INTERNATIONAL TELECOMMUNICATION UNION

CCIR

INTERNATIONAL
RADIO CONSULTATIVE
COMMITTEE

RECOMMENDATIONS AND REPORTS OF THE CCIR, 1986

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

XVIth PLENARY ASSEMBLY
DUBROVNIK, 1986

VOLUME VIII-1

LAND MOBILE SERVICE
AMATEUR SERVICE
AMATEUR SATELLITE SERVICE

Geneva, 1986

CCIR

1. The International Radio Consultative Committee (CCIR) is the permanent organ of the International Telecommunication Union responsible under the International Telecommunication Convention "... to study technical and operating questions relating specifically to radiocommunications without limit of frequency range, and to issue recommendations on them..." (International Telecommunication Convention, Nairobi 1982, First Part, Chapter I, Art. 11, No. 83).

2. The objectives of the CCIR are in particular:

a) to provide the technical bases for use by administrative radio conferences and radiocommunication services for efficient utilization of the radio-frequency spectrum and the geostationary-satellite orbit, bearing in mind the needs of the various radio services;

b) to recommend performance standards for radio systems and technical arrangements which assure their effective and compatible interworking in international telecommunications;

c) to collect, exchange, analyze and disseminate technical information resulting from studies by the CCIR, and other information available, for the development, planning and operation of radio systems, including any necessary special measures required to facilitate the use of such information in developing countries.

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

(Dubrovnik, 1986)

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.
VOLUMES IV/IX-2	Frequency sharing and coordination between systems in the fixed-satellite service and radio-relay systems.
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VOLUME IX-1	Fixed service using radio-relay systems.
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VOLUME XIII	Vocabulary (CMV).
VOLUME XIV-1	Information concerning the XVIth 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 1986 edition, unless otherwise noted; i.e., only the basic number is shown.

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

Volumes I to XIV, XVIth Plenary Assembly, contain all the valid texts of the CCIR and succeed those of the XVth Plenary Assembly, Geneva, 1982.

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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1.3.1 *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.

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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-1

MOBILE SERVICES

(Study Group 8)

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PART 1

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Decision 19	Terms and definitions	XIII

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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.

1982-1986	*Chairman:*	G. HEMPTON (United States of America)
	Vice-Chairmen:	E. GEORGE (Germany (Federal Republic of)) K. P. R. MENON (Malaysia)
1986-1990	*Chairman:*	E. GEORGE (Germany (Federal Republic of))
	Vice-Chairmen:	Y. HIRATA (Japan) J. KARJALAINEN (Finland) R. C. McINTYRE (United States of America) O. VILLANYI (Hungarian People's Republic)

INTRODUCTION BY THE CHAIRMAN OF STUDY GROUP 8, 1982-1986

1. Introduction

CCIR Study Group 8 studies technical and operational questions relating to all the mobile services, all the mobile-satellite services, the radiodetermination service, the radiodetermination-satellite service and the amateur services.

The period between the XVth and XVIth Plenary Assemblies were exceptionally busy, not only with preparing Reports and Recommendations in response to current Questions but also providing technical and operating advice to administrations preparing for several world or regional administrative radio conferences. The following few figures will help to quantify this work; 239 persons from 32 administrations, 26 recognized private operating agencies and 19 international organizations participated in the Final Meeting of Study Group 8. A slightly smaller number participated in the Interim Meeting.

The following table gives a summary of Study Group 8 documentation activity for the period:

	Maintained	Modified	New text	Cancelled
Recommendations	22	14	12	7
Reports	19	44	34	15
Questions and Study Programmes	37	23	12	4

To some non-participants the size and scope of Study Group 8 is too large and it has been suggested that it should be sub-divided into two or more separate Study Groups. The fact is that all the mobile services and radiodetermination services are so closely associated that any separation would severely impede the CCIR studies in these services. Due to the use of Interim Working Parties to do in-depth studies and by sub-dividing our work into suitable Working Groups and excluding non-substantive discussions from Plenary Meetings, Study Group 8 concluded its Final Meeting on time using only six short Plenary Meetings. The present organization works efficiently and should not be changed.

The International Maritime Organization (IMO) and CCIR Study Group 8 have been working very closely together in the development of the Future Global Maritime Distress and Safety System (FGMDSS). The CCIR has now completed the necessary essential technical and operational basis for the IMO to proceed on schedule with the FGMDSS. Also the special meeting of Study Group 8 (30 June – 11 July, 1986) will provide the technical and operational bases to administrations in preparation for the 1987 World Administrative Radio Conference for the Mobile Services. It is noteworthy that the WARC MOB-83 accepted and used without change the CCIR report to that Conference.

2. Highlights of studies and future work

In order to present the highlights of Study Group 8 activities during the 1982-1986 period in an orderly manner they will be given under the organizational headings of the cognizant Working Group.

Working Group 8-A: Land mobile service, amateur service, amateur-satellite service

The Chairman was Mr. W. M. Borman (United States of America).

CCIR activity in the land mobile service, unlike previous cycles, is now very busy. Two draft new Recommendations on analogue cellular systems and modulation techniques and a modification to a Recommendation on radio paging were agreed. Other activity continued on a number of subjects such as simulcast transmission and land mobile/broadcast sharing, cellular mobile telephone systems, digital transmission and automatic vehicle location. An Interim Working Party 8/9 on location registration in public land mobile systems completed its work prior to the Interim Meeting. A new Interim Working Party 8/13 on future public land mobile telecommunication systems has been established (Chairman: Mr. M. H. Callendar (Canada)). In all, there were 20 approved output documents from this Working Group at the Final Meeting. Future work continues at a fast pace in the land mobile service.

Working Group 8-B: Maritime mobile service (telegraphy and telephony)

See Volume VIII-2.

Working Group 8-C: FGMDSS, terrestrial EPIRBs and maritime radiodetermination

See Volume VIII-2.

Working Group 8-D: Maritime mobile-satellite service, land mobile-satellite service, mobile-satellite service, satellite EPIRBs

See Volume VIII-3.

Working Group 8-E: Aeronautical mobile service, aeronautical mobile-satellite service, aeronautical radiodetermination

See Volume VIII-3.

3. Developing countries

3.1 It is noteworthy that there has been a growth in the number of participants in Study Group 8 from developing countries. Most of all, the delegates from developing countries are becoming familiar with Study Group 8 studies and are actively participating and contributing to the work of the CCIR to the benefit of all members.

3.2 *Recommendations and Reports of particular interest to developing countries*

Land mobile and amateur services

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.

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.

4. Conclusion

Study Group 8, although large, is composed of related radio services that are becoming closer, e.g. mobile service facilities serving land mobile and maritime mobile stations. The Study Group is divided into Working Groups with four out of five having nearly identical numbers of output documents. The organization is working well and change is not recommended. The shortened Final Meeting worked satisfactorily except that the extra two days for the Editorial Group was not enough. If future meetings have to be reduced, the Editorial Group should be planned for a minimum of three extra days.

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;

* 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 358-5

PROTECTION RATIOS AND MINIMUM FIELD STRENGTHS REQUIRED IN THE MOBILE SERVICES

(Question 1/8)

(1966–1970–1974–1978–1982–1986)

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 submitted the results of laboratory 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. For some systems this grade of service is acceptable.

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 receiver 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 ability of the receiver to receive the wanted signal is dependent on the passband characteristics of the receiver, the frequency difference between the co-channel wanted and unwanted signals, the frequency deviation, etc., the receiver protection ratios in Table I may be used as the basis for the calculation of system protection ratios for mobile systems for a minimum grade of service. Additional protection should be provided to allow for the effects of multipath propagation, man-made noise, terrain irregularities, and in the case of very closely spaced assignments, adjacent-channel interference (see Report 319).

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 – *Typical receiver protection ratios, for use in calculating system protection ratios*

Wanted emission (Note 1)	Unwanted emission (Note 1)	Receiver protection ratio (dB)
Wideband F3E, G3E	Wideband F3E, G3E	See Report 319
Narrowband F3E, G3E	Narrowband F3E, G3E	See Report 319
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 receiver 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.

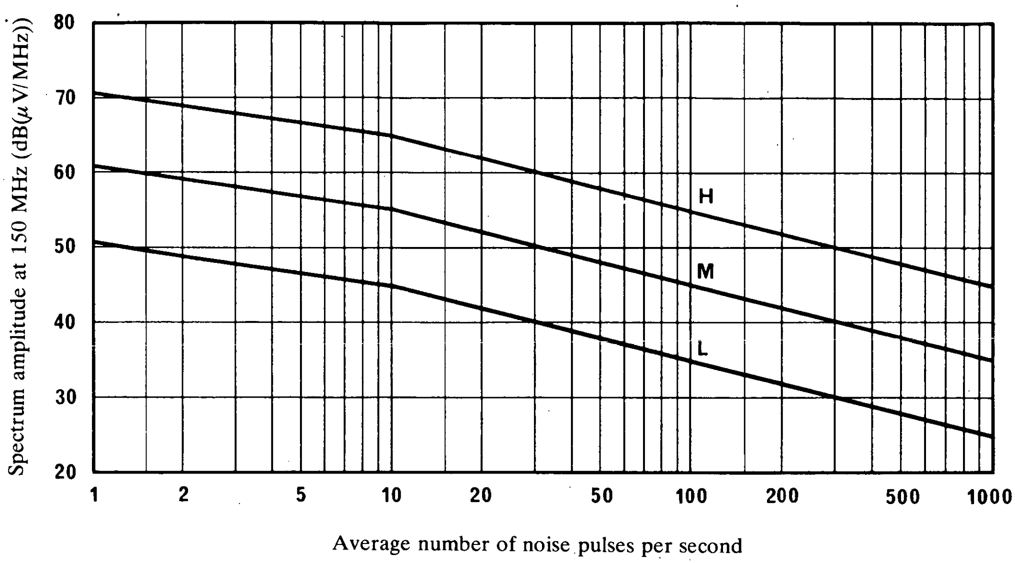

FIGURE 1 – *Noise amplitude distribution at base station (150 MHz)*

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 *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.

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.

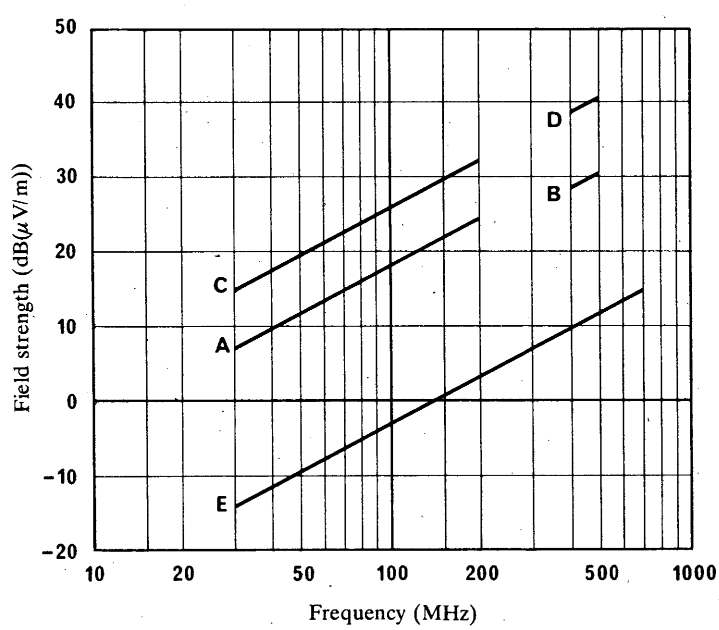

FIGURE 2 – *Minimum usable and median field strengths for typical hand-portable stations (based on minimum usable input of 0.7 μV e.m.f., in the absence of man-made noise)*

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)

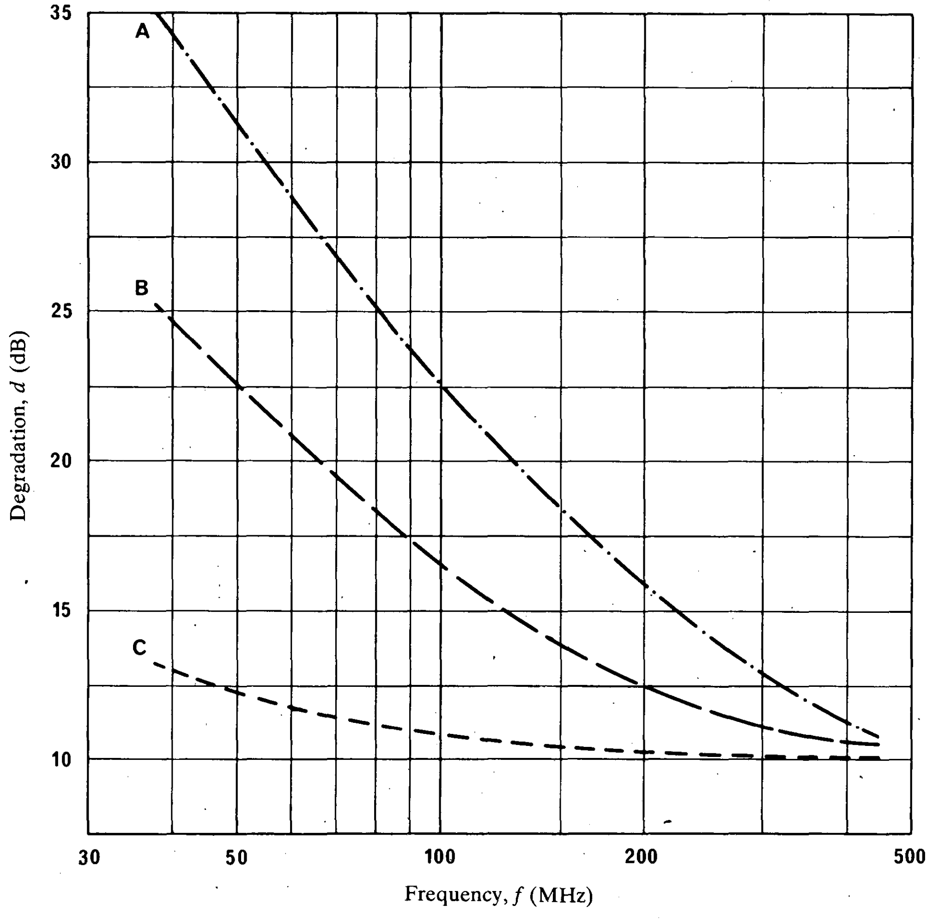

FIGURE 3 – *Variation of degradation of mobile reception and minimum values of field strength to be protected for* signal quality grade 4 *and receiver sensitivity of 0.7 μV e.m.f.*

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

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

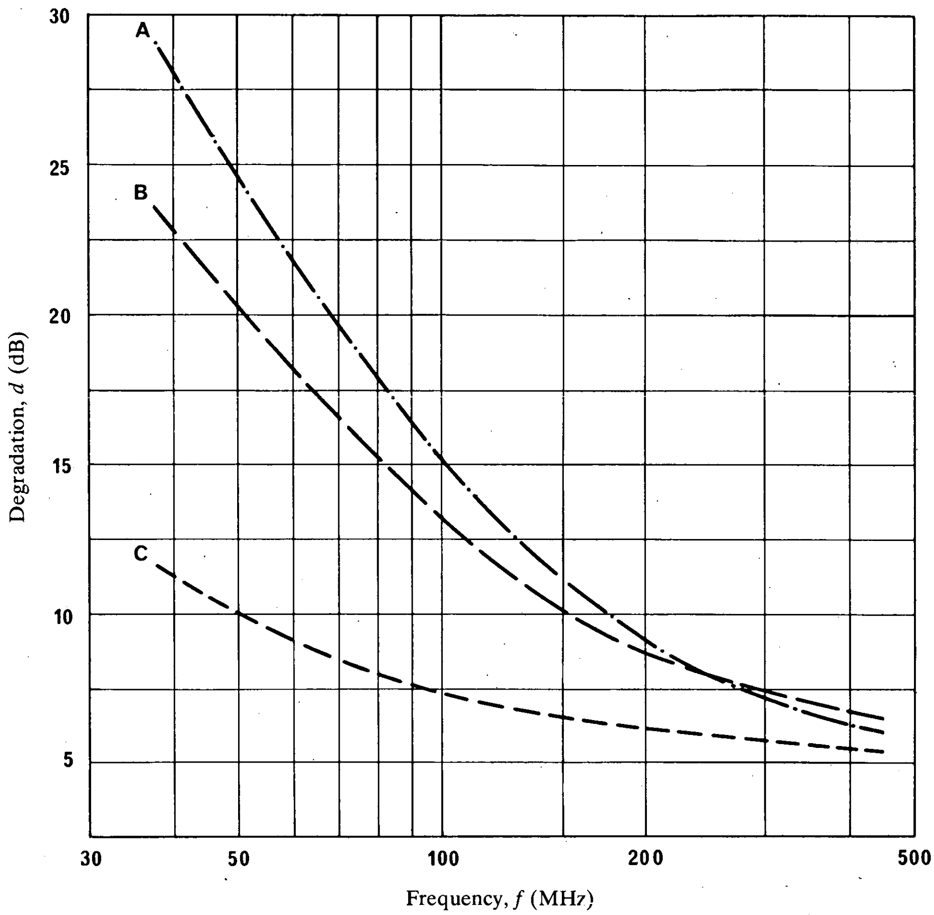

FIGURE 4 – *Variation of degradation of mobile reception and minimum values of field strength to be protected for* signal quality grade 3 *and receiver sensitivity of 0.7 μV e.m.f.*

Field strength = $-41 + d + 20 \log f$ dB(μV/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.

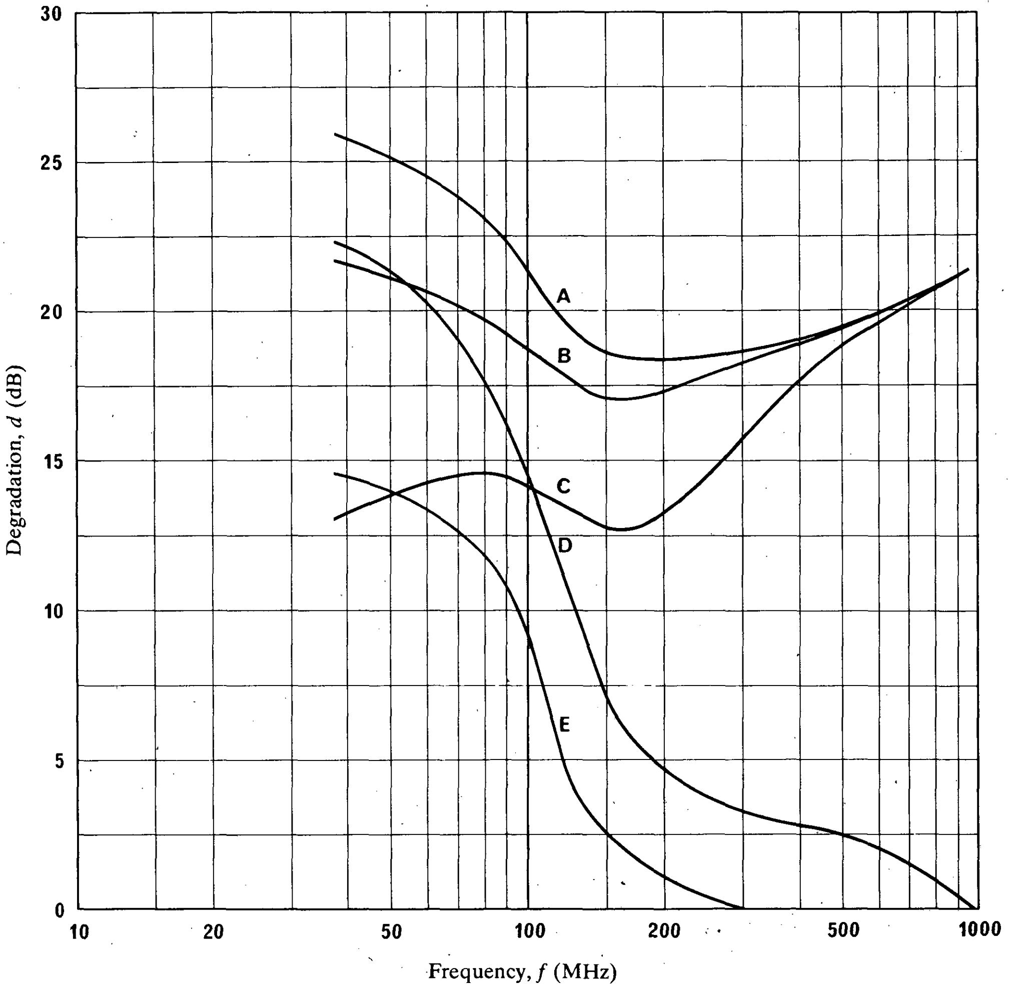

FIGURE 5 – *Variation of degradation of base station reception and minimum values of field strength to be protected* for signal quality grade 4 *and receiver sensitivity of 0.7 μV e.m.f.*

Field strength = $-41 + d + 20 \log f$ dB(μV/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

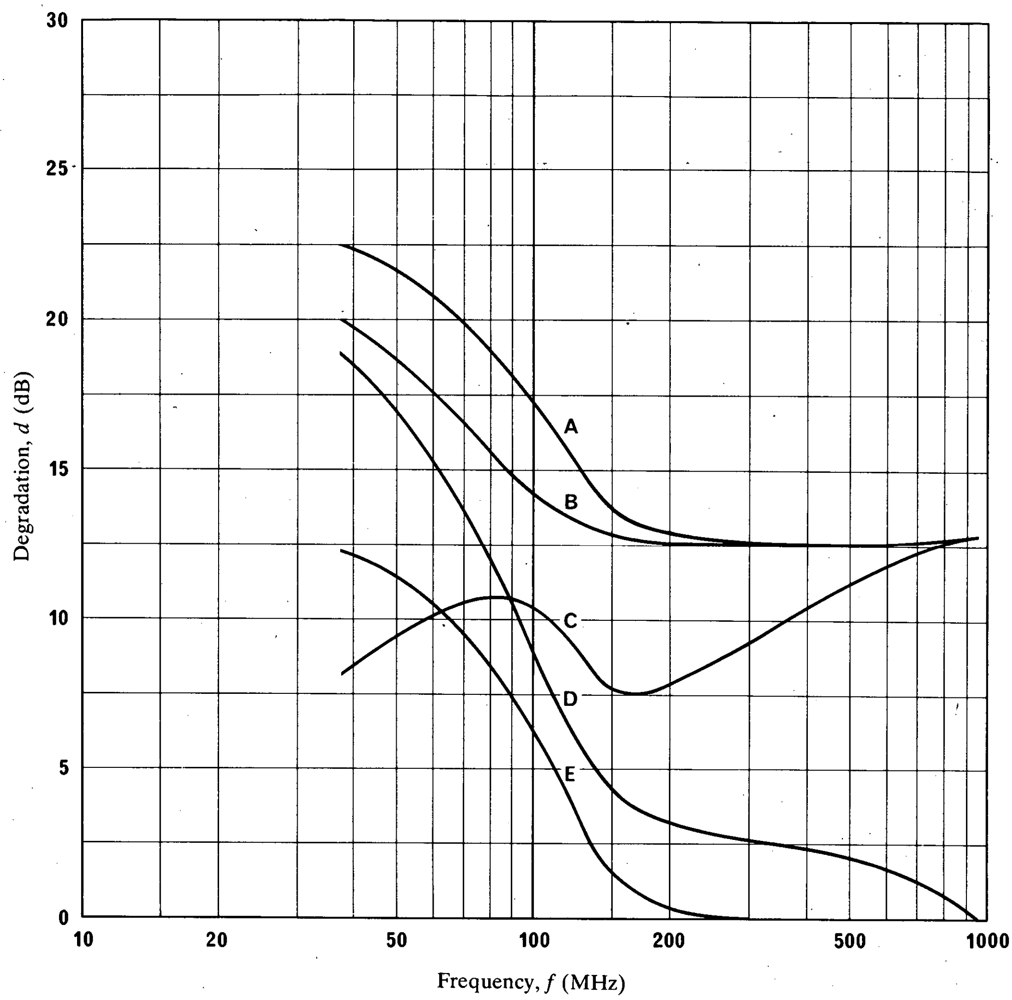

FIGURE 6 – *Variation of degradation of base station reception and minimum values of field strength to be protected for* signal quality grade 3 *and receiver sensitivity of 0.7 μV e.m.f.*

Field strength $= -41 + d + 20 \log f$ dB(μV/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

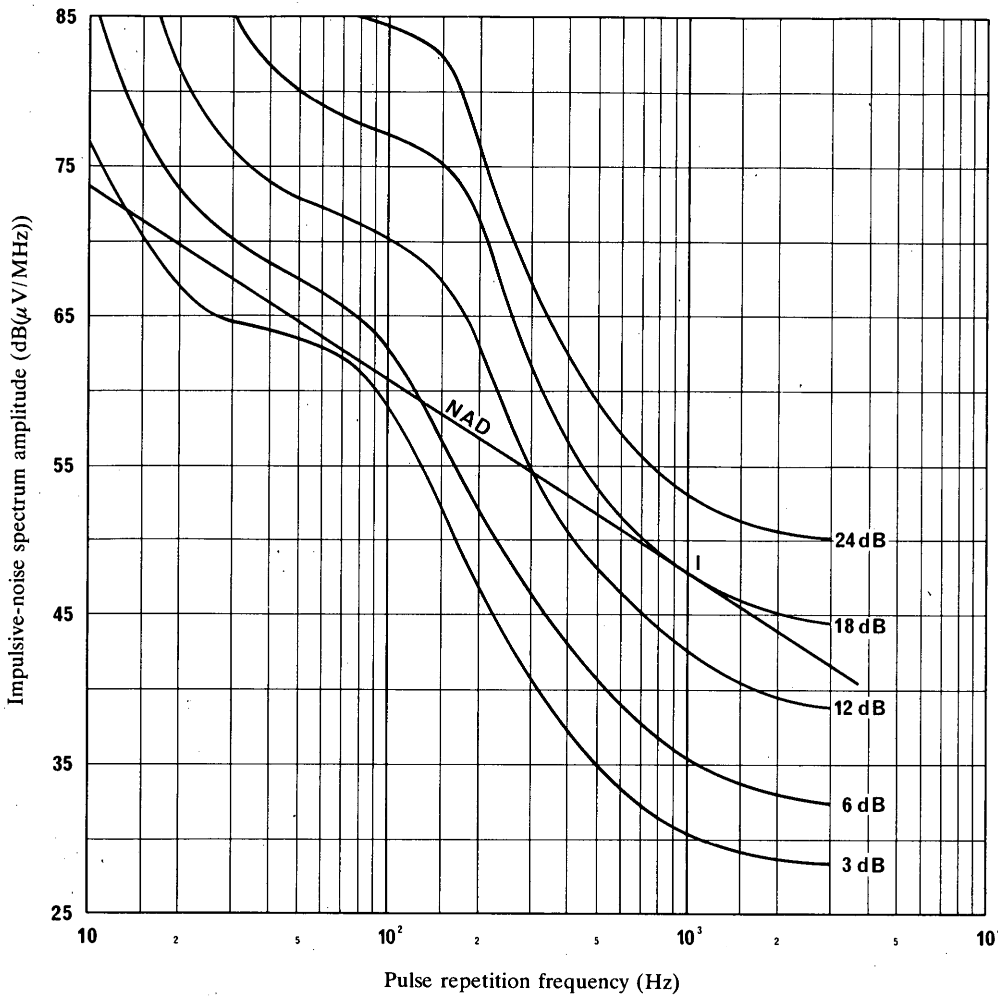

FIGURE 7 – *Example showing 18 dB degradation*
NAD tangent at I to 18 dB curve of the graph for receiver impulse noise tolerance

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.

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[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: ⩽ 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*

	Frequency band											
	35 MHz		80 MHz		160 MHz		300 MHz		450 MHz		900 MHz	
Channel spacing (kHz)	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 319-6*

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

(Resolution 20)

(1970-1974-1978-1982-1986)

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;

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* The Director, CCIR, is requested to draw the attention of IEC to Part B, § 3.4. This Report should be brought to the attention of Study Group 1.

- 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.

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.

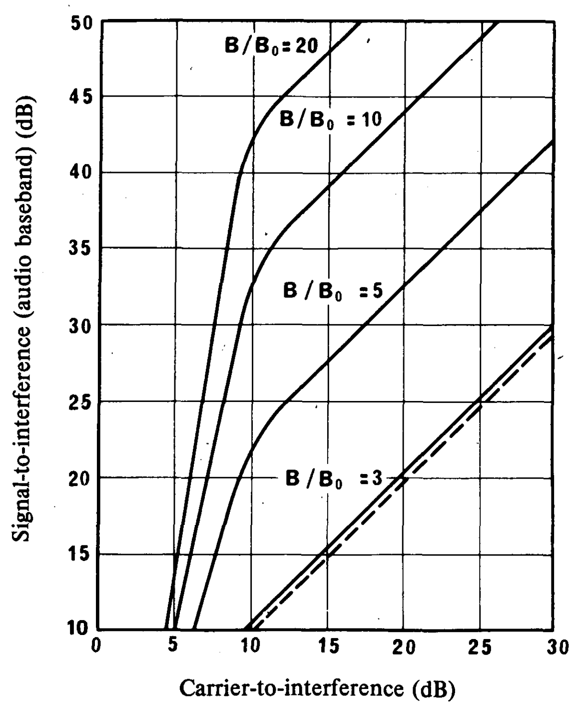

FIGURE 1

— — — SSB

Muilwijk [1978] also showed that the required radio-frequency system bandwidth 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.

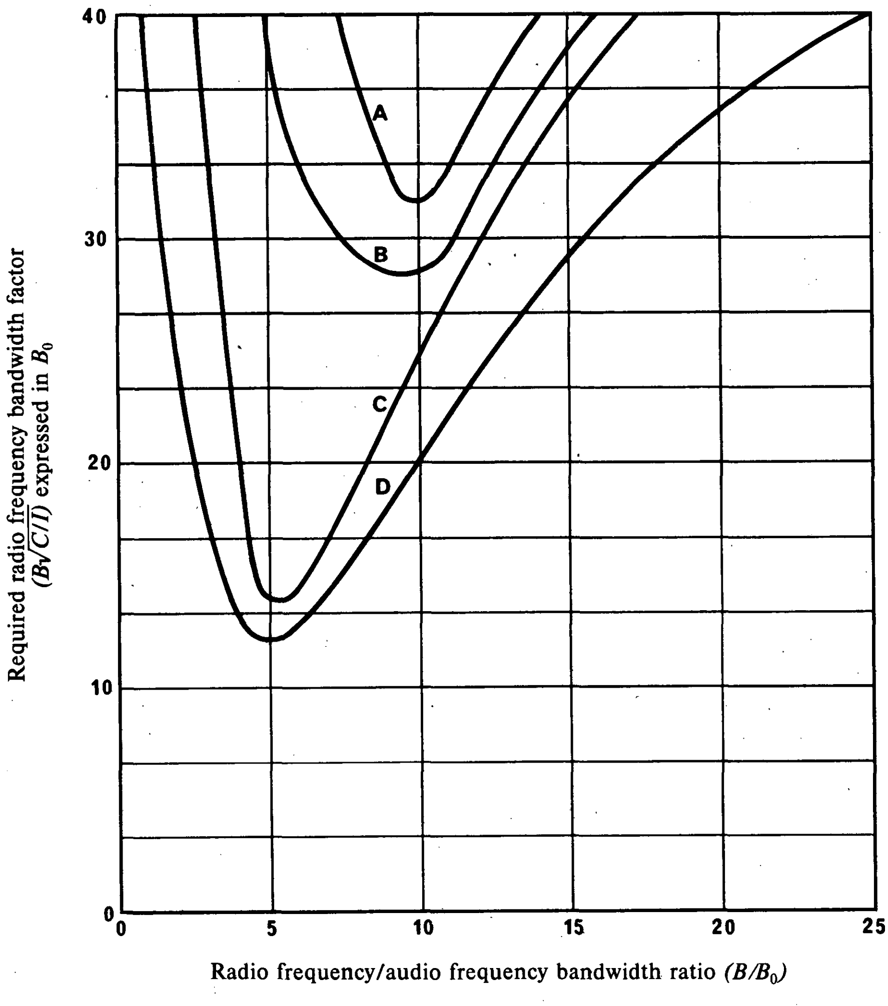

FIGURE 2

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.

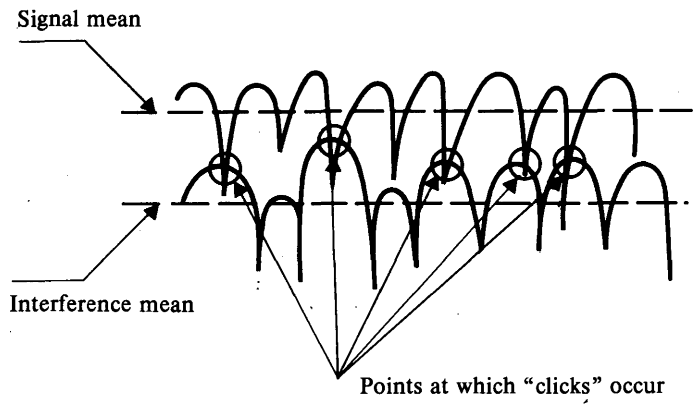

FIGURE 3 – *Effect of Rayleigh fading on subjective interference*

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 unusable).

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.

5. Use of computers in frequency assignments

Computers provide an economical way of maximizing the utilization of channels by optimizing frequency re-use. It is possible to use for planning detailed topographical data and representative propagation models. The application of computers to frequency assignment is under study in Study Group 1.

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 °C to $+60$ °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 °C) and around the upper temperature limit required ($+60$ °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 °C to $+60$ °C and 5 parts in 10^6 over the range -10 °C to $+40$ °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 °C to $+60$ °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 °C to about $+60$ °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 °C to $+60$ °C, for a change of ± 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.

In the United Kingdom use is made of computers in frequency assignment [CCIR, 1982-86a]. For an inclusive assignment, a prediction of the field-strength contours representing service and interfering areas is made, and the assignment decided on the basis of overlap criteria with these areas and those of existing stations. For a shared assignment an assessment of the channel loading at the busiest time of the day is made and the assignment decided on the basis of an acceptable total loading.

Iraq reports [Al-Araji and Abdullah, 1982] that by selecting three bands in the audio frequencies 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 frequencies 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 Table I. 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.

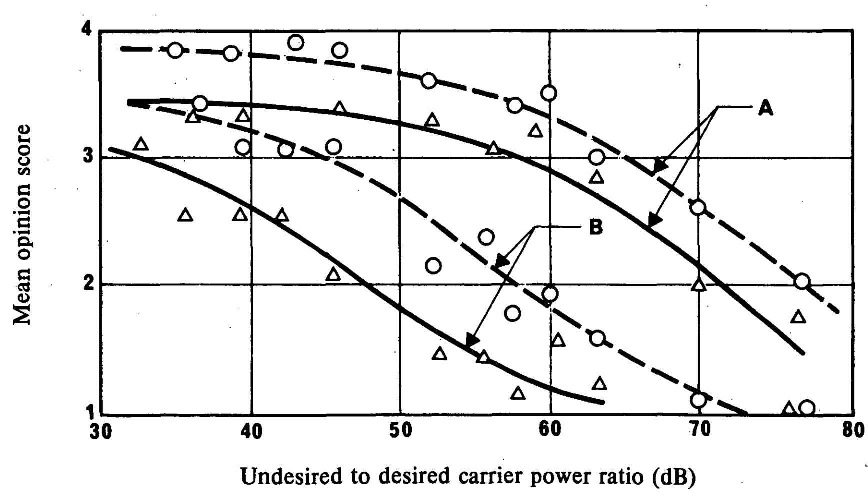

FIGURE 4

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.

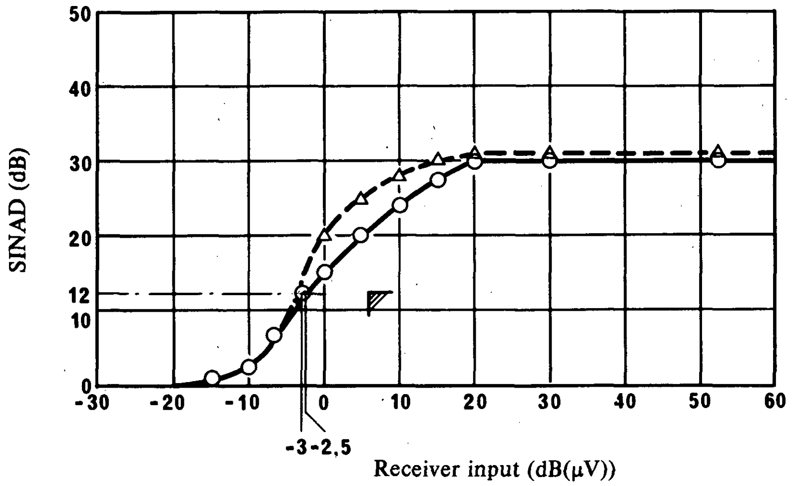

FIGURE 5

O——O——O: 12.5 kHz channel spacing (± 1.5 kHz deviation)

Δ– – Δ– – Δ: 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.

1.11 Japan has confirmed in the laboratory that a 12.5 kHz channelling FM system in the 900 MHz band is achievable in accordance with the specifications in Recommendation 478. Only the specification of frequency stability in the 900 MHz band should be improved to approximately twice that of the 400 MHz band. Frequency stability and speech quality in the presence of thermal noise and co-channel interference are as follows.

1.11.1 *Frequency stability*

The frequency drift in the 900 MHz band should be less than 1.5×10^{-6}. It is possible to achieve this frequency stability by adopting the digital TCXO, as shown in Fig. 7.

1.11.2 *Speech quality*

As shown in Fig. 8, the same speech quality with 12.5 kHz channel spacing as with 25 kHz channel spacing is obtained at almost the same receiver input voltage, since the C/N giving a MOS of 2.5 with 12.5 kHz channel spacing is only 2.5 dB larger than that with 25 kHz channel spacing. When introducing the 12.5 kHz channelling system, it is necessary to improve the required C/I by almost 3 dB to keep speech quality with 12.5 kHz channel spacing as good as that with 25 kHz channel spacing as shown in Fig. 9. These conclusions remain to be confirmed by field tests.

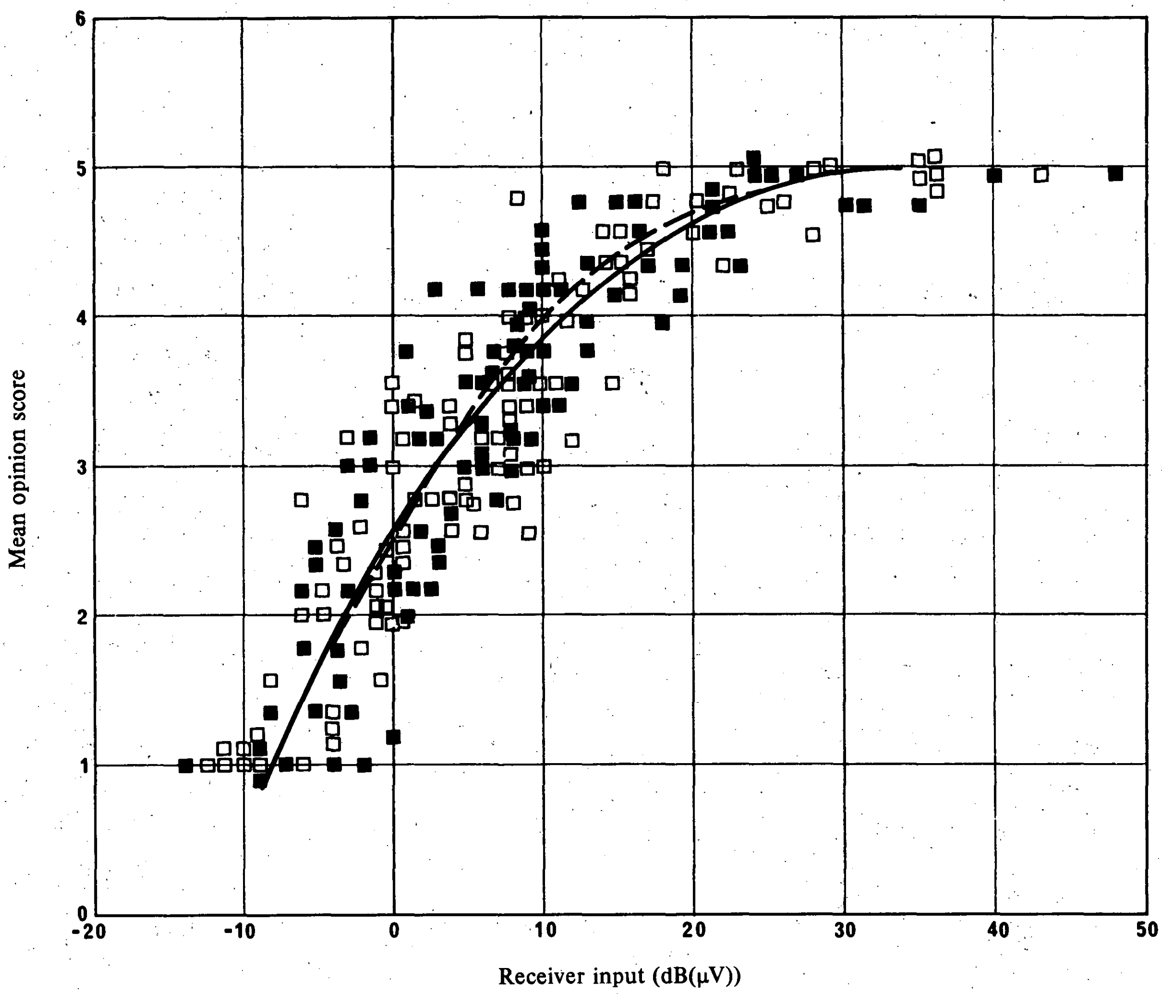

FIGURE 6

□———□ : 12.5 kHz
■— — —■ : 25 kHz

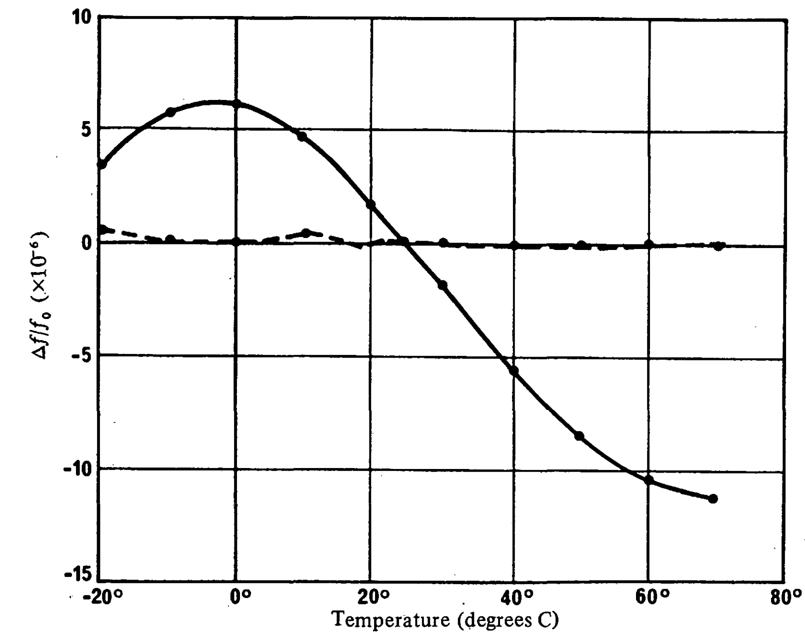

FIGURE 7 – *Frequency temperature characteristics of DTCXO*

f_0 = 12.79985 MHz (AT-cut, fundamental)

—●— uncompensated
- -●- - compensated

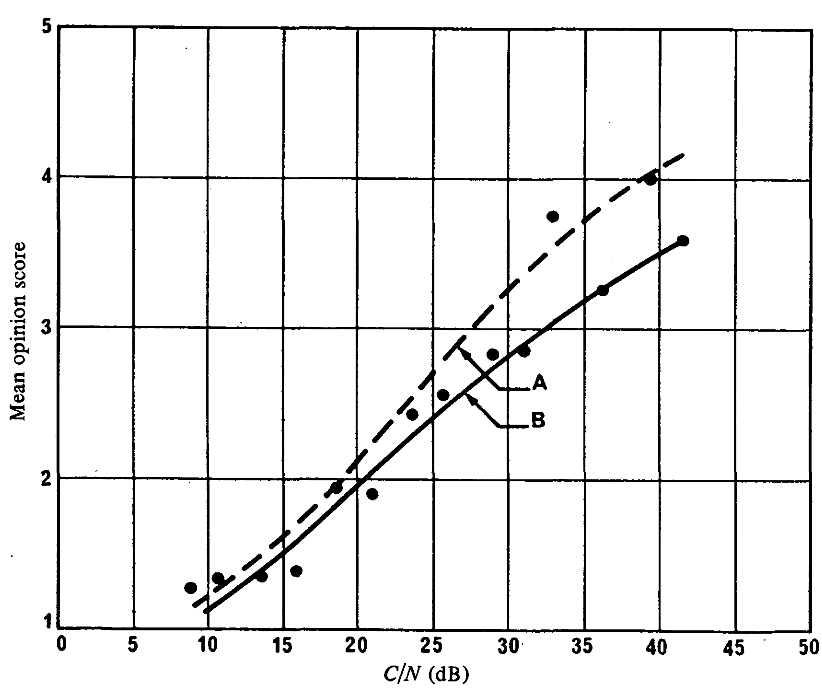

FIGURE 8 – *Mean opinion score versus C/N*

Curves A: standard modulating level = $3/\sqrt{2}$ rad r.m.s., channel separation = 25 kHz
B: standard modulating level = $1.5/\sqrt{2}$ rad r.m.s., channel separation = 12.5 kHz

Fading rate: 34 Hz

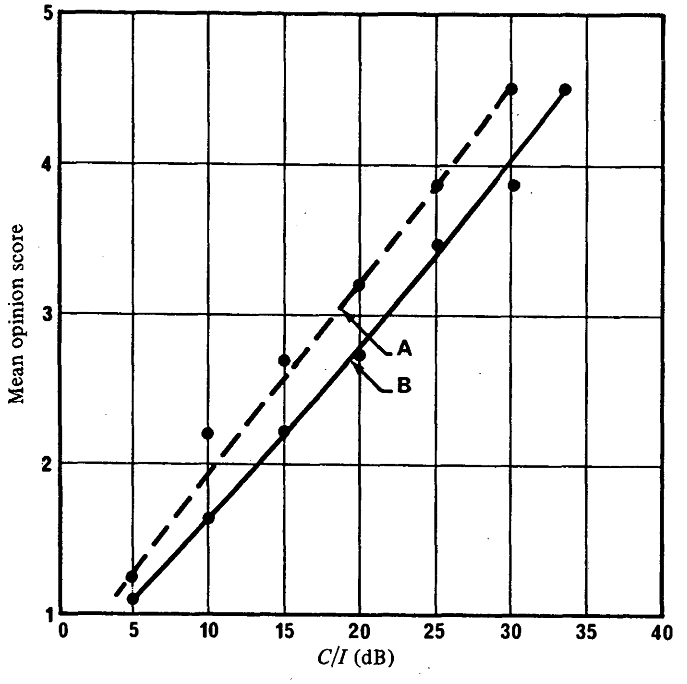

FIGURE 9 – *Mean opinion score versus C/I*

Curves A: standard modulating level = $3/\sqrt{2}$ rad r.m.s., channel separation = 25 kHz

B: standard modulating level = $1.5/\sqrt{2}$ rad r.m.s., channel separation = 12.5 kHz

Fading rate: 34 Hz

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 DNK DNK* NOR* S* SUI* USA				
12.5	NZL F (1)	F (1) G IRL NZL	F (1) G IRL NZL	F (1) NZL J	
15	TCH*	J	USA (2)		
20	CAN D USA	BEL (3) CAN D	BEL (3) D F (1) J	BEL D	
25	AUS CHN DNK E (7) F (1) FNL NOR POL DDR S SUI ROU TCH USSR YUG	BEL (4) CHN D (5) DNK E (7) F (1) FNL G (8) IRL (8) NOR DDR ROU S SUI TCH USSR YUG	BEL (4) CHN D (5) DNK E (7) FNL G (4, 8) IRL (8) NOR POL DDR ROU S SUI TCH USSR YUG	AUS CAN (6) CHN D (5) DNK E (7) F (1) FNL G IRL J NOR POL DDR ROU S SUI TCH USA USSR YUG	AUS CHN J SUI USA USSR
30		AUS	AUS CAN (6) USA		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 was 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.

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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.

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.

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.

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.

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.

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.

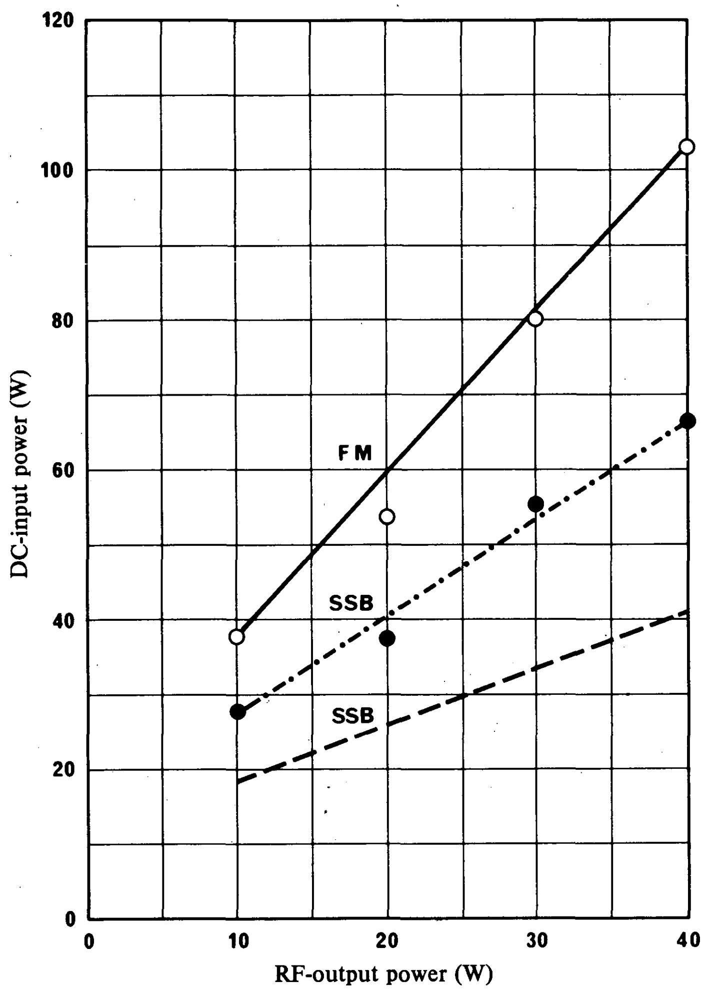


FIGURE 1 – *Comparison of power consumptions at different RF power levels*

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

Intermodulation product level: –30 dB

f = 37 MHz

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.

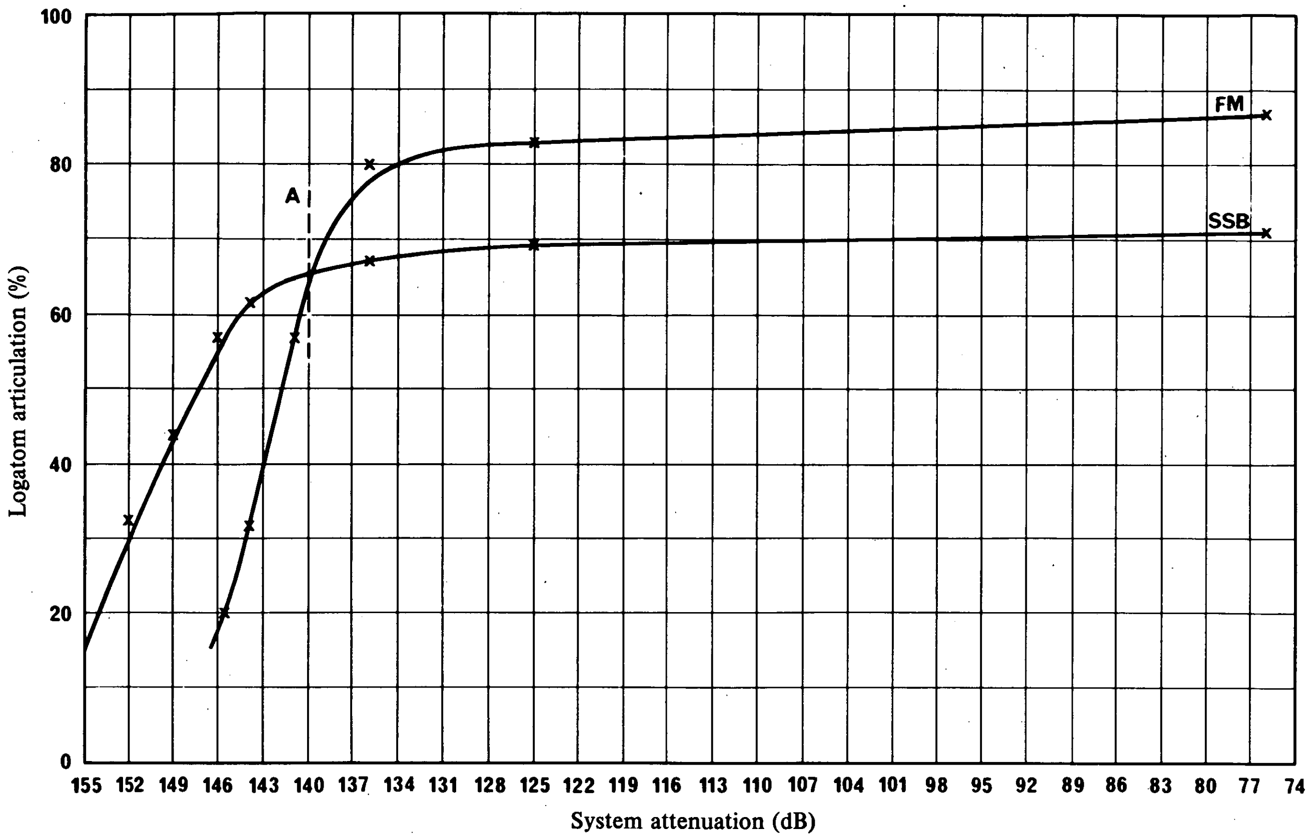


FIGURE 2 – *Logatom articulation versus system attenuation*

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

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.

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.

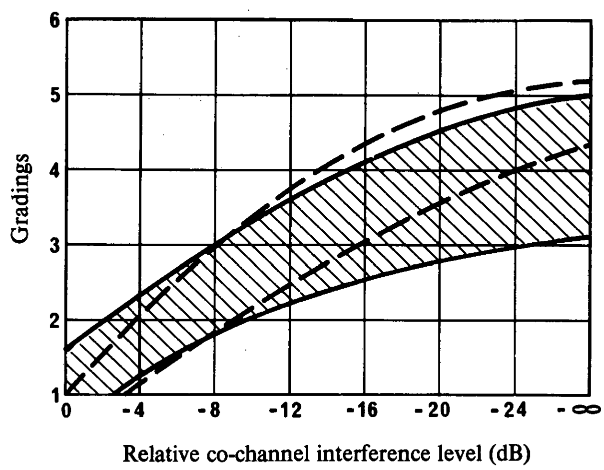


FIGURE 3a

———— : SSB

– – – – : FM

Wanted signal: 10 μV
Carrier offset: zero

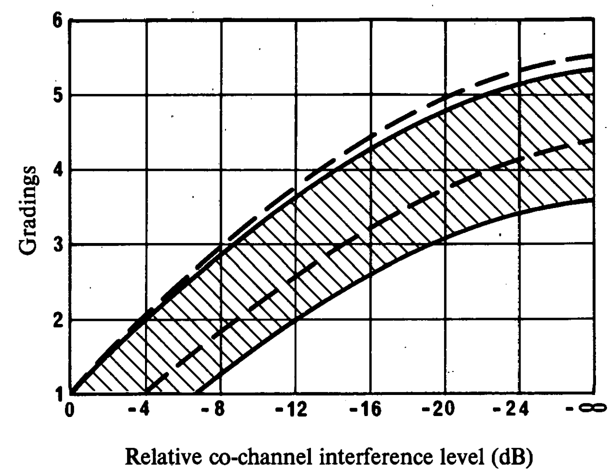


FIGURE 3b

———— : SSB

– – – – : FM

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

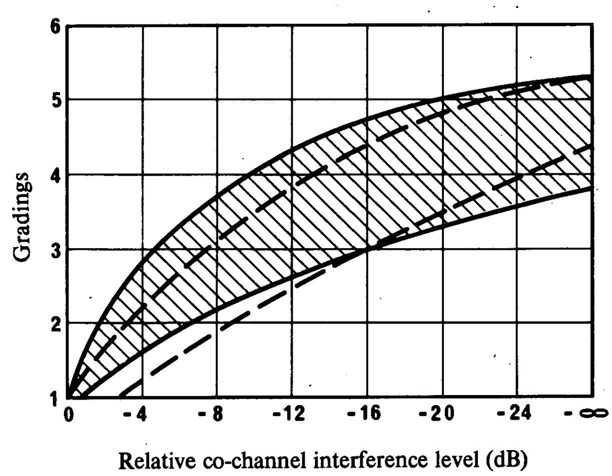


FIGURE 3c

———— : SSB

– – – – : FM

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

4. 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.

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.

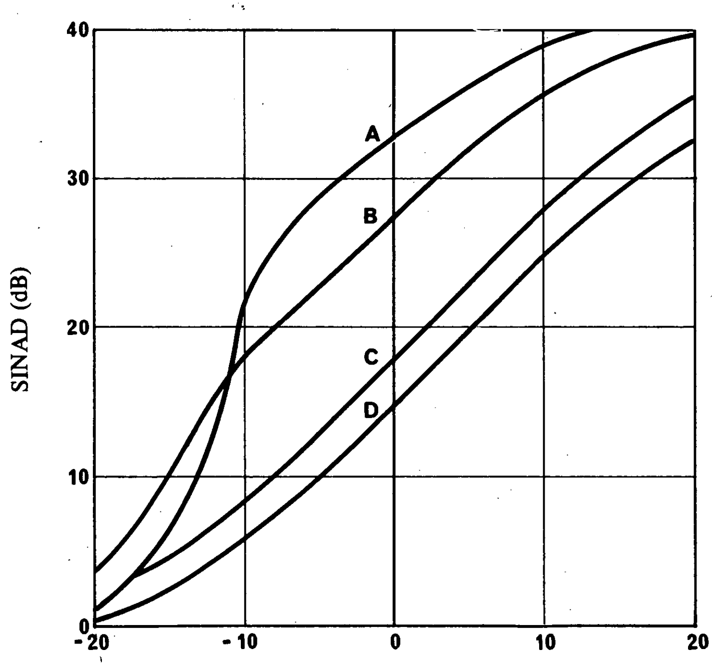


FIGURE 4 – *Receiver sensitivity*

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

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.

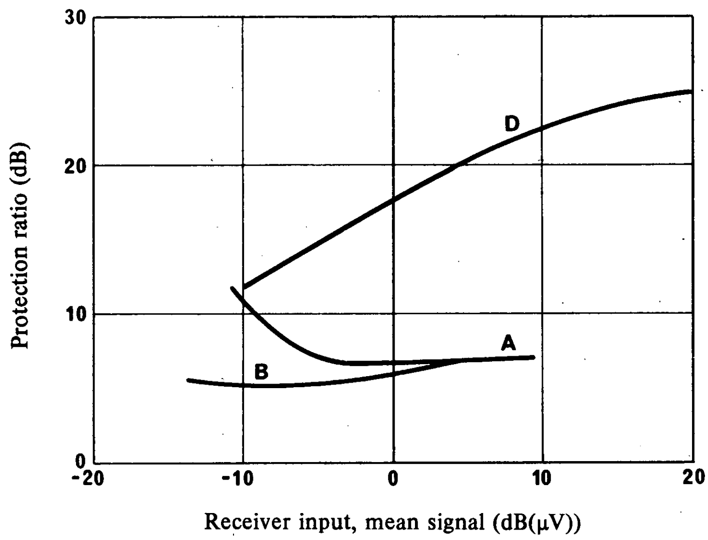


FIGURE 5 – *Co-channel protection ratio voice modulation, Rayleigh fading*

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.

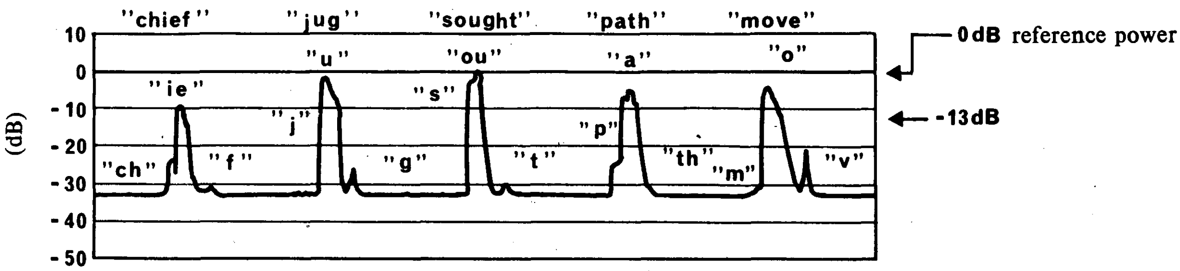
4.3 *Wanted signal voice tests (ACSB receiver)*

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.

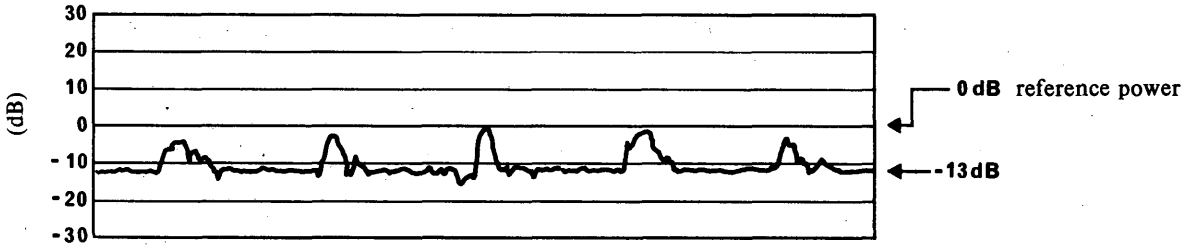
Meaningful measurements of ACSB radio performance have been difficult to obtain using standard objective test procedures because these procedures may not account for the use of voice processing. Subjective tests (diagnostic rhyme test) have indicated that ACSB performance is better than implied by objective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

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

Transmit syllabic power

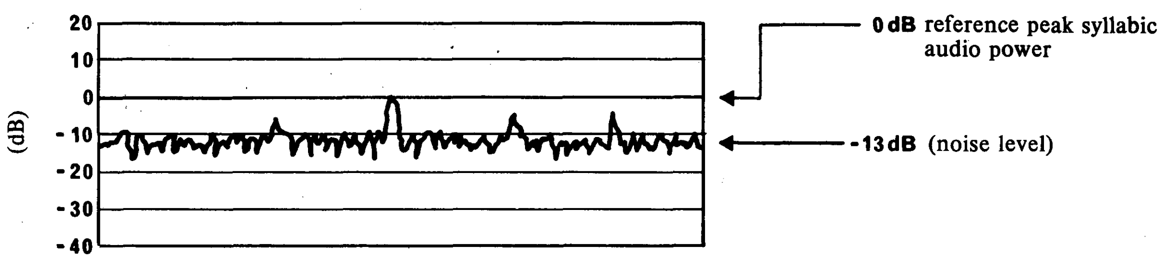


a) SSB

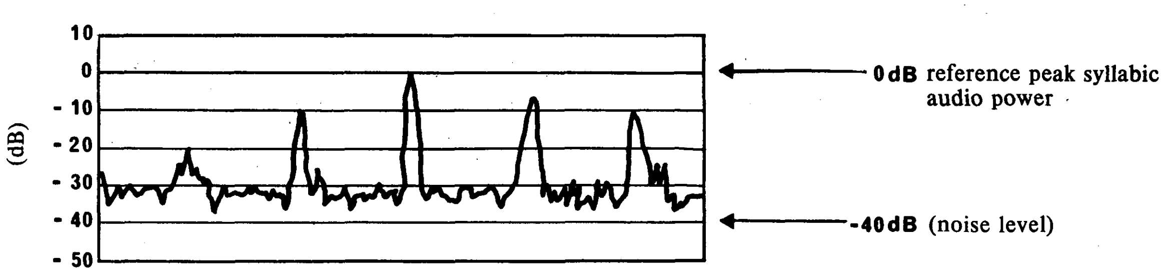


b) ACSB

Receiver audio output signals with noise 13 dB below 0 dB reference power



c) SSB



d) ACSB

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

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REPORT 1018*

CO-CHANNEL AND ADJACENT-CHANNEL COORDINATION CRITERIA FOR SIMULTANEOUS USE OF DIFFERENT MODULATION TECHNIQUES IN THE MOBILE SERVICE

(Study Programme 7B/8)

(1986)

1. Introduction

The United States of America has conducted laboratory and field tests comparing amplitude companded single sideband (ACSSB) to conventional FM for VHF mobile radio. The results of this study are contained in a report issued by the FCC [FCC, 1983]. Some of the information is extracted and included in Figs. 1, 2 and 3. In addition, the National Telecommunications Information Administration [NTIA, 1983] conducted some measurements, and issued a report.

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* This Report should be brought to the attention of Study Group 1.

In Canada, over the last two years, a number of laboratory and field tests were carried out on ACSSB systems. These tests demonstrated satisfactory performance with regard to the quality of reception, coverage and immunity to noise. In these tests ACSSB compared favourably with FM [Bischoff and Sieb, 1982; Bonney, 1982].

During 1984, subjective and objective laboratory tests of ACSSB systems were carried out by the Communication Research Center, Department of Communications, Canada [Burke and Boucher, 1984]. Intelligibility of voice signals was evaluated for various combinations of wanted and unwanted signals, as a function of frequency separations.

A Canadian experiment was also conducted to identify the possible sharing criteria between frequency hopping (FH) spread spectrum and other mobile services.

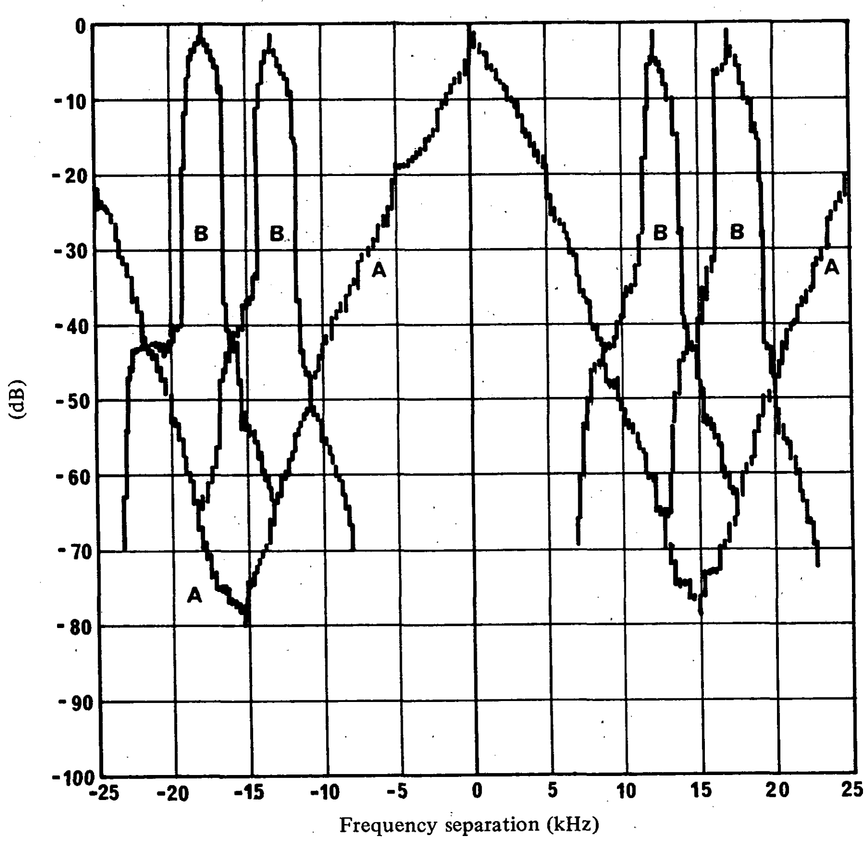

FIGURE 1 – *Superimposed spectrum emissions of FM and ACSSB, 30 kHz spaced FM, with 12.5 kHz offset ACSSB drop-ins*

Curves A: FM

B: ACSSB

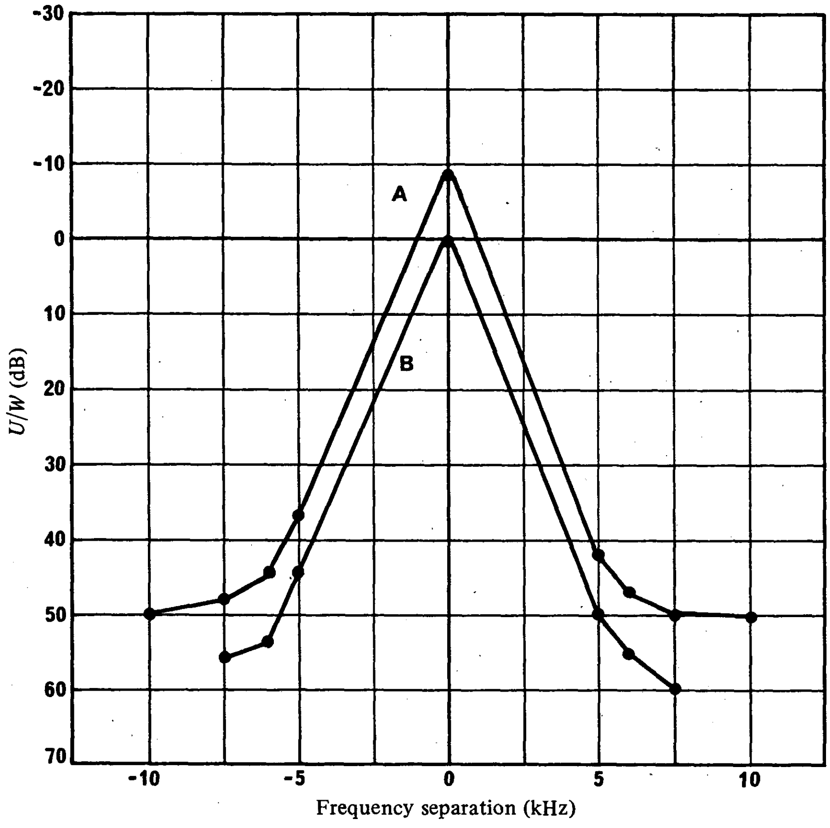

FIGURE 2 – *Unwanted/wanted ratio for ACSSB into ACSSB interference*

Curves A: just noticeable
B: disruptive

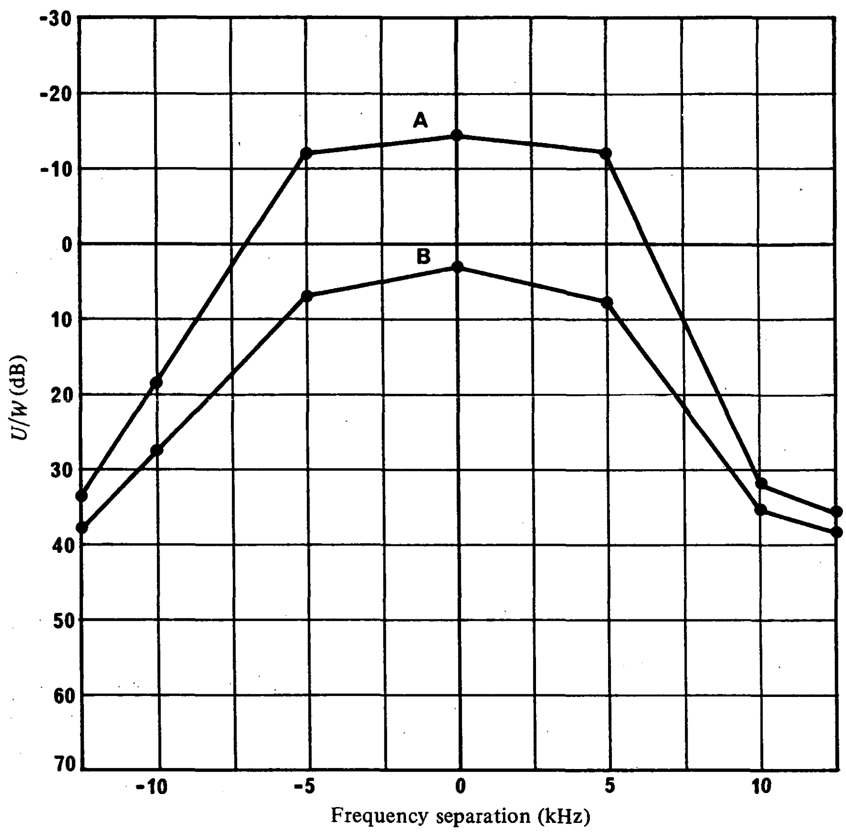

FIGURE 3 – *Unwanted/wanted ratio for ACSSB into FM interference*

Curves A: just noticeable
B: disruptive

2. Results of the United States' tests on ACSSB versus FM

Figure 1 shows superimposed spectrum emissions of FM and ACSSB systems with 12.5 kHz offset ACSSB channels between existing 30 kHz spaced FM channels. This is referred to as ACSSB drop-in channels. This causes degradation of protection to the wanted FM signal because of the full power of the adjacent ACSSB drop-in signal at the band edge of the FM channel. The intermediate frequency (IF) bandpass of typical FM receivers in use today provides only limited attenuation of signals at 12.5 kHz from centre frequency. Therefore, sufficient geographical separation would be necessary in order to place ACSSB channels (drop-ins) between existing FM channels. A typical FM system operating at 25 or 30 kHz spacing can offer in excess of 70 dB adjacent-channel protection to the wanted FM signal. With ACSSB drop-in channels, the adjacent-channel protection to the wanted FM signal could be as low as 40 dB.

The unwanted to wanted (*U*/*W*) ratios for an ACSSB signal from an unwanted ACSSB signal are shown in Fig. 2. The data in Fig. 2 were taken at co-channel, ± 5 kHz, ± 6 kHz, ± 7.5 kHz, ± 10 kHz and ± 12.5 kHz offsets. The data taken beyond 7.5 kHz was limited by the test set-up. The *U*/*W* ratio may be greater than 50 dB beyond 7.5 kHz. A positive *U*/*W* value indicates that the unwanted signal is stronger than the wanted signal.

The *U*/*W* ratios for an FM signal from an unwanted ACSSB signal are shown in Fig. 3. The data in Fig. 3 were taken at co-channel, ± 5 kHz, ± 10 kHz, ± 12.5 kHz offsets. The data shown for both tests represent the average values of what the observers individually obtained. The average difference in data logged between observers was less than 1 dB for "just noticeable" and less than 0.5 dB for "disruptive".

To determine the unwanted to wanted ratios, the wanted channel attenuator in the receiver test area was adjusted for the appropriate test level at the receiver. For each test, the unwanted channel attenuator was adjusted by the observer for "just noticeable" interference, and the difference between attenuators recorded. The unwanted channel attenuator was then adjusted by the observer for "disruptive" interference, and the difference between attenuators recorded. This procedure was repeated for all five wanted levels.

Just noticeable was defined as interference which is detectable but would not be observed if the interfering signal was reduced slightly in level (1 dB).

Disruptive was defined as interference which caused some words to be garbled, requiring occasional repeated message transmissions. Using random sentences with an average length of six words, two or more garbled words in three consecutive sentences was the criterion used to require a repeated transmission.

Any channel plan based on the *U/W* ratio will need to take account of the frequency stability of the interfering transmitter, and the victim receiver. The selectivity characteristics of the receiver will also affect the *U/W* ratio. Development and field testing will continue in the United States of America.

3. Results of the Canadian tests on ACSSB versus FM

3.1 *Criteria used for interference protection*

3.1.1 *Interference protection ratio (objective tests)*

The "interference protection ratio" is the ratio (in decibels) of the interfering signal relative to the wanted signal level present at the receiver input that would result in degradation in the SINAD at the receiver from 12 dB to 6 dB.

3.1.2 *Disruptive interference (subjective tests)*

"Disruptive interference" is that level of interference which will result in some words being garbled, requiring some occasional repeat of message transmission. Both wanted and interfering signals are modulated with voice.

3.1.3 *"Disruptive interference ratio" (subjective tests)*

The "disruptive interference ratio", with the wanted signal level adjusted to the same level as the 12 dB SINAD, is the ratio of interfering signal relative to the wanted signal that would result in disruptive interference conditions.

3.2 *Results for ACSSB to FM and FM to ACSSB interferences*

The results of unwanted to wanted ratios in dB, for ACSSB to FM and FM to ACSSB interferences are given in Fig. 4.

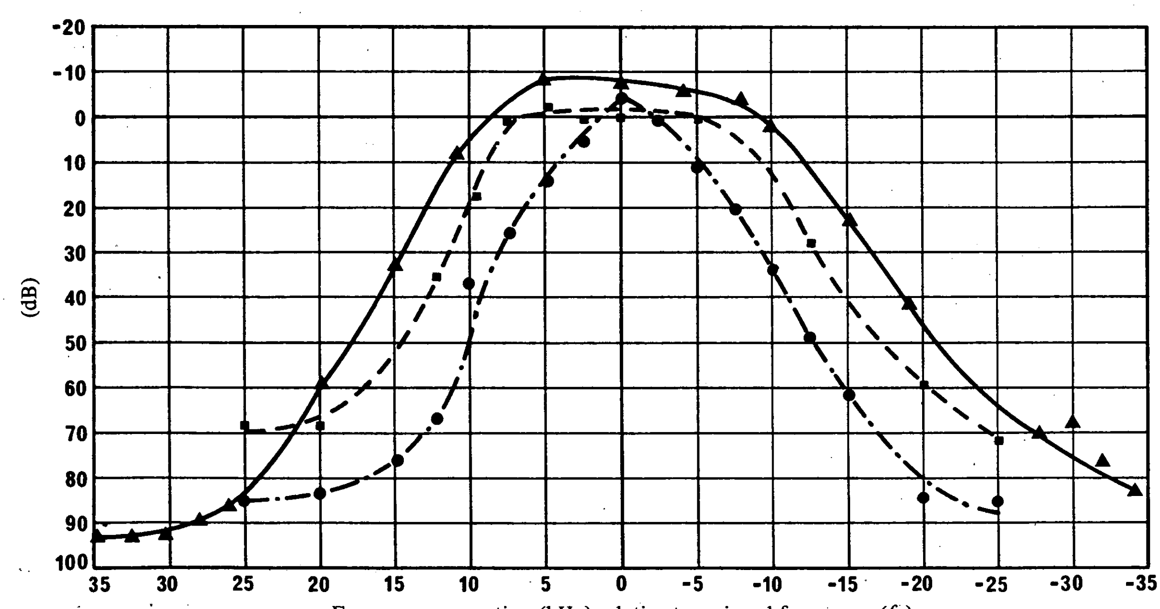

FIGURE 4 – *FM/ACSSB comparison (12 to 6 dB SINAD)*
Protection ratios for FM versus ACSSB

The interference protection ratios between ACSSB and FM systems at various frequency separations are given in Table I.

TABLE I

Interference	Frequency separation (kHz)	Interference protection ratio (dB) (with wanted 1 kHz tone)	Disruptive interference ratio (dB) (with wanted voice signal)
ACSSB to FM	12.5	35	35
	15.0	50	49
	20.0	68	69
FM to ACSSB	12.5	66	57
	15.0	76	70
	20.0	83	80

3.3 *Results for ACSSB to ACSSB, and FM to FM interferences*

The results of the tests for interference protection ratios between proposed and existing base stations in simplex mode of operation for various frequency separations are shown in Fig. 5.

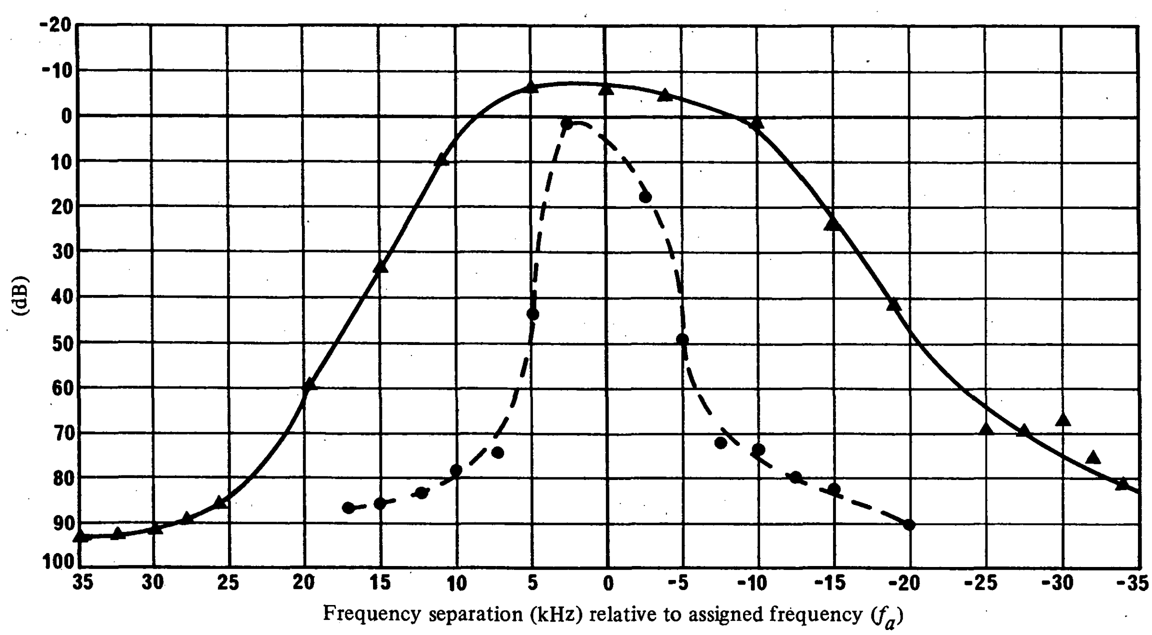

FIGURE 5 – *FM/ACSSB comparison (12 to 6 dB SINAD) FM and ACSSB protection ratios*

FM into FM

ACSSB into ACSSB

The major findings of the interference protection ratios between ACSSB systems and FM systems are given in Table II.

TABLE II

Interference	Frequency separation (kHz)	Interference protection ratio (dB) (with wanted 1 kHz tone)	Disruptive interference ratio (dB) (with wanted voice signal)
FM to FM (with 30 kHz bandwidth)	11.0	9	10
	15.0	33	29
	20.0	59	55
	26.0	86	83
ACSSB to ACSSB	5.0	43	45
	7.5	74	74
	12.5	83	85
	17.5	86	88

4. Canadian measurements of protection ratios from frequency (FH) hopping spread spectrum

Measurements were conducted to identify co-channel interference criteria applicable to the land mobile service operating in the 30-50 MHz band. Three commercial FM receivers, having channel spacings of 20, 50 and 25 kHz respectively, were used in the measurements. Signal-to-interference (S/I) protection ratios for co-channel operation were measured using the just perceptible (JP) and non-intelligible (NI) interference criteria which are respectively about equivalent to the MINIT and 0.3 AI, as defined in Reports 526 and 525. The results of these measurements are reported in detail in Report 826.

The experimental evidence indicates that large propagation losses are required to protect an FM receiver against the just perceptible level of FH co-channel interference. On the other hand surprisingly small propagation losses are required to protect against the non-intelligible harmful interference level. Moreover, considering that present land mobile users of the 30-50 MHz band use analogue transmission techniques, an interference of 10 ms duration, such as the one used in the Canadian experiment, will not be annoying if it does not occur too often. For a given land mobile channel, interference from one source was present on average 0.4% of the time so that a land mobile system (analogue voice) can tolerate a greater number of FH sources, the maximum number being determined by the desired grade of service.

This experiment did not attempt to evaluate the impact of FH interference on digital systems nor did it study the relationship between the number of FH interference sources and the degradation of a land mobile signal.

It should be noted that the degradation is additive, in the sense that the simultaneous operation of *n* frequency hopping transmitters will increase the duty cycle of the interference by a factor *n*. Finally, values given by Recommendation 478 have to be kept in mind (spurious emissions on discrete frequencies are limited to 2.5 μW or to 70 dB below the carrier power).

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REPORT 1019*

SOURCES OF UNWANTED SIGNALS IN MULTIPLE BASE STATION SITES IN THE LAND MOBILE SERVICE

(Question 7-2/8)

(1986)

1. Introduction

The greatly increased use of land mobile services has resulted in a dramatic increase in the number of base stations on any one site, particularly on those sites strategically placed to serve large built-up areas. This has led to instances of severe interference due to unwanted signals being generated at the site. This Report is not intended to examine every possible type of interference but rather to indicate the more commonly occurring sources. It should be particularly noted that transmitters of other services may be involved.

2. Simple frequency relationships

As land mobile frequency bands are used throughout the VHF/UHF spectrum there may be harmonic relationships between frequencies in the various bands. The equipment cabinet, the power supply cabling and land-line cabling can contribute to the level of these unwanted harmonic signals.

Other interfering signals can be caused by simple mixes either in transmitter output stages or at the antenna mast. As an example, if the signal from a VHF broadcasting transmitter at 93 MHz mixes with a signal of the mobile service at 170.5 MHz, a difference signal of 77.5 MHz can be produced. This can cause a problem if it is a receive frequency of the mobile service.

3. Complex frequency relationships

3.1 *Generation of intermediate frequency and/or its derivatives*

Interference can be caused in a receiver where signals are received from two transmitters whose frequencies are separated by an amount equal to the IF, or a submultiple of the IF, of the receiver.

3.2 *Generation of transmit/receive (Tx/Rx) difference frequency*

This problem arises on sites where there are several base stations having "repeater" or "talk-through" facilities, i.e. the transmitters and receivers are in use simultaneously. If the Tx/Rx spacing is constant (D), an incoming signal from a mobile station will produce in the base station transmitter output stage a difference frequency, D. Any other base station transmitter may now mix with D to produce its own receiver frequency in the same band.

4. Intermodulation products

4.1 *Generated external to the site*

Under this heading, products arise from stations on adjacent sites, and, in particular, the third order product i.e. $2f_1 - f_2$, which is prevalent in large built-up areas. In some instances significant intermodulation products up to and including the seventh order have been noted and in exceptional cases the interference has been traced to the nineteenth order.

4.2 *Intermodulation products generated on-site by non-linear junctions on the mast*

More study is required to verify the mechanisms and levels of such interference, which certainly exists in the land mobile bands. However, at lower radiated powers, the significance of these products is reduced, compared with other forms of non-linearity, e.g. § 4.1 and 4.3.

4.3 *Intermodulation products generated on-site by non-linearity in components of the system*

Junctions between dissimilar metals cause non-linearity, and therefore intermodulation products, when subjected to radio frequency currents, and recent work has highlighted such products up to the eleventh order at VHF caused by connectors, cables and dissimilar junctions in what might be regarded as otherwise innocuous components.

For the long-term development of the land mobile radio industry, it may be necessary to define the non-linearity of passive components in the system.

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* This Report should be brought to the attention of Study Group 1.

5. Transmitter noise

Until quite recently, most transmitters on base station sites had valve output stages, which fortuitously were not a major contributor to the noise spectrum compared with the more modern solid-state output stages.

With a valve output stage, the unwanted noise is generally narrow-band, having frequencies which are multiples of the crystal oscillator frequency or a combination derived from the multipliers. However, in the case of solid-state output stages the noise is generally wideband and higher in level.

Figures 1, 2 and 3 give the graphical results of measurements made in the United Kingdom of noise from VHF transmitters with thermionic valve output stages and with solid-state output stages for the VHF "high band" (150-170 MHz) and VHF "low band" (71.5-87.9 MHz).

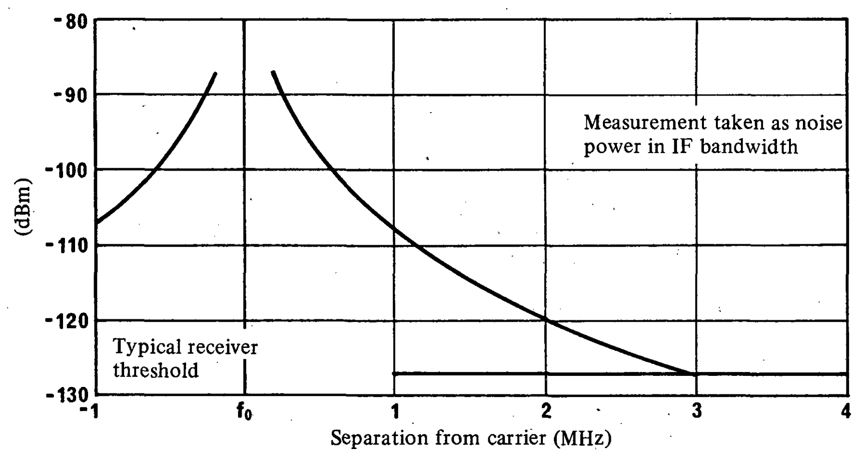

FIGURE 1 – *Typical transmitter noise VHF high band (150-170 MHz): thermionic output stage*

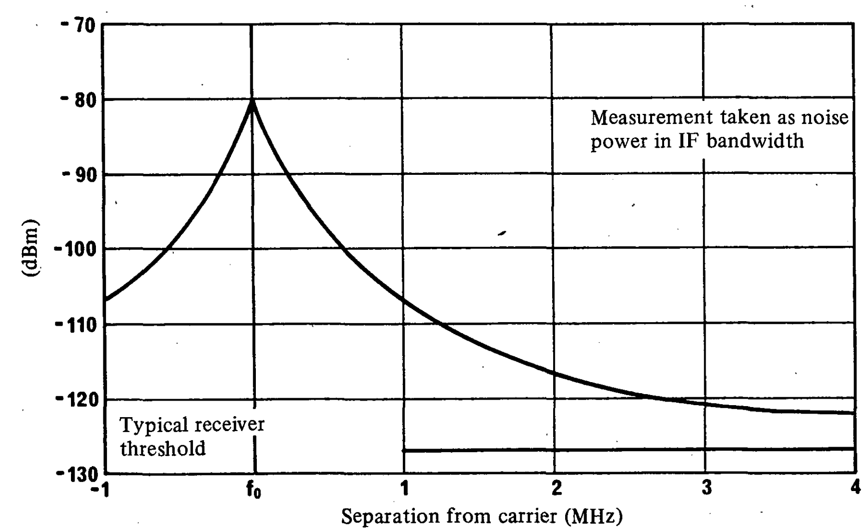

FIGURE 2 – *Typical transmitter noise VHF high band (150-170 MHz): solid-state output stage*

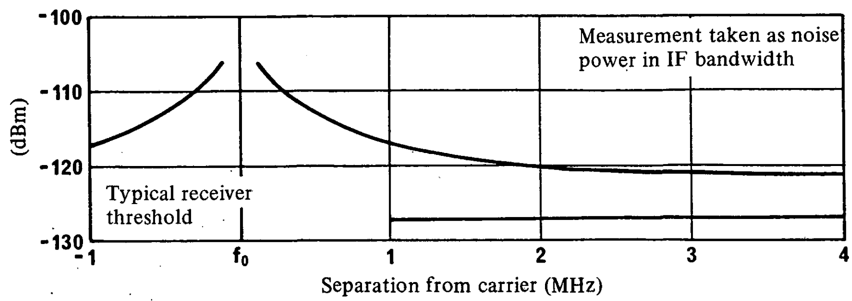

FIGURE 3 – *Typical transmitter noise VHF low band (71.5-87.9 MHz): solid-state output stage*

Figure 4 shows practical operational noise curves for a base station without filtering of spurious emissions and noise from the transmitter output (curves A). These results can be compared with those of curves B which show the benefit of filtering in reducing noise and unwanted emissions by some additional 30 dB.

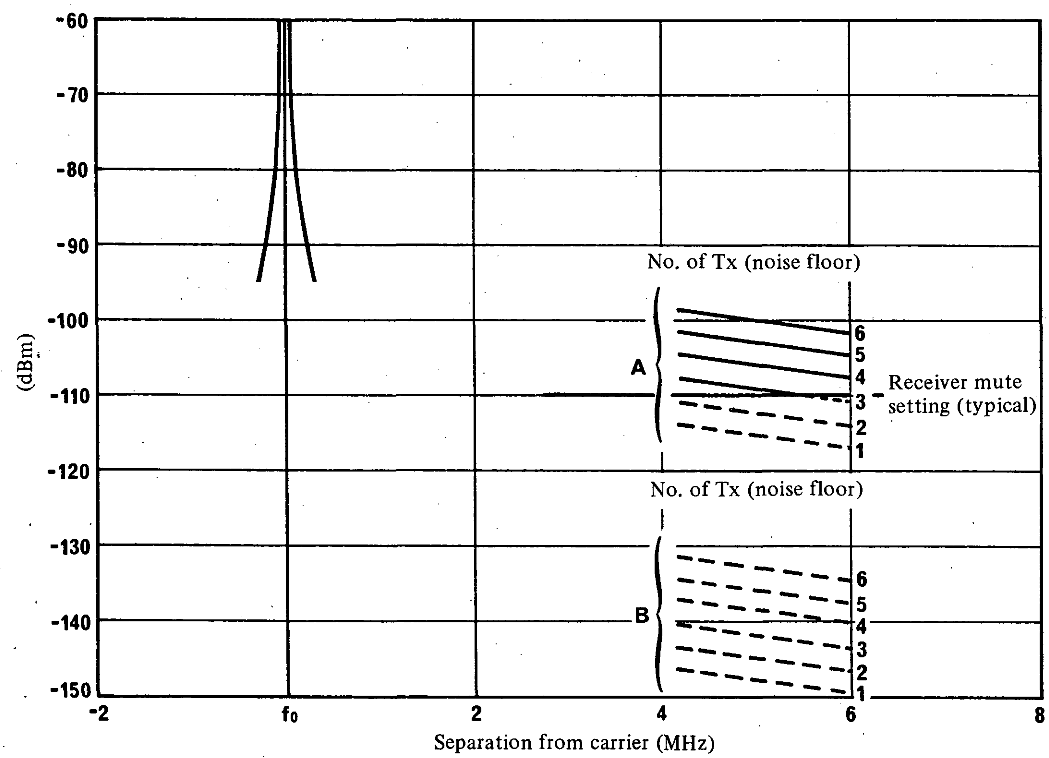

FIGURE 4 – *Practical operational noise curves*

Curves A: site without transmitter filters

B : site with transmitter filters

Minimum isolation at f_{Rx} = 30 dB

All transmitters have solid-state output stages

Carrier power per transmitter typically +43 dBm

Figure 5 shows a typical transmitter filtering system and Fig. 6 shows the detailed response of the spectrum dividing filter shown in Fig. 5.

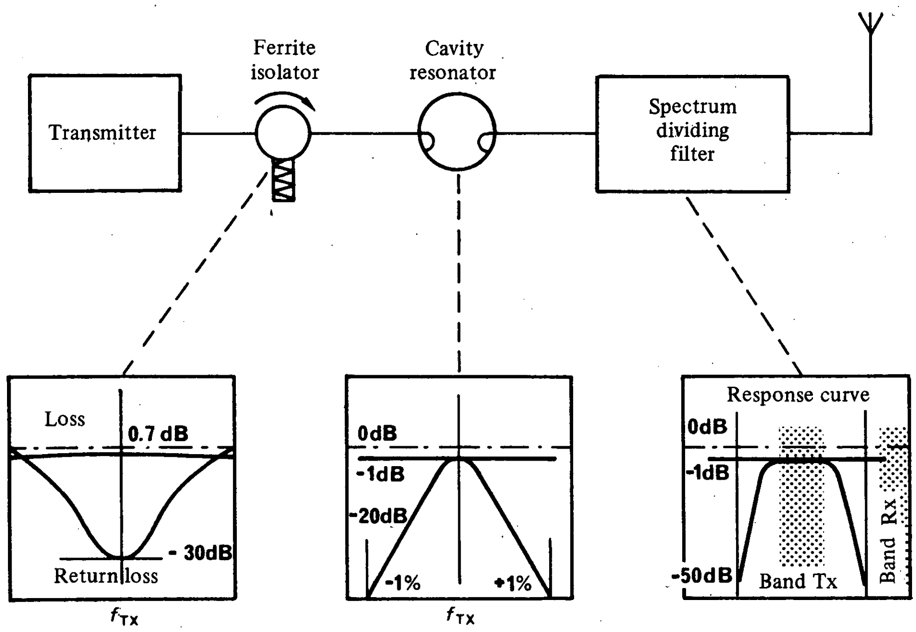

FIGURE 5 – *Typical Tx filter system for talk through operation VHF 150-160 MHz*

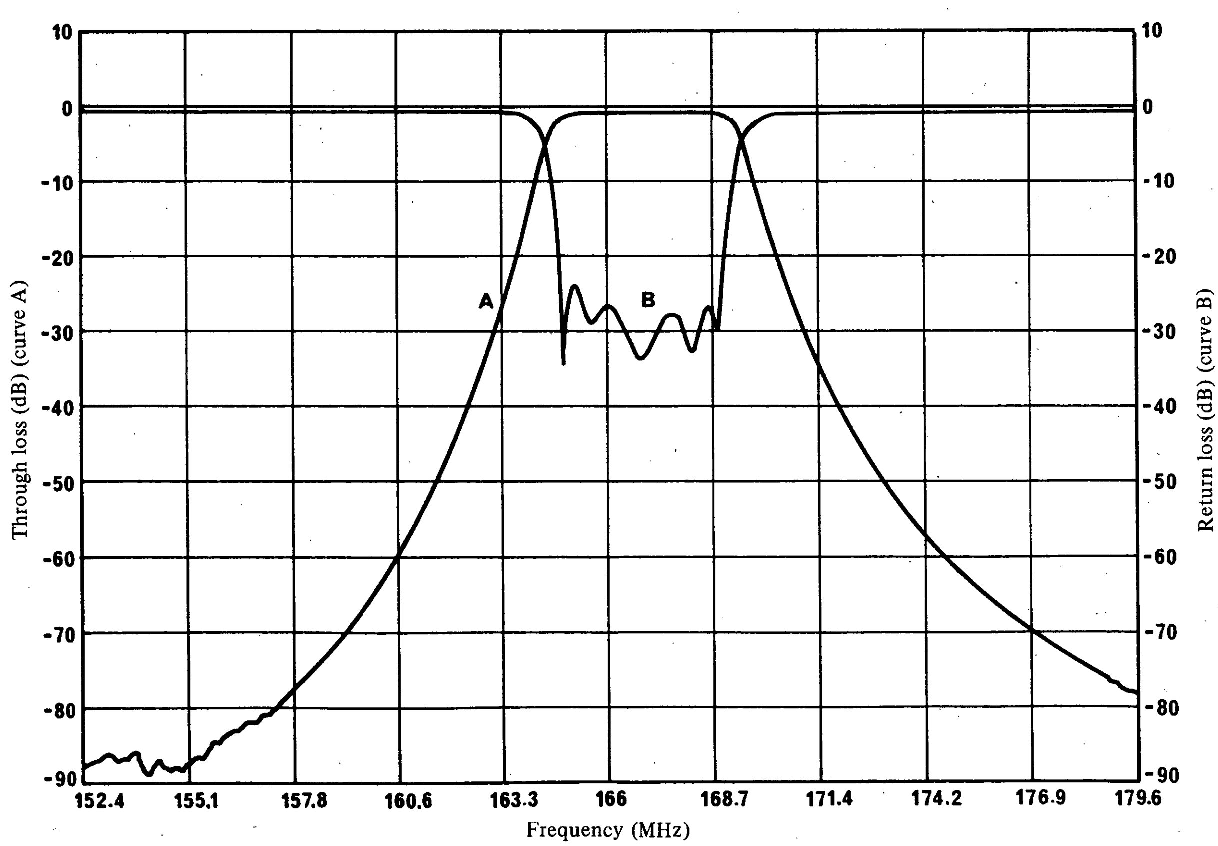

FIGURE 6 – *Spectrum dividing filter response curve*

A typical calculation of the noise levels to be expected on a site with 15 transmitters using the filtering arrangements outlined in Fig. 5 is given below:

Calculation of typical transmitter noise levels
(Tx/Rx spacings 4.8 MHz)
VHF high band 150-170 MHz

Per Tx			
Noise at FRx: (Typical value)			−137 dB (relative to carrier)
Now insert additional isolation:			
Add ferrite (−1 dB)			−138 dB
Add cavity (−30 dB)			−168 dB
Add SD filter (−35 dB) (6 section)			−203 dB
Now take carrier ref. +42 dBm:	Noise	=	−161 dBm
Add say 15 × Tx at (+3 dB/Tx)			+45 dB
		=	−116 dBm
Add say further 5 × Tx at (3 dB/Tx)			+15 dB
Final noise level at *f*Rx		=	−101 dBm
			(i.e. 2 μV p.d.)*

6. External electrical noise

Apart from ignition noise, there are the well-known sources of radio interference, which continue to proliferate, particularly from industrial users, i.e. RF heating, microwave ovens, X-ray and medical equipments. These normally provide a broad spectrum of noise which tends to vary in frequency.

Screening or suppression of the interfering equipment normally reduces the problem to an acceptable level.

There is however, a new family of sources, namely computers and computer peripherals, which are currently causing problems with broadband noise over the VHF spectrum.

7. Summary

There are instances where the present engineering practices in multiple transmitter sites have allowed the generation of excessive unwanted signals. With the increased use of land mobile radio it is desirable to perfect techniques to reduce interference effects in the future. There is a need for better site engineering in order to establish "quiet" base station sites for trunking networks and cellular radio.

The following should be considered:

- spurious emissions from transmitters;
- filtering of transmitter outputs to reduce spurious emissions and noise at frequencies near the carrier;
- use of directive isolators in transmitter output stages;
- additional filtering to provide protection at adjacent frequency bands;
- non-linear effects at all points in the system.

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* μV p.d. is μV potential difference, measured with circuit closed.

RECOMMENDATION 539-2*

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

(Question 12/8)

(1978–1982–1986)

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;

(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.

* 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 non-speech, one-way, personal selective calling system with alert, without message or with defined message such as numeric or alpha-numeric. (This definition should be brought to the attention of the CMV.)

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 499-4

RADIO-PAGING SYSTEMS

(Question 12/8)

(1970-1974-1978-1982-1986)

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. One way to do this is to carry out the synchronization of the code bits via the radio paging channel. Information is required about the bit rates which this synchronization method would permit.

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.

Repeated transmission of calls can be used to improve the paging success rate of tone alert pagers. If p is the probability of receiving a single call, then $1 - (1 - p)^n$ is the probability of receiving a call transmitted n times, provided the calls are uncorrelated. Correlation under Rayleigh fading conditions can be largely removed by spacing the call more than 1 s apart. Longer delays between subsequent transmission (≈ 20 s) are required to improve the success rate under shadowing conditions.

Receivers with numeric or alpha-numeric message display can only take advantage of call repetitions if the supplementary messages are used to detect and correct errors.

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.

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RECOMMENDATION 584-1 *

STANDARD CODES AND FORMATS FOR INTERNATIONAL RADIO PAGING **

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

(1982-1986)

The CCIR,

CONSIDERING

(a) Recommendation 539 and Reports 499; and Report 900 which describes codes and formats presently used by a number of administrations;

(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:* non-speech, one-way, personal selective calling system with alert, without message or with defined message such as numeric or alphanumeric. (This definition should be brought to the attention of the CMV.)

(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.

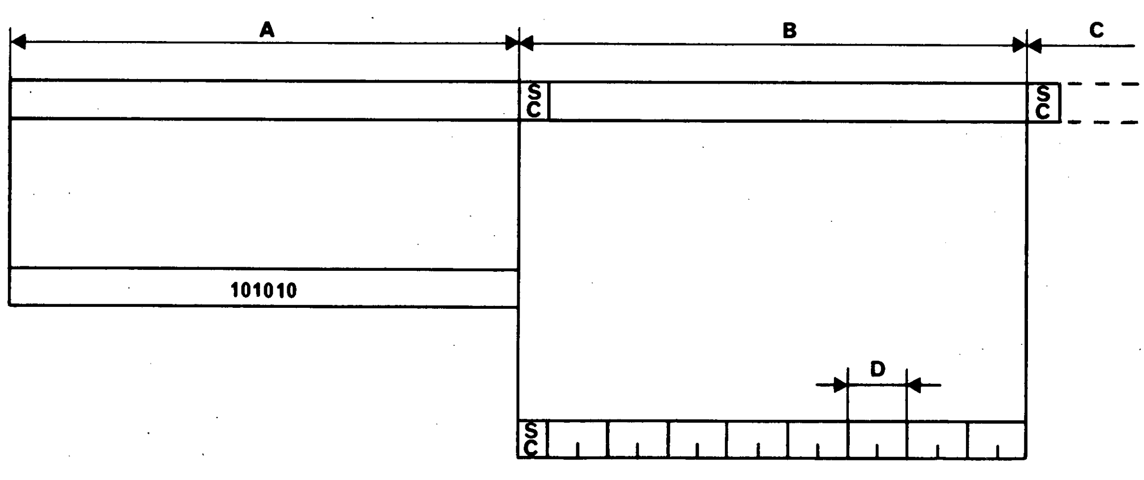


FIGURE 1 – *Signal format*

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.

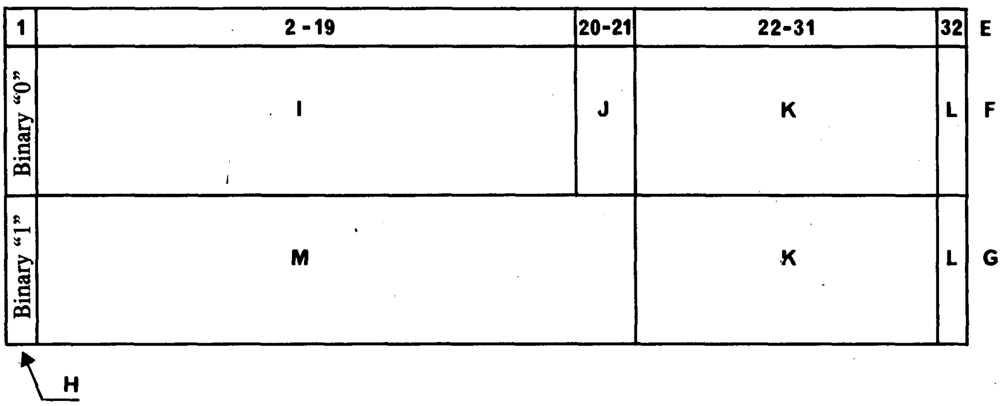


FIGURE 2 – *Form of address and message codewords*

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.

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	[

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.

REPORT 900-1

RADIO-PAGING SYSTEMS

Standardization of code and format

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

(1982–1986)

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 The Swedish radio-paging system is an addition to the radio data system (RDS), recommended for the transmission of information to facilitate station or programme selection in FM receivers (see Recommendation 643). The system has been used for radio paging in Sweden since 1978. It uses a 57 kHz subcarrier on VHF/FM broadcasting transmitters. The modulation method and the code and format are specially designed to be compatible with the broadcast monophonic and stereophonic programmes. A paging address comprises six decimal digits. After that may follow an additional message, either numeric with 10 or 18 decimal digits, or alphanumeric with unlimited length [CCIR, 1978-82a, 1982-86a]. Details can be also found in Annex II.

2.2 Documents submitted by the United States of America describe a binary digital code and format with a single address capacity of up to 400 000 with non-coded battery saving and 4 000 000 with coded preamble. The code uses a Golay (23 : 12) cyclic code with two codewords representing an address. Messages are encoded using a BCH (15 : 7) code. The code and format provide queueing and numeric/alphanumeric message flexibility and ability to operate in a mixed mode of transmission with other formats. The details of this code and format are contained in Annex I [CCIR, 1978-82b; 1982-86b].

2.3 Japan uses a BCH (31 : 16) codeword with a Hamming distance of 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 (address) BCH 15 : 7 (message)	BCH 32 : 21 plus 1 bit even parity	BCH 31 : 16
Hamming distance	3 (Note 1)	7 (address) 5 (message)	6	7
Codeword error detection capability per word (Note 5)	Burst: 10 errors Random: 2 errors	Burst: 11 errors, Random: 6 errors } address Burst: 8 errors, Random: 4 errors } message	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 } address Burst: 4 errors, Random: 2 errors } message	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 (address) 7/15 = 0.47 (message)	21/32 = 0.66	16/31 = 0.52
System related characteristics: Code address capacity	1×10^6	409 600 non-coded preamble Over 4 000 000 coded preamble (Note 3)	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)	1187.5	300/600 (address) (Note 2) 600 (message)	512	200
System message capability and length	Decimal, 18 digits; alphanumeric, unlimited	Dual address, 4 functions, numeric and alphanumeric: length indefinite when asynchronous	4 addresses per identity: unlimited message length, hexadecimal or alphanumeric	Dual address
Battery saving feature and type	Call grouping. Other information transmitted	Yes	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 Sequential: 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, 450 MHz, and 800 MHz	VHF mobile 150 MHz (Note 10)	VHF mobile 250 MHz
In service since	1978	1973 (address) 1982 (message)	(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 known 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. – With known means of expansion.

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	Alphanumeric	1 beep

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

7. Comparison of codes

7.1 *Comparison by simulation*

7.1.1 In Italy both the radio paging Code No. 1 (RPC1) and Golay code are used for the public radio-paging system. In order to control environmental parameters, e.g. propagation, that affect any measurement programme, it was decided to compare the RPC1 and Golay codes by laboratory simulation and to verify this simulation by some field measurements. A computer-aided comparison between the two codes was carried out [CCIR, 1982-86c]. Performances for both address and message reception (numeric and alphanumeric) were evaluated for two radio channel models (Gaussian and Rayleigh fading).

The results indicated that, for message success rate per paging attempt, the Golay code has a better performance with respect to 1 bit error correction per code word of RPC1 and almost the same performance with respect to the foreseen RPC1 2 bit error correction algorithm under these channel conditions. The results for 1 bit error correction are summarized in Table IV in which the performances are presented in terms of S/N(RPC1) – S/N (Golay) (dB) in order to obtain the same (95%) success level per paging attempt.

TABLE IV – *Code performance comparison (dB)* (see text)

Type of signal	Channel		
	Gaussian	Rayleigh at 5 km/h	Rayleigh at 40 km/h
Alert	0.6	1	3
10 character numeric message	1	4	8.5
80 character alphanumeric message	1	8	11

For the criteria of a false message conditioned by a sucessful call, results are shown in Figs. 1 and 2. They indicate that with the 2 bit error correction algorithm of RPC1 the probability of obtaining a false message is highest, that the probability for Golay is less and that for RPC1 with 1 bit error correction is least.

7.1.2 The United States believes that the additional field tests it has carried out confirm these laboratory simulations [CCIR, 1982-86d].

7.2 *Comments on the comparison*

7.2.1 In order to obtain the equivalent results by means of field measurements it would be necessary to mount a large measurement programme, especially to distinguish results that are close to one another.

7.2.2 A bad impression of the service might be given to a subscriber who receives a false message following a successful alert; and thus the curves in Figs. 1 and 2 are of particular interest. The translation of the data from these curves into the terms suggested in Report 499, taking into account also Fig. 3, needs study. Significant pre-knowledge of the likely message content often exists, and this may ameliorate this user impression.

7.2.3 In order to identify the consequences on system planning criteria, study is needed to determine how to weight the simulation results by factors such as time spent in marginal situations.

Field tests carried out in the United Kingdom on an RPC1 alphanumeric pager utilizing a 1 bit error correction algorithm gave the sensitivity decrease between an alert and an 80 character message for a success rate of 90% as approximately;

$$3.2 + 0.055\ W \qquad \text{(dB)}$$

where W was the percentage of time spent *walking* at least 5 km/h inside a single room in each of two buildings and the streets beside one of them [CCIR, 1982-86e].

7.2.4 Message reception with new decoding methods (hard and soft decision) for both RPC1 and Golay has not yet been fully explored [CCIR, 1982-86f].

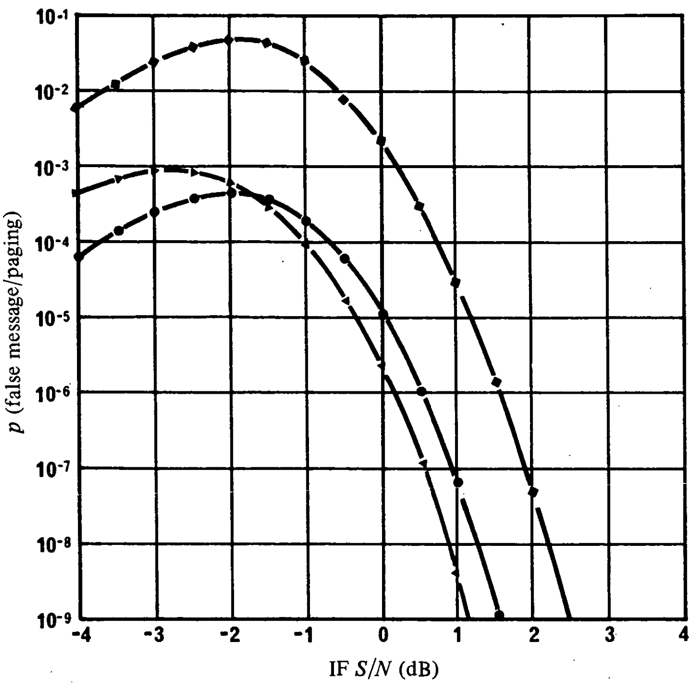


FIGURE 1 – *False numeric message rate (10 figures), conditioned to the probability of associated address reception, for a pager moving in a Gaussian channel*

POCSAG (1 bit correction)
POCSAG (2 bit correction)
GSC

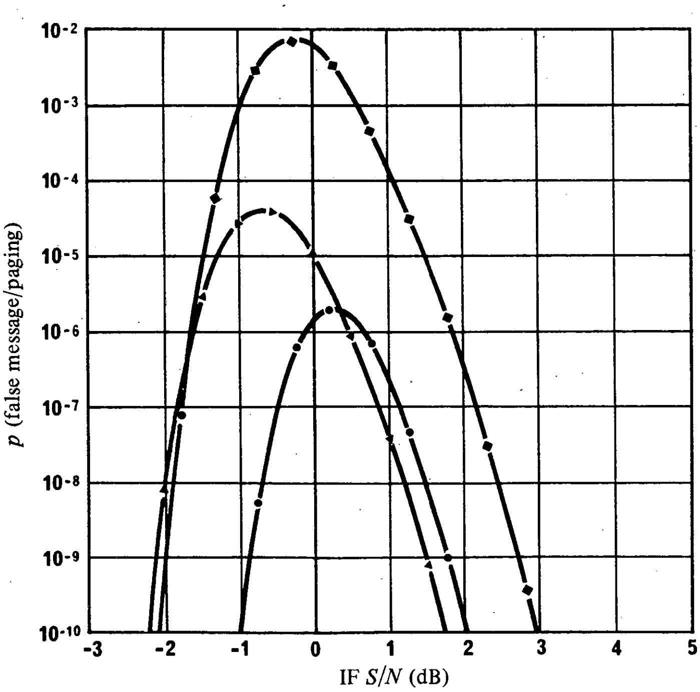


FIGURE 2 – *False alphanumeric message rate (80 characters), conditioned to the probability of associated address reception, for a pager moving in a Gaussian channel*

POCSAG (1 bit correction)
POCSAG (2 bit correction)
GSC

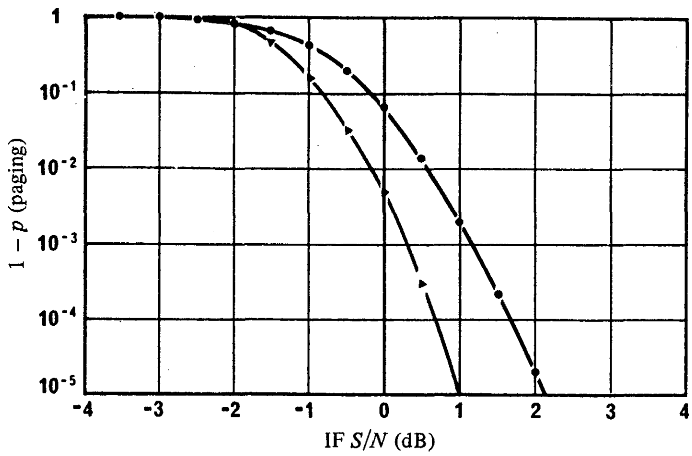


FIGURE 3 – *Paging failure rate, for a pager moving in a Gaussian channel*

—•— POCSAG
—◂— GSC

8. 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).

[1982-86]: **a.** 8/417 (Sweden); **b.** 8/112 and 8/113 (USA); **c.** 8/446 (Italy); **d.** 8/375 (USA); **e.** 8/447 (United Kingdom); **f.** 8/295 (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.

ANNEX I

GOLAY SEQUENTIAL CODE

1. Introduction

Golay paging codes are those codes that use as their basis a binary code discovered by Marcel Golay. The basic code has 23 bits, 12 of which are information bits. This code is used in a binary paging format generally characterized by 300 baud NRZ data. The original Golay code, in service since 1973, has an uncoded preamble and supports up to 400 000 individul pager addresses; it is briefly described in § 2.5. Subsequently, the Golay paging format was expanded to include data and a coded preamble, and it is entitled the Golay sequential code (GSC). The GSC code supports up to 4 million addresses and is compatible with the older Golay paging code under certain address restrictions. Some forms of GSC support voice operation also but are not discussed in this Annex.

2. Signalling format

The GSC code format allows paging calls to be transmitted individually or in batches. Transmission begins with a preamble followed by a start code and a single address or a batch of addresses as illustrated in Fig. 4. The polarity of the preamble identifies the transmission mode (single call or batch). The preamble also serves to divide the population of pagers within the system into groups for improved battery life, as well as to uniquely identify GSC transmissions. The start code delimits the end of the preamble and supplies timing information for batch mode decoding, and the address identifies the individual pager.

In the implementation of the code, a positive frequency shift represents a binary "1", and a negative frequency shift represents a binary "0".

2.1 *Batch operation*

The batch transmission format, as shown in Fig. 4, begins with an inverted preamble followed by the start code and up to 16 pager addresses or data blocks. The arriving paging requests should be grouped as a function of preamble code and transmitted on a time or traffic basis as required for the system.

Unfilled batches should be filled out with comma (see § 2.3). A new preamble batch, however, may be initiated after 11 addresses of the preceding batch have been transmitted or 3.85 s has elapsed since the start of the preceding batch. In message paging, a message (not an address) may be started at the 17th address block or before and may be continued until completion.

2.2 *Extended batch*

As defined herein, a preamble and start code must be transmitted with each additional 16, or equivalent, addresses sent. This differs from some Golay implementations which allow batch extension through the use of start code repeat only.

2.3 *Preamble, start code, and address structure*

The preamble, start code, and address codes are constructed from words selected from the Golay (23 : 12) cyclic code and transmitted at 300 bit/s.

A 1, 0 bit reversal pattern or comma transmitted at 600 bit/s acts as a separator between preamble, start code, and address. One comma bit is half the length of an address bit and identical in length to a message or data bit.

2.3.1 *Preamble structure*

The preamble as shown in Fig. 4 consists of 28 bits of comma followed by 18 repeats of the selected preamble word (ten preambles divide the population of pagers into battery saver groups). The starting polarity of the comma must be the same as the first bit of preamble. As previously noted, an inversion or complement of the preamble and its associated comma bits identifies the batch mode of transmission. The normal polarity of the preamble words is tabulated in Table V (least significant bit (LSB) to the right), and the preamble words are transmitted LSB first. The decimal representation of the information binary bit pattern is tabulated in column 2 of Table V.

TABLE V – *Preamble words*

Preamble number	Decimal	Binary bit pattern	
		Parity	Information
0	2030	10000000011	011111101110
1	1628	00001111110	011001011100
2	3198	11000001001	110001111110
3	647	01111111000	001010000111
4	191	00001111010	000010111111
5	3315	00000111001	110011110011
6	1949	00011110000	011110011101
7	2540	01000001111	100111101100
8	1560	01111111001	011000011000
9	2335	11100010001	100100011111

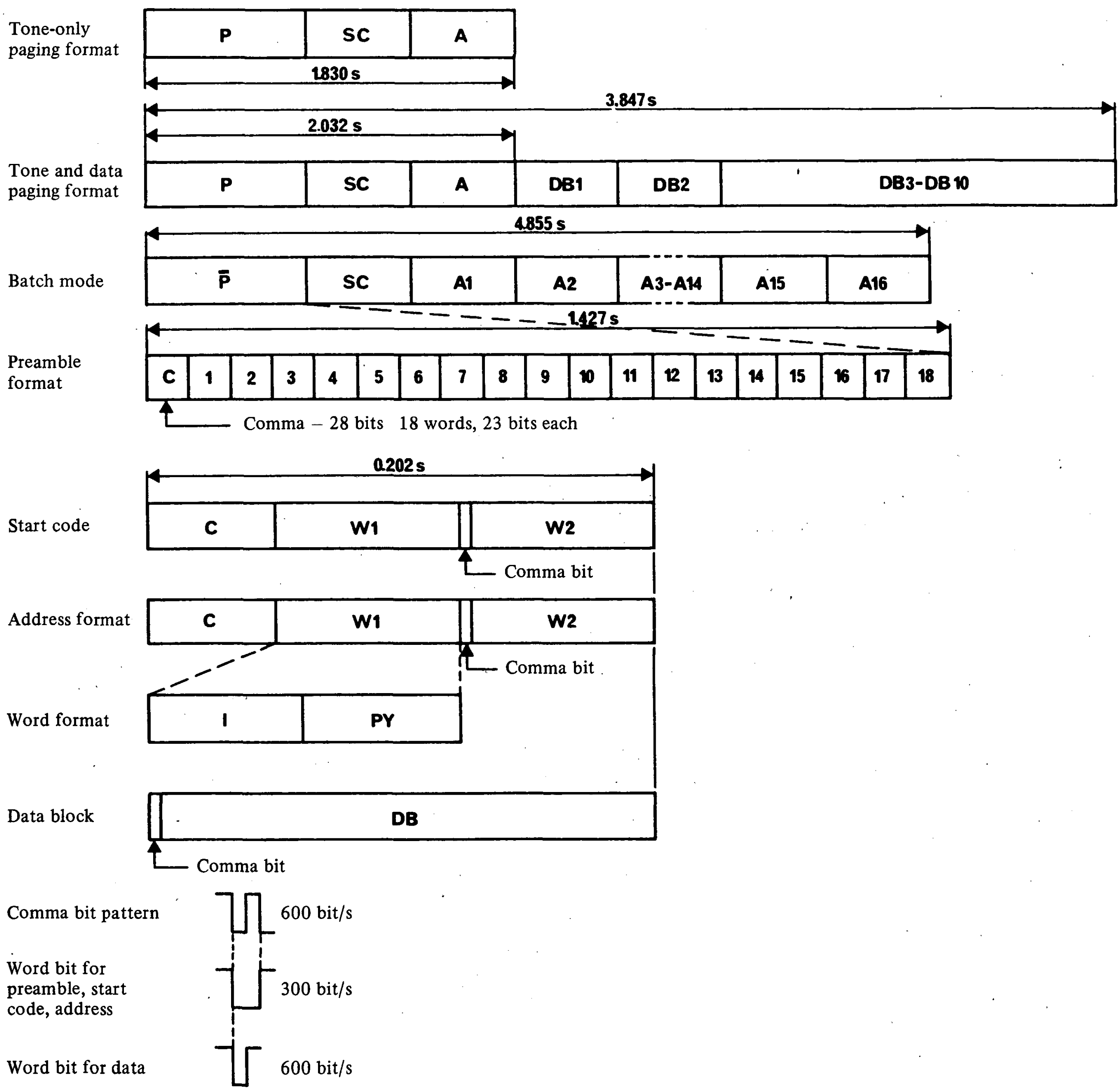


FIGURE 4 – *Golay sequential code format*

P : preamble
SC : start code
A : address
DB : data block (8 (15 : 7) BCH code words)
C : comma – 28 bits
W1 : start code or address word 1-23 bits
W2 : start code or address word 2-23 bits
I : information – 12 bits
PY : parity – 11 bits

2.3.2 *Start code*

The start code and address codes use a two-word format consisting of 28 bits of comma followed by two (23 : 12) code words separated by one comma bit. The starting polarity of the 28 bit comma must be the same as the first bit of the first word and the polarity of the single comma bit between words must be opposite to that of the second word. The start code is fixed for the system, and its Word 2 is the complement of its Word 1. The start code Word 1 is:

Start code	Decimal	Binary bit pattern	
		Parity	Information
Word 1	713	01000000011	001011001001

The start code format permits the pager's decoding circuitry to detect either the start code Word 1 or Word 2 and identify which pattern was detected, thus maximizing start code detection sensitivity.

2.3.3 *Address code*

The address format is identical to the start code format with regard to the number of bits and the rules for comma. The address Word 2 code set consists of all (23 : 12) code words except for all 0's, all 1's, and all cyclic rotations of the start code. Thus, there are approximately 4000 Word 2's. There are 100 first words (50 words and their complements) used in the GSC system. Fifty words are determined by table look-up (Table VI), and the remaining 50 are achieved by complementing the tabulated words. The Word 1 and Word 2 code words for each pager address may be derived from the pager code (see § 3).

TABLE VI – *Address Words 1's*

Word No.	Decimal	Word No.	Decimal	Word No.	Decimal	Word No.	Decimal	Word No.	Decimal
00	721	10	2692	20	2285	30	375	40	1575
01	2731	11	696	21	2608	31	1232	41	3463
02	2952	12	1667	22	899	32	2824	42	3152
03	1387	13	3800	23	3684	33	1840	43	2572
04	1578	14	3552	24	3129	34	408	44	1252
05	1708	15	3424	25	2124	35	3127	45	2592
06	2650	16	1384	26	1287	36	3387	46	1552
07	1747	17	3595	27	2616	37	882	47	835
08	2580	18	876	28	1647	38	3468	48	1440
09	1376	19	3124	29	3216	39	3267	49	160

2.3.4 *Multi-function address capability*

The two-word format of the GSC address code contains a built-in multi-function capability. There are four possible Word 1/Word 2 combinations that can be easily detected (see § 3.3). These combinations are used to designate the type of page (tone-only or data). Each pager in the GSC system is assigned at least one four-function address.

2.4 *Code word generation 23 : 12 Golay*

To generate the binary bit patterns for the (23 : 12) Golay code, the decimal representation of the code word is converted to binary. This binary representation is rewritten LSB to the left. These 12 information bits (there may be leading or trailing 0's) now correspond to the coefficients of a polynominal having terms from x^{22} down to x^{11}. This polynominal is divided, modulo 2, by the generator polynominal $x^{11} + x^9 + x^7 + x^6 + x^5 + x + 1$. The parity bits correspond to the coefficients of the terms from x^{10} 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 parity bits, corresponds to the coefficients of a polynominal which is integrally divisible in modulo 2 fashion by the generator polynominal.

2.5 *Non-battery saver operation*

The older Golay format was based on decoding of the address words independently of any preamble or start code information. This non-battery saver operation is the simplest transmission mode and achieves the highest throughput; however, this form of operation reduces pager battery life and lacks address expansion.

In non-battery saver operation, the coded preamble and start code are not used; only the pager addresses need to be transmitted for tone only paging. However, it is suggested that a preamble consisting of a 1, 1, 0, 0 pattern (75 Hz square wave) be transmitted for at least 1.25 s after transmitter turn-on. Following the simple 75 Hz preamble, any number of consecutive paging calls may be transmitted. Any of the standard preambles can be used in place of the 75 Hz preamble.

When older Golay pagers and GSC pagers are mixed in a system, the address (Word 1, Word 2 combination) independent of the preamble must not be repeated, as is allowed in GSC only systems. Data pagers are also allowed in non-battery saver systems.

2.6 *Data paging*

A data paging consists of a pager address followed by one or more data blocks of alphanumeric characters. A data block is identical in length to an address block and may be freely substituted for addresses in the batch operating mode. The single call mode can also be used by following the pager address with the data message. Data information is transmitted at 600 bit/s using a (15 : 7) BCH code.

2.6.1 *Data block definition*

A data block consists of 8 BCH (15 : 7) code words. The data block structure is defined in Fig. 5; each block consists of 56 information bits and 64 parity bits. A single comma bit opposite in polarity to the first data bit transmitted is added at the start of each message block to make the data block identical in length to an address block.

Transmission on the channel starts with the comma bit followed by the least significant bit (LSB) of Word 1, then the LSB of Word 2 ... LSB of Word 8 then jumps back to the second bit of Word 1, etc. Assembling the data block code words by rows and then transmitting on the channel by columns protects against burst errors.

The method for embedding the information into the data block is shown in Fig. 5. One bit of the data block is used as a continue bit, and 7 bits are used for a block check character to minimize undetected message errors. The continue bit has been assigned the following meaning: a "1" indicates additional data blocks to follows, and a "0" indicates the end of message.

For ease in implementing the block check character, the 7 information words of 7 bits each of each (15 : 7) code word are added together (arithmetically), and the least significant 7 bits of the sum form the block check character.

Partially filled message blocks should be filled out with NULL characters.

2.6.2 *Symbol assignment*

The character sets for use in the numeric and alphanumeric systems are defined in Table VII. In the numeric system, information is assigned on the basis of 4 bits per symbol, and in an alphanumeric system, 6 bits per symbol are used. The numeric set includes the numeric digits (0-9), as well as all necessary control and punctuation characters. The shifted numeric set allows certain alphanumeric designators to be inserted within the numeric data. The alphanumeric set is a slight variation of the ASCII or ISO international 7 bit code with bit number 6 set equal to 1 and not transmitted. Modifications are made to this basic set only to allow insertion of the needed control characters. It is expected that the pagers themselves will display the lower case alphas as upper case alphas.

	Parity								Information						
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1 (First bit)
1									2	2	2	1	1	1	1
2									4	4	3	3	3	3	2
3									6	5	5	5	5	4	4
4									7	7	7	7	6	6	6
5									9	9	9	8	8	8	8
6									11	11	10	10	10	10	9
7									C (Continue bit)	12	12	12	12	11	11
8 (Check sum)									S	S	S	S	S	S	S

12 character numeric data block

	Parity								Information						
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1 (First bit)
1									2	1	1	1	1	1	1
2									3	3	2	2	2	2	2
3									4	4	4	3	3	3	3
4									5	5	5	5	4	4	4
5									6	6	6	6	6	5	5
6									7	7	7	7	7	7	6
7									C (Continue bit)	8	8	8	8	8	8
8 (Check sum)									S	S	S	S	S	S	S

8 character alphanumeric data block

FIGURE 5 – *Data block structure*

TABLE VII – *Numeric and alphanumeric character assignments*

Alphanumeric set						Unshifted (basic) numeric set	Shifted numeric set
	7	0	0	1	1	No applicable	No applicable
Bits (1)	5	0	1	0	1	No applicable	No applicable
4 3 2 1							
0 0 0 0		Space	0	\	p	0	A
0 0 0 1		!	1	a	q	1	B
0 0 1 0		"	2	b	r	2	C
0 0 1 1		#	3	c	s	3	D
0 1 0 0		$	4	d	t	4	E
0 1 0 1		%	5	e	u	5	Space
0 1 1 0		&	6	f	v	6	F
0 1 1 1		'	7	g	w	7	G
1 0 0 0		(	8	h	x	8	H
1 0 0 1		)	9	i	y	9	J
1 0 1 0		*	:	j	z	Null	Null
1 0 1 1		+	;	k	{	U	L
1 1 0 0		,	<	l	CR/LF	Space	N
1 1 0 1		–	=	m	}	–	P
1 1 1 0		.	>	n	Null/EOM	≡	R
1 1 1 1		/	?	o	Spare	Shift or (E) (2)	Spare

(1) Bit No. 6 never sent.
(2) (E) is displayed by pagers not employing the shifted numeric set.

2.6.3 *Number of data blocks per message*

It is sugggested that numeric messages be limited to 2 data blocks (24 characters) and that alphanumeric messages be limited to 80 characters or 10 data blocks. A data message may follow the last address in a 16 address batch transmission and may be continued until completion.

2.6.4 *Code word generation (15 : 7) BCH code*

The generator polynominal for the (15 : 7) code is $x^8 + x^7 + x^6 + x^4 + 1$. The parity information for this code is calculated in the same fashion as was done for the (23 : 12) code. The information bit pattern is divided by the generator polynominal, modulo 2 and the parity bits are the remainder from this division.

3. Pager code structure

The pager code is a six-digit decimal number followed by a series of function digits from which the address Word 1, Word 2 and preamble information can be derived. The pager code digits are defined as follows:

I	G1 G0	A2 A1 A0	f
Preamble index	Group	Address	Function digits

The range of assigned codes is 00001 ⩽ G1 G0 A2 A1 A0 ⩽ 99999. The sixth digit (I) is used to expand the number of address codes from 100 000 to 1 000 000. The range of the preamble index is 0 ⩽ I ⩽ 9. If the letter N is used in place of the preamble index number, non-battery saver operation is specified. The function digits indicate which address functions are active for any particular pager and what type of page is represented by each function. Up to four function digits may be assigned to each pager code. In the basic large system code plan, at least one pager code is assigned per pager in a sequential fashion starting with 000001.

3.1 *Algorithm for obtaining the preamble, Word 1 and Word 2 information from the pager code*

In order to transmit a page to any pager, the preamble, Word 1 and Word 2 information must be derived from the pager code. To obtain this information, follow the flow diagram outlined in Fig. 6. For example, the preamble, Word 1, and Word 2 information for the pager code 954853 is as follows:

- the preamble number = 3 (see Table V);
- the Word 1 number = 4 (see Table VI);
- the Word 2 decimal = 1753. Convert 1753 to binary and calculate the parity information obtaining the following:

Decimal	Parity	Information
1753	00010101101 -	011011011001

The actual polarity of the transmitted bit patterns is determined by the function digit discussed in § 1.3 and whether the single call or batch transmission mode is to be used.

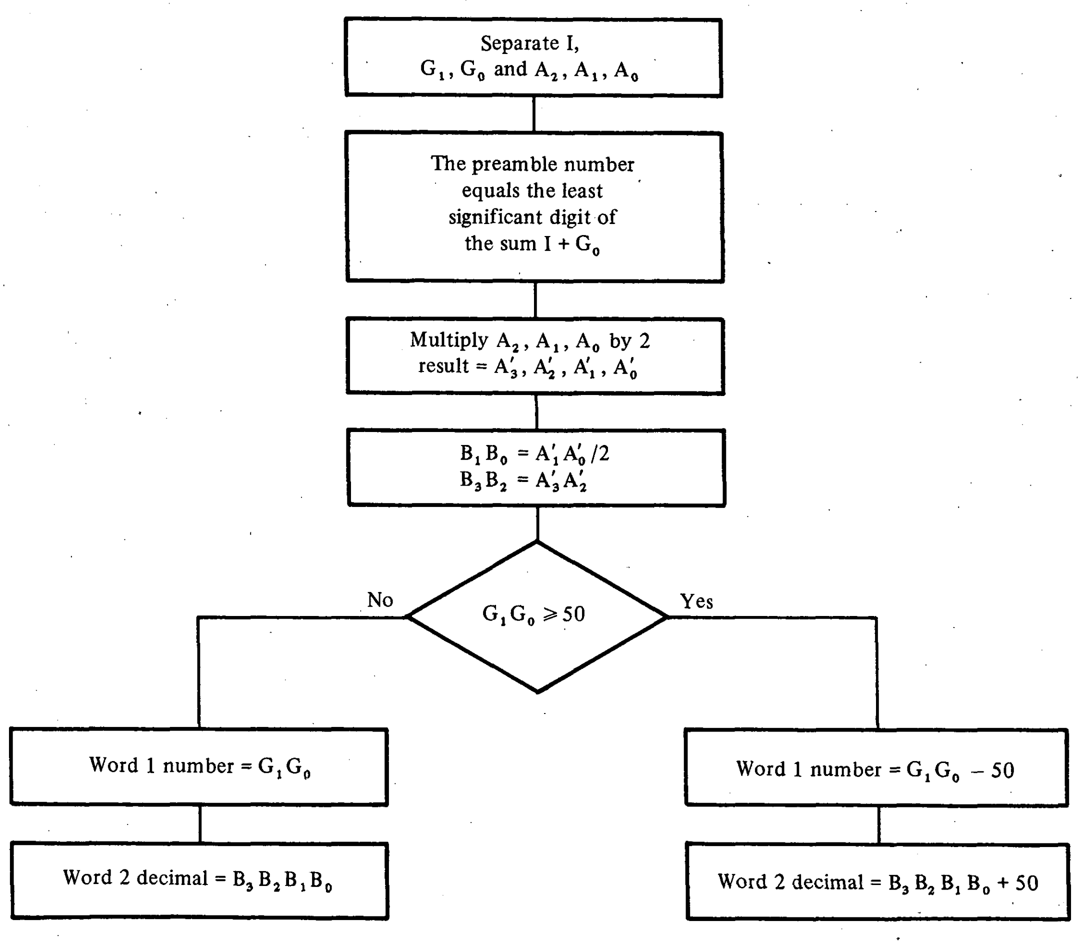


FIGURE 6 – *Algorithm for obtaining preamble, Word 1 and Word 2 information from the pager code*

3.2 *Pager code restrictions*

Since the start code is included within the range of address Word 2's, some assignable pager codes must be eliminated to prevent a false start code detection. These illegal codes are listed in Table VIII.

TABLE VIII – *Illegal pager codes*

If G_1 G_0 equals	Then do not allow A_2 A_1 A_0 to equal
00-49	000, 025, 051, 103, 206, 340, 363, 412, 445, 530, 642, 726, 782, 810, 825, 877
50-99	000, 292, 425, 584, 631, 841, 851

3.3 *Function digit assignment*

The GSC code allows four functions to be assigned to each independent pager address. In turn, each address function may be assigned independently to 1 of 2 page types (tone only or data). The f digit suffix is a means for making this assignment. Table IX relates address function (Word 1 and 2 polarity) with page type and function digit.

TABLE IX – *Function assignment (non-voice)*

Address function	Binary word format	Function suffix (f)	
		If page type is data, f =	If page type is tone only, f =
1	W1 W2	5	9
2	W1 $\overline{\text{W2}}$	6	0
3	$\overline{\text{W1}}$ W2	7	3
4	$\overline{\text{W1}}$ $\overline{\text{W2}}$	8	4

ANNEX II

RADIO PAGING USING THE RADIO DATA SYSTEM (RDS) ON FM BROADCAST TRANSMITTERS

1. Introduction

This Annex describes the additional characteristics of the radio data system (RDS) as defined in Recommendation 643 when it is used to combine FM broadcasting with radio paging.

2. Modulation and baseband coding [EBU, 1984; Swedish Telecommunications Administration, 1976]

The modulation of the data channel and the baseband coding including message format are in accordance with Recommendation 643.

3. **Additional characteristics for paging** [EBU, 1984; Swedish Telecommunications Administration, 1976]

3.1 *General*

3.1.1 Group type 4A, clock-time and date (CT), is transmitted at the start of every minute.

3.1.2 Group type 1A, programme-item number (PIN), is transmitted at least once per second. The five last bits of its block 2 (spare bits) are used as follows:

– bits B4-B2 : 3-bit transmitter network group designation;

– bits B1-B0 : battery saving interval synchronization and identification.

3.1.3 Group type 7A is used to convey the paging information.

3.2 *Transmitter network group designation*

The first three bits of the five spare bits of block 2 of group type 1A are used to designate the transmitter network to a group of pager group codes. Pagers not belonging to the designated group codes must not lock to the transmitter.

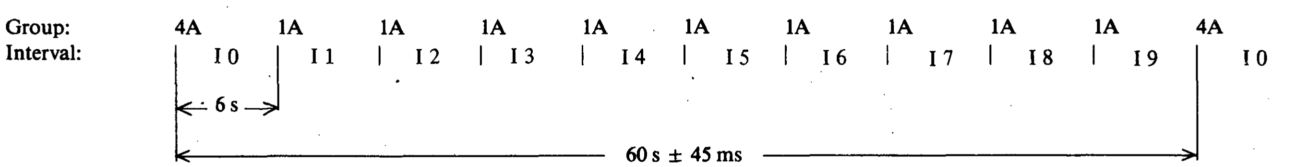
The group designations are as follows:

B4	B3	B2	Group codes	Number of group codes
0	0	0	No paging on channel	
0	0	1	00-99	100
0	1	0	00-39	40
0	1	1	40-99	60
1	0	0	40-69	30
1	0	1	70-99	30
1	1	0	00-19	20
1	1	1	20-39	20

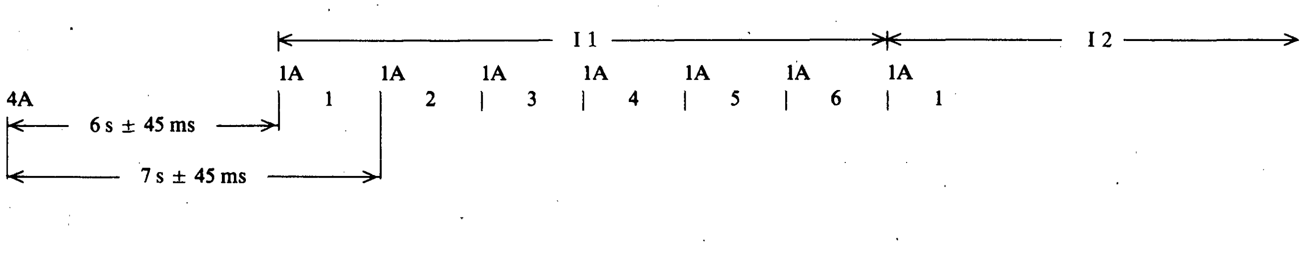
The transmitter network group designation makes it possible to distribute the paging calls over one to four networks, e.g. several networks during day-time and a single network during night-time. The number of group codes in each network are shown below for the different number of networks in operation.

Number of transmitter networks	Number of group codes respectively
1	100
2	40/60
3	40/30/30
4	20/20/30/30

3.3 *Transmission sequence (battery saving)*



Timing within intervals:



1A number within interval	1	2	3	4	5	6	1
Bit B1	1	1	0	0	0	0	1
Bit B0	0	J3	J2	J1	J0	1	0

For battery saving purposes, each minute is divided into 10 intervals of equal length (I 0 ... I 9). Each paging receiver belongs to the interval corresponding to the last digit of its individual code (digit 0 belongs to I 0 and so on). Paging calls are placed within the interval corresponding to the last digit or within the two intervals following that interval.

To enable the receivers to synchronize to the correct interval, the last two bits, B1 and B0, of the spare bits of block 2 of group type 1A are used. The start of an interval is indicated by the transmission of two 1A groups with B1 = 1 (in interval I 0 the first IA group is replaced by 4A). The first 1A (or 4A for I 0) group is transmitted at the start interval and the other 1 s later. Accuracy is ± 45 ms in relation to the medium time of the preceding 4A group. Within an interval at least 3 more 1A groups are transmitted (bit B1 = 0). Bit B0 of 1A groups number 2, 3, 4 and 5 is used to sequentially transmit the four bits J3 J2 J1 J0 of the BCD-coded interval number 0 ... 9. Excessive 1A groups within an interval have their bit B0 = 1.

The receiver may enter battery saving mode after start of its interval:

- if at least 10 groups differing from group type 7A have been received, or
- if a paging call, belonging to an interval different from the receivers' own and the two preceding intervals, has been received, or
- after the start of the third interval after its own interval.

The receiver shall be considered to have lost its interval synchronization:

- if there is a paging call within the receivers' own interval to a receiver not belonging to the interval or the two preceding intervals, or
- if an error-free reception of the interval marking (J3 J2 J1 J0) is not the one expected.

(Checking of J3 J2 J1 J0 is not necessary each time the receiver leaves battery saving mode.)

3.4 *Locking to a channel*

3.4.1 The receiver searches for one of the offset words A ... D. When this is found, it searches for the next expected offset word at a distance of $n \times 26$ bits, $n = 1 \ldots 6$. When two offset words have been found, the receiver is synchronized to both block and group.

After block and group synchronization, the receiver must find the correct country code (within the PI-code) and group designation of the transmitter network.

3.4.2 When scanning the frequency band, block and group synchronization must occur within 1 s and correct country code and group designation must be found within 2 s after block and group synchronization. Otherwise the receiver must leave the channel.

3.4.3 When locking to the channel after battery saving mode, block and group synchronization and the reception of correct country code and transmitter group designation must occur within 15 s. Otherwise the receiver shall leave the channel.

3.4.4 For quick scanning, the information about alternative frequencies in group type 0A may be used.

3.5 *Loss of synchronization*

3.5.1 Clockslip may be detected by using the fact that the program identification (PI) code is very seldom altered. By calculating the syndrome for this block and the block shifted plus/minus one bit, it is possible to see whether clockslip has occurred. If the information becomes correct after a one bit shift, it is considered that a clockslip has occurred, all received data is shifted accordingly and the receiver is correctly synchronized.

3.5.2 When 43 out of the last received 45 blocks have a syndrome different from zero (for the respective offset words), the channel locking is lost and the reeiver shall scan the band for a better channel.

3.5.3 If the group code of the receiver is no longer in accordance with the transmitter group designation code, the receiver shall leave the channel and scan the band for a new channel.

3.6 *Group type 7A message format*

3.6.1 *General*

Group type 7A:

Block 1	Block 2	Block 3	Block 4
PI ***	TP PTY ***	Paging ***	Paging ***
Offset A	Offset B	Offset C	Offset D

Block 2 bit map:

0 1 1 1 :	0	TP	PTY	AB : T3 T2 T1 T0	*Checkword*
7	A	Paging A/B		Text segment address code	

Block 1 comprises the PI code found as the first block of every RDS group type. Blocks 3 and 4 are used for paging information.

In block 2 the five last bits are used to control the paging information. Bit AB, paging A/B, is used as a flag which changes its value between different paging calls thus indicating the start of a new call. Bits T3-T0 are used as a 4-bit text segment address code and to indicate the type of additional message that follows:

T3	T2	T1	T0	
0	0	0	0	no additional message,
0	0	1	X	10 digit numeric message
0	1	X	X	18digit numeric message
1	X	X	X	alphanumeric message

X indicates state 0 or 1.

3.6.2 *Paging without additional message*

Group type 7A:

Block 1	Block 2	Block 3	Block 4	
PI ***	7A TP PTY ***	Y1Y2 Z1Z2 ***	Z3Z4	n.u. ***

Block 2 bit map:

0 1 1 1 :	0	TP	PTY	AB : 0 0 0 0	*Checkword*
7	A	Paging A/B		Text segment address code	

Text segment address code: 0 0 0 0

Y1Y2	denote the group code
Z1-Z4	denote the individual code within the group
Yn and Zn	denote BCD-coded digits 0 . . . 9
n.u.	8 last bits of block 4 not used.

3.6.3 *Paging with additional numeric message*

The additional numeric message is transmitted in 1 or 2 7A groups following the first 7A group of the call. Other group types may be transmitted in between:

Other group types	7A group 1	Other group types	7A group 2	Other group types	7A group 3

Third 7A group only transmitted in case of an 18 digit message.

7A group 1:

PI ***	7A TP PTY ***	Y1Y2 Z1Z2 ***	Z3Z4 A1A2 ***

7A group 2:

PI ***	7A TP PTY ***	A3A4 A5A6 ***	A7A8A9A10 ***

7A group 3 (only with 18 digit message):

PI ***	7A TP PTY ***	A11A12A13A14 ***	A15A16A17A18***

Block 2 bit map:

0	1	1	1 :	0	TP	PTY	AB : T3	T2	T1	T0	*Checkword*
7				A	Paging A/B		Text segment address code				

The text segment address code is used to indicate the contents of blocks 3 and 4 in respective groups:

T3	T2	T1	T0	Contents of blocks 3 and 4
				10 digit message:
0	0	1	0	Group and individual code Y1Y2 Z1-Z4 plus message digits A1-A2.
0	0	1	1	Message digits A3-A10.
				18 digit message:
0	1	0	0	Group and individual code Y1Y2 Z1-Z4 plus message digits A1-A2.
0	1	0	1	Message digits A3-A10.
0	1	1	0	Message digits A11-A18.

Y1Y2 denote the group code

Z1-Z4 denote the individual code within the group

Yn and Zn denote BCD-coded digits 0 . . . 9.

A1-A18 denote the numeric message.

An denotes a binary coded hexadecimal digit 0 . . . A.

Hexadecimal A is used to indicate a blank position in the message.

– A new call is marked by the altering of the "paging A/B" flag.

3.6.4 *Paging with additional alphanumeric message*

The additional message is transmitted in consecutive 7A groups. Other group types may be transmitted in between:

Other group types	7A group 1	Other group types	7A group 2	Other group types	7A group 3	... etc.

7A group 1:

PI ***	7A TP PTY ***	Y1Y2 Z1Z2 ***	Z3Z4	n.u. ***

Following 7A groups:

PI ***	7A TP PTY ***	Cm−Cm+1 ***	Cm+2−Cm+3 ***

Each of the groups contains 4 characters coded in 8 bits each.

Block 2 bit map:

0 1 1 1 :	0	TP	PTY	AB :	T3 T2 T1 T0	*Checkword*
7	A	Paging A/B			Text segment address code	

The text segment address code is used to indicate the contents of blocks 3 and 4 in respective groups:

T3	T2	T1	T0	Contents of blocks 3 and 4
1	0	0	0	Group and individual code Y1Y2 Z1-Z4.
1	0	0	1	Message characters Cn − Cn + 3.
1	0	1	0	Message characters Cn + 4 − Cn + 7.
1	0	1	1	Message characters Cn + 8 − Cn + 11.
1	1	0	0	Message characters Cn + 12 − Cn + 15.
1	1	0	1	Message characters Cn + 16 − Cn + 19.
1	1	1	0	Message characters Cn + 20 − Cn + 23.
1	1	1	1	End of alphanumeric message.

Text segment address code is repeated cyclically 1001 ... 1110 for every 24 characters of the message transmitted (n is increased by 24 for each cycle).

End of message is indicated by the transmission of text segment address code 1111 or a new call (indicated by the altering of the "paging A/B" flag).

Maximum length of message is 80 characters.

Y1Y2	denote the group code
Z1-Z4	denote the individual code within the group
Yn and Zn	denote BCD-coded digits 0 ... 9.
Cn	denotes a message character coded in 8 bits.
n.u.	8 last bits of block 4 of Group 1 not used.

REFERENCES

EBU [1984] Specifications of the radio data system RDS for VHF/FM sound broadcasting. Doc. Tech. 3244. European Broadcasting Union, Technical Centre, Avenue Albert Lancaster 32, B-1180 Brussels, Belgium.

SWEDISH TELECOMMUNICATIONS ADMINISTRATION [1976] Specifications for paging receivers. Doc. 1301-A6943798. Swedish Telecommunications Administration, S-123 86 Farsta, Sweden.

REPORT 739-1 *

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

(Study Programme 7C/8)

(1978–1986)

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

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

where the sum $|C_1| + |C_2| + ... + |C_n|$ 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.

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* This Report should be brought to the attention of Study Group 1.

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.

Figure 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.

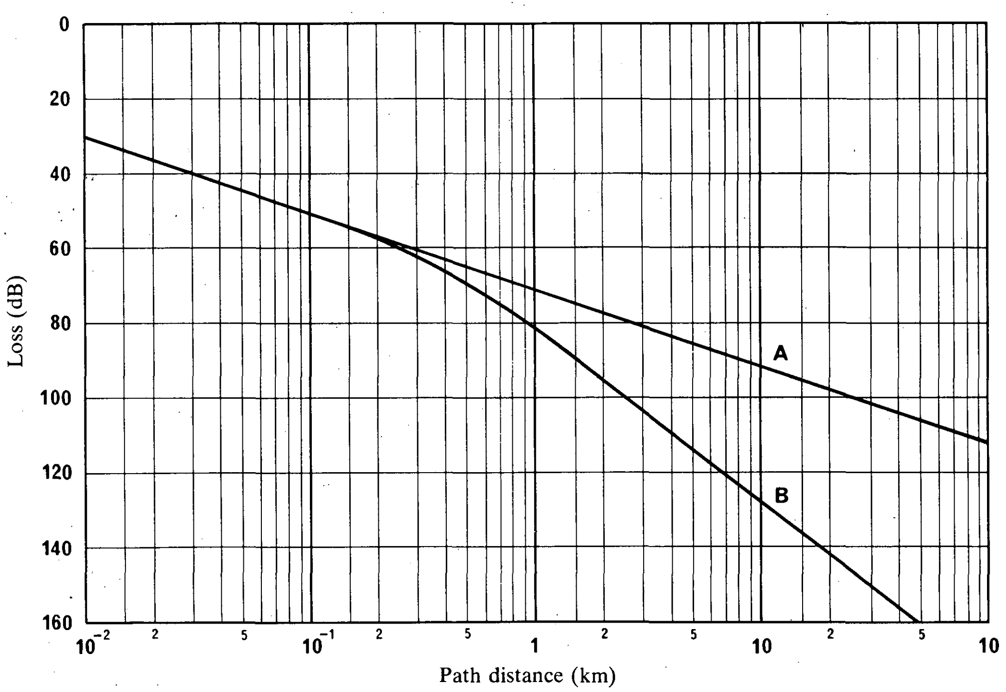

FIGURE 1 – *Short range path loss at 100 MHz ($\frac{\lambda}{2}$ dipoles assumed)*

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.

Figure 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.

When a mobile receiver is used in a multi-channel system it will be subject to an intermodulation response due to many equally spaced high level signals. The following relationship has been suggested by the People's Republic of China to relate the maximum permissible signal level with the intermodulation response rejection ratio of the receiver [CCIR, 1982-86a]:

$$E_s + 3E_M \geqslant 3E_{I\,max} + B + k(n,p)$$

where:

- E_s : wanted signal level (dB) above sensitivity;
- $E_{I\,max}$: maximum interference signal level (dB) above sensitivity;
- E_M : receiver's third-order intermodulation rejection ratio (dB) (for two signals);
- B : RF protection ratio (dB);
- $k(n,p)$: a constant dependent on the number of channels n and channel sequence p.

The derivation of this formula and the calculation of $k(n,p)$ are given in Annex I.

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.

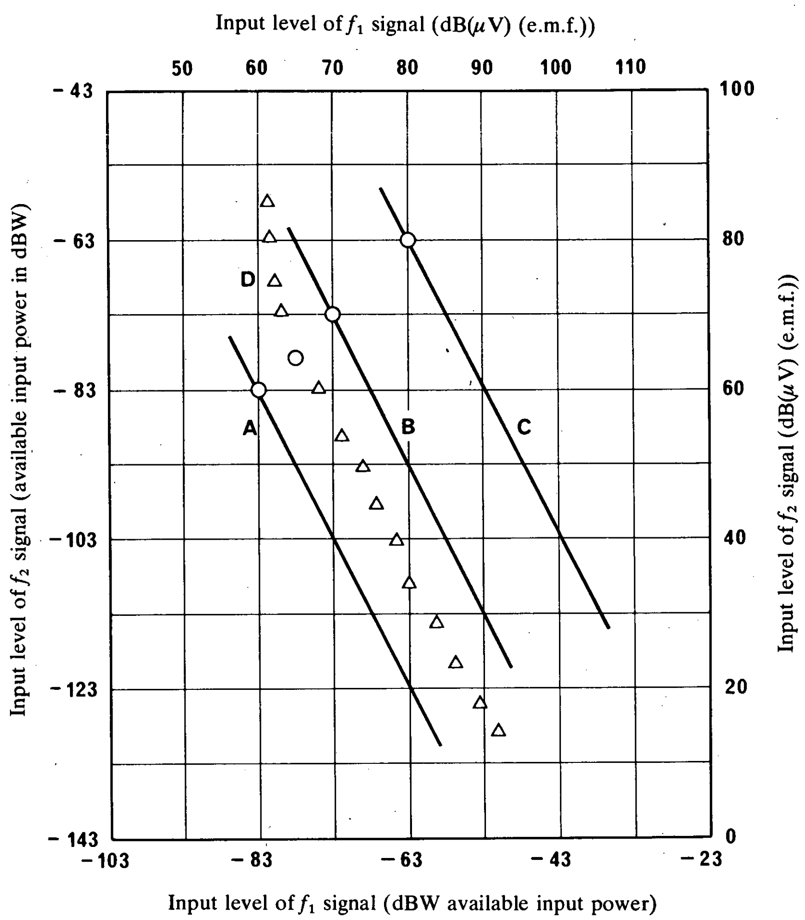

FIGURE 2 – *Receiver intermodulation characteristic*

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).

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.

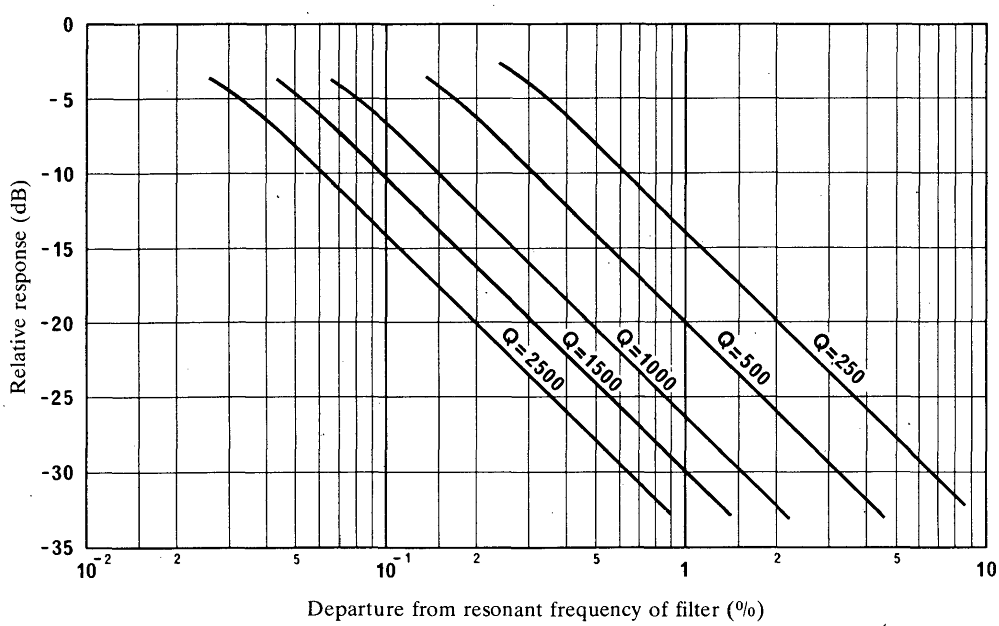

FIGURE 3 – *Theoretical response of cavity band-pass filters*

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.

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.

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	2300	250	14	0.07	1.7
C	4600	500	20	0.14	2.8
D	6900	750	24	0.21	3.3
E	9200	1000	26	0.29	3.9
F	11700	1250	28	0.37	4.6
G	13800	1500	30	0.46	5.3
H	16100	1750	32	0.53	6.8
I	18400	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	13800
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.

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CCIR Documents

[1982-86]: **a.** 8/3 China (People's Republic of).

ANNEX I

RECEIVER INTERMODULATION RESPONSE IN A MULTI-CHANNEL SYSTEM

1. Number of third-order intermodulation products in a multi-channel system

When a system consists of n channels with equal intervals and n is an even number ($n \geqslant 4$), the number of third-order intermodulation products S_p falling into each channel is shown in Fig. 4 [Morinaga, 1972] including types $2A - B$ and $A + B - C$, designated as type III-1 and type III-2 respectively. From channel 1 to channel n, each channel has $\left(\frac{n}{2} - 1\right)$ type III-1 products and the rest are type III-2 products. The type III-2 products are 6 dB above type III-1's. Since there are three unwanted signals involved, it is valid only when $n \geqslant 4$.

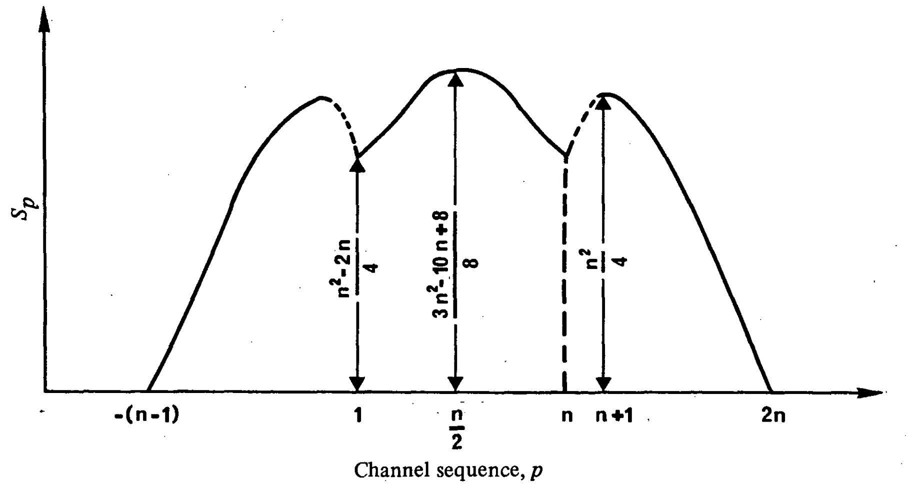

FIGURE 4

Due to the fact that $S_{p\,max}$ with an odd number of n is still equal to or less than that with an even number of n, n can be taken as an even number for the following analysis.

2. Intermodulation products in a multi-channel system

As the third-order intermodulation products are random in phase, the intermodulation product level in each channel will be $k(n,p)$ dB higher than the value of sensitivity.

For mid-channels:

$$k(n,p)_{max} = 20 \log \sqrt{\left[\frac{3n^2 - 10n + 8}{8} - \left(\frac{n}{2} - 1\right)\right] \times 2^2 + \left(\frac{n}{2} - 1\right) \times 1^2}$$

$$= 10 \log \frac{1}{2} (3n - 7)(n - 2)$$

For channels on the edge:

$$k(n,p)_{min} = 20 \log \sqrt{\left[\frac{n^2 - 2n}{4} - \left(\frac{n}{2} - 1\right)\right] \times 2^2 + \left(\frac{n}{2} - 1\right) \times 1^2}$$

$$= 10 \log \frac{1}{2} (2n - 3)(n - 2)$$

3. Influence on systems with adjacent channels

Due to the presence of the third-order intermodulation, the frequency spectrum is extended three times, so a system with n channels would influence the bandwidth for $3n$ channels.

Similarly:

$$k'(n,p)_{max} = 20 \log \sqrt{\left(\frac{n^2}{4} - \frac{n}{2}\right) \times 2^2 + \frac{n}{2} \times 1^2}$$

$$= 10 \log \frac{1}{2} n (2n - 3)$$

$$k'(n,p)_{min} = 0$$

4. If $E_{I\,max} > E_M$ (i.e. the maximum interference signal level exceeds the intermodulation rejection ratio), the third-order intermodulation products level (in dB) will increase by $3\,(E_{I\,max} - E_M)$. So the level of the intermodulation product (E_I) will be:

$$E_I = k(n,p) + 3\,(E_{I\,max} - E_M)$$

For satisfactory system operation:

$$E_s - E_I \geqslant B$$

So:

$$E_s + 3\,E_M \geqslant 3\,E_{I\,max} + B + k(n,p)$$

REFERENCES

MORINAGA, T. [March, 1972] Mobile Communication – Theory and Design. Electronic Communication Academy of Japan, 85-91.

RECOMMENDATION 622

TECHNICAL AND OPERATIONAL CHARACTERISTICS OF ANALOGUE CELLULAR SYSTEMS FOR PUBLIC LAND MOBILE TELEPHONE USE

(Questions 37/8, 39/8)

(1986)

The CCIR,

CONSIDERING

(a) Report 740;

(b) Report 742, which gives details of a number of present analogue cellular systems;

(c) that on-going studies necessary to specify future international cellular mobile telephone systems are not yet complete;

(d) that many administrations are planning, implementing, or operating national and international mobile telephone systems which use analogue speech modulation and which have high capacity and spectrum efficiency;

(e) that a limitation of the number of different analogue cellular systems would greatly facilitate the international use of these systems and would reduce equipment cost,

UNANIMOUSLY RECOMMENDS

that the following technical and operational characteristics of cellular land mobile telephone systems should be adopted for systems intended for international or regional use:

1. General characteristics

1.1 *Operational aspects*

The following general operational aspects should apply:

- automatic setting up and charging of calls to and from the mobile station;
- the ability to set up calls between the mobile station and any fixed telephone subscriber or other mobile telephone subscriber within the system;
- fees should be charged in a manner consistent with principles of the public switched telephone network (PSTN);
- the blocking probability should be designed in a manner similar to the PSTN services;
- continuous control of call quality should be maintained, with automatic hand-over between adjacent base stations within one system if needed;
- full duplex operation;
- speech quality should be comparable to that offered in the existing analogue PSTN.

1.2 *Cellular properties*

The following general aspects should apply:

- possibility to accommodate more than one base station in a service area;
- "hand-over" from one site to another, i.e. from one radio frequency to another if necessary;
- re-use of the same RF assignment simultaneously by more than one base station and for more than one communication;
- growth: the system may be able to start with a few large cells and gradually grow until many small cells are created at points of highest traffic density.

1.3 *Service protection*

- A transmitted serial number or some similar technique should prohibit the use of stolen units or use by unauthorized callers;
- unwanted intelligible signals (cross-talk) should be avoided or suppressed;
- the introduction of means to ensure privacy of communication should not be excluded by the design.

1.4 *Services offered*

The following services should not be excluded:

- non-voice services, such as data services, etc.;
- equipment mounted in any vehicle;
- hand-held equipment;
- other enhancements consistent with the mobile service, such as abbreviated dialling, etc.

2. Technical characteristics

2.1 *Radio cell configuration*

The radio cell configuration should be determined by thermal and environmental noise performance, co-channel interference, the typical multipath (Rayleigh) fading of mobile channels, terrain variability, the antenna patterns selected, and the service quality desired.

2.2 *Control channel configuration*

2.2.1 *Control channel usage:* the following two methods are permissible:

- the exchange of control signals over channels which can also be used as communication channels;
- the provision of channels dedicated either to control or communication but not both.

Both methods reduce the total traffic capacity of the system; the choice between the above methods depends primarily on the amount of signalling traffic.

2.2.2 *Seizure:* multiple seizure reduction techniques such as the busy/idle status on control channels should be used to reduce the effects of collisions during attempts on the same control channel.

2.3 *Speech quality*

For an analogue system, voice processing using a 2 : 1 syllabic compandor might be employed to improve speech quality.

2.4 *Signalling reliability*

To improve signalling reliability, the following methods are preferred:

- forward error correcting coding such as BCH code;
- repeated control signal transmission;
- compelled techniques, e.g. recycle (ARQ) and repeat back techniques;
- diversity techniques.

2.5 *RF equipment characteristics*

- Employment of diversity techniques should not be precluded;
- Recommendation 478 * should apply to each frequency band employed.

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* Except that cellular systems, using exclusive frequency bands, because of their inherent separation in both frequency and space, might have relaxed adjacent-channel and spurious-emission requirements within their own bands.

3. Operational characteristics

3.1 *Call processing*

The following system functions should apply to the cellular system:

- radio channel assignment and set-up control when calls occur;
- radio channel release when calls terminate.

3.2 *Supervision*

To supervise radio channel status and to maintain necessary quality, the system shall perform one or several of the following functions:

- appropriate control channel selection and identification of the registration areas for the mobile station;
- radio cell assignment of the mobile station for origination and/or termination of calls;
- speech channel status monitoring, as appropriate;
- monitoring the proper speech channel assignments;
- speech channel quality monitoring and appropriate radio cell selection for hand-over if necessary;
- monitoring the speech channel reassignment, whenever necessary;
- proper control monitoring at termination.

3.3 *Location registration*

In accordance with Recommendation 624.

3.4 *PSTN interface*

In accordance with CCITT Recommendation Q.70.

3.5 *Numbering plan*

In accordance with CCITT Recommendation E.213.

REPORT 740-2*

GENERAL ASPECTS OF CELLULAR SYSTEMS

(Question 37/8)

(1978–1982–1986)

1. Introduction

Systems are in use for the land mobile service which utilize the frequency spectrum much more efficiently than conventional systems [Schulte and Cornell, 1960; 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.

Appropriate frequency planning permits frequencies to be used several times in a coverage area. The cellular technique can also be combined with the trunking concept (see Report 741), thereby improving spectrum utilization efficiency.

2. General system characteristics

When a mobile unit either originates or is prepared to receive a call, the cell which can best serve the unit is selected (e.g. through an algorithm resident in the logic of the mobile unit) 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.

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* This Report should be brought to the attention of Study Group 1.

The general features of a cellular system are:

- accommodation of more than one base station in a service area and thus the expansion of the service area of the system beyond the coverage that a single site provides;
- "hand-off" or transfer of the responsibility for radio coverage of a mobile or hand-held unit from one site to another, i.e. from one radio frequency to another;
- re-use of the same RF assignment simultaneously by more than one base station and for more than one message; this is the cornerstone of the *spectral utilization efficiency* of cellular systems;
- growth; that is, the system must be able to start with a few large cells and gradually grow until many small cells are created at the points of highest traffic density.

These features are essential for a complete cellular system. However, specific equipment arrangements may create systems that are "cellular compatible" (that is, inter-operable with true cellular systems) even though they do not possess all of these attributes. For reasons of economy, the base station equipment used in a small city may not permit the simultaneous existence of two cell sizes, while more sophisticated equipment used in a large city where maximum capacity is required will be fully compliant; the same mobile units will work in either area.

3. Channel re-use considerations

3.1 *General*

The rejection of co-channel interference depends solely on the carrier-to-interference (C/I) ratio and not on absolute amplitude. Since median C and median I are inversely proportional to a power of the distance from the source, the required co-channel cell spacing (called D) can be specified as some multiple of the cell radius (called R), depending on the median C/I desired.

To a good first approximation:

$$C = k/R^n, \quad I = k/D^n$$

thus:

$$C/I = \left(\frac{D}{R}\right)^n \quad \text{or} \quad D = R\left(\frac{C}{I}\right)^{1/n}$$

Reducing D and R in proportion 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 beyond usable limits, unless other techniques, such as diversity [Lundquist and Peritsky, 1971] and power control [US Advisory Committee, 1967] are used. The re-use distance must be large enough to give an acceptably low probability of co-channel interference as a result of 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 service.

The re-use ratio D/R is related to number of channel sets n by:

$$D/R = \sqrt{3n}$$

A typical value of D/R is 4.6/1, corresponding to $n = 7$. For a regular grid of base sites packed in a hexangular grid, only certain values of n are possible: 3, 4, 7, 9, 12, 13 etc.; these correspond to evaluating:

$$n = i^2 + j^2 + ij$$

for non-negative integer values of i and j.

The system designer must decide what speech quality is required and choose the C/I objective. For example, experience in simulations, subjective tests, field trials, and early operational systems at 850 MHz indicates that a 90th percentile equal to or greater than 17 dB median C/I in an urban propagation environment will achieve a user acceptance goal of "good" or higher by the majority of telephone users [see Report 319, § 3.1.1 and 3.1.2]; systems for dispatch or private usage can be designed for a lower objective. During early growth phases when cells are relatively large and horizon effects limit interference, a 7-channel set re-use pattern is usually adequate, using conventional omnidirectional antennas; this assumes that no more than one or two interfering sites provide signals above the threshold level at any specific point in a base station's coverage area.

As growth to a more densely packed system takes place, either a larger channel re-use pattern (e.g. 12 sets) can be used, or a change-over to directional antennas for transmit and/or receive with a "sector" channel assignment pattern can be implemented. Arrangements using both 60° and 120° sectors have been designed; for a given *n* value, use of a sector assignment plan with directional antennas increases C/I by up to 5 dB (120° sectors) or 8 dB (60° sectors). In any event, the system planner should be satisfied that the *a priori* objective is exceeded in both the mobile-to-base and the base-to-mobile directions. The mobile-to-base direction is more complicated because of the random location of the potential interferers, because of the mix of vehicular and portable transmitters with different powers, and because of the building penetration loss that the portable unit can encounter.

To accommodate varying user density over the area of service, the cell plan should allow for different size cells to coexist in a system at the same growth stage. This generally means a doubling of the number of channel sets into which the allocation must be divided. Administrations should allow for this if the largest city or populated area is to grow to the divided-cell stage.

If the cellular channel plan avoids adjacent channels at the base station sites, the frequency deviation can be increased to enable closer re-use, resulting from an improved protection ratio.

Private dispatch systems which can handle traffic with a blocked-calls-queued strategy can be efficient with a smaller allocation than can mobile telephone systems.

3.2 *Co-channel interference experienced by stationary units*

Stationary units will not experience multipath fading as a loss in speech quality, resulting from rapid movement through the fading pattern, as mobile units do; rather, they will experience a very large number of points where the wanted signal has faded and the channel is unusable because of co-channel interference. In addition, shadowing will result in areas in which this problem is more severe due to a reduced local mean signal level.

The probability of co-channel interference, $P(s_1 \leqslant ps_2)$ for this case of simultaneous fading and shadowing with an uncorrelated wanted signal and a single interferer, has been calculated [French, 1979] as shown in Fig. 1.

Re-use distance ratios calculated using Fig. 1 and an inverse fourth power propagation law to give particular values of interference probability at the cell edge are shown in Table I, for protection ratios, *P*, of, for example 8 and 12 dB and shadowing standard deviations, σ, of 6 and 12 dB. Both fading and shadowing were included in the calculation.

Other values of protection ratio that may arise in particular systems should be used with Fig. 1 and the inverse power propagation law to find the corresponding re-use distances. Note that hand-off techniques may provide some diversity against fading, which would reduce the probability of call cut-off.

3.3 *Other comments*

3.3.1 It should be noted that in situations where it is intended to transmit a single message to a large number of vehicles distributed over several cells, the efficiency of frequency utilization is reduced for the duration of that message. Further studies are needed to determine the effect on spectrum efficiency of combining private and public systems.

3.3.2 Among the methods used to exchange channel control signals (channel assignment, dialling, etc.) are:

- the exchange of control signals over channels which can also be used as communication channels;
- the provision of channels dedicated either to control or communication but not both.

Both methods subtract from the total traffic capacity of the system. 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 dedicated and are capable of being divided into the sub-sets of paging channels and access channels.

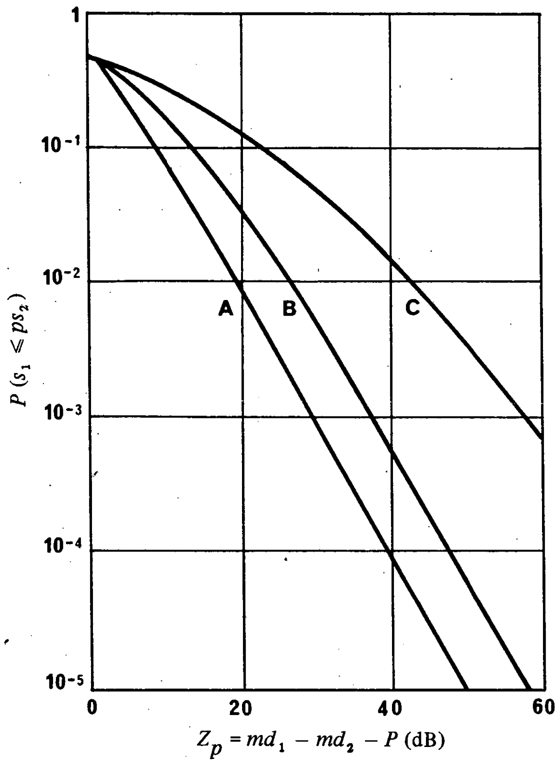


FIGURE 1 – *Probability of co-channel interference (with Rayleigh fading and log-normal shadowing)*

Curves A: σ = 0 dB
B: σ = 6 dB
C: σ = 12 dB

s_1 : wanted signal level (V)
s_2 : interfering signal (V)
p : protection ratio of modulation system
$P = 20 \log_{10} p$
md_1 : area mean level of wanted signal (dB)
md_2 : area mean level of interfering signal (dB)
σ : standard deviation of the shadowing
$Z_p = md_1 - md_2 - P$

TABLE I – *Re-use distance ratio (D/R)*

$P(s_1 \leqslant ps_2)$	σ = 6 dB		σ = 12 dB	
	P = 8 dB	P = 12 dB	P = 8 dB	P = 12 dB
0.5	2.6	3	2.6	3
0.1	4.7	5.6	7.3	8.9
0.03	6.6	8	13	16

3.3.3 If the method which provides control channels for control use only is chosen, control channel frequency assignment may be independent of communication channel cell size.

Two control channel frequency assignment methods are:

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

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

3.3.4 Control channels are subject to similar C/I constraints as communication channels. To ensure that a system is not limited by its signalling capacity, the system designer should set aside an adequate number of signalling (control) channels. Preferably, this quantity should be dynamically changeable as the system grows.

4. 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. While reception diversity at the base station is not a requirement of either a conventional or a cellular system, it can serve:

- to balance the C/I and C/N ratios in the mobile-base and base-mobile directions; and
- to improve the baseband S/N ratio for a given C/I or C/N ratio.

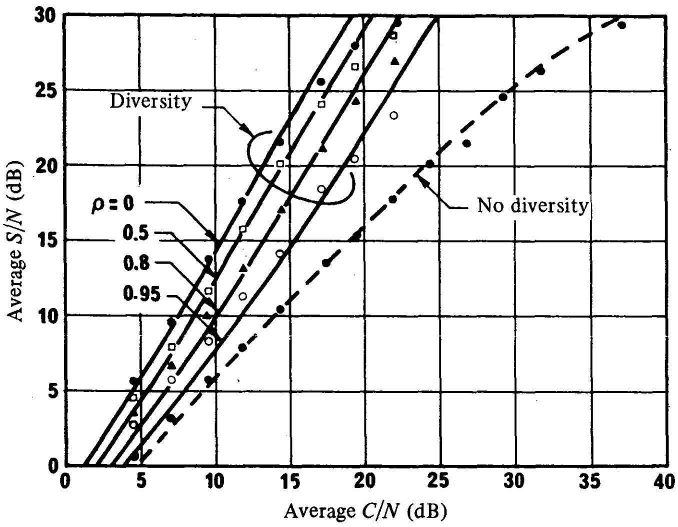
These factors are especially important for service to hand-held portables. At present, space diversity is the preferred method, currently realisable versions of frequency-diversity and time-diversity are not spectrally efficient, although research is continuing in techniques such as spread-spectrum and time-division re-transmission. The coherent combining methods (maximal ratio combining and equal-gain combining) achieve the best improvement compared with other methods. However, the equipment structure is complicated because of the requirement for a control function to ensure that the received signals are aligned in phase. In addition, the cost is high. On the other hand, the antenna switched method has a simple structure but voice quality signal suffers from switching noise and switching delay. A selection combining method with two diversity branches is more practical than two-branch coherent combining, although the former is a little inferior to the latter with respect to voice and data transmission. Switching noise generated in selecting the strongest signal level branch is reduced, and the voice signal quality is improved, by a post-detection selection combining technique. This technique is based on the selection of the baseband demodulated output of the diversity branch with the maximum reception level.

4.1 *Improved characteristics for thermal noise*

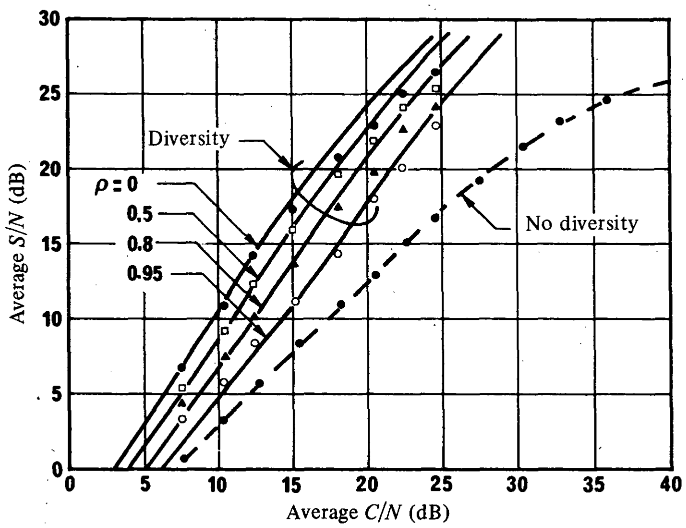
An example of experimental results [Suwa *et al.*, 1984] of thermal noise reduction in a voice signal using post-detection selection combining is shown in Fig. 2. The relative C/N is defined as the difference in average C/N required to obtain a given baseband S/N of 8 dB with diversity compared to the average C/N required to obtain that S/N without diversity. The relative C/N is more than 6 dB for an envelope correlation coefficient $\rho = 0$ and greater than 5 dB for $\rho = 0.5$.

4.2 *Improved characteristics for co-channel interference*

An example of experimental results [Suwa and Hattori, 1985] of co-channel interference reduction in voice signal using post-detection selection combining is shown in Fig. 3. The relative C/I is defined as the difference in average C/I required to obtain a given baseband S/I of 14 dB with diversity compared to the average C/I required to obtain that S/I without diversity. The relative C/I is more than 6 dB for an envelope correlation coefficient of $\rho = 0$ and greater than 5 dB for $\rho = 0.5$.



(a) B = 16 kHz



(b) B = 8 kHz

FIGURE 2 – *C/N versus S/N performance*

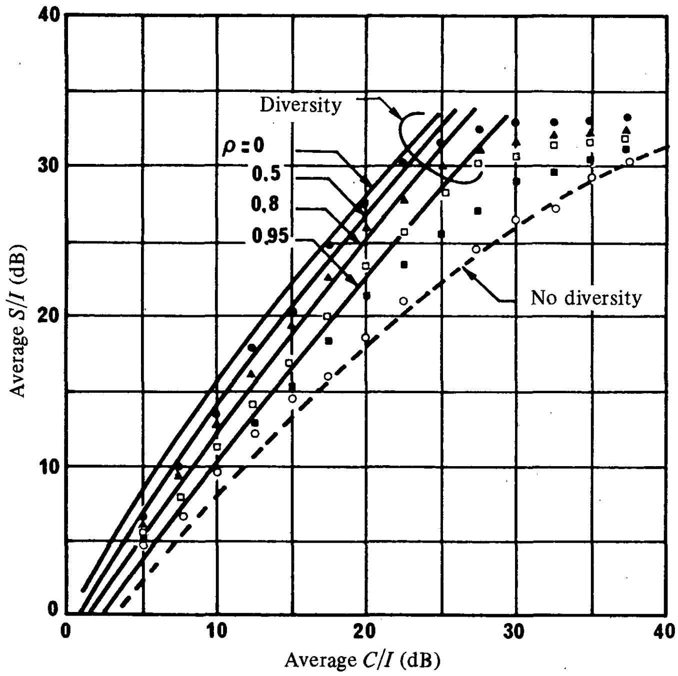
Condition:
- carrier frequency: 900 MHz band
- IF filter bandwidth B: 16 and 8 kHz
- fading rate: 34 Hz
- standard modulation level: $3.5/\sqrt{2}$ rad r.m.s. – B = 16 kHz; $1.75/\sqrt{2}$ rad r.m.s. – B = 8 kHz

Compressor reference level is set equal to standard modulation level

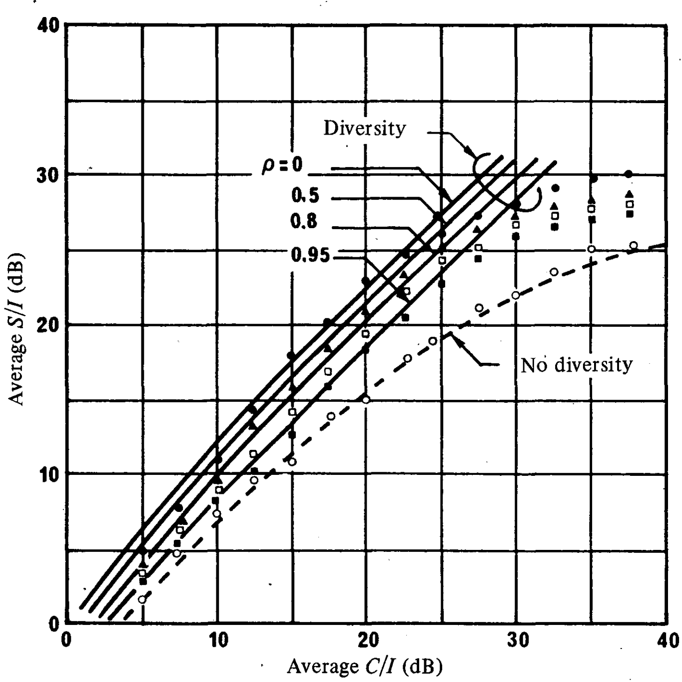
C/N is measured in 16 kHz and 8 kHz IF filter bandwidth

S/N is measured in 0.3-3 kHz baseband filter bandwidth

A 2 : 1 syllabic compandor is applied



a) B = 16 kHz



b) B = 8 kHz

FIGURE 3 – *C/I versus S/I performance*

Condition:	– carrier frequency	:	900 MHz band
	– IF filter bandwidth B	:	16 and 8 kHz
	– fading rate	:	34 Hz
	– standard modulation level:		$3.5/\sqrt{2}$ rad r.m.s. – B = 16 kHz
			$1.75/\sqrt{2}$ rad r.m.s. – B = 8 kHz

Compressor reference level is set equal to standard modulation level

C/I is measured in 16 kHz and 8 kHz IF filter bandwidth

S/I is measured in 0.3-3 kHz baseband filter bandwidth

A 2 : 1 syllabic compandor is applied

5. Coping with vehicle movement

In a cellular system, mobile detection, location and registration as well as inter-cell switching are necessary when a mobile station moves across a cell boundary to:

- limit channel switching traffic;
- maintain adequate transmission quality;
- prevent the increase of co-channel interference;
- minimize the impairment caused by channel switching.

When the signal from a mobile unit engaged in a cell becomes inadequate, 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 would have to, in general, be spaced further apart if "hand-off" is not employed than they would have to be if it is; this adversely affects spectrum efficiency. For these reasons, hand-off is considered an essential feature of all cellular systems. One appropriate method to identify the radio cell from which a moving vehicle can best be served is the field-strength level of the carrier received from the mobile unit.

Field experience indicates that the voice quality of a cellular system is no better than the system's hand-off algorithm permits it to be. Too tight a control on signal level requires more hand-offs than necessary; this

- detracts from the capacity of the controller; and
- can cause frequent distraction to the users.

Too loose control, on the other hand, permits signal statistics to remain at unnecessarily low levels for long periods, can lead to high dropped-call probabilities, and can impair co-channel calls.

Mobile location registration may preferably be retained 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 can autonomously identify itself to the new serving area via a base station in that area. This information can be communicated to the home exchange (see Recommendation 624).

6. Intermodulation interference considerations

In a high capacity mobile telephone system using cells, it is necessary that intermodulation interference be minimized. However, because of the orderly spatial organization and the hand-off capability of cellular systems and as a result of new state-of-the-art transmitter/antenna coupling and combining arrangements used in cellular systems, intra-system intermodulation interference is considered to be controllable.

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REPORT 1020

ADAPTATION OF SYSTEM SPECIFICATION TO EASE THE PRACTICAL IMPLEMENTATION OF RADIO EQUIPMENT

(Question 68/8)

(1986)

1. Introduction

Question 68/8 addresses the possibilities of adapting the technical characteristics of cellular land mobile radio systems (see Report 740) to ease their practical implementation without compromising the system performance. One of the most important system characteristics is good spectrum utilization.

Large systems, based on small-cell structures and allocated an exclusive frequency band, will be of growing importance, at present mainly for mobile telephone use but eventually also for dispatch and data services. A future mobile telephone system might also be integrated with the planned ISDN network.

In advanced cellular systems, mutual interference within the system can be reduced through suitable network arrangements, thus permitting reduced system selectivity (spurious, intermodulation, blocking) with marginal impact on the overall system performance. New technologies such as digital speech transmission and time divided usage of wide-band radio channels (TDMA, packet transmission and time duplex) could be used in new system configurations with improved performance in comparison with present analogue narrow-band systems. Potential improvements are in spectrum economy, transmission quality, new services and ease of implementation.

Small portable terminals will probably be of rapidly growing importance if cost and size can be made attractive for a mass market. It is therefore very desirable that the system specification and configuration ease the implementation of small, inexpensive terminals. The combination of digital transmission, reduced system selectivity and wide-band radio channels could make this possible.

Most of the material in this Report has been presented in more detail in four contributions to the Nordic Seminar on Digital Land Mobile Radiocommunication in Finland, February, 1985 organized by the Telecommunication Administrations of Denmark, Finland, Norway and Sweden [Öhrvik, 1985; Stjernvall, 1985; Ekemark *et al.*, 1985; Uddenfeldt, 1985; Uddenfeldt and Stjernvall, 1985].

Uddenfeldt [1985] discusses the relations between system characteristics and ease of implementation. A more detailed discussion can be found in lecture notes from a post-graduate course held at Lund University, Sweden, in 1984 [Öhrvik, 1984].

2. Comparison between the frequency economy of narrow-band digital speech transmission and present analogue mobile telephone systems

Several research groups have indicated that speech coders of reasonable complexity and power consumption (for portable telephones) could give close to normal telephony speech quality with a total data rate of around 16 kbit/s, including channel coding to accept up to 1% bit error ratio with small degradation in speech quality. Additional channel coding against burst errors due to fading dips, which increases the data rate to around 27 kbit/s, gives a substantial reduction of the required $C/I_{co\text{-}channel}$ during Rayleigh fading. 27 kbit/s can be transmitted over a 25 kHz radio channel with reduced requirements on adjacent-channel attenuation. The reduction in the required C/I corresponds to a substantial reduction in the required frequency re-use distance compared to present mobile telephone systems. As is summarized in Table I [Uddenfeldt, 1985] around three times improvement in spectrum utilization is obtained.

TABLE I – *Spectrum efficiency for companded FM system and two digital narrow-band FDMA systems. Sectorized cells with 3 cells per site are used*

	Analogue system	Digital system	Coded digital system
Description	Comp. FM	RELP/GMSK	RELP/GMSK
Speech coder rate (kbit/s)	–	16	16
Transmission rate (kbit/s)	–	16	27
Channel spacing (kHz)	25	15	25
Minimum C/I in fading (dB)	18	20	13
Frequency re-use:			
– No. of frequency groups	21	27	9
– No. of sites	7	9	3
Spectrum efficiency:			
– No. of channels per MHz and cell	1.9	2.4	4.4
– Capacity per cell for 10 MHz system (erlang)	12.4	17.2	35.1

This is of course no general result. Further improvements in analogue mobile telephone systems have not been considered, but on the other hand, large further improvements in technologies for digital speech transmission over fading radio channels can be expected.

3. Frequency economy implications of introducing wide-band radio channels

One major complication in going over to wide-band radio channels is time dispersion. The final result on the system level might be either a degradation or an improvement in frequency utilization through the influence of time dispersion (or frequency selective fading) on the required $C/I_{co\text{-}channel}$.

Under typical propagation conditions, the modulation bandwidth is considerably larger than the coherence bandwidth. Suitable signal processing could take advantage of this condition by introducing frequency diversity to reduce the required fading margin for multipath fading. The negative consequence might be that the effect on receiver sensitivity (required C/I) from time dispersion (inter-symbolic interference) could not be fully eliminated through suitable signal processing (i.e. adaptive channel equalization).

Much further study is needed, both of the detailed wide-band characteristics of the mobile radio channel and of suitable signal processing to take advantage of or combat time dispersion. The effects will also depend on the total system configuration, i.e. system data rate, other diversity arrangements, channel coding and basic type of radio modem. Frequency diversity could also be introduced through coordinated frequency hopping between the channels allocated to a cell.

An advantage of different combinations of TDMA and packet transmission is increased system flexibility, especially if different non-voice services become an important part of future systems. An obvious disadvantage of present FDMA systems is allocation of unnecessarily large channel capacity for narrow-band data transmission and for certain types of signalling. (However, an advantage of a wide-band channel system is the possibility of accommodating bursts of high speed data, i.e. 16 kbit/s ISDN messages. Also digital speech interpolation (DSI) like arrangements might be incorporated.)

The introduction of TDMA/packet results in much improved system signalling. A radio terminal can exchange system signalling with the base station without interruption of speech and data transmission, using separate time slots. The terminal can also check the signal level from nearby cells (momentarily switching both to a new time slot and radio channel). The frequency economy could be improved both through macro diversity between cells to reduce the required fading margin for shadowing and through rapid dynamic channel re-allocation when C/I becomes marginal. Such a system can be designed for a lower average $C/I_{co\text{-}channel}$, and the co-channel cells can be packed closer together, resulting in improved spectrum utilization.

On the other hand, the introduction of TDMA means a basic penalty in frequency economy due to overheads for guard bands between time slots and for burst synchronization.

4. Adaptation of the system specification to ease the practical implementation

4.1 *Reduced system selectivity*

Analysis of the interference situation in a cellular system with suitable control of terminal transmit power and close to optimal hand-over procedures, indicates much reduced mutual interference in the direction, terminals to base, compared to the situation where small independent systems, with overlapping geographic coverage but different base station sites, share the same frequency band. The system selectivity requirements on terminal transmitters and base station receivers could probably be reduced to around 40 dB without any noticeable increase in the $(C/I)_{co\text{-}channel}$ required for acceptable quality.

The interference situation would be roughly the same in the opposite direction if no dynamic power control is applied to the base station transmitters. A simple way to implement high dynamic range (blocking performance) of the terminal receivers might be to introduce automatic gain control.

A possible complication might be the introduction of power control at the base station transmitters in order to reduce the average level of co-channel signals, thus reducing the probability for harmful co-channel interference. One consequence would be requirements for more stringent specifications on transmitter intermodulation.

Reduced requirements on system selectivity would have a considerable influence on equipment cost and size through reduced requirements on dynamic range, noise performance and filter selectivity of different transmitter and receiver sub-systems. Present extreme requirements on spurious suppression have led to complicated receivers, using several stages of mixing and filtering. Reduced selectivity requirements might give important simplifications such as balanced circuits to suppress spurious emissions and direct conversion between base band and transmit frequency.

4.2 *Increased channel bandwidth*

The introduction of wide-band time-division radio channels will have a considerable impact on the practical implementation.

The cost of the concentrated base station sites will be reduced as each radio channel equipment will be shared by several speech or data channels. A reduced number of more widely separated radio channels will lead to a considerable reduction of the multiplexer complexity. Outside of the major metropolitan areas, the required traffic capacity of a base station site could be served by one wide-band radio channel, eliminating the need for multiplexers.

Considering base station complexity, the optimum system data rate would be a compromise between the needs of the major population centres and the more sparsely populated areas, and also a compromise between the early phase of system growth and the final saturated system.

A more important impact will probably be on the terminal's cost and size, as the terminal's cost is typically the major part of the total cost of a cellular system. Introduction of wide-band radio channels leads to a reduction of the requirements for extreme frequency stability, narrow radio-frequency filters and VCOs with good noise and microphony performance. Also the frequency synthesizer design is simplified, especially if there is a system requirement for fast switching between radio channels.

Reduced system selectivity and increased channel spacing impact mainly on the analogue and very high frequency sub-systems. This is of special importance as remaining digital sub-systems, including digital signal processing, can take full advantage of further developments in custom digital VLSI. Eventually, this might lead to the situation that those sub-systems that could not be realized in digital VLSI, will become the dominating cost and size factors of the terminal electronics.

However, introduction of wide-band radio channels also introduces system limitations and design problems. Too wide radio channels would not be practical.

- In many parts of the world and for many services, digital cellular systems for telephony or for dispatch must be introduced gradually into frequency bands presently organized for, and partly occupied by, narrow-band FDMA channels. A possible compromise might be to use intermediate bandwidth radio channels, i.e. combine FDMA and TDMA with around 300 kHz channel spacing, and to use a combination of frequency and time duplex (frequency duplex to adapt to the present frequency allocation principles and time duplex to eliminate the duplex filter from portable terminals).

- Time synchronization between different cells would probably be required.

- TDMA, and especially packet arrangements with retransmission of lost packages will introduce delays. Delays will also be introduced by the speech coder and channel coder. Echo cancelling will probably be necessary also in local and regional mobile telephone networks.

- Due to the use of a burst transmission with low duty cycle, the peak power will be much higher than the average terminal transmit power. The possibilities for considerably reducing the fading margin for multipath and even part of the shadow fading, as has been suggested above, will however reduce the requirements on average transmit power. (That also helps to reduce the battery size of portable terminals.) Using intermediate bandwidth radio channels ("narrow-band TDMA") the net result could be only moderately higher peak power than the CW power of present terminals.

- Going over to more wide-band radio channels which would probably require more complex circuits to utilize or combat the time dispersion, could result in excessive power consumption of the radio modems, especially considering portable terminals. Unfortunately, further improvements in the packing density of digital VLSI will probably not result in equal progress in reduced power consumption per elementary function. Even with CMOS, the power consumption will be considerable, if very high speed logic must be used. As portable telephones would be a major part of future cellular systems for important markets, the consequences on power consumption should be thoroughly considered before deciding on the width of the radio channels in a digital mobile telephone system.

5. Conclusions

This Report has tried to indicate that new technologies both on the system and practical implementation side could make it possible to combine improved system performance, especially frequency economy, with reduced system cost and reduced size of portable terminals. Key areas to consider the optimum system selectivity and channel spacing. A very tentative suggestion made in the Report is that a "narrow-band TDMA" system using digital speech transmission and a channel spacing around 300 kHz is an interesting possibility that merits further study. An important area that should be studied is the detailed characteristics of the wide-band mobile radio channels, including appropriate mathematical models and channel simulators.

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REPORT 741-2

MULTI-CHANNEL LAND MOBILE SYSTEMS FOR DISPATCH TRAFFIC (WITH OR WITHOUT PSTN* INTERCONNECTION)

(Question 37/8)

(1978–1982–1986)

Introduction

The portion of radio spectrum which is allocated to the land mobile 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.

* Public switched telephone network.

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 is considered to have access to one of the radio channels by means of an access procedure which is still to be defined.

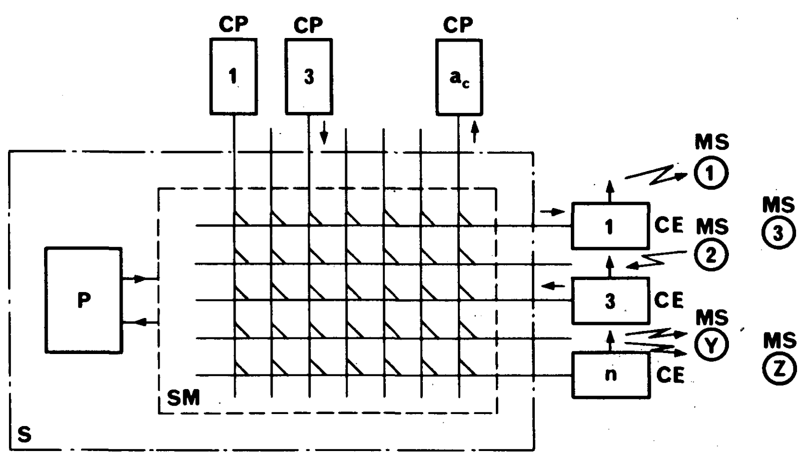

FIGURE 1 – *Arrangement of equipment in a trunked system*

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 an 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 estimating the volume of 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.

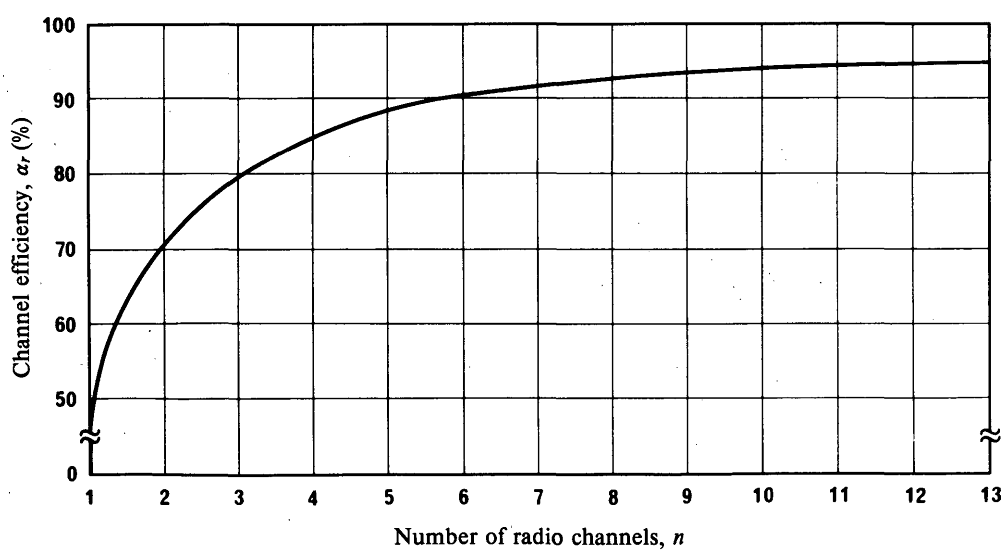

FIGURE 2 – *Radio channel efficiency in a trunked system*
(for a_m = 10, α_m = 0.005 E and P_r = 0.285)

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

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 $n = 5$.

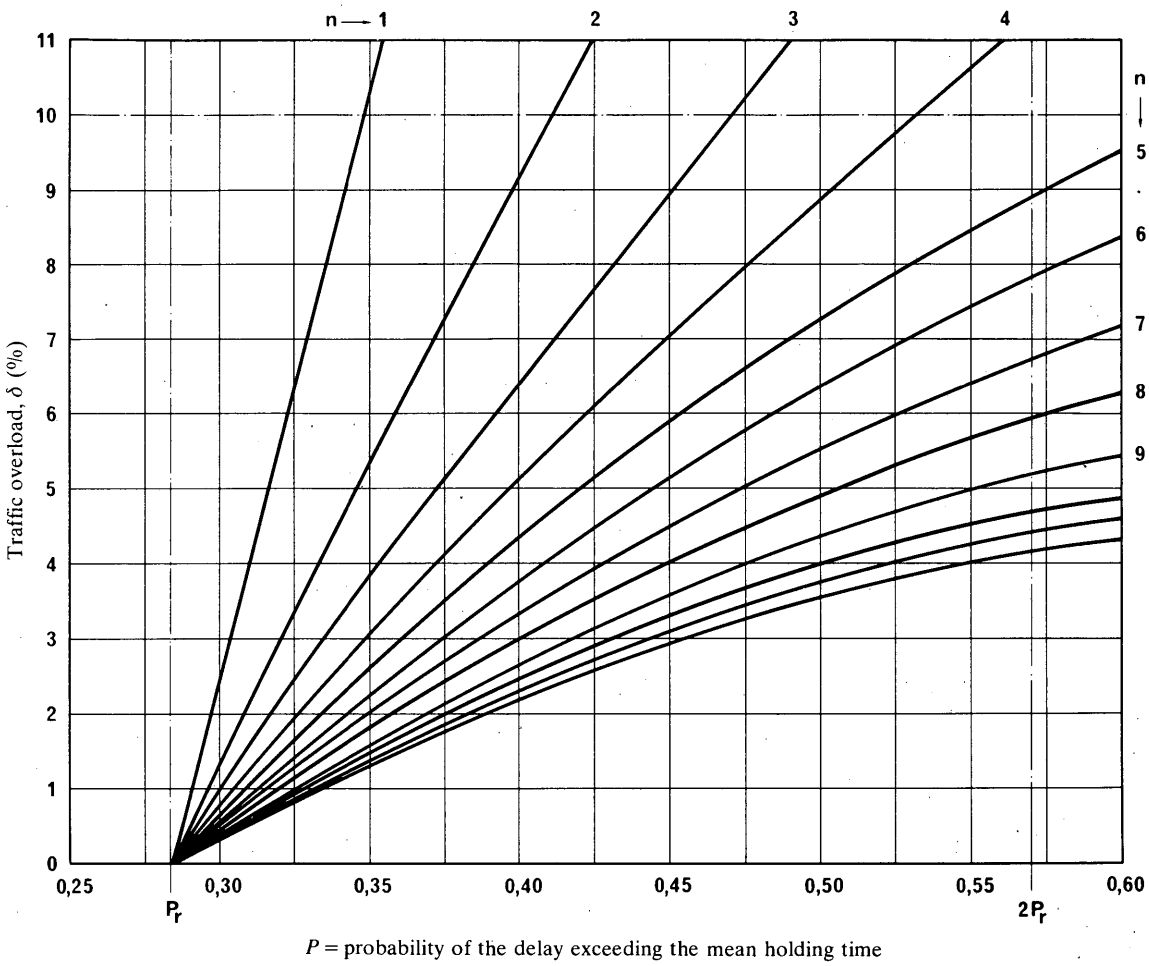

FIGURE 3 – *Traffic overload characteristics in a trunked system*
(for $a_m = 10$, $\alpha_m = 0.005$ E and $P_r = 0.285$)

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

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%.

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. Measured data on performance of trunked systems

In an effort to evaluate the performance of trunked systems, the Department of Communications, Canada, collected monitoring data for a ten-channel trunked radio system, with a single dedicated signalling channel, operating in the 800 MHz band and 12 conventional (non-trunked) channels operating in the 400 MHz band. For this trunked system, channels are occupied for the duration of a transmission only, while for the conventional systems the channel is occupied for the duration of the message.

Based on the average peak-hour traffic conditions, transmission occupancy and average probability of waiting were compared and are given in Table I.

TABLE I

	Average probability of waiting (%)	Average peak hour transmission occupancy (%)
Trunked system	13	64
Conventional system	53	33

Table I shows that the use of trunking resulted in considerable reduction in the waiting time and increase in the channel loading compared with conventional systems with similar types of user.

5. 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.

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.

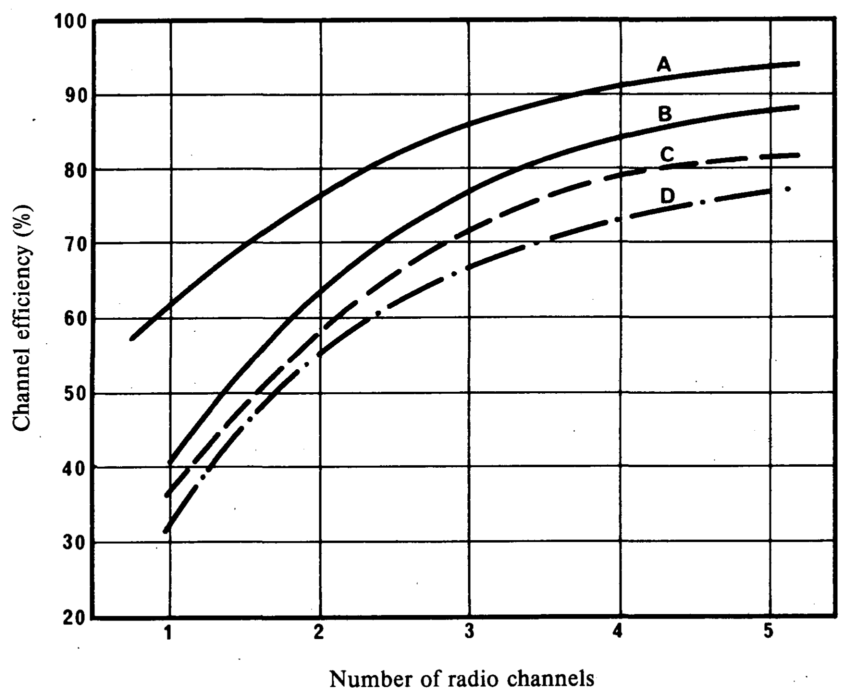

FIGURE 4 – *Radio channel efficiency in balanced and unbalanced systems as a function of the number of channels (such that the cumulative probability of delay greater than the mean holding time equals: 0.165)*

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.

6. Signalling

In trunked systems with queueing 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.

6.1 *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.

6.2 *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 occasionally. 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.

6.3 *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.

6.4 *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.

7. **Other important design considerations**

7.1 *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.

7.2 *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.

8. 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.

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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 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.

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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

In Sweden a new nation-wide trunked dispatch system called MOBITEX is being developed. It will be introduced at the end of 1986. A common infrastructure will be able to serve more than 40 000 mobile stations and 4000 dispatchers throughout the country, using 150-200 base station sites in a cellular structure and some 1000 base station transmitters. Automatic roaming between base stations is included.

In MOBITEX data or text messages as well as speech can be exchanged between mobile stations and their control posts or between mobile stations. FFSK 1200 bit/s is used for data and conventional analogue FM for speech.

Data and text is forwarded using packets with variable length on a store-and-forward basis. For the radio path a protocol comprising error correction coding and selective ARQ is used. For the fixed line part (base station – exchange – control post) CCITT Recommendation X.21 *bis* and high level data link control (HDLC) are used.

The method of contention control is mainly that described in § 3 of Annex I to Part A (slotted ALOHA with dynamic frame-length control) with some added features. The maximum packet length, that can be transmitted from a mobile unit without channel access request and the slot length, can be dynamically and independently changed by the base station. The base station also transmits a silence (busy) signal immediately it detects a transmission addressed to it (compare to CSMA). The contention control protocol also has the ability to permit only parts of the mobile fleet to transmit (to compare the binary search procedure).

The radio channels on a base station can be used for different purposes in a dynamic manner. One of the channels is used as a master control channel sharing the frequency with the other base stations on a time division basis. The rest of the channels can be used for speech or data traffic and as additional random access channels depending on the traffic load. Information on how the channels are to be used by the mobile units is transmitted from time to time by the base station.

To prevent excessive delays, restrictions on speech call holding times are used. Connections to PSTN and public data networks will be included.

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, 1978-82a] 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.

4. Basic characteristics for a planned dispatch system in the USSR

In the USSR, a portion of the spectrum in the band 300-340 MHz is reserved for shared channel dispatch systems using automatic channel selection. The basic technical parameters of the system equipment are established by the State standards in force in the USSR but the network configuration and other parameters of such systems are not standardized.

The following describes a dispatch system in the mobile radio service with automatic channel selection as developed in the USSR. The system is designed for the organization of dispatch radiotelephone communication with stationary and mobile subscribers. A distinctive feature of the system is the fact that a number of users of the same type combine to form groups which are controlled by a single dispatcher. Groups may vary considerably in size, and the number of subscribers in each group is not fixed. Moreover, the system makes provision for priority users who can call individually. In practice, the number of subscribers to the system is determined by the number of dispatchers (user groups) and the number of priority subscribers. In order to maintain the required service quality, limitations are imposed on the period of radio-channel occupancy, i.e. the system is protected against the possibility of excessively long service delays. In the interests of efficient frequency planning in an area, the system uses two-frequency simplex operation.

Technical characteristics

4.1 The equipment operates with eight fixed frequencies (four for reception and four for transmission) forming a group (RF trunk) of four two-frequency channels.

4.2 25 kHz frequency spacing then provides ten groups in a 1 MHz bandwidth.

The minimum frequency separation between the adjacent channels of one trunk is 25 kHz and the maximum separation between the end channels of a trunk is 175 kHz. Frequency spacing within a trunk is not uniform and excludes third-order intermodulation products. This frequency grid structure reduces intra-system interference to a minimum.

4.3 Within a single trunk, three channels are equally accessible and a fourth is used for privileged access by a limited number of subscribers (priority subscribers).

4.4 Seizure of the three equally accessible channels of a trunk is performed by automatic call with free channel finding. For automatic free channel finding, a marker tone is transmitted on all the channels that are free at any given time. A radio subscriber requiring access is thus automatically connected to any one of the three channels which happens to be free.

4.5 Priority mobile subscribers and dispatchers have the option of access to the fourth, priority, channel if the other three are occupied.

4.6 Up to four connections between subscribers can be set up simultaneously within one trunk, and one telephone subscriber can be put on stand-by.

4.7 The system contains a device which clears the radio channels after 20-30 s in the absence of any speech signal.

4.8 The transceivers of the central station may be up to 5 km from the central dispatch point and is connected to it by cable.

4.9 Transceivers of the central station are designed for 24-hour service in reception and transmission. When the traffic drops in the evening, one transceiver is left in operation. If this radio channel is occupied, other transceivers are switched on automatically.

4.10 The subscriber station automatically switches over to watch-keeping operation if the subscriber fails to lift his handset within 10-20 s of receiving the ringing tone.

5. The basic trunked mobile radio dispatch system installed in Japan

5.1 The system consists of a control station and several groups of mobiles. A group has one base station and several land mobile stations. A control station employs one channel as a signalling channel and 15 channels for conducting voice communications. The Hagelbarger code is used for error detection and code correction. The maximum period of voice communication is restricted to 60 s. A waiting system is adopted for call reservation of up to 30 calls. The system provides operational functions such as individual calls, group calls or party calls and it also permits facsimile and data transmission. The service area of the system is within a 20 to 30 km radius. The standardization of the system specifications allows any mobile station to receive the same trunked radio service throughout the country (multi-zone service).

5.2 The system specifications are indicated in Table I.

TABLE I

Frequency	Control station: 399 frequencies between 850.025 MHz and 859.250 MHz with 25 kHz spacing. Base station and mobile station: 399 frequencies between 905.025 MHz and 914.250 MHz with 25 kHz spacing	
Communication mode	Semi-duplex	
Power e.r.p.	Control station Base station Mobile station	40 W e.r.p. or less 10 W or less 10 W
Control signal	Code form Type of modulation Transmission speed Mark frequency Space frequency Frequency deviation	NRZ code MSK-FM 1 200 bit/s 1 200 Hz 1 800 Hz ± 2.5 to ± 5 kHz
Voice signal	Maximum modulating frequency Maximum frequency deviation Instant deviation control	3 000 Hz ± 5 kHz provided

5.3 *Operational status*

In October and December 1982, the system started operation in Tokyo and Osaka, respectively. As of the end of September 1985, 29 systems with approximately 4000 base and 58 000 mobile stations in 11 cities were in operation. According to the operational data of the system in Tokyo as of October 1985, the total number of calls per system is between 20 000 and 22 000 per day. This means that the average number of calls per day for each station is less than 9. The busiest period is between 1300 and 1800 h and for each station the mean holding time in this period is approximately 25 s.

6. Common-relay system used in France – RADIOCOM 200

France has brought into service a system with the following characteristics.

6.1 *General characteristics*

Dispatch-type operation, in which operators' positions are connected by a radio channel at the time of the call to a "relay station" which retransmits the call to the mobile stations. Calls can be placed in the fixed-to-mobile or the mobile-to-fixed direction.

The services provided are:

- calling and routing calls between two mobile stations or between one mobile and a group of mobile stations. From the technical point of view, the operator's station is a mobile station in a fixed position;
- calling from a mobile station to the switched telephone (PSTN) network and *vice versa.*

6.2 *Frequency bands and class of emission*

The system uses about 100 channels in the 200 MHz band, with 12.5 kHz channel spacing, class of emission 11K0G3E and 8 MHz duplex separation.

6.3 *Characteristics of the mobile station* [CNET, 1984]

The synthesized mobile station has access to 8 channels chosen from the 100 or so available.

The system may include portable stations with a power of 2 W.

If a switched-on mobile station does not reply, the number of the caller is stored in the memory of the called mobile station (dispatch application).

6.4 *Characteristics of base or relay stations*

Each relay station is designed to cover an area corresponding to the potential propagation. The mobile station is served in this area only. One relay station controls a group of 8 channels. The transmitters are coupled with low losses to a single antenna. The relay stations operate in duplex mode with simultaneous transmission and reception.

6.5 *Signalling*

The code in Appendix 39 to the Radio Regulations is used for signalling. Signals are sent on a signalling channel transmitting a modulated carrier. In the event of saturation, the common channel may be used as a traffic channel and the first channel that becomes available will then be used as a signalling channel.

The numbering capacity is 1000 codes.

6.6 *Frequency efficiency*

It is estimated that this type of 8-channel network will be able to deal with up to 500 mobile stations, about 100 of them having access to the PSTN.

6.7 *Charging*

The fixed station contains a device for magnetic recording of charges, which are then processed for itemized billing.

6.8 *Number of subscribers, commissioning*

Since the system was first brought into operation (December, 1982) the number of subscribers in Paris has reached about 3000 (May, 1985).

The system capacity in Paris is approximately 6000.

Systems have also been set up in Marseilles (November, 1984) and Lyon (March, 1985).

6.9 *Special features of the service*

Up to 9 sub-fleets can be established in a group or fleet of mobile stations, and one mobile station can belong to several sub-fleets.

Connection to the network is on an individual basis and can be effected by using a subscriber line to a private automatic switchboard or to the PSTN.

Certain subscribers in a fleet may have access to the network while other subscribers in the same group may not have such access.

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REPORT 901-1

FREQUENCY ASSIGNMENT METHODS FOR TRUNKED MOBILE RADIO SYSTEMS

(Question 37/8)

(1982-1986)

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 400 MHz band in Canada and in the 800 MHz band in Canada and 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. Minimum separations between assigned channels within a trunked system are 250 kHz and 100 kHz in the 800 MHz and 400 MHz bands respectively.

Table I gives an example of a channelling plan, used in the United States of America in the 800 MHz band, 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 sub-divides 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.

TABLE I – *Frequency assignment plan for trunked systems in the 800 MHz band in the United States of America*

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

Tables II and III give channelling plans used in Canada for the 800 MHz and 400 MHz bands respectively. Expansion beyond 50 channels would utilize an approach ensuring progressive deployment of trunked systems, while at the same time providing the flexibility of reserving part of the spectrum for future expansion of a given trunked system to multiple blocks of five channels each or the introduction of new technologies that might require different channel bandwidths and channelling plan.

With the methods outlined above, intra-system 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 see also Report 739).

TABLE II – *Frequency assignment plan for trunked systems in the 800 MHz band in Canada*

Block	System	Channels
1	1	1 – 11 – 21 – 31 – 41
	2	2 – 12 – 22 – 32 – 42
	3	3 – 13 – 23 – 33 – 43
	4	4 – 14 – 24 – 34 – 44
	5	5 – 15 – 25 – 35 – 45
	6	6 – 16 – 26 – 36 – 46
	7	7 – 17 – 27 – 37 – 47
	8	8 – 18 – 28 – 38 – 48
	9	9 – 19 – 29 – 39 – 49
	10	10 – 20 – 30 – 40 – 50

TABLE III – *Frequency assignment plan for trunked systems in the 400 MHz band in Canada*

System	Channels
1	1 – 5 – 9 – 13 – 17
2	2 – 6 – 10 – 14 – 18
3	3 – 7 – 11 – 15 – 19
4	4 – 8 – 12 – 16 – 20

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.

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REPORT 742-2*

PUBLIC LAND MOBILE TELEPHONE SYSTEMS

(Questions 37/8 and 39/8)

(1978-1982-1986)

1. Introduction

Public land mobile telephone systems are defined as land mobile systems for public correspondence via radio stations connected to the public switched telephone network (PSTN).

Part A of this Report deals with the general principles of public land mobile telephone systems (both conventional and cellular) and, in particular, with system parameters and technical characteristics which are important for international operation. The basic concept of the cellular techniques is outlined in Report 740.

Part B of this Report considers the implementation of international systems.

The major characteristics of some existing or imminent public land mobile telephone systems are given in Part C of this Report, together with brief descriptive material on the status of these systems and other unique aspects of their design.

PART A

GENERAL PRINCIPLES OF PUBLIC LAND MOBILE TELEPHONE SYSTEMS

1. Operational aspects

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.
- blocking probability should be kept within limits similar to that of the PSTN services at all stages of development;
- continuous control of call quality should be maintained, with automatic hand-over between base stations if needed.

Any specific system must have at least two well-defined interfaces:

- the radio interface between the land-based system and the mobiles it serves; and
- the wire-line interface to the public switched telephone network.

Other internal interfaces may also be defined such as:

- the billing system;
- the interface between controllers for the handling of roamers;
- the methodology for communicating between base sites and controllers; and
- the man-machine interface for operational purposes including maintenance.

2. Interworking with the PSTN

CCITT Recommendation Q.70 specifies the necessary interworking requirements between the PSTN and the mobile network.

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* The Director of the CCIR is requested to bring this Report to the attention of the CCITT.

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. CCITT Recommendations E.212 and E.213 deal with this subject.

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 location to another.

Further studies are required before adequate technical and operational roaming procedures can be defined. For this reason Recommendation 624 has been written.

Roaming also requires compatibility in frequency bands, channel spacing, and operational signalling protocols and codes.

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

Current systems use the 450 MHz band, the 800-900 MHz band, and other bands according to existing possibilities.

Conventional trunked systems can use only a small number of channels, but cellular systems are only efficient when a larger allocation (e.g. 300 channels) is available since the allocation must be divided into sub-sets in order to implement the cellular plan. Further studies may be necessary before the choice of a radio-frequency band for an international public mobile telephone service can be made.

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 location area, and to the hand-over procedure when a call in progress is switched from one base station to another.

Signalling 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 signalling and supervision reliability should be as good as in that network;
- to fail to establish and maintain a traffic channel means that the base station loses control of the mobile station. The probability of failure therefore should be made as small as possible;
- billing accuracy is of high importance.

The reliability of control channels can be improved by (for example) diversity, error-control coding, message exchange protocols and simulcast (see Reports 903 and 1022 and Question 67/8).

Attempts to seize a channel may fail due to simultaneous requests by two or more mobile stations. The problem can be reduced by a polling technique, but in a high-capacity system it is more efficient to mark the busy/idle status of the channel [Fluhr and Porter, 1979; Okasaka, 1978].

8. Reduction of ineffective air-time

In all public radiotelephone systems, including cellular, a significant delay resulting from dialling, switching, and ringing time occurs between the initiation of a call and the start of the conversation. Some cellular systems store the dialled digits in the mobile unit prior to transmission (called "pre-origination dialling") which significantly reduces the ineffective air-time.

The traffic capacity can be increased by assigning traffic radio channels only when both parties are ready to speak [Tridgell, 1977], or by queueing calls on a first-come-first-served basis until they materialize and a free traffic channel becomes available.

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PART B

CONSIDERATIONS FOR THE DEVELOPMENT OF INTERNATIONAL SYSTEMS

1. General

This part identifies considerations that are appropriate for the development of international public land mobile telephone systems and services that may be adopted by many countries around the world. Systems that provide common services amongst a few nearby countries have been implemented.

2. Implementation of international systems

To allow for the implementation of international systems, it would be ideal to select a common band of frequencies with common world-wide service and technical standards. As the development of these agreements could take a long time, it may be necessary to choose methods involving interim stages which immediately take advantage of some of the benefits of international compatibility. Such implementations may be possible by the addition of agreed narrow-band or wide-band systems [Murtonen, 1985].

Narrow-band systems may be added with channels directly adjacent to those of existing systems, or in the case of some existing systems, by interleaving the channels of both systems. In both cases there would be systematic expansion of new channels into existing system channel assignments as over time older systems are retired.

Similarly, wide-band systems (spread spectrum, TDMA, etc.) may be added using new or cleared spectrum adjacent to the channels of existing systems. Expansion of new systems is possible when the older systems are retired.

Additionally, it may be possible to overlay some spread-spectrum systems onto existing assignments and to simultaneously operate both the new and the existing systems; however the overlay of spread-spectrum systems requires further study, especially in the case of a heavy concentration of users of these systems.

3. Factors needing international agreement

- channel allocations and spacing;
- class of emission;
- modulation characteristics;
- transmitter and receiver standards;
- signal processing techniques, such as companding;
- use of diversity reception;
- signalling and supervision methods and protocols.

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PART C

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 of America, in Canada, in the United Kingdom, in the Nordic countries, in Japan, in the Federal Republic of Germany and in Italy to provide a high-quality, nationwide-compatible radiotelephone service.

Systems are now in operation or being installed in the United States of America and Canada, where 666 channels split into two sub-bands and allocated to two systems per city, have been set aside. These consist of a varying number of cells, depending on the area to be served. The system capacity can be expanded to meet the anticipated subscriber demands which are expected to be more than 100 000 in larger cities. Annex I provides more details on the general characteristics of these systems.

Two nation-wide systems (TACS), similar to those in North America but based on channels spaced at 25 rather than 30 kHz have been developed in the United Kingdom, and were brought into use in January, 1985. Each system will offer coverage to at least 90% of United Kingdom inhabitants by 1990. In November, 1985, the total number of subscribers on the two systems exceeded 35 000. Annex V provides more details on the general characteristics of the system.

The Japanese system now provides nation-wide service to more than 454 cities (about 70% of all Japanese cities), using 9 mobile telephone switching centres connected to the common channel inter-office signalling network. At the end of September, 1985, there were 35 mobile control centres and about 470 base stations with about 50 000 subscribers. Annex II provides more details on the general characteristics of this system. In the future the system is expected to use 2000 channels in two 25 MHz allocations in the 800/900 MHz band.

The Nordic mobile telephone system (NMT-450) was put into operation in the participating countries, Denmark, Finland, Norway and Sweden during the end of 1981 and the beginning of 1982 with country-wide continuous coverage and full roaming capability. During the last year, cell splitting has been introduced in the big cities in order to cover the traffic demand. Cells as small as 1.0 km cell radius are used. In October, 1985, the number of subscribers exceeded 200 000 corresponding to 0.9% of the population. During 1986, this system will be expanded to Iceland with full roaming capability between all the countries. The system will be expanded into the 900 MHz band in late 1986 and is designed for 2000 channels including the utilization of interleaving. At start-up, 799 channels were used (NMT-900). Annex III provides more details on the general characteristics of the system.

In Belgium, the Netherlands and Luxembourg, a cellular system providing international roaming is in operation. This system is an NMT-450 system with modifications such as 20 kHz channel spacing and the use of a syllabic compandor.

The C450 network in the Federal Republic of Germany was brought into service in 1985. It provides a complete coverage of the Federal Republic of Germany. The ultimate subscriber capacity is estimated to be at least 200 000. Specific features are: off-air call set-up and queueing operation. Annex IV provides more details on the general characteristics of the system.

The Italian second-generation mobile telephone system operating in the 450 MHz frequency band was brought into service in the Rome and Milan areas beginning in September, 1985. It is expected to provide a complete coverage of the Italian territory by 1988. Annex VI provides more details on the general characteristics of the system.

1.2 *System features*

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

- cellular structure in both base-to-mobile and mobile-to-base directions with frequency re-use and inter-cell hand-over (switching call-in-progress);
- automatic, two-way, direct-dial operation;
- full duplex communications;
- voice channel supervision via continuous tone (North American and United Kingdom systems, NMT system, Italian system), or digital control channel (C450 system);
- automatic roaming;
- dedicated control channels used for call set-up (North American and United Kingdom system, Japanese system, C450 system, Italian system);
- pre-seizure dialling;
- cell splitting during system growth.

1.3 *Conclusions*

Cellular radiotelephone systems using the parameters and features described above have been installed or are planned for the near future. There is a large demand for a 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.

2. Hybrid systems combining public mobile telephone system and dispatching type networks

2.1 In 1985 France opened a system with the main characteristics described below.

2.1.1 *General characteristics*

- Dispatch type operation for half-duplex private network application offering the following links:
  - base-to-mobile or fleet (or sub-fleet);
  - mobile-to-base;
  - mobile-to-mobile or fleet (or sub-fleet);
  - access for certain mobiles to the PSTN;
- duplex public radiotelephone operation; a unique number is used to call the mobile wherever it is located;
- cellular structure covering a wide geographical area with automatic roaming using medium-sized cells (15 to 20 km radius); cell splitting possible during system growth;
- digital data transmission is under study;
- the system provides for priority subscribers;
- hand-over is under study.

Annex VII provides more details on the general characteristics of the system.

TABLE I – *General system specifications*

Feature	North American system	Japanese system	NMT-450 system	NMT-900 system	C450 system	United Kingdom system – TACS	Italian 450 MHz system	French system
Class of emission	Voice 40K0G3E Control 40K0G1D	Voice 16K0G3E Control 16K0F1D	Voice 16K0G3E Signalling 16K0G2D	Voice 16K0G3E Signalling 16K0G2D	Voice 14K0G3E Control 14K0F1D	Voice 32K0G3E Control 32K0F1D	16K0G3E	Voice 11K0G3E
Transmit frequency bands (MHz)								
– base stations	870-890	870-885	463-467.5	935-960	461.3-465.74	935-950	460-465	202.7-205.1 424.8-427.9
– mobile stations	825-845	925-940	453-457.5	890-915	451.3-455.74	890-905	450-455	194.7-197.1 414.8-417.9
Duplex separation (MHz)	45	55	10	45	10	45	10	8 10
Channel spacing (kHz)	30	25 (expected to be 12.5)	25	12.5	20 (10)	25	25	12.5 12.5
Total number of duplex channels	666 (333 in each of two sub-bands, including 21 signalling channels)	600 (expected to be increased to 2000)	180	1999	222	600 (300 in each of two sub-bands, including 21 signalling channels)	196	192 256
Maximum base station e.r.p. (W)	100 [1]	50 (expected to be 20)	50	100	100 (adaptive control)	100	25/2.5	25 to 70
Nominal mobile station transmitter power (W)	3	5 (expected to be 1)	15	Mobile 6 Hand-held 1 (with autonomous power control)	15 (+3 dB antenna gain adaptive control)	7 – class 1 mobile	10/1	11
Typical cell radius (km)	2-20	5 (urban area) [2] 10 (suburban area) [2]	1-40	0.5-20	2-30	2-20	5-20	20
Voice signals								
– type of modulation	PM	PM	PM	PM	PM	PM	PM (FM, if the band inverter is used)	PM
– peak deviation (kHz)	± 12	± 5 (expected to be decreased)	± 5	± 5 (including supervisory signal)	± 4	± 9.5	± 5	± 2.5
– processing	2:1 syllabic compandor	2:1 syllabic compandor	–	2:1 syllabic compandor (CCITT Rec. G.162)	2:1 syllabic compandor	2:1 syllabic compandor	2:1 syllabic compandor (CCITT Rec. G.162)	Syllabic compandor base to mobile

TABLE I *(continued)*

Feature	North American system	Japanese system	NMT-450 system	NMT-900 system	C450 system	United Kingdom system – TACS	Italian 450 MHz system	French system
Control signals								
– type of modulation	FSK	FSK	FFSK	FFSK	FSK	FSK	FM	FFSK
– peak deviation (kHz)	± 8	± 4.5	± 3.5	± 3.5	± 2.5	± 6.4	± 4	± 1.7
– code form	Manchester	Manchester	NRZ	NRZ	NRZ	Manchester	Multifrequency (two of seven) (³)	NRZ
– transmission bit rate (kbit/s)	10	0.3 (expected to be increased)	1.2	1.2	5.28	8		1.2
– effective information transmission rate (kbit/s), (depends on message type)	0.27-1.2	0.12-0.18 (expected to be increased)	About 0.46	About 0.46	1.82	0.22-0.96	About 0.1	0.46
Error protection coding	Shortened (63:51) BCH repeated (⁴)	Shortened (63:51) BCH; shortened (15:11) BCH	Type B1 burst error-correcting convolutional code (Hagelbarger)	Type B1 burst error-correcting convolutional code (Hagelbarger)	(15:7) BCH	Shortened (63:51) BCH repeated (⁴)		Hagelbarger code (6:19)
– base-to-mobile	(40:28) BCH	(43:31) BCH				(40:28) BCH		
– mobile-to-base	(48:36) BCH	(43:31) BCH-access; (11:7) BCH-paging				(48:36) BCH		
Error detection	Min. 11 / Max. 89 } per 200 bits	Min. 3			Min. 40 per 150 bits	Min. 11 / Max. 89 } per 200 bits		
Error correction	Min. 5 / Max. 83 } per 200 bits	1 error	Min. 6 with 19 bit guard space	Min. 6 with 19 bit guard space	Min. 20 per 150 bits	Min. 5 per 200 bits		Min. 6
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	Frame acceptance procedure depending on message category	Adaptive message repetition in case of error	Recycled control signal transmissions; repeated control signal transmissions with bit-by-bit majority voting	Autocorrelation control of the encoded message with repetition, depending on message type, in case of error	Frame repetition

(¹) Exceptions may be allowed, depending on circumstances.

(²) A control zone covers about 10 cells.

(³) The modulation rate is 50 ms/character.

(⁴) Repeated 5 to 11 times, depending on message type, with bit-by-bit majority voting. In addition, to achieve decorrelation, two message streams are interleaved on the common paging channel.

ANNEX I

NORTH AMERICAN SYSTEM

PART 1

GENERAL DESCRIPTION

1. Operational and system characteristics

1.1 *Purpose*

The land mobile telephone system is designed to permit an automatic exchange of traffic with the public switched telephone network (PSTN) and offers a service, from the user's point-of-view, similar to that of land-line calls: high voice quality, high reliability, low blocking, and relatively low cost.

1.2 *Cellular properties*

- Growth from large cells at start-up to small cells at maturity, with a mix of several sizes, is permitted.
- Hand-off is allowed, up to at least one per call per minute.
- For spectrum efficiency (channel re-use), small values for the number of channel sets are used: appropriate to the multipath (Rayleigh) fading typical of urban mobile channels, the terrain variability, the antenna patterns selected and the RF quality desired. A local median C/I target of 17 dB at the 90th perceptile is suggested. (If the standard deviation is 8 dB, this is equivalent to a median C/I of 27 dB, at the nominal boundary of the cell.) Other quality objectives are of course permissible.

1.3 *Signal processing*

- The widest deviation and receiver pre-detection bandwidth appropriate to the cellular concept (which permits separation of the spectrum into channels by both frequency division and spatial separation) are used.
- Voice processing using a 2 : 1 compressor/expandor is employed to enhance the perceived quality of the received signal.
- The coding of digital signalling uses burst-error detection and correction.
- Design for a peak-to-r.m.s. ratio of between 6 dB and 20 dB for the demodulated voice signal at the receiver is possible; that is, a range of quality comparable to land-line service should be accommodated.

1.4 *Service protection*

- A transmitted serial number prohibits the use of stolen units or use by unauthorized callers.
- The introduction of means to ensure privacy of communication is not precluded by the design.
- Means for preventing intelligible crosstalk is included in the system design.
- The successful completion of the entire call takes place on at least 99% of the calls on which an initial two-way connection was established between calling and called parties.

1.5 *Services offered*

- Voice message telephone service with automatic calling to and from the PSTN.
- Data services.
- Vehicular-mounted equipment.
- Hand-held equipment.
- Other enhancements consistent with mobile services: call forwarding, repertory dialling, message waiting, etc.

2. Signalling formats and codes

See Part 2.

3. RF equipment

3.1 The RF equipment allows full duplex operation.

3.2 Frequency tolerance: base station – 1 part in 10^6; mobile – 2.5 parts in 10^6.

3.3 RF power limit: 100 W e.r.p.; more when adjacent systems are not expected.

3.4 Power tolerance: ± 2 dB.

3.5 Mobiles are tunable to each of the allocated channels.

3.6 Receiver sensitivity: −116 dBm from a 50 Ω source applied to the antenna terminals should produce a 12 dB SINAD (C-message weighting).

3.7 Diversity: optional at mobile; also optional, but highly recommended, at base station.

3.8 Antenna height: 30 to 45 m, higher when adjacent systems are not expected to interfere. With careful design, according to local practice, greater heights may be used.

4. Land-based control equipment

4.1 Connection to the PSTN is accommodated on a fully automatic basis.

4.2 Mobile-to-land, land-to-mobile, and mobile-to-mobile calls are permitted.

4.3 Hand-off of mobiles is a feature of the system plan (see § 1.2).

4.4 Supervision of the radio channel is sufficiently robust so that accurate billing timing can be expected (accurate to ± 5 s); billing to the proper number takes place with more than 0.9999 probability.

4.5 The system can provide for automatic roaming within an administration's territory.

4.6 The system is designed for blocking objectives similar to the PSTN.

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PART 2

COMPATIBILITY SPECIFICATION FOR CELLULAR CODES, FORMATS, AND PROTOCOLS*

1. Modulation interface

1.1 *Voice*

- 2 : 1 syllabic compandor (3 ms attack time, 13.5 ms recovery time).
- Pre-emphasis: 6 dB per octave, from 300 to 3000 Hz.
- Deviation limiter: ± 12 kHz.
- r.m.s. deviation: ± 2.9 kHz.

1.2 *Control*

- Manchester bit encoding.
- Deviation: ± 8 kHz for digital signalling: ± 2.0 kHz for continuous out-of-band supervision.

2. Baseband interface

2.1 *Unique mobile identification*

- Mobile unit identification number: 10 decimal digits coded into 34 bits, via specified algorithm.
- Serial number (not changeable): 32 bits, intended as an anti-fraud, anti-theft means.

* These standards are specified in precise detail in the United States Federal Communications Commission Document OST-53 and in the Canadian Department of Communications Document RSS-118, Annex A, dated October 1983, respectively; these are both compatible with EIA Interim Standard CIS-3A, available from the Electronic Industries Association, Engineering Dept., 2001 I (Eye) Street, Washington DC 20006. This specification describes a minimum capability; manufacturers and system providers have also written enhanced versions of this specification to describe capabilities above and beyond this minimum capability. This document comprises about 60 pages; in lieu of publishing that specification in its entirety, this Part 2 summarizes its major points, as they relate to codes, formats, and protocols.

2.2 *System-specific memory*

- Station class.
- Access method.
- First paging channel to use.
- Home system identification: 15 bits.
- Preferred system. The overall plan allows for one or two separate systems (A, B) in any city, and the unit must remember its assignment.

2.3 *Supervision*

Voice channels use a continuous supervisory audio tone (SAT); control channels and digital signals on the voice channels use a digital equivalent called "colour code".

- SAT frequencies: 5970, 6000, 6030 Hz.
- Digital "colour code": 2 bits coded into 7 bits, using a (7 : 4) Hamming code; used to identify the base station to which the message is intended.

In addition to these supervisory signals, a 10 kHz tone (deviation: ± 8 kHz) is used to indicate "on-hook".

2.4 *Malfunction*

Each mobile has a timer running independent of other logic functions, which will shut down the mobile transmitter within 60 s if the main logic ceases to function.

2.5 *Call processing*

Several primary tasks are specified; most important of these are (in order):

- d.c. power start-up and initialization;
- idle;
- activation:
  - origination;
  - paging response;
  - order response;
  - autonomous registration;
- conversation;
- release.

Other tasks, called secondary, are performed concurrent with, and controlled by, these primary tasks; these include:

- control data transmission and reception;
- control channel scanning;
- RF power control;
- response to system control messages;
- user interface management.

The primary tasks can be described briefly:

Initialization: when the unit is first turned on, the logic is made to enter the proper sequence; the memory and other mobile functional units can optionally be audited, and then the potential control channels are scanned, using a logarithmic measurement of signal strength, to find out which one will be able to tell the unit about its current proximity. Depending on whether the unit is "home" or "roaming", it may register its existence with the land system. It should also determine a control channel over which it can be paged if it receives a call.

Idle: without radiating, the unit receives and decodes the continuous stream of system control ("overhead") and paging messages, using the error-detecting and error-correcting algorithms available. During this time, it also monitors signal strength and reinitializes itself if the signal becomes unusable.

Activation: if the unit receives a call or gets a command from the user interface to place a call, the control channels should be rescanned, the idle state of the selected control channel determined, and a seizure of the system attempted. The unit then identifies itself to the system and a voice channel assignment will be given to it by the land system.

Conversation: if the mobile is being called, a ringing sequence is initiated; otherwise, the conversation state begins immediately. During the call, "blank-and-burst" messages (comprising a brief blanking of the voice signal and a burst of control data) may be received, instructing the mobile to change power and/or channel. Supervision via the out-of-band and SAT continues.

Release: when the call is ended normally, the transmitter is turned off and the unit is made to revert to the idle task again. If channel conditions of trouble or low-signal are encountered, release should also take place, so that positive system integrity is maintained.

2.6 *Signalling*

A variety of messages are required to administer the system; these are:

TABLE II

Channel	Types of messages
Base transmit:	
Control channels	Paging messages Channel assignments Overhead information Filler text
Voice channels	Hand-offs Orders
Mobile transmit:	
Control channels	Page responses mobile address serial number Origination mobile address serial number called number Orders Order confirmation
Voice channels	Order confirmation Called numbers

The fundamental signalling format used is a shortened (63 : 51) BCH word in which the first 28 or 36 bits are the message and the final 12 bits are parity check bits calculated from the message bits. Of the message bits, the first four serve a control or "book-keeping" function and the rest form the specific messages. 28 information bits are used in the base-transmit direction and 36 in the mobile-transmit direction, so that the resulting codes are (40 : 28) BCH and (48 : 36) BCH, respectively.

A second level of redundancy – message repetition when transmitting and bit-by-bit majority voting when detecting – is layered on top of the basic block coding. Interleaving of two message streams adds further de-correlation of bit error probability, where this is possible. Messages are typically repeated 5 times, except on the base-to-mobile voice channel when hand-off messages are sent; in this case, the message is repeated 11 times.

Bit sychronization is augmented by providing a long 101010... sequence before each message. Word synchronization employs an 11-bit Barker sequence (11100010010), which possesses unique minimum distance properties.

2.7 *Seizure*

The effects of collisions during control channel contention are mitigated by two devices:

- between each 10 bits on the base-to-mobile control channel, an eleventh bit is inserted; its state informs the mobiles of the busy/idle status of the control channel, and its change relative to the timing of a seizure attempt tells the mobile logic whether or not its seizure was clean;
- a precursor of 48 bits is added to the mobile's asynchronous seizure attempt on the mobile-to-base control channel to
  - provide bit and word synchronization and
  - signify the base station to which the attempt is directed.

This latter scheme lowers false seizures caused by co-channel interference.

3. Other

- Power classes:

  Class I: +6 dBW max.
  Class II: +2 dBW.
  Class III: −2 dBW.
- Power control: 7 steps, 4 dB per step.
- Other specifications: typically state of the art.

ANNEX II

GENERAL DESCRIPTION OF THE JAPANESE SYSTEM

1. Radio link design objectives

1.1 *Service quality*

- Blocking probability: Radio channels are allotted to make the radio path blocking probability less than 3%.
- Speech quality: The design objective of the speech quality is to realize more than 80% sound articulation score, which can produce 100% sentence intelligibility, in the service area.

1.2 *Radio zone configuration*

Coverage reliability of 80% sound articulation score in more than 90% of the service area. To get this reliability:

- Maximum cell size is determined so that 90% of the sites at the zone boundary provide reliable reception. Median C/N = 17 dB.
- Channel re-use is determined so that 90% of the sites at the zone boundary provide a reliable wanted/unwanted signal ratio. Median wanted/unwanted (W/U) = 15 dB.

2. Control channel configuration

2.1 *Control channel allotment*

The control channels are dedicated and divided into sub-sets of the following two channels:

- paging channel: mobile stations always seize this channel and receive the paging signal, location data and access channel data;
- access channel: a mobile station randomly originating calls is controlled with this channel. To prevent double seizures, the base stations detect the access signal from mobile stations and broadcast the busy status on this channel and then prevent the signals from other mobile stations (ISMA: idle signal multiple access).

2.2 *Multi-cell control technique*

A control channel is assigned to cover a group of adjacent traffic cells, and simultaneously transmitted from each base station in the control area.

2.3 *Seizure*

The busy/idle status in the control channel is used to mitigate the effects of collisions during control channel contention.

2.4 *Reduction of co-channel interference*

In order to prevent co-channel interference, control zones and radio zones using the same frequencies are discriminated by J-code and K-code, respectively.

3. Control sequence

3.1 *Mobile origination*

The features required in a mobile origination call are:

- numbering from the mobile station that uses the same format as the PSTN;
- locations of mobile stations are detected at base stations by the field strength of access signals received from mobile stations;
- speech channels are assigned by the access channel and a loop check signal is exchanged on the assigned speech channel between mobile station and base station;
- dialling signals are sent through the speech channel after the speech channel is set up.

3.2 *Mobile termination*

- Numbering for the mobile station is as follows:
  0 + 30 + (2 digits area identification number) + (5 digits subscriber number).
- A paging signal which is checked with the subscriber data at the home memory office, and is then simulcast from each base station in the control zone. If there is an answer from the mobile station, the next process is similar to the mobile origination. When there is no answer, i.e. if the mobile station is off-power or out of the service area, the originating subscriber will get a service announcement of the situation from the exchange (MSC).

3.3 *Hand-over*

A new speech channel is reassigned to mobile stations crossing a zone boundary:

- the base station detects S/N deterioration from the speech channel and asks the control station for hand-over;
- the control station orders an S/N check of the mobile to the original and neighbouring base stations;
- the control station selects a new zone and a new speech channel, after comparing the signals from the ordered base stations, and then assigns a new channel to the mobile station. In order to shorten disconnection time during this procedure (less than 500 ms), the land-line is reserved. If the mobile station cannot change to a new speech channel successfully, it returns to the previous speech channel.

4. Signalling code

Signalling code includes the following characteristics:

- telephone number: 7 decimal digits coded into 24 bits binary;
- serial number (not changeable);
- station class;
- first paging channel to use;
- home area identification: 2 decimal digits.

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ANNEX III

GENERAL DESCRIPTION OF THE NORDIC MOBILE TELEPHONE SYSTEM (NMT)

1. Introduction

The development and specifications of the international Nordic mobile telephone system (NMT) has been carried out by cooperation between Denmark, Finland, Norway and Sweden. The international aspects of the system were taken into account from the very beginning, making the system a true international public land mobile network from the start, e.g. roaming between countries and full access to the international public switched telephone network and its services.

The rapid growth of the number of subscribers in the NMT-450 system in the Nordic countries has led to the need for expanding the system into the 900 MHz band (NMT-900). Therefore, a new specification has been brought forward, taking the experiences from the NMT-450 into account.

Full detailed specifications for the systems and their components are given in the reference list.

2. Technical characteristics

2.1 *RF equipment requirements*

In accordance with Recommendation 478, the adjacent-channel selectivity requirement and adjacent-channel power requirement are met at 25 kHz channel spacing.

2.2 *Cell structure and channel re-use*

It is possible to use large cells (20-40 km radius) in rural areas as well as small cells (down to 0.5 km radius) in urban areas. The base station receiver sensitivity can be adjusted for symmetry in coverage range for the, two propagation directions taking base station (BS) and mobile station (MS) e.r.p.'s and (MS) receiver sensitivity into account.

In peak traffic density areas (e.g. city centres) it is possible to use a "sector" cell structure with directional antennas and a channel concentration at the centre of the traffic peak area.

2.3 *Control signals*

The use of 1200 bit/s FFSK signalling enables generation and detection of the FFSK signal at the mobile service switching centre (MSC) and the use of ordinary telephone network circuits to convey the FFSK baseband signal. At the base stations, the FFSK baseband signal is processed by the ordinary audio signal circuits (including pre- and de-emphasis). The same signalling is used to control BS channel equipment.

The capacity of the control signal is large enough to handle the traffic of at least 25 000 mobile stations per location area (LA) with a traffic load of 0.015 erlang per mobile station.

3. Operational characteristics

3.1 *Channel search procedure*

All channels may be used as calling channels (CC) or traffic channels (TC). The CC of a base station is used mainly to page the mobile stations on calls from the PSTN while the TCs are used to handle the calls and for the call set-up procedure for calls from a mobile station.

The channel search procedure of a mobile station is carried out in order to find either a new CC (current CC may be changed either because current base station has chosen a new CC or when entering a new cell) or to find an idle TC on call set-up.

The channel locking criteria is set in accordance with the frequency planning criteria. The scan of the band is performed at three receiver sensitivity levels.

3.2 *Location registration (roaming)*

The mobile station initiates the location registration procedure when necessary. Full automatic roaming is implemented between mobile service switching centres (MSC) and between countries in accordance with Recommendation 624.

3.3 *Call set-up procedure to MS*

The MS is locked to a CC of a base station in the LA where it was last updated in the system. A paging call is transmitted on the CC of all base stations in the area location. On reception of the call, the MS transmits an acknowledgement on the return frequency of the CC of the current base station. On reception of this signal, the MSC sends a channel switching order to an idle TC on that base station and the call is established on that channel.

3.4 *Call set-up procedure from MS*

MS searches for a free-marked TC (NMT-450 and NMT-900) or an access channel (NMT-900). The channel is seized by transmitting a call set-up request on that channel.

3.5 *Speech channel supervision*

During a call, one out of four supervisory tones with a frequency of about 4000 Hz and a deviation of ± 300 Hz is inserted by the BS together with the voice signal. This tone is looped by the MS and the quality of the tone after looping is evaluated by the BS.

3.6 *Hand-over procedure*

The quality of an on-going call is continuously supervised by the BS using measurements of RF signal level (NMT-900) and supervisory tone quality (NMT-450 and NMT-900). Should the quality fall below a pre-set level, the mobile service switching centre (MSC) is informed. The MSC will order neighbouring base stations (up to 16) to measure the signal quality on the used TC of the old BS, using a special measuring receiver, tunable to all channels. The measuring results from all neighbouring base stations is evaluated by the MSC. If one of the neighbouring base stations provides better reception than the current one, the MSC will allocate a free TC on the new BS for the call, send a channel switch order to the MS on the TC in use for the call on the old BS and re-route the call to the allocated TC on the new BS. Hand-over can also be carried out between base stations in adjacent location areas.

3.7 *Call release procedure*

Calls are released immediately upon reception of clearing signal from the mobile station. If the PSTN party hangs up but not the mobile station, the normal time-out function of the PSTN clears the call. Forced call clearing is carried out if the signal quality at the base station falls below a pre-set level for more than 20 s and hand-over is impossible. In the mobile station, there is an autonomous time-out, switching the transmitter off when the RF signal level is below a certain level for more than 30 s.

3.8 *Numbering plan*

In accordance with CCITT Recommendation E.213, the mobile station is identified in the public land mobile network (PLMN) by a unique seven-digit mobile subscriber number. In NMT-900 the mobile subscriber number is extended with a secret three-digit password.

3.9 *Signalling between MSCs and PSTN interface*

CCITT Signalling System No. 7, permitting hand-over between MSCs by use of mobile use part (MUP), or CCITT Signalling System R2.

The PSTN interface is in accordance with CCITT Recommendation Q.70. The diffferences between various national PSTNs are covered by the MSCs. Connection to the PSTN is made on trunk exchange level. MSC and trunk exchange can be integrated.

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2. Technical specification for the mobile telephone exchange, NMT Document 2;
3. Technical specification for the mobile station, NMT Document 3;
4. Technical specification for the base station equipment, NMT Document 3.

NMT-900:
1. System description, NMT Document 900-1;
2. Technical specification for the mobile telephone exchange, NMT Document 900-2;
3. Technical specification for Signalling System No. 7 mobile user part, NMT Document 900-2, Annex 3;
4. Technical specification for the mobile station, NMT Document 900-3;
5. Technical specification for the base station equipment, NMT Document 900-4;
6. Technical specification for the system simulator, NMT Document 900-5.

Available at any of the Telecommunications Administrations of Denmark, Finland, Norway and Sweden.

ANNEX IV

GENERAL DESCRIPTION OF THE C450 SYSTEM

1. Summary

The C450 system design combines optimum transmission quality and high capacity with very efficient utilization of the frequency spectrum. This is achieved by adaptive power control, distance measurements for cell assignment and hand-over and special switching capabilities like off-air call set-up and queueing operation. All relevant CCIR and CCITT Recommendations are met.

2. Radio-frequency interface

The radio-frequency interface is consistent with Recommendation 478. The system is designed for 20 kHz channel spacing and adjacent channels can be operated at one base station. Channel addresses for 25 kHz spacing are also provided in the equipment, as well as for 10 kHz and 12.5 kHz interleaved channels.

3. Permanent control of connection

Traffic channels have a permanent digital sub-channel control for continuous identification, power and signal quality control, etc. The power of base and mobile transmitters is adaptively controlled with 8 steps over a range of 35 dB.

Field strength and signal-to-noise ratio (phase jitter) are monitored for transmission quality assessment, both from the mobile and base station. As soon as the quality tolerances are violated, an intra-cell hand-over to another channel will be initiated.

During connection, the distance of a mobile station is continuously determined from its base station, and this information is transmitted on the digital sub-channel. By means of a special scanning receiver, each base station observes field strength and distance information of mobile stations in neighbouring base station areas as these approach the boundary of its own cell. In this way, the hand-over is prepared, and will be effected when the boundary is passed. The use of a channel is thus restricted to the defined base station area, which improves channel re-use and spectrum utilization.

A permanent exchange of identifications between mobile and base station prohibits another mobile station from accidentally entering into the connection.

The digital sub-channel is provided by time compression of speech signals, leaving 1.14 ms for the data burst within a period of 12.5 ms. Time compression has no perceptible influence on speech quality.

4. TDMA common control channel

All base stations of the C450 system operate on a common time-shared control channel, so that the mobile station can compare signals of the surrounding cells. The right base station is selected, either by comparison of relative distance (delay) – which is the preferred mode of selection – or by field-strength measurement. Each base station uses 1 time slot out of 32. In areas with high traffic, additional frequency channels can be added for common control (roaming), up to a total number of 8. The switch-over from the first common control channel, which is used in the whole service area, to another control channel is initiated by command from the relevant base station.

The TDMA frame with 2.4 s duration consists of 32 time slots, each containing 396 bits.

If a base station is in the status "blocked waiting queue", the mobile stations will check surrounding cells to determine whether support is possible.

5. Identification of mobile and base station

Mobile station:

– nationality	3 bits
– home mobile switching centre	5 bits
– remaining digits of subscriber number	16 bits

Base station:

– nationality	3 bits
– number of the mobile switching centre	5 bits
– remaining digits	16 bits

Up to 16 decimal digits are transmitted in one message.

6. Location registers

Location registration is consistent with Recommendation 624. There are three types of location registers.

The home mobile switching centre (MSC) has a file of all subscribers assigned to its area, with the following features: class of mobile station, priority status, roaming location, etc.

The visited mobile switching centre keeps a file of the active mobile stations including those originating from other MSCs.

The base station contains a register of active mobile stations within its cell boundaries. On average once in every 4 min, the mobile stations are polled and requested to answer to the base station. This updating procedure discovers the switched-off mobile stations and avoids "dead" entries in the file.

7. Security

Personal subscriber identification cards are used to allow operation of different mobile stations by the same subscriber. The call charge is assigned to the holder of the card. A special security code prohibits the use of lost cards by unauthorized users.

Privacy is provided by means of inversion of the audio frequency band. For data transmission, this band inversion can be switched off at the mobile station.

The mobile station has a built-in monitoring function which will shut down the transmitter when a severe malfunction occurs.

8. Switching capabilities

CCITT Signalling System No. 7 is used between base station and mobile switching centre. The numbering plan is in accordance with CCITT Recommendation E.213. The PSTN interface complies with CCITT Recommendation Q.70.

The time slot capacity of the common control channel is designed for a minimum percentage of access collisions. All other message dialogues are performed under control of the base station.

Optimum utilization of the speech channels is obtained by queueing and off-air call set-up during traffic peaks.

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ANNEX V

GENERAL DESCRIPTION OF THE TOTAL ACCESS COMMUNICATION SYSTEM (TACS)

1. Operational and system characteristics

1.1 *Purpose*

The public land mobile network (PLMN) is designed to permit an automatic exchange of traffic with the public switched telephone network (PSTN) and offers service, from the user's point-of-view, similar to that of land-line calls: high voice quality, high reliability, low blocking, relatively low cost.

1.2 *Cellular properties*

- Growth from large cells at start-up to small cells at maturity, with a mix of several sizes, is permitted.
- Hand-over is allowed, up to at least one per call per minute.
- For spectrum efficiency (channel re-use), small values for the number of channel sets are used, appropriate to the multipath (Rayleigh) fading typical of mobile channels, the terrain variability, the antenna patterns selected, and the RF quality desired. A local median C/I target of 17 dB at the 90th percentile is suggested. (If the standard deviation is 8 dB, this is equivalent to a median C/I of 27 dB, at the nominal boundary of the cell.) Other quality objectives are of course permissible.
- Enhanced mobile station registration techniques are employed to allow automatic roaming both nationally and internationally.

1.3 *Signal processing*

- The widest deviation and receiver pre-detection bandwidth appropriate to the cellular concept (which permits separation of the spectrum into channels by both frequency division and spatial separation) are used.
- Voice processing using a 2:1 compressor/expandor is employed to enhance the perceived quality of the received signal.
- The coding of digital signalling uses burst-error detection and correction.
- Design for a peak-to-r.m.s. ratio of between 6 dB and 20 dB for the demodulated voice signal at the receiver is possible; that is, a range of quality comparable to land-line service should be accommodated.

1.4 *Service protection*

- A transmitted serial number prohibits the use of stolen units or use by unauthorized callers.
- The introduction of means to ensure privacy of communication is not precluded by the design.
- Means for preventing intelligible cross-talk is included in the system design.
- The successful completion of the entire call takes place on at least 99% of the calls on which an initial two-way connection was established between calling and called parties.

1.5 *Services offered*

- Voice message telephone service with automatic calling to and from the PSTN and other mobile users.
- Data services.
- Vehicular-mounted equipment.
- Transportable equipment.
- Hand-held equipment.
- Other enhancements consistent with mobile service: call forwarding, repertory dialling, message waiting, etc.
- Charging information transmitted during a call to allow direct display of call charges: coin-box mobiles, taxi phones etc. are thus facilitated.

2. RF parameters

The major RF parameters of the system are detailed in Table I of Part C of this Report.

Other specific RF parameters are as follows:

2.1 *Modulation characteristics*

The peak FM deviation is around twice that normally associated with 25 kHz channel spacing. This has the major advantage of an improved resistance to co-channel interference, the minimum usable mean carrier-to-interference (C/N) ratio being around 10 dB rather than 15 dB. This means that for the same voice quality, a shorter frequency re-use distance, and hence a smaller frequency re-use pattern, can be employed. There is the effect, however, that adjacent channels cannot be used in the same cell, but this is not a problem for cellular radio systems because only a small proportion of the available channels (typically 1/7th) is used in any one cell.

2.2 *Total number of channels – up to 1000*

2.3 *Control channels*

In order to allow for more than one system operator in a given location, two sets of dedicated control channels are identified. There are 21 control channels in each set and each block of control channels is contiguous.

The dedicated control channels for system A are channels 23 to 43.

The dedicated control channels for system B are channels 323 to 343.

2.4 *Mobile station power*

There are 4 classes of mobile stations corresponding to the following powers:

TABLE III

Class of station	Type of mobile station	Nominal e.r.p. (W)
1	Very high power mobile	10
2	High power mobile	4
3	Mid-range power hand portable	1.6
4	Low power hand portable	0.6

Adaptive power control is employed with 7 steps of 4/8 dB.

2.5 *Supervisory tones*

Supervisory audio tones (SAT) are sent by the system over an assigned voice channel and transponded by the mobile station on the duplex voice channel forming a closed identification loop.

SAT frequencies – 5970 Hz; 6000 Hz; 6030 Hz.

Signalling tone (ST) is an 8 kHz tone transmitted on the assigned voice channel from mobile to base station. It is sent to indicate the status of the mobile handset:
– handset on hook – tone sent;
– handset off hook – tone not sent.

3. Signalling code and format

Signalling occurs in both directions on control channels and voice channels to ensure that the mobile station is always under system control. All data is generated at an 8 kbit/s rate.

Each of the four signalling paths carry different types of information and their operational conditions differ, this would require many compromises if a common signalling format were adopted. Each path is therefore treated independently.

Synchronization (sync.) sequences are chosen to minimize the risk of a random appearance within the data, and to provide sufficient time for the mobile/base station equipment to achieve sync. With the exception of the forward control channel (FOCC), used by the base station, transmission occurs as a burst of data when required.

All channels are subject to fading and interference. To give adequate error protection, each data word is transmitted a number of times and incorporates forward error correction bits to ensure integrity. At the receiving end, the repeats are stored sequentially and a majority decision made bit-by-bit on five stored words (the eleven repeats sent on the forward voice channel ensure that at least five will be received by the mobile station).

A BCH code generator is used to produce 12 bits of parity which are added to the end of the data to produce the overall data word. The forward channels (FOCC; FVC) use 28 information bits and 12 parity bits per word, the reverse channels (RECC; RVC) have 36 information bits and 12 parity bits per word. This code structure is capable of correcting 1 bit errors and detecting 4 bit errors.

Transmission of control data over the voice channels (FVC; RVC) is accomplished by muting the audio paths while transmitting the data burst. This is a very short duration activity not noticeable to the user.

Before FSK transmission, the data is Manchester encoded. This ensures that sufficient data transitions occur to permit accurate bit synchronization within the signal. This is particularly necessary for synchronizing sequences with large strings of zeros and ones.

The data words are complex packets of information sub-divided into groups of bits or single bits each defining a system parameter: serial number, dialled digit, etc. The exact format within a word is dependent on the type of channel in use and the type of message.

4. International mobile station identity

A 34 bit binary mobile identification number is derived from the 10 digit international mobile station identity which comprises a 3-digit mobile counting code, a 1-digit mobile network code and a 6-digit mobile station identification number (see CCITT Recommendation E.212).

A unique 32 bit binary serial number is assigned to each mobile station. The number is non-changeable and is intended as an anti-fraud, anti-theft means.

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ANNEX VI

GENERAL DESCRIPTION OF THE ITALIAN 450 MHz SYSTEM

1. System structure

The Italian territory is sub-divided into 10 *calling areas.* A calling area is characterized by a single calling channel; calls to mobile stations present in that area are transmitted in a simulcast mode by all the base stations included in that area. Adjacent calling areas use different calling channels. The same calling channel is re-used in distant calling areas.

Calls directed to mobile stations are routed through the main mobile control centre (MMCC) of the calling area where the mobile station is present.

When a mobile station crosses the border between two calling areas, it automatically informs the MMCC of the new calling area of its presence. This MMCC will update the location registration of all the other MMCCs, so that each MMCC knows the calling area in which each subscriber is present.

A calling area may either be coincident with a *conversation area* or sub-divided in some conversation areas. A conversation area is characterized by the fact that mobile station originated calls enter the telephone network directly in the satellite mobile control centre (SMCC) of the conversation area, apart from the conversation area where the MMCC is located. The hand-over procedure is only possible within a conversation area. Each conversation area will include several base stations in order to cover the most populated areas and the main roads.

The Italian territory will be sub-divided into 16 conversation areas; the average size of a conversation area will be about 20 000 km^2.

The MMCCs and the SMCCs will be connected to the tertiary centres of the telephone network.

2. Radio-frequency characteristics

2.1 *Frequency band*

The system is planned to operate in the 450 MHz band. There are 200 duplex channels, the highest four channels are utilized as unidirectional calling channels.

2.2 *Base stations and channel grouping*

Each base station will be equipped with a redundant calling transmitter, two monitor receivers utilized for the hand-over procedure and a number of traffic transceivers dependent on the traffic expected in the coverage area of the base station.

The maximum number of duplex channels for each station will be 64; several groups of 64 channels can be used at the same site. Traffic channels utilizing the same antenna system are usually grouped in a self-masking intermodulation arrangement. Normally eight channels with equal spacing of 600 kHz are grouped together; such a spacing allows the utilization of small transmit branching filters.

2.3 *Transceiver characteristics*

Most transceiver performances are in line with those of equipment utilized in other advanced public mobile systems. However, it seems suitable, from the system point of view, to mention the following characteristics:

- the nominal output power of the base station transmitters is 25 W and that of the mobile transmitter 10 W. A 10 dB reduction of the output power is possible. The power reduction of the mobile station is automatic;
- a syllabic compandor is utilized in both directions of transmission in order to improve speech quality;
- band inverters are provided which can be inserted and deactivated by the mobile subscriber during the conversation.

3. Numbering and call procedures

3.1 *Numbering*

The national telephone number of a mobile station consists of a service access code "0333" followed by a six digit subscriber number. The first of the six digits is the same for all the subscribers, and is utilized for control purposes, the second and third digits are related to the MMCC to which the subscriber belongs.

Usually the telephone number is the same as the mobile station identification number; however, there is the possibility for about 10% of subscribers to have an identification number different from the mobile station telephone number; this possibility allows a subscriber whose mobile equipment has been stolen, to keep the same telephone number.

3.2 *Call to a mobile subscriber*

A call to a mobile subscriber is made by dialling his telephone number, including the service code. The service code connects the calling party to the nearest MMCC. This MMCC analyzes the mobile station number with regard to validity, subscriber category and location registration. If the mobile station is in another calling area the call is routed to the corresponding MMCC.

The MMCC of the calling area where the mobile station is present, pages it through all the calling transmitters included in that area.

When the mobile station receives its identification, it starts to search for an idle traffic channel with the same procedure as for mobile station originated calls (see § 3.3). When a free traffic channel is found, the mobile station identification and the acknowledgement signal are transmitted. If the MMCC does not receive the acknowledgement within 10 s, it sends a second paging call.

3.3 *Mobile station originated calls*

The pre-seizure dialling, or off-air call set-up, is employed in order to reduce the channel occupancy due to dialling information. The mobile station searches for a free traffic channel with a double threshold search; in the first attempt a search is only made for a good quality free traffic channel, in the second attempt a search is made for a channel with only acceptable quality. The double threshold search improves the system quality and reduces the number of hand-over events.

Once a traffic channel is found, the mobile station identification and the dialled number are transmitted. The SMCC or the MMCC analyzes the subscriber validity and category and then the call is set up.

4. Hand-over

If during a conversation the quality falls below a given value, the involved base station informs the corresponding SMCC or MMCC which will initiate the hand-over procedure by ordering a field-strength measurement on the relevant traffic channel to the monitoring receivers of adjacent base stations. If one of the base stations offers better transmission quality and at least one traffic channel is free in that station, a command is sent to the mobile station via the previous traffic channel to switch to the new channel.

A confirmation from the mobile station is sent on the new channel and then the switch-over is completed by the control centre.

5. Signalling on the radio path

The main signalling utilized in the radio path is a two-of-seven in band multi-frequency code suitable for operation in a mobile service environment. It has been derived from the code already used in the first generation Italian system for which a long field experience has been gained.

A low frequency pilot with amplitude modulation is used for information that is transmitted during conversation, e.g. band inverter insertion and deactivation command, and call charge pulses to the mobile station.

Up to three different audio frequency pilots can be utilized to identify the same (frequency) channel employed in the three different adjacent clusters.

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ANNEX VII

GENERAL DESCRIPTION OF THE FRENCH NATIONAL SYSTEM

1. Frequency band and class of emission

The system uses blocks of channels (up to 256 per block) with a channel spacing of 12.5 kHz, class of emission 11K0G3E. The frequency bands used in France are the 200 MHz (duplex spacing 8 MHz) and 400 MHz (duplex spacing 10 MHz) bands.

2. Signalling

FFSK modulation at 1200 bit/s; Hagelbarger coding.

3. Characteristics of the mobile stations

The station may be multi-service or only offer some of the services described in § 2 of Part C of this Report.

The mobile station has access to 256 channels.

4. Characteristics of the base stations

The base station comprises a switching unit connected to the PSTN as a time-division PABX with automatic direct routing capabilities ("direct dialling-in").

The base station may have up to 24 transceivers cavity coupled to two or three antennas. The radio channels are managed by queueing. Off-air call set-up is used.

5. Architecture of the system

The PSTN switching exchanges are connected by PCM links to the relays which are comprised of the relay management unit, the switching and radio units. Remote radio units may be connected to the relays, for instance to cover low density areas.

Information exchange and re-routing are carried out using the PSTN.

6. Capacity of the system

The numbering plan provides for 500 000 subscribers.

7. Frequency efficiency

A block of 256 channels in a cell may serve 7000 public telephone type subscribers, 20 000 dispatch type subscribers or any combination of these two types.

8. Charging

Charging is carried out by the relays, and then retransmitted by 1200 bit/s links to an operating centre.

9. Commissioning

Operation will start at the end of 1985 for the Paris area, with 17 000 subscribers expected by the end of 1986 and 135 000 subscribers throughout the territory by the end of 1990.

It is foreseen that 85% of the surface area of metropolitan France will be covered.

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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. Annex I 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 and Kurouchi, 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.

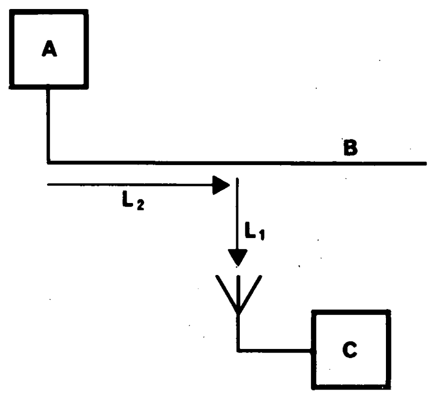

FIGURE 1 – *Basic system*

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].

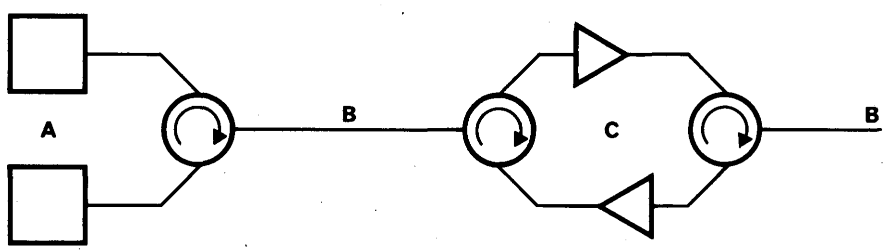

FIGURE 2 – *Extended system using two-way repeaters*

A: base station transmitter and receiver
B: leaky cable
C: two-way repeaters

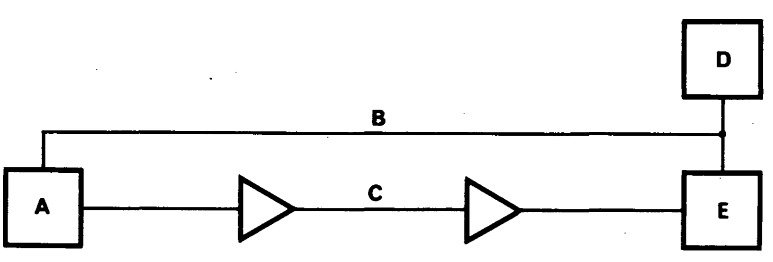

FIGURE 3 – *Daisy-chain system with one-way repeaters*

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.

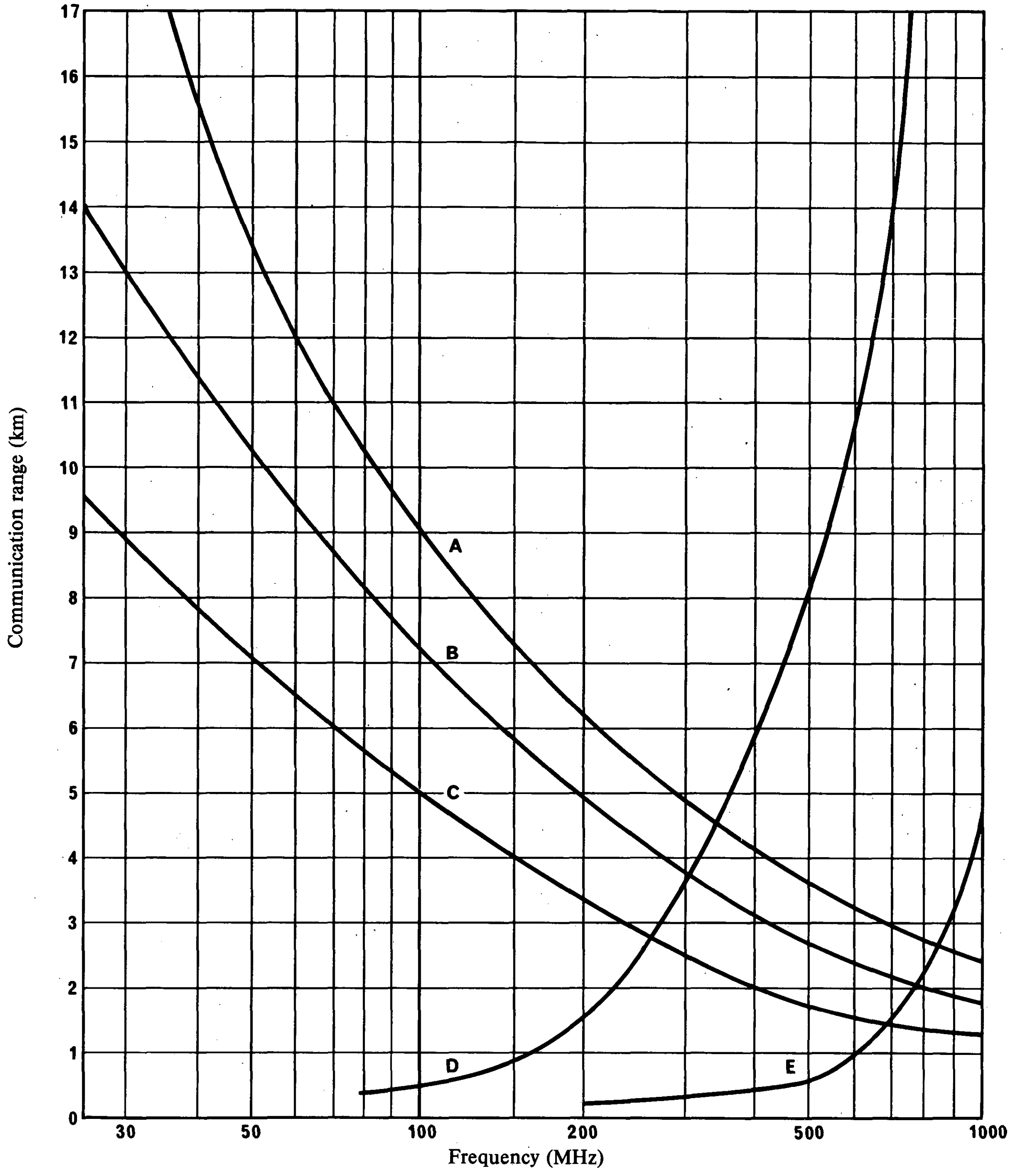

FIGURE 4 – *Linear (end to end) communications range in tunnels*

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)

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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:

$$A = -46.7 + 10 \log (d_1 d_2) + 20 \log f \qquad \text{dB}$$

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:

$$L_{10} = \frac{1,3\ z \times 10^6}{f^2 d_2^3} \qquad \text{dB}$$

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

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REPORT 903-1

DIGITAL TRANSMISSION IN THE LAND MOBILE SERVICE

(Question 40/8)

(1982-1986)

PART A

SPECIFICATION OF DIGITAL TRANSMISSION SYSTEMS

1. Introduction

This Part identifies performance specifications for a digital transmission system and shows how these should be related to the system design parameters. The performance specifications are determined from the operational requirements of the user. The system design parameters are digital modulation methods (Part B), error performance of digital transmission (Part F), formats for data transmission (Part G) and signalling and supervision methods (see Report 741).

2. Performance specifications

The performance specifications to be extracted from the user operational requirements are traffic capacity, system response time, false message probability and coverage area.

2.1 The *traffic capacity* is determined from:

$$T = d \, \zeta \, r \, P_s$$

where:

- d: data rate is related to the digital modulation method and channel bandwidth;
- ζ: channel access control efficiency is related to the signalling and supervision methods;
- r: protocol efficiency is related to the data transmission format;
- P_s: successful message probability is related to the error control techniques.

2.2 The *system response time* is related to the successful message probability, channel access control efficiency and data rate.

2.3 The *false message probability* is related to the error control techniques.

2.4 The *coverage area* is related to the minimum average RF signal level requirement for an acceptable successful message probability. This level will affect the number of radio sites and/or the transmitter power required.

PART B

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 ratio (BER) under fading conditions, 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.

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.

2.5 To minimize the number of errors caused by deep signal fading, rapid bit re-synchronization is required.

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.

The signalling schemes suitable for use on these channels can be divided into the two classes of sub-carrier modulation and direct (data) frequency-shift. Sub-carrier modulation is often preferred because of its characteristic of eliminating all low-frequency components in the modulation signal.

Frequency shift keying of a suitable sub-carrier is a good choice for low speeds. Gaussian filtered minimum shift keying (GMSK)* and tamed frequency modulation (TFM) of a carrier are suitable for high speed, as they produce a nearly constant envelope and a sufficiently compact frequency spectrum when combined with the low-pass filtering normally present in land-mobile radio equipment. Figure 1 shows the spectra of the modulating signals produced by TFM and GMSK methods.

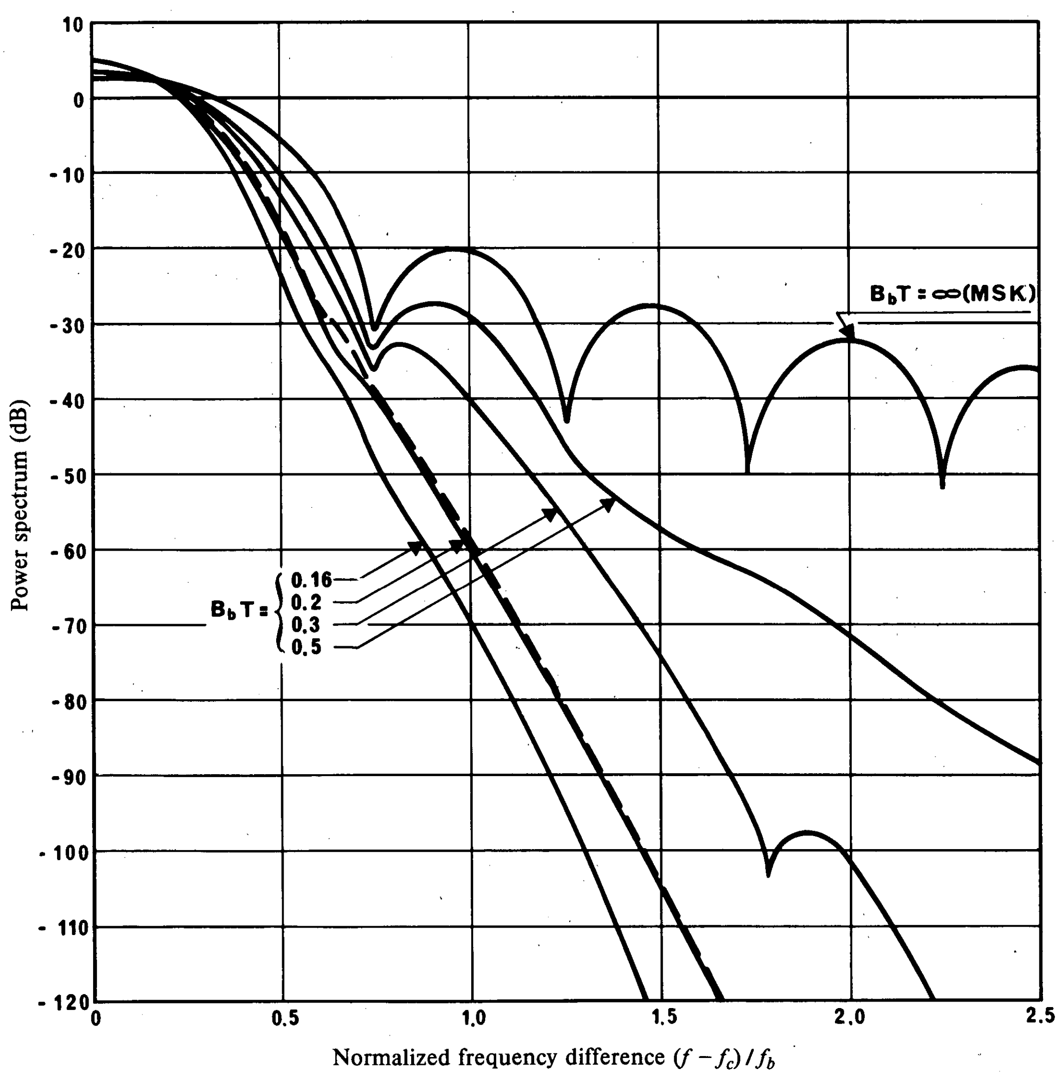

FIGURE 1 – *Power spectra of TFM and GMSK*

----: TFM
B_bT: normalized bandwidth of premodulation gaussian bandpass filter (GMSK)
f_c: carrier frequency (Hz)
f_b: bandwidth (Hz)

* Also known as Gaussian filtered fast frequency shift keying.

In general, the narrower the bandwidth of the Gaussian pre-modulation filter, the more compact the output power spectrum may be made. However, bit error ratio performance may be degraded. For this reason, it may be preferred to use direct frequency-shift operation. The spectrum presented to the modulator in this case is shown in Fig. 2, compared with GMSK. Measured spectra for these two cases are shown in Fig. 3.

Required E_b/N_0 for the specified BER of 10^{-3} versus B_bT* is theoretically estimated for non-fading conditions as shown in Fig. 4, 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. 5. 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 $B_bT = 0.25$. The non-linear process of frequency modulation broadens the spectrum substantially as is shown by Figs. 2 and 3.

In addition to TFM and GMSK, several other digital modulation techniques such as 4-level FM [Akaiwa *et al.*, 1981], PLL-4-PSK [Honma *et al.*, 1980], exist and these are suitable for land mobile radio.

Not only the modulation technique, but also the demodulation technique determine transmission performance. Therefore, it is necessary to study the applicability of coherent, differential and discriminator detections from the viewpoint of performance in fading environment.

4. Channel frequency spacing

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].

Adjacent-channel interference levels for several different modulation schemes and speeds are presented in Table I.

The dominant factor in channel spacing is adjacent-channel interference performance.

Figure 6 shows the adjacent-channel interference performance of digital signals. When the normalized frequency difference (the ratio of frequency difference to transmission bit rate) is 1.5, the ratio of unwanted-to-wanted signal level (U/W) is approximately 45 dB.

The adjacent-channel interference performance is shown in Fig. 7, where the wanted signal is a digital signal and the unwanted signal is an analogue FM signal. At the normalized frequency difference 1.5, U/W is more than 60 dB when the analogue FM signal is modulated by a 1 kHz tone, and approximately 40 dB when the analogue FM signal is modulated by an artificial voice signal.

Figure 8 shows the adjacent-channel interference performance when the wanted signal is an analogue FM signal and the unwanted signal is a digital signal. At the normalized frequency 1.5, U/W is approximately 50 dB.

These results suggest that channel spacing should be determined based on a value equal to 1.5 times the transmission bit rate, conventional channel spacing, and allowable carrier drift conditions.

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* B_bT is the normalized 3 dB bandwidth of the filter.

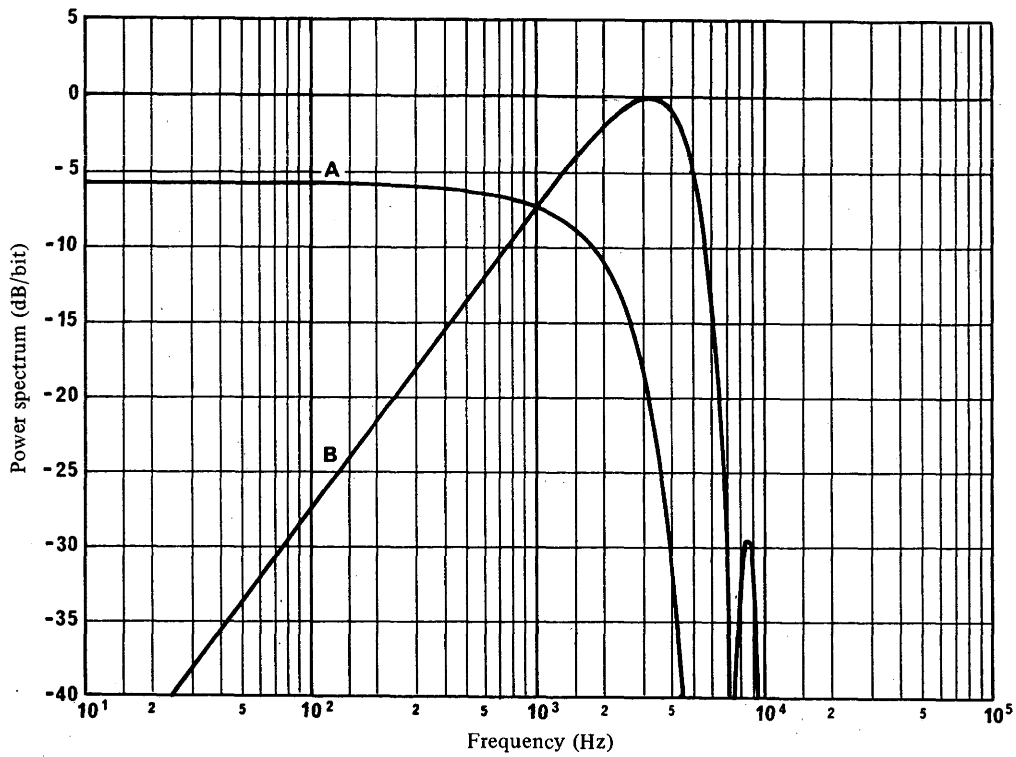

FIGURE 2 – *Power spectra of filtered baseband*

Curves A: baseband spectrum
B: filtered FFSK (GMSK)

Data and GMSK

Data rate: 4800 bit/s

GMSK: 2400 Hz/4800 Hz

B_bT: normalized bandwidth of pre-modulation filter

$B_bT = 1$

Baseband $B_bT = 1/2$

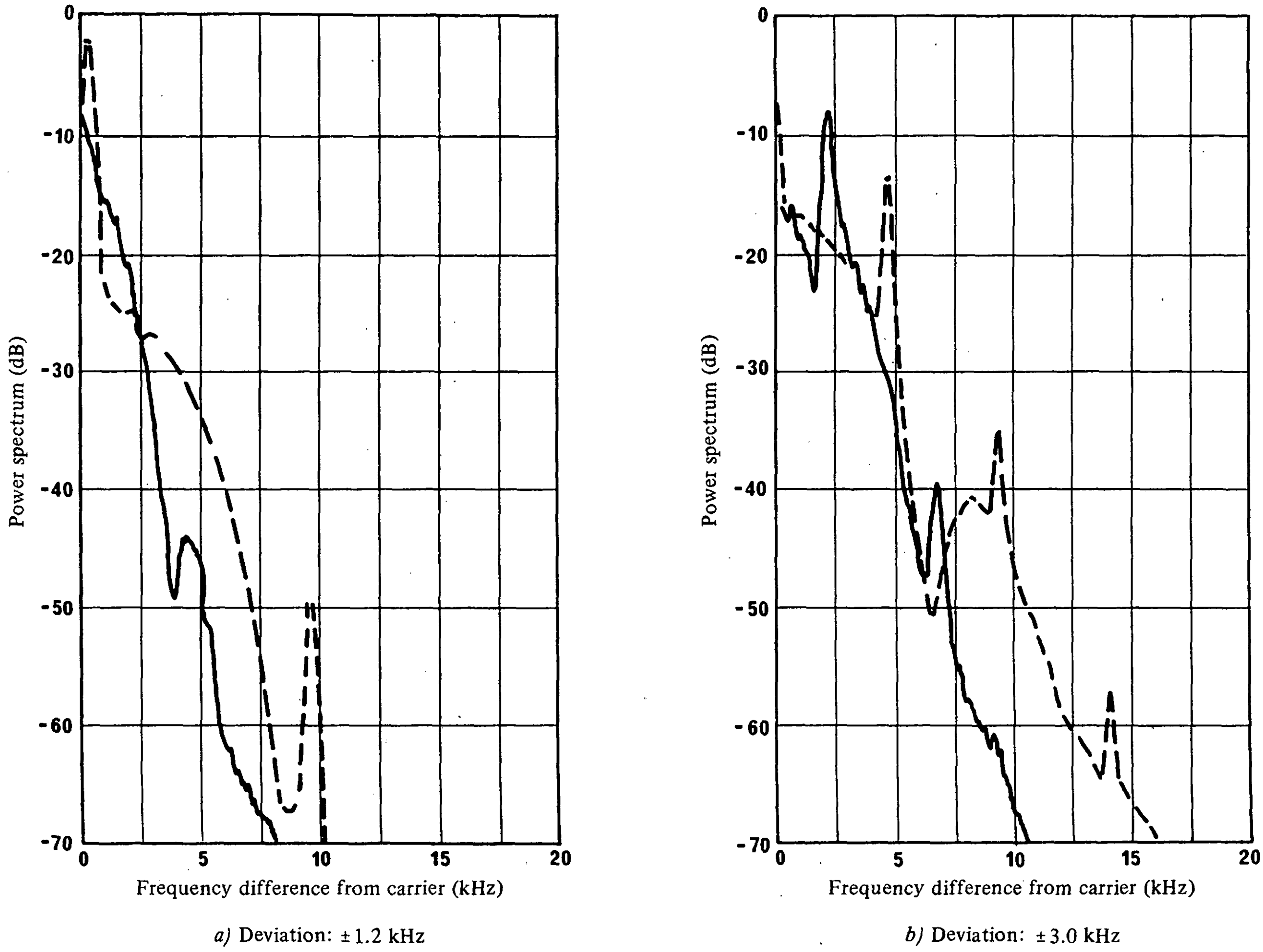

FIGURE 3 – *Interference power spectra of sub-carrier GMSK and filtered direct FM*

——————— filtered baseband

— — — — — filtered FFSK (GMSK) of sub-carrier

Data rate: 4800 bit/s

Data is pseudo-random binary sequence of length $2^{17} - 1$

GMSK $B_bT = 1$

Baseband $B_bT = 1/2$.

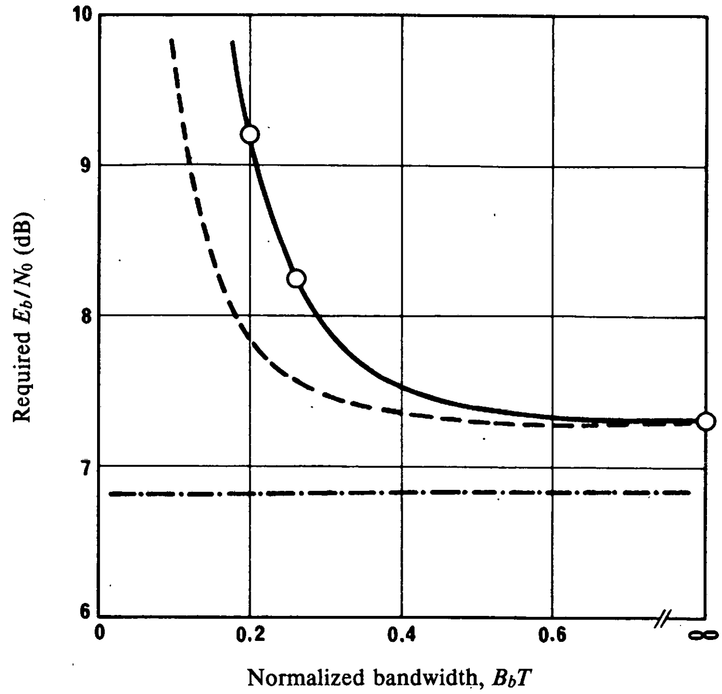

FIGURE 4 – *Required E_b/N_0 versus B_bT*

——————— : 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

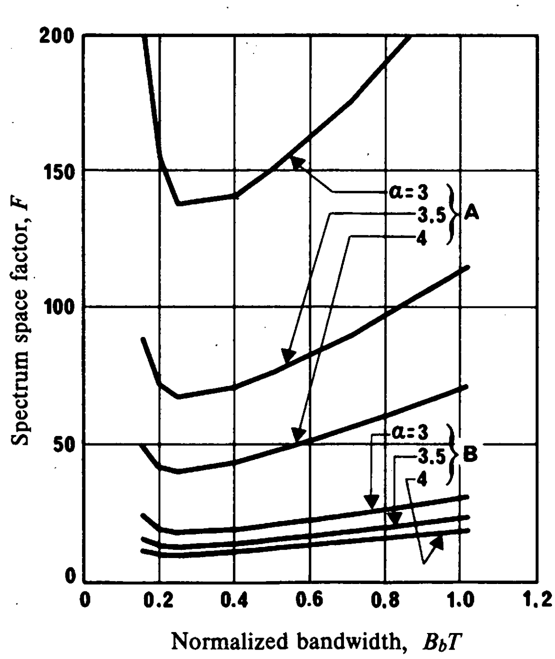

FIGURE 5 – *Spectrum space factor of GMSK*

A: no diversity
B: maximum ratio diversity

TABLE I – *Measured adjacent-channel interference levels (U/W) (dB) by the method specified by CEPT*

		Channel separation				
		12.5 kHz	20 kHz		25 kHz	
		Deviation	Deviation		Deviation	
		±1.2 kHz	±1.2 kHz	±3.0 kHz	±1.2 kHz	±3.0 kHz
Sub-carrier modulation	600 bit/s FSK	76	> 90	> 90	> 90	> 90
	1200 bit/s GMSK	76	> 90	> 90	> 90	> 90
	2400 bit/s GMSK	72	> 90	> 90	> 90	> 90
	4800 bit/s GMSK	55	> 90	60	> 90	78
Direct FM	4800 bit/s	76	> 90	> 90	> 90	> 90
	9600 bit/s	53 (1)	67 (1)	not available	76 (1)	not available

U/W: Ratio of unwanted to wanted signal level.

(1) ± 2.4 kHz deviation.

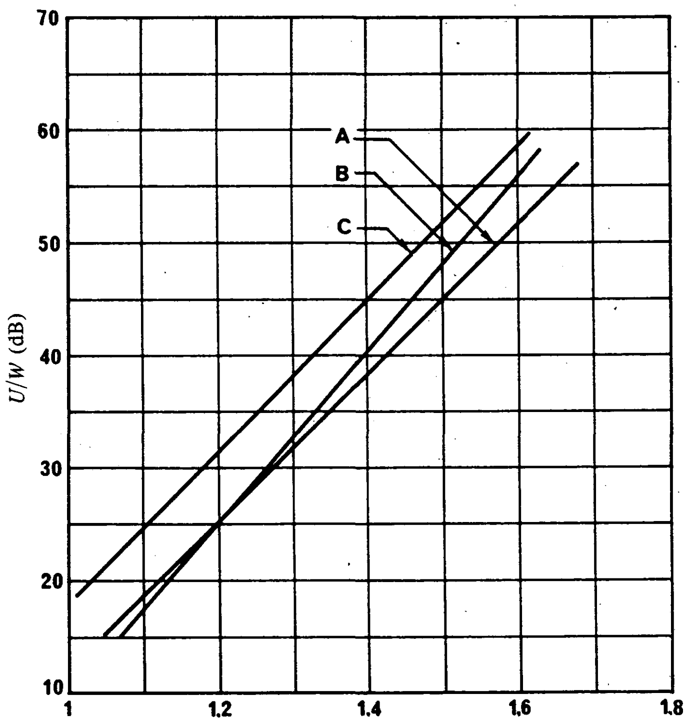

FIGURE 6 – *Adjacent-channel interference performance*

Wanted signal: W-level corresponds to BER = 1×10^{-2}. The signal is modulated with a 9-stage PN sequence

Unwanted signal: U-level corresponds to BER = 1×10^{-2} when desired signal level is 3 dB in excess of W-level. The signal is modulated with a 15-stage PN sequence

Modulation: wanted and unwanted signals are modulated by

A: GMSK;

B: 4-level FM;

C: PLL-4-PSK.

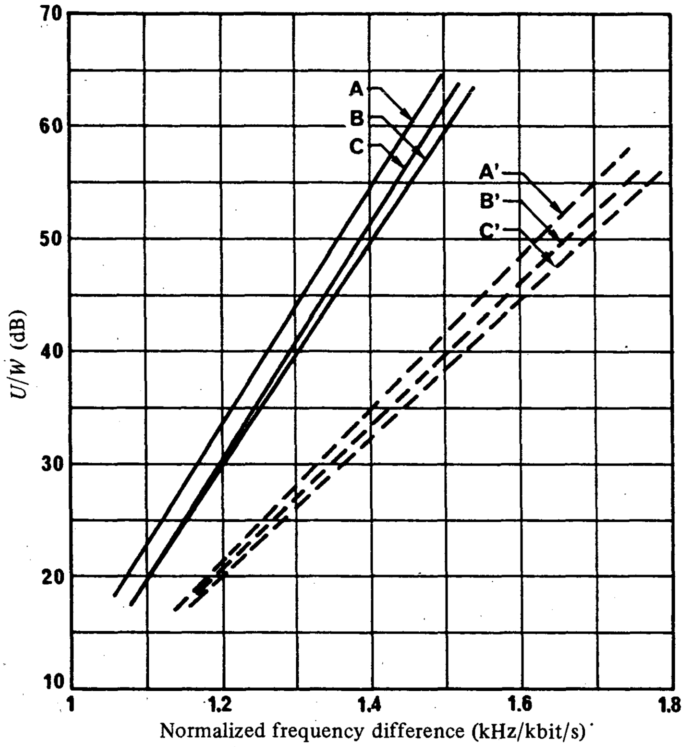

FIGURE 7 – *Adjacent-channel interference performance*

Wanted signal: W-level corresponds to BER = 1×10^{-2}. The signal is modulated with a 9-stage PN sequence

Unwanted signal: U-level corresponds to BER = 1×10^{-2} when wanted signal level is 3 dB in excess of W-level. The signal is modulated with:

- a 1 kHz tone at 1.5 kHz frequency deviation (A, B, C);
- an artificial voice signal specified en Recommendation G.227 of the CCITT (A′, B′, C′)

Modulation: wanted signal is modulated by

A, A′: GMSK;

B, B′ : 4-level FM;

C, C′ : PLL -4-PSK;

unwanted signal is modulated by analogue FM.

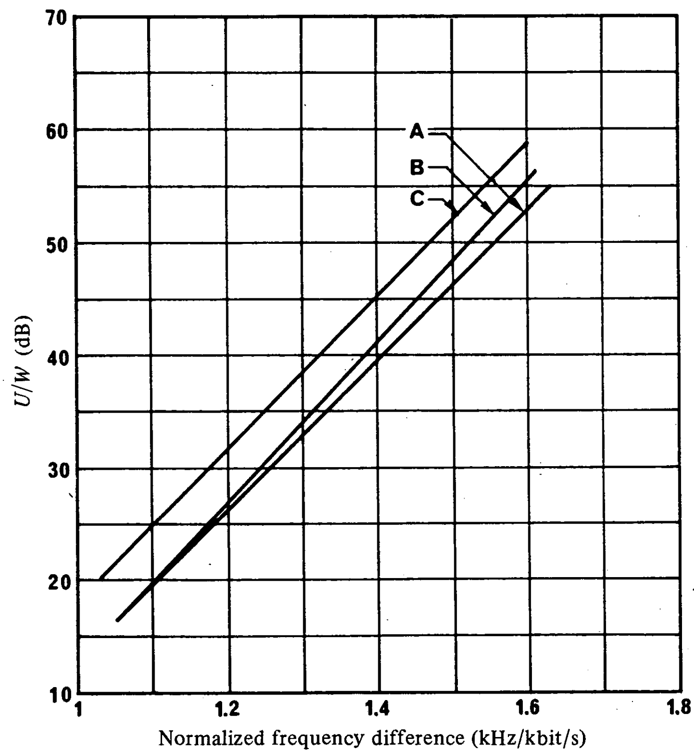

FIGURE 8 – *Adjacent-channel interference performance*

Wanted signal: W-level corresponds to SINAD = 12 dB. The signal is modulated with a 1 kHz tone at 1.5 kHz frequency deviation

Unwanted signal: U-level corresponds to SINAD = 12 dB when wanted signal level is 3 dB in excess of W-level. The signal is modulated with a 15-stage PN sequence

Modulation: wanted signal is modulated by analogue FM, and unwanted signal is modulated by

A: GMSK;

B: 4-level FM;

C: PLL-4-PSK.

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PART C

VOICE TRANSMISSION OVER DIGITAL CHANNELS

1. Introduction

This Part is concerned with digital speech transmission over digital channels.

2. Quality of digitized speech systems

2.1 *Voice coding*

In mobile radio communication, low bit-rate voice coding is desirable to achieve efficient spectrum utilization. Although techniques such as ADM (adaptive delta modulation), ADPCM (adaptive differential pulse code modulation), APC-AB (adaptive predictive coding with adaptive bit allocation), PARCOR (partial autocorrelation), and SBC (sub-band coding) may be suitable, it is necessary to study their quality in a fading channel. The quality will also depend upon other factors, such as synchronization methods and error correcting methods (partial or global) – if any – associated with the speech coder.

2.2 *Use of digitized speech systems*

In the United States of America 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.

Figures 9 and 10 show a comparison between the mean opinion scores for analogue FM transmission and digital voice transmission using GMSK coherent detection with a 16 kbit/s ADM Codec in conventional channel spacing of 25 kHz [Kinoshita *et al.*, 1984]. These figures show that digital voice transmission will be applicable for some systems requiring high security, but with the penalty of quality degradation.

The mean opinion scores for digital voice transmission using GMSK discriminator detection [Hirono *et al.*, 1984] with a 16 kbit/s APC-AB Codec and a 2.4 kbit/s Vocoder are also shown in Fig. 9. A 16 kbit/s APC-AB system achieves the quality comparable with an analogue FM system. A 2.4 kbit/s Vocoder system provides approximately the same quality as a 16 kbit/s ADM system, and is suitable for narrow-band communication.

3. Voice privacy

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.

4. Transmitter emission limitations

In the United States of America 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.

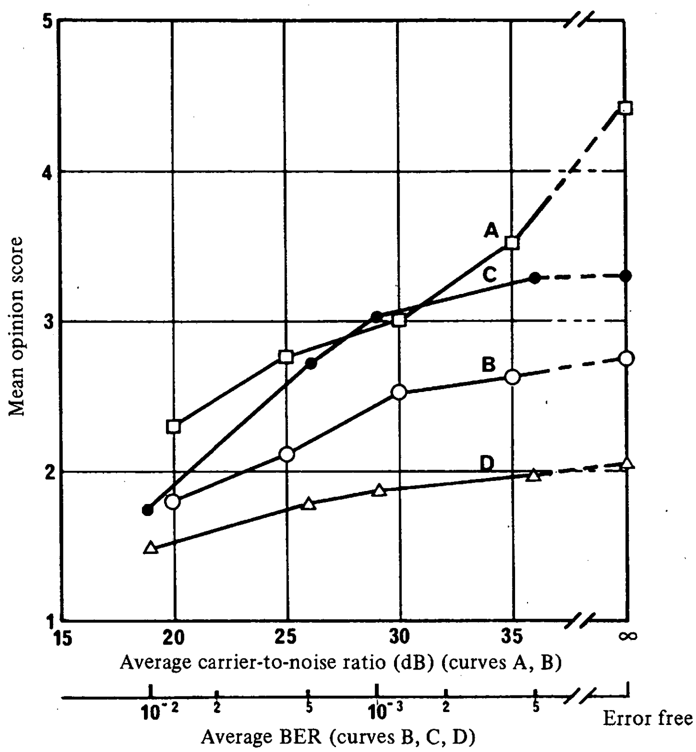

FIGURE 9 – *Comparison of digital and analogue voice transmission; result for thermal noise*

Curves A:	analogue	FM deviation: 3.5 rad/1 kHz
B:	digital	GMSK with coherent detection 16 kbit/s ADM
C:	digital	GMSK with discriminator detection 16 kbit/s APC-AB
D:	digital	GMSK with discriminator detection 2.4 kbit/s Vocoder

Fading rate 20 Hz

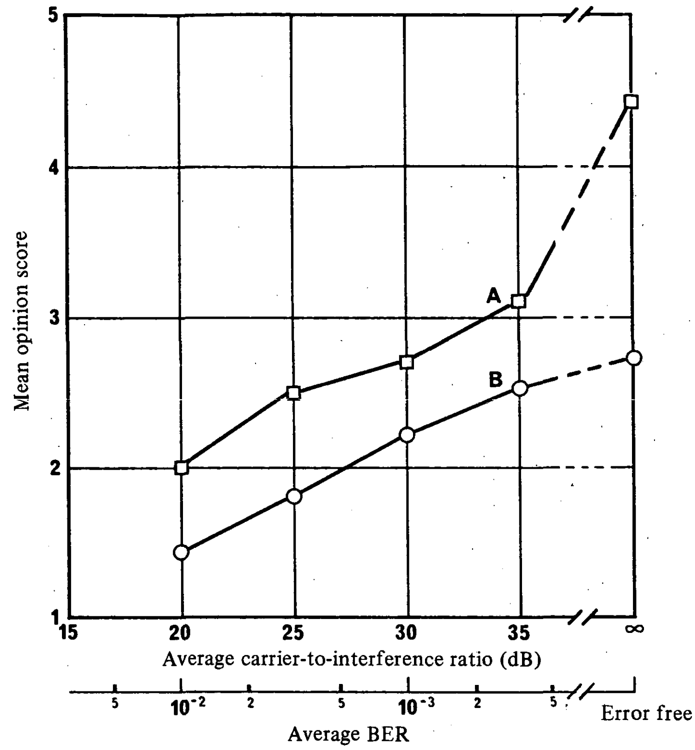

FIGURE 10 – *Comparison of digital and analogue voice transmission; result for co-channel interference*

Curves A:	analogue	FM deviation: 3.5 rad/1 kHz
B:	digital	GMSK with coherent detection 16 kbit/s

Fading rate 20 Hz

5. 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].

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PART D

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.

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*

Bit rates up to 3600 bit/s are presently being used in Canada for transmission over the existing 30 kHz VHF and 25 kHz UHF land mobile channels. One method of transmission is the use of the Miller code [Lindsey and Simon, 1973] over sub-carrier/FM systems passing through the speech processing circuitry (pre-emphasis/de-emphasis). The appropriate equalization circuits are used to minimize the potential inter-symbol interference that will otherwise severely reduce the effective data transmission rates [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 high bit rates it may be necessary to modify the speech circuits or bypass them and apply the sub-carrier data signal directly to the modulator and recover 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 land line 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.

* 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.

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 therefore, at present, 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.

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PART E

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 bit/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.

Data derived from operational experience with 1200 bit/s FSK signalling, a shortened (63 : 45) BCH code with error detection only and a 12 dB reduction in transmitted power towards the mobile when signalling, as compared to the level for voice transmissions [Callendar, 1981] are shown below.

Total successful calls in sample period: 10 533.

TABLE II

Number of retransmissions	0	1	2	3	4	5	6
Number of calls	9619	615	175	64	30	24	6
Percentage	91.3	5.8	1.7	0.6	0.3	0.2	0.05

The handshake protocol for the majority of these calls involved one base to mobile data message. However each individual data message can be repeated, if required, up to six times.

Since 91.3% of these calls required no retransmissions, it was concluded that, in this application with reduced signalling power and no forward error correction, simple ARQ is sufficient for the 8.7% of calls in which retransmissions are required. Correction of even single bit errors in the mobile unit could be expected to significantly reduce the number of retransmissions required.

5. Major system characteristics

Major system characteristics are contained in Report 742.

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PART F

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. 11). The theoretical effect of fading and shadowing together is shown (see Fig. 12). (Shadowing is also known as location variability.) Results at UHF from Japan are shown in Fig. 13 [Daikoku *et al.*, 1981].

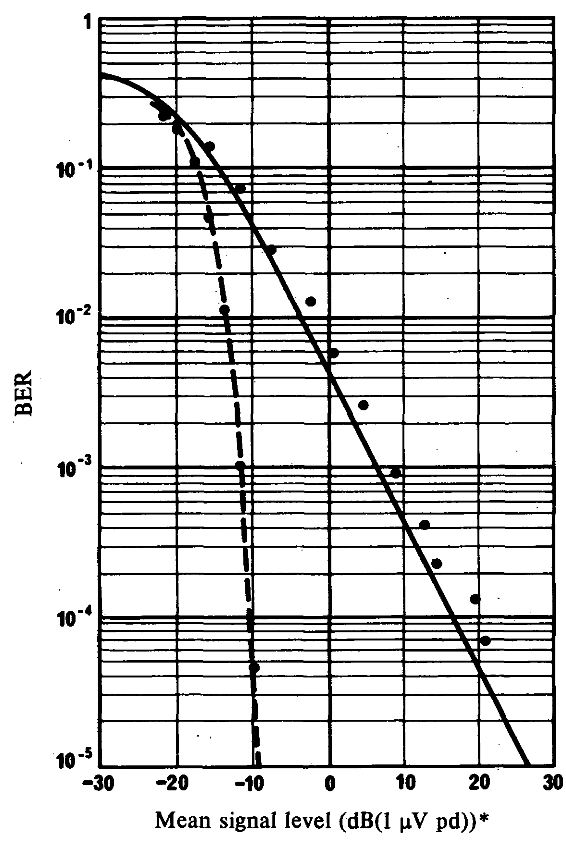


FIGURE 11 – *Measured BER with steady and fading signals*

— — — : 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.

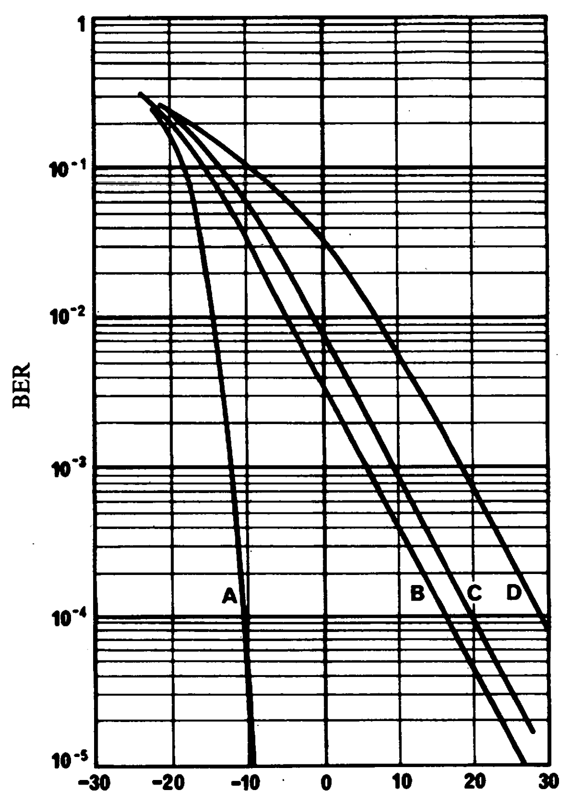


FIGURE 12 – *Impact of fading and shadowing on BER*

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

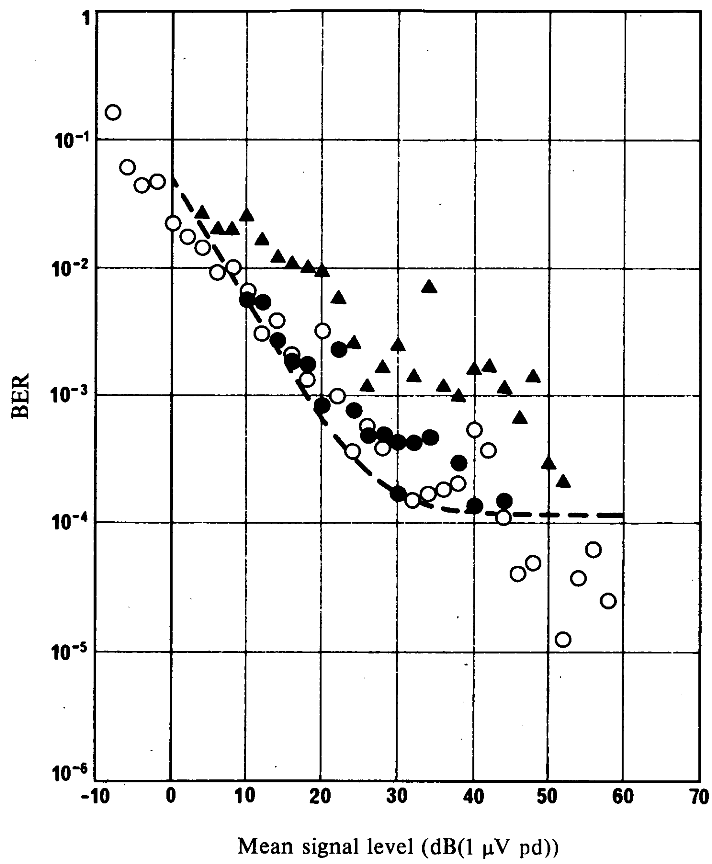


FIGURE 13 – *BER performance under fading conditions*

– – – : 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

2.1 *Spaced frequency correlation function*

The performance of a digital communication system on land mobile radio channels is affected, among other things, by the coherence bandwidth [Bello and Nelin, 1963; 1964] over which random variations on the channel are statistically correlated. The value of correlation that defines the coherence bandwidth B_c is a function of the transmitted symbol shape and the modulation technique employed.

Figure 14 represents a cumulative distribution function computed from the measured data collected during an experiment in the 900 MHz mobile radio band in the urban centre of Ottawa, Canada [Bultitude, 1983]. This figure shows the probability that bandwidths, at which frequency correlation drops below 25%, are greater than the value of the abscissa. Since computed correlation functions were assymetrical with respect to the centre frequency, the minimum of the positive and negative bandwidth figures for each correlation function were used in the computation. The coherence bandwidth results from time dispersion. It can be considered that inter-symbol interference would be negligible if transmission bandwidths were maintained below 10% of the value shown in Fig. 13. Nevertheless, systems may be designed to include equalization, diversity or other features to counteract or make use of time dispersion.

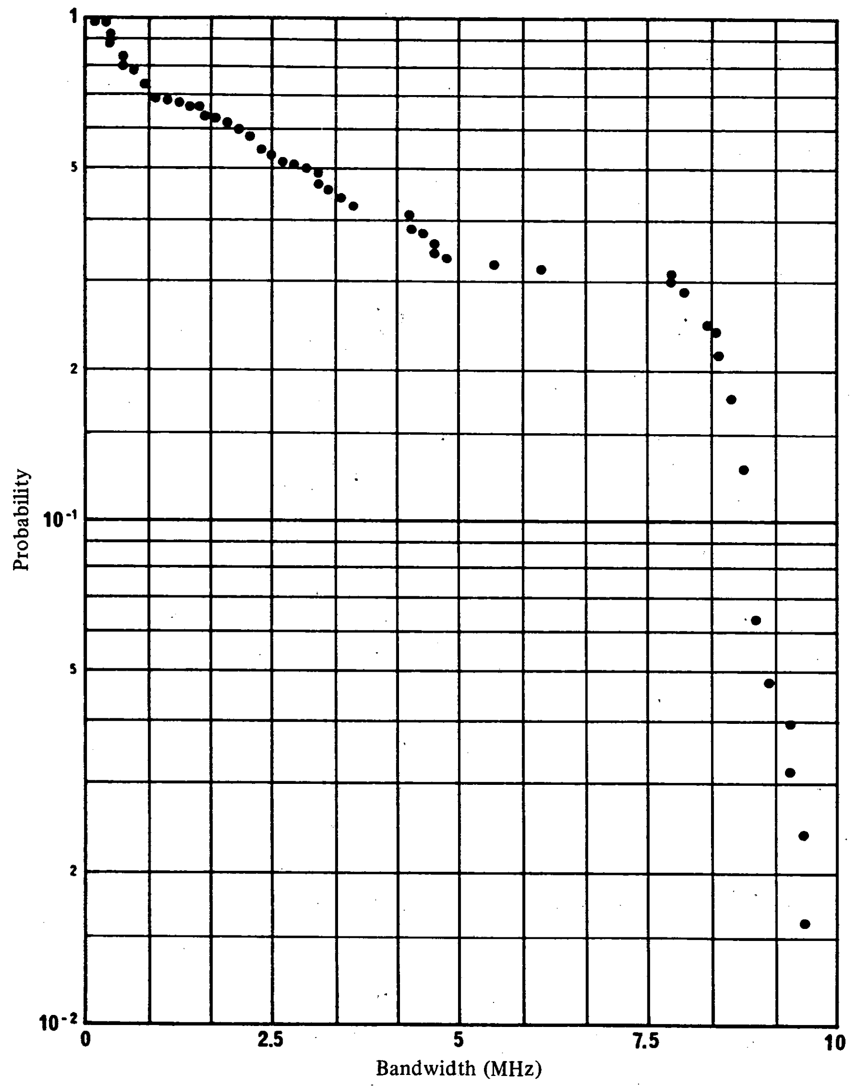


FIGURE 14 – *Probability that bandwidth (MHz) is ⩾ abscissa for the spaced frequency correlation function below 25%*

2.2 *Dependence on bit rate*

Figure 15 [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.

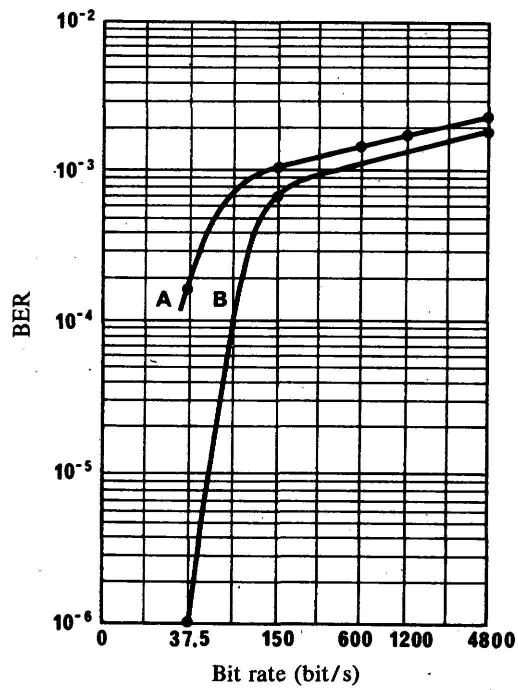


FIGURE 15 – *Measured BER as a function of bit rate, with fading only*

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)

Figure 16 [Hata and Miki, 1984] shows the BER performance of MSK with differential detection, measured in an urban environment. When the transmission bit rate is higher than 64 kbit/s, some corrective techniques are required to mitigate the effects of multipath propagation.

In high speed digital transmission, bit and frame synchronizations are of major importance. Trial systems using transmissions at bit rates higher than 1 Mbit/s have been reported [Böhm, 1982].

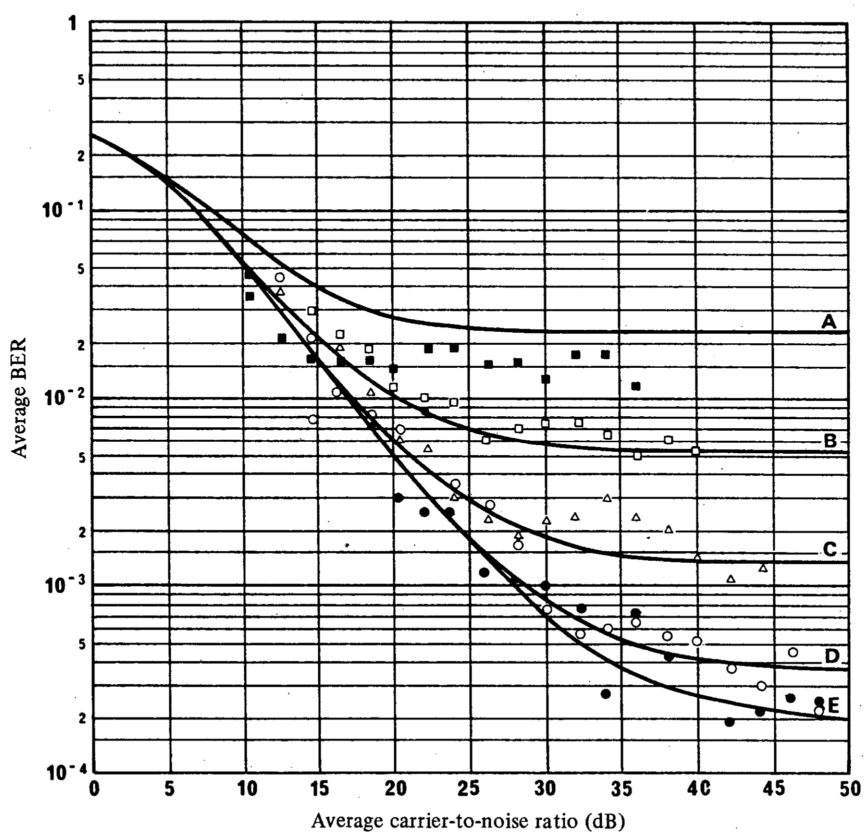


FIGURE 16 – *Average BER performance of 16 to 256 kbit/s MSK transmission obtained during field tests*

Transmission bit rate
Curves A: ■ 256 kbit/s
B: □ 128 kbit/s
C: △ 64 kbit/s
D: ○ 32 kbit/s
E: ● 16 kbit/s

MSK 2-bit differential detection
Fading rate: 40 Hz
Propagation delay: 1 μs

2.3 *Error distribution*

Typical error distributions at VHF and UHF (see Figs. 17 and 18) 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.

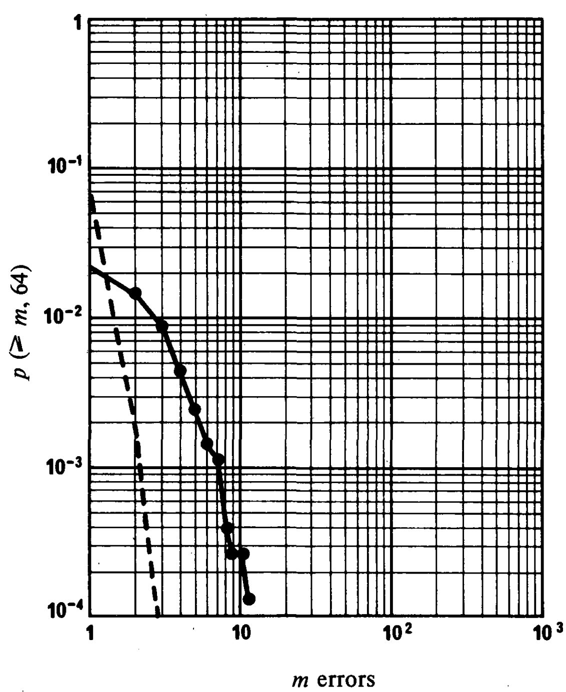


FIGURE 17 – *Distribution of errors caused by fading at 165 MHz with 2.4 kHz deviation*

– – – – – : random
———— : fading

Bit rate : 1200 bit/s
Vehicle speed : ≈ 30 km/h
Type of modulation: direct FM
Error ratio (BER) : $= 0.9 \times 10^{-3}$

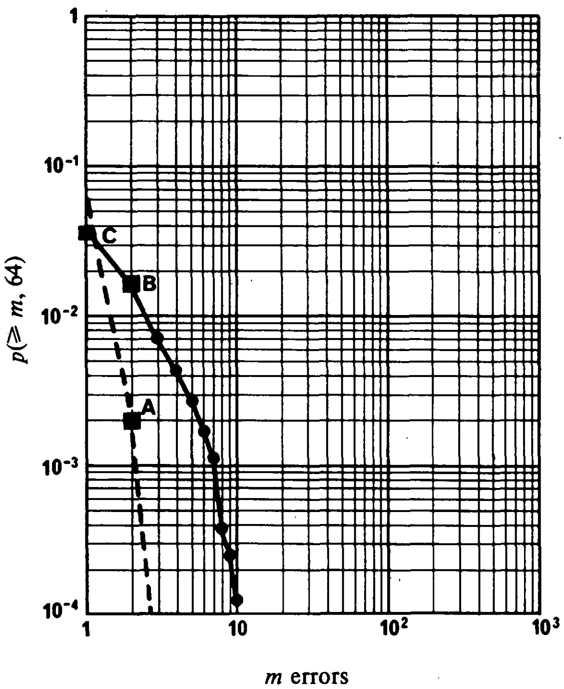


FIGURE 18 – *Distribution of errors caused by fading at 465 MHz with 4.8 kHz deviation*

– – – – : 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 ratio (BER) : = 1.0×10^{-3}

3. Errors caused by ignition noise

Typical BERs in dense vehicle traffic in the UK are shown in Figs. 19 and 20 [French, 1980].

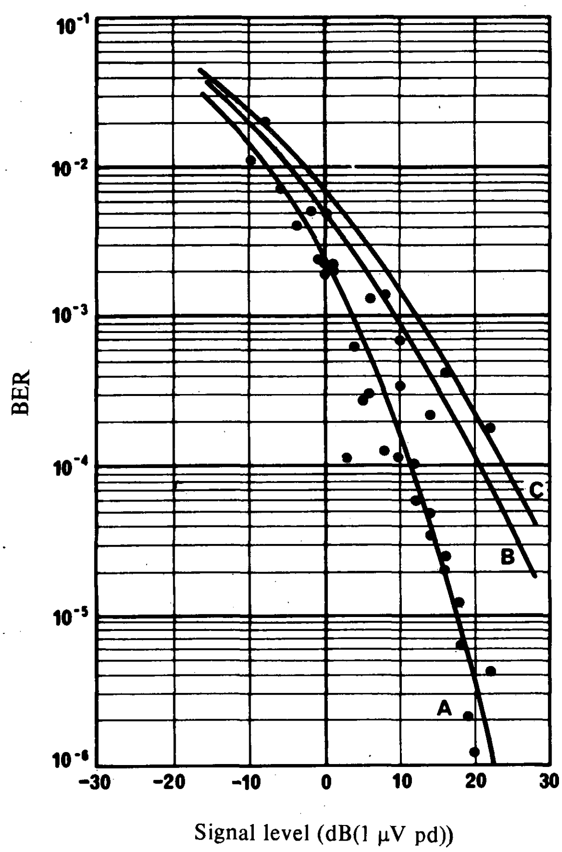


FIGURE 19 – *Errors due to ignition noise at 1 200 bit/s and 165 MHz*

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

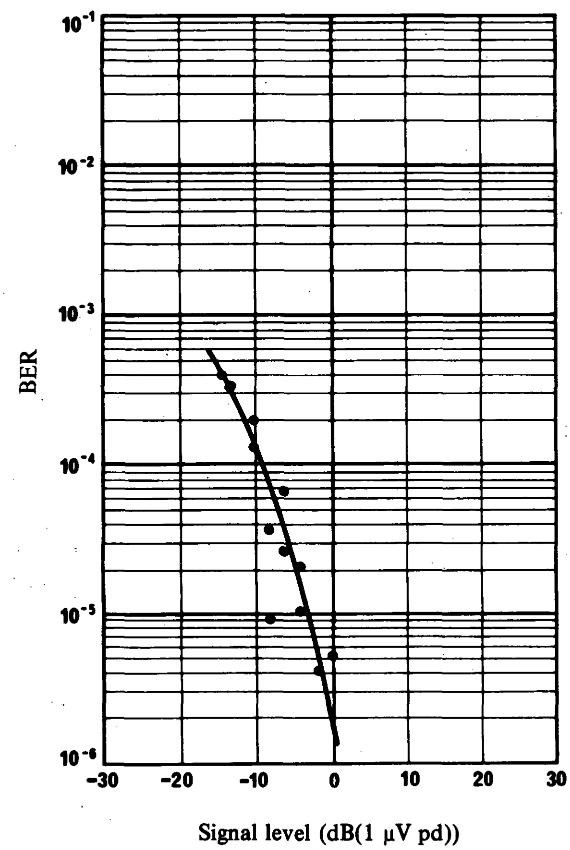


FIGURE 20 – *Errors due to ignition noise at 1200 bit/s and 465 MHz*

———— : 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 ratios (see Figs. 21 and 22) occur at VHF and UHF at 4800 bit/s, but fewer errors at UHF at 1200 bit/s than at VHF [French, 1980].

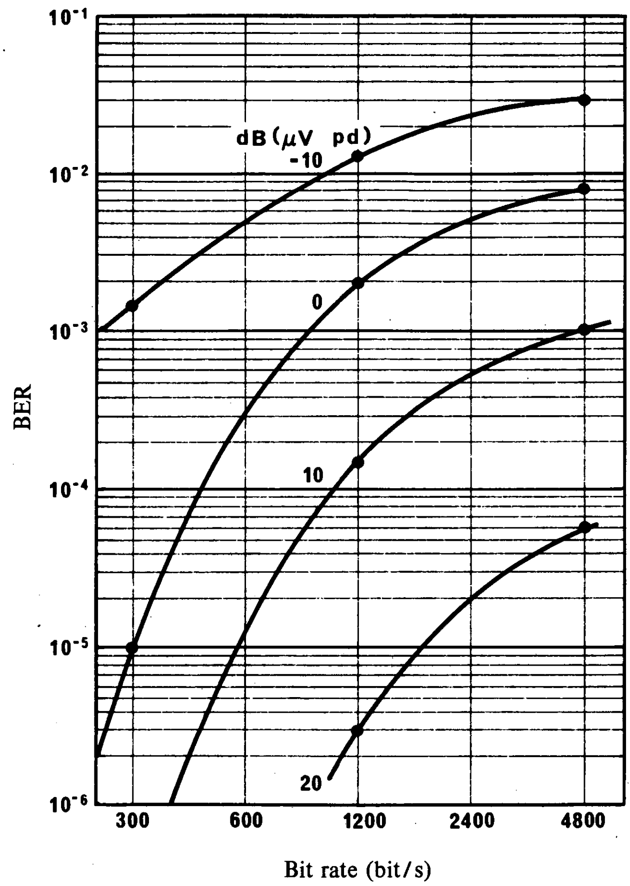


FIGURE 21 – *Dependence of ignition noise errors on bit rate at 165 MHz with signal level as parameter.*

Vehicle speed : ≈ 30 km/h
Type of modulation: direct FM
Deviation : 2.4 kHz

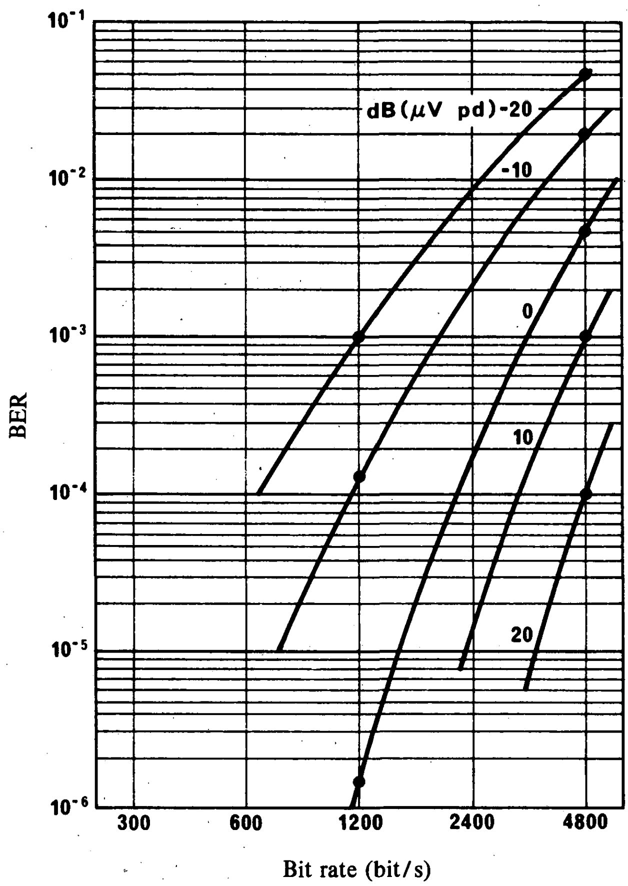


FIGURE 22 – *Dependence of ignition noise errors on bit rate at 465 MHz with signal level as parameter*

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. 23 and 24) [French, 1980].

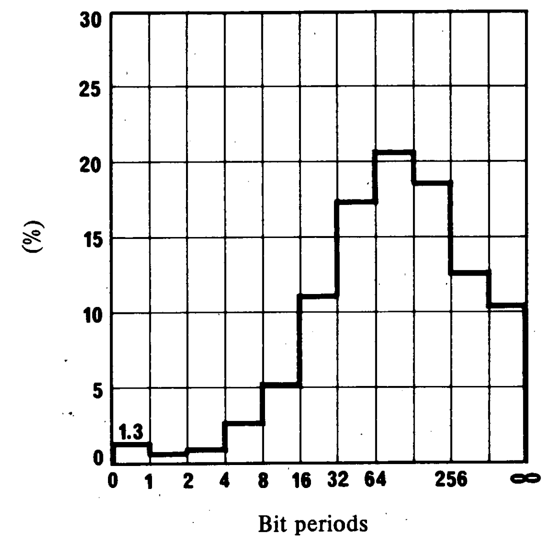


FIGURE 23 – *Error spacing at 165 MHz due to ignition noise*

Bit rate : 1200 bit/s
Type of modulation: direct FM
Deviation : 2.4 kHz
Error ratio (BER) : 1.3×10^{-3}

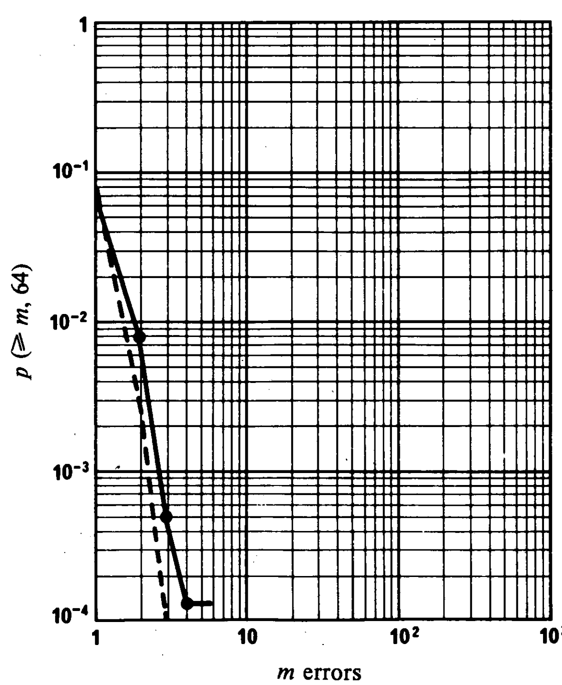


FIGURE 24 – *Distribution of errors due to ignition noise at 165 MHz*

- - - - : random
——— : ignition

Bit rate : 1200 bit/s
Type of modulation: direct FM
Deviation : 2.4 kHz
Error ratio (BER) : 1.3×10^{-3}

4. Error-free run length distribution

Data obtained from a field trial in the city of Ottawa, Canada [Towaij *et al.*, 1983] on continuous digital transmission at 2400 bit/s showed that, as anticipated, errors occur in bursts. The statistical distribution of error-free runs is shown in Fig. 25. An error-free run is defined as the number of error-free bits between consecutive error bits. It is shown that the 450 MHz band maintains a consistent behaviour with fluctuations in the S/N from 24 dB to 16 dB while both the 850 and 150 MHz bands resulted in a considerable variation in the error-free run length.

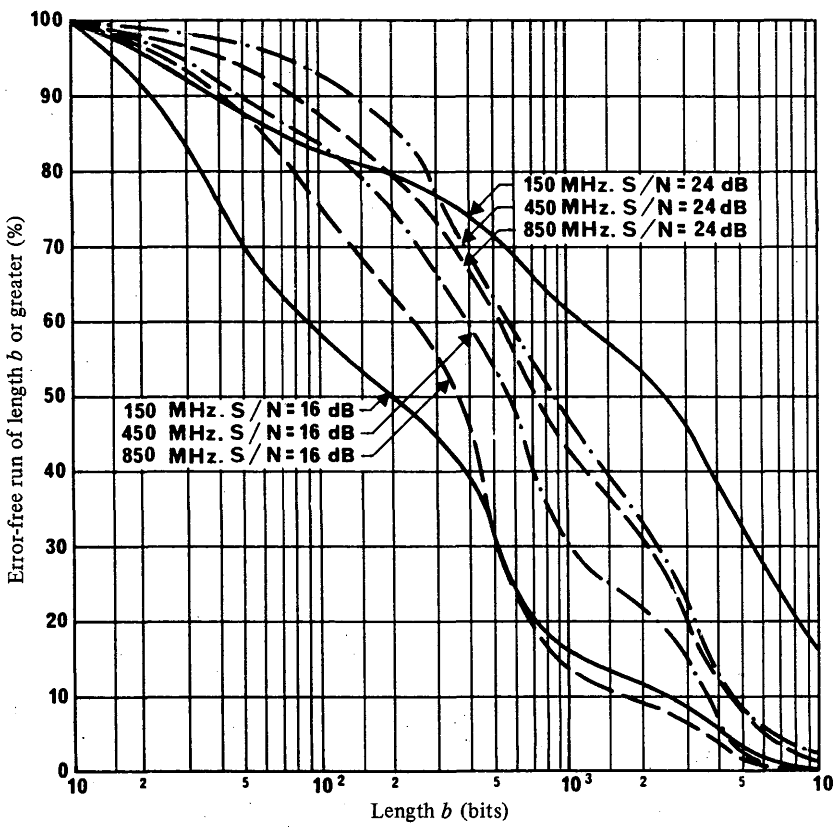


FIGURE 25 – *Error-free run of length b in bits*

5. Errors caused by co-channel interference

Figures 26 and 27 show measurements of BER against signal level with signal-to-interference ratios, S/I, as a parameter, for both frequency and amplitude modulation with non-fluctuating signals. At low signal levels ($S = -10$ dB(1 μV)) the BER is high due to front end receiver noise. At medium signal levels (e.g. $S = 10$ dB) the BER is strongly dependent on S/I ratio. For example in Fig. 27 with $S/I = 1$ dB the BER $= 10^{-2}$, but with $S/I = 2$ dB the BER drops at least two orders of magnitude. At high signal levels (e.g. $S \geqslant 20$ dB) errors are caused solely by co-channel interference and the error probability [French, 1981] is as follows:

$$P_e = 0.5 \qquad \text{when } S < I$$

$$P_e = 0 \qquad \text{when } S > I \text{ or}$$

$$\therefore P_e = 0.5 \qquad \text{Prob } (S < I)$$

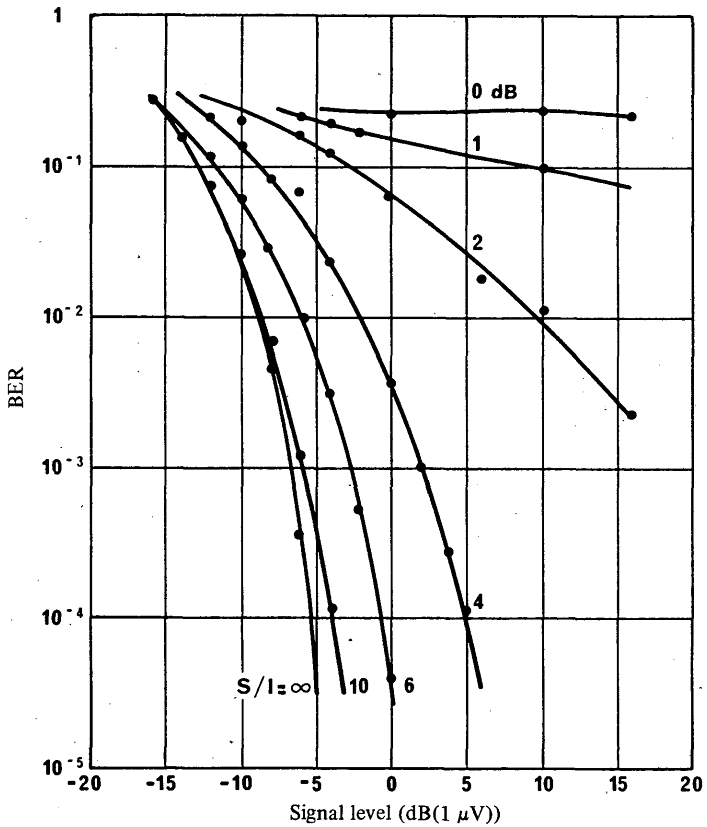


FIGURE 26 – *BER due to co-channel interference, stationary, FM 1200 bit/s FFSK*

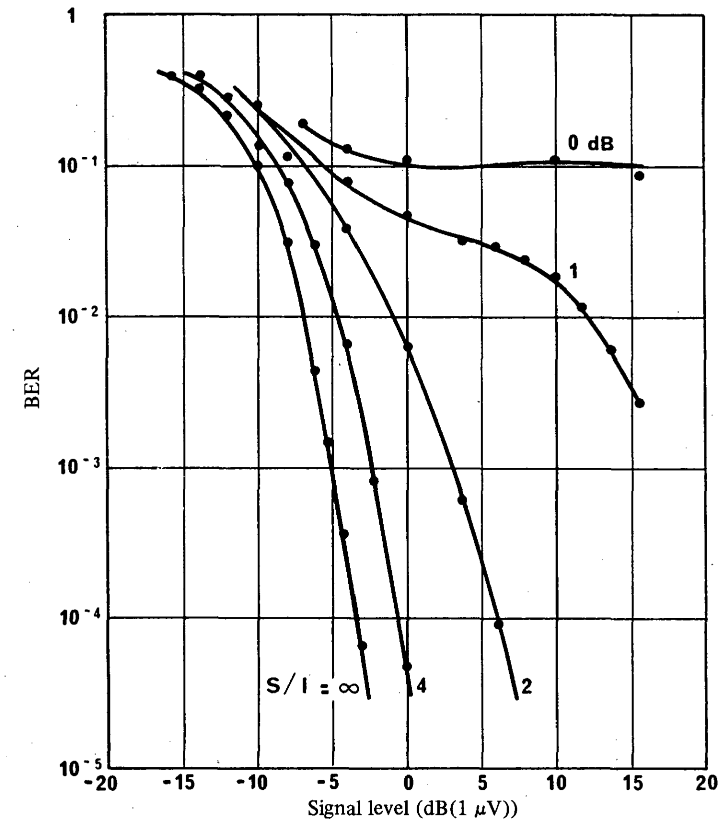
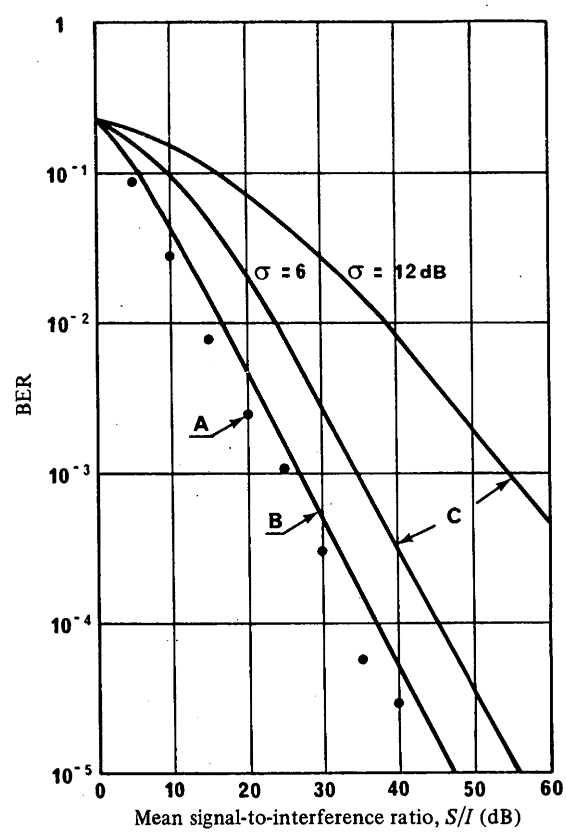


FIGURE 27 – *BER due to co-channel interference, stationary, AM 1200 bit/s FFSK*

Figure 28 shows the measured BER (on a route where the signal and interference were slightly correlated) compared with the theoretical BER with multipath fading and also with both fading and shadowing, for a moving vehicle. The corresponding error distribution is shown in Fig. 29 [French, 1981].



FIGURTE 28 – *BER caused by co-channel interference, moving vehicle, 165 MHz, direct FM 1200 bit/s*

Curves A: measured BER

B: fading

C: fading and shadowing

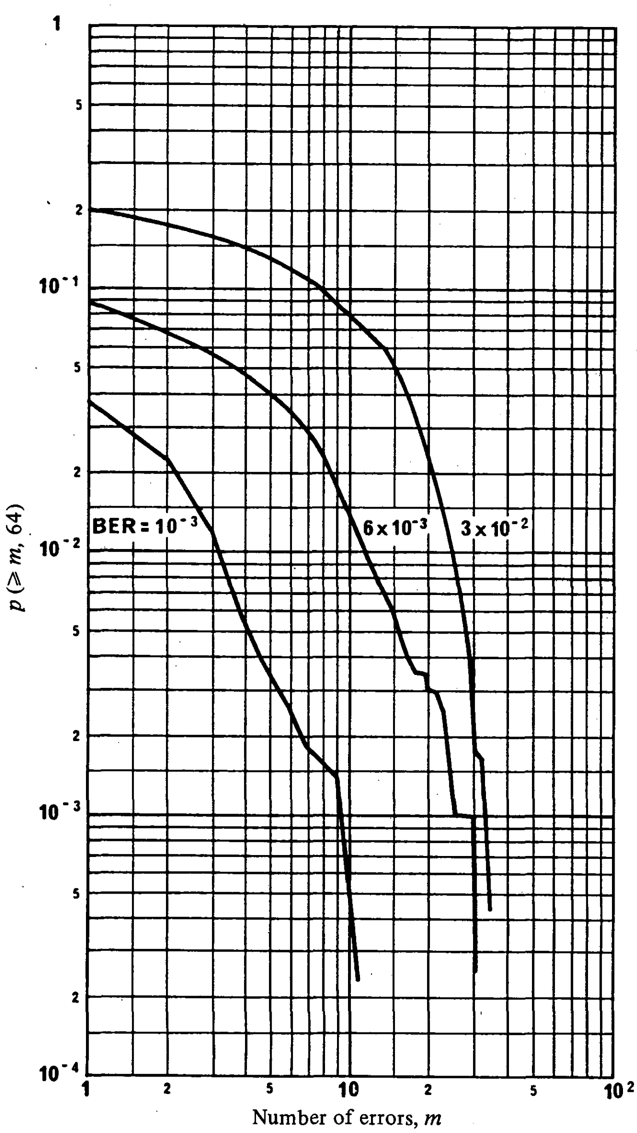


FIGURE 29 – *Error distribution with fading and co-channel interference*

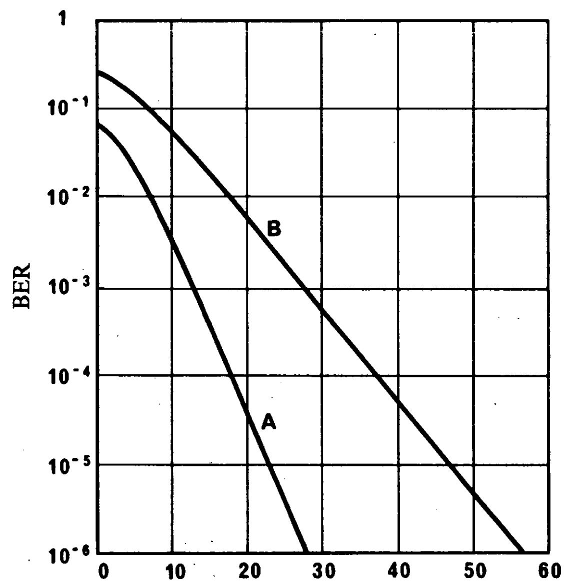


FIGURE 30 – *BER performance under fading conditions with co-channel interference*

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

6. Error reduction technique

Diversity reception is considered to be an effective technique to mitigate multipath fading.

Figures 31 and 32 [Miki and Hata, 1984] show the effects of post-detection selection diversity improvement on dynamic thermal noise and co-channel interference performance measured in laboratory simulation tests. The experimental results agree closely with theory. Similar performances have been measured in field experiments at 920 MHz in an urban environment [Miki and Hata, 1984].

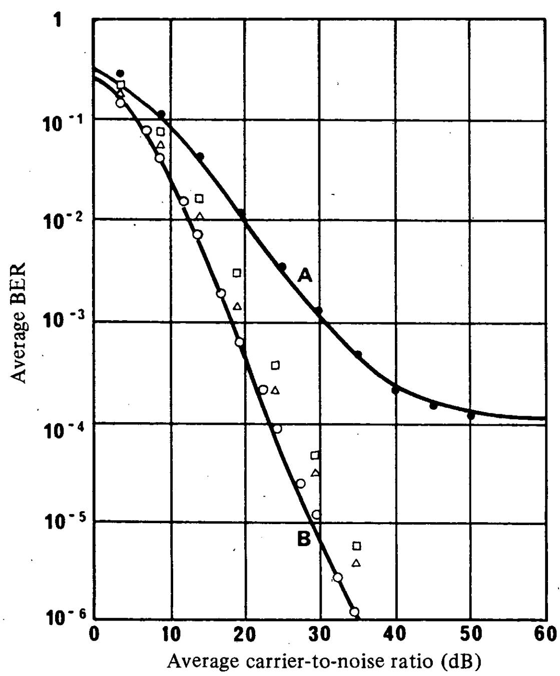


FIGURE 31 – *Thermal noise performance of GMSK transmission with correlated two-branch selection diversity*

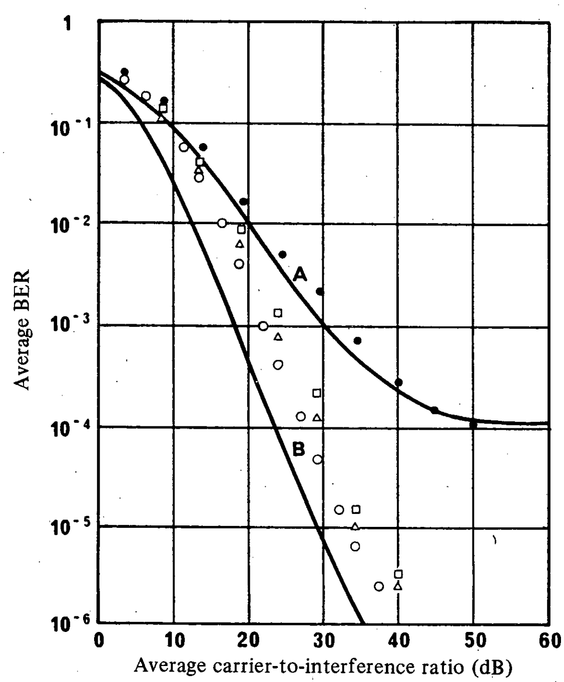


FIGURE 32 – *Co-channel interference performance of GMSK transmission with correlated two-branch selection diversity*

Curves A: no-diversity
B: 2-branch selection diversity
○: $\rho = 0$
△: $\rho = 0.5$
□: $\rho = 0.8$

16 kbit/s – GMSK ($B_b T = 0.25$)
cos $2T$ differential detection
Fading rate 40 Hz

7. 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 a message error rate that is acceptable for relatively short transmissions. However, it has been shown [Freeburg, 1979] that longer transmissions can benefit from the application of error-correcting techniques.

Dorsch [1980] has shown that there is a continuing improvement to be gained by increasing the redundancy of a code and increasing the transmission speed to compensate, up to the maximum practical rate for the channel in question, set by interference criteria. This effect tends to flatten for code rates less than about 1/3.

Also, recent work [Daikoku *et al.*, 1981] indicates that there is a minimum achievable error ratio, mandating the use of error-correcting techniques for messages of any substantial length.

Further improvement can be achieved for both error correction and detection with the introduction of bit interleaving which can also result in reduction in the required overhead.

7.1 *Bit interleaving technique*

In the land mobile environment, both random and burst errors occur. Random error correcting codes or single-burst error-correcting codes will not be very effective in combating this problem. Techniques such as bit interleaving can be used to distribute the errors, thus leading to an effective means for detection and/or correction of errors and at the same time can reduce the overhead required for the code design.

Figure 33 demonstrates the improvement of packet errors with the introduction of the interleaving technique for digital transmission in the land mobile radio environment.

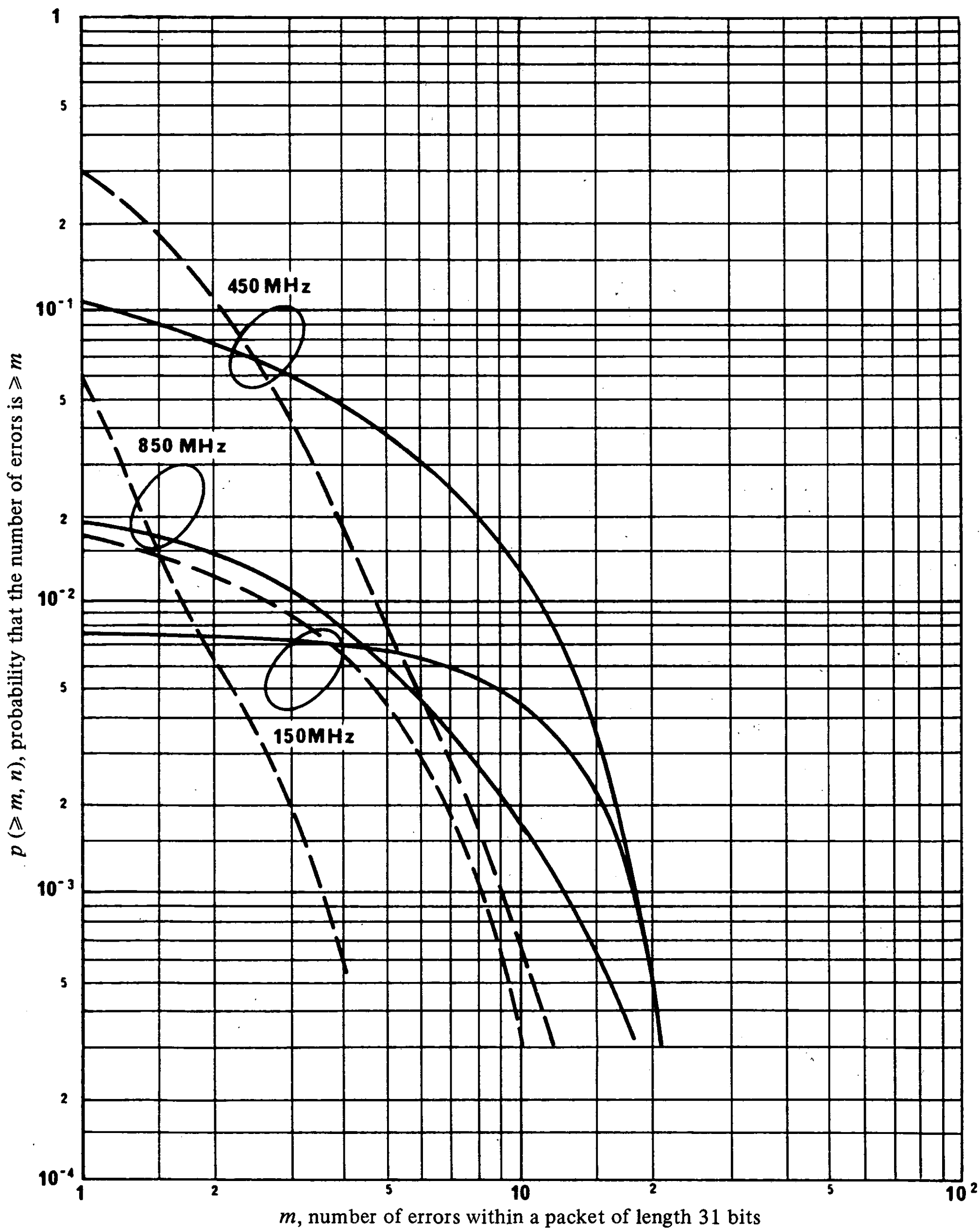


FIGURE 33 – *Probability distributions as a function of number of errors within a packet*

———— without interleaving

— — — with interleaving

150 MHz, BER = 1.3×10^{-3}

450 MHz, BER = 1.6×10^{-2}

850 MHz, BER = 2.0×10^{-3}

Interleaving degree i = 32

Bit rate = 4800 bit/s

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PART G

FORMATS FOR DATA TRANSMISSION

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*

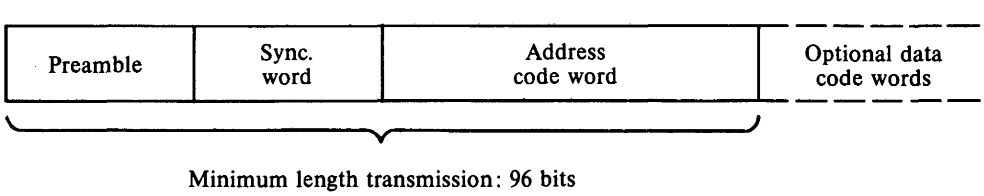


FIGURE 34 – *The format*

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 35 – *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*

Bit No.	1	2 ... 8	9 ... 48	49 ... 64
Number of bits	1	7	40	16
	"1"	user's identity	addresses + data	check bits

FIGURE 36 – *Address code word structure*

Bits:

1:	always "1" to indicate address word		
2-8:	user's identity		
9-20:	addressee's identity	(i.e. to)	optional
21-32:	addressor's 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.

Bit No.	1	2 ... 48	49 ... 64
Number of bits	1	47	16
	"0"	data	check bits

FIGURE 37 – *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 $x^{15} + x^{14} + x^{13} + x^{11} + x^4 + x^2 + 1$. 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.

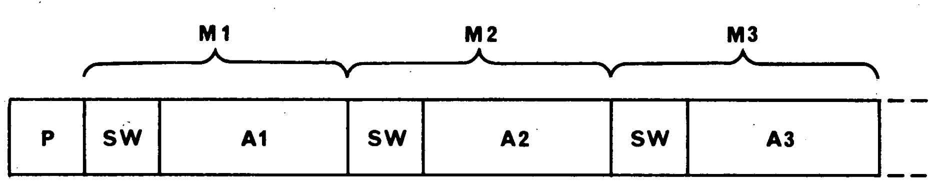
2.1.8 *Concatenated messages*

Figure 38 illustrates how several messages may be sent in one transmission.

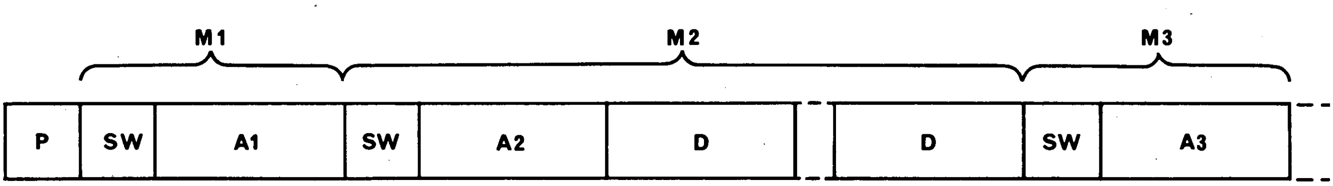
2.2 *Format design*

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 38 – *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. 39 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.

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. 40.

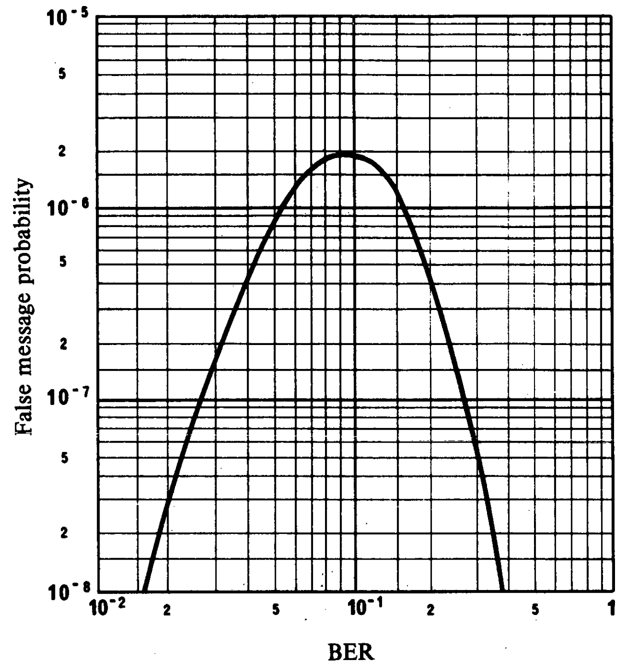


FIGURE 39 – *False message probability with a steady signal*

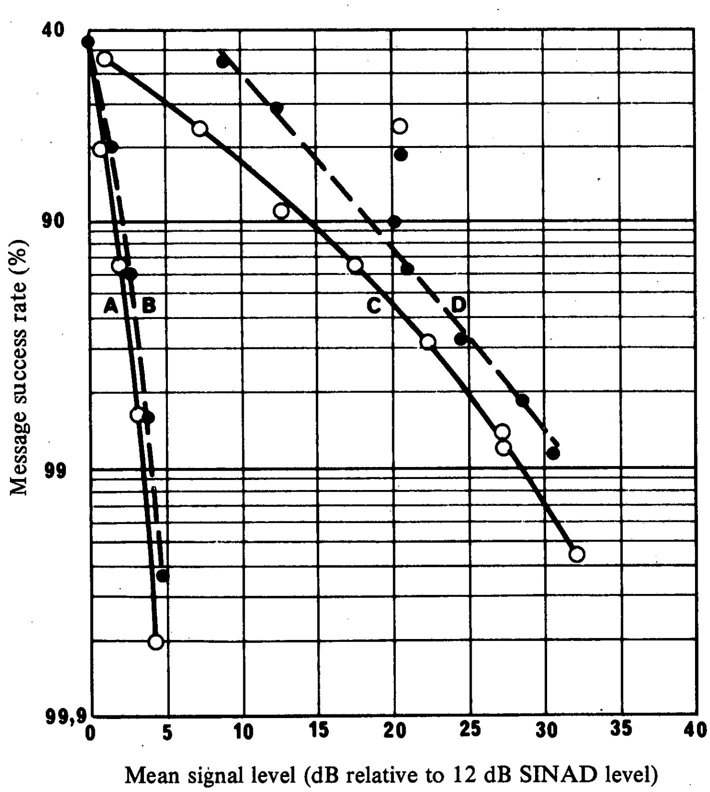


FIGURE 40 – *Field measured performance*

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

3. Alternate characteristics preferred in other countries

In France the following synchronization word is preferred:

Bit number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Value	1	0	1	1	0	1	0	0	0	0	1	1	0	0	1	1

It has the following properties:

- the minimum number of errors for which there may be a false synchronization when receiving the preamble followed by the synchronization word is 7. This number is almost independent of the preamble chosen (all "0", all "1", alternating "0" and "1");
- under these circumstances when using this word, synchronization is achieved if one bit of the synchronization word has been received with one error.

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REPORT 1021

EQUIPMENT CHARACTERISTICS FOR DIGITAL TRANSMISSION IN THE LAND MOBILE SERVICES

(Study Programme 7A/8)

(1986)

1. Introduction

This Report describes major characteristics of land mobile digital modulation equipment: BER performance, adjacent signal selectivity, and acceptable bandwidth.

2. BER performance (sensitivity)

The measured BER performance of a bit rate of 8 kbit/s under no-fading conditions using different modulation methods is shown in Fig. 1. The reference sensitivity is defined as E_b/N_0 (signal energy per bit/noise power density) corresponding to BER of 1×10^{-2}. The reference sensitivities were less than 12 dB for these modulation methods. Similar results were obtained for other transmission bit rates, such as 2.4 kbit/s, 4.8 kbit/s and 16 kbit/s.

The E_b/N_0 = 12 dB corresponds to the receiver's input level of $(\sqrt{R}/2)$ µV (R: bit rate in kbit/s) when the receiver noise figure is equal to 13 dB.

3. Adjacent signal selectivity

Typical adjacent signal interference performance of bit rates of 8 kbit/s is shown in Fig. 2. The measurements were conducted by setting the level 3 dB above the sensitivity level given in § 2, and adjusting the unwanted signal level until the bit error ratio degraded to 1×10^{-2}. Similar results were obtained for transmission bit rates of 2.4-16 kbit/s.

At the normalized frequency difference (the ratio of frequency difference to transmission bit rate) of 1.5 kHz/kbit/s, the ratio of unwanted to wanted signal level (U/W) becomes greater than 45 dB.

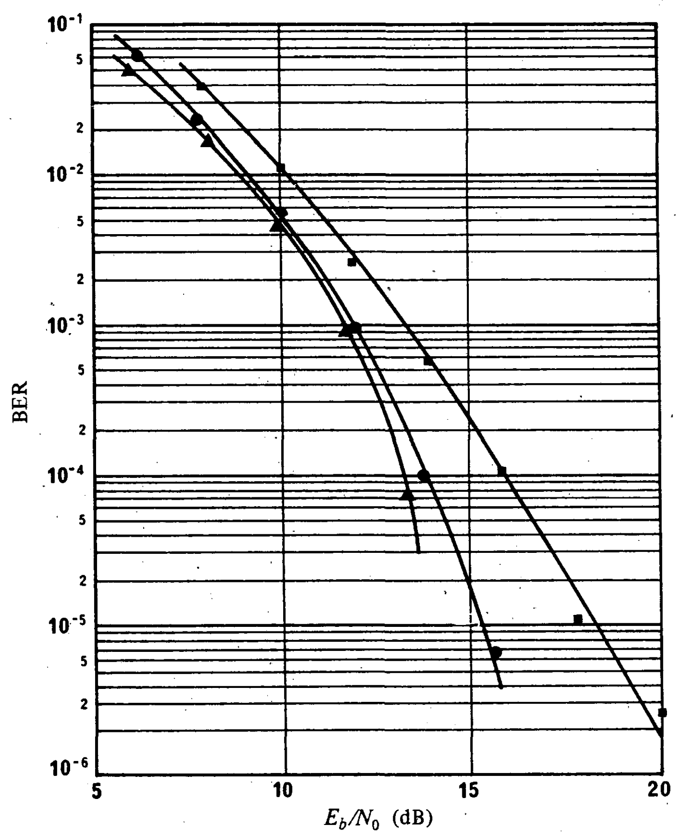

FIGURE 1 – *BER performance under no-fading condition (measured)*

Modulation:

■ : GMSK with coherent detection

● : 4-level FM with discriminator detection

▲ : PLL-4-PSK with discriminator detection

Transmission bit rate: 8 kbit/s

E_b/N_0 : signal energy per bit/noise power density

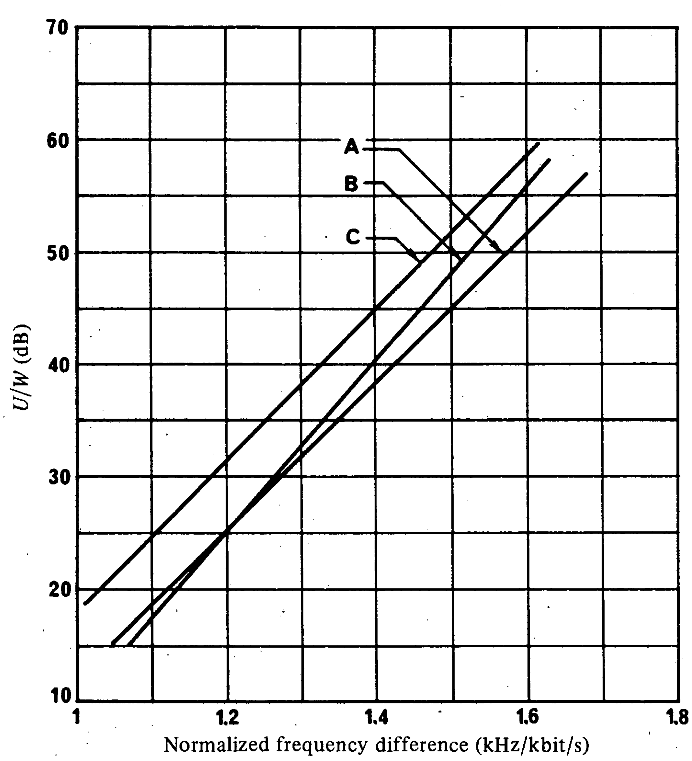

FIGURE 2 – *Adjacent signal interference performance (measured)*

U/W:	ratio of unwanted to wanted signal level
Wanted signal:	*W*-level corresponds to BER = 1×10^{-2}
Unwanted signal:	*U*-level corresponds to BER = 1×10^{-2} when wanted signal level is 3 dB in excess of *W*-level
Modulation:	wanted and unwanted signals are modulated by A: GMSK; B: 4-level FM; C: PLL-4-PSK.

4. Acceptable bandwidth

The acceptable bandwidth of a receiver can be defined as the frequency bandwidth within which a bit error ratio of less than 1×10^{-2} is obtained when the signal level is set at the level 6 dB above the sensitivity level given in § 2.

Typical measured values of the acceptable bandwidth for 2.4-16 kbit/s are shown in Fig. 3. All measured values were more than 0.4 kHz/kbit/s. Taking account of performance fluctuations due to production, the acceptable bandwidth should be specified as wider than $0.3R$ kHz (R: bit rate in kbit/s).

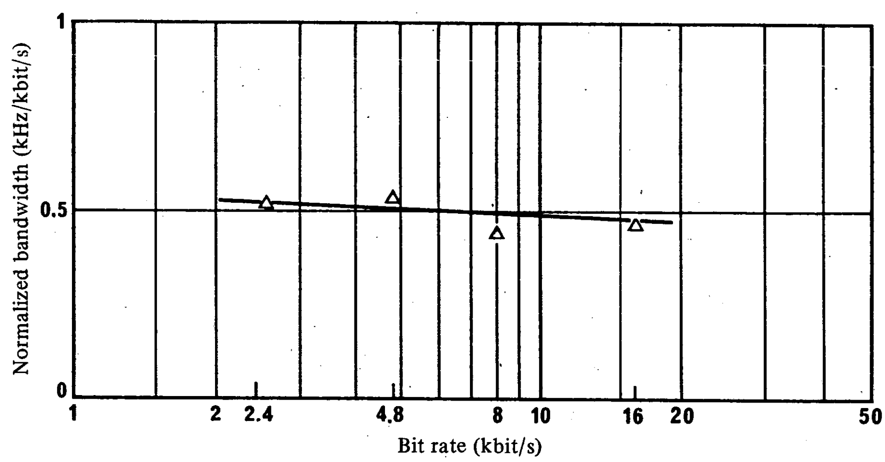

FIGURE 3 – *Acceptable bandwidth (typical measured value)*

4-level FM with discriminator detection
$BT = 1.0$

(B: bandwidth; $T = 2R$; R: bit rate in kbit/s)

5. Conclusion

As mentioned above, the following specification is desirable:

- the sensitivity should be such that for a 1×10^{-2} bit error ratio, the input signal level should not be greater than ($\sqrt{R}/2$) μV (R: bit rate in kbit/s);
- the adjacent signal selectivity should be more than 45 dB at the normalized frequency difference of 1.5 kHz/kbit/s;
- the acceptable bandwidth should be wider than $0.3R$ kHz (R: bit rate in kbit/s).

In addition to these specifications, the following technical characteristics require study in accordance with Study Programme 7A/8:

- frequency tolerance;
- occupied bandwidth;
- adjacent-channel power;
- spurious response;
- spurious emissions;
- radio-frequency intermodulation;
- low-pass filtering modulation signal.

RECOMMENDATION 623

DATA TRANSMISSION BIT RATES AND MODULATION TECHNIQUES IN THE LAND MOBILE SERVICE

(Question 40/8)

(1986)

The CCIR,

CONSIDERING

(a) that digital signals are being increasingly used to improve communication efficiency in the land mobile service;

(b) that benefits will result from standardization of data signalling bit rates conforming to CCITT Recommendations V.5 and V.6 by facilitating the interworking of synchronous data transmission in the land mobile service with synchronous data transmission over telephone circuits;

(c) that standardization of modulation techniques is one of the steps required for international interworking;

(d) Report 903,

UNANIMOUSLY DECIDES

1. that the following data signalling bit rates should be preferred for synchronous data transmission in the land mobile service: 600, 1200, 2400, 4800 or 9600 bit/s (see Note 1);

2. that the following modulation techniques be preferred for constant envelope radio systems (see Notes 2 and 3), and that the FM deviation be adjusted so as to meet the spectral emission constraints of each administration:

2.1 Direct RF-carrier modulation technique (see Note 4): constant envelope modulation:

GMSK,
tamed FM,
4-state-FM,
PLL-4-PSK.

2.2 Sub-carrier modulation technique:

Transmission bit rate (see Note 3)	*Modulation method*	*Additional information*
1200 bit/s	FFSK	"0" = 1800 Hz; "1" = 1200 Hz
2400 bit/s	FFSK	"0" = 2400 Hz; "1" = 1200 Hz
4800 bit/s	FFSK	"0" = 4800 Hz; "1" = 2400 Hz
4800 bit/s	bipolar	

3. that due to fading on the radio channel some kind of error correction and retransmission should be used, resulting in a higher transmission bit rate than the data source bit rate.

Note 1. – Other data transmission bit rates may be of interest (e.g. 6 kbit/s for 12.5 kHz channel spacing). This also may be the case when the system design does not require the same data rate on both the radio and telephone parts of the communication channel.

Note 2. – For source bit rates up to 1200 bit/s sub-carrier data signals can pass through the speech processing circuits of the radio equipment and can be, in some cases, directly interconnected to the telephone network. For higher data signalling rates it may be necessary to provide separate data paths between the sub-carrier data signal and the RF-modulator and/or demodulator.

Note 3. – For 9600 bit/s direct carrier modulation and for 4800 bit/s sub-carrier modulation, the necessary bandwidth may not be accommodated in a 12.5 kHz channel spacing scheme.

Note 4. – There are a number of different direct modulation techniques which are not necessarily compatible (see Report 903).

RECOMMENDATION 624*

PUBLIC LAND MOBILE COMMUNICATION SYSTEMS LOCATION REGISTRATION

(Question 39/8)

(1986)

The CCIR,

CONSIDERING

(a) that interconnection of a roaming mobile station with a public switched network involves a knowledge of the location of the mobile station, together with the means of registering this information, so that appropriate routing and charging can be applied;

(b) that the connection of calls to a roaming mobile station from a public switched network requires that technical and operational procedures for location registration be agreed and that this agreement is essential for international service;

(c) that standardized procedures for location registration can provide benefits, particularly for roaming mobile stations which need to operate in more than one service area;

(d) that the roaming mobile station may best determine when its location status needs to be up-dated,

UNANIMOUSLY RECOMMENDS

1. that the definitions given in Annex I should be used in connection with location registration;

2. that allocation of identities to location areas for transmission to the mobile station should be as follows:

LAI	CI

where:

LAI: identification of a location area;

CI: identification of a cell within the location area if required for other purposes than location registration.

The sequence LAI must also identify the country with which the location area is associated;

3. that a mobile station should initiate a location registration procedure only when the sequence LAI received differs from the actual LAI information stored in the mobile station;

4. that the location registration procedure should be initiated by the mobile station and considered successful only when the registration is confirmed by the mobile services switching centre (MSC);

5. that the general procedures in the mobile station for location registration should be as shown in Fig. 4.

* The Director, CCIR, is requested to bring this Recommendation to the attention of the CCITT.

ANNEX I

DEFINITIONS

For an extensive list of definitions to be used in connection with land mobile systems refer to CCITT Recommendation Q.70 (1984). In this Annex only definitions necessary for the understanding of the Recommendation are included.

1. Mobile services switching centre (MSC)

In an automatic system, the mobile services switching centre (MSC) constitutes the interface between the radio system and the public switched networks (PSTN, PDN, ISDN). The MSC performs all necessary signalling functions in order to establish calls to and from mobile stations. A mobile station is registered at one MSC which functions as its home centre for charging and billing purposes and for administering its subscriber parameters such as category.

In order to obtain radio coverage of a given geographical area, a number of base stations (radio transmitters/receivers) are normally required; i.e. each MSC would thus have to interface several base stations. In addition, several MSCs may be required in order to cover a country. The definition of the MSC may be prefixed by the term "land" or "maritime" if that is more suitable in a specific application.

2. Location register

To establish a call to a mobile station the network must know where this mobile station is located. This information is stored in a "location register".

3. Location area

The location area is defined as an area in which a mobile station may move freely without updating the location register. A location area may comprise several base stations.

4. Location registration

Location registration is defined as the procedure by which details of the location of a mobile station are entered into a location register.

The location register may be:

- centralized, i.e. there is one common register for several MSCs (see Fig. 1);
- distributed, i.e. there is a minimum of one location register assigned to each MSC (see Fig. 2);
- segmented, i.e. the precise location of the mobile station can only be known after concatenation of fractional information distributed in a set of "partial" location registers (e.g. in a "hierarchical distribution" of location information (see Fig. 3).

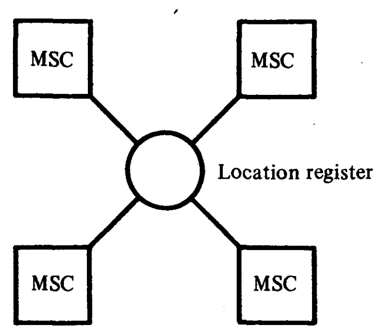

FIGURE 1 – *Centralized register*

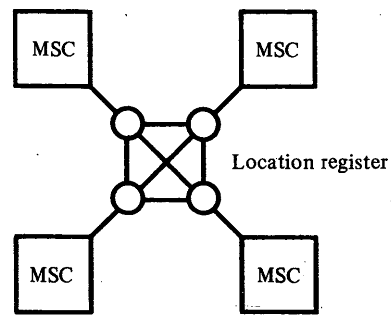

FIGURE 2 – *Distributed system*

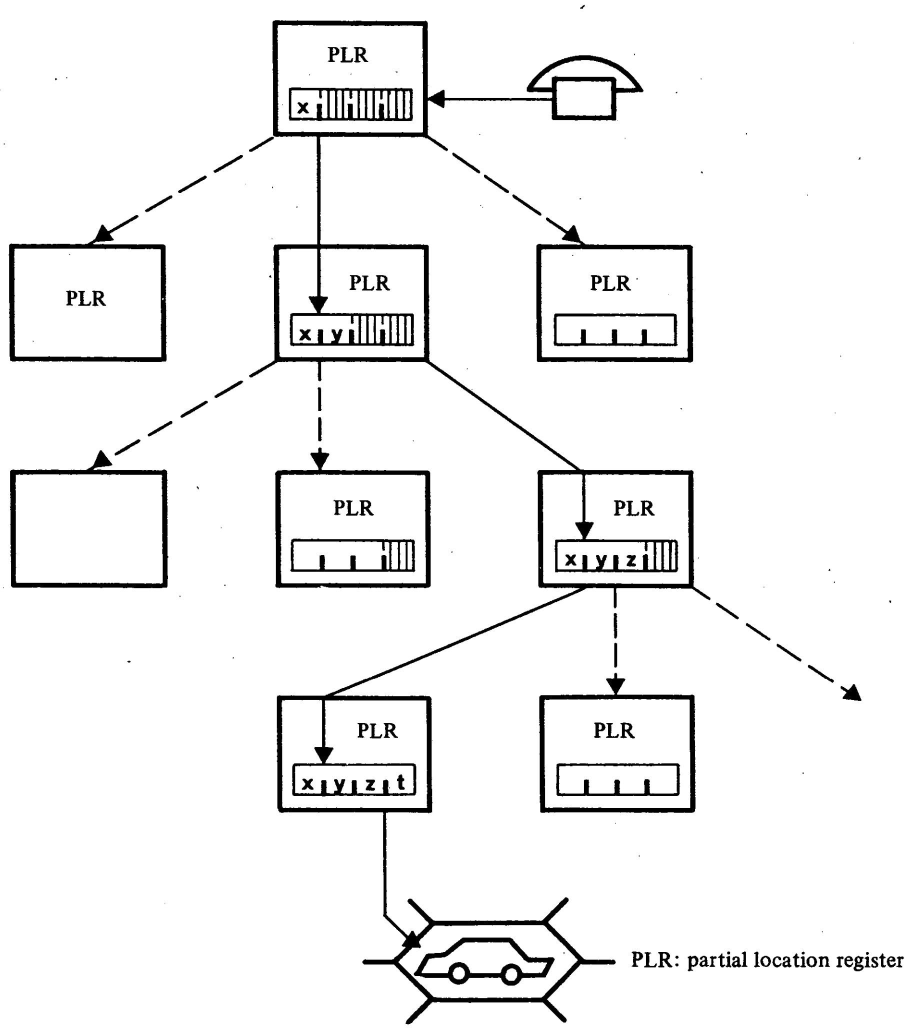

FIGURE 3 – *Segmented location register*

5. Cell

The area covered by a base station or by a sub-system (sector antenna) of that base station corresponding to a specific logical identification on the radio path – whichever is smaller.

Every mobile station in a cell can be reached by the corresponding radio equipment of the base station.

6. Base station area

The area covered by all the cells served by a base station.

7. Service area

The service area is defined as an area in which a mobile station is obtainable by a fixed subscriber in the PSTN, PDN or ISDN without the subscriber's knowledge of the actual location of the mobile station within the area. A service area may consist of several public land mobile networks (PLMN, see CCITT Recommendation Q.70). One service area may consist of one country, be a part of a country or comprise several countries. The location registration system associated with each service area must thus contain a list of all mobile stations located within that service area.

Note 1. – This definition does not take into account any constraints on routing imposed by the international telephone network. Fixed subscribers located within one service area will, by definition, have access to all mobile stations within the area. However, for fixed subscribers located outside the area, such constraints may involve that the subscriber needs to know in which part of the service area the called mobile station is located, e.g. in which country, if the service area comprises more than one country.

Note 2. – The service area may vary for interconnection of land mobile stations with different networks such as PSTN, PDN and ISDN.

8. Hand-off

Hand-off is the action of switching a call in progress from one cell to another cell. Hand-off is used to allow established calls to continue when mobile stations move from one cell to another cell.

ANNEX II

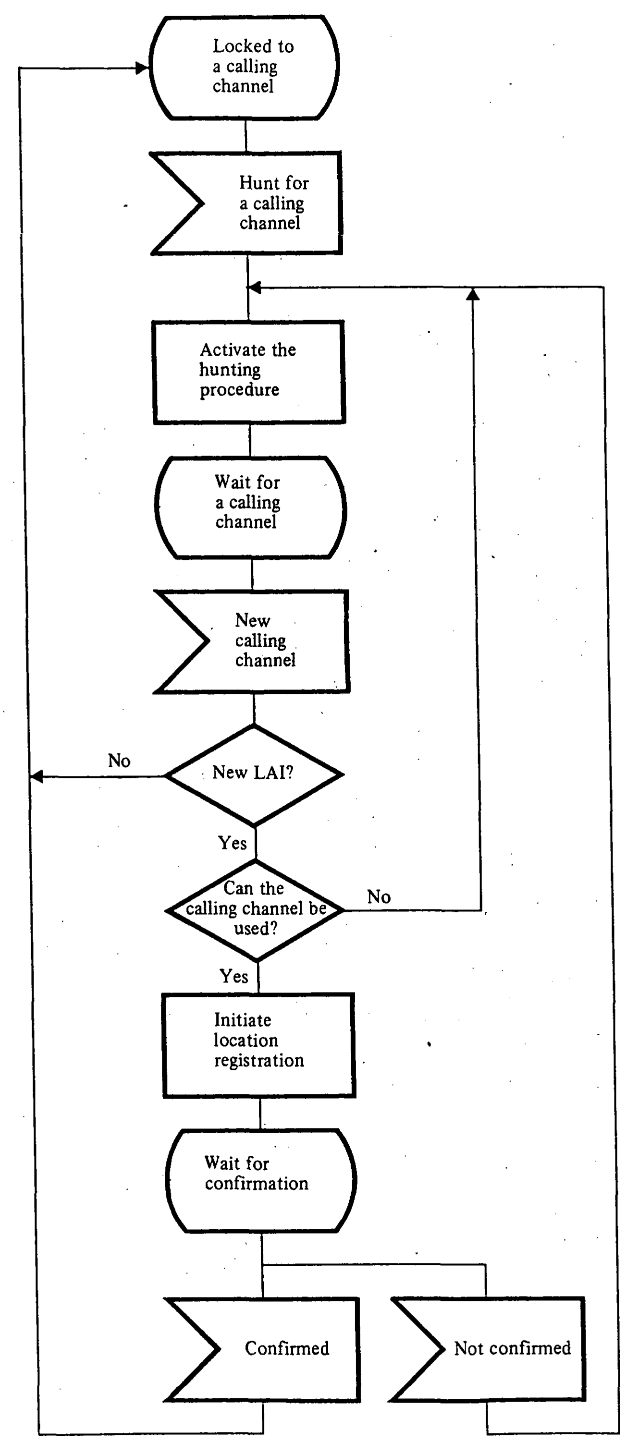

FIGURE 4 – *General procedures at the mobile station related to location registration*

REPORT 904-1

AUTOMATIC DETERMINATION OF LOCATION IN THE LAND MOBILE SERVICE

(Question 51/8)

(1982-1986)

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.

An operational AVL system in Japan is described in Annex II.

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 the operational fleet.

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-dating*

Ideally once per minute or so for vehicles which are required to be quickly deployed in limited areas (e.g. police, fire tenders, ambulances) but less frequently for dispatch operations over larger areas or defined routes.

In practice, attainable updating intervals may be governed by the rate at which choices of route are presented to each vehicle. These rates are proportional to the occurrence of road junctions in the area of travel and to vehicle speeds.

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.
- Improved efficiency of response during emergencies and for dispatching a replacement vehicle.
- Increased passenger loads due to more convenient and up-to-date location information available to the public.

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. AVL techniques

AVL techniques that might be capable of meeting operational requirements of land mobile radio users can be classified into three major categories: proximity, dead reckoning and radio-frequency positioning.

6.1 *Proximity techniques*

The location of the vehicle is determined as it passes fixed elements (signposts), the locations of which are precisely and accurately known to the system. Signposts can be passive or active while the coupling between them and vehicles may be magnetic or electromagnetic. The accuracy of proximity techniques is directly related to the spacing between signposts. There are two proximity methods:

- *direct proximity:* the signpost transmits its location address to the vehicle, which in turn transmits it together with its own identification to the system computer;
- *inverse proximity:* the vehicle identification is transmitted to the signpost, which in turn transmits it together with its own identification to the system computer.

6.2 *Dead reckoning techniques*

These techniques employ heading and distance travelled (e.g. odometers) sensors for calculating the location of vehicles relative to fixed known location references. The computation may be made on board the vehicle or in the system computer. Location determination accuracies depend on the sensing devices, frequency of reference updates and the severity of external factors such as magnetic field variations, wheel slippage and road camber, etc.

6.3 *Radio-frequency positioning techniques*

The locations of vehicles are determined from distance differences of vehicles from three or more fixed sites. These differences can either be expressed by phase differences between received signals (phase multilateration) or differences in the time of arrival of leading edges of synchronized pulse signals (pulse multilateration) producing hyperbolic lines of constant phase or time differences. The location of vehicles can be determined from the intersection of these lines. The positioning techniques can employ dedicated systems for land mobile application or utilize existing navigation systems such as Loran-C or Decca.

7. Applicable radiodetermination systems

7.1 *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.

7.2 *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.

7.3 *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 $\pm$ 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.

7.4 *Radio-determination satellite systems*

The TRANSIT satellite system [Blanchard, 1983] is of little use to land vehicles because the minimum measuring time is about 1000 s. For stationary vehicles or vehicles moving along a well-defined track, a positional accuracy of about 200 m can be achieved from one fix.

The NAVSTAR satellite system can achieve 200 m accuracies with a measuring time of less than 10 s [Diederich *et al.*, 1983].

A proposed radiodetermination satellite system being developed for operation in the United States of America starting in the 1987-1988 time frame is expected to be capable of achieving accuracies of the order of 5-10 m when 2 of the 3 satellites are visible, with a measuring time of less than 1 s. The system, which will utilize geostationary satellites in the radiodetermination satellite service, is described in Report 1050.

8. 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.

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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 signalling 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

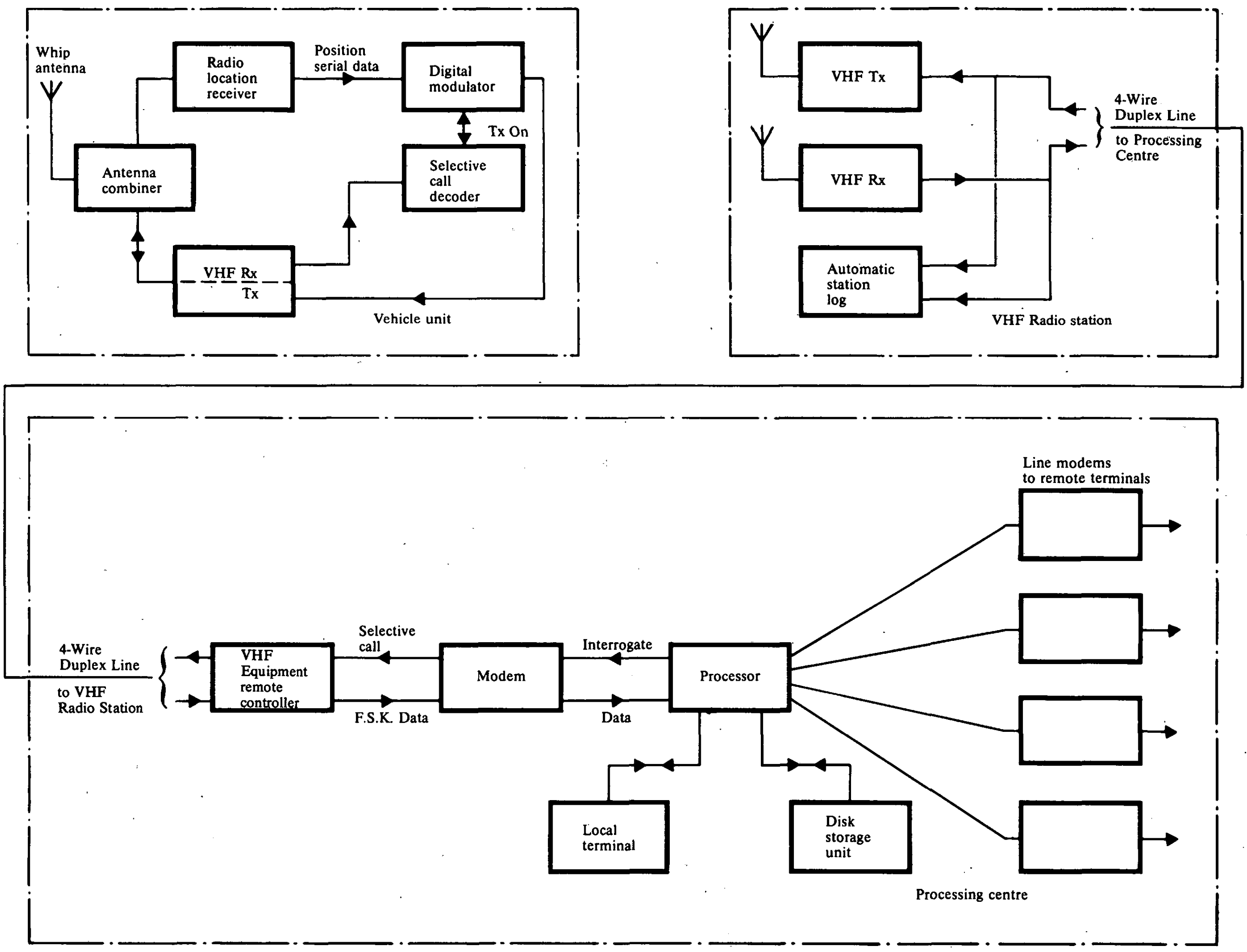

FIGURE 1 – *Vehicle location system*

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 : 2500 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.

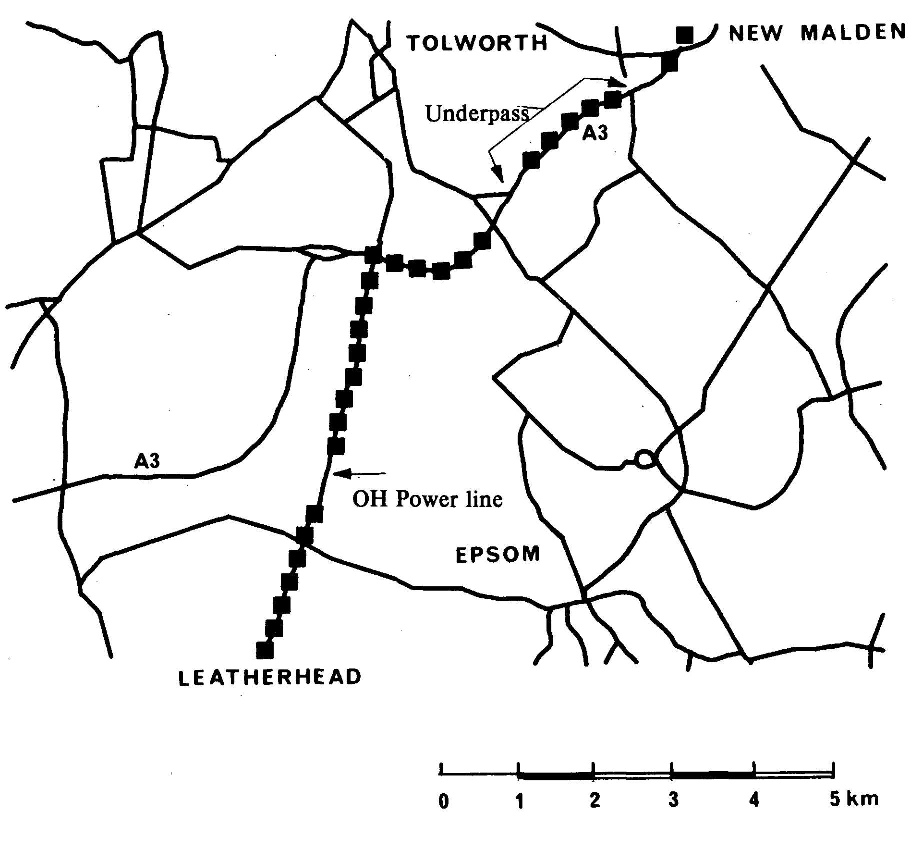

FIGURE 2 – *Decca Navigator receiver*

(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.)

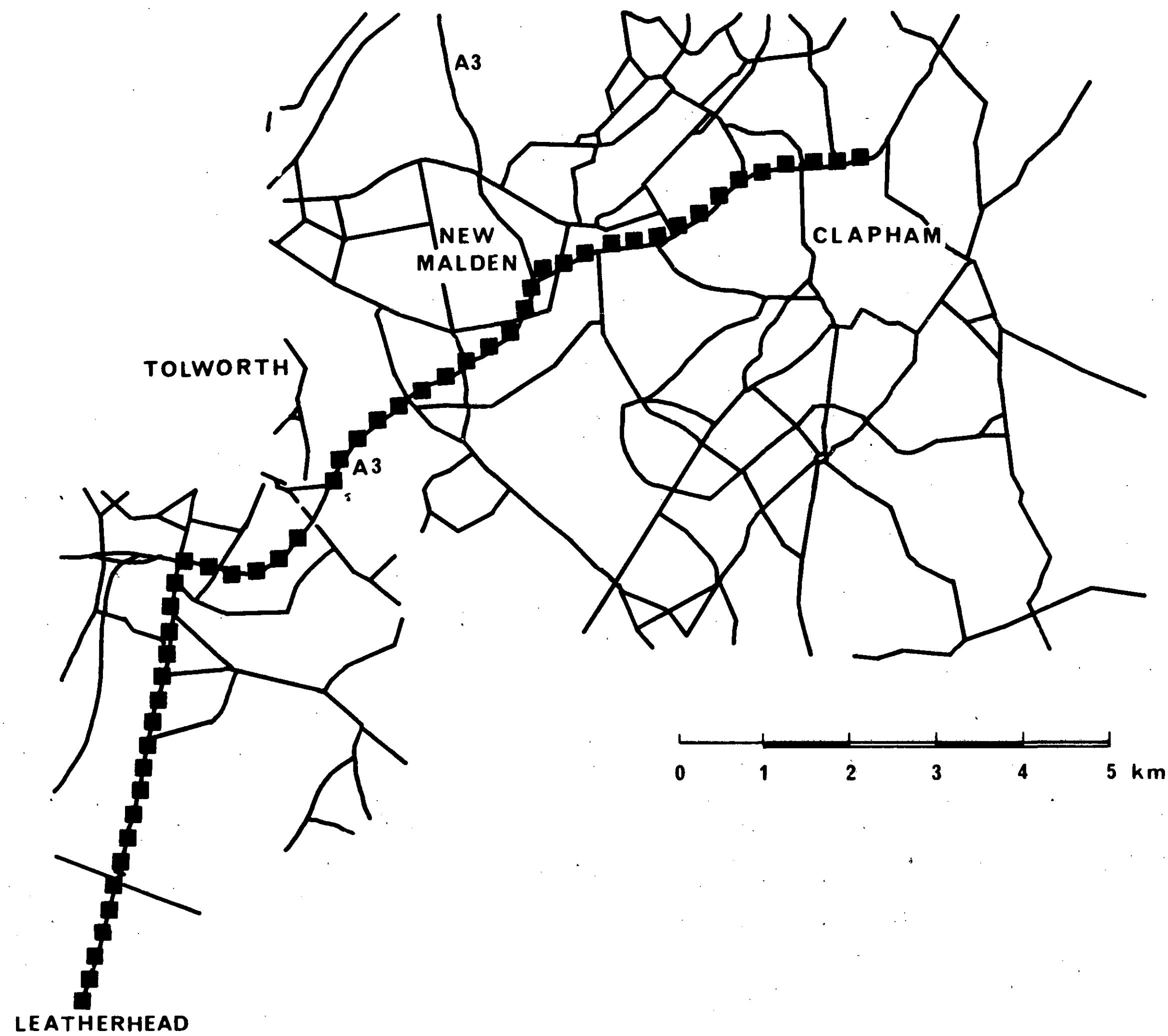

FIGURE 3 – *Low frequency Hi-Fix/6 receiver*

(Vehicle tracks from Clapham to Tolworth and from Tolworth to Leatherhead)

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.

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ANNEX II

AVL SYSTEMS IN JAPAN

Since 1980 Japan has introduced direct proximity AVL systems in 7 cities and inverse proximity systems in 16 cities.

In the Tokyo metropolitan area, a direct proximity AVL system with 29 signposts is used by about 5400 taxis (October, 1983). For direct proximity systems, the country is divided into 50 km squares, each with an area code and a reference point in the North-West corner. Each signpost is assigned an area code (2 digits) and an x and y position code (2 times 3 digits) relative to the reference point.

The signposts transmit on 426 MHz with a power of 0.01 to 1 W using sub-carrier FM modulation (1500 Hz, 1900 Hz FSK at 200 bit/s). A 15 bit frame synchronization signal is followed by the area and position code in which each digit is BCD coded with added parity bit.

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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.

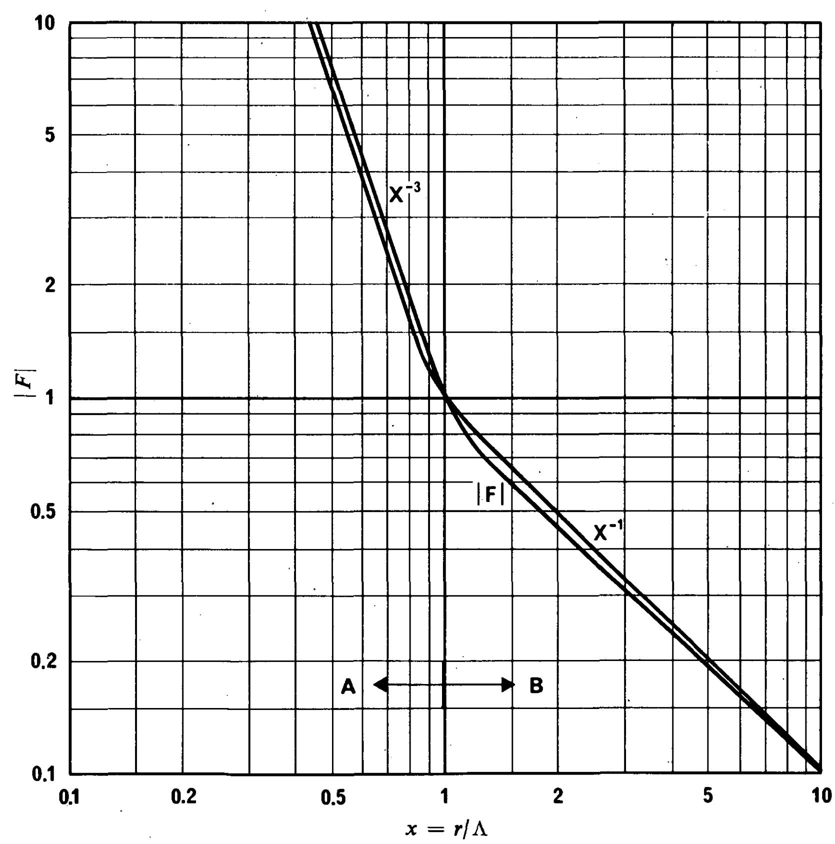

FIGURE 1 — *The field in free-space near a small dipole*

The field intensity $|F|$ in the equatorial plane is proportional to

$$|1/r^3 + j/\Lambda r^2 - 1/\Lambda r^2|.$$

Λ is the radian wavelength $= \lambda/2\pi \approx 48$ metres divided by frequency in MHz

A: Induction
B: Radiation

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.

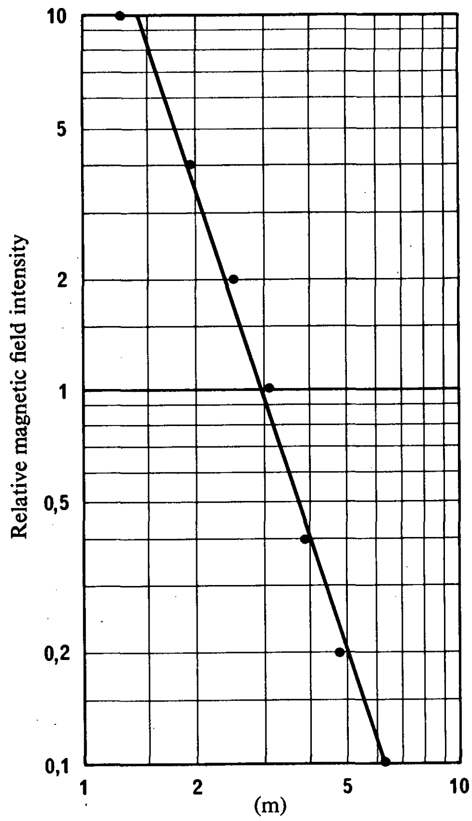

FIGURE 2 — *The measured decay of a magnetic induction field*

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.

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.
- 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.

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.

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REPORT 1022

MULTI-TRANSMITTER RADIO SYSTEMS USING QUASI-SYNCHRONOUS (SIMULCAST) TRANSMISSION IN THE LAND MOBILE SERVICE

(Question 67/8)

(1986)

1. Introduction

Special care must be taken with multi-transmitter systems in which the same message is transmitted at the same time in the same radio channel by two or more transmitters (such systems are known as quasi-synchronous or simulcast). They are used where:

– a large service area must be covered by transmitters of moderate power, in which case there will be a small overlap in the coverage of the transmitters;

– intensive coverage is needed, e.g. in some paging systems. In this case there will be a substantial overlap in the coverage of the transmitters which are used to provide diversity against shadowing (slow fading).

Note. – No diversity advantage is obtained against multipath fading.

Multi-transmitter simulcast transmission can be classified into three categories as follows:

– carrier frequency offset method [Hattori and Hirade, 1978];

– waveform offset method [Hattori and Ogose, 1980; Hattori *et al.*, 1982]; and

– modulation index offset method [Adachi, 1979].

It is necessary to study these methods with respect to transmission performance under fading conditions and their applicability to mobile radio transmission.

The following parameters are important:

- difference between the carrier frequencies of the transmitters;
- relative timing of the modulation at the transmitters caused by different delays in telephone lines and modulation circuits;
- differences in modulation depth and frequency response.

2. Error performance of digital transmission to moving receivers

With a small carrier frequency difference (< 10 Hz) and accurate modulation timing (< 0.2 bit period) the BER at a moving receiver, in Rayleigh fading conditions, in a multi-transmitter system is approximately the same as with a single transmitter, for a given received signal level, as shown in Fig. 1 (for the case of direct frequency modulation of the RF carrier). Typical error distributions are shown in Fig. 2 [French, 1980].

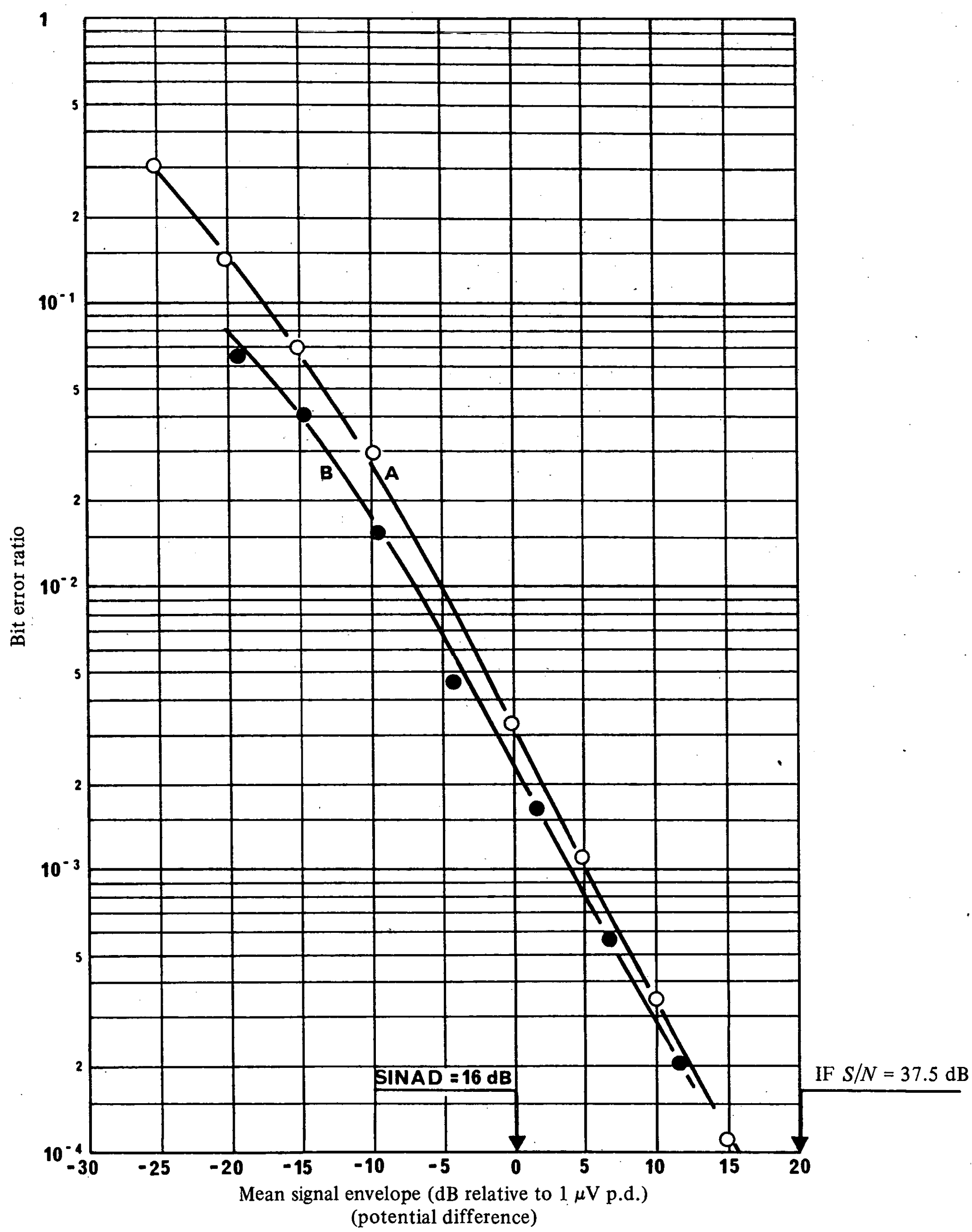

FIGURE 1 – *Error performance, mobile, 1200 bit/s, direct FM*

SINAD: 12 dB at 0.5 μV pd

Curves A : two transmitters

B : single transmitter

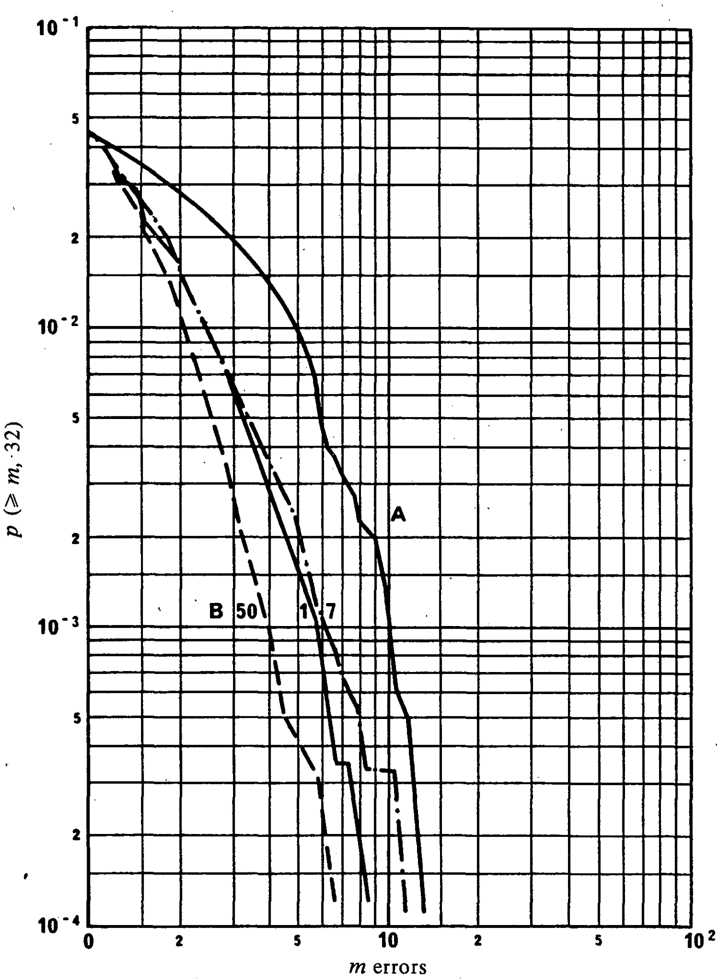

FIGURE 2 – *Error distribution, mobile, 1200 bit/s, direct FM*

BER ≈ 3 × 10^{-3}

Curves A: one transmitter

B: carrier frequency difference Δf_c

To avoid an excessive BER due to difference in modulation timing, the timing difference should be less than 0.3 bit period for direct frequency modulation of the carrier, as indicated in Fig. 3. With sub-carrier data modulation the timing difference must be small compared to the period of the sub-carrier.

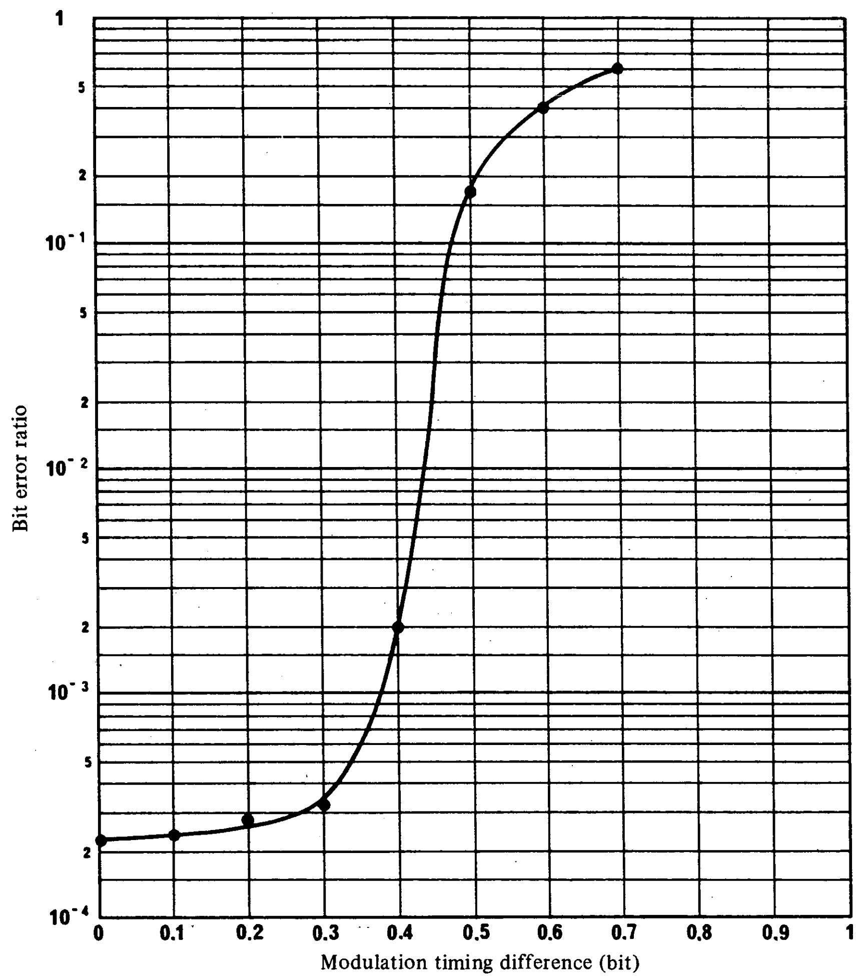

FIGURE 3 – *Bit error ratio modulation timing, mobile, 1200 bit/s, direct FM*

$\Delta f_c = 7$ Hz

Increasing the carrier frequency difference to approximately the bit rate, reduces the BER by two orders of magnitude, as in Fig. 4 [French, 1980]. At higher bit rates this difference in carrier frequency reduces spectrum efficiency.

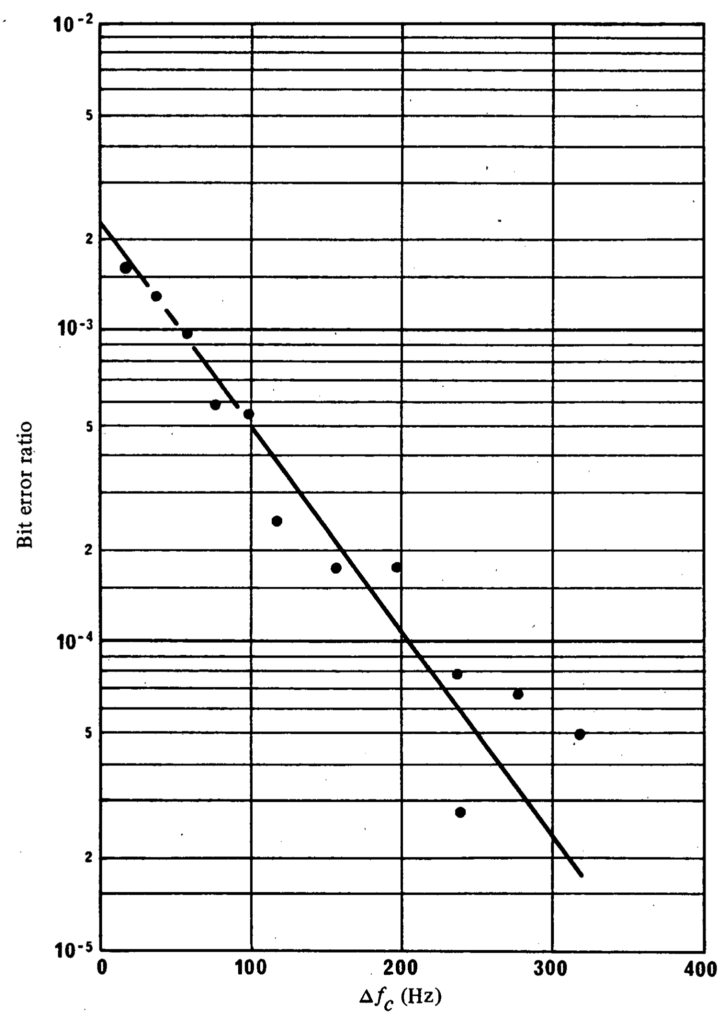

FIGURE 4 – *Bit error ratio against carrier frequency difference, 300 bit/s, direct FM*

Laboratory test results concerning offset methods of carrier frequency, waveform and modulation index are shown in Figs. 5 to 9 inclusive. As shown in Fig. 5, each method results in performance improvement (diversity effect of more than 10 dB) when the average equivalent levels of two received signals are combined.

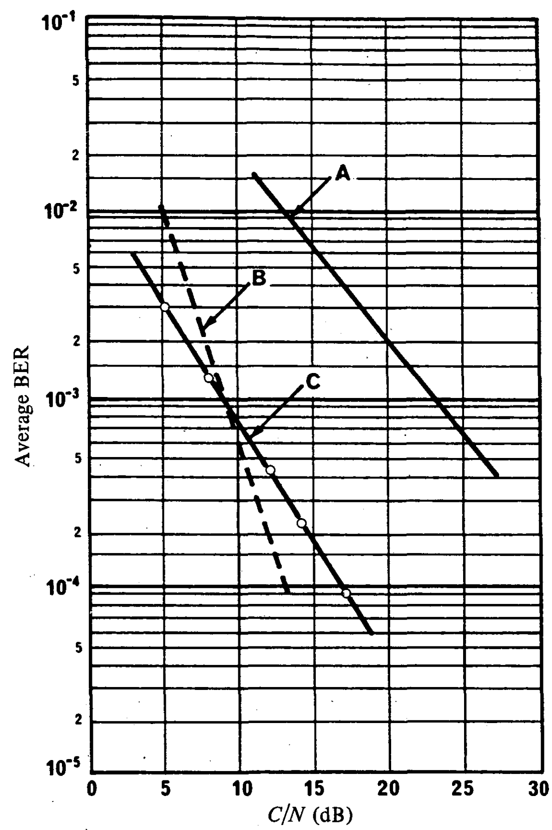

FIGURE 5a – *BER performance versus C/N of carrier frequency offset method and waveform offset method for 300 bit/s Manchester coded signal with direct FM*

Curves A: single transmitter ($\Delta f_D = \pm 3$ kHz)

B: two transmitters with carrier frequency offset ($\Delta f_C = 1$ kHz, $\Delta f_D = \pm 3$ kHz)

C: two transmitters with waveform offset ($\Delta f_d = \pm 3.5$ kHz, $\Delta f_{dh} = \pm 1$ kHz)

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

Δf_C : carrier frequency difference

Δf_D : maximum frequency deviation

Δf_d : average frequency deviation of offset waveform method

Δf_{dh} : frequency deviation corresponding to the peak amplitude of the sinusoidal wave ($= \Delta f_D - \Delta f_d$)

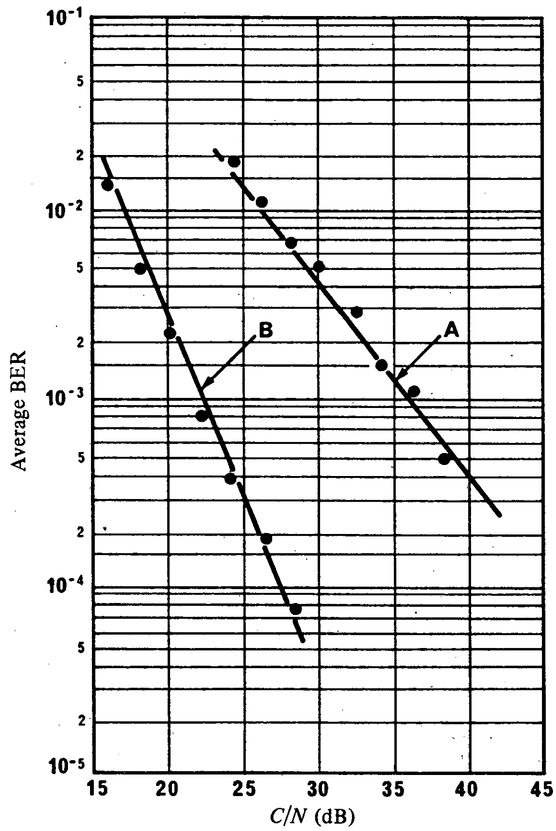

FIGURE 5b – *BER performance versus C/N of modulation index offset method for 600 bit/s differentially encoded Manchester coded signal with direct FM*

Curves A: single transmitter (modulation index $\beta = 9.7$)

B: two transmitters with modulation index offset (modulation index $\beta_1 = 11.7$, $\beta_2 = 9.7$)

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

•: experimental results

If the carrier frequency fluctuates, performance improvement using the frequency offset method changes greatly in the range from 0 to 2 kHz, as shown in Fig. 6 by the broken line. The waveform offset method results in more stable and better performance, as shown in Fig. 6 by the solid line.

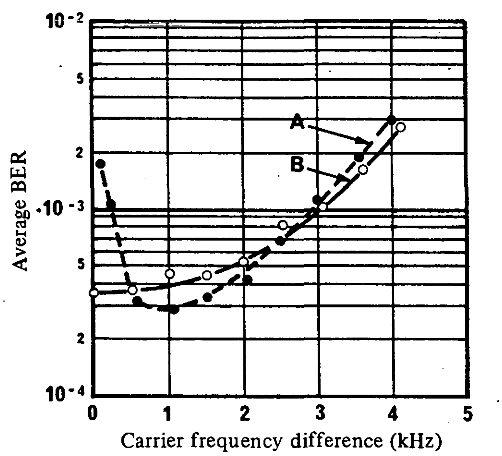

FIGURE 6 – *BER performance versus carrier frequency difference*

Curves A: carrier frequency offset method ($\Delta f_D = \pm 3.5$ kHz)

B: waveform offset method ($\Delta f_d = \pm 3.5$ kHz, $\Delta f_{dh} = \pm 1$ kHz)

Maximum Doppler frequency: 40 Hz

Transmission bit rate: $f_b = 300$ bit/s

The diversity effect decreases as the modulation signal phase difference increases. The improvement characteristics of the phase difference for the frequency offset and the waveform offset methods are similar. In addition, the allowable value for each method is approximately 60° (0.16 bit duration), as shown in Fig. 7.

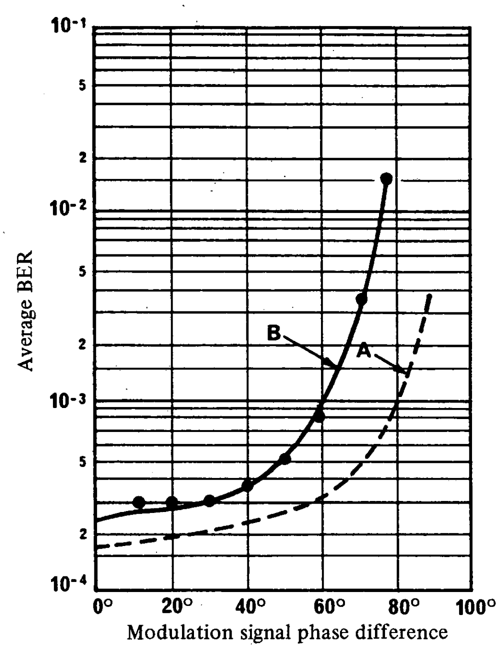

FIGURE 7 – *Effect of modulation signal phase difference on BER performance*

Curves A: carrier frequency offset method (Δf_C = 1 kHz, Δf_D = ±3 kHz)

B: waveform offset method (Δf_d = ±3.5 kHz, Δf_{dh} = ±1 kHz)

Transmission bit rate: f_b = 300 bit/s

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

In the modulation index offset method, BER is reduced by an order of magnitude and the optimum index value difference is 2, as shown in Fig. 8.

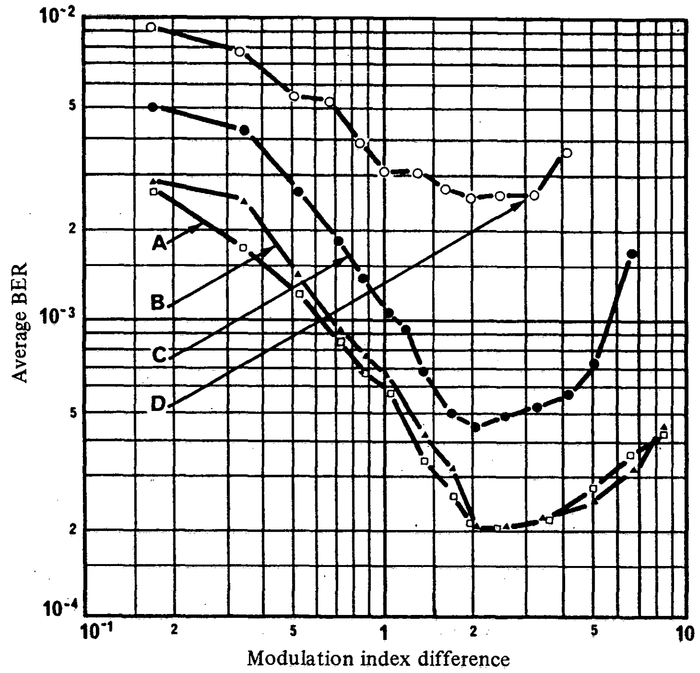

FIGURE 8 – *BER performance in the modulation index offset method for 600 bit/s differentially encoded Manchester coded signal with direct FM*

Modulation index of one transmitter is set as:

Curves A: β_1 = 13.3
B: β_1 = 11.7
C: β_1 = 8.3
D: β_1 = 5

C/N = 26 dB

Modulation index difference: $\Delta\beta = \beta_1 - \beta_2$ $(\beta_1 > \beta_2)$

Cross-correlation coefficient: 0

The waveform offset method has an advantage in that it maintains good diversity effect uniformly in a wide range of phase difference between superimposed sinusoidal signals, as shown in Fig. 9. This results in uniform and good performance in all the overlapping surrounding cell areas when a phase difference of 60° among base stations is chosen. The carrier frequency offset and waveform offset methods are successfully used in the Japanese land mobile telephone systems.

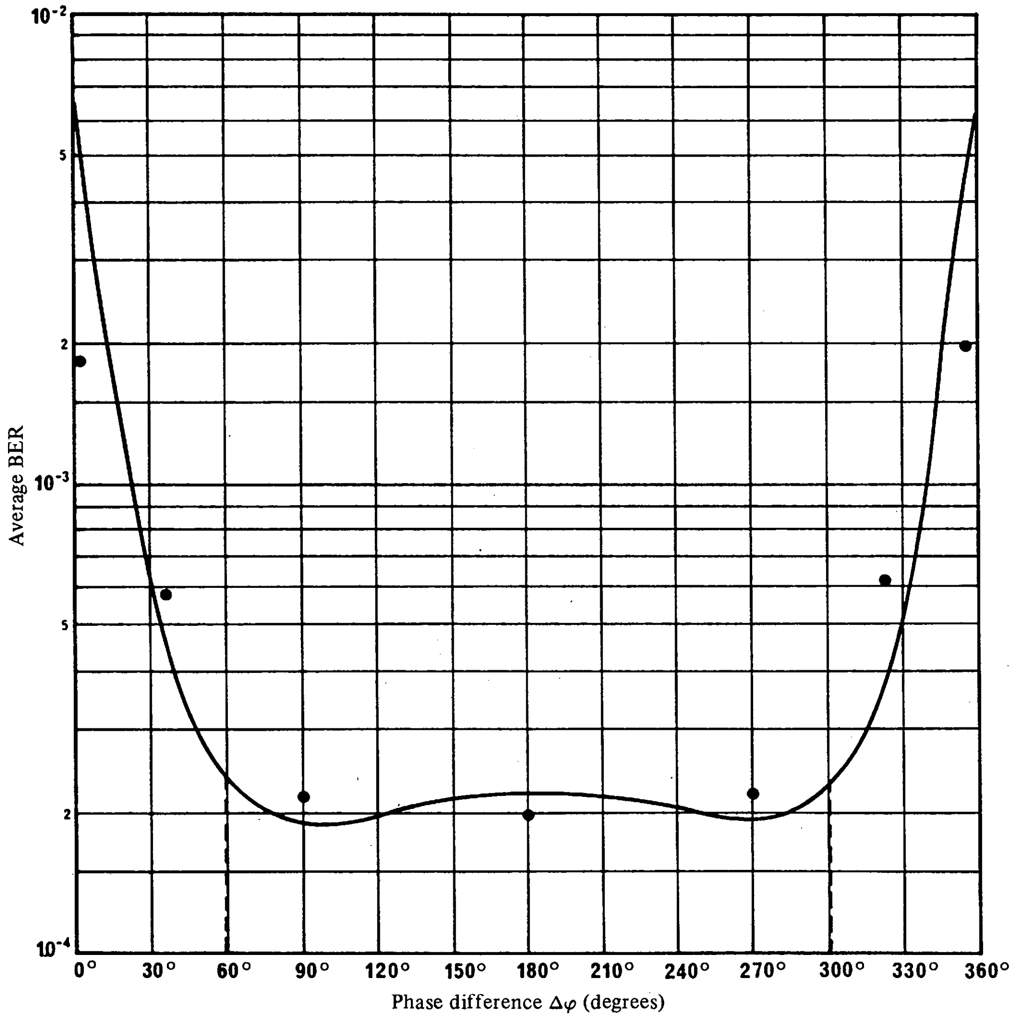

FIGURE 9 – *Effect of phase difference between two superimposed sinusoidal waves*

Waveform offset method (Δf_d = ±3.5 kHz, Δf_{dh} = ±1 kHz)

Transmission bit rate: f_b = 300 bit/s

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

3. Error performance of digital transmission to stationary receivers

At a stationary receiver the steady signals received from say two transmitters will suffer carrier interference, leading to a periodic variation of the amplitude of the resultant signal at the carrier difference frequency. The measured BER as a function of the absolute and relative levels of the two received signals, compared with theory, is shown for amplitude modulation (sub-carrier 1200 bit/s FFSK) in Fig. 10. Similar results are shown for frequency modulation (sub-carrier 1200 bit/s FFSK) in Fig. 11.

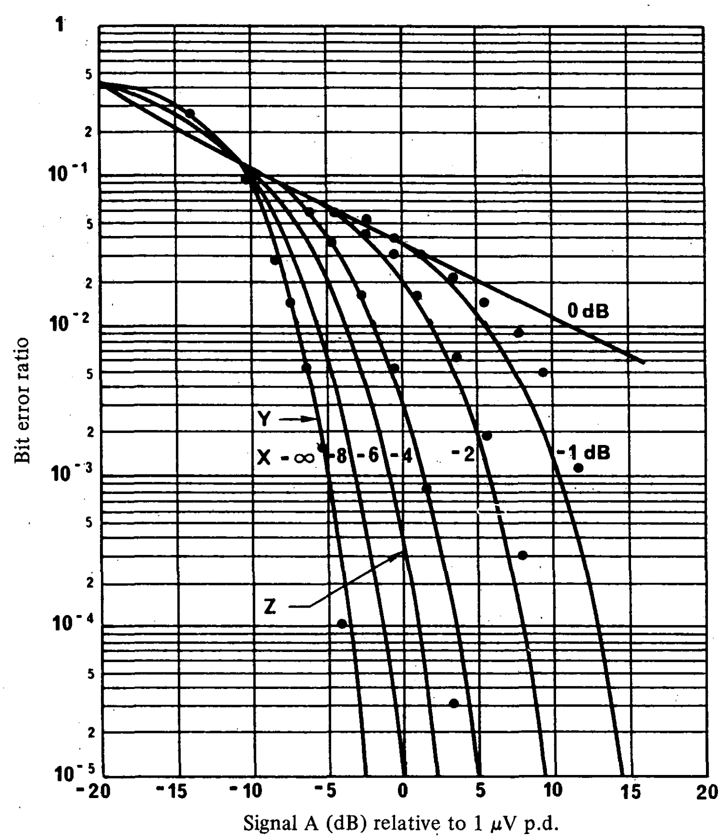

FIGURE 10 – *Stationary AM quasi-synchronous error performance*

12 dB SINAD at –6.5 dB

$\Delta f_c = 2$ Hz

X: level of signal B relative to A

Y: A alone

Z: theory

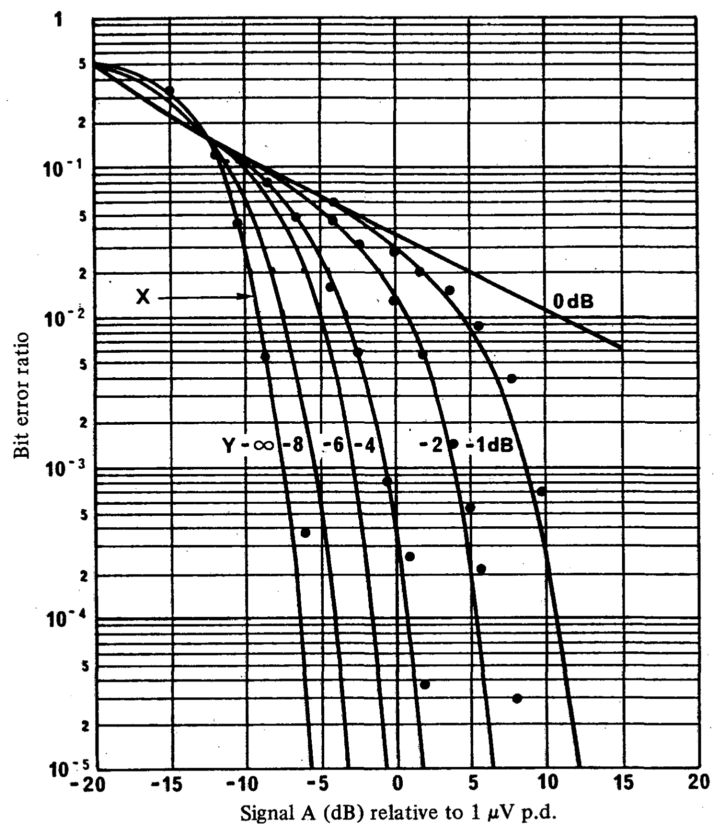

FIGURE 11 – *Stationary FM quasi-synchronous error performance*

12 dB SINAD at –9 dB

Δf_c = 2 Hz

X: A alone

Y: level of signal B relative to A

The mean word error ratio, averaged over a large number of stationary receivers in Rayleigh fading conditions is given in Fig. 12, compared with single transmitter operation, for 64 bit code words and a carrier frequency difference of 1.8 Hz. At lower signal levels (< 12 dB relative 1 μV) performance is improved with the second transmitter (= 2.5 dB) but at high signal levels it is degraded by about 4.5 dB. At higher carrier frequency differences of 18 Hz (see Fig. 13) and 180 Hz, the performance is degraded by between 5 and 10 dB [French, 1982].

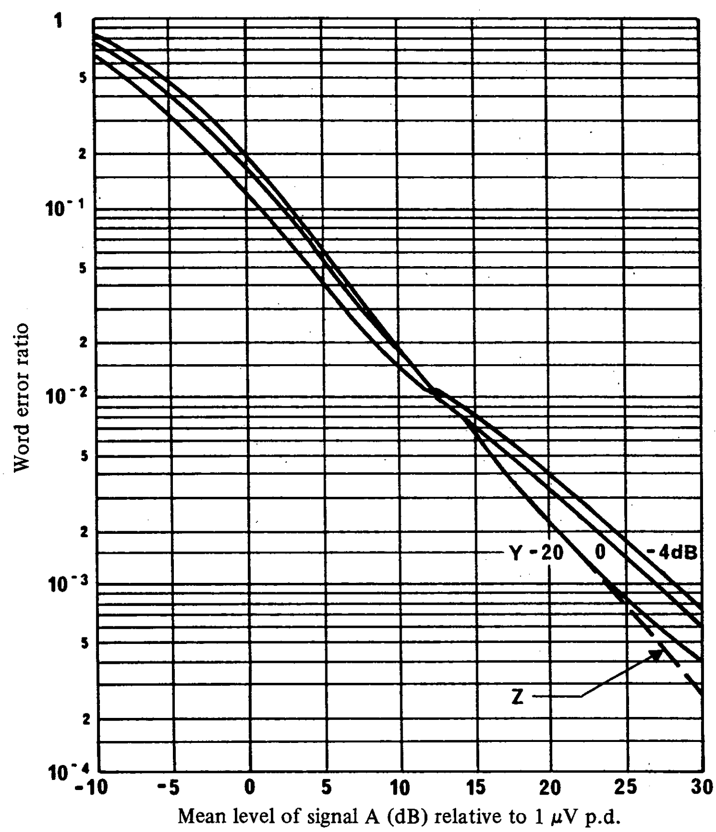

FIGURE 12 – *Mean word error ratio, amplitude modulation*

Δf_c = 1.875 Hz,

f_b = 1200 bit/s,

64-bit words.

Y: relative mean of signal B

Z: A alone

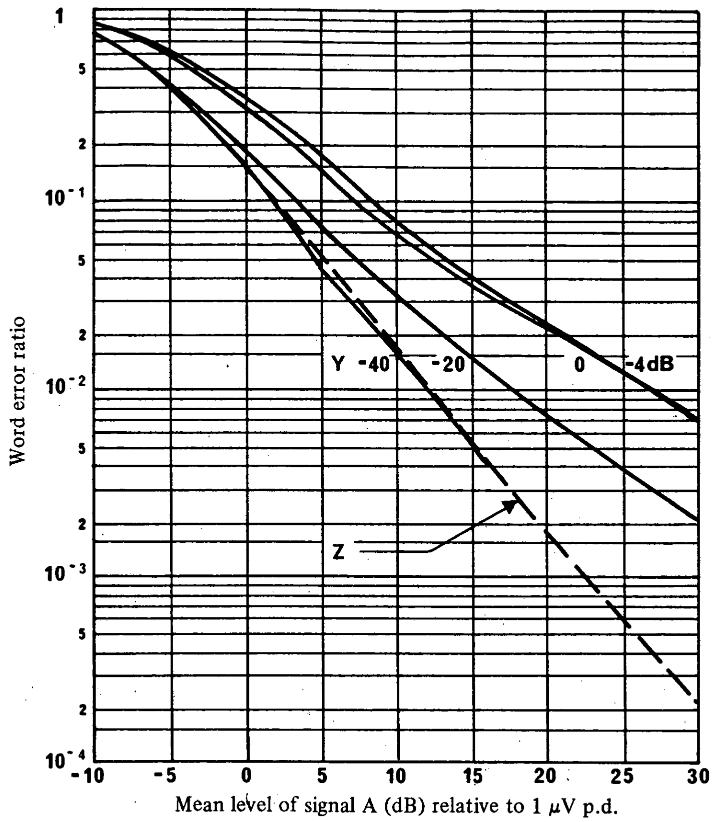

FIGURE 13 – *Mean word error ratio, amplitude modulation*

Δf_c = 18.75 Hz

f_b = 1200 bit/s,

64-bit words

Y: relative mean of signal B

Z: A alone

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REPORT 1023*

FREQUENCY SHARING BETWEEN THE LAND MOBILE SERVICE AND THE BROADCASTING SERVICE (TELEVISION) BELOW 1 GHz

(Question 69/8)

(1986)

1. Introduction

The WARC-79 increased the number of frequency bands that might be shared between the broadcasting service and the mobile service below 1 GHz.

If the same portion of the frequency spectrum is allocated to two or more services, sharing may be effected in one of the following ways:

a) use of the same frequency band by different services at different times;

b) simultaneous use of different parts of the shared bands by different services;

c) simultaneous use of the same parts of the shared bands by different services, but in separate geographical areas.

This Report examines the case of sharing in separate geographical areas as in c) above.

2. Characteristics of the two services

Television services typically operate with considerably larger radiated powers than mobile services (typically 40 dB more) and mobile services typically operate with considerably smaller usuable field strengths than television (typically 30 dB less). This total difference of 70 dB in the planning criteria of the two services suggests initially that sharing will have very limited application. However, in practice the following criteria assist the mobile services:

- the protection ratio required by the mobile services is typically less than that for the television service (typically 10 dB as opposed to 50 dB);
- the service areas in the mobile service are smaller, so antenna heights are less than broadcasting antenna heights and the height gain correspondingly less;
- the television service employs a much wider bandwidth than the mobile service (typically 8 MHz against 12.5 kHz) so the full power of the television signal will not be present in any one mobile channel. In fact, the power density of the television signal is not constant across the television channel, as discussed below.

3. Power spectral density of a television signal

Figure 1 shows the limit of the power spectral density of a television signal when measured in a 7 kHz bandwidth (appropriate to a 12.5 kHz channelled mobile radio receiver). This mask is a composite for the PAL and SECAM systems in use in Europe. The frequency separation between the various carriers is different for the different systems but the relative power levels do not change greatly. It can be seen that between the carriers the power is at least 30 dB below the total power and for much of the television channel is at least 40 dB below.

Figure 1 refers to normal picture scenes. The power spectral density of electronically generated pictures requires further study.

4. Example of sharing

As an example of the sharing possibilities, consider the case of mobile operation around 200 MHz in television Band III (174-230 MHz). From Report 358 for Grade 4 signal quality the requirements of the mobile service are:

- median field strength to be protected: 22 dB(μV/m);
- protection ratio: 10 dB;
- maximum interfering field strength: 12 dB(μV/m).

* This Report should be brought to the attention of Study Groups 1 and 11.

Assume the following typical characteristics for the mobile service:

- base station effective antenna height: 75 m (height gain relative to 10 m: +9 dB) *;
- mobile station effective antenna height: 3 m (height gain relative to 10 m: −4.5 dB) *.

Assume the following to be typical for the television service:

- effective antenna height: 300 m;
- effective radiated power: 250 kW.

Then from Recommendation 370 the separation distances required (for 10% time 50% location) are given in Table I.

TABLE I – *Required separation distances to protect the mobile service (television radiated power between carrier frequencies assumed 30 dB below total radiated power)*

	On carrier frequencies (km)	Between carrier frequencies (km)
Base station	560	260
Mobile station	430	180

It can be seen that, whereas the distances are large for operation on the carrier frequencies, the distances are considerably reduced for operation on frequencies between the carriers. Thus, mobile operation may not be practicable on the television carrier frequencies, but a substantial amount of spectrum remains in which operation may be practicable.

5. Receiving antenna discrimination

Mobile services are constrained to use vertical polarization due to the difficulty otherwise of mounting the mobile antennas, particularly at the lower frequencies. Television services may, however, use horizontal or vertical polarization. The use of horizontal polarization by the television service greatly facilitates frequency sharing by the mobile and television services as advantage can be taken of an antenna discrimination factor of around 15 dB. This discrimination applies only to base stations. In the case of mobiles the discrimination will be much less – perhaps 3 dB – but the base station interference is the dominant case as shown in Table I. The separation distance of 260 km reduces to 160 km in the example of Table I if orthogonal polarization is assumed.

6. Protection of television services

According to Recommendation 417 the minimum (median) field strengths for which protection may be sought in planning television services are 48, 55, 65, or 70 dB(μV/m) for bands I (47-68 MHz), III (174-230), IV (470-582 MHz) and V (582-960 MHz), respectively. The use of lower values militates against sharing. It can be seen from Fig. 1, that (apart from in the vicinity of the carriers) moderate increases in television transmitter power to improve the field strength at the edge of the service area can have little effect on mobile usage. Also, since the carrier frequencies are unlikely to be usable by the mobile service, the interference will not be increased if low power "fill-in" transmitters are employed, providing that the carrier frequencies align to the same frequency grid. Sharing is further facilitated if higher protected field strengths can be accepted for the service areas of these fill-in transmitters.

* These values require further study.

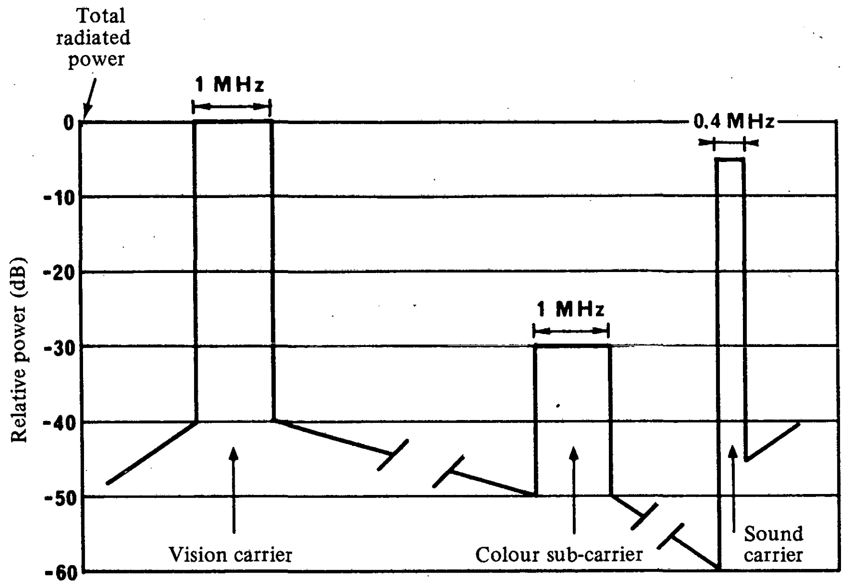

FIGURE 1 – *Relative values of peak radiated power (measured in a 7 kHz band)*

7. Protection ratios

Protection ratios for television signals are given in Recommendation 418 and Report 306. These references show that the protection ratio is not constant, for narrow-band interference across the television channel, being greatest (around 50 dB) near the vision carrier and least (around 30 dB) near the sound carrier. Mobile services can be planned to take advantage of this by assigning frequencies near the sound carrier to base station sites having the greatest interference potential and frequencies near the vision carrier to those having the least interference potential, or to mobiles.

8. Multiple interference

A new consideration that will arise with sharing between the mobile and television services is the effect on the television signal of multiple interfering sources. This arises because of the large difference in bandwidth used by the two services which implies that there could be 300 or 400 mobile service transmitters operating in a television channel.

It is possible that the simplified multiplication method as detailed in Report 945, is appropriate to this case, but further study is required. Also, it is unlikely that all the mobile service transmitters would be operating simultaneously and further study is required on the statistics of mobile operation noting that sharing will be facilitated if mobile operation can be confined to specific areas.

9. Interference from base and mobile stations

Base stations are likely to cause a greater interfering effect to television than mobile stations. The lower antenna height of mobiles, coupled with their limited radiated power and the general clutter effects caused by buildings, combine to make the interfering field strength from a mobile station to be around 20 dB less than that from the corresponding base station. This factor will not be achieved if the mobile is operating from a high clear site, but interference from mobile stations will be transitory.

A typical base-station radiated power in the mobile service is 25 W. By using directional antennas this can be effectively reduced, typically to 2.5 W, in the direction of the television broadcast service area.

Annex I gives a method showing how the effect of multiple interference from narrow-channel land mobile stations may be aggregated within the wider bandwidth of a television channel, and demonstrates the advantages accruing from the use of directional antennas.

10. Conclusions

Sharing between the mobile and broadcasting (television) services is practicable in separate geographical areas, particularly if the television carrier frequencies are avoided.

Sharing becomes easier as the protected field strength of both services is increased. Also, sharing is facilitated if horizontal polarization is used in the television service. However, where polarization discrimination could be employed to facilitate sharing within the broadcasting service, the overall spectrum advantages will need careful study.

The effects of multiple sources of interference on the television service are not fully understood and require further study.

ANNEX I

At sites close to the coast that offer a predominantly sea path, particular care should be taken to reduce field strengths that interfere with the television service. It is possible for a single base station installation to produce an interfering field strength equal to the value of field strength of the television service to be protected. This prevents use of the television channel by the land mobile service.

The interfering, or nuisance, field is calculated by (see Report 945):

$$E_n = \sqrt{\sum_{i=1}^{n} (a_i + b_i + e_i)^2}$$

where:

a_i: radio-frequency protection ratio (dB) associated with the ith unwanted transmitter;

b_i: receiving antenna discrimination (dB);

e_i: field strength of the unwanted transmitter (dB(μV/m)).

By using a directional base-station antenna, the interfering field strength can be reduced by at least 10 dB.

It now remains to demonstrate what this means in terms of channel usage.

The simplified multiplication method for the assessment of multiple interference (see Report 945) gives the following formula for calculating usable field strength (field strength to be protected):

$$p_c = 0.5 = \prod_{i=1}^{n} L(E_u - F_i)$$

These terms are defined in Report 945, but the following should be noted:

$$F_i \equiv E_{si} \text{ (in Report 945)}$$

$$F_i = P_i + E_{ni}(50, T) + A_i + B_i + K_i \qquad (1)$$

where:

K_i: directional antenna correction factor associated with the ith unwanted transmitter.

Now, if k interfering fields are introduced such that:

$$F_{(n+1)} = F_{(n+2)} = F_{(n+3)} = \ldots F_{(n+k)} = F'$$

and the new value of protected field strength $(E_u) = E_p$, then:

$$p_c = \prod_{i=1}^{n+k} L(E_p - F_i)$$

$$= \left[\prod_{i=1}^{n} L(E_p - F_i)\right] \times \left[L(E_p - F_{(n+1)}) \times L(E_p - F_{(n+2)}) \times \right.$$

$$\left. \times L(E_p - F_{(n+3)}) \times \ldots \times L(E_p - F_{(n+k)})\right]$$

$$= \left[\prod_{i=1}^{n} L(E_p - F_i)\right] \times \left[L(E_p - F')\right]^k$$

therefore:

$$k \log_e \left[L(E_p - F')\right] = \log_e \left[\frac{p_c}{\prod_{i=1}^{n} L(E_p - F_i)}\right] \quad (2)$$

Note. – $L(E_p - F_i) = 0.5 + 0.5\,\varphi\left(\frac{E_p - F_i}{8.3\sqrt{2}}\right)$ (see Report 945)

and $$\varphi(x) = \frac{2}{\sqrt{2\pi}} \int_0^x [\exp(-t^2/2)]\, dt$$

In this example E_p has been taken to be 70 dB(μV/m) and F_i to be 60 dB(μV/m).

$$k \log_e [L(70_p - F')] = \log_e \left[\frac{0.5}{L(70 - 60)}\right]$$

$$= -0.4736002$$

Therefore, various values of interfering field strength, F', can be equated to k extra interfering base-station transmitters, each giving rise to an interfering field strength F' (F' being calculated using equation (1)) and operating simultaneously with the re-engineered base station giving rise to the interfering field strength F_i.

TABLE II – *Number of base-station transmitters giving rise to an interfering field strength F'*

Interfering field strength F' (dB(μV/m))	No. of additional base stations k $\left[k = \frac{-0.4736002}{\log_e L(70-F')}\right]$
30	1446
40	89
50	10
60	2

The value of k can be increased still further by careful choice of base-station transmit frequency and keeping the antenna heights as low as possible.

REPORT 1024

PERSONAL RADIO SYSTEM

(Question 71/8)

(1986)

1. Introduction

This Report relates to the personal radio system used in Japan as an example of multi-channel access technique without a central controller. Intended as an initial technical response to Question 71/8, this Report introduces the basic characteristics, connecting procedure, and receiver input level versus connection reliability.

2. Basic characteristics

2.1 *Frequency:* 903.0125 to 904.9875 MHz

2.2 *Channel separation:* 25 kHz

2.3 *Number of channels:* 80 channels (one control channel and 79 traffic channels)

2.4 *Class of emission:* F2D: control channel
F3E: traffic channels

2.5 *Type of operation:* Simplex

2.6 *RF power output:* 5 W

3. Connecting procedure

3.1 *Configuration of control signal*

An automatic transmitter identification system (ATIS) is included in a read-only memory (ROM) obtained from the licensing authority. The ROM is required for the operation of the personal radio system (PRS) transceivers.

Code configuration for ATIS and circuit linkage

Bit synchronization:	50 bits 101010 . . .
Word synchronization:	15 bits 111011001010000
Selective calling number:	20 bits, 5 BCD bits
Channel number:	8 bits, binary
Reserved bits:	4 bits, 0000
ATIS code:	48 bits binary: identification codes (for more than ten million stations, licence issue date and scrambling)
Length of Hagelbarger code:	2 × data bit length + 12 = 172 bits
Total:	172 + 65 + 237 bits (197.5 ms)
Code type:	NRZ
Bit rate:	1200 bit/s
Modulation method:	MSK 1200 Hz mark 1800 Hz space

3.2 *Receiver (RX) input versus connection reliability*

In Fig. 1, an example of receiver input level versus bit error ratio (BER) is shown. Line C of BER = 10^{-2} corresponds to 90% connection reliability for the personal radio system.

3.3 *Flow chart*

Figure 2 is a simplified communication procedure flow chart for the personal radio system. The procedure of connection is as follows. All the radios in the system are in the stand-by state on the control channel. The calling station looks for and finds an idle traffic channel and stores the channel number in its memory. Then it emits the control signal on the control channel. Those radios whose selective call number coincides with the control signal transfer to the specified traffic channel and enter into conversation. The call sign consisting of the ATIS code is automatically transmitted before the start of conversation, every 60 s through conversation and at the end of the conversation. A selective call number is specified before transmission. On the other hand, up to two selective call numbers can be set for receiving.

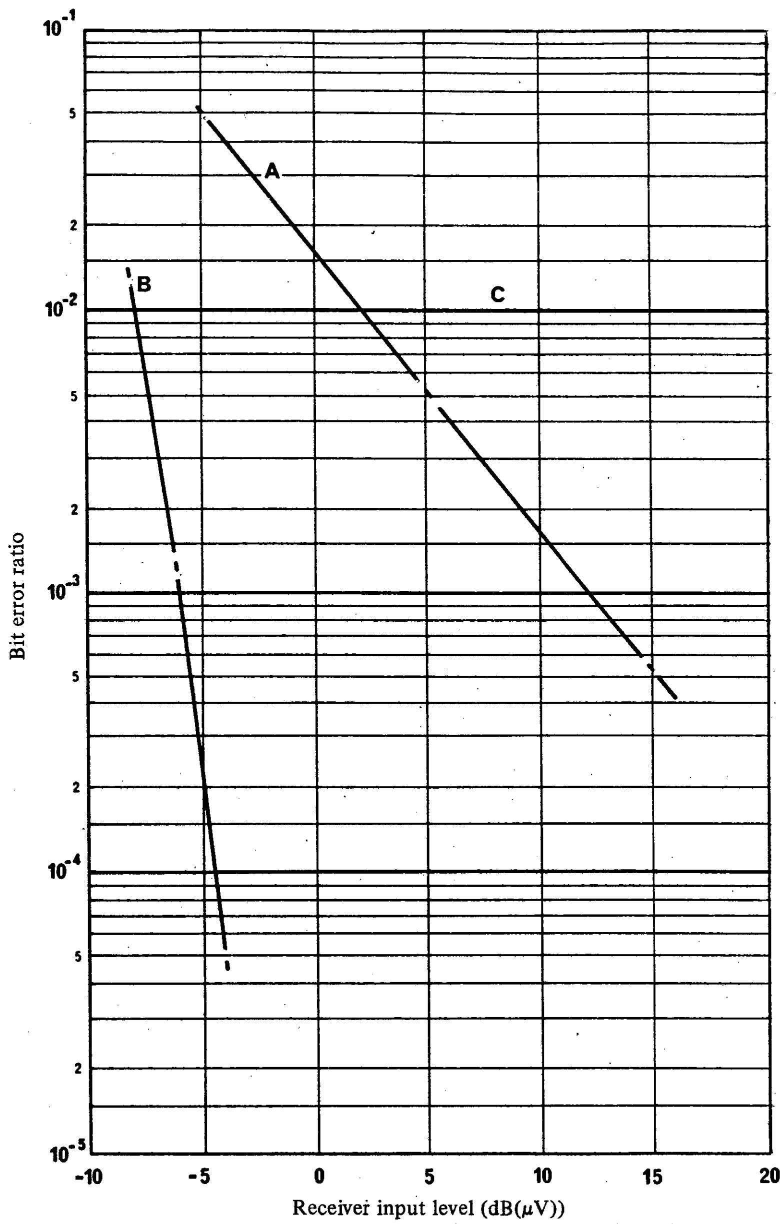

FIGURE 1 – *Receiver input level versus bit error ratio performance*

Curves A: Rayleigh fading
– Centre frequency: 903.8875 MHz
– Fading frequency: 20 Hz

B: no fading

C: connection reliability: 90% or more

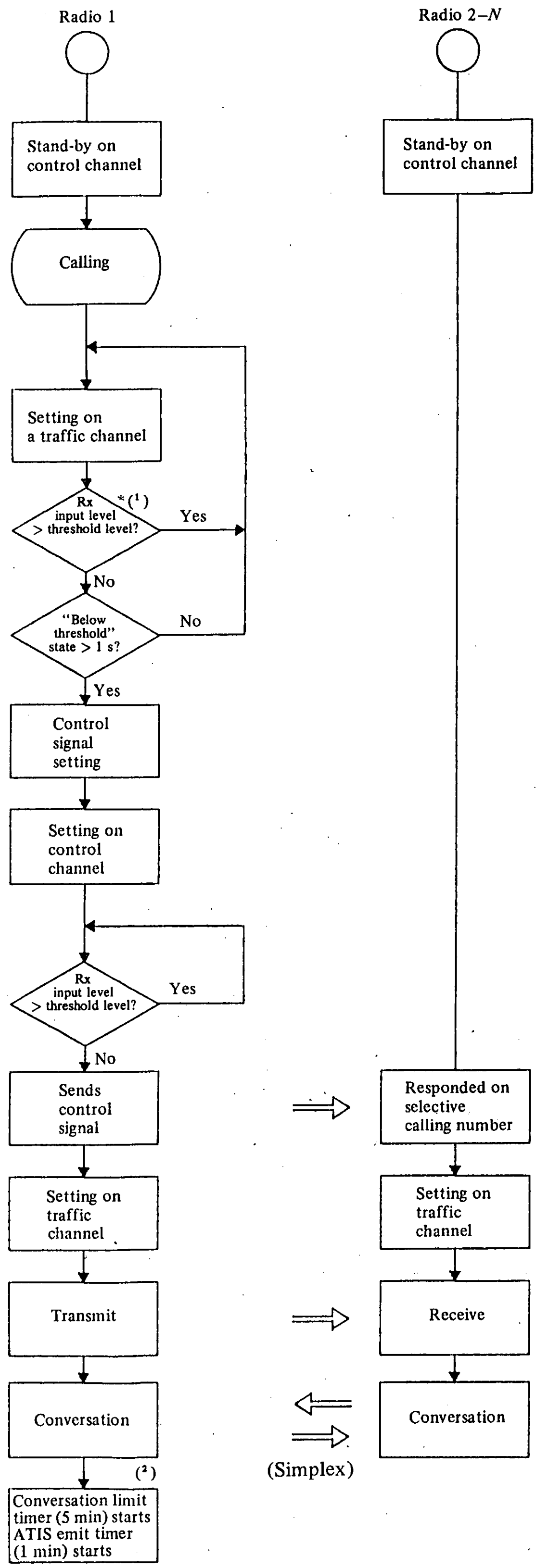

FIGURE 2 – *Simplified communication procedure flow chart*

(1) Threshold level.

The standard threshold carrier level for the receiver is set at 1 μV (open voltage).

(2) In consideration of traffic congestion, a conversation timer is provided.

4. Conclusion

Without a central controller, a personal radio system has been implemented as an economical communication system of relatively high reliability. Thus, this system is popular in use.

REPORT 1025

TECHNICAL AND OPERATING CHARACTERISTICS OF CORDLESS TELEPHONES

(Question 71/8)

(1986)

1. Introduction

In recent times, cordless telephones which can be connected into the public switched telephone network (PSTN) and have a small service area limited to a few hundred metres, have gained widespread popularity. To meet the growing demand for these cordless telephones, it would be advantageous to develop a system using multi-channel access techniques that does not rely on a central system controller and provides efficient frequency utilization.

Part A of this Report deals with the general principles of cordless telephones using multi-channel access techniques, in particular, with the basic objective and technical characteristics which are important for their operation.

The major characteristics of some existing cordless telephones are given in Part B of this Report together with a brief description and other aspects of system operation.

PART A

1. Objectives

The basic objectives of the application are:

- that the radio spectrum be used efficiently;
- that a system of high subscriber capacity be realized;
- that simple and minature circuits be used to ensure that the weight and size of the equipment are compatible with ordinary telephones and that it can be provided economically;
- that the system must provide good quality for public communication and that a flexible system of operation can be provided that does not require complicated frequency management;
- that the system shall perform as much as possible as a normal telephone set;
- that the system be provided security of call charges.

2. Technical and operational aspects

A cordless telephone system consists of two parts:

- a fixed set which is connected to the subscriber line of the ordinary telephone network; and
- a portable cordless telephone set.

Each cordless telephone set uses multi-channel-access techniques and individually performs the following operations:

- searches for idle channels among multiple radio channels during waiting periods;
- sets up speech paths using the selected channel;
- detects interference from other cordless telephones;
- checks identification codes in the signals between the fixed set and the portable set in order to ensure that only associated units will lock to each other.

As a consequence, the following operation and management procedures can apply:

- in system operation, it is only necessary to manage the number of cordless telephones within the area determined by the distance at which interference occurs, while taking into account the subscriber capacity which is determined by the number of radio channels and the channel traffic;
- flexible operation can be provided, so as to permit the use of a greater number of cordless telephones than the subscriber capacity per zone, if the number of cordless telephones in use in the adjacent zones is small.

PART B

SYSTEMS BEING USED OR PLANNED IN THE NEAR FUTURE

1. Systems features

Analogue cordless telephones employing frequency division multiple access techniques (FDMA) have been developed in many countries.

A summary of major system specifications is given in Table I.

In Annexes I and II the main features of the proposed two systems are described.

2. Conclusion

The technical basis and system features of analogue cordless telephone system using multi-channel access techniques which do not rely on a central system controller have been presented. The techniques described here would provide efficient frequency utilization, high subscriber capacity and flexible system operation.

TABLE I – *System characteristics*

	System 1 (¹)	System 2 (²) [CEPT, 1983]
Class of emission	F3E, F1D	F3E or G3E
Transmit frequency band (MHz):		
– fixed set	380-381	959-960
– portable set	253.5-254.5	914-915
Channel spacing (kHz)	12.5	25
Number of channels	46	40
Transmitter power, e.r.p. (mW):		
– fixed set	6	max. 10
– portable set	6	max. 10
Typical service area (m)	– indoor: within 50 m of fixed set – outdoor: within 200 m of fixed set	– indoor: within 50 m of fixed set – outdoor: within 200 m of fixed set
Voice signals:		
– type of modulation	angular	angular
– processing		syllabic compandor CCITT Rec.162 (suggested)
Signal-to-noise ratio (dB)	40	45
Identification code	5.10^5 combinations	1.10^6 combinations

(¹) System 1 is in use in Japan.

(²) System 2 is used by several European countries.

REFERENCES

CEPT [1983] Recommendation T/R 24-03 on radio characteristics of cordless telephones. CEPT, Cannes, France.

ANNEX I

GENERAL DESCRIPTION OF SYSTEM 1

1. System configuration

The configuration of an analogue cordless telephone of system 1 employing the analogue multi-channel access technique is shown in Fig. 1.

The system configuration which has been adopted does not use a central controller. In the system, each cordless telephone itself performs the functions of searching for idle channels, detecting interference and setting up a speech path over the selected channel.

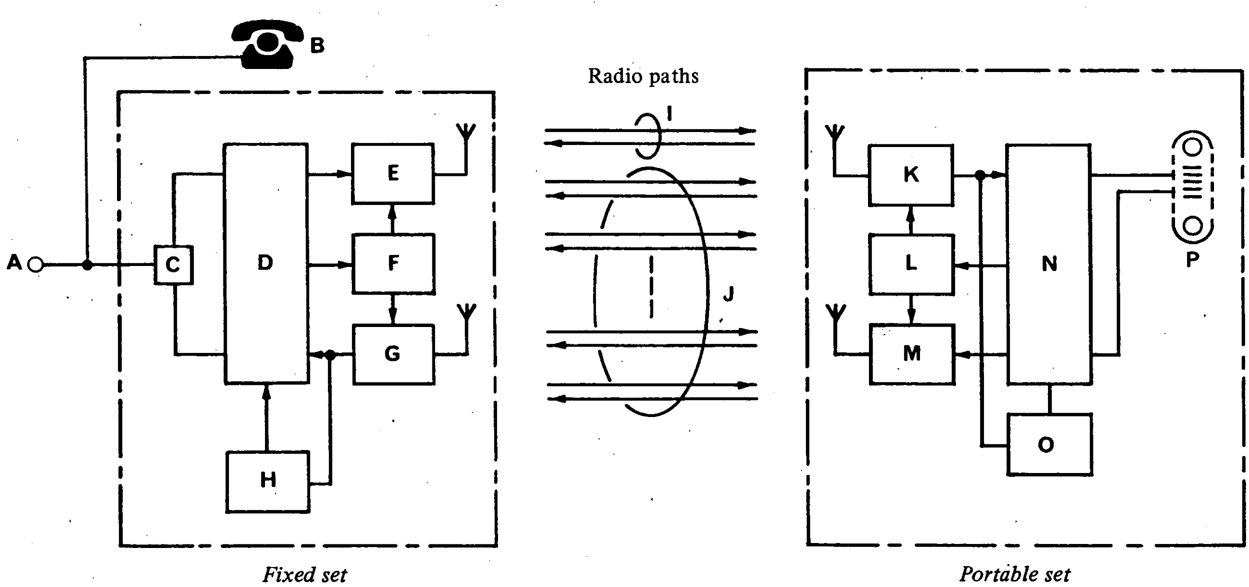

FIGURE 1 – *Block diagram of a cordless telephone system using multi-channel accessing techniques*

- **A**: subscriber line
- **B**: ordinary telephone
- **C**: hybrid
- **D**: signal controller
- **E**: transmitter
- **F**: synthesizer
- **G**: receiver
- **H**: idle channel detector and interference detector
- **I**: control channel
- **J**: speech channels
- **K**: receiver
- **L**: synthesizer
- **M**: transmitter
- **N**: signal controller
- **O**: idle channel detector
- **P**: handset

2. Call setting-up procedures

The procedures for setting-up a call are given in Fig. 2.

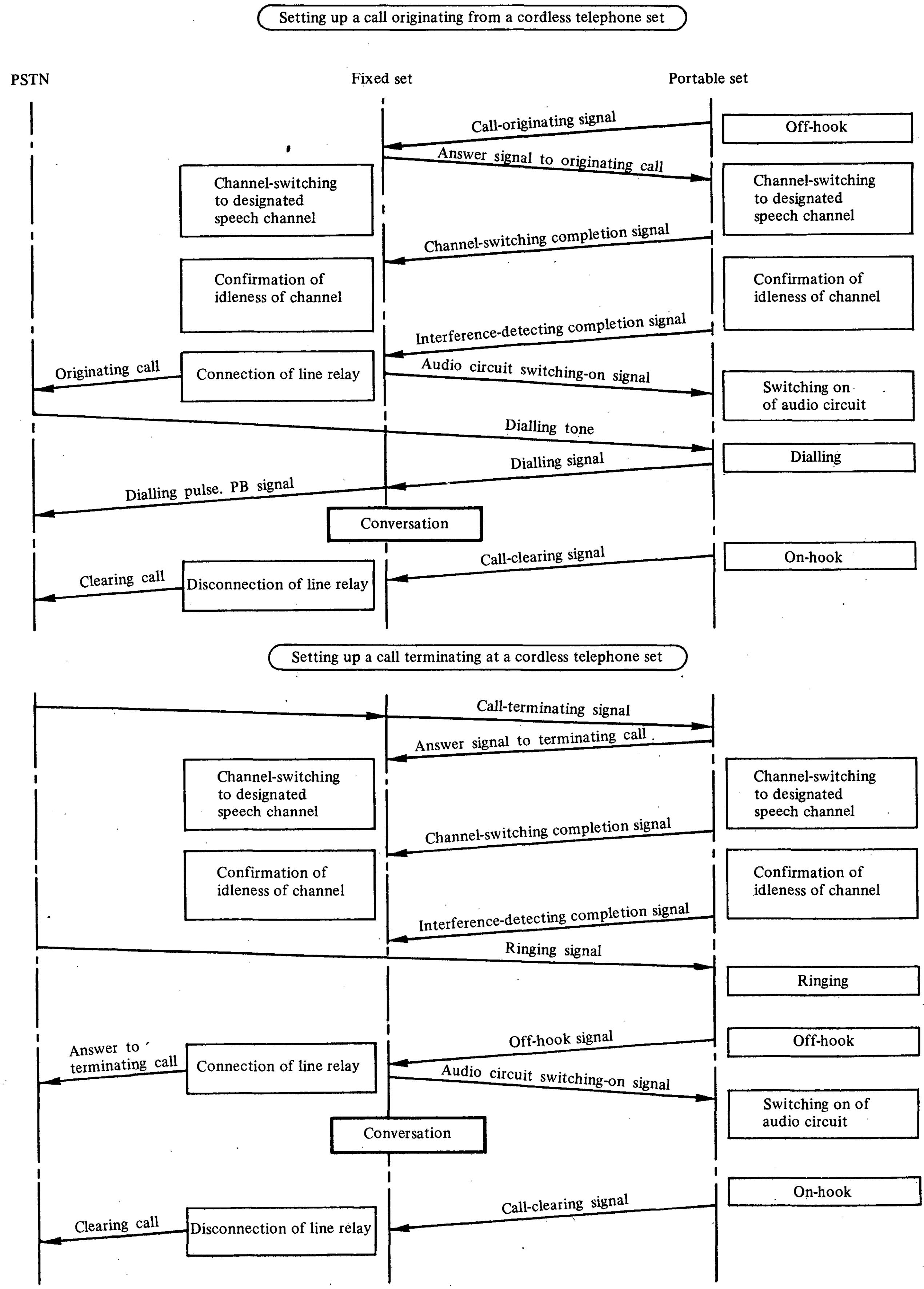

FIGURE 2 – *Call setting-up procedure*

2.1 *Waiting and monitoring mode*

In this mode, the fixed set carries out the operations of monitoring the radio channel utilization by channel scanning and of measuring the field strengths of the speech channels in use. As a result of these operations, suitable idle channels are selected and stored in the memory for use during actual conversation transmissions.

2.2 *Call originating and terminating mode*

When a call is originated or terminated, the fixed set communicates with the portable set by means of the control channel, with one of the idle channels stored in its memory. Both the fixed and portable sets then switch the radio path from the control channel to the designated idle speech channel and confirm that it is not in use. Following this procedure, the speech path is set up.

2.3 *Conversation mode*

If the portable set is moved during conversation, there is a possibility of interference with other cordless telephones. The fixed set therefore always monitors the speech channel during conversations and if interference is detected, the radio path is changed to one of the other idle speech channels stored in the memory.

ANNEX II

GENERAL DESCRIPTION OF SYSTEM 2

1. System configuration

The configuration of an analogue cordless telephone of system 2 employing the multiple channel access technique is shown in Fig. 3.

The system configuration which has been adopted, does not use a control channel to set up the RF connection between fixed and portable sets. Occupancy of an RF channel may be initiated by the fixed set or the portable set by following the same procedure.

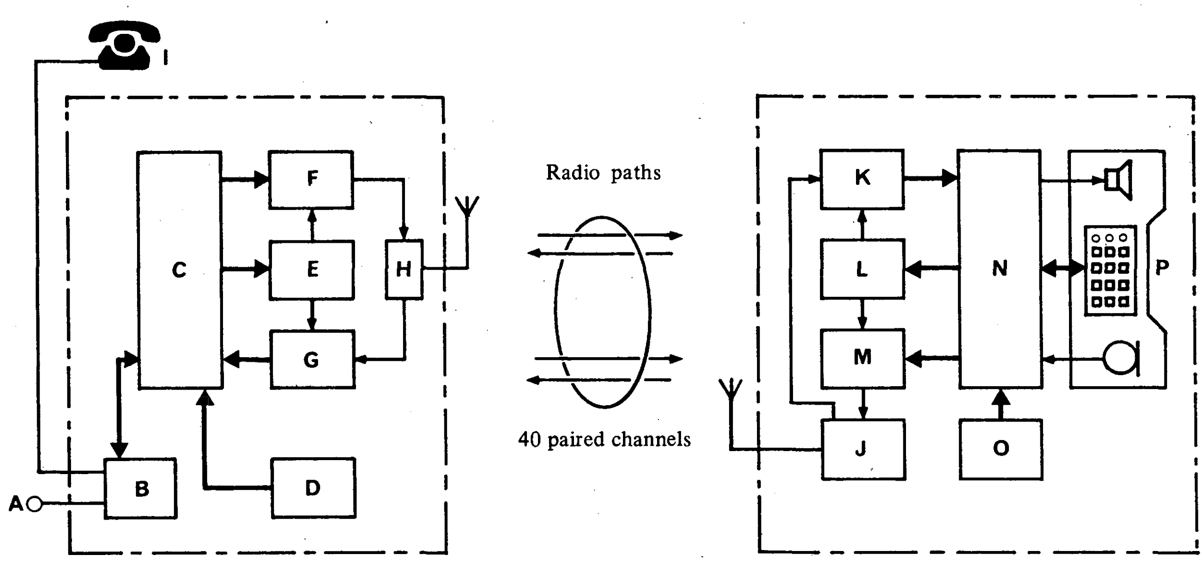

FIGURE 3 – *System configuration*

- **A** : subscriber line
- **B** : line interface
- **C** : signal controller and CPU
- **D** : identification code PROM
- **E** : frequency synthesizer
- **F** : transmitter
- **G** : receiver
- **H** : duplexer
- **I** : associated telephone
- **J** : duplexer
- **K** : receiver
- **L** : synthesizer
- **M** : transmitter
- **N** : signal controller and CPU
- **O** : identification code PROM
- **P** : handset

2. Call setting-up procedures

The procedures for setting-up a call are given in Fig. 4.

2.1 *Waiting mode*

In this mode, the receiver of each part of the cordless telephone set is constantly scanning the available RF channels, searching for a signal which contains its matching identification code.

2.2 *Call originating mode*

When the need for a radio-frequency channel arises in either of the two parts of a cordless telephone set, that part searches for an idle duplex channel by sensing the field strength on that channel.

On the idle channel, the initiating part starts transmitting its identification code. Upon detection of this code, the receiver stops scanning and initiates its transmitter to occupy the corresponding return frequency of the duplex channel and to transmit its identification code to the initiating part. As soon as the receiver of the initiating part detects its matching identification code on the return frequency of the selected duplex channel, the initiating transmitter stops transmitting the identification signals and the RF channel becomes available for the transmission of dialling tones and speech.

2.3 *Conversation mode*

To ensure continued locking during a call, the identification procedure is periodically repeated.

2.4 *Call terminating mode*

When the RF connection is to be terminated, the part of the cordless telephone set which initiates the termination procedure transmits a proper termination message including the identification code. The RF circuit is immediately disconnected and the cordless telephone set returns to the idle condition.

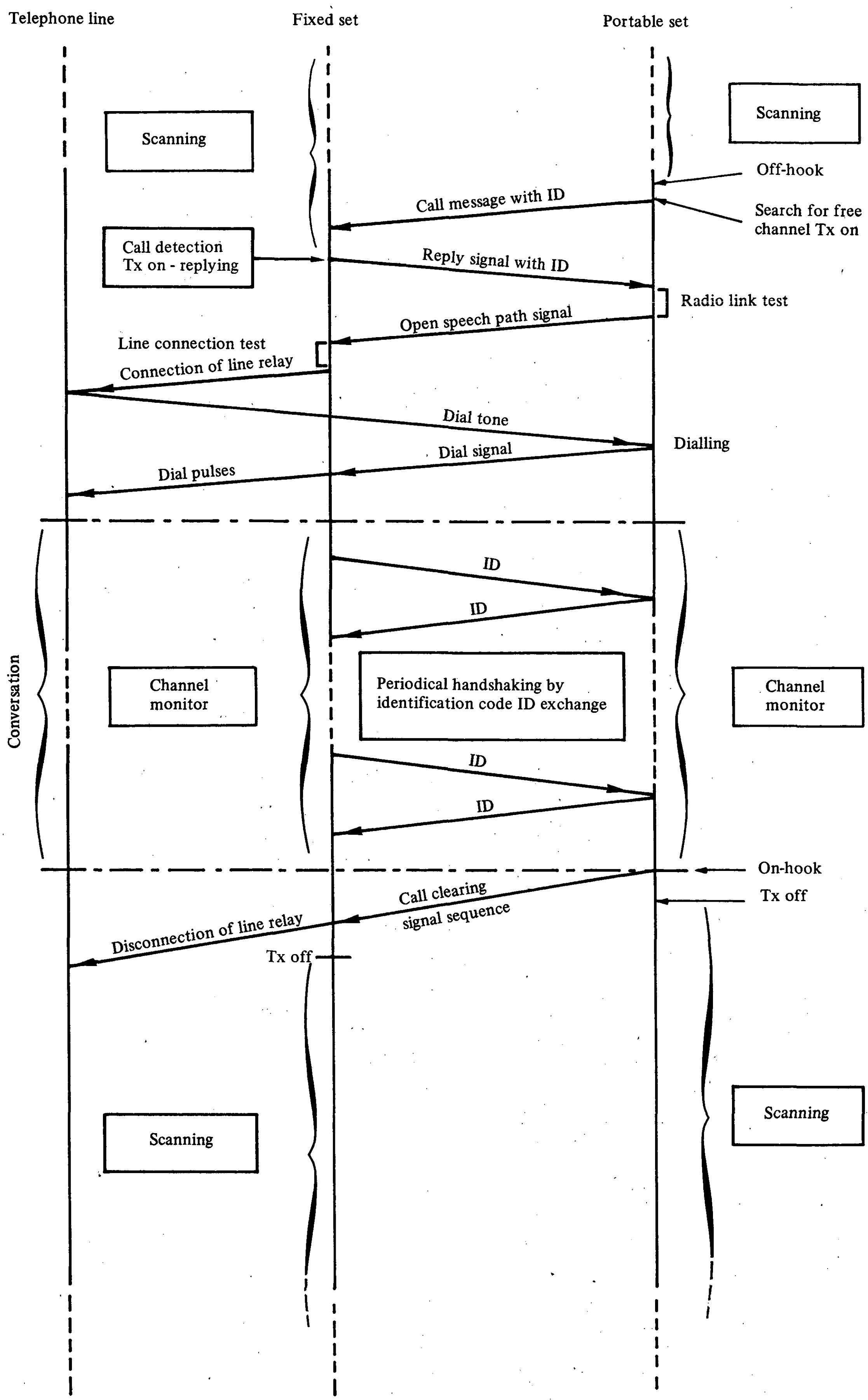

FIGURE 4a – *Cordless originated call*

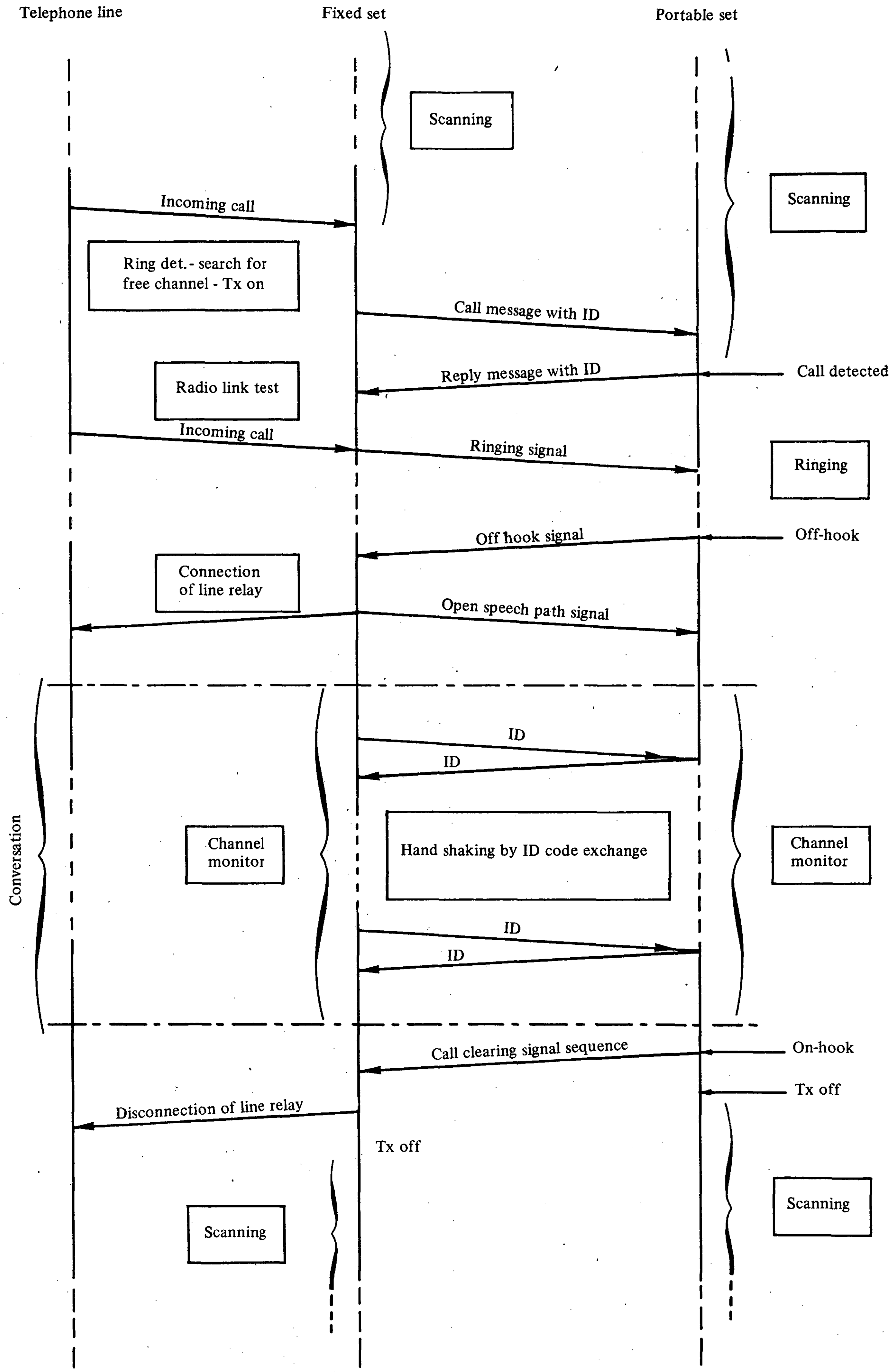

FIGURE 4b – *Cordless terminating call*

SECTION 8J: AMATEUR SERVICE; AMATEUR SATELLITE-SERVICE

Reports

REPORT 905-1

TECHNICAL INVESTIGATIONS IN THE AMATEUR SERVICE

(Question 48/8)

(1982-1986)

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 *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.

2.3 *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.

2.4 *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 are under way in several countries [ARRL, 1981; 1983; 1984; 1985], generating improved protocols at all layers of the ISO open system interconnection reference model. Work is also being done on computer-based message systems, including the development of inexpensive packet assembler/disassemblers and modems.

2.5 *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.

2.6 *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:

2.6.1 *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 and Harris, 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 Fig. 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 ± 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.

2.6.1.1 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 (see Fig. 2).

2.6.1.2 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.

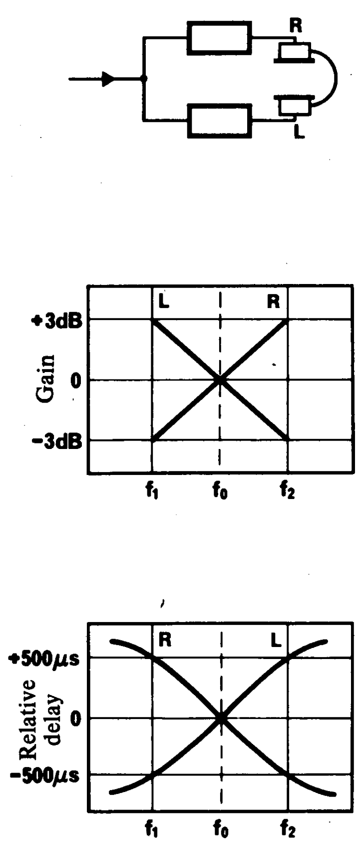

FIGURE 1 – *Stereocode filter. Gain and delay dispersion.*

R: right
L: left

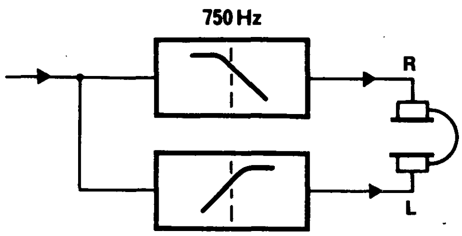

FIGURE 2 – *Stereocode using highpass-lowpass filtering.*

R: right
L: left

2.6.2 *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.

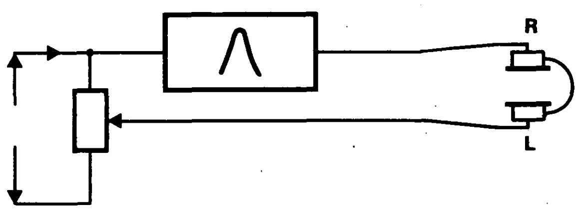

FIGURE 3 – *Wideband-narrowband selective filter.*

R: right
L: left

2.6.3 *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. Figure 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.

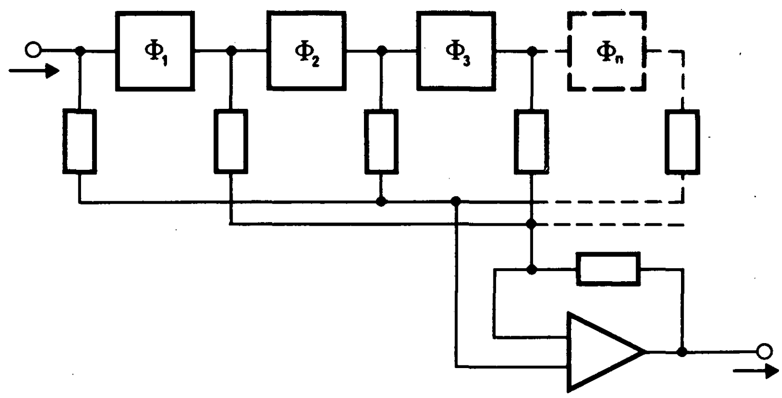

FIGURE 4 – *Coherent audio filter – basic concept.*

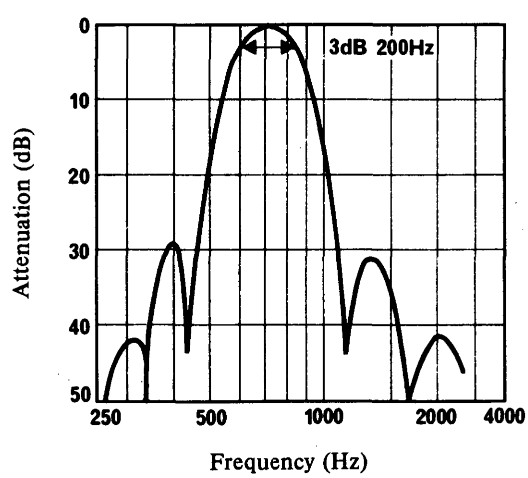

FIGURE 5 – *Coherent audio filter – frequency response.*

2.6.4 *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.

2.6.5 *The frequency-agile filter*

This filter [Tong, 1978] combines all the functions described in § 2.6.4 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.

2.6.6 *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.

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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, narro w-band frequency modulation and data systems using essentially the bandwidth of a voice signal.

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* This Report should be brought to the attention of Study Group 6.

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.

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	Sunspot 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 ER1 110-ITS [ESSA, 1978].

Reliability of 90%, field strength greater than 1 μV/m for power 1 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

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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.

* This Report has been drawn up by Study Group 2 is brought to the attention of Study Group 1.

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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.

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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:

$$W_0 = P_D + L_L + L_D - A \qquad \text{dB(W/m}^2) \tag{5}$$

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:

$$t = \frac{F\theta_H}{6000\,\omega} \quad \% \tag{7}$$

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:

$$W_i = kTB + NF + L_{BT} + L_L + L_D + L_s + L_p + L_i - A \quad \text{dB(W/m}^2) \tag{8}$$

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 m², 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:

$$W_0 = (-204 + 60) + 9 + 16 + 1 + 2 + 13 + 3 + 5 - 10 = -154 + 49 = -105 \text{ dB(W/m}^2)$$

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.

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QUESTIONS AND STUDY PROGRAMMES, RESOLUTIONS, OPINIONS AND DECISIONS

QUESTION 1-1/8

SIGNAL-TO-INTERFERENCE PROTECTION RATIOS AND MINIMUM FIELD STRENGTHS REQUIRED IN THE MOBILE SERVICES

(1963–1986)

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 mobile services utilizing modulation techniques such as FM, AM, amplitude companded single sideband (ACSSB), digital, etc.;

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 mobile services utilizing modulation techniques such as FM, AM, ACSSB, digital, etc;

3. what are the appropriate fading allowances in the mobile services utilizing modulation techniques such as FM, AM, ACSSB, digital, etc.?

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 5-4/8

THE INTRODUCTION OF DIRECT-PRINTING TELEGRAPH EQUIPMENT IN THE MARITIME MOBILE SERVICE

(1965–1966–1970–1978–1982–1986)

The text of this Question can be found in Volume VIII-2.

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, 1019 Recommendation 478 and Resolution 20.

STUDY PROGRAMME 7A-3/8*

TECHNICAL CHARACTERISTICS OF LAND MOBILE EQUIPMENT BETWEEN 25 AND 1000 MHz

(1966-1974-1981-1986)

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;

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* The Director of the CCIR is requested to bring this Study Programme to the attention of the International Electrotechnical Commission (IEC) and the CCITT.

(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;

2.5 receiver characteristics, particularly:

- frequency stability;
- selectivity;
- radiation;
- intermodulation;
- choice of intermediate frequency;
- sensitivity;
- audio-frequency response;

3. for systems utilizing digital modulation techniques:

3.1 optimum bandwidth for direct modulation;

3.2 direct and indirect digital modulation methods;

3.3 the bit rate;

3.4 the bit error ratio (BER);

3.5 harmonics and other spurious emissions:

3.5.1 falling on any other land mobile channel;

3.5.2 falling within the bands of other radio services;

3.6 typical and maximum output powers of base and mobile station transmitters;

3.7 receiver characteristics;

3.8 frequency tolerance, and its definition, in the case of direct digital modulation;

4. for amplitude companded single sideband (ACSSB) systems:

4.1 frequency and channelling plans;

4.2 frequency tolerance of transmitter;

4.3 companding characteristics;

4.4 pre-emphasis and de-emphasis characteristics;

4.5 pilot characteristics;

4.6 typical and maximum output powers of base and mobile station transmitters;

4.7 harmonics and other spurious emissions:

4.7.1 falling on any other land mobile channel;

4.7.2 measurement method;

4.8 receiver characteristics;

5. 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;
- measuring adjacent-channel and co-channel interference for the digital to analogue, digital to digital, and analogue to digital cases;
- measuring BER;
- measuring of frequency tolerance in the case of direct digital modulation.

Note. – Study Programmes 7B/8, 7C/8, 7E/8 and Question 37/8 should be borne in mind.

– See Report 1021.

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 Reports 899, 1018.

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 9-5/8

DIGITAL SELECTIVE-CALLING SYSTEM FOR FUTURE OPERATIONAL REQUIREMENTS OF THE MARITIME MOBILE SERVICE

(1967–1970–1974–1978–1982–1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 12-2/8

RADIO-PAGING SYSTEMS *

(1968–1974–1986)

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 or systems, and arrange some degree of technical and operational harmony if there is more than one 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, including consideration of harmonization if more than one solution (for example, to cater for a range of transmission rates) is needed;

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.

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* Radio-paging: a non-speech, one-way, personal selective calling system with alert, without message or with defined message such as numeric or alphanumeric.

STUDY PROGRAMME 12A-1/8

RADIO-PAGING SYSTEMS

Standardization of code and format

(1980–1986)

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;

(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 or rates of code transmission required;

1.6 any differences in code made necessary if more than one rate is required, bearing in mind the need to achieve as much harmonization as possible;

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 text of this Question can be found in Volume VIII-2.

QUESTION 17-3/8

TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS PROVIDING COMMUNICATION AND/OR RADIODETERMINATION USING SATELLITE TECHNIQUES FOR AIRCRAFT AND/OR SHIPS

(1968–1970–1974–1982–1986)

The text of this Question can be found in Volume VIII-3.

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 text of this Study Programme can be found in Volume VIII-3.

STUDY PROGRAMME 17B-3/8

TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS PROVIDING RADIOCOMMUNICATION AND/OR RADIODETERMINATION USING SATELLITE TECHNIQUES FOR DISTRESS AND SAFETY OPERATIONS

(1972–1974–1980–1986)

The text of this Study Programme can be found in Volume VIII-3.

STUDY PROGRAMME 17F-2/8

AVAILABILITY OF CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(1978-1980-1981)

The text of this Study Programme can be found in Volume VIII-3.

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 text of this Study Programme can be found in Volume VIII-3.

QUESTION 20-1/8

BLACK AND WHITE FACSIMILE TRANSMISSIONS OVER COMBINED METALLIC AND RADIO CIRCUITS IN THE MARITIME MOBILE SERVICE

(1972-1974)

The text of this Question can be found in Volume VIII-2.

STUDY PROGRAMME 21A-2/8

DEFINITION OF INTERFERENCE AND UNITS AND METHODS OF MEASUREMENT

(1972-1974-1982)

The text of this Study Programme can be found in Volume VIII-2.

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;

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* See also Questions 22/3, 22/4 and 20/9.

(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 text of this Question can be found in Volume VIII-2.

STUDY PROGRAMME 23A/8

PREFERRED FREQUENCY BANDS FOR AN AUTOMATED UHF MARITIME MOBILE RADIOCOMMUNICATION SYSTEM

(1980)

The text of this Study Programme can be found in Volume VIII-2.

QUESTION 26-3/8

USE OF CLASS J3E EMISSIONS FOR DISTRESS AND SAFETY PURPOSES

(1974-1978-1982-1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 27-2/8

TECHNICAL PARAMETERS OF RADAR BEACONS (RACONS)

(1982-1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 28-1/8

FREQUENCY REQUIREMENTS FOR SHIPBORNE TRANSPONDERS

(1974–1982)

The text of this Question can be found in Volume VIII-2.

QUESTION 29-2/8

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

(1974–1982–1986)

The text of this Question can be found in Volume VIII-2.

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 text of this Question can be found in Volume VIII-2.

QUESTION 31-3/8

FUTURE USE AND CHARACTERISTICS OF EMERGENCY POSITION-INDICATING RADIO BEACONS IN THE MOBILE SERVICE AND THE MOBILE-SATELLITE SERVICE

(1974–1978–1982–1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 32-3/8

PREFERRED TECHNICAL AND OPERATING CHARACTERISTICS FOR A MOBILE-SATELLITE SYSTEM

(1976–1978–1982–1986)

The text of this Question can be found in Volume VIII-3.

STUDY PROGRAMME 32A/8

A GLOBAL LOW-ORBIT SATELLITE SYSTEM FOR DETECTION AND POSITIONING OF LOW-POWER TRANSMITTERS

(1980)

The text of this Study Programme can be found in Volume VIII-3.

QUESTION 33-1/8

INTERFERENCE TO RADIONAVIGATION SERVICES FROM OTHER SERVICES IN THE BANDS BETWEEN 70 kHz AND 130 kHz

(1976–1978)

The text of this Question can be found in Volume VIII-2.

QUESTION 35-1/8

EFFICIENT USE OF THE RADIO SPECTRUM BY RADAR STATIONS IN THE RADIODETERMINATION SERVICE

(1977–1978)

The text of this Question can be found in Volume VIII-2.

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.

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 Recommendation 622, 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 text of this Question can be found in Volume VIII-2.

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 Recommendations 622, 624, Report 742.

STUDY PROGRAMME 39A/8

FUTURE PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEMS

(1985)

The CCIR,

CONSIDERING

(a) the need to improve spectrum utilization efficiency and hence system capacity per MHz per unit area;

(b) that system compatibility is necessary for international operation, and that maximum commonality is desirable in any event to ensure that the overall system cost per mobile user is significantly less than it is with present systems;

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* The Director, CCIR, is requested to bring this Question to the attention of the CCITT.

(c) the need for a flexible system structure able to match network investment to revenue growth, readily to adapt to environmental factors and to respond to new development rather than restrict innovation;

(d) the increasing importance of the various types of data and telematic services;

(e) Study Programme 40A/8 on digitized speech transmission, Question 68/8 on equipment with reduced cost, Question 37 on cellular systems;

(f) Recommendation 622 on analogue cellular systems;

(g) the possible need for a common frequency band or channel to allow worldwide operation, particularly with the increasing use of personal (hand-held, portable) terminals;

(h) CCITT Recommendations and on-going work items that are relevant to this work,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the overall objectives for future public land mobile telecommunication systems such as (see Note):
- type of service – voice, data, other;
- mode – vehicular, personal (hand-held, portable), combined;
- flexibility to provide a wide range of services, national and local adaptation, and accommodation of future state-of-the-art advancement;

2. the degree of compatibility or commonality which is desirable or achievable such as (see Note):
- international, regional, national compatibility (roaming);
- radio interface compatibility;
- components and technological commonality;

3. the significant impacts (quantified) on system solutions which arise from environmental and economic factors such as (see Note):
- estimated demand, e.g.: total demand and demand distribution (temporal, geographical and service by service);
- status of technology;
- spectrum availability;
- costs (user equipment and infrastructure);
- propagation factors;
- network interfaces;
- integration of services;

4. the frequency band or bands which would be suitable for future public land mobile telecommunication systems taking into account DECIDES 1, 2 and 3;

5. the technical characteristics of future systems such as (see Note):
- modulation and radio transmission techniques,
- access methods,
- radio channel interfaces and control methods,
- system configurations,
- deployment of transmission resources, for example, demand assignment,
- techniques to provide system flexibility as in DECIDES 1,
- other.

Note. – The list of examples is not exhaustive.

QUESTION 40-2/8

DIGITAL TRANSMISSION IN THE LAND MOBILE SERVICE

(1978-1982-1986)

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 ratio and error distribution will occur as a result of the following channel impairments:

3.1 multipath propagation, shadowing and receiver noise (the effects of multipath propagation are different at low and high bit rates);

3.2 ignition noise;

3.3 co-channel and adjacent-channel interference;

4. how does the service area of a digital data system compare with the service area of digital and analogue speech systems;

5. 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;

6. what are the possibilities of conveying digitally encoded speech signals in the systems referred to in § 5;

7. 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 Recommendation 623, 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;

(e) that a digitized speech system based on a wider channel separation may have more spectrum efficiency than a corresponding analogue system;

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* See V and X Series Recommendations of the CCITT.

(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 text of this Question can be found in Volume VIII-2.

QUESTION 42/8

CHARACTERISTICS OF DIGITAL CHANNELS IN THE MARITIME MOBILE SERVICE

(1978)

The text of this Question can be found in Volume VIII-2.

QUESTION 45-3/8

TECHNICAL AND OPERATING CONSIDERATIONS FOR A FUTURE GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM

(1978-1982-1983-1986)

The text of this Question can be found in Volume VIII-2.

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 text of this Question can be found in Volume VIII-3.

QUESTION 47-1/8

PREFERRED TECHNICAL AND OPERATIONAL CHARACTERISTICS FOR THE LAND MOBILE-SATELLITE SERVICE

(1978–1982)

The text of this Question can be found in Volume VIII-3.

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;

* 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 antennas;

(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 51-1/8

AUTOMATIC DETERMINATION OF LOCATION IN THE LAND MOBILE SERVICE

(1982-1986)

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 frequency bands of operation and bandwidth requirements for the various AVL techniques;

4. what are the advantages and disadvantages of the different AVL techniques;

5. 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;

6. can existing radio location systems in other services be used to meet the needs of the land mobile service;

7. how can existing land mobile installations and frequency assignments be used to provide AVL;

8. 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;

9. what are the costs/benefits of AVL to land mobile dispatch operations;

10. what is the impact of AVL on spectrum efficiency as a result of the reduction in voice communications?

Note. – See Report 904.

QUESTION 52-1/8*

INTEGRATION OF PUBLIC MOBILE RADIOCOMMUNICATION SERVICES IN THE VHF/UHF FREQUENCY BANDS

(1982-1986)

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) Question 74/8 on a public mobile telephone system with aircraft;

(g) 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;

(h) 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;

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* The Director, CCIR is requested to bring this Question to the attention of the International Civil Aviation Organization, the International Maritime Organization and the CCITT.

(j) that the degree of integration might be influenced by operational constraints;

(k) that there is an urgent need to identify suitable frequency bands;

(l) Recommendation 478, especially in regard to the separation of transmit and receive frequencies;

(m) that some propagation characteristics differ for the respective mobile services;

(n) 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?

QUESTION 53-2/8

USE OF FREQUENCIES BY THE MARITIME MOBILE SERVICE IN THE BAND 435-526.5 kHz

(1982–1983–1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 54/8

TECHNICAL CHARACTERISTICS FOR MARITIME RADIO EQUIPMENT USING NARROWBAND PHASE-SHIFT KEYING (NBPSK) TELEGRAPHY

(1982)

The text of this Question can be found in Volume VIII-2.

QUESTION 55-1/8

DEVELOPMENT AND FUTURE IMPLEMENTATION OF DATA EXCHANGE SYSTEMS AND SHIP MOVEMENT TELEMETRY, AND TELECOMMAND SYSTEMS

(1982–1986)

The text of this Question can be found in Volume VIII-2.

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.

QUESTION 57/8

SHARING CRITERIA FOR THE INTER-SATELLITE SERVICE AND THE RADIONAVIGATION SERVICE IN THE BAND 32-33 GHz

(1982)

The text of this Question can be found in Volume VIII-3.

QUESTION 58-1/8

TECHNICAL CHARACTERISTICS OF MARITIME RADIOBEACONS

(1982–1986)

The text of this Question can be found in Volume VIII-2.

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* 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 60/8

BROADCASTING AND AERONAUTICAL RADIONAVIGATION SERVICES IN THE LF BANDS

Interference between Regions

(1982)

The text of this Question can be found in Volume VIII-3.

QUESTION 61-1/8

COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT 87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-137 MHz

(1982–1986)

The text of this Question can be found in Volume VIII-3.

QUESTION 62-1/8

INTERFERENCE TO THE AERONAUTICAL MOBILE AND AERONAUTICAL RADIONAVIGATION SERVICES

(1982–1986)

The text of this Question can be found in Volume VIII-3.

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 text of this Question can be found in Volume VIII-2.

QUESTION 64-1/8

HF BANDS ALLOCATED ON AN EXCLUSIVE OR SHARED BASIS TO THE MARITIME MOBILE SERVICE

(1983–1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 65/8

PROTECTION OF THE BAND 406-406.1 MHz ALLOCATED TO THE MOBILE-SATELLITE SERVICE

(1983)

The text of this Question can be found in Volume VIII-2.

QUESTION 66/8

RELATING TO THE FUTURE USE OF THE BAND 2170-2194 kHz

(1983)

The text of this Question can be found in Volume VIII-2.

QUESTION 67/8

MULTI-TRANSMITTER RADIO SYSTEMS USING QUASI-SYNCHRONOUS (SIMULCAST) TRANSMISSION IN THE LAND MOBILE SERVICE

(1986)

The CCIR,

CONSIDERING

(a) that multiple transmitters using quasi-synchronous transmission are already used in the land mobile service;

(b) that propagation conditions and radiated power, limit the range and coverage of a single transmitter,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the advantages and disadvantages in using multiple transmitters for quasi-synchronous operation;

2. what performance can be obtained;

3. what provisions must be made to ensure satisfactory operation with speech systems and data systems?

Note. – See Report 1022.

QUESTION 68/8*

TECHNICAL CHARACTERISTICS FOR LAND MOBILE RADIO SYSTEMS WHICH USE EQUIPMENT OF REDUCED COST WITHOUT LOSS OF SYSTEM PERFORMANCE

(1986)

The CCIR,

CONSIDERING

(a) that significant savings in equipment cost, size and power consumption can be realized by a moderate reduction of currently existing equipment specifications;

* This Question should be brought to the attention of Study Group 1.

(b) that in systems using an exclusive frequency band, mutual interference can be reduced through suitable network arrangements;

(c) that techniques such as improved modulation and multiple access methods will have a considerable impact on system design and on the optimum system selectivity;

(d) that it may be appropriate to limit the extent of the specification, leaving more freedom to the system designers to make a total optimization;

(e) that there is a need to achieve good spectrum utilization efficiency,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the technical characteristics to be considered for systems using an exclusive frequency band, to allow for equipment of reduced cost without loss of system performance, and without compromising spectrum utilization efficiency;

2. what kind of radio system can provide an acceptable system performance using equipment of reduced cost.

Note. – See Report 1020.

QUESTION 69/8*

FREQUENCY SHARING BETWEEN THE MOBILE SERVICES AND THE BROADCASTING SERVICE (TELEVISION) BELOW 1 GHz**

(1986)

The CCIR,

CONSIDERING

(a) that the WARC-79 increased the number of frequency bands that might be shared between the broadcasting service and the mobile services including the mobile satellite service below 1 GHz;

(b) that those bands which might be shared are given in Article 8 of the Radio Regulations;

(c) that there are no well-established criteria for sharing the spectrum between these services;

(d) that the CCIR was invited by the WARC-79 to study this problem as stated in its Resolution No. 702 relating to the convening of a Regional Administrative Radio Conference to establish criteria for the shared use of the VHF and UHF bands allocated to fixed, broadcasting and mobile services in Region 3;

(e) that some administrations are already introducing mobile services into the new bands,

UNANIMOUSLY DECIDES that the following question should be studied:

what planning criteria apply for the protection of the mobile services and broadcasting service (television) from mutual interference in those parts of bands 8 (30-300 MHz) and 9 (300-3000 MHz) that may be shared, taking into account where appropriate, the mobile satellite service?

Note. – See Report 1020.

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* This Question should be brought to the attention of Study Group 11.

** See also Questions 51/1 and 39/11.

QUESTION 70/8*

FREQUENCY SHARING BETWEEN THE MOBILE SERVICE AND THE SOUND-BROADCASTING SERVICE AND OTHER SERVICES USING THE SAME BAND AT MF**

(1986)

The CCIR,

CONSIDERING

(a) that the WARC-79 allocated the band 1606.5-1705 kHz to the fixed, mobile, radiolocation and radionavigation services in Region 3 and to some of these services in Region 1;

(b) that the WARC-79 allocated the band 1605-1625 kHz exclusively to the broadcasting service and the band 1625-1705 kHz on a shared basis to the mobile, fixed, and broadcasting services in Region 2;

(c) that the CCIR was requested by Recommendation Nos. 301 and 504 of the WARC-79 to perform the necessary technical studies including the need for sharing criteria;

(d) that at present there are no well-established criteria for sharing the spectrum between these services,

UNANIMOUSLY DECIDES that the following question should be studied:

what criteria apply for the protection of the mobile service and fixed and broadcasting services from mutual interference in those parts of the 1605-1705 kHz band that may be shared?

QUESTION 71/8

TECHNICAL AND OPERATING CHARACTERISTICS OF LAND MOBILE SYSTEMS USING MULTI-CHANNEL ACCESS TECHNIQUES WITHOUT A CENTRAL CONTROLLER, INCLUDING CONSUMER-TYPE SYSTEMS

(1986)

The CCIR,

CONSIDERING

(a) that new land mobile services such as cordless telephones and personal radio now being introduced have different characteristics from existing services and may be available to a large public;

(b) that these services can use consumer-type devices which may create difficulties to administrations, and may be misused;

(c) that the utilization of the radio spectrum should be economical as possible and that the use of multi-channel access techniques conserves frequency spectrum;

(d) that highly flexible and economical systems can be achieved without using a central controller for radio path setting-up control;

(e) that the widespread and increasing use of these equipments and the characteristics of their utilization may create operational problems;

(f) that systems may require coordination of certain system parameters on a national and international basis,

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* This Question should be brought to the attention of Study Groups 1, 3 and 10.

** See Questions 44/10 and 32/3.

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the required radiocommunication parameters for analogue and digital systems circuit connection quality and speech quality;

2. what is the preferred multi-channel access technique and its protocol including detection of an idle radio channel;

3. how does the spectrum efficiency compare with systems which use a central controller;

4. what steps should be taken to ensure the quality of the communications;

5. what technical steps should be taken to avoid adverse effects of misuse of these equipments;

6. what methods can be used to optimize spectrum conservation and service area or range;

7. what measures should be taken in order that a large number of equipments may coexist in the same frequency band with minimum mutual interference;

8. what technical parameters are required in order to allow these equipments to function without creating interferences to other services, noting the potentially very large number of users;

9. what are the system parameters and technical characteristics of equipment on which international agreement is desirable?

Note. – See Reports 1024 and 1025.

QUESTION 72/8 *

CO-CHANNEL AND ADJACENT-CHANNEL COORDINATION CRITERIA FOR SIMULTANEOUS USE OF DIFFERENT MODULATION TECHNIQUES IN SYSTEMS OF THE MOBILE SERVICE

(1986)

The CCIR,

CONSIDERING

(a) that the radio spectrum is a limited resource to be used efficiently;

(b) that due to various approaches in technological development, systems with widely different characteristics may be using the same band;

(c) that both transmitter and receiver characteristics will have a direct impact on effective utilization of the spectrum;

(d) that emission characteristics are directly dependent on parameters including the modulation technique;

(e) that the identification of the appropriate parameters affecting the use of spectrum is important;

(f) that the development of a common approach in deriving co-channel and adjacent-channel coordination criteria is desirable,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the frequency coordination criteria, considering co-channel and adjacent-channel interference between systems which use different modulation techniques;

2. what are the equipment characteristics that are considered to have an impact on co-channel and adjacent-channel interference for different modulation techniques;

3. what are the appropriate values for the co-channel and adjacent-channel parameters, e.g. spurious emissions, receiver selectivity, etc., and how should they be specified;

4. what is the impact of the value of these parameters on efficient spectrum utilization;

5. what are the relationships and trade-offs amongst parameters and the impact on equipment complexity?

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* This Question should be brought to the attention of Study Group 1.

QUESTION 73/8

VHF RADIOTELEPHONE SYSTEM FOR THE MARITIME MOBILE SERVICE WITH AUTOMATIC FACILITIES

(1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 74/8

PUBLIC MOBILE TELEPHONE SERVICE WITH AIRCRAFT

(1986)

The text of this Question can be found in Volume VIII-3.

QUESTION 75/8

MARITIME RADIOLOCATION OPERATING IN THE MEDIUM FREQUENCY BAND AND USING SPREAD-SPECTRUM TECHNIQUES

(1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 76/8

DATA COMMUNICATION IN THE MARITIME MOBILE SERVICE

(1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 77/8*

ADAPTATION OF MOBILE RADIOCOMMUNICATION TECHNOLOGY TO THE NEEDS OF DEVELOPING COUNTRIES

(1986)

The CCIR,

CONSIDERING

(a) the Questions submitted by the Plan Committee for Latin America at its meeting in Paramaribo in December 1985, in accordance with Provision No. 93 of the International Telecommunication Convention (Nairobi, 1982);

(b) the work carried out so far by Study Group 8 on mobile radiocommunication systems;

(c) the work carried out by Study Group 5 so far on radio propagation,

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* This Question should be brought to the attention of Study Group 5 and to the CCITT.

UNANIMOUSLY DECIDES that the following question should be studied:

1. how can cellular-type mobile radiocommunication technology be adapted to the needs of developing countries;

Note. – Particular emphasis should be given to the following items:

- software simplification of the central control unit;
- universal protocols and standards for terminal-to-base station and base station-to-central control unit, etc.;
- standard equipment for land, maritime and aeronautical mobile use;
- standardization of the interface with the public switched telephone network (PSTN);
- standardization of the use of the channels for control, voice and data;
- standardization of channel separation;
- standardization of frequency bands used;

2. what are the optimum arrangements and technical characteristics for land mobile equipment (cellular type or others) for use in rural areas or low-income urban areas?

Note. – Special attention should be paid to:

- rugged, tropicalized, simple-to-maintain terminal units,
- optimum spectrum utilization,
- interference between adjacent channels,
- central office traffic-handling capacities,
- propagation problems in mountainous regions or building complexes.

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;

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 text of this Opinion can be found in Volume VIII-2.

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 32-4

TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Question 17/8)

(1978-1980-1981-1984-1985)

The text of this Decision can be found in Volume VIII-3.

DECISION 69

FUTURE PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEMS

(1985)

CCIR Study Group 8,

CONSIDERING

(a) that different future systems are under study;

(b) that system compatibility is necessary for international operation, and that commonality is desirable in any event to ensure that the overall system cost per mobile user is significantly less than it is with present systems;

(c) the need for a flexible system structure able to match network investment to revenue growth, to adapt readily to environmental factors and to respond to new developments without restricting innovation;

(d) the possible need for common channels or frequency band to allow world-wide operation, particularly with the increasing use of personal (hand-held, portable) terminals;

(e) Study Programe 39A/8,

DECIDES:

1. that an Interim Working Party 8/13 should be established;

2. that the Interim Working Party shall determine:

2.1 the overall objectives for future public land mobile telecommunication systems;

2.2. the frequency band or bands which would be suitable for future public land mobile telecommunication systems;

2.3 the degree of compatibility or commonality which is desirable or achievable and the essential characteristics of systems necessary for this purpose;

3. that the Interim Working Party should aim to complete its work in time for consideration by Study Group 8 at the Interim Meeting of the 1986-1990 study period;

4. that the Chairman and composition of Interim Working Party 8/13 will be as shown in Annex I.

ANNEX I

At the end of the XVIth Plenary Assembly, 1986, the following Administrations and International Organizations have indicated their participation in the work of Interim Working Party 8/13:

Administrations:

Germany (Federal Republic of)
Saudi Arabia
Australia
Brazil (Federative Republic of)
Canada
Costa Rica
Denmark
United States of America
Finland
France
Greece
Hungary
India
Iran
Italy
Japan
Mexico
Netherlands
New Zealand
Norway
Oman
United Kingdom
Singapore
Sweden
Switzerland
USSR

International Organizations:

European Space Agency (ESA)
International Electrotechnical Commission (IEC)

Chairman of Interim Working Party 8/13:

Mr. Michael H. Callendar
British Columbia Telephone Company
10th Floor
3777 Kingsway
BURNABY BC V5H 3Z7
Canada

Telephone: + 1 604 432 4616
Telex (TWX): 610 922 6044
Telefax: + 1 604 438 0444

DECISION 71

CONTINUATION OF STUDIES ON COMPATIBILITY BETWEEN THE AERONAUTICAL RADIONAVIGATION SERVICE IN THE BAND 108-117.975 MHz, THE AERONAUTICAL MOBILE (R) SERVICE IN THE BAND 117.975-137 MHz AND THE FM SOUND BROADCASTING STATIONS IN THE BAND ABOUT 87-108 MHz

(1985)

The text of this Decision can be found in Volume VIII-3.

ALPHABETICAL INDEX OF KEY WORDS AND TERMS OF VOLUME VIII.1 – PART 1

S

T

U

V

W

ABREVIATIONS

A

ACK . . . . acknowledgement
ACR . . . . average crossing rate
ACSB . . . . amplitude companded single sideband
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 narrowband FM
APD . . . . amplitude probability distribution
ATIS . . . . automatic transmitter identification system
AVL . . . . automatic vehicle location

B

B/B_0 . . . . ratio of radio-frequency bandwidth to audio frequency bandwidth
BCD . . . . binary coded decimal
BCH . . . . Bose-Chaudhuri-Hocquenghem code
BER . . . . bit-error ratio
BINOR . . . . binary optimum ranging
BPSK . . . . binary phase shift keying
BWO . . . . backward wave oscillators

C

CCITT . . . . International Telegraph and Telephone Consultative Committee
CDM . . . . companded delta modulation
CE . . . . channel equipment
CI . . . . identification of a cell
C/I_0 . . . . carrier-to-intermodulation-noise density ratio
CISPR . . . . International Special Committee on Radio Interference
C/N . . . . carrier to noise
C/N_0 . . . . carrier-to-noise density ratio
CNES . . . . Centre national d'etudes spatiales
(C/N)p . . . . carrier-to-noise ratio of the swept pulse before compression
CP . . . . central control posts
CPSK . . . . coherent phase shift keying
CT . . . . international transit centre

D

DECPSK . . . . . . differentially encoded phase shift keying
DM . . . . delta modulation
DPSK . . . . differential phase shift keying
DSI . . . . digital speech interpolation
DTCXO . . . . digital temperature control crystal oscillator

E

ESA . . . . European Space Agency

F

F_a . . . . effective antenna noise factor
FDMA . . . . frequency division multiple access
FDM/PM . . . . . . frequency division multiplexed before phase modulating
FFSK . . . . fast frequency shift keying
FMS . . . . status message transmission system of the police in the Federal Republic of Germany
FRENA . . . . frequency and amplitude
FSK . . . . frequency shift keying

G

GMSK . . . . Gaussian filtered MSK
G/T . . . . gain-to-noise temperature ratio

H

HDLC . . . . high level data link control

I

IEC . . . . International Electrotechnical Commission
ISO . . . . International Organization for Standardization
IT . . . . interrogator transponder

L

LAI . . . . identification of a location area
LHC . . . . left-hand circularly polarized
LNA . . . . low noise amplifier
LOS . . . . line-of-sight
LPC . . . . linear predictive coding

M

MSC . . . . mobile services switching centre
MSK . . . . minimum shift keying
MTBF . . . . mean-time between failure
MTTR . . . . mean-time-to-repair

N

NAD . . . . noise amplitude distribution
NBFM . . . . narrowband frequency modulation
NBPSK . . . . narrowband phase shift keying
NBVM . . . . narrowband voice modulation
NC . . . . narrow coverage
NCK . . . . negative acknowledgement
NMT . . . . Nordic mobile telephone system

O

OACSU . . . . off-air call set-up
OSCAR . . . . orbiting satellites carrying amateur radio

P

PB . . . . phonetically balanced
P_n . . . . mean noise power
PN . . . . pseudo noise
PRF . . . . pulse repetition frequency
PRFD . . . . pulse repetition frequency
PRN . . . . pseudo-random noise code
PSK . . . . phase shift keying
PSK/PM . . . . sub-carrier PSK
PSTN . . . . public switched telephone network

Q

QAM . . . . quadrature amplitude modulation
QPSK (4-PSK) . . . quaternary phase shift keying

R

RELP . . . . residual exited linear predictive coding
RT . . . . radiotelephone
RX . . . . retransmission

S

SCPC . . . . single channel per carrier
S/D filter . . . . . . smear desmear filter
SDL . . . . specification and description language
SINAD . . . . signal plus noise plus distortion to noise plus distortion
S/N . . . . signal-to-noise ratio

T

TACS . . . . total access communication system
TCXO . . . . temperature compensated crystal oscillators
TDAL . . . . tunnel diode amplifier/limiter
TDMA . . . . time division multiple access
TFM . . . . tamed frequency modulation
TWT . . . . travelling wave tube
TWTA . . . . travelling wave tube amplifier

V

V_{ap} . . . . quasi-peak voltage
V_{avg} . . . . average voltage
V_d . . . . impulsiveness ratio (= 20 log V_{rms}/V_{avg})
VDU . . . . video display unit
VFT . . . . voice-frequency telegraphy
V_p . . . . peak voltage
V_{rms} . . . . root-mean-square voltage

Z

ZVEI . . . . digital selectocall system of the Federal Republic of Germany

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