described in Recommendation 541;

(e) that IMCO has supported a proposal that CCIR should coordinate trials of digital selective-calling,

DECIDES:

1. that an Interim Working Party 8/10 should be established;

1.1 that the Interim Working Party should aim to complete its work concerning the number of channels likely to be needed in time for consideration by Study Group 8 at its Interim Meeting in 1983 and the rest of its work in time for consideration by Study Group 8 at its Final Meeting in 1985;

1.2 that the Interim Working Party should attempt, as far as practicable, to carry out the work by correspondence. However, to ensure that basic functions are to be completed within the necessary time scale, meetings may be required. Procedures in Resolution 24 should be followed.

2. that the Interim Working Party shall:

2.1 coordinate trials carried out by administrations on the digital selective-calling system which are intended to meet one or more of the following objectives:

- proving the system described in Recommendation 493;
- testing the provisions and procedures for distress and safety calls described in Annex I to Recommendation 541;
- testing the provisions and procedures for calls other than distress and safety described in Annex II to Recommendation 541;
- establishing the number of channels likely to be needed for distress and safety calls;
- establishing the number of channels likely to be needed for calls other than for distress and safety;

2.2 prepare a coordinated trials programme which ensures, as far as is practical, that the total coverage of the trials is adequate to provide an efficient commercial calling system and to ensure that the Future Global Maritime Distress and Safety System, as proposed by IMCO, will provide effective distress alerting and safety calling;

2.3 evaluate the test data;

2.4 prepare a report on the final test results;

2.5 recommend, in the light of the trials and other associated studies, the number of channels necessary for the system to operate satisfactorily.

3. that the actual trials would need to be financed and carried out by individual participating administrations in accordance with the programme.

4. that the Chairman and composition of the Interim Working Party 8/10 shall be as shown in Annex I.

ANNEX I

At the end of the Final Meeting, 1981, the following Administrations and International Organizations have indicated their participation in the work of Interim Working Party 8/10:

Administrations:

Germany (Federal Republic of)
Australia
Denmark
United States of America
France
Japan
Norway
Netherlands
United Kingdom
Sweden
U.S.S.R.

International Organizations and Recognized Private Operating Agencies:

IMCO
CIRM

Chairman of Interim Working Party 8/10:

Mr. K. W. Oborne
British Telecom International
Maritime Radio Services Division
Room 307
Landsec House
23 New Fetter Lane
LONDON EC4A 1AE
United Kingdom

DECISION 49 *

THE INTRODUCTION OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(1981)

CCIR Study Group 8, at its Final Meeting (Geneva, 1981),

CONSIDERING

(a) Question 5/8;

(b) the provisions of Resolution 24,

DECIDES

1. that an Interim Working Party 8/11 should be established;

2. that this Interim Working Party shall determine:

2.1 whether master, slave or both master and slave identifications should be transmitted during initial establishment, re-establishment or both establishment and re-establishment of the radio circuit, and how this should be provided;

2.2 whether the address capability of the call signal system should be expanded, taking into account the future assignment of maritime mobile service identities and, if so, what the preferred method should be to provide such an expanded address capability;

2.3 the technical characteristics and operational procedures relevant to §§ 2.1 and 2.2 above, including the compatibility with land-line networks;

3. that the Interim Working Party should aim to complete its work in time for consideration by Study Group 8 at its Interim Meeting in 1983;

4. that the Chairman and composition of the Interim Working Party 8/11 shall be shown in Annex I.

ANNEX I

At the end of the Final Meeting, 1981, the following Administrations and International Organizations have indicated their participation in the work of Interim Working Party 8/11.

Administrations:

Germany (Federal Republic of)
Australia
Denmark
United States of America
France
Japan
Norway
Netherlands
United Kingdom
Sweden
U.S.S.R.

International Organizations and Recognized Private Operating Agencies:

CIRM
Marconi Int. Marine Co. Ltd.

Chairman of Interim Working Party 8/11:

Mr. T. de Haas
NTIA/ITS
US Department of Commerce
Boulder, Colorado, 80303
USA

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* The Director of the CCIR is requested to bring this Decision to the attention of CCITT.

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ALPHABETICAL INDEX OF KEY WORDS AND TERMS OF VOLUME VIII

Introduction

The Index of Vol. VIII is divided into the following sections:

- Aeronautical mobile service;
- Amateur satellite service;
- Amateur service;
- Land mobile service;
- Maritime mobile service, including radiodetermination and radionavigation;
- Mobile service, general;
- Radio paging;
- Satellite systems: aeronautical, maritime, radiodetermination and radionavigation;
- Satellite systems: land mobile and mobile;
- Abreviations of terms used in Vol. VIII.

The attention of the reader is also drawn to the Terms and Definitions of Art. 1 of the Radio Regulations and to the publication "Terms relating to the mobile services (Glos. 3)" published by the ITU, Geneva 1982.

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W

World Meteorological Organization (WMO) (Rec.540, Rep.588)

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ABBREVIATIONS

ACK	acknowledgement
ACR	average crossing rate
ACSB	amplitude companded single sideband
ADF	automatic direction finding
ADVM	adaptive (variable slope) delta modulation voice modem
AFC	automatic frequency control
AGC	automatic gain control
AI	articulation index
AIRT	asynchronous interference reduction techniques
AMPS	advanced mobile phone service
ANBFM	adaptive narrow-band FM modem
APD	amplitude probability distribution
ARBs	aeronautical radar beacons
ARINC	Aeronautical Radio Inc
ATC	air traffic control
AVL	automatic vehicle location
B/B_0	ratio of radio-frequency bandwidth to audio frequency bandwidth
BCD	binary coded decimal
BCH	Bose-Chaudhuri-Hockenghem code
BER	bit-error rate
BITEs	backward interworking telephony events
BINOR	binary optimum ranging
BPSK	binary phase shift keying
BWO	backward wave oscillators
C/N_0	carrier-to-noise density ratio
C/N	carrier to noise
$(C/N)_p$	carrier-to-noise ratio of the swept pulse before compression
CBSS	station sending in the collective B-Mode
CCITT	International Telegraph and Telephone Consultative Committee
CDM	Companded Delta Modulation
CE	channel equipment
CES	coast earth station
C/I_0	carrier-to-intermodulation-noise density ratio
CIGRE	International Conference on High Tension Electric Systems
CISPR	International Special Committee on Radio Interference
CNES	Centre national d'Etudes spatiales
CP	central control posts
CPSK	coherent phase shift keying
CT	international transit centre
CTP	coordinated trials program
DECPSK	differentially encoded phase shift keying
DF	direction finding
DM	delta modulation
DME	distance measuring equipment
DN	Decca navigator
DPSK	differential phase shift keying
DRCS	distress radio call system
DSC	digital selective calling
DSI	digital speech interpolation
DX	first transmission
EC	earth coverage
ELBA	emergency location beacon aircraft
ELT	emergency locator transmitter
EPIRB	emergency position-indicating radio beacons
ESA	European Space Agency
ETX	end of text
F_a	effective antenna noise factor
FDM/PM	frequency division multiplexed before phase modulating
FDMA	frequency division multiple access
FEC	Mode B forward error correction
FFSK	fast frequency shift keying
FITEs	forward interworking telephone events
FMS	status message transmission system of the police in the Federal Republic of Germany
FRENA	frequency and amplitude
FSK	frequency shift keying
G/T	gain-to-noise temperature ratio
GMSK	Gaussian filtered MSK
GOES	geostationary experimental satellite
GSFC	Goddard Space Flight Center
GTDS	global telecommunications system
HDLC	high level data link control
IALA	International Association of Lighthouse Authorities
ICAO	International Civil Aviation Organization

IEC . . . . . International Electrotechnical Commission
IFRB . . . . . International Frequency Registration Board
IHO . . . . . International Hydrographical Office
ILS . . . . . instrument landing systems
IMCO . . . . . Inter-governmental Maritime Consultative Organization (see IMO)
IMO . . . . . International Maritime Organization (since 22 May 1982)
INMARSAT . . . . . International Maritime Satellite Organization
INTELSAT . . . . . International Telecommunications Satellite Organization
IOC . . . . . index of cooperation
IRS . . . . . information receiving station
ISO . . . . . International Standards Organization
ISS . . . . . information sending station
IT . . . . . interrogator transponder
LHC . . . . . lefthand circularly polarized
LNA . . . . . low noise amplifier
LOS . . . . . line-of-sight
LPC . . . . . linear predictive coding
LUT . . . . . local user terminal
MCS . . . . . maritime transponder on INTELSAT-V satellites
MIC . . . . . marked idle channel
MOS . . . . . mean opinion score
MRIT . . . . . maritime radar interrogator transponder
MSC . . . . . maritime switching centre
MSK . . . . . minimim shift keying
MSS . . . . . mobile satellite service
MTBF . . . . . mean-time-between failure
MTTR . . . . . mean-time-to-repair
NAD . . . . . noise amplitude distribution
NASA . . . . . United States National Aeronautics and Space Administration
NAVSTAR GPS . . . NAVSTAR global positioning system
NBDP . . . . . narrowband direct printing
NBFM . . . . . narrowband frequency modulation
NBPSK . . . . . narrowband phase-shift keying
NBVM . . . . . narrowband voice modulation
NC . . . . . narrow coverage
NCAR . . . . . National Center for Atmospheric Research
NCK . . . . . negative acknowledgment
NOAA . . . . . United States National Oceanographic and Atmospheric Administration
NDB . . . . . non-directional beacons
NID . . . . . nationality identification digits
NMT . . . . . Nordic mobile telephone system
NRL . . . . . Naval Research Laboratory
OACSU . . . . . off-air call set up
OSCAR . . . . . orbiting satellites carrying amateur radio
PB . . . . . phonetically balanced
P_n . . . . . mean noise power
PN . . . . . pseudo noise
PPI . . . . . plan position indicator
PRF . . . . . pulse repetition frequency
PRFD . . . . . pulse repetition frequency discrimination
PRN . . . . . pseudo-random noise code
PSK . . . . . phase-shift keying
PSK/PM . . . . . subcarrier PSK
PSTN . . . . . public switched telephone network
QAM . . . . . quadrature amplitude modulation
QPSK . . . . . quaternary phase shift keying
RACON . . . . . radar beacon
RAMS . . . . . Nimbus-6 random access measurement system
RCC . . . . . rescue coordination centre
RHC . . . . . righthand circularly polarized
ROSES . . . . . receive-only ship earth station
RT . . . . . radiotelephone
RX . . . . . retransmission
SAMSARS . . . . . satellite-aided maritime search and rescue system
S/D filter . . . . . smear desmear filter
S/N . . . . . signal-to-noise ratio
SACP . . . . . satellite aeronautical prober
SAR . . . . . search and rescue
SBSS . . . . . station sending in the selective B-Mode
SCPC . . . . . single channel per carrier
SDL . . . . . specification and description language
SELCAL . . . . . selective calling
SES . . . . . ship earth station
SHOSAC . . . . . shore-to-ship distress alerting channel
SINAD . . . . . signal plus noise plus distortion to noise plus distortion
SIT . . . . . shipborne interrogator-transponder
SOLAS . . . . . International Convention for the Safety of Life at Sea
SPITEs . . . . . switching process interworking telephony events
SSB . . . . . single sideband
SSFC . . . . . sequential single frequency code

TCXO . . . . . temperature compensated crystal oscillators

TDAL . . . . . tunnel diode amplifier/limiter

TDMA . . . . . time division multiple access

TFM . . . . . tamed frequency modulation

TWEB . . . . . transcribed weather broadcast

TWERLE . . . . . wind, energy conversion and reference level experiment

TWT . . . . . travelling wave tube

TWTA . . . . . travelling wave tube amplifier

USGCSS . . . . . United States Government Communications Satellite System

V_{avg} . . . . . average voltage

VDU . . . . . video display unit

VFT . . . . . voice-frequency telegraphy

VOLMET . . . . . aeronautical mobile meteorological service channels

VOR . . . . . VHF omnidirectional radio range

V_p . . . . . peak voltage

V_{qp} . . . . . quasi-peak voltage

V_{rms}/V_{avg} . . . . . impulsiveness ratio $V_d = 20 \log$

V_{rms} . . . . . root-mean-square voltage

WMO . . . . . World Meteorological Organization

ZVEI . . . . . digital selectocall system of the Federal Republic of Germany

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