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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-3

**MOBILE SATELLITE SERVICES (AERONAUTICAL, LAND,
MARITIME, MOBILE AND RADIODETERMINATION)
AERONAUTICAL MOBILE 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.



INTERNATIONAL TELECOMMUNICATION UNION

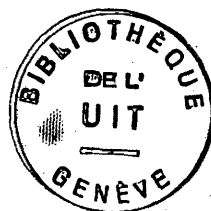
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**PLAN OF VOLUMES I TO XIV
XVITH PLENARY ASSEMBLY OF THE CCIR**

(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.
VOLUME V	Propagation in non-ionized media.
VOLUME VI	Propagation in ionized media.
VOLUME VII	Standard frequencies and time signals.
VOLUME VIII-1	Land mobile service. Amateur service. Amateur-satellite service.
VOLUME VIII-2	Maritime mobile service.
VOLUME VIII-3	Mobile satellite services (aeronautical, land, maritime, mobile and radiodetermination). Aeronautical mobile service.
VOLUME IX-1	Fixed service using radio-relay systems.
VOLUME X-1	Broadcasting service (sound).
VOLUMES X/XI-2	Broadcasting-satellite service (sound and television).
VOLUMES X/XI-3	Sound and television recording.
VOLUME XI-1	Broadcasting service (television).
VOLUME XII	Transmission of sound broadcasting and television signals over long distances (CMTT).
VOLUME XIII	Vocabulary (CMV).
VOLUME XIV-1	Information concerning the XVlth 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, XVth 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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139	X-1	374-376	VII	481-484	IV-1
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⁽¹⁾ Published separately.

1.3 *Reports (cont.)*

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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.

1.4 *Resolutions*

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1.6 Decisions

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6	VI	51	X/XI-2	64	IV-1
9-11	VI	52	X-1	65	VII
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42	XI-1	59	X/XI-3	71	VIII-3 + X-1
43	X/XI-2	60	XI-1	72	X-1 + XI-1

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-3

MOBILE SERVICES

(Study Group 8)

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MOBILE SERVICES

STUDY GROUP 8

Terms of reference:

To study the technical and operating aspects of systems in:

1. all mobile services and all mobile-satellite services;
2. the radiodetermination services and the radiodetermination-satellite services; and
3. the amateur service and amateur-satellite service.

1982-1986 *Chairman:* G. HEMPTON (United States of America)

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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 was 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) provided 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

See Volume VIII-1.

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

The Chairman was Captain C. Dorian (United States of America).

This Working Group continued to be exceptionally active and depended significantly upon the work of Interim Working Party 8/7 which will continue developing the technical and operating characteristics of systems in the maritime mobile-satellite service under its Chairman, Dr. Y. Hirata (Japan).

Examples of significant work included: Recommendations on satellite EPIRBs, Reports on modulation and coding techniques suitable for mobile-satellite services, future ship earth stations and the radiodetermination-satellite service.

Future work will continue along current studies but will see growth in radiodetermination-satellite service. The developments in smaller, lower-cost maritime mobile-satellite systems will have a profound influence on maritime telecommunications and probably other mobile satellite services.

There were 24 output documents from this Working Group at the Final Meeting.

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

The Chairman was Mr. J. Karjalainen (Finland).

Studies on compatibility between the FM sound broadcasting service in the band of about 87-108 MHz and the aeronautical services in the bands 108-133.6 MHz were continued.

* Emergency position-indicating radio beacon.

On the bases of the report of Joint Interim Working Party 8-10/1, the Final Acts of the Regional Administrative Radio Planning Conference (CARR-1) and new contributions by administrations, a complete revision of Report 929 was made. However, further work on this subject is needed and both Study Groups 8 and 10 agree that this can best be accomplished through continuing Joint Interim Working Party 8-10/1 (Chairman: Mr. J. Karjalainen (Finland)) with revised terms of reference responsive to the Second Session of CARR-1. Accordingly a revised Decision was drafted which was coordinated with the Chairman of Study Group 10.

A draft new Report on a public mobile telephone service with aircraft was produced. Although it was recognized that this Report only represents an initial step in defining the operational and technical characteristics of a new service, it is hoped that it will be helpful and stimulating for future studies.

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*

Mobile satellite services

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

Aeronautical mobile service

- General considerations relative to harmful interference from the viewpoint of the aeronautical mobile services — Report 927.
- Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-136 MHz — Recommendation 591 and Report 929.

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 8E: MARITIME MOBILE-SATELLITE SERVICE; INTERFACE AND ACCESS

Recommendations and Reports

RECOMMENDATION 546-1 *

**HYPOTHETICAL TELEPHONE REFERENCE CIRCUIT
IN THE MARITIME MOBILE-SATELLITE SERVICE**

(Study Programme 17A/8)

(1978-1982)

The CCIR,

CONSIDERING

- (a) that it is desirable to establish a hypothetical telephone reference circuit for systems in the maritime mobile-satellite service, including its associated feeder links, to afford guidance to designers of equipment and systems for use in telephone networks;
- (b) that the hypothetical telephone reference circuit given in Recommendation 352, whilst relevant for the fixed-satellite service, may not satisfy the needs of the maritime mobile-satellite service;
- (c) that, in a system in the maritime mobile-satellite service, including its associated feeder links, many technical characteristics of the link in the shore-to-ship direction may differ substantially from those of the link in the ship-to-shore direction and hence two hypothetical telephone reference channels are required,

UNANIMOUSLY RECOMMENDS

1. that the hypothetical telephone reference channel in the shore-to-ship direction should consist of one coast earth station-to-satellite-to-ship earth station link (see Fig. 1);
2. that the hypothetical telephone reference channel in the ship-to-shore direction should consist of one ship earth station-to-satellite-to-coast earth station link (see Fig. 2);
3. that the hypothetical telephone reference circuit should comprise a link between a 4-wire coast earth station audio-frequency band interface and a 4-wire ship earth station audio-frequency band interface as defined in Fig. 3;
4. that echo suppressors should not be included within the hypothetical telephone reference circuit;
5. that should any voice processing equipment be used, for example, compandors, coders, decoders or voice-activated carrier switches, such equipment should be included within the hypothetical telephone reference circuit.

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

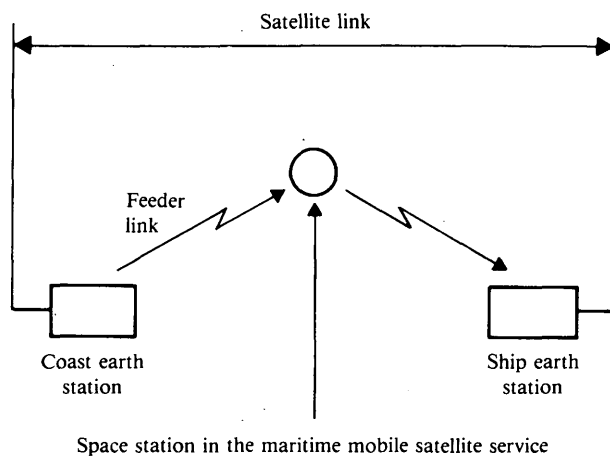


FIGURE 1 – *Shore-to-ship hypothetical telephone reference channel*

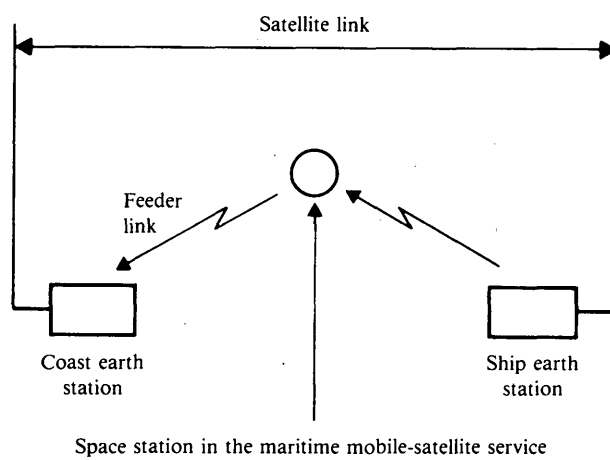


FIGURE 2 – *Ship-to-shore hypothetical telephone reference channel*

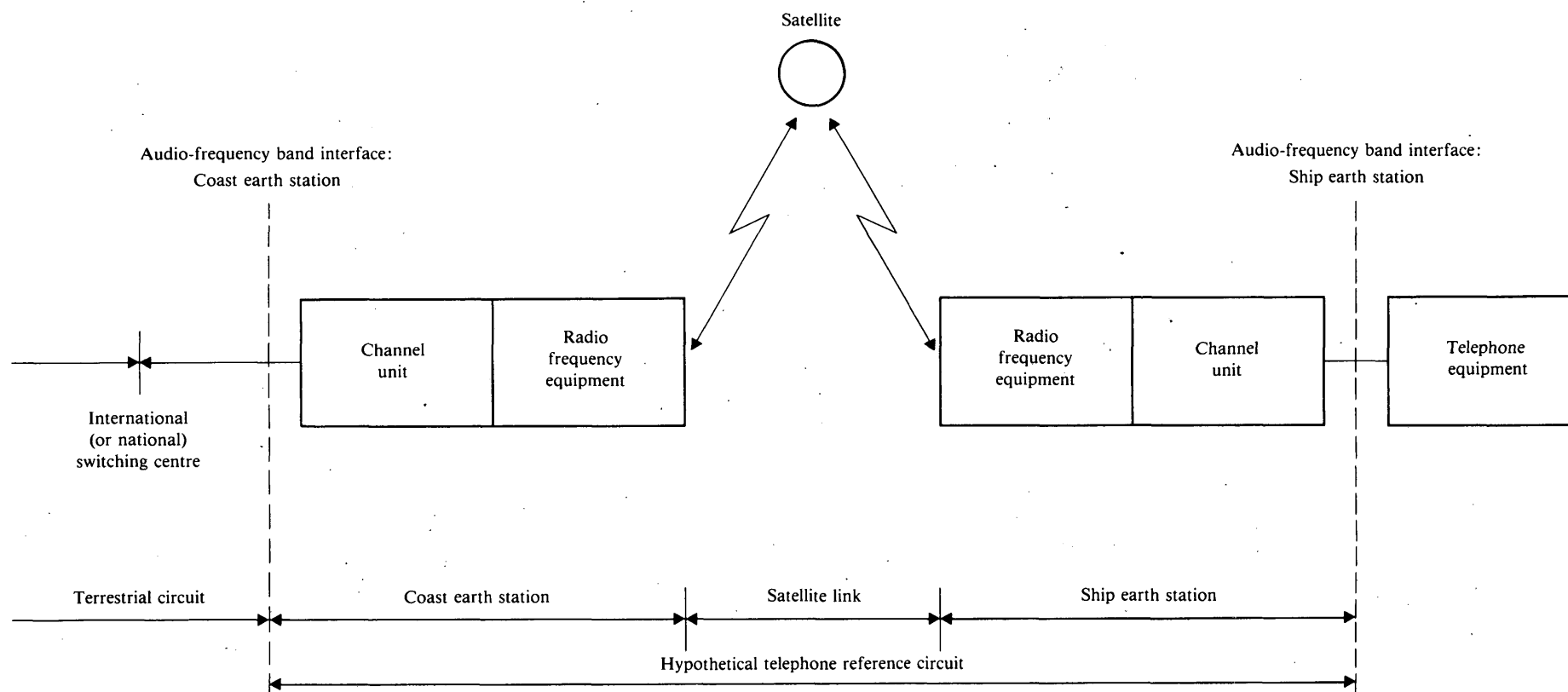


FIGURE 3 – Functional block diagram of a maritime mobile satellite system defining the hypothetical telephone reference circuit

RECOMMENDATION 547

**NOISE OBJECTIVES IN THE HYPOTHETICAL REFERENCE CIRCUIT
FOR SYSTEMS IN THE MARITIME MOBILE-SATELLITE SERVICE**

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

- (a) that the hypothetical reference circuit is intended as a guide to the design and construction of actual systems;
- (b) that the costs of establishing and maintaining maritime mobile satellite systems are critically dependent on the overall signal-to-noise performance requirements;
- (c) that maritime mobile satellite systems will be connected to the international telephone network implying that CCITT Recommendation G.473 should be met;
- (d) that the total noise power in the hypothetical reference circuit (subjectively equivalent) should not unduly degrade conversation in most telephone calls;
- (e) that voice companding most probably will be used in order to reduce the constraint imposed by power limitation of the satellites;
- (f) that the extent of fading cannot be determined fully until more experimental data are available;
- (g) that the fading will depend on the elevation angle of the ship-borne antenna, the antenna directivity, the occurrence of calm sea conditions in various ocean areas, and the location of the ship-borne antenna relative to the reflecting surfaces of the ship;
- (h) that operator-to-operator calls should be possible even at small angles of elevation though with a degraded performance;
- (j) that there may be other sources of noise of short duration,

UNANIMOUSLY RECOMMENDS

1. that the subjectively equivalent speech signal to psophometrically weighted noise ratio in the hypothetical reference circuit as defined in Recommendation 546 should exceed the values shown in Fig. 1;
2. that these values of signal-to-noise ratio should be referred to non-faded conditions and to an angle of elevation of 10° of the ship-borne antennas;
3. that the modulation technique should give an acceptable decrease in quality with decreasing carrier-to-noise density ratio;
4. that the modulation technique and voice processing method adopted should permit quality comparable to that obtained in the fixed-satellite service when more satellite power is available.

Note 1. — The noise objectives indicated in RECOMMENDS 1 above should include the effect of interchannel interference noise, co-channel interference noise, intermodulation noise as well as noise from atmospheric sources.

Note 2. — The noise objectives stated in this Recommendation are applicable to systems using ship terminals with high-gain antennas (see Report 594).

Note 3. — The requirement for non-faded condition will probably be met for more than 80% of the time. When sufficient data on fading become available, this Recommendation should be supplemented to give noise objectives in terms of two percentages of time, e.g. 80% and 99%.

Note 4. — The requirement in RECOMMENDS 1 corresponds to a noise level of 10 000 pW0p for speech levels below -35 dBm0 and of 25 000 pW0p at a speech level of -20 dBm0. For speech levels above -20 dBm0, the speech signal to psophometrically weighted noise ratio should exceed 26 dB.

Note 5. — The speech level is defined as the mean (time average) speech power while active.

Note 6. — As soon as sufficient experimental and theoretical data for a particular system are available this Recommendation should be supplemented by a Recommendation stating the performance objectives in terms of measurable quantities such as idle channel noise power and test-tone-to-noise ratio.

Note 7. — It is assumed that noise surges and clicks from power supply systems and from switching apparatus are reduced to negligible proportions and therefore will not be taken into account when calculating the noise power.

Note 8. — This Recommendation does not take into account requirements to be met if facsimile and data transmission are required over telephone channels.

Note 9. — In order to assure proper quality for high speech levels the minimum overload point of the channel should be defined.

It should be taken into account that the average speech level and the range of variation of level as will be experienced at the inputs to the satellite system, may be different for shore originated and ship originated calls.

It should be further noted that different modulation techniques may require different overload levels in order to yield an optimum performance.

Note 10. — For an explanation of subjectively equivalent noise, and for methods by which it can be derived, see Report 751.

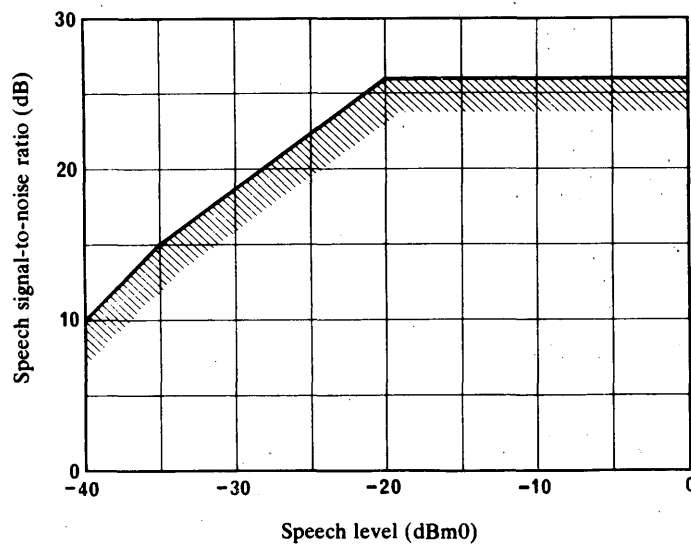


FIGURE 1 — Limits of subjectively equivalent speech signal to psophometrically weighted noise ratio as a function of speech level

REPORT 751 *

METHODS FOR THE SUBJECTIVE ASSESSMENT OF SPEECH QUALITY IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

1. Introduction

The assessment of the performance of a telephone connection involving a maritime mobile satellite system, which may be connected to switched national or international circuits, presents some complications in view of the diversity of conditions and degradations likely to be encountered in a typical connection. At least one of the links will always introduce a long propagation time of the order of 270 ms (mean one-way); echo suppressors and possibly other voice-switched equipment will be necessary. Other forms of degradation such as loss, circuit noise, attenuation/frequency distortion and, possibly, quantizing distortion will be contributed by the various circuit elements that form the connection containing the maritime system. It must also be taken into account that the mean speech and noise levels over the satellite link may be different in the two directions of transmission.

Ideally, the ultimate criterion of performance of such a connection is its performance in service when providing communication between customers drawn from the population of potential users. Under such conditions, all talking, listening and conversation degradations will be present. Such an approach, however, may not be practicable for various reasons, and the communication efficiency of the system must be tested by alternative methods. Laboratory simulation of both-way connections for conversation tests is feasible, provided the connections are truly representative and the tests are carried out in a methodical manner. Listening-only tests have a place in the assessment process, but it would be imprudent to attempt to predict entirely on the basis of results of listening-only tests the performance of maritime satellite systems under conversational conditions.

The purpose of this Report is to summarize various methods that could be used for listening-only and for conversational tests. The Report suggests which methods are most appropriate to study the effects of various types of degradation that may be encountered in establishing a maritime mobile-satellite service and which are most appropriate to establish the various performance requirements.

2. Transmission objectives

A major aim in establishing a maritime mobile-satellite service is to enable connections to be made between ships and terrestrial subscribers that are as good as, or nearly as good as, normal terrestrial connections. Several decisions have to be made in developing the service and the following is a list of areas where assessment methods play a part in making the decisions:

- determination of the most suitable speech modulation system;
- for modulation systems that produce speech correlated noise, the determination of the level of white noise that is subjectively equivalent to the speech correlated noise (see Report 750, Kyoto, 1978);
- the determination of the minimum performance standards for distress communication;
- the determination of the effect of delay, echo, and voice activated carrier switching;
- the determination of the required performance of the overall system;
- the in-service investigation whether the service meets the required level of performance and where particular areas of difficulty may exist.

3. Listening-only tests

There are many types of listening-only tests, but they can be divided into two broad categories: those that measure the intelligibility of speech received over the channel under test and those that measure the overall quality of the received speech.

Articulation tests are used for the former purpose. These are relatively simple to perform, although requiring trained subjects, and the analysis is straightforward.

Opinion scales and isopreference tests are amongst those used for the latter. In general, these methods require untrained subjects.

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

3.1 *Articulation tests*

3.1.1 *General principles*

The purpose of articulation tests is to obtain a measure of the intelligibility of the speech transmitted over the channel under test.

Generally, the tests are conducted by reading standardized speech material over the channel under test. The percentage of speech sounds received correctly by a team of listeners is taken as a measure of the intelligibility of the channel. This may be expressed as word, logatom, sound, consonant, or vowel articulation.

A great variety of practical methods exists, differing mainly on the speech material used and the general experimental conditions, and are well suited for the determination of the minimum performance standards for distress communications.

The task presented to the subjects is simple and tests of this kind are relatively easy to perform. The analysis of the results is also straightforward. The interpretation of results will depend upon the specific experimental method used.

3.1.2 *Logatom articulation method*

Logatoms are meaningless syllables consisting of three components as follows:

consonant(s)-vowel-consonant(s).

Each of the sounds constituting the logatom is chosen at random from a list of phonemes which are representative of different languages.

The method of forming logatoms is described in detail in CCITT Recommendation P.45, Red Book, Volume V, page 74.

The method consists of having at the receive end of the channel under test a trained subject listen to a logatom list. At the other end, the logatoms (without a carrier phrase) are enunciated either directly by speakers or by means of a previously recorded magnetic tape. (A complete test may comprise 500 logatoms, pronounced by several speakers.) The subject writes down the sounds he hears, thus making a list of "received" logatoms, which are then compared with those of the list read out.

The percentage of correctly received logatoms is called "logatom articulation".

3.1.3 *Sound articulation method*

A complete test comprises 100 syllables (each consisting of one or more sounds), which are chosen at random from a given language (e.g. Japanese).

A trained speaker pronounces these syllables at a constant speaking level and a subject writes down the syllables he hears. The percentage of correctly received sounds is called "sound articulation".

3.1.4 *CCITT articulation method*

Attention is also drawn to the method specified in (CCITT Recommendation P.45, Red Book, Volume V, pages 69-114).

This method was originally designed for the measurement of Articulation Reference Equivalents (AEN), but may be used for other purposes.

3.1.5 *Phonetically balanced word method (PB)*

Attention is further drawn to voice intelligibility measurements using the PB-50 word test of the American National Standard S3.2-1960: Method for the Measurement of Monosyllabic Word Intelligibility.

Experiments have shown that the PB-50 word tests can be modified from the standard procedures without significantly affecting measurement reliability and accuracy [Milner, 1973; Milner and Golab, 1975]. In order to conduct a comprehensive intelligibility test programme within a limited time in both maritime and aeronautical experiments over ATS-6, the reading rate was increased to one word per 2.5 s, the carrier phrase was dropped, the tests were limited to 400 words per test, and 68 scrambled orders of the word lists were created. These modifications in the American National Standard PB word test procedures did not comprise listener performance. Listener memorization was precluded and a wide range of parametric conditions were accommodated while maximizing the efficiency of use of satellite and flight test time (see Report 599).

3.2 *Opinion scales*

The opinion-scale methods seek to characterize speech transmission channels by using a limited set of verbal descriptions (opinion scale) of the channel quality. After listening to speech transmitted through the channel under test, untrained subjects are asked to indicate which quality description is the most appropriate for this channel.

The results from tests of this kind may be expressed as the percentage of responses in each of the various categories adopted.

In addition, certain categories may be grouped together – for example, if a seven-point scale is used, adding together groups 4, 5 and 6 will give the percentage of satisfied users and adding together groups 3, 4, 5 and 6 will give the percentage of fairly satisfied users. If a five-point scale is used, the corresponding groups are A and B and A, B and C.

A mean opinion score may also be computed if numerical values are allocated to the categories.

In general, opinion tests are easy to administer and the analysis of the results is straightforward. In this method, however, the task of the listeners is difficult in the sense that they must express their opinion by choosing one of a set of quality descriptions. The results are dependent upon the scale description which must adequately reflect the quality range covered in the test. When adequate formulations are used, the interpretation of the results is then straightforward.

Furthermore the results can be used to calculate by interpolation the level of white Gaussian noise that would be subjectively equivalent to the level of speech correlated noise. The subjects would listen to channels containing speech correlated noise and to channels containing white Gaussian noise (reference channels). The noise levels introduced into the reference channels should cover a range of Mean Opinion Score (MOS) values larger than the channels containing speech correlated noise.

Two typical opinion scales are given below:

3.2.1 7-point scale

<i>Score</i>	<i>Quality description</i>
6	Ideal circuit.
5	Excellent circuit. Possible to relax completely during call. Very agreeable.
4	Good circuit. Necessary to pay attention, but not necessary to make a special effort. Agreeable circuit.
3	Fair circuit. A moderate, but not too great, effort is necessary. Not a very agreeable circuit.
2	Poor circuit. Listening is possible, but somewhat difficult. Listening disagreeable.
1	Bad circuit. Can be used only with great difficulty. Listening very disagreeable.
0	Very bad circuit. Practically unusable.

3.2.2 5-point (listening effort) scale (Reference: Annex 5 to Question 1/XII, Part C, CCITT Green Book, Volume V)

A	Complete relaxation possible: no effort required.
B	Attention necessary: no appreciable effort required.
C	Moderate effort required.
D	Considerable effort required.
E	No meaning understood, even with considerable effort.

One of the problems of the above scales is that they are not easily translated into other languages, causing difficulties to subjects in their understanding of the difference between scale points. A possible consequence is that tests conducted in different languages but otherwise with the same parameters may not be comparable. To overcome this language problem a simple scale, easy to translate into different languages – such as very good, good, fair, poor, very poor – might be used. It is, however, very important in using such a scale that the correct question is presented to the subject; otherwise it may not be clear whether the speech or the channel is being judged, the results being as a consequence inconsistent.

Opinion scale methods are suitable for assessing the effect of most types of degradation, especially when the transmission aim is for good quality rather than mere intelligibility. They are not able to assess the effects of delay and echos.

3.3 *Comparison methods for determination of equivalent noise*

3.3.1 *General*

The use of equivalent noise is motivated by the need for assessing the effect on overall transmission quality of circuits introducing speech correlated types of distortion. For this purpose, the equivalent noise of the “unknown” system can be determined for this system alone without any additional degradation introduced (Report 750, Kyoto, 1978). The overall quality of various connections may then be calculated using ordinary transmission performance calculations. (Reference: CCITT Orange Book, annexes to Question 7/XII).

Being concerned with basically ordinary telephone connections, the subjective assessment methods used to determine equivalent noise should be based on judgement of overall quality. Also, if consistent results are to be obtained, this judgement process should obey a transitivity law, i.e., if $A = B$ and $B = C$ then $C = A$.

The tasks presented to the subject in the methods described below are somewhat different, asking for preference, similarity and rank order respectively. It is believed however that the methods are all based on overall quality judgements.

3.3.2 *Isopreference method*

In the isopreference method, the channel under test is assessed by comparison with a reference channel which carries varying amounts of noise. For each pair of reference and test channels, the subject is asked to indicate which of the two speech samples he or she would prefer to listen to. The isopreference (noise) level is then the value where 50% of the listeners prefer one channel and 50% the other channel. Since, in practice, the isopreference level is unlikely to be obtained, an interpolation procedure is used to arrive at the isopreference level and tests have shown that the transitivity requirement is met by this method.

3.3.3 *Adjustment method*

This method is also called the method of average error. In this method, the subjects control the noise power in the reference channel. They are asked to adjust the reference channel by selecting the amount of noise required so that this channel and the channel under test are equivalent with respect to overall quality. In this method, the equivalent noise level is obtained directly by the setting of the noise level.

Tests have shown that the transitivity requirement is also met by this method.

3.3.4 *Rank order method*

The method consists of rank ordering a mixture of known and unknown processing techniques in order of performance and is known in statistical experimentation as the Youden Squares (YS) design. The term “known” transmission technique refers to one where the subjective quality is known in terms of an analogue signal with Gaussian noise. An “unknown” transmission processing technique is any technique for which the quality is to be determined.

The mixture of known and unknown transmission techniques is composed such that, by careful preselection, the quality range of the known techniques embraces those of the unknown techniques. Then the equivalent noise values for the unknown techniques are obtained by interpolation.

The Youden Squares design allows the subjective rank ordering of many stimuli such as speech samples processed by different techniques by presenting only a small fraction at one time to test subjects. This fraction is called a block. For example, one can rank order thirteen stimuli by presenting only blocks of four at a time and the design is called a 4×13 YS. The stimuli, as used here and designated S_i , are recorded speech samples processed by different techniques under specified conditions.

The Youden Square assures that the division into blocks for ranking maintains a certain balance, in particular, that each stimulus S_i is listened to an equal number of times in the experiment and each possible pair of stimuli occurs equally often in an equal number of blocks.

Because it is generally too difficult for most people to compare more than 4 samples at a time, the 13×4 Youden Square design is most often used. In this design 6 “unknown” systems are mixed with 7 systems of known analogue signal to noise ratio.

For each block the subject is asked to rank the 4 stimuli by assigning numbers from 1 (for the best) to 4 (for the worst) to the speech samples in accordance with his own preference.

The coefficient concordance test should be performed to ensure a high probability that the observed rank order exists. The analysis consists of computing the mean rank for each system. For the conversion from rank order to equivalent noise, a regression curve mean rank versus S/N , for the analogue treatments is determined. The mean ranks of the unknown treatments are transferred to the S/N domain with this regression curve.

Example of the use of this method may be found in Report 752, Annex II.

4. Conversational tests

4.1 General principles

Conversational tests are primarily concerned with the overall quality of telephone connections. The effects arising in a conversation are taken into account in as realistic a way as possible.

The tests are performed by having pairs of untrained subjects conduct conversations over the connection under test. Immediately after having completed the conversation task without any disturbance, the subjects are examined on their opinion of the circuit. The method might therefore be used on either real or simulated connections.

The questionnaires used may vary, but generally an opinion scale is included. The subjects are asked to indicate which quality description is in accordance with his opinion of the circuit quality. In addition, subjects may be asked whether they experienced difficulty or not. If they did, further questions may be asked to probe the nature of difficulty, but without suggesting possible types of difficulty. The subjects are interrogated independently and they are not allowed to discuss their opinions (Reference: Appendix 2 to Annex 2 to Question 4/XII, CCITT Green Book, Volume V).

The conduct of conversation tests is very time-consuming, since the subjects are allowed to perform their task at their own speed. The generation of a realistic conversation between them is one of the main problems posed in experiments of this kind.

The method of analysis of the results is similar to that used in opinion scale testing. The mean opinion score and the percentage score in each category and in groups of categories are computed. In addition, the percentage of subjects who experienced either difficulty or any of the special kinds of distortions listed in the questionnaire is also given.

4.2 Practical methods

A particular method of carrying out conversational tests is described in Annex 2 to Question 4/XII, CCITT Green Book, Volume V. A five-point rating scale is generally used and contains, for example, the quality descriptions "Excellent", "Good", "Fair", "Poor" and "Bad". The mean Opinion Score (MOS) is computed as follows:

$$\text{MOS} = (4E + 3G + 2F + P) / N$$

where,

E : number of calls rated excellent,
 G : number of calls rated good,
 F : number of calls rated fair,
 P : number of calls rated poor,
 N : total number of calls.

(The number of calls rated "Bad" is given a zero coefficient and affects the MOS by being included in N .)

5. Experimental set-up

Figure 1 shows a laboratory simulation of a typical subscriber-to-subscriber connection which includes degradations that might be experienced on a maritime satellite call. When listening-only tests are performed, some of these degradations cannot be evaluated and equipment such as propagation delay equipment and echo suppressors can be removed from the simulated connection.

For practical reasons, it may be desirable to carry out listening-only tests over the satellite link taken in isolation. However, care must be taken in drawing conclusions from such tests, since, ideally, these tests should take into account factors such as loss, distortion and circuit noise which may influence the speech signal applied to the satellite system modulators, both at the ground station and at the ship terminal; also the presence and characteristics of any ambient noise at the listening locations must be considered. Tests should be conducted, separately, in both directions of transmission.

The noise arising in the terrestrial extension and which is to be injected into the simulated connection needs to be determined and will have to take into account the fact that terrestrial extensions will vary considerably in length.

For comparison purposes during tests, a reference connection is needed; this should be similar to the connection under test, but the maritime link should be replaced by a fixed service satellite link.

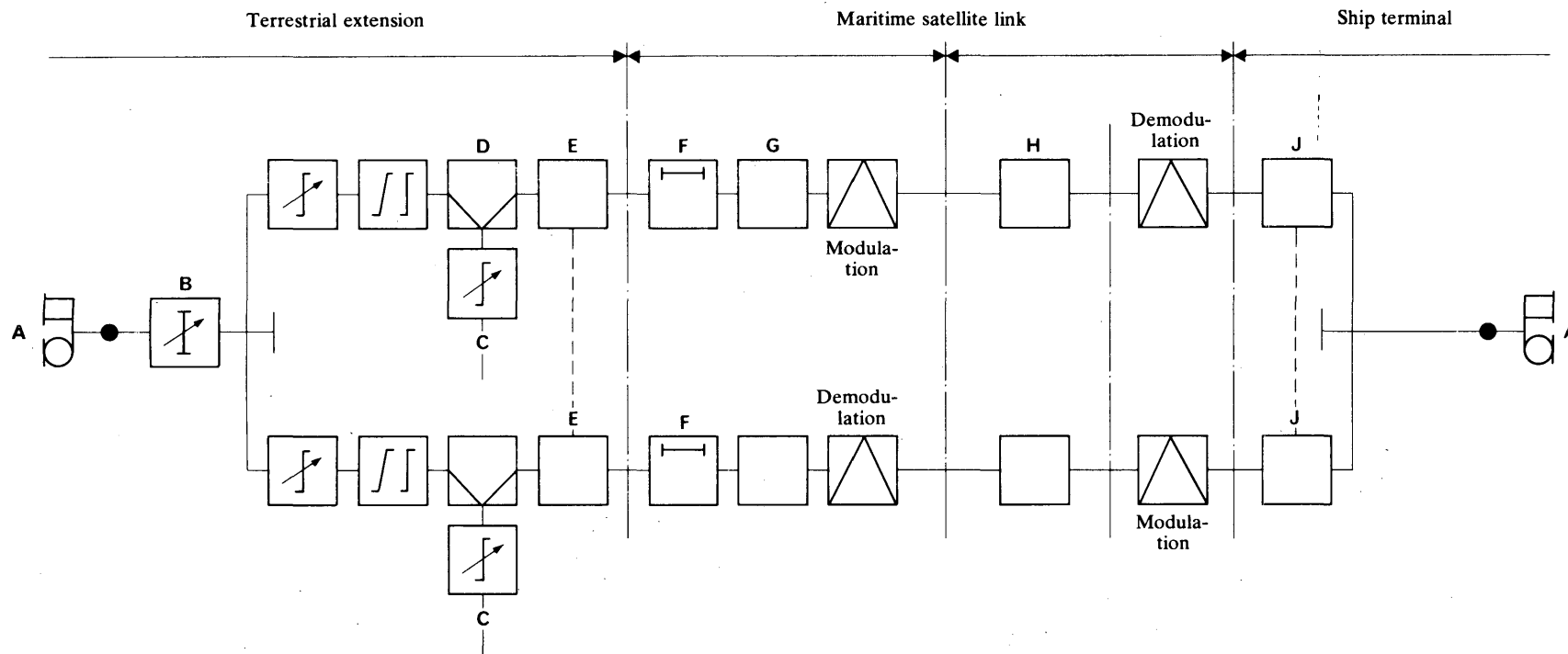


FIGURE 1 – Laboratory simulation of typical subscriber to subscriber connection

A: ambient noise	D: noise inject pad	G: voice activator
B: artificial line of variable length	E: half-echo suppressor	H: satellite simulator
C: noise	F: delay	J: half-echo suppressor

Note. — With four-wire telephone system on board ship, the four-to-two-wire terminating set will not be required. See also Recommendation 550 as regards the half-echo suppressor at the ship end of the connection.

6. Conclusions

Subscriber-to-subscriber conversation tests are the only satisfactory method of evaluating the performance of a telephone connection involving a system in the maritime mobile-satellite service. Such tests are the only ones that can take into account the degradations introduced by propagation delay through the satellite. Unfortunately, conversation tests are difficult and time consuming to carry out; listening-only tests are simpler to carry out and have a place in certain aspects of evaluation, but their limitations must be borne in mind when making decisions based on results from such tests.

Especially, it should be recognized that articulation tests are not very suitable for the assessment of ordinary telephone connections. These methods, however, may be applied for special purposes, e.g. determination of the effect of voice activated carrier switching (trunkation of initial syllables) and performance standards for distress communication.

For the determination of the most suitable speech modulation method and assessment of equivalent noise levels of the satellite link, listening-only methods assessing overall quality should be used.

The following recommendations are submitted:

- listening-only tests may be used in preliminary tests for the comparison of modulation methods; ideally they should be carried out over a complete connection;
- listening-only tests assessing the equivalent noise of the modulation methods may be carried out to enable transmission performance calculations to be performed on a variety of representative complete connections;
- conversational laboratory tests over a simulated connection should be carried out, preferably under the auspices of an international forum;
- eventually, in-service conversational tests should be performed.

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RECOMMENDATION 548

OVERALL TRANSMISSION CHARACTERISTICS OF TELEPHONE CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

- (a) that, when studying the interworking of a maritime satellite system with the automatic telephone network, a maritime satellite system can, from the technical point, be regarded as somewhat analogous with a national network and the ship terminals regarded as somewhat analogous to subscribers' locations within that network, implying the network configuration of Fig. 1 (Note 1);
- (b) that, although several CCITT Recommendations of the G Series should apply to the maritime systems, these could involve requirements which would be too stringent for the maintenance of performance of ship terminal equipment;
- (c) that relaxed requirements could be permitted where they will not cause a significant deterioration in the performance of the international network as experienced by subscribers in the existing terrestrial networks;
- (d) CCITT Recommendation G.473,

UNANIMOUSLY RECOMMENDS

that the design of the various items comprising a maritime system should permit the following transmission characteristics to be met:

1. the nominal frequency-band of a maritime satellite circuit should be either 300 to 3000 Hz or 300 to 3400 Hz.

From a transmission performance point of view the latter is desirable but economic and/or technical considerations may favour the former;

2. the attenuation/frequency characteristics of any pair of ship terminal and shore station equipment should be within the limits shown in Fig. 2, referring to 800 Hz;

3. at 800 Hz the difference between the mean value (over time and over circuits) and the nominal value of the transmission loss of a maritime satellite circuit should not exceed 1 dB, and the standard deviation of the variation in transmission loss should not exceed 2 dB;

4. the linear crosstalk ratio (for potentially intelligible crosstalk only) between any two maritime satellite circuits should not be less than 58 dB, and between the go and return channels of any circuit not less than 55 dB;

5. if a maritime circuit is to be interconnected to a special quality leased international telephone circuit, then the group-delay distortion of the maritime circuit should not exceed the following limits:

500 Hz to 2800 Hz: 3 ms

600 Hz to 2600 Hz: 1.5 ms

1000 Hz to 2600 Hz: 0.5 ms

Note 1. — Figure 1 illustrates three possible configurations for the shipboard installations and defines the nomenclature used for transmission study purposes in this Recommendation. This nomenclature is in accordance with the conventions of Recommendation 546.

Note 2. — According to the conventions of CCITT Study Group IV, 800 Hz is the recommended frequency for single-frequency maintenance measurements on international circuits. However, by agreement between the administrations concerned, 1000 Hz may be used for such measurements. Multifrequency measurements made to determine the loss/frequency characteristic will include a measurement at 800 Hz, and therefore the reference for such characteristics can still be 800 Hz.

Note 3. — Experience has shown that, in the case of equipments and apparatus complying with CCITT Recommendations, the level of non-linear distortion encountered in the general telephone network has no unacceptable effects on speech transmission, or on the various non-speech signals conveyed by the network (e.g.: signalling, voice-band data, etc.).

Note 4. — The attenuation/frequency characteristics given in § 2 of this Recommendation could be apportioned equally between the shore station equipment and the ship terminal equipment or, if advantageous, be apportioned unequally to the various elements comprising a maritime system.

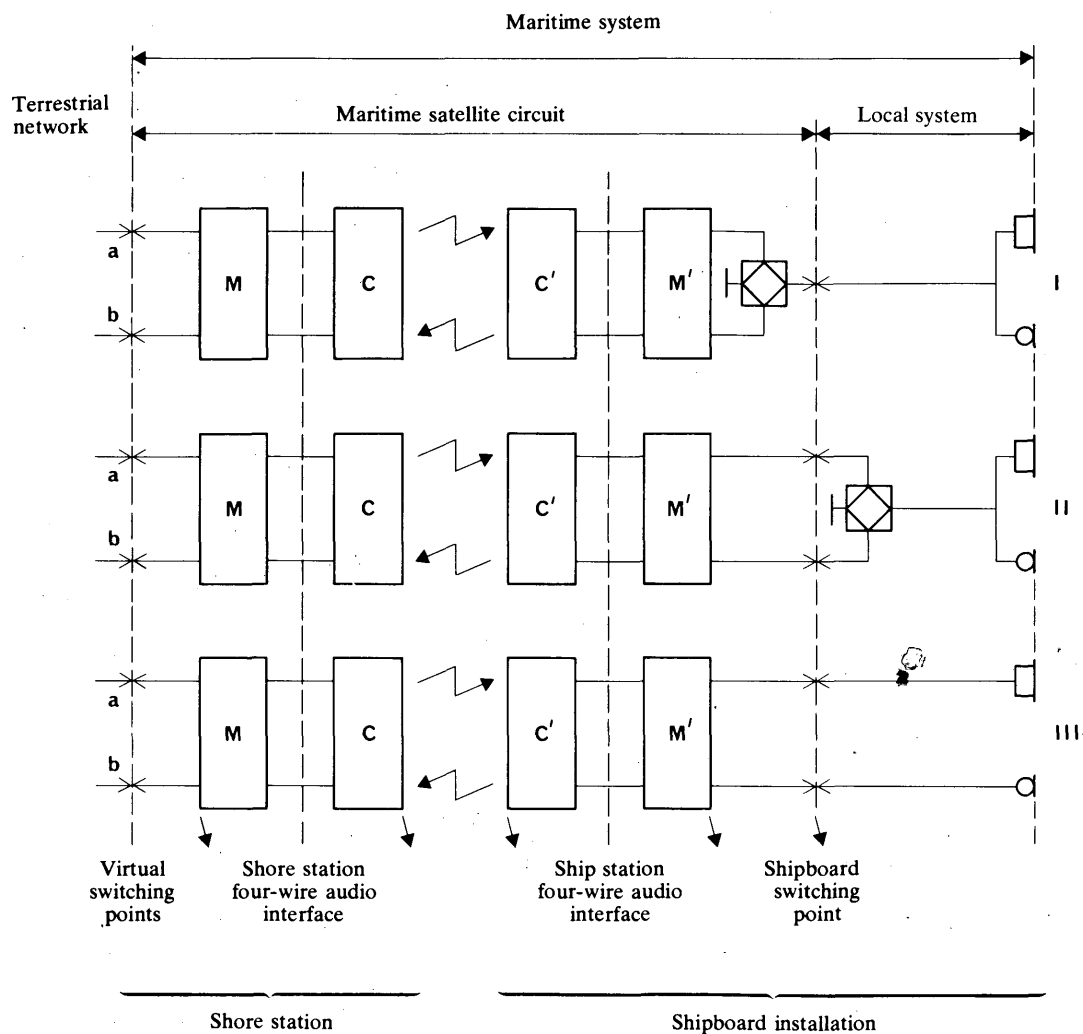


FIGURE 1 – Interconnection of circuits in the Maritime Mobile Satellite Service to the terrestrial network and corresponding nomenclature

Notes:

- (1) From the point of view signalling and switching the shore station performs some of the functioning of an international transit centre (CT).
- (2) *a* and *b* are the virtual switching points of the most-directly connected international circuit in the terrestrial network.
- (3) *M* and *M'* are the miscellaneous telephone equipment needed for the maritime satellite circuit, eg: signalling terminations, echo suppressors.
- (4) *C* and *C'* are the channel units (i.e.: the channel transmitting and receiving equipments) which include voice-processing apparatus, eg: voice activated switches, companders, etc.
- (5) The attenuation-distortion of the two-wire/four-wire terminating unit is taken to be negligible over the band 300 to 3400 Hz.

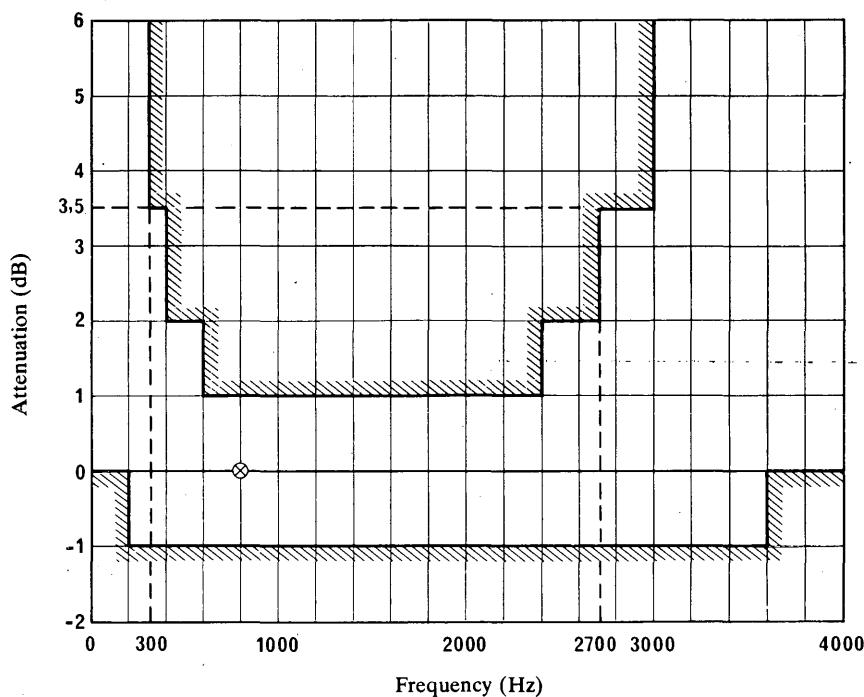


FIGURE 2 – Attenuation/frequency characteristics

REPORT 509-4

MODULATION AND CODING TECHNIQUES FOR MOBILE SATELLITE
COMMUNICATION SERVICES

(Study Programme 17A-1/8)

(1970-1974-1978-1982-1986)

1. General

This Report describes modulation and coding techniques which will be suitable for mobile satellite communications services. Possible techniques are briefly described and their fundamental performance characteristics are surveyed.

2. Modulation technique**2.1 Analogue voice modulation****2.1.1 General**

Among analogue voice modulation techniques, frequency modulation (FM) and single-sideband amplitude modulation (SSB) have the potential for providing a speech quality which would be tolerable for the public mobile telephone service at reasonable expenditures of satellite power, frequency band, and mobile-borne equipment complexity and cost.

For systems where the maximum number of channels is essentially limited by the satellite power available, the more power efficient FM system with its relatively wider bandwidth requirements is superior to SSB. Where no such power limits are present, SSB could provide higher quality.

2.1.2 Comparison of SSB and FM in terms of articulation index (AI)

The relation between articulation index and signal-to-noise density at the receiver is shown in Fig. 1 for typical SSB and FM modulation techniques. For example, for the condition of a peak power limited satellite and a signal-to-noise density of 46 dBHz, it is noted that single-sideband yields an articulation index of 0.43 and that frequency modulation using bandwidths of 8 kHz and 18 kHz yields articulation indices of 0.53 and 0.57, respectively. This C/N_0 is 1 dB above the threshold value of an 8 kHz system and is 3 dB below threshold point of an 18 kHz system. A signal-to-noise density of 49 dBHz yields articulation indices of 0.52 for single-sideband, 0.60 for 8 kHz frequency modulation and 0.68 for 18 kHz frequency-modulation, and is above threshold in both of these frequency-modulation systems.

The results shown are based upon a theoretical analysis of data generated by tests with the English language.

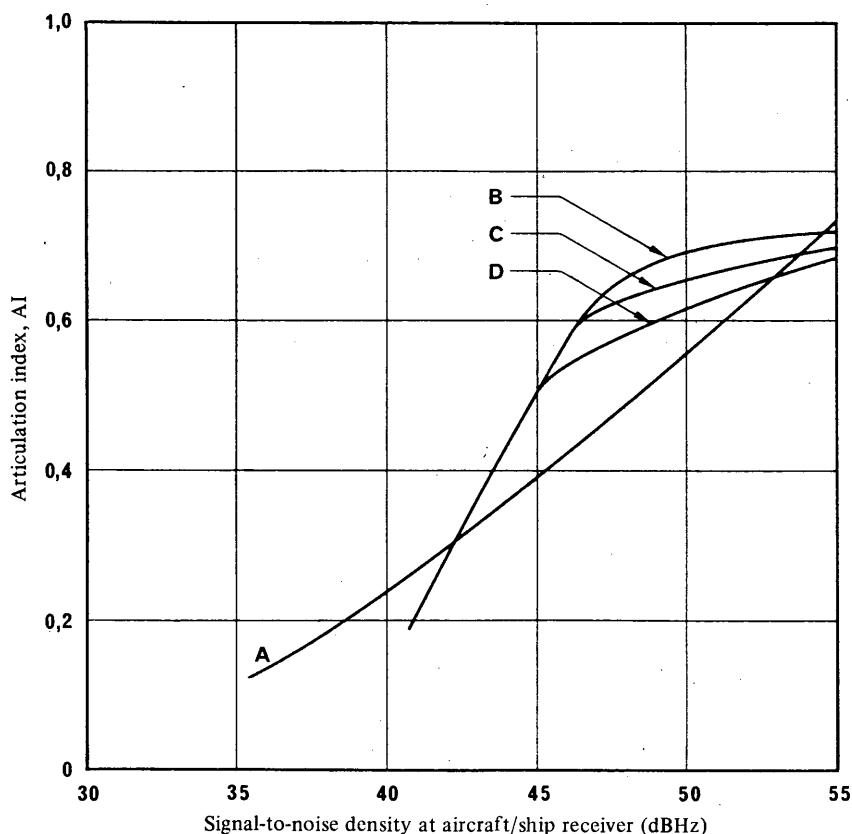


FIGURE 1 – Comparison of analogue voice modulation techniques

- A: 5 kHz single sideband-peak radio-frequency power
- B: frequency modulation (18 kHz)
- C: frequency modulation (10 kHz)
- D: frequency modulation (8 kHz)

Note. – The articulation index (AI) of a speech circuit indicates the effective proportion of an ideal voice channel (with respect to intelligibility) which that circuit will provide under the given signal and noise conditions [Beranek, 1947]. The audio band is unequally divided into 20 segments, each of which contributes equally to the intelligibility of speech. This contribution is independent of what happens in other segments. To achieve an articulation index of 1.0, a signal-to-noise ratio of 30 dB must be provided in each of the segments, i.e. each contributes 5% of the articulation index when the speech spectrum is not masked by noise and is sufficiently loud to be above the threshold of audibility. Noise density may or may not be constant over the audio baseband so the effect in each segment will vary.

2.1.3 INMARSAT system

For the INMARSAT system which is essentially power-limited at present, narrow-band frequency modulation (NBFM) is used for telephony. Table I shows the major parameters of the NBFM used in the INMARSAT system. This NBFM system offers good speech quality with a link C/N_0 of 52 dBHz and gives tolerable speech quality with a link C/N_0 of 48.6 dBHz when a demodulator employing threshold extension technique, is used.

TABLE I – Major parameters of NBFM used in the INMARSAT Standard-A system

Baseband	300-3000 Hz
Emphasis	None
Companding	2 : 1 syllabic As specified in CCITT Recommendation G.162 with unaffected level equal to 0 dBm0
Peak clipping level	At peaks of an 800 Hz test tone of 0 dBm0
Peak frequency deviation	12 kHz at 0 dBm0 baseband level in the absence of peak clipping
Mean speech level	– 14 dBm0
Standard deviation	6 dB

Figure 2 shows the equivalent speech-to-noise ratio of an NBFM system, with parameters very similar to those shown in Table I, as a function of link C/N_0 against talker level (dBr) (r.m.s. power of talker to r.m.s. power for full deviation).

2.1.4 Other factors

In addition to voice quality and satellite radiated power requirements, other factors must be considered before selecting the modulation technique. Some of these factors are: spectrum requirements, effects of oscillator instabilities and Doppler shifts, system reliability and costs.

2.2 Digital modulation

The modulation methods to be used in the transmission of digital signals in a mobile satellite system should meet the following requirements:

- good bit error ratio (BER) as a function of E_b/N_0 performance;
- efficient bandwidth utilization;
- inexpensive and simple implementation.

In addition, it is preferable if the modulation method adopted results in a constant amplitude signal to make it possible to use a class C power amplifier for the mobile transmitter. If amplitude variation exists in the modulated signal waveform, higher power-spectrum side lobes of the signal will be produced in the process of amplification by a non-linear transmitter, i.e. a class C amplifier.

The following modulation methods can be considered as candidates for the mobile satellite service application:

- unfiltered 4-PSK;
- filtered 4-PSK in which baseband rectangular signals are filtered or shaped before being applied to the 4-PSK modulator;
- offset 4-PSK in which baseband digital signals in one channel are offset by the duration of a half symbol interval relative to those in the orthogonal channel prior to the filtered 4-PSK modulation;
- minimum shift keying (MSK) [de Buda, 1972] often referred to as fast frequency shift keying (FFSK), i.e. FSK with a deviation ratio of 0.5;
- tamed frequency modulation (TFM) [de Jaeger and Dekker, 1978; Muilwijk and Noordanus, 1980] which is a class of modulation methods known as “correlative phase shift keying”;
- Gaussian filtered MSK (GMSK) [Hirade and Murota, 1979] which is a modified MSK using a premodulation Gaussian low-pass filter.

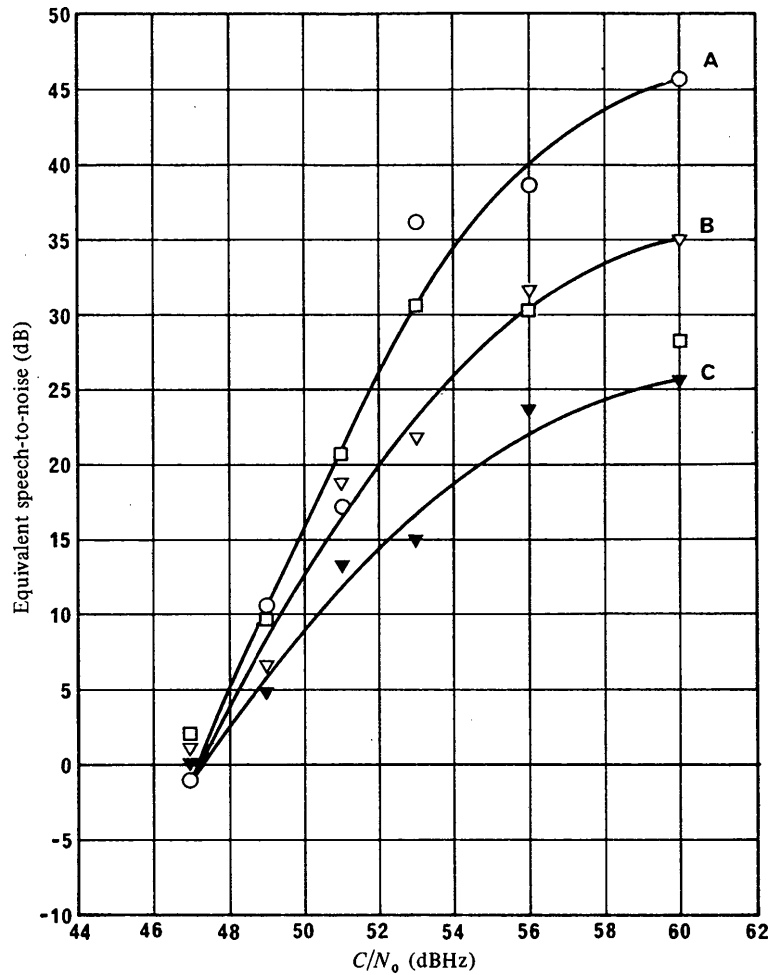


FIGURE 2 – Results of subjective assessments in terms of equivalent noise of a -15 dBm0 talker as a function of C/N_0 .

Talker level A, B and C (dBr) (r.m.s. power of talker relative to r.m.s. power for full deviation).

A: ○ : -15 dBr

B: ▽ : -25 dBr

C: ▼ : -35 dBr

r.m.s. test-tone deviation: 8.5 kHz at 0 dBm0

Demodulator: threshold-extended type of regenerative-feedback IF limiter

Unfiltered 4-PSK provides a constant amplitude property, but has a high-level side lobe in its power spectrum. In the case of filtered 4-PSK the level of side lobes in the power spectrum can be adjusted to suit the coding method. An optimum exists between achieving minimum bit error rate and best spectrum utilization. Since filtered 4-PSK does not have a constant amplitude property non-linear amplification (such as class C) cannot be used, due to the spectrum regrowth which this would cause. However, offset 4-PSK can reduce this problem as it has less amplitude variation.

In MSK, the baseband rectangular signal in each channel is sinusoidally shaped in the time domain prior to the offset 4-PSK modulation process. In this sense, MSK can be recognized as a modification of offset 4-PSK. MSK has a constant envelope property with more concentrated power spectrum than 4-PSK.

TFM and GMSK can substantially suppress the out-of-band spectrum at the cost of a moderate BER degradation, while their constant amplitude properties are almost maintained.

Figure 3 shows the calculated power spectra of signals modulated by the methods listed above. Figure 3 demonstrates that the spectral density distribution of TFM and GMSK is superior to the other modulation methods particularly for frequencies well separated from the carrier. For filtered 4-PSK and offset 4-PSK, a square-root Nyquist filter such as the square-root raised-cosine shaped filter can be used for premodulation, when a transmitter with a good linearity is used on board the mobile. In this case, filtered 4-PSK and offset 4-PSK can achieve a spectrum compactness comparable to or superior to TFM and GMSK without BER performance degradation.

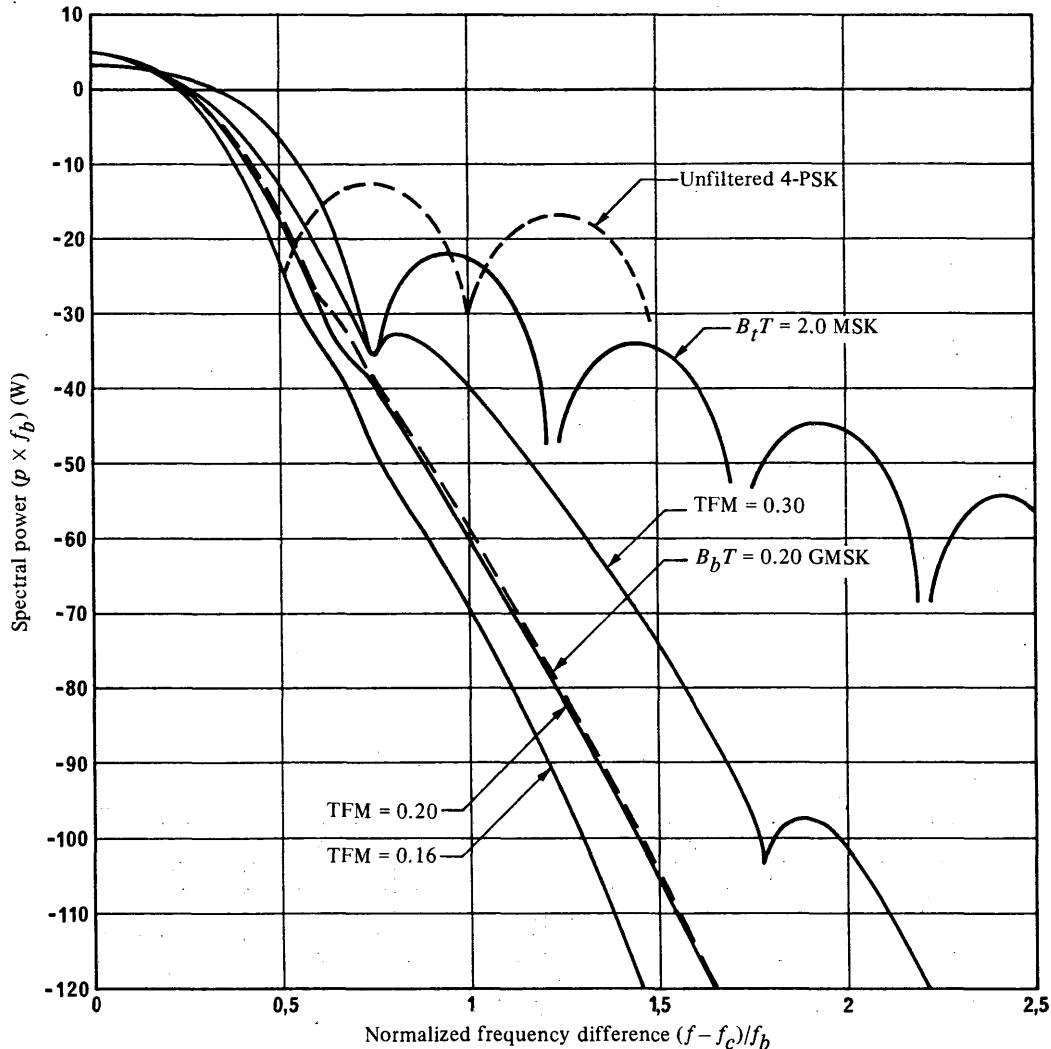


FIGURE 3 – Power spectral density of typical modulation methods

- $B_b T$: normalized bandwidth of premodulation
Gaussian bandpass filter (GMSK)
- $B_t T$: normalized bandwidth of transmitting
Gaussian bandpass filter for MSK
- f_c : carrier frequency (Hz)
- f_b : bandwidth (Hz)
- P : spectral density (W/Hz)

Figure 4 shows BER as a function of E_b/N_0 for typical modulation methods, and shows that theoretical 4-PSK performance can be used as a reference for the judgement of robustness of a modulation method against noise. Filtered 4-PSK can achieve the same BER performance as that for theoretical 4-PSK, when the transmission channel is linear and a square root Nyquist filter is used for premodulation and pre-detection filters, respectively.

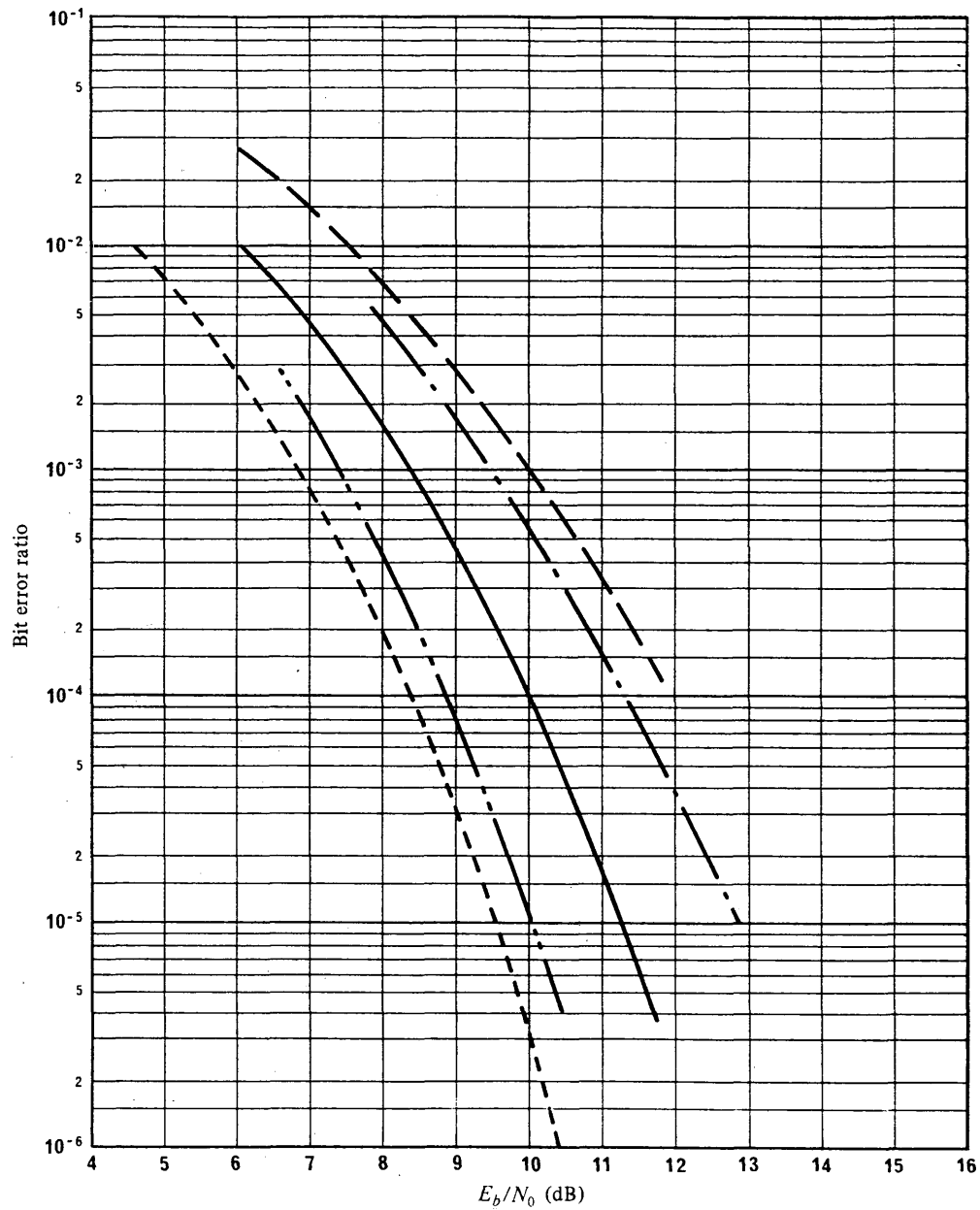


FIGURE 4 – Bit error ratio as a function of normalized signal-to-noise ratio

- TFM (measured) [Muilwijk, 1979]
- GMSK $B_b T = 0.20$ (measured)
- GMSK $B_b T = 0.25$ (measured) and TFM (theoretical)
- · - · MSK $B_t T = 2.0$ (measured) [Murota and Hirade, 1981]
- theoretical 2-PSK, 4-PSK and MSK

$B_t T$: normalized bandwidth of transmitting Gaussian bandpass filter for MSK

$B_b T$: normalized bandwidth of transmitting Gaussian low-pass filter in GMSK modulator

The BER performance in the actual satellite link can be degraded by a number of factors. They are modem circuit imperfections, band-limiting effect of transmitting and receiving filters, adjacent-channel interference, intermodulation interference and other miscellaneous interference. These factors are closely related to each other. For instance, narrower transmit filtering results in lower adjacent-channel interference level, but in general, results in a poorer BER performance. Another factor affecting BER performance is the susceptibility of the receiver to interference from other users of the same channel frequency. In this respect, it has been demonstrated that both 2-PSK and MSK have approximately the same sensitivity to co-channel interference and that they are both superior to 4-PSK.

The BER performance of digital modulation methods can be improved by the use of forward error-correcting (FEC) techniques, which is covered in Report 708. The final selection of modulation method should be made taking into account the parameters and requirements of each system such as channel spacing between carriers, required BER values, advantage to be gained from FEC and the effect of interference as listed above, taking into account expected level differences and the variation of carriers due to fading etc.

Table II briefly compares the relative merits and demerits of a number of modulation methods using the same parameters as those in Fig. 4.

TABLE II — *Relative merits and demerits among typical modulation methods*

Modulation method	BER performance	Bandwidth utilization efficiency	Amplitude
Unfiltered 4-PSK	Excellent	Poor	Constant
Filtered 4-PSK	Excellent	Good	Varying
Offset 4-PSK	Excellent	Good	Varying
MSK	Excellent	Fair	Constant
TFM	Fair	Good	Constant
GMSK	Fair	Good	Constant

Note. — Typically, 24 kbit/s filtered 4-PSK occupies 20 kHz bandwidth and the same bit rate MSK occupies 30 kHz bandwidth.

3. Voice coding technique

3.1 General

When a digital modulated transmission channel is used for telephone signal transmission, the analogue voice signal has to be coded into a digital data stream prior to modulation. 64 kbit/s pulse coded modulation (PCM), where the analogue voice signal is sampled at 8 kHz and every sample is quantized with 8 bits, is generally used for the public telephone services. However, the coding bit rate of 64 kbit/s is too high to be applied to the mobile satellite communications service, because the transmitting power from the satellite is severely limited and satisfactory BER performance cannot be achieved for such a high bit rate channel with reasonable satellite power. Therefore, voice coding with a bit rate lower than 64 kbit/s is desired. Furthermore, the voice coding technique used has to be robust against the channel bit errors, because the bit error ratio achievable is generally high in the mobile satellite services.

Note. — Report 921 also provides information on this topic specifically for ship earth stations.

3.2 Medium bit rate voice coding

In order to achieve the speech quality which NBFM employed in the INMARSAT Standard-A system achieves, a medium bit rate such as not lower than 16 kbit/s would be required [Flanagan *et al.*, 1979]. Possible candidates of voice coding technique for mobile satellite services are the 16 kbit/s and 32 kbit/s waveform coding techniques listed below:

- adaptive differential PCM (ADPCM);
- adaptive predictive coding (APC);
- adaptive transform coding (ATC);
- adaptive delta modulation (ADM);

- sub-band coding with ADPCM (SBC-ADPCM);
- sub-band coding with APC (SBC-APC);
- adaptive predictive coding with adaptive bit allocation (APC-AB) which is an advanced version of SBC-APC, but which requires more complicated hardware than conventional SBC-APC;
- multi-pulse excited coding (MPEC).

Mean opinion scores (MOS) can be used to evaluate the speech quality of voice coding techniques. The MOS is obtained by averaging the scores which are voted through subjective assessment tests having a 5-point scale with categories, i.e. “excellent”, “good”, “fair”, “poor” and “bad”. A comparison of the results of speech quality in MOS among typical coding methods under an error-free environment as a function of coding bit rate has been reported [Daumer, 1982]. In the literature, as an example of an actual circuit environment, a simulated subscriber loop of approximately 2 km with bandpass filtering of 200-3400 Hz, which simulates the bandpass filter in the channel bank, prior to coding, and a subscriber loop of approximately 2 km after decoding were considered. It was concluded that APC provided the highest MOS value at a coding bit rate of 16 kbit/s.

Another example comparing the speech quality of typical 32 kbit/s and 16 kbit/s coding methods is shown in Fig. 5 [Yatsuzuka *et al.*, 1983]. In Fig. 5, the MOSs under a BER of 10^{-3} as well as those under an error-free environment are shown. MOS for NBFM as used in the INMARSAT Standard-A system and for standard PCM with various bit rates are also indicated. In Fig. 5, a 0.5 mm diameter 2 km simulated subscriber loop with circuit noise of 10 000 pW0p was taken into account, and bandpass filtering of 300-3400 Hz was also used. As shown in Fig. 5, 16 kbit/s APC and 16 kbit/s SBC-APC can achieve, under an error-free environment, a subjective quality comparable to NBFM with C/N_0 of 53 dBHz and, under a BER of 10^{-3} , better quality than NBFM with C/N_0 of 48.6 dBHz which is the threshold link level C/N_0 for the faded condition in the INMARSAT Standard-A system design.

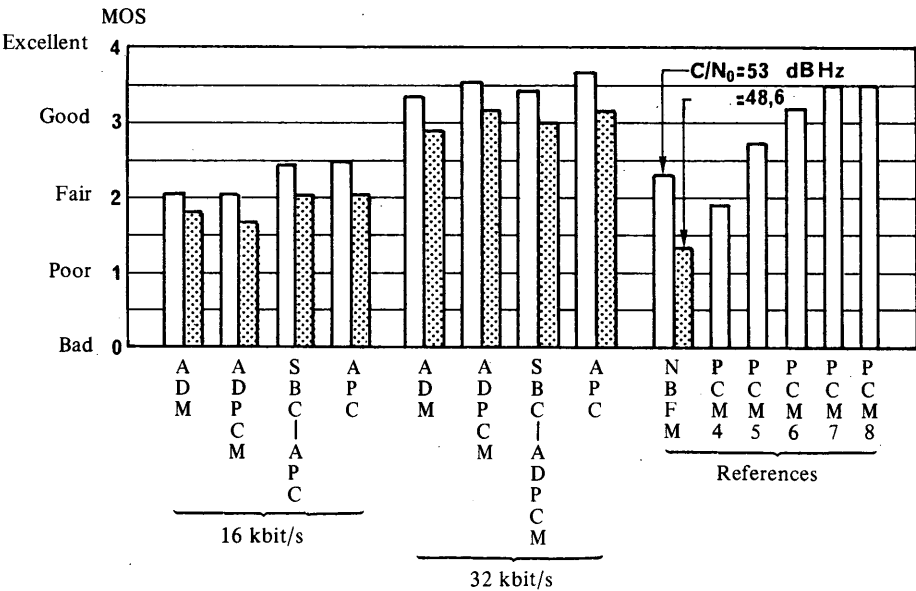


FIGURE 5 – MOSs for typical 32 kbit/s and 16 kbit/s voice coding methods [Yatsuzuka *et al.*, 1983]

- Error free
- ▨ Random error (BER = 10^{-3})
- PCM4: 4 bit/sample PCM
- PCM5: 5 bit/sample PCM
- PCM6: 6 bit/sample PCM
- PCM7: 7 bit/sample PCM
- PCM8: 8 bit/sample PCM

Annex I to Report 921 also discusses this specific topic.

It should also be noted that the final selection of coding technique will be affected by coding delay and relative equipment complexity. Table III demonstrates relative complexity of the coder and decoder hardware for typical medium bit rate voice coding methods.

TABLE III — *Relative complexity of typical medium bit rate voice coder and decoder*
[Flanagan *et al.*, 1979]

Coding method	Relative complexity
ADM	1
ADPCM	1
APC	50
ATC	50
SBC	5

3.3 Low bit rate voice coding technique

At coding bit rates below 16 kbit/s and specifically the bit rate range 9.6 to 7.2 kbit/s, the waveform coding method can provide reproduced speech which is highly intelligible, but which has noticeable quality degradation with some detectable distortion, and perhaps reduced talker recognition. At coding bit rates in the range 4.8 kbit/s and below, source coding (vocoder) methods can provide synthetic quality, although the signal usually has lost substantial naturalness, typically sounding reedy [Flanagan *et al.*, 1979].

Possible candidates for voice coding methods in this coding bit rate range are listed below [Flanagan *et al.*, 1979]:

- APC,
- ATC,
- MPEC,
- voice excited linear predictive coding (VELP),
- residual excited linear predictive (REL P) coding,
- channel vocoder (CV),
- formant vocoder,
- linear predictive coding (LPC).

The first three are forms of waveform coding and the last three are forms of vocoder. VELP and RELP are categorized as hybrid coding method.

With a vocoder, only essential speech parameters are extracted and transmitted. Vcoders consist of a speech analyzer part, which extracts speech parameters, and a speech synthesizer which reconstitutes the original speech on the basis of the received parameters. The speech analyzer of a pitch excited vocoder tracks the continuous variation of the speech pitch frequency, indicates the presence of voiced or unvoiced sounds and provides information on the short-term speech spectrum. Depending on the way in which the short-term speech spectrum is determined, vocoders are classified as belonging to various categories, e.g. channel-, formant- or LPC (linear predictive coding) vocoder [Flanagan *et al.*, 1979]. A channel vocoder uses filter banks to extract rectified smoothed amplitude information for each band. A formant vocoder also uses filter banks to detect the instantaneous frequency and the average amplitude for each band. An LPC vocoder extracts the so-called vocal tract parameter by minimizing mean square error between the input signal and signal values predicted by a linear weighted summation of past values of the signal.

Two particular points of interests are:

- there is a strong relation between the voice quality of a vocoder and the accuracy of pitch extraction; and
- the extraction of the pitch frequency from a speech signal is one of the most critical and difficult tasks in speech analysis.

In this latter regard, a fairly recent major achievement reported in literature is a new type of pitch extractor which forms the basis of a high-quality type of pitch-excited vocoder at low bit rate (Sluyter *et al.*, 1980).

Rather than looking at pitch extraction as a purely technical problem, this particular technique is based on the understanding of human pitch perception. The indicated concept includes spectral analysis and harmonic pattern recognition. Using a well-chosen algorithm, the pitch parameter can be calculated in agreement with perception and in real-time.

An example comparison result of speech quality in MOS among typical coding methods can be seen in Fig. 6 [Yato *et al.*, 1983]. Also shown are comparative MOS for narrow-band FM at particular C/N_0 values and for a 4-bit PCM system.

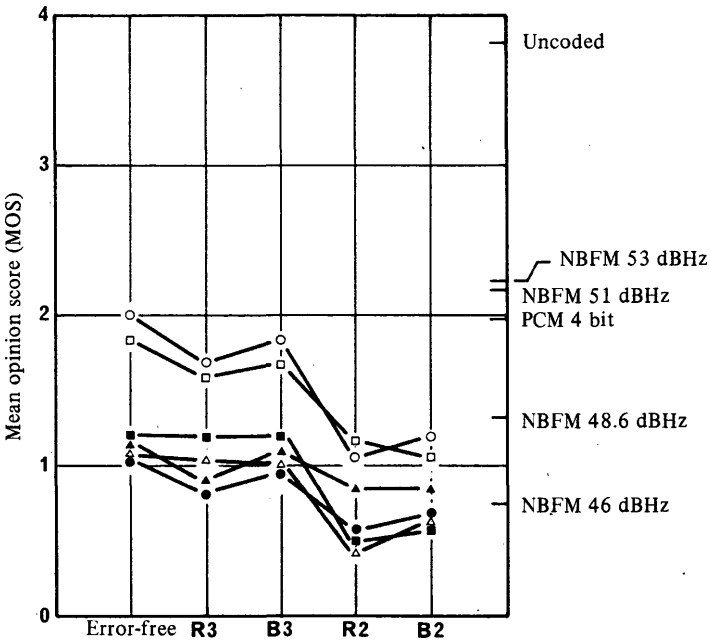


FIGURE 6 – MOSs for typical low bit rate voice coding methods [Yato *et al.*, 1983]

- RELP 9.6 (kbit/s)
 - RELP 7.2
 - ▲ RELP 4.8
 - LPC 4.8
 - △ LPC 2.4
 - CV 2.4
- R3: random errors of BER = 10^{-3} were added
B3: burst errors of BER = 10^{-3} were added
R2: random errors of BER = 10^{-2} were added
B2: burst errors of BER = 10^{-2} were added

Regarding the speech quality of LPC vocoders, some intelligibility tests have been carried out with several types of LPC vocoders developed in Japan. For instance, it is reported that one type of 2.4 kbit/s LPC vocoder achieves a syllable articulation score of about 68% in Japanese [Kurematsu *et al.*, 1979] and another type of LPC vocoder PARCOR [Itakura and Saito, 1968] obtains AEN values (see Note) (CCITT Recommendation P.41-45) of 6 dB and 3 dB at 2.4 kbit/s and at 4.8 kbit/s, respectively.

Regarding the performance of channel vocoders, intelligibility tests have been carried out on 2.4 kbit/s channel vocoders (1.8 kbit/s vocoder with 0.6 kbit/s FEC) developed in the United Kingdom using phonetically balanced word lists [Lehiste and Peterson, 1959] which resulted in percentage intelligibility approaching 80% even for BER up to 5%. It is generally accepted that a minimum acceptable score for such tests is 55-60%. Tests have been carried out in practical environments and in noise chamber simulations on the suitability of channel vocoders for use in vehicles with very high levels of acoustic noise, considerably worse than would be expected in a ship, and they were found usable with high acoustic noise combined with a BER of 2.5% (with FEC) [Kingsbury and Amos, 1980]. In these tests on channel vocoders the microphones used were practical types in common use; however carbon microphones were not used. The FEC used was designed specifically for use with the vocoder, and only applies correction to the most significant bits i.e. those that affect the speech most.

It can be expected that high-quality vocoder systems will be available in the foreseeable future. However, with regard to the applicability of vocoders in the specific situation of the maritime satellite service, further study is required on several aspects. e.g.:

- influence of a limited-quality input speech to the vocoder, as will be experienced especially in the shore-to-ship direction (band-limitation, range of talker levels, impulse noise, carbon microphones, etc.);
- sensitivity to transmission errors (BER-performance);
- influence of ambient noise, especially on board the ship.

It is noted that subjective tests will be necessary to evaluate the overall quality of the received speech signals.

Note. — AEN (Affaiblissement équivalent pour la netteté; Articulation reference equivalent) value is the difference between the attenuation level of the reference circuit and that of a circuit under test, each of which is adjusted so that a sound articulation score of 80% is obtained.

4. Data coding techniques

Very low G/T mobile earth stations (e.g. $-24 \text{ dB(K}^{-1})$) may suffer from bad propagation conditions (multipath at low elevation, shadowing effects even at higher elevation). A communication system which is designed to cope with all possible link conditions including those occurring at low elevation angles, may lead to protocol and coding overheads which are more powerful than necessary for much of the time. One way to improve the overall system efficiency is to utilize adaptive coding. The description and evaluation of such a coding method as applied to low G/T maritime, aeronautical and land mobile earth stations is presented in Annex II. The concept under consideration relies on the use of short Reed-Solomon block codes with a bi-dimensional arrangement and the implementation of an ARQ scheme. As can be seen in Annex II, the proposed adaptive coding scheme leads to a greater efficiency in normal operation than convolutional encoding.

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ANNEX I

RESULTS OF SUBJECTIVE TESTS ON VOICE CODING TECHNIQUES

1. Introduction

This Annex presents the results of a subjective test programme on voice coding techniques in the range 7.2-16 kbit/s, undertaken by INMARSAT in conjunction with ten of its signatories. This programme was part of an overall study on candidate digital voice coding techniques for potential future INMARSAT ship earth-station applications (see also Report 921).

The objectives of the tests were to assess the subjective voice quality of the techniques and determine possible language sensitivities of the different countries.

2. Voice coding techniques

The five digital voice coding techniques investigated and the associated channel test conditions are summarized in Table IV. These techniques were implemented either in the form of hardware codecs or by means of computer simulation; in the case of sub-band coding (SBC), the algorithm used in the simulation differed from that in the hardware SBC coder. Also included in the tests were reference conditions of speech correlated noise (modulated noise reference unit: MNRU) at specific values of signal-to-noise ratio (S/N).

3. Test procedures

The ten participating INMARSAT signatories were from France, the Federal Republic of Germany, Greece, Italy, Japan, the Netherlands, Norway, Sweden, the UK and the USA.

Each participant prepared a national language source tape which was then processed with the voice coding techniques and test conditions shown in Table I. Processed tapes were then returned to each participant for subjective evaluation by a number of listener subjects (between 12 and 56), on a mean opinion score (MOS) basis similar to that described in § 3.2 of Report 751, but according to the following scale:

Rating	Score
Excellent	4
Good	3
Fair	2
Poor	1
Bad	0

TABLE IV – Voice coding techniques and test conditions

Technique	Bit rate (kbit/s)	BER or S/N (dB)	Code
Adaptive predictive coding (simulation)	16	BER = 0 10^{-3} 10^{-2}	APC 0 APC 3 APC 2
Sub-band coding (simulation: S)	16	BER = 0 10^{-3} 10^{-2}	SBC 16 0(S) SBC 16 3(S) SBC 16 2(S)
Sub-band coding (hardware: H)	16	BER = 0 10^{-3} 10^{-2}	SBC 16 0(H) SBC 16 3(H) SBC 16 2(H)
Sub-band coding (hardware)	9.6	BER = 0 10^{-3} 10^{-2}	SBC 9 0 SBC 9 3 SBC 9 2
Residual excited linear predictive coding (simulation)	7.2	BER = 0 10^{-3} 10^{-2}	REL P 0 REL P 3 REL P 2
Reference conditions of speech correlated noise	(MNRU)	S/N = 5 10 15 20 25 30	MNR 05 MNR 10 MNR 15 MNR 20 MNR 25 MNR 30

4. Test results

Table V shows the average MOS for each voice coding technique and test condition for the participant and the average for all participants. The following observations are made on these results (see also Fig. 7):

- the adaptive predictive coder (APC) at 16 kbit/s is clearly the best coding scheme of those tested. The influence of transmission errors on quality up to a BER of 10^{-3} appears to be very small. The speech quality remains “fair” at a BER of 10^{-2} which is encouraging for the future possible implementation of Standard-B ship earth-station codecs;
- the performance of the hardware sub-band coder at 16 kbit/s appears to have been comparable to the simulated version under the error-free condition, but less resistant to transmission errors; however, the algorithm used in each implementation was different, because they were provided from different sources;
- the particular 9.6 kbit/s sub-band coder used in these tests would appear to exhibit poor performance;
- the residual excited linear predictive coder (REL P) at 7.2 kbit/s tolerates transmission errors well, but its overall performance is rather poor.

Table VI shows the country-to-country correlations for MOS results on the MNRU test conditions. These correlations are generally high, as were those for the voice coding techniques (not shown in this Annex). Using the MNRU conditions, it would thus be possible to reliably predict results in one country based on measurements performed in another country.

It was not possible to isolate language or cultural factors from other aspects of the test situation specific to the country providing test results (such as recording and listening equipment or interpretation of opinion scales). Accordingly, it is not possible to say that a particular type of coder performs better with one language than with another. The overall results, however, suggest that the implementation of 16 kbit/s voice coding, particularly with APC, could provide acceptable speech quality for the languages tested.

TABLE V – Average MOS results

Condition	Code	USA	Norway	Japan	Sweden	UK	Netherlands	Greece	France	Germany (Federal Republic of)	Italy	Total
16 kbit/s adaptative predictive coding	APC 0	3.17	2.46	2.82	2.88	3.04	2.58	2.9	3.11	3.05	2.70	2.87
	APC 3	2.93	2.46	2.52	2.79	2.92	2.48	2.8	2.95	2.81	2.63	2.72
	APC 2	1.93	1.97	1.39	2.13	1.98	1.10	1.8	1.90	2.05	1.43	1.75
16 kbit/s sub-band coding (simulation: S)	SBC 0(S)	2.39	2.44	1.98	2.56	2.55	2.01	2.1	2.91	2.51	2.44	2.39
	SBC 3(S)	2.25	1.79	1.61	2.34	2.17	1.65	2.2	2.38	2.56	2.07	2.10
	SBC 2(S)	1.32	1.12	0.70	1.42	1.22	0.91	1.1	1.27	1.14	0.91	1.11
16 kbit/s sub-band coding (hardware: H)	SBC 16 0(H)	2.44		2.09	2.44	2.70	2.19	2.6	2.73	2.71	2.28	2.46
	SBC 16 3(H)	1.61		1.36	1.61	1.78	1.38	1.0	2.08	1.03	1.30	1.46
	SBC 16 2(H)	0.27		0.04	0.65	0.17	0.08	0.1	0.16	0.05	0.12	0.18
9,6 kbit/s sub-band coding	SBC 9 0	0.93		0.74	0.95	0.72	0.74	1.2	0.88	0.91	0.56	0.85
	SBC 9 3	0.21		0.24	0.34	0.52	0.21	0.2	0.26	0.22	0.33	0.28
	SBC 9 2	0.03		0.02	0.0	0.0	0.0	0.0	0.02	0.01	0.01	0.01
7,2 kbit/s REL P (vocoder)	REL P 0	1.61	1.66	1.30	1.70	1.94	1.19	1.8	1.95	2.10	1.43	1.66
	REL P 3	1.57	1.44	1.09	1.68	1.97	1.10	1.5	1.95	1.86	1.07	1.52
	REL P 2	0.32	0.12	0.08	1.32	0.44	0.23	0.2	0.24	0.21	0.15	0.33
Modulated noise reference unit	MNR 05	0.72	0.42	0.63	0.79	0.92	0.43	0.6	0.63	0.43	0.72	0.63
	MNR 10	1.44	0.77	1.25	1.19	1.53	0.83	1.3	1.42	1.20	0.95	1.19
	MNR 15	2.24	1.12	2.07	1.59	1.97	1.59	1.8	2.16	1.46	2.00	1.80
	MNR 20	3.14	2.39	2.72	2.56	2.68	2.39	3.0	3.20	2.82	2.66	2.76
	MNR 25	3.38	2.48	3.07	3.17	3.10	2.58	2.9	3.37	3.15	3.15	3.03
	MNR 30	3.18	3.25	3.19	3.46	3.02	2.83	3.0	3.27	3.03	2.56	3.07

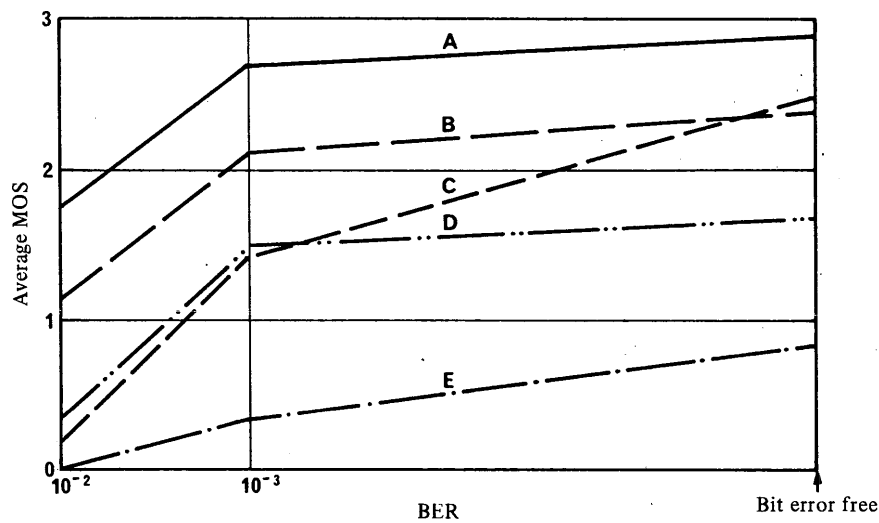


FIGURE 7 – Average MOS for all participants versus BER

- Curves A: APC 16 kbit/s
 B: SBC 16 kbit/s (simulation)
 C: SBC 16 kbit/s (hardware)
 D: RELP 7.2 kbit/s
 E: SBC 9.6 kbit/s

TABLE VI – Country-to-country correlation of mean opinion score for MNRU reference conditions

USA	1.00									
NOR	0.924	1.00								
JPN	0.990	0.952	1.00							
SWE	0.945	0.985	0.969	1.00						
UK	0.989	0.952	0.993	0.977	1.00					
NET	0.983	0.972	0.995	0.978	0.987	1.00				
GRE	0.989	0.952	0.981	0.951	0.982	0.984	1.00			
FRA	0.999	0.956	0.991	0.951	0.991	0.986	0.994	1.00		
GER	0.980	0.959	0.975	0.974	0.991	0.977	0.987	0.985	1.00	
ITA	0.980	0.876	0.964	0.916	0.964	0.957	0.951	0.972	0.949	1.00
	USA	NOR	JPN	SWE	UK	NET	GRE	FRA	GER	ITA

ANNEX II

AN ADAPTIVE CODING SCHEME FOR
DATA ONLY MOBILE TERMINAL**1. Introduction**

This Annex describes a coding scheme used in the ESA PRODAT data only communication system based on a G/T of $-24 \text{ dB(K}^{-1})$ which is appropriate for land, maritime and aeronautical applications.

Several types of services, and/or functions are provided in addition to the usual system organization function requirements (channel assignment, random access etc.). The system provides, on a primary basis, a message handling service (electronic mail box system), but also broadcast/paging mode, polling mode, and possibly dialogue modes.

The PROSAT Phase I [PROSAT, 1985] propagation experiments demonstrated that the channel quality for all the three applications varies from very good conditions (almost non-faded channel), corresponding to open area for a land mobile system or "reasonable" elevation angles for the maritime (see Report 884) and aeronautical channels, to extremely bad situations, characterized by a C/M ratio of 7 dB for the maritime channels, or complete black-out in the case of the land-mobile application.

In order to accommodate satisfactory operation over extreme propagation conditions whilst preserving system efficiency in normal conditions, it is proposed to implement an ARQ scheme which provides for auto-adaptability.

2. Description of the selected coding scheme**2.1 Bi-dimensional coding scheme**

Short Reed-Solomon (RS) block codes with a bi-dimensional arrangement have been selected.

The information is organized in "blocks", each block comprises a set of 8 elementary Reed-Solomon code vectors. In addition each block is encoded in the other dimension, using again RS coding technique, as follows (see Fig. 8):

- in one dimension (vertical): one extended RS code forms a vector (k data symbols, $n - k$ redundancy symbols) and is used to correct random errors, and to detect error burst which exceeds the capability of the code;
- in the other dimension (horizontal): another extended RS code (k' primary vectors and $n - k'$ redundancy vectors) is used to correct burst errors, taking advantage of the erasure correction capability of the code;
- as an example, with a forward link having the structure of a TDM frame, each vertical vector could correspond to a slot in the frame (see Annex VI to Report 921); if the vertical code vector transmission time is short with respect to the fading bandwidth, deep fading will correspond to erasure of a complete code vector. The "vertical code" has to be used to correct the random errors. In addition, as it is in any case necessary to use the channel state information to detect that fading situation, which may exceed the error detection capability of the code itself, the channel state information could also be used to extend the capability of the code to its maximum by using the erasure correction technique.

This scheme, like any bi-dimensional code can be considered as an interleaving scheme for the horizontal code, and as a consequence, is inherently capable of coping with error bursts. The method of adapting the scheme of ARQ follows.

2.2 RS bi-dimensional coding + ARQ

In a "classical" ARQ system, one asks for a retransmission, when a vertical vector erasure situation would have been detected. The transmission delay in the particular case of satellite systems, imposes either the numbering of the blocks, or/and restriction in the selection of frame parameters. In addition, the quality of the return channel is not better than the direct channel, and therefore, the acknowledgement procedure is by itself a source of difficulty. It should therefore be limited as far as possible, or used in a safe way.

The basic principle of the scheme is as follows:

- in the vertical direction, no modification;
- in the horizontal direction (time axis) the selected code is a rate $\frac{1}{2}$ code, i.e. a (16 : 8) code, which means that the block is a set of $k' = 8$ vectors of information, plus additional redundancy vectors, as required. The decoding in that direction is performed by considering that a vertical vector is either correct (after having applied the correction algorithm) or erased. With the selected code, it is possible to decode a code vector which has up to 8 erasures, or in other words, we can say that as soon as we have received successfully 8 vectors, we have enough information for the decoding. We can, then, acknowledge the reception of this set of information vectors and proceed with the next set. The only risk is that the transmitter sends one or two information blocks more than required.

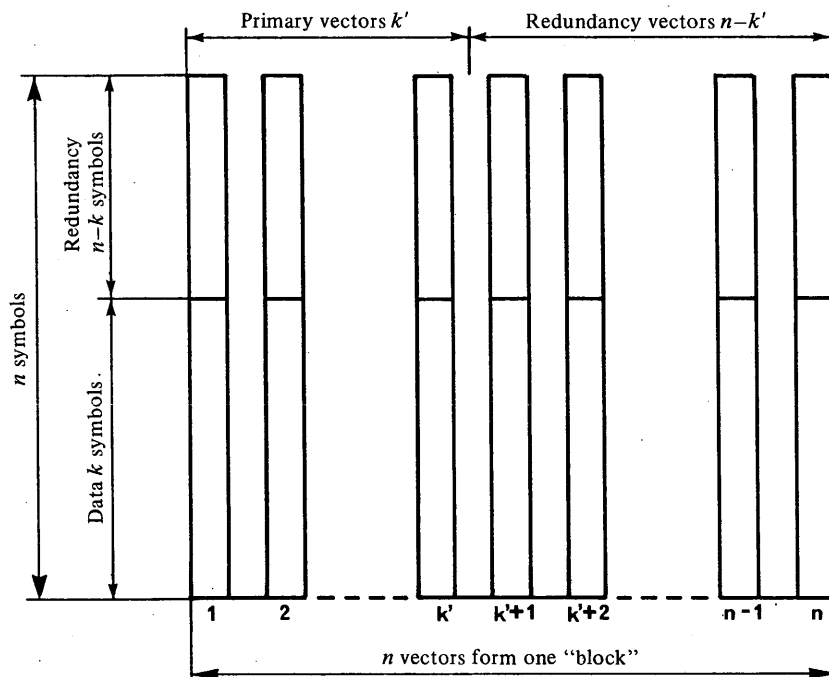


FIGURE 8

Theoretically, the vertical vector throughput must be at least 80% to achieve a block transmission failure rate of 10^{-3} . As a result a (16 : 12) code for the forward link (which has a TDM structure) was adopted, e.g. a rate as large as possible. For the return link, a lower rate code is required and therefore a (16 : 10) code is used, because the vertical vectors are not interleaved but are transmitted sequentially.

3. Comparison against convolutional coding techniques

The main advantage of convolutional coding techniques is the possibility to implement a soft decision decoder which provides some additional coding gain. As such it could be considered as a good reference for the evaluation of the block code scheme, in particular with respect to the vertical vector throughput. However, the convolutional decoding technique is not necessarily well adapted to the particular channels being considered. The classical Viterbi decoder performance is impaired by the error bursts, in general, and differential detection at low E_b/N_0 s.

In order to reduce this degradation it is necessary to introduce a high degree of interleaving to break up the errors. For the maritime channel this is possible by using interleaving periods of many seconds. However, for the land mobile channel where blockage of the signal can occur for undefined periods, it is impractical. Interleaving also suffers from the problem of spreading errors into good data.

Therefore, coherent detection with sign ambiguity resolution by a unique word at the start of the message, is required. The length of a data block between unique words is governed by the probability of a cycle skipping, leading to phase reversals during a block. In order to evaluate the performance of such a scheme, a block length of 100 bits was selected as a reasonable size. Within each block a unique word of 16 bits is used to resolve the phase ambiguity and synchronize the Viterbi decoding. A pattern of 8 trailing zeros is added to the data to flush out the encoder, and to form an uncoded data pattern 42 bits long. The data is $\frac{1}{2}$ rate convolutionally encoded, using a constraint length of 5, to form a coded data pattern 84 bits long, to which the unique word is added.

A simulation was carried out for the return link, at a C/M value of 7 dB, using soft decision decoding as shown in Fig. 9. If we define the threshold as in the case of the RS block code for a C/M of 7 dB, and a block throughput of 80%, the required E_b/N_0 is 7 dB for the convolutionally coded return link, a value somewhat lower than for the RS block code link. However, a selective repeat ARQ scheme would require that each encoded block is received correctly, and therefore the block throughput would have to be nearer 90% for an overall efficiency of around 80%. This would require an E_b/N_0 of nearer 10 dB which is significantly higher than the RS block code scheme.

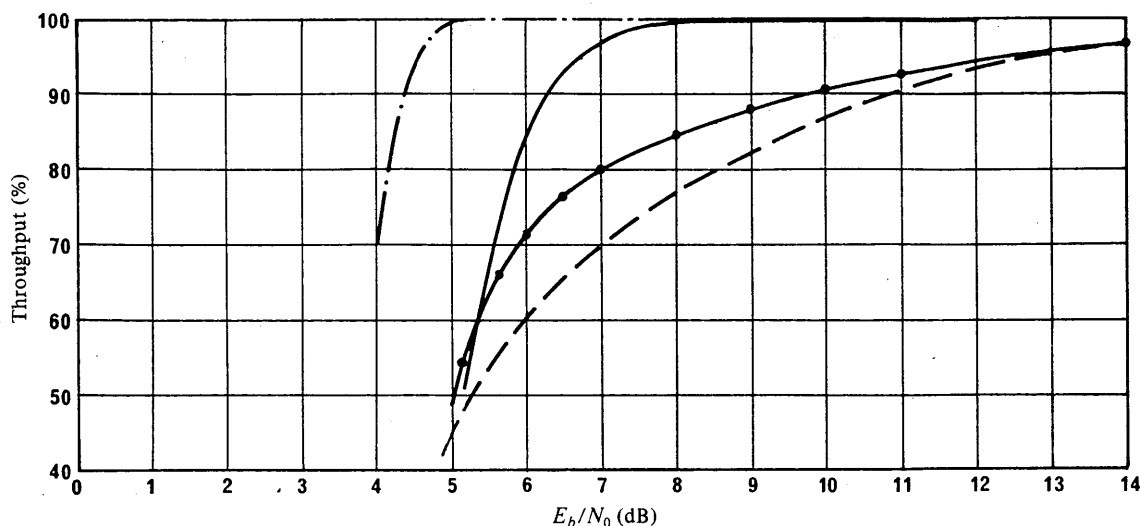


FIGURE 9 – Throughput as a function of E_b/N_0 (300 Bd – fading bandwidth = 3 Hz)
(percentage of error-free decoded vectors or blocks)

Rician fading $C/M = 7$ dB:

- Viterbi $k = 5$, coherent demodulation, 1/2 rate, 100 bit blocks
- - - RS vectors
- RS blocks (8 successful RS vectors)

Non-faded condition:

- . - . RS blocks

When considering the overall system efficiency as defined in the case of block code, the value of 50% corresponding to the half rate code is further reduced when considering the overhead which is imposed by the need for a unique word and additional tailing bits. In addition the basic Viterbi decoder does not detect residual errors. The convolutional code has to be concatenated with a short block code to detect these residual errors. The channel state information would also most likely be used.

Thus the complete overall system efficiency for the convolutionally coded return link would be nearer 30%, assuming an error detection code equal to 10% of the data and with the above defined overheads. This is to be compared with the 35% efficiency experimentally found on the Reed-Solomon scheme (16 : 10 code). On the forward link, the convolutional code could never match the derived Reed-Solomon efficiency of 60%. Also the convolutional code has a fixed coding rate, whilst the Reed-Solomon scheme has an adaptive coding rate which leads to a greater system efficiency in normal operation.

It is interesting to note that the curves showing the non-faded and Rician channel ($C/M = 7$ dB) throughputs for the RS block code are only 2 dB apart, demonstrating the high performance of the scheme.

It is recognized that the convolutional link efficiency could be increased by using a higher rate code, for instance the punctured codes whose performances have also been estimated through experimental simulation. However, this will have an opposite effect on the E_b/N_0 threshold value, and a variable rate punctured code scheme would have to be implemented to equal the efficiency of the Reed-Solomon code.

However, with the low data rates used in the defined system, and modified to form the PRODAT system, convolutional codes suffer from such high overheads, as to make the Reed-Solomon scheme seem more attractive.

REFERENCES

PROSAT, Phase 1 Report [1986] ESA STR-216. European Space Agency, Paris, France.

RECOMMENDATION 549-1

**SIDE TONE REFERENCE EQUIVALENT OF HANDSET USED ON BOARD A SHIP
IN THE MARITIME MOBILE-SATELLITE SERVICE AND IN AUTOMATED
VHF/UHF MARITIME MOBILE RADIOTELEPHONE SYSTEMS**

(Study Programme 17A/8)

(1978-1982)

The CCIR,

CONSIDERING

- (a) that the ambient acoustic noise to be expected on board ships is often significantly higher than on terrestrial telephone locations;
- (b) that room noise picked up by the side tone path of the handset should not introduce any further transmission impairment;
- (c) CCITT Recommendation G.121, Section E,

UNANIMOUSLY RECOMMENDS

that the side tone reference equivalent of the handset in the ships' installation should be at least 17 dB.

Note 1. — Noise levels in the range 50 to 80 dBA are to be expected on board ships, the actual level being dependent on locations on board ship, the ship's size and structure.

Note 2. — The need for a side tone may be discussed in view of the degradations it can create. Even when the value 17 dB is attained, room noise at expected levels may still have an adverse effect (CCITT Recommendation G.121). The recommended value is a compromise between the need for limiting impairment due to room noise and the possible need for a certain "liveliness" in the handset.

Note 3. — The CCITT Recommendations on side tone could be subject to change as all aspects of side tone are under review.

RECOMMENDATION 550-1

USE OF ECHO SUPPRESSORS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1986)

The CCIR,

CONSIDERING

- (a) that maritime mobile-satellite systems will be interconnected with the international telephone network;
- (b) that in order to achieve transmission objectives for the maritime mobile-satellite service which are in accordance with those of other international telephone connections, it is necessary to take into account the effects of echo;
- (c) CCITT Recommendation G.131 concerning the rules governing the use of half-echo suppressors;
- (d) CCITT Recommendation G.164 concerning the characteristics of half-echo suppressors;
- (e) CCITT Recommendation G.165 concerning the characteristics of echo cancellers;
- (f) CCITT Recommendation Q.115 regarding control of echo suppressors,

UNANIMOUSLY RECOMMENDS

1. that half-echo suppressors or echo cancellers shall be fitted in the terrestrial part of the connection;
2. that if two-wire telephone sets are used at the ship terminal, a half-echo suppressor or an echo canceller shall be fitted at the ship end of the connection;
3. that if echo suppressors are fitted, they should have characteristics in accordance with CCITT Recommendation G.164;
4. that if echo cancellers are fitted, they shall have characteristics in accordance with CCITT Recommendation G.165;
5. that it should be possible to disable echo suppressors, as described in CCITT Recommendation G.164, in both the terrestrial and the ship end of the connection;
6. that control of echo suppressors in the terrestrial connection should follow the requirements established in CCITT Recommendation Q.115;
7. that manual disabling of echo suppressors at the ship end of the connection should be possible;
8. that enabling of the echo suppressor, located at the ship end of the connection, must be done automatically when a call is terminated, independently of the disabling technique used.

Note 1. — See also CCITT Recommendations G.473 and M.1100 concerning the transmission plan for maritime satellite systems.

Note 2. — For disabling of echo cancellers see CCITT Recommendation G.165, § 3.5 and 4.

Note 3. — When tone disabling is used precautions must be made to ensure that the echo suppressor or echo canceller is not disabled by speech.

Note 4. — CCITT Recommendation G.161 may still be used for the design of analogue echo suppressors.

RECOMMENDATION 552

**QUALITY OBJECTIVES FOR 50-BAUD START-STOP TELEGRAPH TRANSMISSION
IN THE MARITIME MOBILE-SATELLITE SERVICE***

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

- (a) that proper interworking of this telegraph transmission with the international telegraph services must be ensured;
- (b) CCITT Recommendation F.10 concerning character error rate for telegraph communications,

UNANIMOUSLY RECOMMENDS

that, for the shore station-to-mobile terminal and mobile terminal-to-shore station links, sufficient margin should be included to overcome adverse propagation conditions. The objective should be that propagation conditions should not contribute any character errors for at least 95% of all calls with mobile terminals within the satellite service area. With the exception of blockage effects, propagation conditions should not contribute more than 8 errors in 100 000 characters with a 99% confidence level for mobile terminals at the edge of the service area.

* This Recommendation corresponds to CCITT Recommendation F.112.

RECOMMENDATION 553

INTERFACE REQUIREMENTS FOR 50-BAUD START-STOP TELEGRAPH TRANSMISSION
IN THE MARITIME MOBILE-SATELLITE SERVICE *

(Study Programme 17A/8)

(1978)

The CCIR,

CONSIDERING

- (a) that proper interworking of this telegraph transmission with the international telegraph services must be ensured;
- (b) that the shore station equipment will interface with the international terrestrial telegraph networks and will therefore need to conform to CCITT Recommendations where applicable;
- (c) that the ship station will include a local end with its termination consisting of start-stop equipment using International Telegraph Alphabet No. 2,

UNANIMOUSLY RECOMMENDS

1. that the shore station equipment interfacing with terrestrial telegraph channels should conform to CCITT Recommendation R.101 (see Annex I) as applicable to 50-baud services:

1.1 for signals from the terrestrial network entering the shore station, the relevant points are:

TABLE I

Item	Parameter	Recommendation R.101 Point
<i>a</i>	Input modulation rate	2.1
<i>b</i>	Isolated character stop elements	2.2
<i>c</i>	Minimum interval between start elements	2.3
<i>d</i>	No restrictions on the use of combinations of International Telegraph Alphabet No. 2	2.4
<i>e</i>	Effective net margin	2.5
<i>f</i>	Minimum input start element duration	2.6

1.2 for signals from the shore station entering the terrestrial network, the relevant points are:

TABLE II

Item	Parameter	Recommendation R.101 Point
<i>g</i>	Output distortion	3.1
<i>h</i>	Output modulation rate	3.2
<i>i</i>	Minimum output stop element	3.3

2. that the transmission characteristics of the ship terminal start-stop equipment should conform to CCITT Recommendation S.3 as applicable to 50-baud services.

* The CCITT is at present considering the adoption of a similar Recommendation.

ANNEX I

The relevant sections of CCITT Recommendation R.101* are reproduced below for information:

"2. Start-stop channel inputs

- 2.1 The maximum speed tolerance that shall be accepted on continuous incoming 50-baud start-stop signals where a stop element of 1.4 units is employed shall be $\pm 2\%$.
- 2.2 The system shall accept isolated incoming 50-baud start-stop signals that have a 1-unit stop element.
- 2.3 The minimum interval between start elements of undistorted successive continuous characters that may be presented at the channel input when the nominal modulation rate is 50 bauds shall be 145 5/6 ms.
- 2.4 There shall be no restriction on the continuous transmission of all characters specified in 1. above (e.g. combination No. 32 of International Telegraph Alphabet No. 2) when they are presented at the maximum permitted rate.
- 2.5 The effective net margin on all channel inputs when undistorted signals are received from a transmitter having a nominal character length and rate shall be at least 40%.
- 2.6 To be recognized as valid, an input character start element shall be of at least 0.4 units' duration at the nominal modulation rate of the input channel.

3. Start-stop channel outputs

- 3.1 The maximum degree of gross start-stop distortion shall be 3%.
- 3.2 The maximum difference possible between the mean modulation rate of the channel output signals and the nominal modulation rate shall be 0.2%.
- 3.3 When 50-baud characters are presented at any input rate within the specified range of this Recommendation, the minimum stop element duration released at the output shall be 1.25 units."

REPORT 917-1 ****PERMISSIBLE LEVELS OF INTERFERENCE INTO TELEPHONE CHANNELS
IN THE MARITIME MOBILE-SATELLITE SERVICE**

(Question 17/8)

(1982-1986)

1. Introduction

Consideration is given in this Report to the possible effects of interference on telephone channels in the maritime mobile-satellite service. Particular attention is given to the shore-to-ship direction, and to the effects of interference on satellite channel quality and capacity.

It is assumed that interference could arise from other services sharing the same frequency bands, i.e. from the fixed and fixed-satellite services. Based on satellite characteristics which are typical of those being considered for maritime mobile-satellite systems, a possible interference noise power budget and interference protection criteria are proposed.

* This Recommendation is at present under study and may be modified.

** The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Satellite Organization (INMARSAT) and Study Group 4.

2. Sources of interference

Interference may enter the channels of a maritime satellite network via the receivers of the 4/6 GHz feeder links (i.e. at coast earth stations and at the satellite), and also via the receivers of the 1.5/1.6 GHz links between ships and the space station (i.e. at ship earth stations and at the satellite). Most of this interference is expected to originate from the transmitters of stations in those services which share the same frequency bands as the maritime mobile-satellite service. Potential sources of interference therefore include the fixed-satellite service operating at 4/6 GHz, and terrestrial services operating at 4/6 GHz and 1.5/1.6 GHz. Further potential sources of interference into a maritime mobile-satellite network are the links of another maritime mobile-satellite system. In the case of the 1.5/1.6 GHz links, the interference mechanism arises because of the relatively broad beamwidth of ship earth station antennas and their resultant poor discrimination characteristics. Such interference can therefore be reduced only by an efficient design of maritime mobile-satellite systems; this will be an important consideration in the design of future systems. On the 4/6 GHz feeder links, coast earth station antenna discrimination characteristics are superior to those for ship earth stations at 1.5/1.6 GHz. Nevertheless, interference from other satellite systems in the 4/6 GHz bands might be a critical factor in coordinating suitable geostationary satellite orbit positions for space stations in maritime mobile-satellite systems.

3. Performance objectives for telephony

Performance objectives for telephone channels in the maritime mobile-satellite service are given in Recommendation 547, in terms of the permissible subjectively-equivalent noise power. As an example, the permissible subjectively-equivalent noise power in a telephone channel for a speech level of -20 dBm0 is assumed to be 25 000 pW0p. Tests conducted with typical voice modems (Report 752) indicate that the 25 000 pW0p objective can be achieved with a carrier-to-noise density ratio (C/N_0) of between 52 and 53 dBHz.

4. Typical satellite link characteristics

In terms of satellite output power requirements and system capacity, transmission parameters in the shore-to-ship direction are far more critical than in the ship-to-shore direction, and hence are the only ones considered here. Table I shows the main noise contributions on the shore-to-ship link, assuming satellite characteristics which are typical of those being considered for maritime mobile-satellite systems (Report 760). No allowance has been made for interference in Table I.

TABLE I — *Typical parameters for shore-to-ship transmission*

Parameter	Value
Up-path C/N_0 (thermal noise) with 5° coast earth station elevation (dBHz)	70
Coast earth station C/I_0 (intermodulation noise) (dBHz)	75
Satellite C/I_0 (intermodulation noise) (dBHz)	63.8
Down-path C/N_0 (thermal noise) with 10° ship antenna elevation angle (dBHz)	53.5
Overall $C/(N_0 + I_0)$ for satellite link (dBHz)	53
Satellite nominal e.i.r.p. required to achieve overall $C/(N_0 + I_0)$ channel objective (dBW)	18.1 per carrier

5. Effects of interference

In considering the effects of interference, it is useful to recall the permissible interference limits for the fixed-satellite service. For the fixed-satellite service, the total noise power allowance under clear-sky conditions is 10 000 pW0p (Recommendation 353), of which 20% can be contributed by interference from other networks in the fixed-satellite service (Recommendation 466) and a further 10% can arise from interference from terrestrial line-of-sight radio-relay systems (Recommendation 356). The total permissible interference noise contribution can thus be as much as 30% of the total noise power, or 3000 pW0p. In considering the applicability of such limits to the maritime mobile-satellite service, it should be noted that satellite output stages in current maritime mobile-satellite systems are severely power-limited in the satellite-to-ship path, and hence the contribution of interference to the total permissible noise power could have a significant effect on channel quality or system capacity. In order to compensate for this, speech processing is now used in maritime mobile-satellite systems, and hence the interference (which is assumed to be noise-like), as well as internal system noise, must be considered in terms of its subjective effect.

Future satellites might not be so power-limited, making an overall noise objective of 10 000 pW0p attainable and resulting in performance comparable to that of the fixed-satellite service. Consequently, it is reasonable to allocate no more than 3000 pW0p to interference from other systems to a maritime mobile-satellite system.

6. Noise power budget

From the above considerations, a possible noise power budget can be derived as shown in Table II. Values of C/N_0 corresponding to the noise allocations in Table II assume linear relationships between subjectively-equivalent noise power and pre-detection RF noise power.

TABLE II — Noise power allocations for telephone channels

Noise source	Equivalent C/N_0 (80% of the time) (dBHz)	Noise budget (subjectively-equivalent noise power) (pW0p)
<i>Satellite link:</i>		
up-path thermal	70 ⁽¹⁾	
coast earth station intermodulation products	75 ⁽¹⁾	
satellite intermodulation products	63.8 ⁽¹⁾	
down-path thermal	<u>53.5⁽¹⁾</u>	
<i>Total satellite link:</i>	53	22 000
<i>Interference:</i>		
satellite systems	63.4	2 000
terrestrial services	<u>66.4</u>	<u>1 000</u>
total interference	<u>61.7</u>	<u>3 000</u>
<i>Total channel noise:</i>	52.5	25 000

(¹) Typical parameters for shore-to-ship direction.

The total satellite link noise power of 22 000 pW0p has not been broken down in Table II for the various components of the link. In addition, the total interference noise power allocation of 3000 pW0p is assumed to apply in both directions of transmission to all sources of interference on both up and down links. Individual allocation of either satellite link or interference noise would be determined by the particular maritime-satellite system being considered and by the relationship between up-path and down-path noise which would differ for each direction of transmission. This allocation of interference noise requires further study.

It can be seen from the down-path C/N_0 in Table II that the interference allowance necessitates an addition 0.5 dBW of satellite e.i.r.p. in order to maintain an overall channel quality of 53 dBHz. This corresponds to a capacity loss of about 11%.

7. Provisional permissible interference protection criteria

It has been assumed in Table II that interference allocations for other satellite systems and the terrestrial services are the same as the corresponding protection criteria adopted for the fixed-satellite service. Assuming further that the same criteria can be applied for single-entry interference, the following provisional interference protection criteria might be used for the maritime mobile-satellite service:

7.1 Interference from satellite services:

- total interference from satellite systems should not exceed 2000 pW0p in the hypothetical reference circuit for more than 20% of any month;
- interference from a single satellite system should not exceed 600 pW0p in the hypothetical reference circuit for more than 20% of any month.

7.2 *Interference from terrestrial services:*

- total interference from terrestrial systems should not exceed 1000 pW0p in the hypothetical reference circuit for more than 20% of any month;
- interference from a single terrestrial station should not exceed 333 pW0p in the hypothetical reference circuit for more than 20% of any month.

In Annex I, detailed consideration is given to the potential problem of interference from fixed service transmitters operating in part of the frequency band 1550-1645.5 MHz, to satellites operating in the maritime mobile-satellite frequency band 1626.5-1645.5 MHz.

8. **Conclusions**

A preliminary assessment of the effects of interference on telephone channel quality and capacity in the maritime mobile-satellite service has been made, with respect to satellite systems currently being planned. It is proposed that the permissible level of interference in a telephone channel should not exceed 3000 pW0p for more than 20% of any month. Allocations for individual interference entries have been suggested. These allocations and other aspects of interference into a maritime mobile-satellite network require further study.

ANNEX I

INTERFERENCE TO FREQUENCY MODULATED TELEPHONE CHANNELS IN THE MARITIME MOBILE-SATELLITE SERVICE FROM THE FIXED SERVICE AT 1.6 GHz

1. **Introduction**

In this Annex consideration is given to the potential problem of interference to frequency modulated telephone channels in the maritime mobile-satellite service from transmitters of the fixed service at 1.6 GHz.

At the WARC-79, the frequency band 1626.5-1645.5 MHz was allocated for use by the maritime mobile-satellite service (Earth-to-space direction), the allocation being effective from January, 1982 (previously the band was limited to 1636.5-1644 MHz). However, the band 1550-1645.5 MHz which overlaps it was also allocated for use by the fixed service in 17 countries on an equal primary basis (see No. 730 of the Radio Regulations).

This shared allocation with the fixed service gives rise to two potential interference problems. Firstly, interference from ship earth-station transmitters to receivers of the fixed service, and second, interference from fixed service transmitters into maritime mobile-satellite receivers.

This Annex addresses the second potential problem and considers a number of techniques, including e.i.r.p. limitations which might be applied to fixed service transmitters in order to protect maritime mobile-satellite receivers from unacceptable interference. It also discusses other possible means of reducing the interference.

2. **Permissible interference levels into a maritime mobile-satellite system**

There is not as yet a CCIR Recommendation on permissible interference levels. However, Report 917 considers a possible interference noise budget, and, based on interference limits applied to the fixed service proposes provisional protection criteria for that part of the total interference emanating from terrestrial sources. These are:

- total interference from terrestrial systems should not exceed 1000 pW0p in the hypothetical telephone reference circuit of a satellite system for more than 20% of any month;
- interference from a single terrestrial station should not exceed 333 pW0p in the hypothetical telephone reference circuit for more than 20% of any month.

On the basis that the required overall C/N_0 is 52.5 dBHz, and that this corresponds to a subjectively equivalent noise power of 25 000 pW0p, then the single entry interference of 333 pW0p becomes equivalent to a C/N_0 of 71.2 dBHz, assuming as in Report 917 a linear relationship between subjectively equivalent noise power, and pre-detection RF noise power.

Reference to a typical link power budget for a maritime mobile-satellite system, as shown in Report 760, gives an up-path C/N_0 of 63.4 dBHz due to thermal noise sources from an unfaded link, as compared with the value of 71.2 dBHz for the single-entry interference – a difference of 7.8 dB.

3. Fixed service e.i.r.p. limits

In the INMARSAT system, NBFM modulation is used for voice carriers with a single carrier bandwidth of about 28 kHz, and in this Annex the bandwidth within which interference should be controlled is taken as 30 kHz. Link power budgets appearing in Report 760 give a value of $-12.2 \text{ dB(K}^{-1})$ for a typical edge-of-coverage satellite G/T at 1.6 GHz. Based on this, the following calculation derives the maximum permissible e.i.r.p. per 30 kHz towards the satellite from a fixed service transmitter in order to meet the assumed 333 pW0p single-entry interference criterion, and relates to unfaded transmission conditions:

- noise power in bandwidth "B" at the satellite receiver (dBW): kTB
- interference noise power (equivalent to 333 pW0p) (dBW): $kTB - 7.8$
- interference noise power into satellite antenna (where G is the gain of the antenna) (dBW): $kTB - 7.8 - G$
- e.i.r.p. from fixed service transmitter (dBW): $kTB - 7.8 - G + 188.9$
 $kB - G/T + 181.1$
- hence, permissible e.i.r.p. per 30 kHz: $- 228.6 + 44.75 - (- 12.2) + 181.1$
 $= + 9.5(\text{dB(W/30 kHz)})$ (see Note)

Note. – Provisional value, which may need to be adjusted based on application of other sharing techniques.

It should be noted that no allowance has been made for an additional margin of up to 3 dB which may result from the use of linear polarization on fixed service links, and circular polarization on satellites' systems. Also, the value of G/T assumed here ($-12.2 \text{ dB(K}^{-1})$) is likely to change.

4. Radio Regulations

Article 27 of the Radio Regulations relates to power limits for terrestrial services sharing frequency bands with space radiocommunications above 1 GHz. Radio Regulations Nos. 2502, 2505, 2506 and 2507 are of particular interest since they relate to the band 1.626.5-1645.5 MHz for the countries mentioned in No. 730. It can be seen that with the power limitations as set out in the above provisions, the e.i.r.p. towards the geostationary-satellite orbit could be at least 35 dBW rising to +47 dBW if the former limit is impracticable.

5. Fixed service characteristics at 1.6 GHz

Information on the characteristics of fixed services in this band may be taken from Report 739 (characteristics of simple radio-relay equipment operating in bands 8 and 9 for the provision of telephone trunk connections in rural areas). Typical systems in the 1500 MHz frequency band are shown as comprising 24 and 60 channel frequency division multiplex carriers.

Typical characteristics of such systems are represented in Table II of Annex II of Report 379. It can be seen from Table II that the power of the residual carrier approaches within 0.49 dB and 1.81 dB of this for the 24 and 60 channel systems respectively. Hence, to meet the e.i.r.p. limits derived in § 3, the e.i.r.p. of the fixed-service system towards a maritime mobile satellite would need to be no more than 10 dBW (24 channel system) and 11.3 dBW (60 channel system) as compared with the power limitations quoted by the Radio Regulations (see § 4).

6. Discussion

It is recognized that the limits of e.i.r.p. proposed in § 5 (10 dBW for 24 channel and 11.3 dBW for 60 channel radio-relay systems, and which are principally attributable to carrier spikes), if directed at maritime mobile satellites in the geostationary-satellite orbit, would impose severe restrictions on the fixed service, e.g. distances between typical repeater stations would be restricted to less than 3 km for an unmodulated carrier level of around 10 dBW; it is also recognized that modification to existing fixed-service systems would be very difficult to implement.

It should be noted however that maritime mobile satellites will occupy relatively few locations in the geostationary-satellite orbit. Consequently, a considerable improvement in the interference position would be achieved if fixed-service transmitters avoided pointing the main lobe of their antenna radiation pattern towards those arcs of the geostationary-satellite orbit occupied by maritime mobile satellites.

Secondly, it is suggested that an improvement in the potential interference position could be effected by use of these additional techniques:

- by applying energy dispersal to the radio-relay system at a frequency below the lowest baseband frequency, at an appropriate deviation and with a suitably high periodicity. This would have the effect of spreading the unwanted energy, and particularly that of the residual carrier, over a wide bandwidth, and would thus enable the fixed system e.i.r.p. to be increased by the improvement factor obtained, without increasing the effective interference level (see Report 384);
- by greater carrier suppression either by employing suppressed carrier modulation on the radio-relay system, or by increasing the modulation index so as to reduce the level of residual carrier. The e.i.r.p. of the fixed-service transmitter could then be increased by an amount equal to the additional carrier suppression;
- by careful frequency coordination between the systems concerned, to avoid assigning fixed-service carriers coincident with satellite transponder channels.

An additional improvement in the interference position may be effected by using a combination of these three techniques.

7. Conclusions

Following a preliminary assessment of the potential interference problem due to fixed services operating in those parts of the 1.6 GHz frequency band shared with the maritime mobile-satellite service and which comply with the power limits defined in the relevant provisions of the Radio Regulations, it is concluded that unacceptable interference could be caused to the latter service. Further study is required of the interference problem, both in extent and degree, and possible means to reduce it.

REPORT 918*

AVAILABILITY OF COMMUNICATIONS CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17F/8)

(1982)

1. Introduction

The availability of communications circuits in the maritime mobile-satellite service needs to be defined in order to provide guidance to system planners and equipment manufacturers, and thus to provide an adequate standard of service to the user. In deriving a suggested philosophy for availability criteria, differences between the maritime mobile-satellite service and the fixed-satellite service are identified. However, it is considered that the concept of availability for the maritime mobile-satellite service should, as far as possible, be compatible with similar concepts adopted for the fixed-satellite service (Report 706) and for radio-relay systems (Report 445).

2 General definitions and philosophy

2.1 Definition of circuit availability

The availability of communications circuits in the maritime mobile-satellite service will depend on the availability objectives set for each component part of the circuit. In this Report, consideration is given to availability objectives for the space sector, earth-station equipment and auxiliary functions, and for the radio paths between satellite and earth stations. The overall availability of the communications circuit is thus determined.

* The Director, CCIR, is also requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT) and to the CMBD.

In the maritime mobile-satellite service, circuit availability (A) can be derived from the duration and rate of occurrence of interruptions to the component parts of the circuit, and can be defined as follows:

$$A = \frac{(\text{scheduled operating time}) - (\text{down-time})}{(\text{scheduled operating time})} \times 100 (\%)$$

where scheduled operating time is the time during which the circuit of interest is expected to perform its intended function, and down-time is the cumulative time of circuit interruptions within the scheduled operating time.

When the concept of availability is applied to individual component parts of a circuit, and in particular to equipment at coast earth stations and ship earth stations, the definition of availability for these component parts (A') may be written in terms of mean-time-between-failure (MTBF) and mean-time-to-repair (MTTR), as follows:

$$A' = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100 (\%)$$

When considering the availability of telephone circuits, use can be made of the hypothetical reference circuit (Recommendation 546).

The time for which a communications circuit is said to be unavailable should include delays in setting up the call arising from failures in the satellite signalling system. Failures in the shore-to-ship signalling channel, the ship-to-shore random access channel or the shore-to-shore signalling channel, due to adverse propagation conditions on the radio paths, would result in a lost call, but it is difficult to quantify the effect on a communications circuit in terms of the time for which that circuit is unavailable. However, it is expected that signalling channels will be designed to a high reliability, and that signalling outage effects will be insignificant compared to other possible causes of interruptions to communications circuits. It is therefore proposed that such effects should not be taken into account in availability considerations.

Calls lost due to congestion in the terrestrial network or the satellite network are not included in availability considerations as they relate to grade-of-service requirements rather than to availability.

2.2 Definitions of interruption

The following sections give definitions of interruption for telephony and telegraphy. In view of the differing nature of these services, different availability criteria may be required for them, and this should be the subject of further study. Interruptions to data channels are also considered below.

2.2.1 Telephony

The following definition for interruption to telephony circuits in the maritime mobile-satellite service has been suggested in [CCIR 1974-78]:

A telephone circuit in the maritime mobile-satellite service should be considered to be interrupted if a channel experiences one of the following conditions for more than 10 consecutive seconds:

- the wanted signal entering one end of the channel is not received at the other end,
- for analogue transmission, the unweighted subjectively equivalent noise power in the telephone channel exceeds 10^6 pW0p.

This definition of interruption is consistent with that proposed for the fixed-satellite service (Report 706).

2.2.2 Telegraphy

The following definition for interruption to telegraphy circuits has also been suggested in [CCIR 1974-78]:

A telex circuit in the maritime mobile-satellite service should be considered to be interrupted if N character errors are detected in a time interval less than $1.5 N$ s, where N is between 10 and 20.

This definition is considered to provide for sufficient measurement time and accuracy, and to take account of character error rates of the order of one error in 10 characters, but further study may be required.

2.2.3 *Data*

The availability of data channels will require study once the service has been defined. The definition of interruption will depend on the bit rate adopted for the service, the required error rate and the distribution of the errors.

2.3 *Scheduled operating time*

Availability criteria proposed for the fixed-satellite service apply to the availability of full-time circuits (telephony and television), where the scheduled operating time is the same as the calendar time. In the maritime mobile-satellite service the shore-to-ship telegraphy/signalling channels will be operated on a full-time basis in that the carriers will be permanently activated, but telephony channels (shore-to-ship and ship-to-shore) and the telegraphy/signalling channels transmitted by ships will only be activated for the duration of the call. It is anticipated that equipment availability at coast earth stations and ship earth stations will not be affected significantly by the inherently demand-assigned nature of the maritime service (compared to the availability of essentially the same equipment operating with permanently activated carriers), and hence it is proposed that scheduled operating time be provisionally equated to calendar time for all equipment.

In this Report, no account has been taken of the fact that ships spend a considerable proportion of their time in port, and of the fact that in this circumstance, transmission by ship radio equipment is not permitted by some administrations.

2.4 *Factors affecting availability*

The overall availability of circuits in the maritime mobile-satellite service will depend on the availability criteria adopted for the following:

- *Space sector*, including satellite equipment, the effects of satellite manoeuvres and the provision of spare satellites;
- *Coast earth station equipment*, including the effects of natural phenomena on equipment performance (e.g., sun interference and natural disasters), and the effects of human error;
- *Ship earth station equipment*, including the effects of natural phenomena on equipment performance (e.g., sun interference and environmental conditions), and the effects of human error;
- *Auxiliary functions*, such as might be performed by control coast earth stations (e.g. frequency control, power control and channel assignment);
- *Shore/satellite and ship/satellite RF links*, in particular the effects of attenuation and excess noise due to precipitation, the effects of multipath fading and the effects of interference such as might arise from terrestrial and space services.

In determining realistic availability objectives, it would not be feasible to take account of all the above eventualities. The philosophy adopted here is to consider only those factors which can be accommodated by adequate system planning, equipment design and maintenance procedures.

2.5 *Influence of natural or extreme phenomena*

For the purpose of availability considerations for coast earth station and ship earth station equipment, interruptions may be classified as follows:

- *Foreseen interruptions*: either unscheduled interruptions which are known to occur at some time and which can be tolerated for relatively short periods (e.g. equipment faults, propagation fading), or scheduled interruptions which are known to occur at specific times (e.g. certain types of preventive maintenance on equipment, sun interference at coast earth stations);
- *Unforeseen interruptions*: those interruptions whose occurrence or duration cannot be predicted and which could cause prolonged outages (e.g. natural disasters such as earthquakes, high winds or exceptionally severe sea conditions, and natural blockage effect such as shielding by mountains).

For the coast earth stations and ship earth stations, interruptions due to unforeseen circumstances should be excluded from availability considerations, and account should be taken only of foreseen interruptions. In addition, for ship earth station equipment, the following foreseen interruptions should be ignored:

2.5.1 *Interruptions due to sun interference*

With fixed earth stations, outages due to excessive noise on the down-path when the sun passes through the antenna beam can be predicted; durations of outages will depend on individual station locations, but degradations will be encountered for about 30 min for 3-4 days twice a year. Adverse effects on the service can, therefore, be minimised by arranging to pass traffic via alternative routes. With mobile

stations, such as ship earth stations, the occurrence of sun interference will depend on the ship's route, which will vary from ship to ship, and this phenomenon could therefore be encountered several times in the course of a year by particular ships. The duration of the interference would be longer than for shore stations because of the relatively broad beamwidth of the ship-borne antenna, although the degradation in receiver noise temperature would be less severe.

2.5.2 Interruptions due to severe weather conditions

Current ship earth station equipment is designed to withstand severe environmental conditions such as temperature variations, humidity, precipitation, wind and vessel motions; typical conditions are given in [INMARSAT, 1978]. Additional protection to the above-deck equipment is provided by a radome, but at some time most ships will encounter weather conditions which will render the equipment inoperable, e.g. inability to maintain antenna-pointing due to high sea state conditions. It is therefore considered that such interruptions should not be included in the assessment of ship terminal availability, although equipment manufacturers and system planners should not be discouraged from investigating means of maintaining ship terminal operation under extreme conditions.

2.5.3 Interruptions due to antenna blockage effects

Although ship owners and manufacturers should be encouraged to install ship earth stations in locations which minimize the probability of antenna blockage, such locations may not be available in all cases. It is therefore proposed that these outages be excluded from availability criteria.

2.6 Measurement of circuit availability

Taking account of the exceptions outlined in § 2.5 above, the following expression should be used for the measurement of communications circuit availability in the maritime mobile-satellite service:

$$A = \frac{T_s - (T_{sat} + T_1 + T_2 + T_{shore} + T_{ship} + T_{aux})}{T_s} \times 100 \quad (\%)$$

where:

- T_s : scheduled operating time;
- T_{sat} : cumulative time of circuit interruptions caused by failures of the satellite;
- T_1 : cumulative time of circuit interruptions attributable to factors on the shore-to-ship radio path
(i.e. $T_1 = T_{shore/sat} + T_{sat/ship}$,
where $T_{shore/sat}$ refers to the shore-to-satellite link, and
 $T_{sat/ship}$ refers to the satellite-to-ship link);
- T_2 : cumulative time of circuit interruptions attributable to factors on the ship-to-shore radio path
(i.e. $T_2 = T_{ship/sat} + T_{sat/shore}$,
where $T_{ship/sat}$ refers to the ship-to-satellite link, and
 $T_{sat/shore}$ refers to the satellite-to-shore link);
- T_{shore} : cumulative time of circuit interruptions caused by failures of shore station equipment and communications capability;
- T_{ship} : cumulative time of circuit interruptions caused by failures of ship terminal equipment and communications capability;
- T_{aux} : cumulative time of circuit interruptions caused by failures of auxiliary functions at ship earth stations.

In the event of two or more items occurring simultaneously, only the duration of the longest interruption should be taken into account.

3. Assessment of availability objectives

3.1 Space sector

The likely availability of the space sector for the maritime mobile-satellite service can be assessed from past experience with the fixed-satellite service, and in particular from the in-orbit performance of INTELSAT satellites. Over the period 1970-73, in-orbit INTELSAT space sector availability was 99.988%, 99.997%, 99.998% and 99.999% respectively [Edelson *et al.*, 1975]; the main operational satellites during this period were of the INTELSAT IV type. Since 1973, the average space sector availability with the INTELSAT IV and IVA generations has been of the order of 99.999%. Such a figure would be a reasonable availability objective for the maritime mobile space sector.

3.2 *Earth station equipment*

Availability criteria for coast earth stations can be derived from experience gained with earth stations in the fixed-satellite service, and may therefore be readily defined. The derivation of availability criteria for ship earth stations, however, cannot be obtained so precisely, for the following reasons:

- the performance of ship earth stations is not under the direct control of operating administrations, and cannot be easily monitored full-time on a long-term basis;
- compared to earth stations on land environmental conditions for ship earth station operation are more severe, and facilities available on ships at sea for repair and maintenance purposes are limited; furthermore, both the environmental conditions and the maintenance facilities will vary from ship to ship.

Account should be taken of the respective roles of coast earth station operators and ship earth station users: an outage at a coast earth station would result in loss of service to a considerable number of ships, whereas an outage of a ship earth station would generally affect only that ship. Hence, in theory, the availability objectives for shore stations should be higher than for ship earth stations.

Auxiliary functions provided by control stations will affect all coast earth stations and ships in the coverage area, and hence an outage could lead to complete system disruption. Availability objectives for these functions will therefore need to be high.

3.2.1 *Coast earth stations*

Examples of the availability achieved by earth stations in the fixed-satellite service are given in Report 706, from which the average availability achievable would appear to be 99.9%. The availability of US coast earth stations operating in the MARISAT system was 99.962% for 1978. Until further experience has been gained from operation in the maritime mobile-satellite service the following availability objectives should be provisionally adopted for coast earth stations:

- a station availability of 99.9%, based on the sum of out-of-service time due to faults and out-of-service time due to routine or preventive maintenance,
- a minimum availability of 99.95% for each communications circuit, based on the out-of-service time for channel equipment and common equipment.

3.2.2 *Ship earth stations*

Faults on ship terminal equipment can occur at any time, and it would be unreasonable to assume that ships will carry sufficient spare components and maintenance expertise to cope with all eventualities at sea. Availability criteria should, therefore, take account of the prolongation of outages caused by a ship having to make port in order to effect repairs and an estimate of the average down-time, including the time taken to make port, would be about 3 days. (It should be recognized that this figure is strongly dependent upon the maintenance organization.) This figure may then be equated to MTTR in the expression for A' in § 2.1.

An MTBF objective of 6000 h would be compatible with current and future equipment designs. The corresponding availability objective would be of the order of 99%, or about 80 h down-time per year.

The above considerations apply to standard A ship earth station of $-4 \text{ dB(K}^{-1})$, G/T , as defined in [INMARSAT, 1978], and assume that satellite-pointing is maintained towards the satellite.

3.2.3 *Auxiliary functions*

The maritime mobile-satellite service will require the provision of auxiliary functions for network coordination purposes, and these could include power control, frequency control and channel assignment functions. These could be provided either at coast earth stations or at separate control stations. If any function is so essential that loss of that function will adversely affect operation of the total network a very high availability objective should be established for that function e.g. 99.999%. Such an objective would require a high redundancy provision, with at least 2 stations per coverage area being capable of performing the auxiliary functions and each station have an availability of the order of 99.95%.

3.3 Radio paths

For telephony, the performance objective under non-faded conditions requires that the subjectively equivalent noise power should not exceed 25 000 pW0p (Recommendation 547). In order to render the channel unavailable, 10^6 pW0p of noise would be required (see § 2.2.1), which from Report 752 would require a fade on the radio path of 5 to 6 dB.

Similar considerations would apply to telegraphy.

3.3.1 Shore-to-ship path

3.3.1.1 General

The shore-to-ship radio path comprises a shore-to-satellite link (assumed here to be in the 6 GHz frequency band) and a satellite-to-ship link (1.5 GHz). The more critical of these is the 1.5 GHz link to ships, where satellite power is likely to be at a premium and hence a large allowance for fading is not feasible.

3.3.1.2 Up link

On the 6 GHz up link, a margin of around 2 dB would enable the required performance objective under fading conditions to be achieved for 99.99% of the time at 5° elevation angle; the actual margin for up-path fading required at each coast earth station will depend on local climatic conditions. In order to render the circuit unavailable, a fade of 5 to 6 dB would be required on the up link; the corresponding percentage time for which such a fade would apply is estimated at less than 0.005%, even under the most unfavourable propagation conditions i.e. corresponding to an availability figure of 99.995%. The use of up-path power control at shore stations would improve link performance and availability still further.

3.3.1.3 Down link

On the satellite-to-ship link at 1.5 GHz, fading is caused primarily by multipath reflections. In the worst case, which is defined here as occurring at the edge of the satellite service area (i.e., at a ship earth station elevation angle of 5° , see [INMARSAT, 1978]), fading statistics indicate that a fade of 4 to 5 dB would be encountered for 1% of the time, and hence the percentage time applicable to a 5 to 6 dB fade would be somewhat less than 1%.

3.3.1.4 Worst case (case of a ship at 5° elevation angle).

Bearing in mind the small contribution from the 6 GHz up-path, and taking account of interference effects on both the up-path and the down-path, an objective availability of 99% would be reasonable.

3.3.1.5 General case (case of a ship travelling in regions where multipath effects are insignificant). The down-time due to fading is negligible in this case.

3.3.2 Ship-to-shore path

The ship-to-shore radio path comprises a ship-to-satellite link (1.6 GHz) and a satellite-to-shore link (assumed here to be at 4 GHz). Multipath fading will again be the dominant effect, and hence from considerations in § 3.3.1 the availability under worst-case conditions will be of the order of 99%, but for the general case the down-time will be negligible.

3.4 Overall availability objective

The expression for communications circuit availability (A) in the maritime mobile-satellite service can be written in terms of percentage down-time ($D = 100 - A$), as follows:

$$A = \frac{T_s - (T_{sat} + T_{ship} + T_{shore} + T_{aux} + T_1 + T_2)}{T} \times 100 \quad (\%)$$

$$= 100 - D_{sat} - D_{ship} - D_{shore} - D_{aux} - D_1 - D_2 \quad (\%)$$

Concerning D_1 and D_2 , it is shown in § 3.3 that these outages are due predominantly to multipath fading effects on the satellite-to-ship and ship-to-satellite links respectively. Fading on these links at 1.5/1.6 GHz will be correlated i.e. the effects will occur simultaneously and hence only the outage of longest duration should be considered. This may be denoted by $D_{1, 2}$.

From considerations in this and previous sections, down-time values for the various component parts of the communications circuit may be assumed to be as shown in Table I. The overall circuit availability is then about 99% in the general case and 98% in the worst case. If account is taken of the time for which ships are in port and are not permitted to transmit, the availability would be considerably reduced.

4. Conclusions

The availability objectives applicable to component parts of communications circuits in the maritime mobile-satellite service have been considered taking into account not only experience gained from operation with the fixed-satellite service but also the characteristics of the maritime mobile-satellite service and likely user requirements. Based on this information and on the limited experience to date with Marisat operation it is proposed that the circuit availability objective be set provisionally at 99% in the general case, (case of a ship travelling in regions where multipath effects are insignificant), and 98% for the worst case (case of a ship at 5° elevation angle). These figures take account of factors which can be accommodated by adequate system planning and equipment design procedures.

It is recommended that the circuit availability objective be reassessed periodically and if necessary revised once sufficient operational experience has been acquired with the service.

TABLE I — *Down-time for component parts of a communication circuit in the maritime mobile-satellite service*

Symbol	Component part	Down-time (%)	Notes
D_{sat}	Space sector	0.001	(1)(2)(3)
D_{shore}	Coast earth station equipment	0.05	
D_{ship}	Ship earth station equipment	1	
D_{aux}	Auxiliary functions	0.001	
$D_{1,2}$	Radio paths	General case: 0 Worst case: 1	
D_{total}	Total circuit down-time	General case: 1 Worst case: 2	

(1) Assumes ship terminal antenna pointing can be maintained.

(2) No consideration given to times when ship is in port in a territory where its use may be prohibited.

(3) Assumes standard A ship earth station G/T of -4 dB (K^{-1}).

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SECTION 8F: MARITIME MOBILE-SATELLITE SERVICE; RADIO AND RELATED SUBJECTS

Recommendations and Reports

REPORT 760-1

LINK-POWER-BUDGETS-FOR-A-MARITIME-MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The purpose of this Report is basically two-fold:

- to list the parameters which must be taken into account when determining link power budgets for a future maritime mobile-satellite system, and the conditions under which these parameters apply;
- to provide examples of link power budgets to illustrate the application of these parameters.

Link power budgets are required in order to determine the likely power requirements and physical characteristics of the space sector (satellite) and the earth sector (coast earth stations and ship earth stations). The overall design for a future system will rely to a great extent on the experience acquired in the development and operation of existing and planned maritime satellite systems, and hence considerable guidance on the choice of suitable power budget parameters can be obtained by reference to the INMARSAT system [INMARSAT, 1978; MARISAT, 1977].

2. Power budget philosophy

The philosophy adopted in this Report is to assume a "reference" system configuration from which corresponding parameters for other configurations may be derived. From the propagation viewpoint, the channel quality obtained with a maritime satellite system will be strongly dependent on the satellite elevation angle, and so it would appear reasonable to adopt the elevation angle as one of the parameters on which to base the reference system. The reference configuration for the power budgets is assumed here to apply at satellite elevation angles of 5° for coast earth stations and 10° for ship earth stations; corresponding parameters and resultant channel qualities for elevation angles other than these may then be derived.

A further criterion adopted here is to assume that parameters for the earth sector are the same as for existing, or planned, systems; in particular, INMARSAT standard-A ship earth stations are assumed.

3. Telephony channel parameters

Telephony is expected to be the dominant service in terms of system power requirements and hence the power budgets are based on a telephony channel.

For the purpose of presenting information on link budget examples in this paper, as a reference it has been assumed that an overall carrier-to-noise density ratio (C/N_0) of 53 dBHz should be achieved for at least 80% of the time in both directions of transmission, with satellite elevation angles of 5° at coast earth stations and 10° at ship earth stations and with no multipath fading on ship/satellite links. This objective has been used as the reference configuration for the power budgets, as shown in the extreme right-hand column of Tables I and II. The current CCIR telephone channel quality objective for telephone channels in the maritime mobile-satellite service corresponds to an overall C/N_0 of about 52 to 53 dBHz (see Recommendation 547 and Report 752 [INMARSAT, 1978]).

In addition to the reference configuration, example power budgets are shown in Tables I and II for ship elevation angles of 5° and 10° when multipath fading occurs on ship/satellite links. The fading parameters are assumed to be applicable to conditions obtaining for at least 99% of the time. However, insufficient experimental data is available to reliably establish required fading margins for any confidence level.

Single-channel-per-carrier operation in frequency division multiple access is envisaged for telephony, with narrowband frequency modulation and speech processing (e.g. 2 : 1 syllabic companding). With C/N_0 of 53 dBHz at the demodulator input, a suitable receiver noise bandwidth would be 30 kHz with 50 kHz channel spacing; the corresponding carrier-to-noise ratio (C/N) would be about 8 dB.

Threshold extension demodulators, with a nominal threshold of around 50 dBHz, would be required to ensure a graceful degradation of speech quality with reducing signal level.

4. Space sector parameters

The space sector configuration assumed here is based on global coverage in both shore-to-ship and ship-to-shore directions of transmission. Assumptions regarding the characteristics of the 1.5/1.6 GHz antenna and the intermodulation noise performance of the transponders are summarized below.

4.1 1.5/1.6 GHz antenna

The critical transmission path, from the viewpoint of satellite power requirements, is that in the satellite-to-ship direction at 1.5 GHz. Efficient use of the available satellite power for earth coverage may be obtained by assuming a shaped beam antenna [Wood and Boswell, 1974; Lancr  non *et al.*, 1976]. The trade-off between beam-centre and beam-edge gain with this antenna provides an almost constant received flux density at the earth's surface for all elevation angles, and thus optimizes system performance for those ship earth stations at the edge of the coverage area where propagation effects are at their most severe. Similar compensation may also be provided on the up-path at 1.6 GHz.

4.2 Intermodulation noise performance

The satellite amplifier carrier-to-intermodulation-noise density ratio (C/I_0) in Table I for the shore-to-ship link is shown to be a limiting factor in determining the resultant C/N_0 and therefore must be optimized against amplifier output power. For typical amplifiers and suitable frequency plans that minimize intermodulation noise in occupied channels, a C/I value of about 19 dB in a 30 kHz bandwidth may be reasonably achieved with significant satellite amplifier loading. This results in the assumed C/I_0 of 63.8 dBHz for the shore-to-ship direction.

In the ship-to-shore direction, as given in Table II, a C/I_0 of 70 dBHz has been assumed as the satellite amplifier is not expected to be as power limited as in the shore-to-ship direction.

5. Earth sector parameters

The following ship earth station and coast earth station radio frequency characteristics have been adopted as the basis for the power budgets:

Ship earth station G/T : -4 dB(K⁻¹) (Standard-A);

Ship earth station e.i.r.p. : 37 dBW;

Coast earth station G/T : 32 dB(K⁻¹);

Coast earth station e.i.r.p. : 60 dBW.

5.1 Ship earth station

The assumed G/T of -4 dB(K⁻¹) is a net value which includes allowances for power losses due to pointing accuracy, misaligned polarization ellipses, diplexer and dry radome; an additional allowance is shown in the link budgets for loss due to a wet radome. This sensitivity may be achieved with an antenna of 23 dBi gain and a transistorized receive amplifier of 500 K total system noise temperature. An appropriate antenna would be a paraboloid of 1.2 m diameter, with 60% illumination efficiency, and a beamwidth of approximately 10° to the -3 dB points; an axial ratio of about 2 dB has been assumed. For the purposes of the link budget calculations, the pointing and polarization losses have been considered separately.

No allowance has been made in the power budgets for blockage effects from the ship's superstructure; these would depend on the individual ship and could, in theory, be eliminated by choosing an unobstructed site.

5.2 Coast earth station

For a clear-sky G/T of 32 dB(K⁻¹) at 5° elevation, a total system clear-sky noise temperature of 100 K has been assumed for the calculation of noise temperature degradation under fading conditions. Fading parameters for 4/6 GHz links are assumed to be applicable to propagation conditions obtaining for 99.99% of the time; the channel quality of the overall links between coast earth stations and ship earth stations is thus mainly determined by the loss parameters on ship/satellite links at 1.5/1.6 GHz.

An appropriate coast earth station's antenna diameter would be 13 m, assuming an illumination efficiency of 60%. The antenna axial ratio has been assumed to be 0.5 dB; for the purposes of the link budget calculations, polarization and pointing losses have been considered separately.

The up-link intermodulation noise from all coast earth station transmit amplifiers has been assumed to result in a total up link C/I greater than 30 dB in a 30 kHz bandwidth. This assumption is consistent with the current INMARSAT Coast Earth Station Technical Requirements Document and the expected performance of typical frequency plans that could be employed. This results in the C/I_0 value of 75 dBHz used in Table I.

6. Derivation of link margins

The margins necessary to achieve the desired objectives for the satellite links are dependent upon many factors including the satellite characteristics, ship earth station and coast earth station characteristics, weather, sea states and satellite elevation angles. The overall system design should include link margins consistent with the following factors:

- minimum elevation angle considered for service;
- tolerable performance degradation for elevation angles lower than the minimum design point.

The choice of link margins in relation to elevation angle (α) and the system design will affect the performance of the entire system (as seen from the terrestrial network). A system designed to achieve a specified quality for a stated percentage of time, with margins to allow for degradations occurring at low elevation angles, will achieve this quality for much higher percentages of time when calls to and from all ships within the coverage area are considered.

The margins required to compensate for losses other than the basic free space path loss can be grouped into categories of long-term (fixed and random losses) and short-term.

6.1 Long-term losses

Long-term losses may be defined as those which would tend to last for a period of at least a minute per occurrence.

6.1.1 Fixed long-term losses

Long-term losses which occur with certainty should be included in the path loss for all calculations. The composite margin for these losses in dB is their sum:

$$L_f = \sum_j L_{f,j} \quad (1)$$

6.1.2 Random long-term losses

Several of the long-term losses tend to occur randomly and are generally independent of each other. The cumulative mean loss ($\bar{L}_l$) and variance (σ_l^2) may be obtained by summing the individual means and variances:

$$\bar{L}_l = \sum_j \bar{L}_{l,j}, \quad \sigma_l^2 = \sum_j \sigma_{l,j}^2 \quad (2,3)$$

6.2 Short-term losses

Short-term losses may be defined as those which would tend to last for a period of less than a minute per occurrence. Since the occurrence of a significant short-term fading period may be infrequent, uncertain, or may only occur at certain times of the day, consideration should be given to the fading statistics when establishing fade margins.

Short-term losses tend to be independent of each other and to have different statistical distributions. The cumulative margins needed for these losses may be strongly dependent on elevation angle (α), since the elevation angle independent losses are relatively small or infrequent.

The cumulative mean loss ($\bar{L}_s$) and variance (σ_s^2) for the cumulative short-term losses may be obtained by summing the individual mean losses and variances:

$$\bar{L}_s = \sum_i \bar{L}_{s,i}; \quad \sigma_s^2 = \sum_i \sigma_{s,i}^2 \quad (4, 5)$$

6.3 Cumulative margins for all losses

Since the long-term and short-term losses are reasonably numerous and independent, the total margin requirements can be approximated by a normal loss distribution having a mean given by:

$$L \approx L_r + \bar{L}_l + \bar{L}_s \quad \text{dB} \quad (6)$$

and standard deviation given by:

$$\sigma \approx (\sigma_l^2 + \sigma_s^2)^{1/2} \quad \text{dB} \quad (7)$$

The appropriate cumulative margin in dB, corresponding to time-percentages of 80%, 99% and 99.99%, would then be given by:

$$\begin{aligned} M(80\%) &= L + 0.85 \sigma \\ M(99\%) &= L + 2.33 \sigma \\ M(99.99\%) &= L + 3.72 \sigma \end{aligned} \quad (8)$$

7. Margins at 1.5/1.6 GHz for ship/satellite links

7.1 Long-term losses

Long-term losses for which margins may be needed are as follows:

$L_a(\alpha)$: atmospheric absorption in dB: a function of the ship-to-satellite elevation angle (α); derived here from Report 714;

$L_e(\alpha)$: excess attenuation in dB, exceeded for not more than 20% or 1% of the time; this is considered to be negligible at 1.5/1.6 GHz;

L_r : radome (if used) loss in dB; the losses due to a dry radome (0.2 dB) may already be accounted for in the definition of ship earth station antenna gain and receive sensitivity (G/T), as is assumed here;

L_p : polarization coupling loss in dB: a function of ship earth station antenna and satellite antenna axial ratio (2 dB and 3 dB respectively); the worst case is misaligned polarization ellipses;

L_b : ship structure blockage loss in dB: a function of antenna placement, size and shape of the obstruction, direction and ship earth station antenna beamwidth.

Additional degradations due to an increase in system noise temperature caused by various losses are as follows:

DT_r : ratio in dB of the system noise temperature, when a radome is fitted to the system noise temperature without the radome; this may already be accounted for in the G/T value, as has been assumed here, but an allowance is required for the degradation in noise temperature due to a wet radome;

ΔT_a : temperature increase due to atmospheric absorption; this is considered negligible for a system noise temperature of 500 K.

7.1.1 Fixed long-term losses

The composite margin for fixed long-term losses is given by:

$$L_f(\alpha) = L_a(\alpha) + L_r(\text{dry}) \quad (9)$$

7.1.2 Random long-term losses

Cumulative statistics for random long-term losses would include, for example, L_p and L_r (wet); typical means and standard deviations for these loss factors might be as follows:

Loss factor	Mean Loss (dB)	Standard deviation (dB)
L_p	0.2	0.09
L_r (wet)	0.2	0.13
DT_r (wet)	0.1	0.09 (reference noise temperature = 500 K)

The inclusion of blockage loss (L_b) in the margin calculations may not be consistent with ship earth station installation practice and operational objectives. Normal practice may be to install the ship earth station antenna with a completely unobstructed view for elevation angles above the system design point and not to provide a system-wide margin for blockage, as has been assumed here.

7.2 Short-term losses

Short-term losses for which margins may be needed are as follows:

- L_t : ship earth station transmitter power level fluctuations: are assumed here to be ± 0.5 dB for about 95% of the time, corresponding to a mean loss of 0 dB and a standard deviation of 0.25 dB;
- ΔG : ship earth station antenna pointing loss in dB: a function of the ship antenna pointing system performance which tends to be worse in high sea states; some designs may exhibit high tracking errors at certain orientations such as in the zenith direction;
- L_i : ionospheric fading loss, in dB, due to scintillation; a function of ship location, season and time of day;
- $L_m(\alpha)$: multipath fading loss, in dB, due to reflections from the sea and ship structure: the magnitude of the loss for a given percentage of time, and the rate at which the loss varies, will depend upon the sea state, elevation angle (α), link polarization, ship antenna pattern, ship antenna axial ratio in the direction of the reflection region, antenna height above the sea, and antenna system pointing accuracy.

7.2.1 Antenna pointing loss

The antenna pointing loss (ΔG) may be small, especially if the ship earth station antennas are equipped for automatic pointing. Typical pointing errors may be normally distributed with a standard deviation of 0.1 beamwidth or less under worst case design conditions, and the corresponding loss distribution would be chi-squared. For simplicity, a 99% loss figure of 0.5 dB has been assumed with a mean loss of 0.3 dB and a standard deviation of 0.09 dB.

7.2.2 Ionospheric scintillation loss

Band 9 fading losses due to ionospheric scintillation tend to be noticeable only in the spring and autumn equinox seasons, and primarily near the geomagnetic equator and at high geomagnetic latitudes [Canada, 1973; Golden and Sessions, 1972]. Furthermore, the fading near the geomagnetic equator tends to be more severe than at the high latitudes, and the periods of such fading range from about one to three hours and occur shortly after local sunset. Measurements indicate that maximum fading losses below free space are normally in the range of 3 to 5 dB for the worst fading days and that the deepest fades usually last less than 15 s. During fading periods a loss of about 1.1 dB is expected to be exceeded for not more than 1% of the hours, and 1.8 dB is expected to be exceeded for not more than 0.1% of the hours [Golden and Sessions, 1972]. Cautious estimates of the corresponding standard deviation would be 0.6 dB.

Inclusion of the ionospheric scintillation loss in the cumulative margin would yield the worst case statistics, which would be applicable for a very short time during a few days of the year and to limited geographical locations. For some systems it may be the governing short-term loss and should, therefore, be considered in the selection of "worst hour" margins, but for the purposes of this Report it will not be included.

7.2.3 Multipath fading loss

Multipath fading loss statistics are very dependent on elevation angle and could be the dominant factor in the link margin requirement. A considerable number of studies and experiments have been performed to assess the effects of multipath fading; see also Reports 505 (Kyoto, 1978), 599 and 763 [ESRO, 1974; IMCO, 1973; ESA, 1976].

With normal sea conditions in most ocean areas, multipath reflections from the sea surface will be predominantly diffuse and the composite indirect signal will have narrowband Gaussian statistics. Unlike the ship earth station receiver noise, the received carrier-to-multipath-interference ratio (C/I_{mp}) will not be reduced by increasing the satellite transmitter power. Consequently, margins provided for diffuse multipath interference do not serve to increase C/I_{mp} , but only to provide an adequate carrier-to-receiver-thermal-noise ratio such that the ship earth station receiver performance is still acceptable when the multipath fading occurs.

Once the expected value of C/I_{mp} is established for the minimum design elevation angle, the fade depths not exceeded for more than $p\%$ of the time can be determined. For example, extrapolation from measured test data shows that a directive antenna with 24 dBi nominal beam-centre gain (10° beamwidth) in a circularly polarized link at 5° elevation would normally enjoy a $C/I_{mp} \approx 16$ dB. The fading depth would be expected to be less than 2.5 dB for at least 99% of the time [ESRO, 1974; Norton *et al.*, 1965]. In deriving this result, the following assumptions have been made:

- (a) the discrimination angle to the reflecting area is approximately 10° ;
- (b) the antenna pointing system uses a reference independent of the received signal in compensating for ship roll and pitch etc.;
- (c) the polarization efficiency factor of the antenna to the multipath energy is unity (i.e. cross-polar response).

Such extrapolations, although useful in deriving an order of magnitude for typical fade depths, should be treated with some caution; in particular, the assumption (c) above would not apply in practice as the cross-polar response of the antenna is expected to be worse off-axis than at beam centre. Furthermore, the corresponding fade depth adopted in existing and planned systems is 4 dB at 5° elevation and 1.8 dB for 10° elevation. These values are in reasonable agreement with the results given in Report 763.

On the basis of analysis and some experiments, the margins required for low percentage fading ($p \leq 99\%$) with diffuse multipath fading will be larger than the maximum specular fade for the same conditions.

Loss statistics for diffuse multipath fading are approximately Gaussian for high direct to indirect power ratios ($C/I_{mp} > 10$ dB). The cautious approximation adopted here is to use a zero average ($L_m = 0$ dB) and a standard deviation estimate which is based on the 99% loss values given above.

7.3 Cumulative margins

It may be seen that inclusion of margins for blockage and ionospheric scintillation loss may be significant; the approach adopted here is to assume no normal blockage and scintillation losses in establishing the system-wide margins. However, these losses should be included in a "worst case" margin which may be used in conjunction with a "marginally acceptable" quality objective lower than the normal quality criterion for telephony.

8. Margins for feeder links

8.1 Fixed long-term losses

The only fixed long-term loss occurring in the power budgets is atmospheric absorption, $L_a(\alpha)$.

8.2 Random long-term losses

Random long-term losses include:

- L_p : polarization coupling loss: mean loss = 0.05 dB, standard deviation = 0.02 dB for shore/satellite antenna axial ratios of 0.5 dB/3 dB.
- L_t : transmitter power fluctuations for 6 GHz operation: mean loss = 0 dB, standard deviation = 0.12 dB.
- $L_e(\alpha)$: excess attenuation exceeded for not more than 0.01% of the time: mean loss = 0 dB, standard deviation = 0.27 dB for 6 GHz operation and 0.14 dB for 4 GHz operation.

8.3 Random short-term losses

Coast earth station antenna pointing loss is assumed here to be 0.2 dB with a mean loss of 0 dB and a standard deviation of 0.05 dB. No allowance has been made for ionospheric scintillation in the 99.99% loss figures.

$DT_s(\alpha)$: degradation due to excess sky noise in dB : mean loss = 0 dB standard deviation = 0.32 dB.

9. Link power budgets

Cumulative random loss margins in Tables I and II have been calculated from the loss values assumed for each parameter and have been calculated independently for each part of the overall link. The power budgets may be used to determine likely system power requirements and are based on an assumed resultant C/N_0 requirement of 53 dBHz for the telephony reference budget; this assumes 5° elevation at coast earth stations, 10° elevation at ship earth station and no multipath fading on ship/satellite links. The C/N_0 values when multipath fading does occur on ship/satellite links are also indicated, for ship elevation angles of 5° and 10°. It is assumed that the contribution due to all translation local oscillator phase noise is negligible and consequently is not included in the link power budgets.

10. Other factors affecting the link power budget

10.1 Relative transponder loading

Since the satellite capacity is designed to meet traffic requirement at a specified grade-of-service, on the average substantially fewer than the full load number of carriers will be busy during the busiest hour. Due to the non-linear amplification characteristic typical of most satellite amplifiers near saturation, the e.i.r.p. per carrier increases in almost direct proportion to the decrease in the number of carriers from full load. Consequently the average per carrier e.i.r.p. during the busiest hour will be greater than the full load e.i.r.p. over a small range of about 1 dB.

For single channel per carrier (SCPC) telephony systems in which blocked calls are cleared (erlang B), the probability, $P(n)$, that exactly n channels or less out of s channels are in use during the busy hour is given by [Cooper, 1972],

$$P(n) = 1 - \sum_{j=n}^s p_j$$

where, p_j is the probability that exactly j channels are in use, and is given by

$$p_j = \begin{cases} B(s,a) & \text{for } j=s \\ \frac{B(s,a)}{s} & \text{for } j < s \end{cases}$$

$$\prod_{k=j+1}^s a/k$$

where $B(s, a)$ is the busy hour blocking probability [Dill and Gordon, 1978], and “ a ” is the busy hour offered traffic (erlangs).

Assuming that the transmitter is operated at saturation, the increase in the per carrier e.i.r.p. relative to the full load per carrier e.i.r.p. is with probability $P(n)$,

$$\Delta = 10 \log(s/n)$$

Table III provides several numerical examples in the range of interest. It should be noted, that during the busy hour, all channels or less are in use for $(1 - B(s,a)) \times 100\%$ of the time. For a 2% blocking probability ($B(s,a) = 0.02$), this amounts to 98% of the time.

10.2 Adaptive control of satellite transmitting power

In the previous sections, fixed satellite transmitting power is assumed. However, in an SCPC system, in which satellite transmitting power can be changed by controlling coast earth station transmitting power for each SCPC carrier, shore-to-ship satellite link quality (C/N or S/N) could be maintained at the required constant value. This can be achieved by sending back the shore-to-ship satellite link quality measured at the ship earth station through the ship-to-shore link and adaptively controlling the shore earth station transmitting power using the sent back information.

By applying this power control method, random slow variations in satellite link quality caused by satellite antenna gain differences, precipitation or fading can be almost compensated for. Consequently, the number of SCPC channels in the satellite transponder could be increased [Egami *et al.*, 1980].

The study of adaptive power control methods, as a possible means of making more efficient use of satellite power in the long term, should include consideration of the practical, operational and economic effects on current designs of coast earth stations, ship earth stations and the satellite signalling system.

11. Summary

This Report has illustrated how fixed and variable link parameters may be taken into account when developing link power budgets for a maritime mobile-satellite system.

The cumulative loss statistics used to derive the margins have been approximated as normal, with the mean and variance taken to be the sum of the means and the variances of the individual losses.

The independence of the loss factors and the normal distribution assumptions should be checked for any particular link budget design.

Further study will be required on the power budgets for services other than telephony, and for ship earth stations having a G/T other than $-4 \text{ dB(K}^{-1}\text{)}$. Further study is also required into the relationship between traffic, satellite capacity and e.i.r.p. requirements.

TABLE I — Shore-to-ship link power budget

	Units	Satellite elevation angle		
		5°		
1. Shore-to-satellite (6.42 GHz, 99.99% time)				
Coast earth station e.i.r.p. per channel (nominal value)	dBW	60		
Loss due to transmitter power fluctuations ⁽¹⁾	dB	[0.5]		
Loss due to pointing errors ⁽¹⁾	dB	[0.2]		
Free space path loss	dB	200.9		
Atmospheric absorption loss	dB	0.5		
Excess attenuation due to precipitation ⁽¹⁾	dB	[1.0]		
Polarization coupling loss ⁽¹⁾	dB	[0.1]		
Total margin for random losses	dB	1.2		
Satellite G/T	dB(K ⁻¹)	− 16		
Boltzmann's constant	dB(J/K)	− 228.6		
Up-path C/N_0 (thermal noise)	dBHz	70		
Coast earth station C/I_0 (intermodulation noise)	dBHz	75		
Satellite transponder C/I_0 (intermodulation noise)	dBHz	63.8		
Transmitted $C/(N_0 + I_0)$	dBHz	62.6		
		99% time		80% time
		5°	10°	10°
2. Satellite-to-ship (1.54 GHz)				
Satellite e.i.r.p. per channel (useful power)	dBW	18.0	18.1	18.1
Free space path loss	dB	188.5	188.4	188.4
Atmospheric absorption loss	dB	0.4	0.2	0.2
Multipath fading loss ⁽¹⁾	dB	[4.0]	[1.8]	[0]
Wet radome additional loss ⁽¹⁾	dB	[0.5]	[0.5]	[0.4]
Noise temperature degradation ⁽¹⁾	dB	[0.3]	[0.3]	[0.2]
Polarization coupling loss ⁽¹⁾	dB	[0.4]	[0.4]	[0.3]
Loss due to tracking errors ⁽¹⁾	dB	[0.5]	[0.5]	[0.4]
Total margin for random losses	dB	4.8	2.7	1.1
Ship earth station G/T	dB(K ⁻¹)	− 3.5	− 3.5	− 3.5
Boltzmann's constant	dB(J/K)	− 228.6	− 228.6	− 228.6
Down-path C/N_0	dBHz	49.4	51.9	53.5
Transmitted $C/N_0 + I_0$	dBHz	62.6	62.6	62.6
Resultant $C/(N_0 + I_0)$	dBHz	49.2	51.5	53.0

⁽¹⁾ Random loss; figures indicated [] are not included directly in budget, but are combined as described in § 6.3.

TABLE II — Ship-to-shore link power budget

	Units	Satellite elevation angle		
		99% time		80% time
		5°	10°	10°
1. Ship-to-satellite (1.64 GHz)				
Ship earth station e.i.r.p. (nominal value)	dBW	37	37	37
Loss due to transmitter power fluctuations ⁽¹⁾	dB	[0.5]	[0.5]	[0.5]
Loss due to pointing errors ⁽¹⁾	dB	[0.5]	[0.5]	[0.4]
Wet radome additional loss ⁽¹⁾	dB	[0.5]	[0.5]	[0.4]
Free space path loss	dB	189.0	188.9	188.9
Atmospheric absorption loss	dB	0.4	0.2	0.2
Multipath fading loss ⁽¹⁾	dB	[4.0]	[1.8]	[0]
Polarization coupling loss ⁽¹⁾	dB	[0.4]	[0.4]	[0.3]
Total margin for random losses	dB	4.8	2.6	1.0
Satellite G/T	dB(K ⁻¹)	-12.2	-12.1	-12.1
Boltzmann's constant	dB(J/K)	-228.6	-228.6	-228.6
Up-path C/N_0 (thermal noise)	dBHz	59.2	61.8	63.4
Satellite transponder C/I_0 (intermodulation noise)	dBHz	65.8	68.4	70
Transmitted $C/(N_0 + I_0)$	dBHz	58.3	60.9	62.5
		5°		5°
2. Satellite-to-shore (4.20 GHz, 99.99% time)				
Satellite e.i.r.p. per channel (useful power)	dBW	-12.3	-9.7	-8.1
Free space path loss	dB	197.1	197.1	197.1
Atmospheric absorption loss	dB	0.5	0.5	0.5
Excess attenuation due to precipitation ⁽¹⁾	dB	[0.5]	[0.5]	[0.5]
Degradation due to excess sky noise ⁽¹⁾	dB	[1.2]	[1.2]	[1.2]
Polarization coupling loss ⁽¹⁾	dB	[0.1]	[0.1]	[0.1]
Loss due to tracking errors ⁽¹⁾	dB	[0.2]	[0.2]	[0.2]
Total margin for random losses	dB	1.4	1.4	1.4
Coast earth station G/T (clear-sky)	dB(K ⁻¹)	32	32	32
Boltzmann's constant	dB(J/K)	-228.6	-228.6	-228.6
Down-path C/N_0	dBHz	49.3	51.9	53.5
Transmitted $C/(N_0 + I_0)$	dBHz	58.3	60.9	62.5
Resultant $C/(N_0 + I_0)$	dBHz	48.8	51.4	53.0

⁽¹⁾ Random loss; figures indicated [] are not included directly in budget but are combined as described in § 6.3.

TABLE III — Relative e.i.r.p. per carrier for 2% blocking probability

Busy hour offered traffic (Erlang) (a)	Number of channels (s)	Number of channels (n)	$P(n)$ (%)	Δ (dB)
17.5	25	21	79.6	0.76
21.93	30	26	81.3	0.62
31.00	40	36	83.4	0.46
40.26	50	45	79.9	0.46
87.97	100	94	80.8	0.27

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RECOMMENDATION 632*

**TRANSMISSION CHARACTERISTICS OF A SATELLITE EMERGENCY POSITION
INDICATING RADIOBEACON (SATELLITE EPIRB) SYSTEM
OPERATING THROUGH GEOSTATIONARY SATELLITES
IN THE 1.6 GHz BAND**

(Study Programme 17B/8)

(1986)

The CCIR,

CONSIDERING

- (a) that satellite EPIRBs will be one of the prime alerting means in the Future Global Maritime Distress and Safety System (FGMDSS) developed by the International Maritime Organization (IMO);
- (b) the time-frame foreseen by the IMO for the implementation of the FGMDSS;
- (c) the necessity to carry out pre-operational demonstrations within that time-frame and to develop satellite EPIRB production units;
- (d) that the frequency band available through the first generation INMARSAT space segment is 1644.3-1644.5 MHz;
- (e) that the second generation INMARSAT space segment, which is planned to commence operation from 1988 onwards, will cover both the band 1644.3-1644.5 MHz and the band 1645.5-1646.5 MHz,

UNANIMOUSLY RECOMMENDS

- 1. that the transmission characteristics for a satellite EPIRB operating through geostationary satellites at 1.6 GHz should be in accordance with Annex I to this Recommendation;
- 2. that the transmission frequencies of EPIRBs be distributed uniformly across the frequency band appropriate to the space segment in use.

* The Director, CCIR, is requested to bring this Recommendation to the attention of the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

ANNEX I

TRANSMISSION CHARACTERISTICS OF A SATELLITE EMERGENCY POSITION-INDICATING
RADIOBEACON (SATELLITE EPIRB) SYSTEM OPERATING THROUGH
GEOSTATIONARY SATELLITES IN THE 1.6 GHz BAND

Modulation:	non-coherent binary frequency shift keying (FSK)
Transmit frequency:	within the bands 1644.3-1644.5 MHz */1645.5-1646.5 MHz **
Deviation:	-120 Hz (0) + 120 Hz (1) tolerance $\pm 1\%$
Accuracy of clock frequency:	$\pm 2 \times 10^{-6}/\text{year}$ ***
Transmit frequency:	
– long term accuracy (for 1 year):	better than $\pm 3 \times 10^{-6}$
– short term stability:	1×10^{-8} for 1 min
FSK switching time:	80% transmit power within 1.5 ms
Transmit power:	0 dBW $\pm 1/3$ dB at the input to the antenna
Antenna:	0 dBi nominal gain (shaped beam or hemispherical)
Antenna axial ratio:	≤ 5 dB for $\pm 90^\circ$ from zenith
Polarization:	Right-hand circular
Frame length:	
– data:	100 bits (see Appendix I)
– synchronization:	20 bits (see Appendix I)
– parity bits:	40 bits (see Appendix II)
Code:	NRZ-L
Modulation rate:	32 Bd
Total transmission duration:	40 min
Number of transmissions:	4 (see Appendix III)

* INMARSAT first generation space segment.

** INMARSAT second generation space segment.

*** This requires a clock accuracy of $\pm 2 \times 10^{-7}/\text{year}$ in the receiver processor.

APPENDIX I OF ANNEX I

1. The following items, listed in the preferred priority order for entry and read-out, should be included in distress messages to the extent practicable and necessary:

TABLE I — *Content of distress message*

Item	Contents	Number of bits
1	Ship station identity	30
2	Position co-ordinates and information in the following order:	
2.1	Latitude in degrees and minutes	14
2.2	Longitude in degrees and minutes	15
2.3	Date and time of position up-date	11
3	Nature of distress	4
4	Course	9
5	Speed	6
6	Date and time of activation	11
7	Assistance desired and any other information which might facilitate the rescue ⁽¹⁾	

(¹) Item 7 may be included with the data sent in item 3, if necessary.

Note. — The order of items does not necessarily mean that the message sequence during transmission follows exactly in this order but the input/output data could be used in the order as proposed by IMO and as given above.

2. The format of the transmitted message and string is shown in Table II and Fig. 1 of Appendix II.

TABLE II — *Format of the transmitted message*
(See Note, Table I)

Synchronization bits	20 bits	Hex EDE20
Distress message	30 bits	Ship station identity range: 0-999.999.999
	1 bit	Longitude hemispherical symbol 0: east; 1: west
	1 bit	Latitude hemispherical symbol 0: north; 1: south
	8 bits	Degrees of longitude range: 0-180
	6 bits	Minutes of longitude range: 0-60
	7 bits	Degrees of latitude range: 0-90
	6 bits	Minutes of latitude range: 0-60
	9 bits	Course: degrees (true) range: 0-360
	5 bits	Time of position up-date: h (UTC) range: 0-24
	6 bits	Time of position up-date: min range: 0-60
	5 bits	Time of activation: h (UTC) range: 0-24
	6 bits	Time of activation: min range: 0-60
	6 bits	Speed: knots range: 0-63
Parity bits	4 bits	Nature of distress (see Table III)
	40 bits	See Appendix II for composition

In those systems where it is desirable to provide on activation, a specific indication of the nature of distress, the following indications should be used:

TABLE III – Nature of distress indications

IMO indicator	Binary code	Nature of distress
1	0001	Fire/explosion
2	0010	Flooding
3	0011	Collision
4	0100	Grounding
5	0101	Listing, in danger of capsizing
6	0110	Sinking
7	0111	Disabled and adrift
8	0000	Undesignated (unspecified distress)
9	1000	Abandoning ship
10	1111	Test (1)

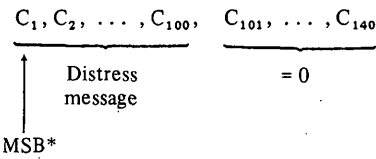
(1) Use of this indicator should be restricted to those applications where transmission of the distress alert (or call) is required to ascertain that the system is operating properly. Provisions may be required to confirm that the complete system is functioning.

Additional capacity should be provided if practical.

APPENDIX II OF ANNEX I
FORWARD ERROR-CORRECTION CODE

40 parity bits for error correcting purpose. A (140, 100, 5) BCH code is used resulting in a minimum code distance of 11.

The input message



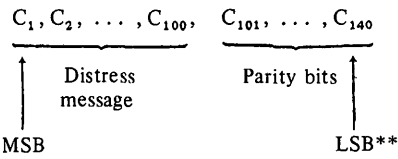
is divided modulo 2 by the following generator polynomial:

$$\begin{aligned} g(x) = & x^{40} + x^{37} + x^{36} + x^{33} + x^{32} \\ & + x^{30} + x^{29} + x^{28} + x^{27} + x^{26} + x^{24} + x^{23} + x^{22} + \\ & + x^{20} + x^{17} + x^{16} + x^{15} + x^{13} + x^{11} \\ & + x^{10} + x^8 + x^4 + \\ & + 1 \end{aligned}$$

The remainder of this division represents the parity bits C101, ..., C140.

The output message is generated by inserting the parity bits in the output message.

Resultant output message:



* MSB: most significant bit.

** LSB: least significant bit.

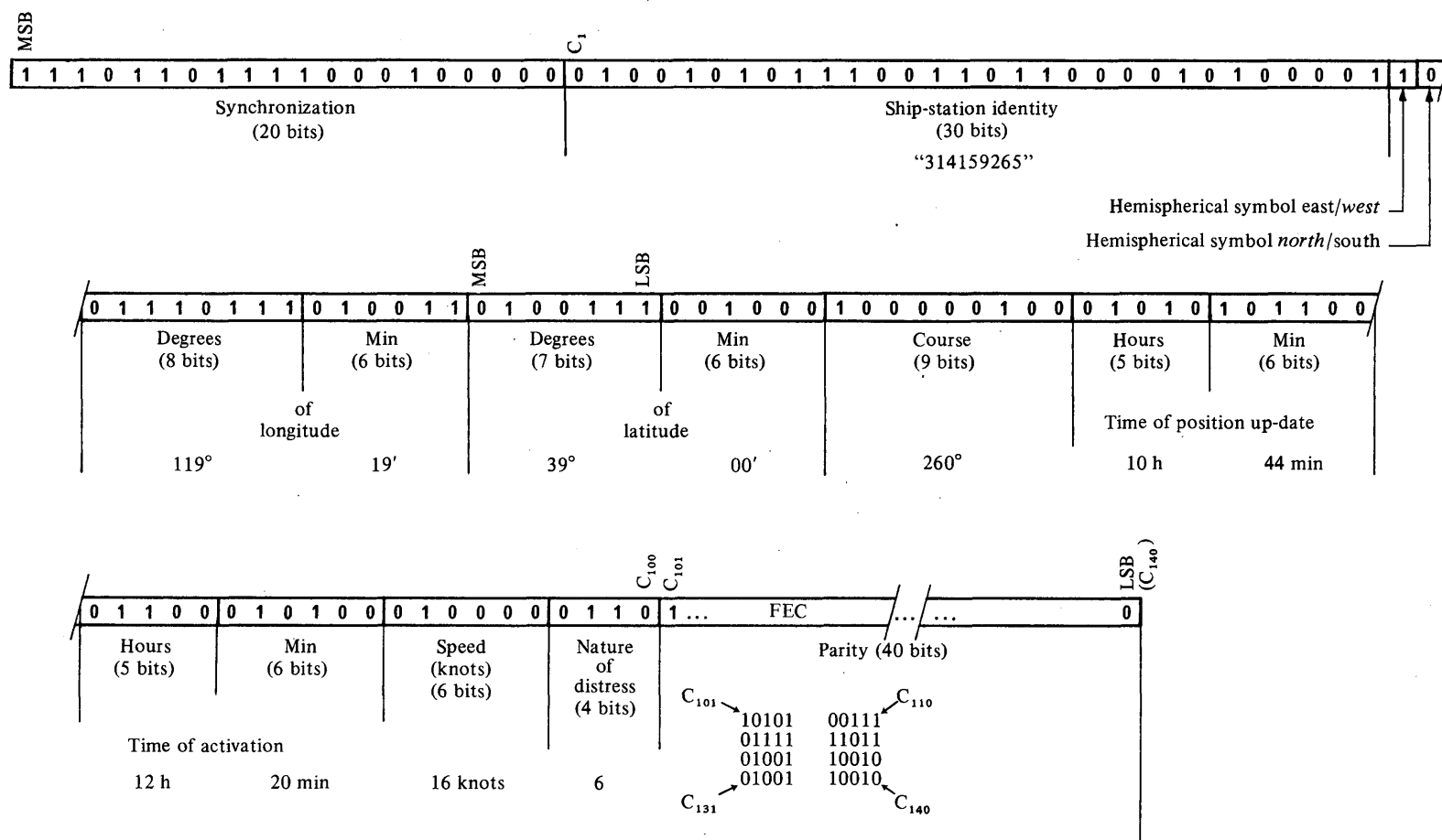


FIGURE 1 – Transmitted message string (example)
(See Note, Table I)

MSB: most significant bit

LSB: least significant bit

FEC: forward error-correction code

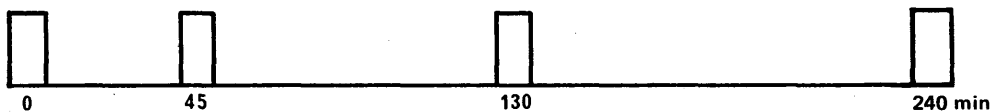
– The data frame is periodically repeated during the whole operating time

– The HSD of the data frame is transmitted first

APPENDIX III OF ANNEX I

DUTY CYCLE

1. The duration of each transmission period should be 10 min.
2. The first transmission should be initiated when the distress occurs either by manual activation from on board the ship or when the satellite EPIRB floats free.
3. The second transmission should begin 45 min after the start of the first, to overcome possible interruptions caused by shadowing due to the superstructure of the abandoned ship.
4. To further increase the probability of a successful transfer of the distress alert, two additional transmissions should follow the first two, the third 130 min, and the fourth 240 min, after the start of the first transmission.
5. The transmission repetition rate is illustrated as follows:



REPORT 1045*

**SATELLITE EPIRB COORDINATED TRIALS PROGRAMME
USING THE INMARSAT GEOSTATIONARY SPACE SEGMENT OPERATING
IN THE 1.6 GHz BAND**

(Study Programme 17B/8)

(1986)

1. Introduction

1.1 At the twenty-first session of the International Maritime Organization (IMO) Sub-Committee on Radio-Communications (28 January-1 February 1980), the IMO requested the International Radio Consultative Committee (CCIR) to coordinate the trials of various geostationary-satellite Emergency Position-Indicating Radio Beacon (EPIRB) systems being developed by several administrations. This request was brought to the attention of CCIR Study Group 8.

1.2 At the same time, the IMO recommended that the International Maritime Satellite Organization (INMARSAT) include a Satellite EPIRB service in the INMARSAT geostationary-satellite system.

1.3 In response to this request, INMARSAT indicated its willingness to consult with the CCIR on the space segment performance characteristics suitable for satellite EPIRB operation. INMARSAT also noted that satellite EPIRBs will be an essential element of the IMO Future Global Maritime Distress and Safety System (FGMDSS), and considered that the CCIR should develop the technical characteristics of such an EPIRB service as a matter of priority, taking account of operational needs.

1.4 Subsequently, INMARSAT indicated support to the CCIR in its role in coordinating and carrying out the planned trials of various satellite EPIRB designs that would use 1.6 GHz geostationary links, and expressed its willingness to make space segment capacity available for the CCIR coordinated trials.

1.5 These views were brought to the attention of the Chairman, Study Group 8, during the Study Group's Interim Meeting in Geneva, 26 November-19 December 1980. In response to the requests from the IMO and INMARSAT, Study Group 8 amended the terms of reference of CCIR Interim Working Party (IWP) 8/7 in order to be able to perform the tasks requested.

* The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

1.6 At the Final Meeting of Study Group 8 (Geneva, 1981), the Study Group considered the work of IWP 8/7 including the coordinated test plan. Document [CCIR, 1978-82a] describes the objectives of the trials, as agreed by Study Group 8. This document was forwarded for consideration by the INMARSAT Council.

1.7 Study Group 8 approved the formation of a Sub-Group of IWP 8/7 under the Chairmanship of Mr. M. A. Johnson (United Kingdom) to agree the details of the trials. The Chairman of the Sub-Group would also provide liaison between the Sub-Group and INMARSAT. The Sub-Group's terms of reference were later extended to include the evaluation of results and the basis for a Recommendation.

1.8 The coordinated trials programme, (CTP) of satellite EPIRBs was conducted between January 1982 and April 1983 in five phases.

Phase 1: Laboratory tests using a test down-converter to replace the satellite link and using a simple simulator.

These tests were carried out in order to evaluate and optimize the design and to analyse interference resistance.

Phase 2: Land tests through the satellite.

Phase 3: Sea trials using a satellite carried out independently at various locations and coast earth stations in order to verify the results of Phases 1 and 2.

Phase 4: Concurrent simulator trials using the satellite. These trials formed the basis of the data on which the comparison of the various systems was made. All systems were subjected to similar controlled conditions to ensure uniformity of evaluation.

Phase 5: Concurrent sea trials using the satellite to verify that the results obtained using the simulator accurately represented those obtained at sea.

1.9 The main objective of the trials was to enable a direct comparison of the performance of the various candidate geostationary systems operating at 1.6 GHz by testing them under similar conditions. The tests also avoided duplication of effort by the countries involved and ensured the best use of the available resources.

The specific tasks of the trials were:

- to prepare a detailed operations test plan for a coordinated trials programme (CTP) of satellite EPIRB designs using the INMARSAT space segment;
- to evaluate the test data resulting from the CTP;
- to prepare a report on the final test results of the CTP;
- to prepare a draft Recommendation on the satellite EPIRB characteristics for a geostationary satellite at 1.6 GHz.

1.10 Six countries were involved in these trials: the Federal Republic of Germany, Japan, Norway, the United Kingdom, the United States of America, and the Union of Soviet Socialist Republics.

1.11 INMARSAT made arrangements for space and ground segments, the European Space Agency provided the earth station for Phase 4 and Phase 5, the German Aerospace Research Establishment (DFVLR) provided the channel simulator in Phase 4, and the German Hydrographic Institute provided the trials vessel for Phase 5.

1.12 Japan was unable to participate in Phase 4 or Phase 5 but carried out some simulator trials independently as well as sea trials in an extended Phase 3 campaign.

1.13 The IWP 8/7 Sub-Group met on seven occasions. The Final Report was agreed at the final meeting held at the IMO, London from 25 October to 3 November 1983.

1.14 This Report is a concise version of the Sub-Group's Final Report and includes a summary of the evaluation procedure, a comparison of the systems' performance parameters together with the conclusions reached, and the basis of the draft Recommendation together with a recommended specification for a future common Satellite EPIRB. The complete Final Report of the IWP 8/7 Sub-Group on the Coordinated Trials Programme is available for consultation in the CCIR Secretariat.

2. Summary of evaluation

2.1 Correlation of Phase 4 and Phase 5 test results

A comparison of Phase 4 and Phase 5 test results can be made for the German Federal Republic system since the same buoy was used to record the Phase 4 tapes as was used in the German Federal Republic Phase 5, and the receiver processor was not modified between the two phases. There is good agreement between the results, within the accuracy range of the C/N_0 measurements.

The Japanese simulator tests and sea trials also showed good correlation for both the FSK and PSK systems.

For the other systems a correlation can only be made if the modifications carried out between the Phase 4 and Phase 5 tests are taken into account. These include:

- different buoy design;
- different antenna pattern; and
- modification of the processing technique.

2.2 Message transfer time and the receiver sensitivity of the systems

The message transfer time (MTT) is defined as the time between the initiation of transmission by the satellite EPIRB and the read-out of an error-free message at the coast earth station. The MTT used in the evaluation is the time interval within which 90% of the messages were received with a 1% or less probability of error (MTT₉₀).

The received sensitivity of each of the systems was measured in terms of the minimum averaged C/N_0 at which the performance of the systems remained within the IMO specified message transmission reliability of 99% for a single EPIRB transmission, taking account of the associated MTT₉₀. The MTT₉₀ and the (averaged) C/N_0 were taken by the IWP 8/7 Sub-Group as the most important parameters in the evaluation of the system's performance.

The C/N and MTT₉₀ were determined in Phase 4 tests using the DFVLR channel simulator with tape numbers T4 and ST2. Japan carried out independent simulator tests using ST2, T16 and T26. The main characteristics of these tapes are shown in Table I (T26 was a 406 MHz tape and is not included in Table I).

TABLE I – Tapes used for main test

	Elevation angle (degrees)	Wave height (m)	Fading margin ⁽¹⁾ (dB)	C/M ⁽²⁾ (dB)	Doppler spread bandwidth (Hz)	Maximum long-term Doppler offset (Hz)
T4	2.5	1.5-2.5	18	4.3	0.6	± 15
ST2	5	16	24	2	1	± 17.2
T16 ⁽³⁾	5	1	16.5	5.4	1	± 25

⁽¹⁾ 98% of all fades are within this range.

⁽²⁾ Carrier to multipath ratio.

⁽³⁾ Japan only.

In order to maximize the amount of data obtained, the transmissions were continuous and the signal discontinuity was made at the receiver. To verify that this procedure gave representative results, a comparison was made with the MTT obtained by switching the transmission on/off.

Data obtained in Phase 4 and Phase 5 tests were accumulated within a range of at most 1.5 dB in $<C/N_0>$.

The averaged quantities for $<C/N_0>$ used for further evaluations were obtained by weighting the results with the number of transmissions and $<C/N_0>$ of each particular data set. The following formula was used:

$$<C/N_0> = \frac{\sum_{i=1}^m (C/N_0)_i \cdot n_i}{\sum_{i=1}^m n_i}$$

In deriving MTT₉₀, all data of the C/N_0 sets within the accumulation range of 1.5 dB were considered.

It was decided to use only ST2 in the final evaluation in Phase 4 as this tape represented the worst-case condition of wave height and elevation angle; however the tape did not include wave blockage effects.

2.3 System capacity

System capacity was defined as the number of simultaneous satellite EPIRB transmissions that are capable of being processed within a period of 10 min. This parameter, used by the IWP 8/7 Sub-Group for comparative evaluation of the various candidate systems, was derived on the basis of empirical data gathered during the Phase 4 tests and on statistical analysis assuming a 200 kHz bandwidth, transmission time of $2 \times \text{MTT}_{90}$ and the recommended duty cycle as proposed in Appendix III of Recommendation 632.

The methodology used in the system capacity computations, takes account of the frequency separation measurements between interfering satellite EPIRBs (obtained during Phase 4 tests), the EPIRB manufacturing process (i.e. distribution of transmitter centre frequencies and oscillator stability tolerances), transmission spectral characteristics (e.g. for the spread-spectrum systems, the amount of power in the side lobes, location of the side lobes, etc.), satellite EPIRB geographical dispersion (limited only to effects from transmissions at high and low elevation angles), duty factor, and the desired probability of non-interference (given by the IMO to be $0.95/0.99 = 0.9596$). The detailed description of the methodology used in this computation including the software program listing, is provided elsewhere [Kaminsky *et al.*, 1983].

2.4 Resistance to interference

The systems' resistance to interference was determined in terms of the minimum frequency separation required between the wanted signal and the interfering signal, at which there was no significant degradation in performance. This was determined in Phase 4 for a CW transmission and an FM simulated voice transmission with e.i.r.p. of 10 dB and 15 dB respectively above the nominal satellite EPIRB e.i.r.p. Δf was determined at the end of the test. The results are given in Table II.

2.5 Multi-channel system implementation

It should be noted that in developing the system from a single channel to a multi-channel system, the implementation of the processing system may affect the performance due to:

- signal detection in a wide frequency band;
- discrimination of noise and unwanted (interfering) signals;
- correlating a buoy in a multi-buoy and heavy fading environment to the same processor during the whole MTT;
- tracking/demodulating many buoy signals.

3. Comparison of performance parameters

3.1 Table II provides a comparison of the performance in both Phase 4 and Phase 5 of the various systems in terms of system sensitivity (C/N_0), message transfer time (90 percentile) (MTT_{90}), resistance to interference represented by both CW and voice transmissions in terms of the minimum frequency offset at which there is no performance degradation (Δf_{CW} and Δf_{FM} respectively), and system capacity in terms of:

- the number of transmissions that can be processed in a 10 min period;
- an analysis using the frequency offset of the mutual interferer (Δf_{sc});
- the recommended duty cycle;
- the measured MTT_{90} .

3.2 It should be noted that the Phase 4 results in Table II are those obtained using the channel simulator and ST2. Tape ST2 represents the worst-case environmental conditions of 16 m wave height and 5° elevation angle; however, the tape does not include wave blockage effects.

3.3 Furthermore, the Phase 5 results quoted for each administration are those obtained on the specific day of the sea trials which provided the maximum number of evaluation points according to previously agreed criteria. In all the tests, more emphasis was given by the IWP 8/7 Sub-Group for nominal performance in high sea states and/or low elevation angles. The results shown in Table II are all from EPIRB deployment at the most northerly latitudes of around 71° N, except for that of Japan which was at around 15° S operating to the Indian Ocean Satellite. Elevation angles $< 5^\circ$ and wave heights of around 1.5 and 2.5 m were encountered.

TABLE II — Comparison of performance parameters

	C/N_0 (dBHz)		MTT ₉₀ (min.)		Interference rejection (Δf) (Hz)		System capacity	
	Phase 4	Phase 5	Phase 4	Phase 5	CW	FM	f_{sc} (Hz)	Number of transmissions
Nominal values	30	30	15	15	1000	1000	Not available	20
Germany (Federal Republic of)	15.6	15.1	7.1	5.9	180	0	280	33
Japan ⁽¹⁾ FSK	19.3	18.0	1.1	2.5	570 (calculated)	570 (calculated)	422 ⁽²⁾	133
PSK	23.4	26.6	2.9	3.4	0 ⁽³⁾	0 ⁽³⁾	40 ⁽³⁾	407
Norway	20.6	19.2	3.3	4.97	1000 ⁽⁴⁾	0	340	57
United Kingdom	37	35.5	12	5.6	0	No test	10	218
United States of America	27.5	22.4	3.8	4.2	32	32	90	170
USSR	16.5	18.6	6.4	6	500	0	400	26

⁽¹⁾ Based on independent simulator tests and extended Phase 3 sea trials.

⁽²⁾ Tape 16 used, not ST2 as with other systems.

⁽³⁾ Tape 26 used, not ST2 as with other systems.

⁽⁴⁾ 5 transmissions showed that the system is able to operate with $\Delta f = 500$ Hz.

3.4 During the testing of all systems in both Phase 4 and Phase 5, no false alarms occurred.

3.5 The system capacity values given in Table II would be greater for an operational system in which the C/N_0 levels would be increased, thereby reducing the message transfer time and required transmission burst duration. Because of the geographical dispersion of satellite EPIRBs, and the relative variation in sea-state conditions, it is expected that the required message transfer time for some of the satellite EPIRBs will be shorter than the transmission period of the satellite EPIRB; under these conditions an increase in capacity will result due to a potential overlap in the start of the transmissions. On the other hand, due to possibilities of a non-uniform distribution in satellite EPIRB frequencies the capacity may also decrease.

3.6 The nominal chosen values for the parameters are given in Table II. Systems achieving better than the nominal value were considered as suitable. The margin between the nominal value and the recorded value was taken as an indication of the relative quality of the systems. The systems were compared for an optimum combination of minimum elevation angles and high sea states.

4. Conclusion

4.1 The results of the CTP confirmed the expected advantages and disadvantages of both narrow-band and wideband systems. The narrow-band systems provided operation at lower values of C/N_0 and the wideband systems had better interference rejection and a larger multiple access capability.

4.2 The three wideband systems (United States of America, United Kingdom and Japan) employed PN-PSK modulation which gave good performance in a Gaussian channel. The United Kingdom and Japanese systems suffered from loss of signal tracking during deep signal fades with fast Doppler frequency shifts. The United States overcame this problem by employing non-coherent detection.

4.3 The USSR system employed narrow-band PSK with non-coherent detection. This system provided good sensitivity using a digital processing technique, and showed good potential although it is not fully optimized.

4.4 The German Federal Republic system employs FSK modulation and showed the best receiver sensitivity. This system has been developed and tested over a ten-year period and is near to its optimum performance capability.

4.5 The Japanese narrow-band system employs FSK modulation and showed good sensitivity and a short message transfer time. Japan realized that further development of their systems (PN-PSK and FSK) beyond the German Federal Republic system would not be finished in time for the pre-operational satellite EPIRB demonstration which is planned to be carried out in the FGMDSS transitional period. The Japanese FSK system uses 63 bit/s compared to the German Federal Republic system's 32 bit/s. This enabled the Japanese system to achieve a shorter message transfer time but with a loss of sensitivity.

4.6 The Norwegian narrow-band system using PSK sub-carrier modulation, also showed good sensitivity together with a short message transfer time, though it is far from being fully developed. Due to the short time before entering the pre-operational demonstration, Norway has no intention of further developing their system without firm international backing.

4.7 As a result of the coordinated trials programme, the following conclusions can be drawn:

- most systems tested in the CTP achieved suitable criteria for message transfer time and error-free reception, with low satellite EPIRB power requirements;
- in general the narrow-band systems provided lower C/N_0 than wideband systems, but in an operational system could prove to be more susceptible to interference;
- in particular the narrow-band FSK system with binary forward error correction developed by the Federal Republic of Germany demonstrated performance at lower C/N_0 values than other systems.

4.8 It was recognized that, in general, all systems had the potential for further development to improve their performance. However, it was also recognized that there is an urgent need to begin the implementation of an operational satellite EPIRB system as soon as possible. It was therefore concluded that a modified version of the German Federal Republic narrow-band FSK system would provide an adequate basis for the CCIR Recommendation for a geostationary satellite EPIRB system operating at 1.6 GHz.

4.9 On this basis, the following comments should be noted with respect to the recommended system:

- in the worst case (i.e. severely adverse sea-states, elevation angles less than 5° and a low C/N_0 of around 15-16 dBHz) a mean message transfer time of less than 10 min is achievable;
- a satellite EPIRB e.i.r.p. of 0 dBW appears to provide sufficient system margin and could provide a message transfer time of the order of 1 min;
- the expected capacity based on modified characteristics of the German Federal Republic system, is at least 46 simultaneous transmissions;
- in an operational system, attention needs to be given to the following points:
 - the need to uniformly distribute 1.6 GHz satellite EPIRB transmit frequencies across the total available band in order to minimize the potential for co-channel interference from other satellite EPIRBs;
 - the need to minimize the potential interference effects of unwanted transmissions.

4.10 It was recognized that a shorter data frame than was used in the CTP (see Appendix I of Recommendation 632) could result in a reduction of MTT.

4.11 The link budgets appropriate to the recommended satellite EPIRB system are shown in Table III for first generation and specified second generation INMARSAT space-segment transponders. These demonstrate that a minimum of 13 dB additional transponder gain so as to provide up-link limited operation, would save 5-6 dB in satellite EPIRB power requirements.

4.12 The total transponder bandwidth requirement for an operational satellite EPIRB system has yet to be determined.

4.13 The trials programme provided the opportunity to evaluate the candidate systems and to make some comparison between their performance characteristics. A direct comparison of the modulation systems employed was difficult due to, amongst other things, the varying levels of development of each system. Many of the candidate systems are some way from their theoretically expected threshold and given time, effort and money, their performance could further improve. Taking the time-frame of the IMO Future Global Maritime Distress and Safety System (FGMDSS) into account, it was recognized that pre-operational demonstrations of a system intended for full implementation with the FGMDSS by 1990, should begin as early as possible. These demonstrations should permit the development of low-cost production satellite EPIRBs including the release mechanism, data interface and homing facility if required. They would also permit a demonstration of the capabilities of the system and confidence to be gained in its operation.

TABLE III — *Satellite EPIRB link budgets*

	INMARSAT space segment		
	First generation		Second generation
	MARECS ⁽¹⁾	INTELSAT MCS	Specified ⁽¹⁾
<i>EPIRB-satellite 1.645 GHz</i>			
EPIRB elevation angle (degrees)	5		
EPIRB e.i.r.p. (nominal) (dBW)	0		0
Free-space path loss (dB)	189.2		
Atmospheric absorption loss (dB)	0.4		
Polarization coupling loss (dB)	0.5		
Satellite G/T (dB(K ⁻¹))	-10.7	-13.0	-12.5
Boltzmann's constant (dB(J/K))	-228.6		
Up-path C/N_0 (dBHz)	27.8	25.5	26
Satellite C/IM_0 (dBHz)	50.5	34.0	65
Transmitted $C/(IM_0 + N_0)$ (dBHz)	27.8	24.9	26
<i>Satellite-shore 4.2 GHz</i>			
CES elevation angle (degrees)	5		
Satellite e.i.r.p. (dBW)	-27.7	-40.9	-28.6
Free-space path loss (dB)	197.3		
Atmospheric absorption loss (dB)	0.1		
Polarization coupling loss (dB)	0.1		
CES G/T (dB(K ⁻¹))	32		
Boltzmann's constant (dB(J/K))	-228.6		
Down-path C/N_0 (dBHz)	35.4	22.2	34.5
Transmitted $C/(IM_0 + N_0)$ (dBHz)	27.8	24.9	26
Resultant link (unfaded) (dBHz)	27.1	20.3	25.3
$C/(IM_0 + N_0)$			
Required minimum C/N_0 (dBHz)	16	16	16
System margin (dB)	11.1	4.3	9.3

⁽¹⁾ Assumes 13 dB additional transponder gain.

4.14 For a pre-operational demonstration using INMARSAT satellites without the high gain amplifier (HGA), a 0 dBW satellite EPIRB e.i.r.p. could still provide adequate performance for pre-operational demonstration purposes but with a lower system margin (see Table III). It is considered that the HGA would be essential for a fully operational service, although the lack of such a facility should not delay the implementation of the system.

4.15 It was agreed that the pre-operational demonstrations should be limited to a common satellite EPIRB system. It was accepted, however, that administrations may arrange further national trials and present the results of these trials directly to CCIR Study Group 8. For example, the USSR intends investigating the possible advantages to system capacity of an M-ary (multi-position) coding technique.

4.16 Several administrations indicated an interest in being involved in pre-operational demonstrations.

4.17 The schedule assumed by the IWP 8/7 Sub-Group leading to the full implementation of a satellite EPIRB system in 1990 is as follows:

June, 1984 Interim Meeting of CCIR Study Group 8 to produce draft Recommendations;

1984 Development of satellite EPIRB production units;

1985 Planned start of pre-operational demonstrations;

1986 IMO-MSC approve performance standards;

1986 Technical specifications for satellite EPIRB and receiver processor;

1987 Type approval of production units and fitting;

1987 WARC for mobile services;

1988 Planned start of INMARSAT second generation space segment deployment;

1985-1990 FGMDSS transitional period;

1990 FGMDSS implementation.

5. Recommendations by IWP 8/7

5.1 The transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through geostationary satellites at 1.6 GHz as given in Recommendation 632 is based on the evaluation of the data presented in each participant's test report according to the procedures indicated in § 2, a comparison of the performance parameters of each system as summarized in § 3 and the conclusions reached in § 4. This recommendation does not take account of the cost of implementation of the system.

5.2 As a consequence of utilizing the satellite EPIRB characteristics given in Recommendation 632 there is a need to distribute the transmit frequencies of all satellite EPIRBs as uniformly as possible across the total available band.

5.3 In order that the effectiveness of a 1.6 GHz satellite EPIRB system can be demonstrated, and satellite EPIRB production units can be developed (including release mechanism, data interface and possible homing facilities), it is recommended that pre-operational demonstrations begin as soon as possible.

To ease the transition from the pre-operational stage to the fully implemented stage, and to facilitate satellite EPIRB operation it is suggested that INMARSAT include in its second generation space segment a high-gain satellite EPIRB band of 1644.3-1644.5 MHz in addition to 1645.5-1646.5 MHz in all Ocean Regions.

5.4 A number of operational, technical and administrative questions require study to enable the implementation of an operational satellite EPIRB system.

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[1978-82]: a. 8/501 (INMARSAT).

REPORT 761-2 *

**TECHNICAL AND OPERATING CHARACTERISTICS OF DISTRESS
SYSTEMS IN THE MARITIME MOBILE-SATELLITE SERVICE**

(Study Programme 17B/8)

(1978-1982-1986)

1. Introduction

The use of maritime mobile satellites for the handling of safety and distress communications is a matter of increasing importance. The International Maritime Organization (IMO) is placing a major reliance on the use of satellites for the relay of distress signals in the development and design of their Future Global Maritime Distress and Safety System (FGMDSS), which is scheduled to become operational in the early 1990s. IMO has requested that the International Maritime Satellite Organization (INMARSAT) include a satellite emergency position-indicating radio beacon (EPIRB) service in the initial INMARSAT satellite system.

This Report considers the major factors influencing the design of maritime distress systems using satellites and the associated technical and operating characteristics. Section 1 reviews the present terrestrial distress systems, the development of the satellite EPIRB concepts, and the developing operational requirements for a future system. Section 2 discusses some of the considerations to be taken into account when deciding on the development of such operational requirements. The technical requirements will depend on the various techniques used in individual systems; however, some of the considerations that will need to be taken into account, when deciding on technical trade-offs, are reviewed in § 3.

In § 4, a brief delineation of the characteristics of the various candidate systems designed to operate through geostationary satellites at 1.6 GHz and tested during the CCIR coordinated trials programme (CTP) is given. Also included in this section is a more detailed description of the system recommended for the FGMDSS as a result of these trials.

Section 5 briefly describes the low polar-orbiting system using the 406 MHz band and summarizes the test results obtained during an 18 month demonstration and evaluation phase. An assessment of this system's use through geostationary satellites together with a description of the planned tests to evaluate such use is given in § 6. The latter section also describes a possible 1.6 GHz system configuration that could be employed with high altitude, polar-orbiting satellites.

A summary of the highlights of the Report is given in § 7. An analysis of message integration and reliability for a geostationary system using the 406 MHz band is given in Annex I. Areas for further study needed to standardize systems are given in Annex II. Factors for a pre-operational demonstration of the 1.6 GHz satellite EPIRB system using geostationary satellites are described in Annex III.

1.1 Present terrestrial distress system

Statistics published by Lloyds of London show that there was an annual loss of 1113 vessels of over 100 gross tons for the year 1982. The growth of worldwide shipping and the introduction of larger, faster, more capital-intensive vessels will result in an increasing threat to loss of life and property at sea.

The probability of human survival decreases rapidly with time, following a distress occurrence, in particular, in cold weather conditions or where the survivors are in the sea. It is, therefore, fundamental to any distress system that the existence of the distress occurrence and its location is made known to those capable of rendering assistance in the minimum practical time. The present maritime distress system is based on a complicated interlinking of several elements, and uses telephony, Morse code telegraphy, or EPIRBs on existing allocated terrestrial frequencies. In most cases, the transmission of the message requires manual activation and manual operation. The successful receipt of a distress message depends on the propagation characteristics of the various available frequencies which in turn depend on the geographical location, the time of day, and season. Delays of several hours may result. Past failure to successfully execute a rescue, in some cases, has raised considerable concern internationally about the adequacy and effectiveness of distress and safety communications.

* The Director, CCIR, is requested to bring this Report to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

In order to overcome some of these problems, EPIRBs using terrestrial frequencies were developed for alerting ships in the vicinity, overflying aircraft, and shore stations of the occurrence of a distress. These EPIRBs have two separate designs:

- float-free, which is automatically activated in the event of a ship sinking,
- manually activated, to be carried in each survival craft.

The advent of maritime communication satellites (INMARSAT) presents the possibility of overcoming the problems referred to above. In addition, low altitude, polar-orbiting satellites as used in the COSPAS/SARSAT (see Note) system have demonstrated a significant improvement in the monitoring and locating capability of the EPIRBs operating at 121.5/243 MHz.

Chapter III of the Convention for the Safety of Life at Sea, 1974 (as amended), which refers to life-saving appliances, states that each ship to which the Convention applies shall carry on each side of the ship a manually activated EPIRB operating on 121.5 MHz and 243 MHz.

Note. – Space system for search of distressed vessels – search and rescue satellite-aided tracking.

1.2 *Space systems and satellite EPIRB concept development*

Satellite links are largely unaffected by propagation variations. A vessel in distress fitted with a ship earth-station would have a priority channel available for the transmission of the distress message. Such a service capability is currently provided by the INMARSAT system. More than 2500 vessels are currently equipped with INMARSAT ship earth-stations.

Not all vessels can be expected to be fitted with ship earth-stations. There also remains a need for automatic distress alerting in the event of a sudden foundering. Furthermore, if the crew of a vessel in distress take to survival craft, the use of the satellite system to maintain two-way communication with the shore or rescue vessels raises technical problems because survival craft cannot carry antennas of sufficiently high gain, although the concept of low *G/T* ship earth-stations is under study (see Report 921).

In order to meet these needs, the concept of a satellite EPIRB dedicated to providing distress alerting via satellite has evolved. Such equipment should be capable of fulfilling an alerting role in one or more of the following applications:

- manual activation from the bridge of the ship;
- float-free and automatic activation in the case of a sudden foundering;
- manual activation from on board a survival craft.

The same signalling techniques could be used in the three applications.

1.3 *Operational requirements*

The IMO Sub-Committee on Radiocommunications has defined the following operational requirements for satellite EPIRBs:

- (a) The Satellite EPIRB system should be part of the FGMDSS and so configured as to promote safety of life at sea in the highest possible manner.
- (b) To achieve this aim, the system should cover all navigable waters including those north of 70° N and south of 70° S. From considerations within IMO it has been agreed that the long range alerting function of the FGMDSS will be based primarily on the use of satellite techniques and will include the use of satellite EPIRBs. In COM 26/12 IMO stated: "...the development of satellite EPIRBs should adhere to the principles laid down in the carriage requirements (COM 25/12, Annex II, Part 3, § 4.3) and consequently be capable of alerting via the polar-orbiting system and the INMARSAT geostationary-satellite system."
- (c) From an operational point of view, no clear choice of a particular frequency exists. However, it is highly desirable that the future satellite EPIRB is designed in compliance with a single international standard and transmits on only one satellite frequency. It is desirable that a common frequency for satellite EPIRB transmissions should be provided for both geostationary and polar orbiting satellites. It is noted that 1.6 GHz band is used in the first generation INMARSAT satellites and that experiments are being conducted at 406 MHz with low polar-orbiting satellites.
- (d) The satellite EPIRB system should take into consideration the requirements of the aeronautical mobile service where a shared system might yield mutual benefits to both services and to search and rescue organizations.

- (e) Provision should be made in the system for satellite EPIRB signals to be treated as distress messages and correctly routed to the appropriate search and rescue authorities.
- (f) The satellite EPIRBs should operate for sufficient time to ensure a 0.99 probability of distress message reception and interpretation. It is desirable to achieve this probability as quickly as possible; however, the exact specification of this time will be dependent on system characteristics and implementation.
- (g) In regard to the number of simultaneous transmissions of satellite EPIRB alerting signals in any one ocean area, IMO is of the opinion that a satellite EPIRB system should support at least 20 satellite EPIRBs in a 10 min interval. In obtaining this estimate, both IMO convention and non-convention vessels were considered in an entire ocean area. The system should support this with a probability of 0.95. (However, in deriving this capacity figure, no consideration was given to the possible use of the system by the aeronautical and land mobile communities or to the possibility of satellite EPIRB generating false alarms.)
- (h) As a minimum, the satellite EPIRB system should provide the following information:
 - distress alerting;
 - identification of the unit in distress;
 - data which enables the SAR (Search and Rescue) authorities to determine the position of the unit in distress.
- (j) Optionally, and in addition to the above minimum, the satellite EPIRB system could provide information concerning the nature of distress.
- (k) A capability for homing is required. However, this is a terrestrial communication function which must operate and be compatible with the Future Global Maritime Distress and Safety System under consideration by the IMO.

2. Operational considerations

The operational requirements identified by the IMO for satellite EPIRBs, listed in § 1.3, call for worldwide coverage with negligible delay in the receipt of the distress message, together with a capability for the simultaneous reception of multiple transmissions. It can be assumed that these criteria will apply equally to ship and survival craft satellite EPIRBs. The preparation of operational requirements for a maritime distress system is the responsibility of the IMO. However, the following considerations are thought to be relevant to the development of these requirements:

- message transfer time and receiver sensitivity;
- system capacity;
- resistance to interference;
- coverage;
- effect of various sea states and environmental conditions on performance;
- contents of distress message;
- methods of positioning;
- maintenance of system integrity;
- the complexity and cost of distress equipment, satellite and coast earth-station equipment.

2.1 Message transfer time (MTT) and receiver sensitivity

The message transfer time (MTT) is defined as the time between the initiation of transmission by the satellite EPIRB and the read out of an error-free message at the receiving earth station with a 0.99 probability.

The receiver sensitivity is defined in terms of the minimum average C/N_0 at which the performance of the system remains within the IMO specified message reception probability for a single EPIRB transmission of 0.99.

With polar-orbiting satellite systems, the MTT will include a waiting time between satellite passes. This time is a function of latitude, orbit, and the number of satellites and the number and location of receiving earth stations.

2.2 System capacity

The system capacity is defined as the ability of the system to process a number of near-simultaneous transmissions with a probability of 0.95 without suffering degradation within the maximum allowable MTT or requiring additional satellite EPIRB transmitter power.

2.3 Resistance to interference

Resistance to interference is defined as the ability of the system to meet the IMO specified message reception reliabilities in the presence of a variety of interference types (of maximum specified power levels and minimum frequency separations) without suffering degradation within the maximum allowable MTT or requiring additional satellite EPIRB transmitter power.

2.4 Coverage

Systems designed to use geostationary satellites will have their coverage limited to latitudes approximately between the 70° parallels but would still serve the majority of world shipping. However, to provide coverage of the polar regions, polar orbiting satellites would be necessary. With polar orbiting satellites, distress alerting delays due to the intermittent passing of satellites will occur. This delay is greatest at the equator and depends on the number of satellites and receiving earth stations. One advantage of polar-orbiting satellites is that real-time positioning information is obtainable by Doppler measurement of the received satellite EPIRB signal. Up-dating of the distress position using Doppler measurement could expedite the search when satellite EPIRBs are carried on board survival crafts.

There would appear to be a case, therefore, for combining the advantages of geostationary and polar orbiting systems.

2.5 Effects of various sea states and environmental conditions on performance

Systems adopted for use in the FGMDSS must be capable of operating under extremely adverse sea states and environmental conditions without suffering degradation within the maximum allowable MTT or requiring additional satellite EPIRB transmitter power and should still meet the IMO specified message reception probability.

2.6 Contents of distress message

The distress message should contain, as far as possible, all relevant information about the incident. However, in the interest of decreasing the probability of error and also message acquisition time, the contents of the distress message should be limited to that which is essential. The possible contents of the message and the number of bits are shown in Table I in order of priority.

TABLE I – Content of distress message

The following particulars, listed in the preferred priority order for entry and read-out, should be included in distress messages to the extent practicable and necessary:

Item	Contents	No. of bits
1	Ship station identity	30
2	Position co-ordinates and information in the following order:	
2.1	Latitude in degrees and minutes	14
2.2	Longitude in degrees and minutes	15
2.3	Date and time of position up-date	11
3	Nature of distress	4
4	Course	9
5	Speed	6
6	Date and time of activation	11
7	Assistance desired and any other information which might facilitate the rescue ⁽¹⁾	

⁽¹⁾ Item 7 may be included with the data sent in item 3, if necessary.

Note. – The order of items does not necessarily mean that the message sequence during transmission follows exactly in this order but the input/output data could be used in the order as proposed by IMO and as given above.

2.7 *Methods of positioning*

Upon determination that an emergency or distress exists, the problem becomes one of determining the geographical position of the distress to a sufficient accuracy so that assistance can be effectively rendered.

Geostationary satellites can be used for position location by re-transmission of position data obtained by satellite EPIRBs from on board navigational systems, or by re-transmission of signals received by satellite EPIRBs from existing radionavigation or navigational satellite systems. Low-orbiting satellites can use either of these methods or can determine real-time satellite EPIRB position by Doppler shift measurements of the received satellite EPIRB signals.

2.8 *Maintenance of system integrity*

In the interest of the users, it would be highly desirable to ensure continued availability of adequate space segment facilities which meet the technical requirements that need to be established.

There may also be a need for the establishment of mandatory technical requirements for the satellite EPIRB, appropriate commissioning procedures, and the maintenance of an up-dated register.

2.9 *The complexity and cost of distress equipment, satellite and coast earth station*

In the interest of widespread acceptance, the cost of the system should be minimized. In particular the cost to the user, that is, the cost of the shipboard equipment, should be as low as possible.

The release mechanism for a float-free satellite EPIRB is also a particularly important area for further investigation.

3. **Technical considerations**

3.1 *Satellite orbits*

Two alternative satellite orbits are being considered: geostationary (at an approximate altitude of 36 000 km) and low altitude, near-polar (at an approximate altitude of 850 km). The satellite EPIRB should provide sufficient energy for maximum operational slant ranges. At 5° elevation angle these respective ranges are approximately 41 000 km and 3000 km.

Another parameter to be considered in the orbit evaluation is the resultant satellite earth coverage antenna beamwidth at the half power points. In the case of the geostationary satellite this beamwidth is around 17.3°, and for the low altitude satellite it is about 123°.

3.2 *Frequency considerations for distress systems*

The band 406-406.1 MHz is exclusively allocated to the mobile-satellite service (Earth-to-space) for satellite EPIRB use and development. The band 1645.5-1646.5 MHz is also allocated exclusively to the mobile-satellite service (Earth-to-space) and limited in use to distress and safety operations. The bands 121.45-121.55 MHz and 242.95-243.05 MHz are allocated by footnote to the mobile-satellite service for reception on board satellites of EPIRBs transmitting at 121.5 MHz and 243 MHz.

As a practical matter the up-link frequency choice is limited to the 406 MHz and 1.6 GHz bands. Either of these could be used with geostationary or near-polar orbiting satellites. However, trials with geostationary satellites have used the 1.6 GHz band because this band is used for normal communications, whilst tests with polar-orbiting satellites have been performed using a 406 MHz system based on a number of years of experience with operational 401 MHz meteorological satellite data collection systems.

The band 1544-1545 MHz is allocated exclusively to the mobile-satellite feeder service (space-to-Earth) for distress and safety operations which would include feeder links for satellite EPIRB systems and possibly down links to ship earth stations for distress and safety communications (see Report 921). Feeder links could also operate in fixed-satellite service bands used for normal satellite-to-Earth communications (e.g. 4 GHz band). Either down link could accommodate geostationary-satellite operations. However, feeder links for near-polar orbiting satellites would be limited to 1545 MHz, where experiments are being performed since geostationary satellites have priority in fixed-satellite bands (see No. 2613 of the Radio Regulations) and power flux-density limits in the 4 GHz band make large earth-station antennas necessary.

The other frequencies allocated in the maritime mobile satellite service may be used for distress and safety purposes.

The COSPAS/SARSAT system using low altitude, near-polar orbiting spacecraft has adopted the 406 MHz band for the up link and the 1544-1545 MHz band for the feeder link (space-to-Earth).

The first generation INMARSAT geostationary-satellite system does not have a 406 MHz capability; however, it provides a 1.6 GHz satellite EPIRB capability with feeder links in the 4 GHz band. Future generations of INMARSAT satellites are expected to continue this provision.

3.3 *Interference considerations*

The bands for the space-to-Earth feeder link (e.g. 4 GHz band) are heavily used for fixed-satellite systems. These bands are also allocated to other services such as fixed and mobile services. At this time, a channel is not allocated exclusively for satellite EPIRB use. The two bands 1544 to 1545 MHz and 1645.5 to 1646.5 MHz are allocated on an exclusive basis to the mobile-satellite service and are limited by a footnote to distress and safety operations.

The frequency band 1626.5-1645.5 MHz is also allocated on a primary basis by provision 730 of the Radio Regulations to the fixed service in seventeen countries. Satellite EPIRBs used in this band should be designed to operate reliably in the presence of anticipated interference since safety of life at sea is involved. Further study is therefore needed into the magnitude of the potential interference and the satellite EPIRB design implications (see Annex I to Report 917 and Report 1045).

3.3.1 *Interference from radio relay equipment*

A particular site selection for radio relay equipment could cause interference to a satellite EPIRB signal under certain circumstances. This small probability of interference could be eliminated by avoiding use of those specific channels used by satellite EPIRBs.

The use of suitable frequency co-ordination techniques, such as avoiding pointing at the geostationary orbit, could eliminate even this small probability (see Annex I to Report 917).

3.3.2 *Interference in the 406 MHz frequency band*

The 406-406.1 MHz frequency band has been allocated exclusively to satellite EPIRB transmission. This allocation was confirmed by the WARC MOB-83 and a Resolution was approved requesting elimination of all non-authorized transmissions at 406 MHz (see Resolution No. 205 (Mob-83)). However, interference has been experienced during the COSPAS/SARSAT demonstration and evaluation phase (see Report 919). A method for locating non-authorized transmissions has been successfully developed using COSPAS/SARSAT satellites (see Report 979) and several interfering transmitters have been eliminated from the frequency band.

4. **Geostationary-satellite systems using the 1.6 GHz band**

4.1 *Configuration*

As an important part of the FGMDSS defined by the IMO, satellite EPIRBs are required to be operational in the year 1990. It is expected that by this time the second generation of INMARSAT satellites will be operational and that they will be equipped with special amplifiers providing additional gain of approximately 13 dB compared to the normal maritime communication channels, thus resulting in the overall link improvement (down link included) of approximately 5 dB.

Tests in the coordinated trials programme (CTP) were carried out in the band 1644.3-1644.5 MHz using the available INMARSAT space segment. Continued use of this band is anticipated for the lifetime of the first generation space segment. Although it is expected that the second generation INMARSAT space segment will provide a continuing capability in this band, it will be desirable to encourage an eventual transfer of the satellite EPIRB operations to the band 1645.5-1646.5 MHz, which is limited by Radio Regulation No. 728 to distress and safety operation. This latter band will be implemented in the second generation INMARSAT space segment. In order to facilitate introduction of this distress and safety band, and to assure that uninterrupted service will be available to all potential users of satellite EPIRBs in this band, it will be necessary during the transition period to provide for receiver-processors operating in both bands.

4.2 Coordinated trials programme

The coordinated trials programme (CTP) of satellite EPIRBs was conducted between January 1982 and April 1983 and is described in Report 1045.

A list of the main characteristics of the systems tested in the CTP is provided in Table II. The capacity numbers shown in this table were derived for CTP conditions and were calculated in accordance with the method given elsewhere [Kaminsky *et al.*, 1983].

As a result of the CTP, the transmission characteristics of the recommended 1.6 GHz satellite EPIRB system are listed in Recommendation 632.

TABLE II – Summary of tested system parameters

System Parameter	DRCS, Germany (Fed. Rep. of)	FSK, Japan	SAMSARS, USA	United Kingdom	PN-PSK, Norway/ESA	EPIRB, USSR	PN-PSK, Japan
Frequency up-link (MHz)	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5
e.i.r.p. (W)	0.1	0.15	0.4	8	0.2	0.15	1
Information bit rate/modulation	32 bit/s, non-coherent FSK	63 bit/s, FSK	0.2- 0.7 bit/s, bi-phase PSK	10 bit/s, bi-phase PSK	11.61 bit/s, PSK on a sub-carrier	24 bit/s, FSK	2.5 bit/s, bi-phase, PSK
System capacity in 200 kHz bandwidth	33	133	170	218	57	26	407

4.3 System description

After activation, the satellite EPIRB transmits the distress message containing the ship station identity, position information, and additional information as shown in Table I. The transmission is repeated with a pre-selected duty cycle. Additionally, a transmitter for homing purposes is activated.

A block diagram of the system is shown in Fig. 1a. The parallel/serial shift register (memory element) contains the last up-dated distress message as provided through the ship navigation interface. Before transmission, a forward error-correcting code is applied which is described in Recommendation 632. An example of a transmitted data frame could consist of 20 sync. bits (not included in coding), 100 information bits, and 40 parity bits.

After being relayed by the satellite, the distress signal is down-converted at the earth station to the specified intermediate frequency and transferred to the computer-aided multi-channel receiver for satellite EPIRB message detection. The first stages are a down-converter to audio frequencies, an A/D converter, a filter bank, and an energy meter (Fig. 1b). The absolute values of each digital output are summed to provide a measure of the signal plus noise energy. The digital filter bank uses a polyphase principle and analyzes the spectrum with filters of 30 Hz bandwidth and in steps of 15 Hz which thus overlap each other. The channel identification after scanning all outputs follows a special strategy which includes correlation of the frequency offset between two filters which are equal to the transmitted deviation of the FSK signal; in addition, suppression of potential interferers and additional feedback from the bit sync. detector device are provided.

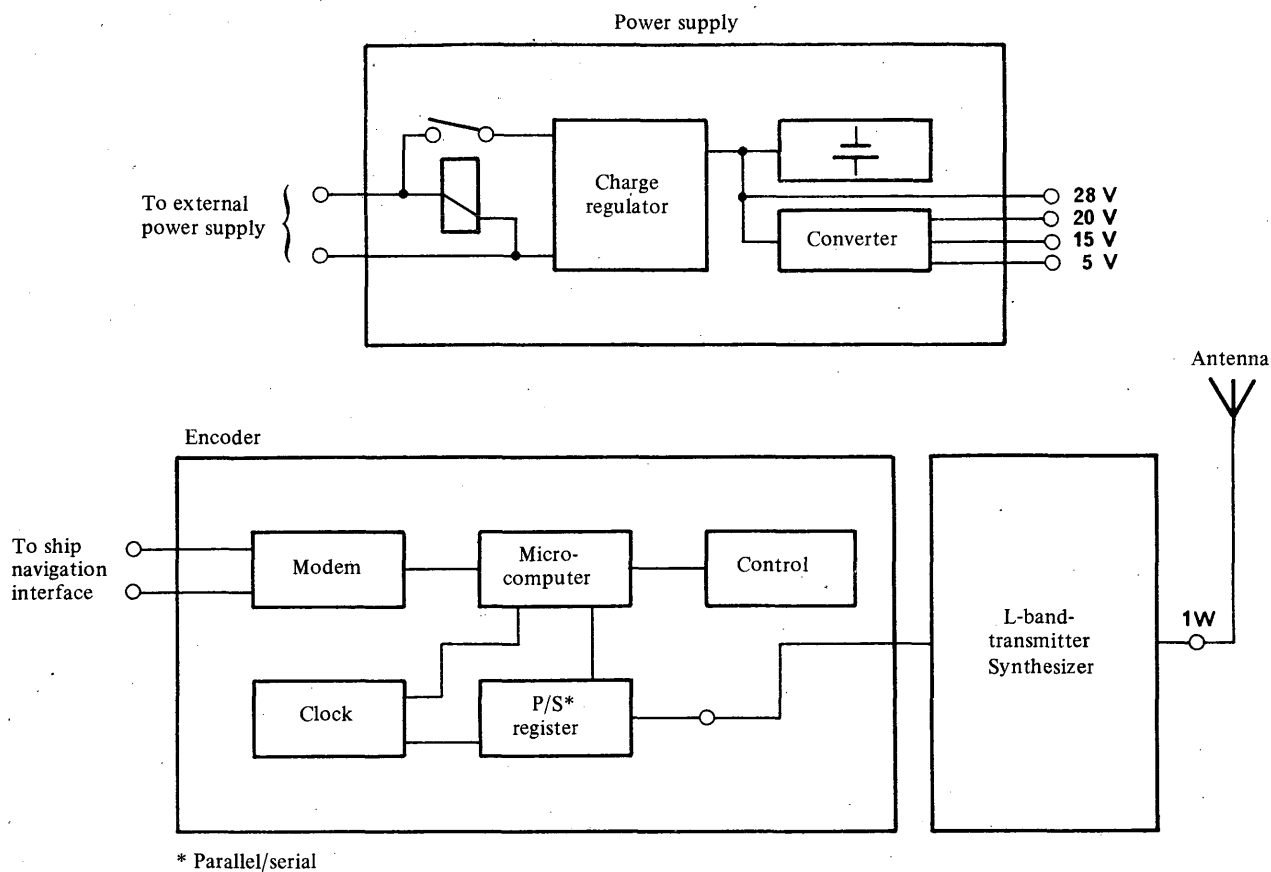


FIGURE 1a – Block diagram of the 1.6 GHz satellite EPIRB

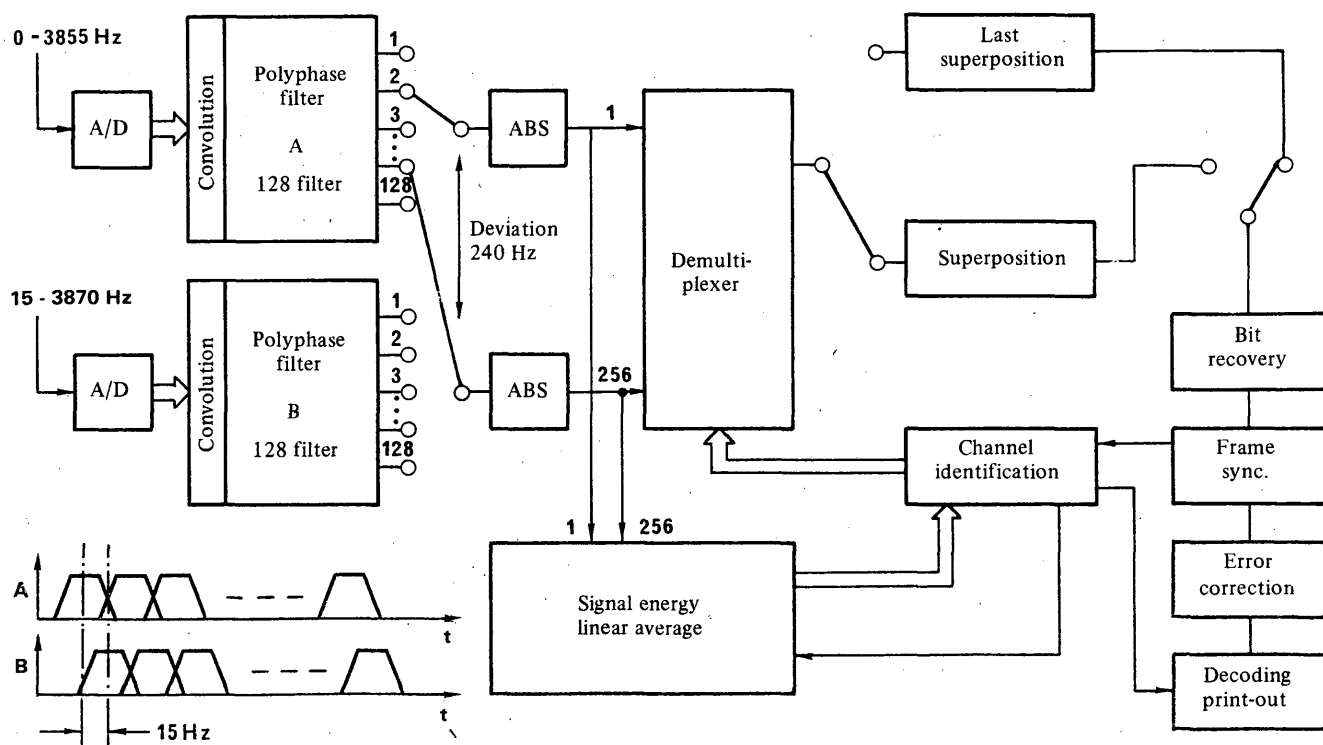


FIGURE 1b – Functional block diagram of the receiving and detection unit

A/D: Analogue-Digital converter

ABS: Automatic band switching

After the signal channels are identified, they are assigned to processor channels where the incoming signal plus noise is kept in a memory. In practice every doubling of the number of data frames results in a C/N_0 improvement of approximately 2 to 3 dB.

Every minute, which is equivalent to 12 superimposed frames, the memory is read out to obtain bit sync., frame sync., and for detecting the parity bits of the FEC. If synchronization is achieved and no more than 4 bit errors are detected, the message is decoded and printed out. If more than 4 bit errors are detected, the superposition is continued with a new trial every minute until the message is adequately detected.

The operating characteristics of this system are as follows:

- sensitivity limit for message reception
 - non-fading channel 13 dBHz
 - fading channel (1.6° elevation, 2.5 m wave height) 15.1 dBHz
- rejection of interferers outside signal filters (compared signals)
 - CW interferer > 10 dB
 - broadband interferer > 20 dB
- filter bank search rate (full performance) 60 Hz/s.

The superposition technique integrates all real-time signal fluctuations (Rayleigh distribution) in such a way as to produce a signal with a Gaussian distribution.

The basis of the system is that during all processing procedures, no decision is made prior to signal improvement by the superposition principle. In the data processing unit, an integration time of 10 s is used for superimposing the signal energy equivalent to $10 \times 32 = 320$ bits upon the noise energy in the time period. The decision for which sample the bit change occurs is made from 160 possible transitions. The decision of a bit being “1” or “0” is made from up to 128 superpositions of the data frame, the minimum being 12.

This signal processing technique is carried out in a non-coherent FSK system. A further important characteristic of this technique is the short acquisition time and the smoothing of the fading effects.

A system with a 1 W transmitter will have a margin of approximately 10 dB which gives additional safety against potential effects due to interference, sun noise degradation on the down link, equipment ageing, unfavourable conditions caused by shadowing by high waves and, to some extent, blockage by the ship. The nominal message transfer time using a 1 W transmitter is 1 min.

The high sensitivity of the receiver processor together with the inherent link margin enable operation at elevation angles down to approximately 0°, thus increasing the coverage area.

4.4 Other possible applications

A further application of this satellite EPIRB system is a small portable unit known as a “keyboard sender” which was tested in 1975 with the United States National Aeronautics and Space Administration (NASA) Application Technology Satellite (ATS-6).

The technique of message transfer is identical to the satellite EPIRB system except that a longer data frame is used. Thus, the keyboard sender, which is initiated by hand, is able to transmit not only the distress message of the satellite EPIRB but also an individual message of alphanumeric characters which may be input to a memory by means of a waterproof keyboard. It can be installed on the ship, using the vessel’s power supply and connected to a fixed antenna. Under these circumstances it can be used as a reserve transmitter. The same distress keyboard sender may also be easily disconnected in order to be used in a survival craft. The power is then supplied by an internal battery and the signal is transmitted via an antenna which is an integral part of the equipment.

5. Low altitude, polar-orbiting satellite system using the 406 MHz band

5.1 Frequencies and configuration

The COSPAS/SARSAT system was developed in order to receive and process distress alerting, reporting, and position location transmissions from satellite EPIRBs operating in the 406.0-406.1 MHz and 121.5 MHz frequency bands.

Further background information is contained in [Redisch and Trudell, 1978; Zurabov *et al.*, 1979; COSPAS-SARSAT, 1981; CNES, 1984] and in Report 919.

For the COSPAS system, search and rescue instrument packages are carried on board navigational satellites. Two launches have already taken place: Cospas-1 in June 1982, and Cospas-2 in March 1983. For both satellites the nominal orbital altitude is 1000 km, inclined 83° with respect to the equator.

For the SARSAT system, search and rescue instrument packages are placed on board meteorological satellites operated by the United States National Oceanic and Atmospheric Administration (NOAA). The first SARSAT instrument package was placed on board NOAA-8 and launched in March 1983. The orbital altitude is 833 km, inclined 98.7° with respect to the equator.

It is planned to maintain two COSPAS and two SARSAT satellites operating in orbit until at least 1990. The COSPAS/SARSAT satellite system serves the aeronautical community as well as the maritime community and will, in the future, also serve the land mobile community. This system has been used at 121.5 MHz to significantly augment the existing terrestrial distress alerting, reporting, and position location facilities by providing improved coverage, increased probability of detecting a distress event, and by decreasing the time elapsed between the occurrence of a distress event and its reporting to the SAR authorities.

5.2 *System description*

The satellite instrument package contains receivers operating at 121.5, 243.0 and 406.025 MHz, frequency translators, a signal processor, and a phase modulated transmitter operating in the 1544-1545 MHz band. Signals received by the satellite in the 121.5, 243.0 and 406.025 MHz bands are linearly down-converted and frequency division multiplexed before phase modulating (FDM-FM) the 1544.5 MHz transmitter. The signals received in the 406.025 MHz band undergo additional processing. A two-channel signal processor similar to the ARGOS processor (see Report 538) has been included in the instrument package. The processor demodulates the digital message from the received satellite EPIRB carrier and measures the carrier frequency to an accuracy of ± 0.5 Hz. Two channels of received digital messages and carrier frequency measurements are time tagged, formatted, bi-phase-L encoded, and transmitted in real time at a 2.4 kbit/s rate by direct phase modulation of the 1544.5 MHz carrier. The processed 406.025 MHz information is also stored in the spacecraft memory for later read-out. It is this feature that provides global coverage independent of earth-station location.

The 1544.5 MHz transmissions are received by local user terminals (LUTs). These earth stations use a 3 m diameter tracking parabolic antenna to achieve an antenna gain-to-noise temperature ratio (G/T) of $3 \text{ dB}(K^{-1})$. The 2.4 kbit/s bit stream is obtained by coherent demodulation of the carrier and is demultiplexed to obtain the satellite EPIRB message, frequency measurements, and time tags. The satellite EPIRB position is computed using the spacecraft ephemeris and time-tagged Doppler shift embedded in the satellite EPIRB carrier frequency measurements. Position location accuracy at 406.025 MHz is of the order of 2 to 5 km.

The linearly translated 406.025 MHz spectrum is also recovered by the coherent demodulation of the carrier and is used primarily for the purpose of characterizing the 406.025 MHz Earth-to-space channel. The characteristics of the 406 MHz satellite EPIRB and the message formats are given in Recommendation 633.

5.3 *Demonstration and evaluation phase*

The COSPAS/SARSAT system demonstration and evaluation phase involving tests at 121.5 and 406 MHz was started in February 1983. Search and rescue agencies and administrations from participating countries are involved in the system evaluation. LUTs and Mission Control Centres have been established in six of the participating countries and operational use of the system began in 1985, after the completion of the demonstration and evaluation phase.

Preliminary results of the system demonstration and evaluation are contained in Report 919 and in [CNES, 1984]. Despite the presence of interference in some areas of the world, basic performance requirements of the 406 MHz COSPAS/SARSAT system have been met. These performance requirements are summarized in Table III.

At 406 MHz, the system sensitivity, location accuracy (5 km), and capacity (over 90 simultaneous transmissions) meet or exceed the goal established for the COSPAS/SARSAT system. The trials and participation in actual distress incidents have proven that the COSPAS/SARSAT system provides an effective interaction with SAR services.

TABLE III — *Summary of system operational characteristics*

Operational requirements	Geostationary satellite	Low altitude polar orbiting satellite	Combined geostationary and low altitude, polar-orbiting satellite system	Combined geostationary and high altitude, polar-orbiting satellite system
Immediate alerting	Immediate alerting within coverage area	Average of 1 hour for a 4 satellite system	Immediate alerting except average of ½ hour in polar regions with a 4 satellite low altitude polar orbiting system [ORI, 1979]	Immediate alerting with three satellites in a high altitude, polar orbit
Identification	In message content	In message content	In message content	In message content
Positioning	Re-transmission of NAVAIDs or ship's position	Doppler measurement and possibly re-transmission of NAVAIDs or ship's position	Re-transmission of NAVAIDs or ship's position plus Doppler measurement	Re-transmission of NAVAIDs or ship's position plus Doppler measurement
Coverage	Limited to approximately between 70° N and 70° S	Global	Global	Global
Nature of distress (optional)	In message content	In message content	In message content	In message content

6. Other systems and arrangements under consideration

6.1 Introduction

The use of satellites for the handling of safety and distress communications is a matter of increasing importance. Both low altitude, polar orbiting systems and geostationary systems are under development and evaluation and these systems are complementary in terms of their ability to provide safety and distress communication. For example, a geostationary satellite system can provide near instantaneous alerting between the 70° parallels but not in the higher latitude regions. However, to provide coverage of the polar regions, deployment of polar orbiting satellites is necessary. These are subject to distress alerting delays due to the intermittent passing of satellites. The delays are greatest at the equator and they depend on the number of satellites and on the number of ground receiving stations. One advantage of polar orbiting satellites is that real-time position information is obtainable by Doppler measurement of the received satellite EPIRB signal.

There would appear to be a case, therefore, for combining the advantages of geostationary and polar orbiting systems (see Table III).

6.2 Use of geostationary satellites at 406 MHz

An experimental programme to evaluate the feasibility of using geostationary satellites in conjunction with the present polar-orbiting system to relay 406 MHz satellite EPIRB transmissions is under way. Tests will be conducted with satellite EPIRBs conforming to the technical characteristics contained in Recommendation 633.

A comprehensive demonstration and evaluation phase will be conducted with 406 MHz repeaters on board two NOAA geostationary operational environmental satellites, GOES-G and -H, starting in 1986 [Friedman *et al.*, 1984].

Following these tests, three subsequent GOES satellites, referred to as GOES-NEXT series, will be equipped with an improved transponder package to work with COSPAS/SARSAT beacons. This new transponder package has been funded to be available for use, if desired, starting about 1989 and continuing into the mid-1990s.

It is also possible that future generations of the INMARSAT geostationary satellite system could provide for operation with 406 MHz satellite EPIRBs.

6.2.1 *GOES experiment development summary and spacecraft coverage*

In order to demonstrate the performance of a combined system, the United States National Aeronautics and Space Administration (NASA) has embarked on a programme to develop a 406 MHz ground processor and a 406 MHz repeater on the GOES-G and GOES-H spacecraft. The Centre National d'Etudes Spatiales (CNES) in France, Morflot in the Soviet Union and the Canadian Department of Communications, are developing a similar ground processor. The Royal Norwegian Council for Scientific and Industrial Research (NTNF) will also participate in this programme.

The 406 MHz geostationary experiment will utilize a ground processor and the GOES-G and -H spacecraft, integrated with the *in situ* COSPAS/SARSAT system, to determine the role of instantaneous alerting in improving overall SAR operations.

An improved transponder package will be provided aboard the GOES-NEXT series of spacecraft. It is expected to yield an overall 3 to 4 dB improvement in the earth station received C/N_0 . This improvement will be derived as a result of three modifications in the spacecraft:

- reduction of the receiver RF filter bandwidth from about 120 kHz to 80 kHz;
- 1 to 2 dB improvement in G/T due to tapping the signal from the antenna with an optimized diplexer, thus not sharing the power with the data collection platform (DCP) channel; and
- addition of a dedicated down link at 1544.8 MHz with increased power output, which will occupy a bandwidth of about 100 kHz.

The approximate earth coverage achievable with two GOES spacecraft deployed over 135° W and 75° W longitudes, respectively, is depicted in Fig. 2.

6.2.2 *The 406 MHz geostationary satellite test plan*

The goal of the 406 MHz SARSAT-GOES experiment is to check the utility of integrating a near-instantaneous alerting capability achievable by the geostationary-satellite system with the already demonstrated location capability of the low altitude, near-polar orbiting satellite system. In recognition of the extensive work recently performed in the 1.6 GHz frequency band by the CCIR coordinated trials programme (CTP) participants, who used the geostationary satellites of the International Maritime Satellite Organization (INMARSAT) [Johnson, 1983], it is intended to carry out the 406 MHz GOES technical tests in a similar manner so as to simplify later comparisons and to take advantage of the extensive experiment design work already performed.

6.2.3 *406 MHz SARSAT-GOES tests*

6.2.3.1 *Objectives*

The objectives of the 406 MHz SARSAT-GOES tests are:

- an evaluation of the technical performance of a variety of SARSAT beacons (EPIRBs, emergency locator transmitters (ELTs), and hand-held devices) transmitting through a geostationary-satellite system under different operational environment conditions;
- the establishment of an integrated communications and information network between geostationary and low altitude, near-polar orbiting satellite system alert terminals and rescue forces;
- the conduct of pseudo-real distress incident demonstrations using separately and jointly the low altitude, near-polar orbiting and geostationary-satellite systems;
- the conduct of a coordinated test programme with other interested nations; and
- the design of experiments to parallel the CTP in order to allow for a near-direct comparison of results.

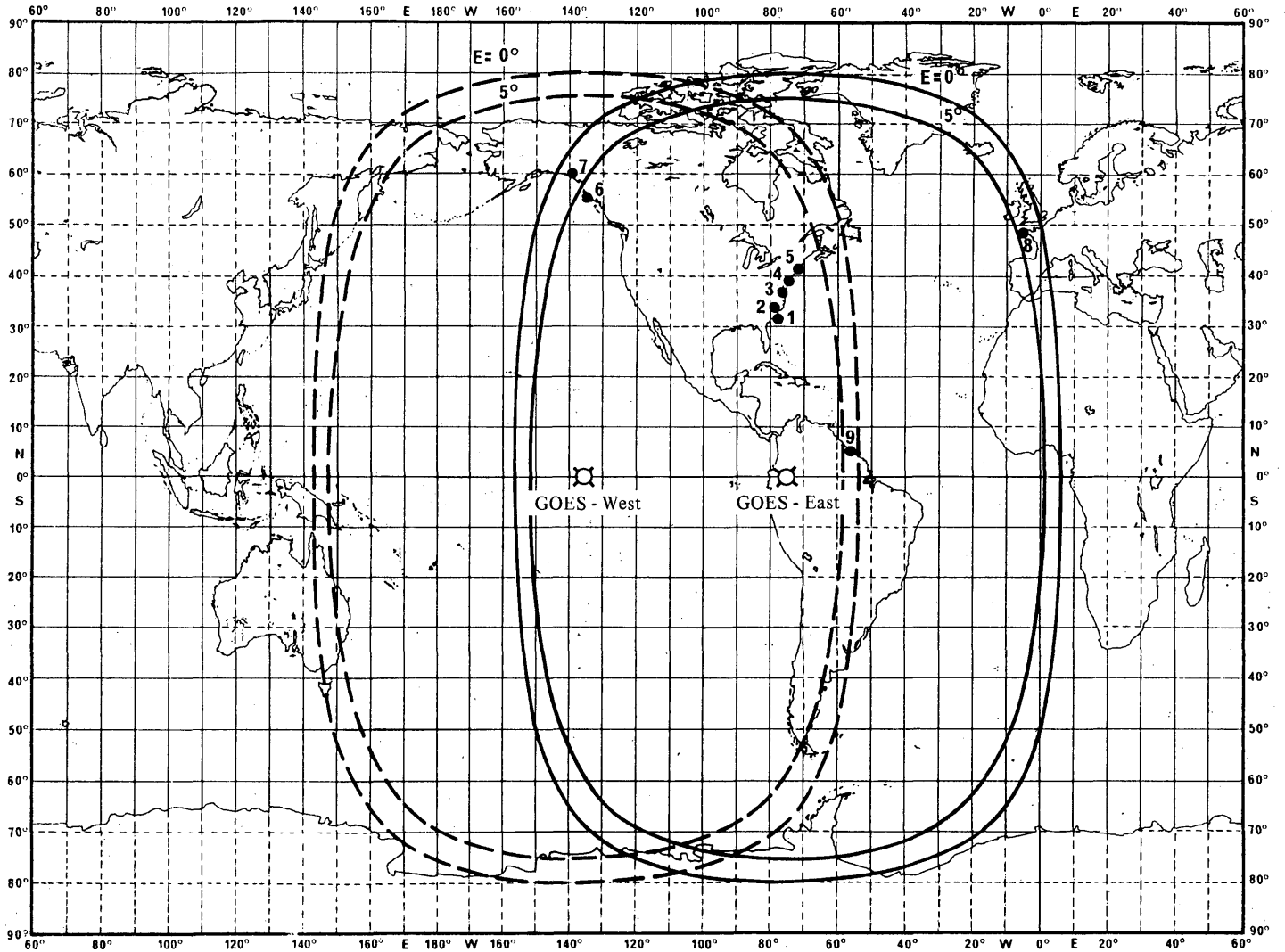


FIGURE 2 - Earth coverage by GOES satellites

- GOES - East coverage
- - - GOES - West coverage
- E - Elevation angle
- 1 - SEDL Greenbelt, MD
- 2 - Wallops Island, VA
- 3 - Long Island, NY
- 4 - Portsmouth, ME
- 5 - Jonesport, ME
- 6 - Sitka, AK
- 7 - Yakutat, AK
- 8 - Lannion
- 9 - Kourou

6.2.3.2 Configuration

The present United States experiment design envisages the use of the NASA/Goddard Space Flight Center SEDL (System Evaluation and Development Laboratory) and the GTL (GOES Test Laboratory) facilities as the earth station; the two GOES satellites, East and West, as the test spacecraft; and a number of locations at sea and on the ground for beacon deployment in Maine (between Jonesport and Portsmouth) and Alaska (around Yakutat and Sitka). There is also a possibility of additional deployment of satellite EPIRBs off the coast of Wallops Island, Virginia or Long Island, New York. Under the current plan, the ground processor in France is to be implemented at the Lannion, Brittany, Meteorological Space Centre. The test sites are proposed to be located off the coast of Brittany and near the Kourou Space Centre in French Guyana. Such a deployment of beacons would assure an entire elevation angle range from about 3.5° to 63° (if necessary, lower elevation angles could also be attained). The various proposed sites and their elevation angles with respect to GOES-East and GOES-West spacecraft are shown in Table IV.

TABLE IV — *Proposed SARSAT-GOES test sites*

Test site		Elevation angle	
Name	Approximate co-ordinates	GOES-East	GOES-West
<i>USA</i>			
SEDL, Greenbelt, MD	39.0° N, 77.0° W	45.0°	16.0°
Wallops Island, VA	37.8° N, 75.5° W	46.5°	16.2°
Long Island, NY	40.5° N, 74.0° W	43.3°	13.4°
Portsmouth, ME	43.0° N, 71.2° W	40.5°	10.4°
Portland, ME	43.6° N, 70.2° W	39.5°	9.4°
Jonesport, ME	44.5° N, 67.5° W	38.0°	7.3°
Sitka, AK	57.2° N, 135.9° W	6.8°	25.0°
Yakutat, AK	59.5° N, 139.9° W	3.6°	22.5°
<i>France</i>			
Lannion, Brittany	48.7° N, 3.5° W	3.4°	Not visible
Coast of Brittany	49.0° N, 6.0° W	4.9°	Not visible
Kourou, French Guyana	5.2° N, 52.7° W	63.2°	Not visible

6.2.3.3 Test description

6.2.3.3.1 Calibration tests at SEDL

The first series of SARSAT-GOES tests will consist of calibration tests, where the SEDL/GTL facilities would serve as a transmitting and a receiving site. During these tests, the beacons will transmit signals to the GOES spacecraft using calibrated directional antennas from the SEDL. The SEDL equipment complement includes a steerable Yagi antenna designed for this purpose. After the re-transmission of signals by GOES at 1698.65 MHz, they would be received by GTL's 7.3 m dish, down-converted, and then demodulated, displayed, and recorded for post-test analysis by SEDL.

It is presently planned to conduct two types of calibration tests: non-fading channel tests and fading-channel tests. During the non-fading tests, the signal would be transmitted and received as previously described. However, for the fading-channel tests, a channel simulator characterizing a satellite EPIRB signal fading characteristic in amplitude and phase would be inserted between the output of the beacon and the SEDL up-link equipment. The remainder of the transmissions and their reception would be the same as for the non-fading tests. Also, the non-fading channel tests will be conducted without additional outside interference. However, the fading-channel tests are planned to be conducted with and without interference. Based on the results of some of the interference tests, the approximate capacity of the system will be computed.

Testing of the Lannion ground processor during the SEDL calibration transmissions is also envisaged.

6.2.3.3.2 *Environmental tests*

During the second series of SARSAT-GOES tests, the beacons (EPIRBs, ELTs, and hand-held devices) will be deployed at specially pre-selected sites. The receivers will be located at SEDL and Lannion.

The objective of these tests would be the determination of effects caused by such geometric and environmental parameters as elevation angle, sea state, wave blockage for EPIRBs, or foliage and terrain blockage for ELTs and hand-held devices, and signal level degradation.

6.2.4 *Link budgets*

The experiment is designed to be performed with the minimum impact on existing spacecraft design. The GOES-G and -H spacecraft modifications include a 100 kHz bandwidth receiver channel at 406.050 MHz and a combiner to allow transmission using the same down-link equipment as the existing data collection platform receive (DCPR) channel. The transmitter power allocated to SARSAT has been kept to the minimum possible to avoid degradation of the operational DCPR system.

As is evident from the link calculations, (see Table V), the relayed beacon signals will have marginal signal-to-noise ratio for detection by conventional techniques. The transmission characteristics of the COSPAS/SARSAT satellite EPIRB (i.e., a transmission rate of 400 bit/s) when used with the SARSAT demodulator/signal processor, require detection of the preamble within 100 ms and near-instantaneous lock-on of a phase-lock receiver for detection of the data bits. At 400 bit/s, even assuming ideal demodulation, the resulting S/N of approximately 5 dB will not support reliable data transmission. One would expect an element error probability under non-fading conditions or approximately 2×10^{-1} with an additional degradation of 3 to 6 dB under conditions of Rayleigh fading.

6.2.5 *Conceptual design of ground processor*

Fortunately, the 406 MHz beacon (see Recommendation 633) has several attributes that permit the development of a technique that will allow the demodulation of the beacon data with acceptable error rates. The first characteristic is that the essential portion of the beacon message, i.e., the 60-bit field that uniquely identifies the particular beacon associated with a specific vessel or aircraft, does not vary from transmission to transmission. This property allows one to develop a means for multiple message integration. By integration of multiple messages, one can increase the effective signal-to-noise ratio and achieve the desired error rate. The existence in the 406 MHz signal of a robust error correction code allows the desired goal of an error rate of 1×10^{-5} to be more rapidly achieved. The truncated (127 : 106) BCH code used, reduces the required S/N ratio. Therefore, one can expect reasonable data reception with an integration of up to 10 messages (see Annex I).

The problem is complicated by several other parameters of the system. First, the beacons, by design, do not transmit at precisely controlled intervals; rather, their nominal transmission time interval of 50 s includes a random variation of $\pm 5\%$. Given this designed time variability one cannot predict, except in a relatively gross sense, the time of occurrence of subsequent messages. Second, the field of view of a geostationary satellite can be expected to contain several active beacons. At a minimum, there are the calibration beacons that are maintained for the low-orbiting system. The field of view of GOES-East (at 75° W), for example, encompasses at least four calibration beacons sited at locations where the elevation angles are optimal, and there are potentially two others that, although at relatively low angles, can be expected to appear in the spectrum. These beacons can be considered as the minimum overhead on the system.

These primary characteristics determine the base-line requirements for the processing system. The processor must:

- operate on individual messages at C/N_0 of less than 30 dBHz;
- be capable of identifying, collecting, and sorting subsequent messages from a particular satellite EPIRB and to perform the integration functions;
- be capable of integrating at least 10 messages;
- be capable of performing its functions with at least 20 simultaneously activated satellite EPIRBs in the field-of-view;
- be capable of interpreting the BCH code and performing appropriate corrections to data;
- operate in presence of CW interference; and
- operate in near real-time.

TABLE V — SARSAT-GOES satellite power budgets

Satellite	GOES-West	GOES-East
Parameter	Nominal	Nominal
<i>Up link</i>		
Frequency (MHz)	406.05	406.05
Elevation angle (degrees)	5	5
EPIRB/ELT power output (dBW)	7.0	7.0
Antenna gain (dBiC) ⁽¹⁾	-3.0	-3.0
Free-space loss (dB)	176.9	176.9
Satellite antenna G/T ratio (dB(K ⁻¹))	-22.0 ⁽²⁾	-24.0 ⁽³⁾
Boltzmann's constant (dB(J/K))	-228.6	-228.6
Up link C/N_0 (dBHz)	33.7	31.7
<i>Down link</i>		
Frequency (MHz)	1698.65	1698.65
Elevation angle (degrees)	16.0	45.0
e.i.r.p. satellite (dBW) ⁽²⁾	3.0	3.0
Power sharing loss (dB) ⁽⁴⁾	17.0	18.8
e.i.r.p./EPIRB (dBW)	-14.0	-15.8
Satellite antenna off beam loss (dB)	1.7	0.9
Atmospheric attenuation (dB)	0.2	0.1
Free-space loss (dB)	189.0	188.5
Ground antenna G/T ratio (dB(K ⁻¹)) ⁽⁵⁾	15.5	15.5
Boltzmann's constant (dB(J/K))	-228.6	-228.6
Down link C/N_0 (dBHz)	39.2	38.8
Up link C/N_0 (dBHz)	33.7	31.7
Overall C/N_0 (dBHz)	32.6	30.9

⁽¹⁾ dB relative to an isotropic antenna with circular polarization.

⁽²⁾ Per specification.

⁽³⁾ Assumes additional 2 dB pad inserted between antenna and pre-amp.

⁽⁴⁾ Power sharing between noise and 8 simultaneously transmitting signals.

⁽⁵⁾ Using NASA/Goddard Space Flight Center GOES Test Laboratory's 7.3 m antenna.

The concept that has been adopted [Davisson *et al.*, 1984] utilizes a digital processing technique. Conceptually, it consists of a high resolution fast Fourier transform (FFT) followed by an array processor operating in conjunction with a general purpose computer. This system, to date, has been tested with computer-generated simulated data and has produced successful results.

6.2.6 406 MHz SARSAT-GOES test schedule

The 406 MHz SARSAT-GOES Experiment is a 5-part test programme that already has been funded and is presently scheduled to continue through 1989. It consists of:

- spacecraft development and deployment:
 - GOES-G launch — first quarter 1986
 - GOES-H launch — first quarter 1987;
- receiver/processor development completion — first quarter 1986;
- MCC interface development completion — last quarter 1986;
- experiment preparation and execution — mid-1986 to mid-1988; and
- data analysis and reporting — to mid-1989.

6.3 Use of polar-orbiting satellites at 1.6 GHz (SERES)

Studies are being carried out in the Federal Republic of Germany to demonstrate the possible use of polar-orbiting SEArch and REscue Satellites (SERES) for the purpose of satellite EPIRB distress alerting with a minimum MTT and position up-dating using the 1.6 GHz band. Two ranges of orbit altitudes for the polar-orbiting satellites have been considered:

- low altitudes below the Van-Allen belt (up to 1400 km); and
- high altitudes above the Van-Allen belt (from 11 000 km).

For these orbit altitudes, the number of satellites and orbital planes have been optimized (i.e. minimized). The MTT which is a function of the inclination, the minimum elevation angle, and the orbit altitude had also been analyzed.

A requirement exists for the use of the minimum number of satellites for achieving 100% coverage in the polar regions with a short (about 10 min) alerting time.

To meet this requirement the analysis showed that low altitude orbits required 24 satellites (4 orbital planes with 6 satellites each), whereas the high altitude orbits required 3 satellites. Therefore, the SERES study concluded that only orbits with altitudes above the Van-Allen belt ($\geq 11\,000$ km) should be considered. In Fig. 3 such an orbit configuration is shown: one orbit with three satellites, altitude 12 000 km, inclination 90° . In this configuration no time delays occur for buoy positions above 59° N (or south).

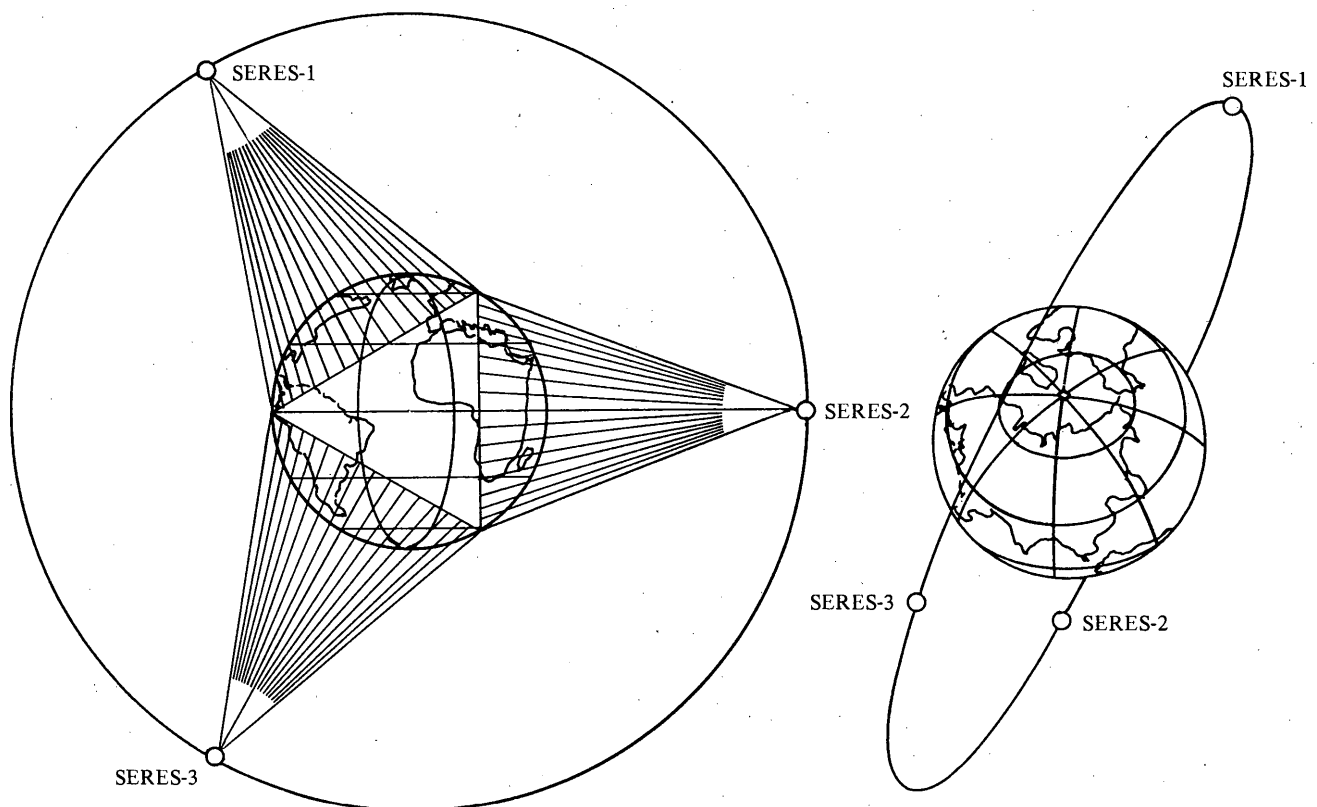


FIGURE 3 – Orbit configuration above the Van-Allen belt

The SERES system, if combined with the INMARSAT system, will provide primary FGMDSS functions which are summarized as follows:

- Distress alerting through:
 - geostationary satellites with a coverage between the latitudes of 70° S and 70° N;
 - SERES satellites in the polar regions.

- Positioning by:
 - transmission of ship-originated data through the geostationary INMARSAT satellites in the INMARSAT coverage areas;
 - Doppler shift measurement by the polar-orbiting SERES satellites in the polar regions.

In addition, such a combined system would automatically provide a back-up system:

- for distress alerting through SERES satellites in the INMARSAT coverage areas;
- for positioning by Doppler shift measurement through SERES in the INMARSAT coverage areas; and
- for positioning by transmission of the position data through SERES in the polar areas.

Therefore, 3 INMARSAT satellites (of the next generation) and only 3 additional SERES satellites are necessary. In Fig. 4 the INMARSAT constellation and the SERES orbit configuration above the Van-Allen belt are shown. There are no contact time delays between INMARSAT and SERES satellites.

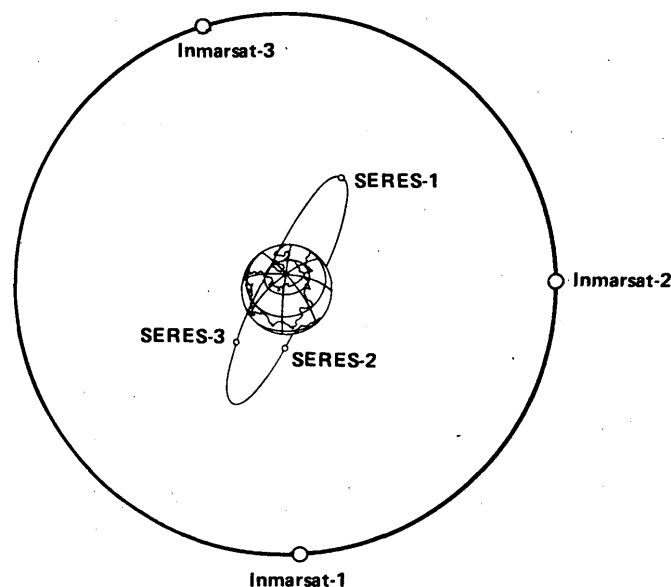


FIGURE 4 – INMARSAT and SERES – orbit configuration

In addition to these SAR functions, the SERES may also include a limited number of communication channels for offering commercial service in the polar regions. The type of communication, voice or telex, requires further study in the area of acceptable cost-benefit relationships.

Under consideration in the present studies of the Federal Republic of Germany is a network of earth stations capable of tracking the SERES satellites. These stations may be collocated with INMARSAT CESs as shown in Fig. 5. Initial results show that eight stations (four in Southern Hemisphere, four in the Northern Hemisphere) are required to track the satellites and to give near-instantaneous alerts.

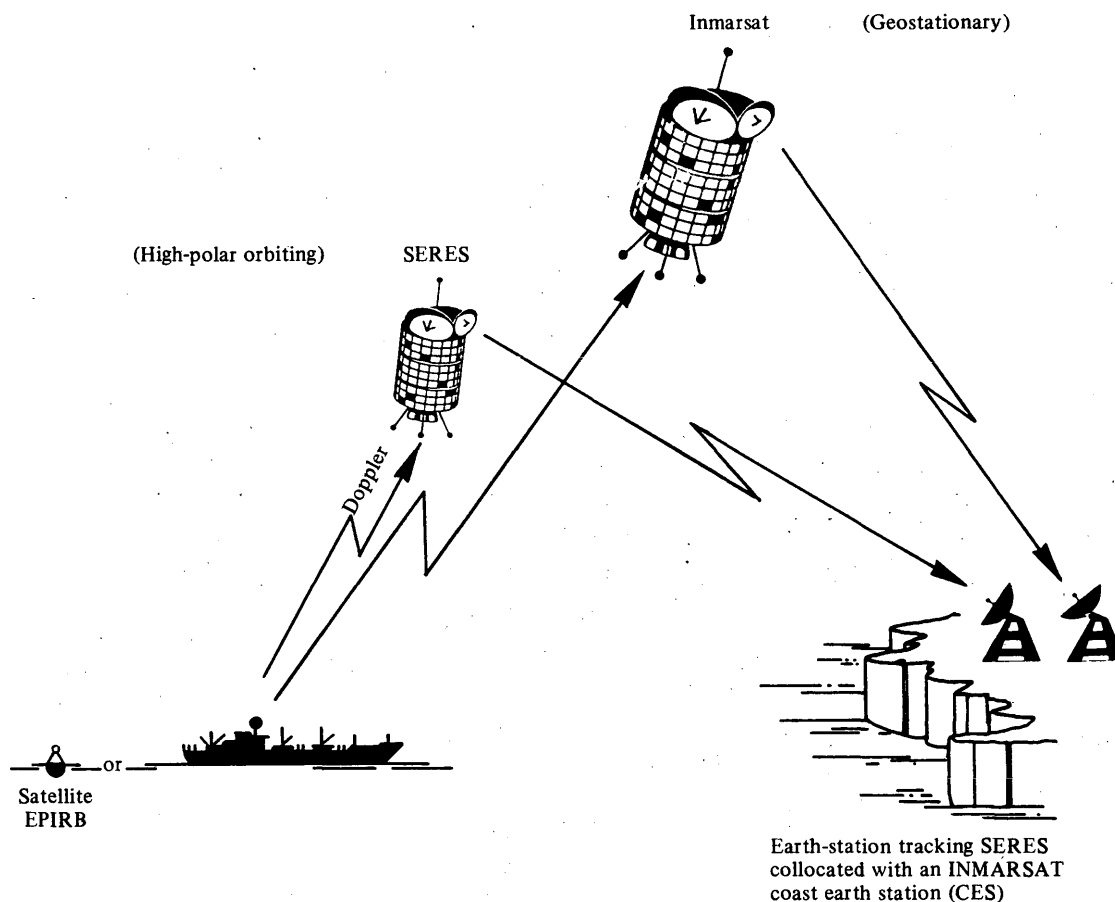


FIGURE 5 – SERES/INMARSAT system

Compatibility of the 1.6 GHz satellite EPIRB system with the high polar orbit satellite system (12 000 km) is under study in the Federal Republic of Germany. Initial results indicate that it is feasible to detect with minor degradation, the signal within a short message transfer time.

6.4 Position up-dating for satellite EPIRBs operating through a geostationary satellite

6.4.1 Position up-dating using navigation data

The position up-dating in the polar-orbiting satellite EPIRB system is accomplished by measuring the Doppler shift in the signal received on board the moving satellite in combination with the position of the satellite at the moment of the reception of the signal from the satellite EPIRB. In a satellite navigation system, the position is obtained by using Doppler shift in the opposite direction, i.e. on board the ship, the Doppler shift is measured in the signal transmitted by the moving satellite in combination with the position of the satellite at the moment of transmission. If the transmission of such a moving satellite were received and the satellite EPIRB re-transmits this signal through the geostationary-satellite system to a coast earth station, then position up-dating could be obtained using the navigation satellite position information and the Doppler shift in the signal.

For position up-dating in geostationary-satellite EPIRB systems, two methods are presently provided: the input of actual position data into satellite EPIRBs at regular time intervals is performed either manually during the change of the watch using a keyboard or by automatic data transfer from terrestrial or satellite navigation systems used on board ship. Alternatively a position-determining device could be built into the satellite EPIRB thereby making either an interface with the ship's navigation system or a manual keyboard unnecessary.

Only satellite navigation systems would offer world-wide random access. With a built-in position determination device, the capability for rapid alerting in combination with an independent and near real-time position up-dating for EPIRBs operating through geostationary satellites, could be achieved. If satellite EPIRBs are developed with this capacity, the duty cycle should be reconsidered to include operation over at least 24 h.

The global positioning system (GPS) currently offers one possibility for providing for position determination inside the satellite EPIRB. This system is described in Report 766. Its frequency $L_1 = 1575.42$ MHz would be close to the EPIRB transmission frequency, and thus the same antenna could be used. GPS provides an accuracy of about 150 m. The first fix would be obtained in about 15 min if the EPIRB was switched on without knowledge of the ephemeris.

Two other potential navigation systems are under study. NAVSAT is a system proposed by ESA for civil users. With 24 satellites in 12 h orbits, at least 6 satellites will be visible from any point of the Earth. The receiving technique is based on Doppler measurements with accuracies similar to GPS. The estimate for the time-to-first-fix is 3 min.

The Global radio navigation system (GRANAS) is a system proposed by the Federal Republic of Germany. With 20 satellites in 12 h orbits, at least 5 satellites will be visible from any point of the Earth. Each Granas satellite would determine its own position by two-way ranging. Each burst used for user position computation, based on pseudo-range measurements, contains the complete position information of the satellite. Thus, the estimation for the time-to-first-fix is reduced to 20 s.

6.4.2 *Position up-dating by other means*

A different approach which would make up-dated position information available at the RCC could be to utilize a satellite EPIRB capable of operating with the COSPAS/SARSAT low polar orbiting satellite system as well as with the geostationary-satellite system (see also § 2.4).

6.5 *Position location and distress signalling using radiodetermination-satellite service systems*

A radiodetermination-satellite service (RDSS) system is currently proposed for operation in the United States of America and nearby coastal waters, beginning in the 1987-1988 time frame. It is expected to have the capability of providing position determination and short digital message service to land-based, maritime and airborne users within its service area. The satellite as currently proposed would transmit a continuous carrier to all of its users in the band 2483.5-2500.0 MHz. Those users wishing to have the system compute position information or to send a brief digital message (e.g. distress condition) would respond to certain time markers in the satellite transmissions with a position request and/or a message. The response by the user is transmitted in the frequency band 1610.0-1626.5 MHz and would be received by two or more geostationary RDSS satellites and relayed to a central control earth station. Based on the propagation delay of the signals relayed through the satellites and known information concerning the elevation at the Earth's surface, a computer at the central earth station computes the precise position of the responding user. The user's position could then be sent to the user and/or message relayed to other users. A more detailed description of the RDSS system is contained in Report 1050 and [O'Neill, 1985].

One function of the RDSS system could be to relay distress messages, along with the precise position of the user in distress, to the appropriate search and rescue authority. The distress signal would be initiated by entering a distress code into the transceiver. Activation could be manual or automatic. This code would then be transmitted to the satellites and relayed to the central control earth station which would interpret the code as well as determine the position of the sender. This information could then be relayed to the appropriate authority. The design objectives of such a system are low cost and small size of the user transceiver, nearly instantaneous system access and the fact that users in distress do not need to know their position. In addition, the RDSS system would be a continuously operating system, providing position information and message service to a large group of users on an on-going basis. The currently proposed RDSS system would be limited to coverage of the United States of America and nearby coastal waters, and any similar RDSS system utilizing geostationary satellites would be limited to serving users located between the latitudes of about 70° N and 70° S.

7. **Summary**

The opportunity for achieving a means of long range distress alerting by the use of satellite techniques has been identified. The possible considerations to be taken into account when deciding on the operational requirements have been suggested.

Extensive experimental work has already been carried out with favourable results. Demonstration of the 406 MHz low orbiting satellite COSPAS/SARSAT system and a geostationary-satellite system using 1.6 GHz has already provided positive results on the use of satellite EPIRBs for search and rescue operations.

Pre-operational demonstration of 1.6 GHz satellite EPIRBs using the INMARSAT satellites is under consideration; demonstration of 406 MHz COSPAS/SARSAT satellite EPIRBs is scheduled in 1986 for operation with United States of America GOES geostationary environmental satellites.

Operational requirements have been identified by the IMO for satellite EPIRBs. It has been assumed that these will apply equally to ship and survival craft satellite EPIRBs.

IMO's attention should be drawn to the need to study release mechanisms and activation.

The frequency allocations in the 1.5/1.6 GHz bands provide for both communications and distress and safety operations, whereas the allocation at 406 MHz provides an exclusive band for satellite EPIRBs in the Earth-to-space direction. These frequency allocations appear to be adequate.

The Future Global Maritime Distress and Safety System may include the use of geostationary and low altitude near-polar orbiting satellites. The technical, operational, and economic impacts of satellite EPIRBs operating at one or more frequencies via one or more satellite systems on both the satellites and coast earth stations need to be assessed.

It is highly desirable operationally that each system conform to a single international standard.

The list of areas for further study given in Annex II is regarded as a necessary step for achieving standardization.

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ANNEX I

MESSAGE INTEGRATION AND RELIABILITY
FOR GEOSTATIONARY SYSTEM USING 406 MHz BAND

1. Message integration and alerting time

The use of multiple messages (e.g. majority logic decoding) may reduce the necessary threshold levels. This in turn may reduce satellite antenna gain or increase signal margins but will increase the time necessary for alerting. The alerting time also depends on the number of users. The detailed trade-offs for system capacity and alerting have not yet been undertaken for the geostationary system using the 406 MHz beacons. However, a first estimate may be obtained by considering only message overlap probability with no majority logic decoding.

The probability of mutual interference is given by [Texas Instruments, 1977].

$$P_I = 1 - \left(1 - \frac{2\tau}{T} \cdot \frac{2\Delta f}{F}\right)^{N-1}$$

where:

- P_I : the probability of mutual interference
- N : the number of satellite EPIRBs in the field of view
- τ : the duration of a burst transmission in seconds (440 ms)
- Δf : the total signal bandwidth in kHz (1.5 kHz for -10 dB bandwidth)
- T : the period between burst transmissions in seconds (50 s)
- F : the total search spectrum in which signals may exist in kHz ($F = 8$ kHz)

The quantity F is the band of frequencies over which the satellite EPIRB centre frequencies are distributed. The value for F is estimated from the total search bandwidth of the onboard processor in SARSAT which is 24 kHz [SARSAT, 1979] reduced by the total Doppler excursion (± 8 kHz) which only exists for the low altitude satellite system.

Substituting,

$$P_I = 1 - (0.9934)^{N-1} = 0.4809$$

The probability of no interference on the first burst is P where $P_s = 1 - P$ and on subsequent bursts the probability of at least one burst in j tries without interference is given by:

$$P_{sj} = 1 - P_I^j = 1 - \binom{j}{0} P_s^0 (1 - P_s)^{j-0}$$

The parameter j is related to the maximum delay in alerting, T_a , by $T_a = (j - 1)T$

For $N = 100$ platforms $j = 1$ and $T = 0$ s

$$P_{sj} = 0.52$$

For $j = 7$, $T_a = 300$ s

$$P_{sj} = 0.99$$

Using this preliminary analysis it is possible for the geostationary system to provide alerting within 6 min when 100 satellite EPIRBs are within the coverage area. It is necessary to further refine this analysis to carefully consider and include the effects of the actual dispersion of frequencies and the likelihood of detecting and correctly decoding the transmitted messages.

2. Message reliability

The experimental 406 MHz satellite EPIRB message contains a BCH error-correcting code capable of correcting 3 bit errors in the fixed portion of the satellite EPIRB message (82 bits). Using this code, the probability of a message error in the fixed (see Recommendation 633) portion of the message is the probability of the occurrence of four or more errors. Assuming that the errors are independent, the probability of a resulting message error is:

$$P_{mf} = \sum_{i=4}^{82} \binom{82}{i} P_e^i (1 - P_e)^{82-i}$$

where P_e is the probability of a bit error.

For the varying portion of the short message (6 bits) the probability of a message error is not improved by the code and is given by:

$$P_{mv} = 1 - (1 - P_e)^6$$

For the optional long message (32 additional bits) the probability of a message error is given by:

$$P_{ml} = 1 - (1 - P_e)^{32}$$

Table VI gives results for two different bit error probabilities.

TABLE VI

P_e	P_{mf}	P_{mv}	P_{ml} (optional long)
10^{-2}	8.0×10^{-3}	5.9×10^{-2}	0.28
10^{-3}	1.8×10^{-5}	6.0×10^{-3}	3.2×10^{-2}

Thus for a 10^{-3} bit error probability, the message error is reasonably small in all cases ensuring correct reception within a few message repetition intervals.

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ANNEX II

This Annex addresses a number of subjects, some of which concern the technical and operational matters still to be resolved or published before either one or the other satellite EPIRB system can be available to users. Others concern administrative and regulatory matters affecting the way such devices may be used.

An X in Table VII indicates that it is expected that the related organization will have an active interest in the topic. It should be noted that, although not shown in every table entry, the prerogatives of administrations to assume a role in any of these topics is recognized.

An attempt has also been made to indicate by the symbol ⊗ those organizations which are thought to have a particular responsibility and involvement for study and related development activities.

TABLE VII

	ITU CCIR/ CCITT	IMO	INMAR- SAT	Adminis- trations	COSPAS- SARSAT	Manu- facturers
1. The satellite EPIRB release arrangements required to allow reliable float-free operation as well as manual deployment, trickle-charging of batteries and operation <i>in situ</i>		⊗		X		X
2. The data entry device			⊗		⊗	X
3. The data interface with ship's navigational equipment			X	⊗		X
4. The types of satellite EPIRB packaging and interface arrangements necessary for different applications and ship types and the standard of any associated cabling required		⊗		X		X
5. The design and development of low-cost production satellite EPIRBs and their installation				⊗		⊗
6. Satellite EPIRB environmental and mechanical requirements, including anything which could affect the probability of equipment survival in hazardous situations (e.g. heavy seas, burning oil, icing)		⊗	X	X	X	
7. The measures to minimize unwanted and unauthorized satellite EPIRB activations (e.g. means to detect and indicate satellite EPIRB activation)	X			⊗		X
8. The regulations governing the testing of the complete system including any need for self-checks and periodic inspections		X		X		
9. The duty cycle.	X	⊗				
10. The possible operational requirement to change the distress message after manual activation		⊗	X		X	
11. The type approval requirements and procedures			X	X	X	
12. The commissioning procedures for the satellite EPIRBs			X	X	X	
13. Possible radiation hazards and path blockage, especially if the satellite EPIRB is carried in a survival craft	X			X		
14. The location and number of satellite EPIRBs carried on ships		⊗		X		
15. The pre-operational demonstration			X		X	
16. The possible operational requirement for alternative message formats (e.g. emission of time of activation)	X	⊗	X		X	
17. The measures to minimize the repeated print-out of an alert message at RCC	X	X	X	⊗	X	
18. The communication link requirements needed to implement the IMO distress message routing arrangements and operational procedures		X		X		

TABLE VII (continued)

	ITU CCIR/ CCITT	IMO	INMAR- SAT	Adminis- trations	COSPAS- SARSAT	Manu- facturers
19. The implications of the implementation of a combined polar-orbiting and geostationary satellite system on the design of a satellite EPIRB operating at 1.6 GHz	⊗		X			
20. The desirability and characteristics of a dual frequency (1.6 GHz and 406 MHz) and/or dual standard satellite EPIRB system	⊗	⊗	X		X	
21. The effect on system performance of the implementation of multi-channel capability as a function of the bandwidth necessary to meet the IMO requirement for simultaneous transmission capability			X		X	
22. The effect on EPIRB design and performance of the incorporation of a homing facility	X		X	X	X	X
23. The incorporation of satellite EPIRB receiving, processing and handling facilities at coast earth stations and related costs			X		X	
24. The effects on system reliability of the application of the satellite EPIRB system to users other than IMO convention ships	X	X	X	X	X	
25. The number of coast earth stations to be fitted with receiver processor in each Ocean Region		⊗	X	X		
26. Means of obtaining position up-dates in a geostationary-satellite EPIRB system	⊗		X			
27. The estimate of the cost of a receiver processor			X		X	⊗
28. Means to minimize effects of potential interference	⊗		X		X	

ANNEX III*

FACTORS FOR A RECOMMENDED PRE-OPERATIONAL DEMONSTRATION
USING THE 1.6 GHZ SATELLITE EPIRB OPERATING
THROUGH GEOSTATIONARY SATELLITES

To achieve a meaningful pre-operational demonstration, account should be taken of the following:

- The pre-operational demonstration should aim to provide the maritime community, IMO, INMARSAT, etc. with the assurance that the CCIR recommended system will work satisfactorily when it goes into full operation as part of the Future Global Maritime Distress and Safety System. A further aim is to enable industry to become involved in the development of the overall EPIRB system;
- different types of buoy shapes, release mechanism and antennas may be used;
- the homing signal transmitter.

* This Annex should be referred to the design authority assumed to be INMARSAT.

This is a matter for IMO to decide upon, but as available space, weight and antenna installation must be taken into account in the buoy design, an agreed estimate on these homing parameters should be made:

- the receiver processor used during the pre-operational demonstrations should not only have sufficient capacity for that period, but be capable of capacity expansion to provide for 20 simultaneous alerts in a 10 min period;
- an invitation to take active part in the pre-operational demonstration should be extended by the CCIR and the IMO to their member administrations;
- there should be simulation of distress incidents with full involvement of national and international RCC functions;
- a variety of environmental conditions should be tested by fitting satellite EPIRBs on ships sailing in different geographical areas;
- results from planned or real incidents should be reported to INMARSAT, the coast earth station owner and manufacturers providing the receiver processor and satellite EPIRBs.

REPORT 1046 *

CONSIDERATIONS ON THE FEASIBILITY OF A SINGLE FREQUENCY BAND FOR SATELLITE EPIRB OPERATION IN THE FGMDSS

(Study Programme 17B/8)

(1986)

1. Introduction

This Report identifies options and issues that urgently require further study to determine the practicability of using a common frequency for satellite EPIRB transmissions through both geostationary and polar-orbiting satellites in the Future Global Maritime Distress and Safety System (FGMDSS).

The material contained in this Report is of a summary nature and is provided for the purpose of giving insight into the technical issues. Needed additional information may be obtained from [CCIR, 1982-86a] and from the results of on-going studies (see Reports 761, 919 and 1045).

Assessment of the various options should be made relative to the IMO draft carriage requirements for the FGMDSS. Accordingly, ships should be capable of alerting via polar-orbiting and geostationary-satellite systems, using satellite EPIRBs depending on their area of operation. The information provided by both satellite systems would allow short (less than 10 min) alerting time, global coverage and up-dated position location. The IMO has also expressed preference for operating the geostationary and polar-orbiting satellite systems on the same frequency and has requested that urgent consideration be given to the provision of an integrated geostationary/polar-orbiting system.

One thought behind the use of a simple single-frequency satellite EPIRB was to improve the reliability of the alerting in the FGMDSS by a concurrent alert through both geostationary and polar-orbiting satellite systems. However, the use of two frequencies may be an appropriate means for overcoming the effects of terrestrial interference.

Although this Report addresses the specific question of a single frequency band for satellite EPIRBs, the following comments are relevant to the possible implementation of a single EPIRB standard:

- the satellite EPIRB system for operation in an early time frame with geostationary satellites at 1.6 GHz should conform to Recommendation 632;
- the satellite EPIRB system for operation in an early time frame with polar-orbiting satellites at 406 MHz should conform to Recommendation 633;
- the COSPAS/SARSAT system operating at 406 MHz with low, polar-orbiting satellites has application to the maritime, aeronautical and land mobile communities;

* The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

- the polar-orbiting satellite by its movement relative to the Earth's surface creates a Doppler shift in the signal received from the EPIRB. By using the information of the Doppler shift and the position of the satellite while receiving the signals, the position of the transmitting satellite EPIRB can be defined even when it has floated free. The time delay of the alert is determined by the number of satellites in orbit, the latitude of the satellite EPIRB, the location and number of local user terminals relative to the position of the satellite EPIRB, together with some processing time on the ground (see Report 919);
- in all major shipping areas the satellite EPIRB can "see" at least one INMARSAT geostationary satellite. The position information of the distress case has to be included in the alert message and will not be up-dated after the satellite EPIRB has floated free. Using an appropriately equipped INMARSAT space segment and coast earth station, the distress alert message will be received by the satellite as soon as the EPIRB starts transmitting and will be retransmitted to (a) coast earth station(s) on receipt of the message. A small delay in the alert will be caused by the time needed to process the message on the ground (see Report 1045);
- the possible advantages of using a single band having an influence on minimizing the cost of satellite EPIRBs and simplifying their design should be studied. The possible disadvantages which might be caused by the large number of potential users of satellite EPIRBs and the effect this may have on the probable number of simultaneous users and false transmissions should also be studied;
- other combinations of satellite EPIRB standards, frequency and satellite orbits, for example, the retransmission of navigation signals, are either not currently available or are the subject of further study and testing, as reported below.

2. Frequencies for satellite EPIRB operation

Study Programme 17B/8 identifies four possible bands for satellite EPIRB operation.

These are:

121.45 to 121.55 MHz
242.95 to 243.05 MHz
406 to 406.1 MHz
1645.5 to 1646.5 MHz

The 121.5 and 243.0 MHz bands are not suitable for reasons to be stated later.

It is difficult, at present, to separate the choice of frequency from the modulation technique and the satellite orbit. Studies and testing have concentrated on proving the feasibility of a modulation and signalling scheme optimized for a particular satellite orbit. The coordinated trials programme of 1.6 GHz satellite EPIRBs has used various modulation techniques optimized for message integration which is necessary with geostationary satellites where the signal levels are weak. The Federal Republic of Germany is conducting studies of the feasibility of using the 1.6 GHz satellite EPIRB system recommended for geostationary satellites with polar-orbiting satellites but no tests are being planned at present.

A similar but not identical situation exists for the 406 MHz band. This signalling system is optimized for polar-orbit operation and is under evaluation at present. No test data exist for evaluation with a geostationary satellite but GOES-G and H satellites (due to be launched by mid-1986) will be equipped with 406 MHz transponders for testing purposes with the satellite EPIRB recommended for polar-orbiting satellites. Report 761 indicates the feasibility of using the same frequency satellite EPIRB for the geostationary as well as polar-orbiting use.

It is possible that satellite EPIRBs can be made, if necessary, to "alternate" between polar-orbiting and geostationary-signalling formats while operating on the same frequency but such operation could create interference at the satellite when multiple satellite EPIRB alerts occur.

Satellite EPIRB operation at two separate frequencies within the same band could reduce interference between signal formats and, in the case of geostationary satellites, could further provide protection against potential narrow-band interference from other sources.

Two frequency operations alternating with successive 10 min bursts at irregular intervals could take place within the same band using the same format to provide protection against narrow-band interference. With this later concept the satellite EPIRB could be automatically switched between well-separated frequencies.

A consideration of the overall message reliability in the face of broadband interference effects may indicate the desirability for two separate frequency bands (i.e. 406 MHz and 1.6 GHz) within the same satellite EPIRB, with the signalling in each band optimized for a particular satellite orbit. This would allow the possibility of operation through either the polar-orbiting or geostationary system. If interference did occur in one of the frequency bands of one satellite system, then operation could still take place through the other system.

The potential interference from fixed-service transmitters using the 1.6 GHz band in some countries, is indicated in Report 761. Report 919 shows that interference during the current COSPAS/SARSAT demonstrations at 406 MHz, has decreased the probability of obtaining position information using polar-orbiting satellites in certain areas of the world.

However, it has to be noted that dual frequency operation can only be achieved at the expense of an increase in the complexity and cost of the satellite EPIRB and receiving station, the extent of which is yet to be determined.

3. Use of 121.5 and 243 MHz bands for satellite EPIRB operation

Currently there are over 300 000 aircraft emergency locator transmitters (ELTs) and 10 000 maritime emergency position-indicating radio beacons (EPIRBs) operating on these frequencies world-wide. The COSPAS/SARSAT satellite system in polar orbit has been used to aid in the successful rescue of many vessels and small aircraft in distress. The current 121.5 MHz and 243 MHz performance demonstrates a very high false alarm rate of over 90% in the USA. Perhaps more importantly under the present Radio Regulations, these frequency bands are not solely allocated for satellite distress transmitter operation, but share the band with much higher power voice transmitters used on aircraft for terrestrial distress alerting. The effect of the high false alarm rate and use of 25 W voice transmitters cause a considerable amount of interference in these bands at the present time. The lack of user identification coding in the ELTs and EPIRBs makes it difficult to distinguish between a real alert and a false alarm. Even if user identification and position information were included, the low power used by the ELTs and EPIRBs (75 mW e.r.p. in North America) and the presence of strong signal interference would not permit reliable reception of this information. Although new, higher power devices could be designed to overcome these drawbacks, the severity of interference due to sharing makes the 121.5 and 243 MHz bands unattractive for use with satellite systems in the FGMDSS. Despite these interference problems, this band will continue to be used for terrestrial alerting and homing and will continue to provide distress information with polar-orbiting satellites for some considerable time.

4. The use of the 406 MHz band for geostationary-satellite EPIRB operation

Transmission characteristics of satellite EPIRBs operating in the 406.0-406.1 MHz band (see Recommendation 633), although primarily designed for use with polar-orbiting satellites, may be extended for use with geostationary satellites. Three items require study:

- the possible need to distribute the centre frequency of the satellite EPIRBs over a number of spot frequencies within the 406.0-406.1 MHz band so as to ensure adequate simultaneous alerting capability;
- the possible need for processing gain using message integration; and
- if processing gain is necessary, the impact this might have on the design of the geostationary satellite.

Despite the fact that the allocation of this band is limited to satellite EPIRB operation, serious interference problems are known to exist in this band for the COSPAS/SARSAT polar-orbiting satellites (see Report 919 and Resolution No. 205 of the World Administrative Radio Conference for Mobile Services (WARC MOB-83)). Some of the interference sources can be located using polar-orbiting satellites. Actions have been taken through the IFRB to monitor (see Report 979) and eliminate the sources of interference. Should this action fail, interference effects would probably be more serious for a geostationary satellite than for a polar-orbiting satellite, due to the wider field of view. In such circumstances the impact of interference on the performance of polar-orbiting and geostationary-satellite systems needs to be studied.

5. The use of the 1646 MHz band for polar-orbiting satellite EPIRB operation

The satellite EPIRB system recommended for geostationary operation may not be compatible with a low-altitude polar-orbiting satellite system due to the duty cycle or on-to-off time of the satellite EPIRB, high Doppler shifts, and the limited visibility time which is available for a polar-orbiting satellite. Compatibility with a higher orbit satellite system (12 000 km) is under study in the Federal Republic of Germany.

The altitude of the COSPAS/SARSAT satellite system is 800 to 1000 km. In principle, these satellites are able to locate a satellite EPIRB if the satellite is visible for at least 4 min. Overhead satellite passes can last more than 15 min. These low Earth-orbit satellite systems require on-board processing in order to provide world-wide coverage without a large number of earth stations. A satellite EPIRB working with this system cannot have long off-periods since this will cause misses when a satellite overpass occurs. Such a duty cycle could be used with a satellite EPIRB operating with a geostationary satellite to save battery power. The signalling must also be compatible with on-board processing in the satellites.

If polar-orbiting satellites were placed at a higher altitude orbit, for example 12 000 km, on-board processing may not be necessary. The recovery of the satellite EPIRB carrier frequency is required to allow a Doppler derived location to be obtained. The high altitude of the orbit, however, would require a more accurate frequency measurement. For the recommended 1.6 GHz system using FSK, location data is determined using a specific processing technique in the receiver processor. The possible need for higher satellite EPIRB power and more stringent oscillator stability is under study by the Federal Republic of Germany.

6. Summary

A number of important issues that require further study are identified concerning the practicability of using (a) common frequency(ies) for satellite EPIRBs for the FGMDSS operating through an integrated system using geostationary and polar-orbiting satellites.

REFERENCES

CCIR Documents

[1982-86]: a. 8/149 (Netherlands).

RECOMMENDATION 633 *

TRANSMISSION CHARACTERISTICS OF A SATELLITE EMERGENCY POSITION-INDICATING RADIO BEACON (SATELLITE EPIRB) SYSTEM OPERATING THROUGH A LOW POLAR-ORBITING SATELLITE SYSTEM IN THE 406 MHz BAND

(Study Programme 17B/8)

(1986)

The CCIR,

CONSIDERING

- (a) that satellite EPIRBs will be one of the prime alerting means in the Future Global Maritime Distress and Safety System (FGMDSS) being developed by the International Maritime Organization (IMO);
- (b) the time-frame foreseen by IMO for the implementation of the FGMDSS;
- (c) the necessity to gain operational experience with globally received data within that time-frame and to make available satellite EPIRB production units from 1985 onwards;
- (d) the current availability of the COSPAS/SARSAT ground system (10 local user terminals (LUTs) in 6 countries as of 1985);
- (e) the assured availability of four operational COSPAS/SARSAT type satellites in orbit through the 1990s and the planned availability thereafter;
- (f) the test results presented in Report 919,

UNANIMOUSLY RECOMMENDS

1. that the transmission characteristics for a satellite EPIRB operating through a low polar-orbiting satellite system in the 406 MHz band should be in accordance with Annexes I and II to this Recommendation;
2. that administrations be discouraged from using data formats not covered by this Recommendation.

* The Director, CCIR, is requested to bring this Recommendation to the attention of the International Maritime Organization (IMO), the International Maritime Satellite Organization (INMARSAT), and the COSPAS/SARSAT partners.

ANNEX I

TABLE I — 406 MHz satellite EPIRB characteristics

Parameter	Value
<i>RF signal:</i>	
Carrier frequency ⁽¹⁾ :	
initial	406.025 ± 0.002 MHz
after five years	406.025 ± 0.005 MHz
Frequency stability ⁽¹⁾ :	
short term (100 ms)	2 × 10 ⁻⁹
medium term:	
mean slope ⁽²⁾	1 × 10 ⁻⁹ /min
residual noise ⁽²⁾	3 × 10 ⁻⁹
For the interim period until 1 January 1988, the following relaxation in frequency stability is permitted:	
short term (100 ms)	2 × 10 ⁻⁹
medium term:	
mean slope ⁽²⁾	2 × 10 ⁻⁹ /min
residual noise ⁽²⁾	5 × 10 ⁻⁹
Power output	5 W ± 2 dB into 50 Ω load with VSWR ≤ 1.25 : 1
Spurious	50 dB below 5 W in 5 MHz carrier harmonics: 30 dB below 5 W
Data encoding	Bi-phase L (see Fig. 1)
Modulation	Phase modulation 1.1 ± 0.1 rad peak
Modulation rise time	The rise and fall times of the modulation waveforms must be between 50 μs and 250 μs
<i>Digital message:</i>	(See Fig. 2)
Repetition rate	50 s ± 5%
Transmission time	440 ms ± 1% or 520 ms ± 1%
CW preamble	160 ms ± 1%
Digital message	280 ms ± 1% or 360 ms ± 1%
Bit rate	400 bit/s ± 1%
Bit sync.	All "1" (15 "1")
Frame sync.	000101111
<i>Continuous emission failure mode</i>	Transmission should not exceed 45 s
<i>Antenna ⁽³⁾:</i>	
Elevation	5°-60°
Pattern	Hemispherical
Polarization	Circular (RHCP) or linear
Gain (vertical plane)	Between -3 dBi and 4 dBi over 90% of the above region
Gain variation (azimuth plane)	< 3 dB
VSWR ⁽⁴⁾	≤ 1.5 : 1
<i>Temperature range:</i>	
Minimum acceptable	-20 °C to + 50 °C Long-term temperature gradient of 5 °C/h Thermal shock: 30° C temperature difference with a degraded performance for 15 min
Optional ⁽⁵⁾	< -20 °C to > +50 °C Long-term temperature gradient of 5 °C/h Thermal shock: 30° C temperature difference with a degraded performance for 15 min
<i>Minimum operating life time</i>	24 h

Footnotes relative to Table 1:

- (¹) Specified values apply after 15 min warm-up and for VSWR ≤ 3 : 1.
- (²) The mean slope and residual noise shall be measured as follows. Data shall be obtained by making 18 frequency measurements, one every 50 s over a 15 min interval. Each measurement shall be a 100 ms frequency average performed during the modulated part of the message. The mean slope is defined as that of the least square straight line fit to the 18 data points. Residual noise is defined as the r.m.s (root mean square) error of the points relative to the least square estimate.
- (³) Antenna characteristics should be verified in a configuration as close as possible to its operational condition.
- (⁴) The beacon shall not be damaged by any load from open circuit to short circuit.
- (⁵) This specification is to be applied at the discretion of each administration.

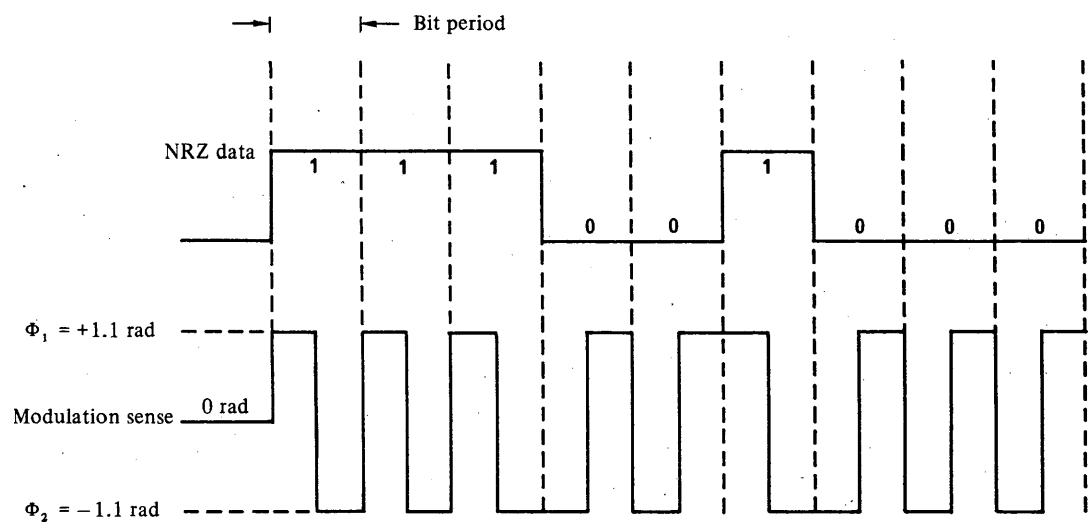


FIGURE 1 – Data encoding and modulation sense

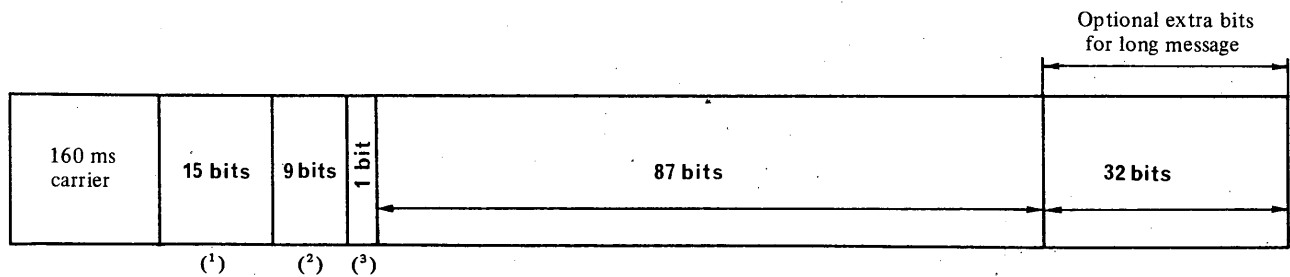


FIGURE 2 – Transmitted message format

- (¹) Bit synchronization: 15 "1" bits
- (²) Frame synchronization: 000101111
- (³) "0" bit indicates short message format
"1" bit indicates long message format

ANNEX II

BEACON CODING

1. General

This Annex defines the 406 MHz beacon digital message coding (see Fig. 3). The digital message is divided into six major fields. For each field, the most significant bit (MSB) is transmitted first.

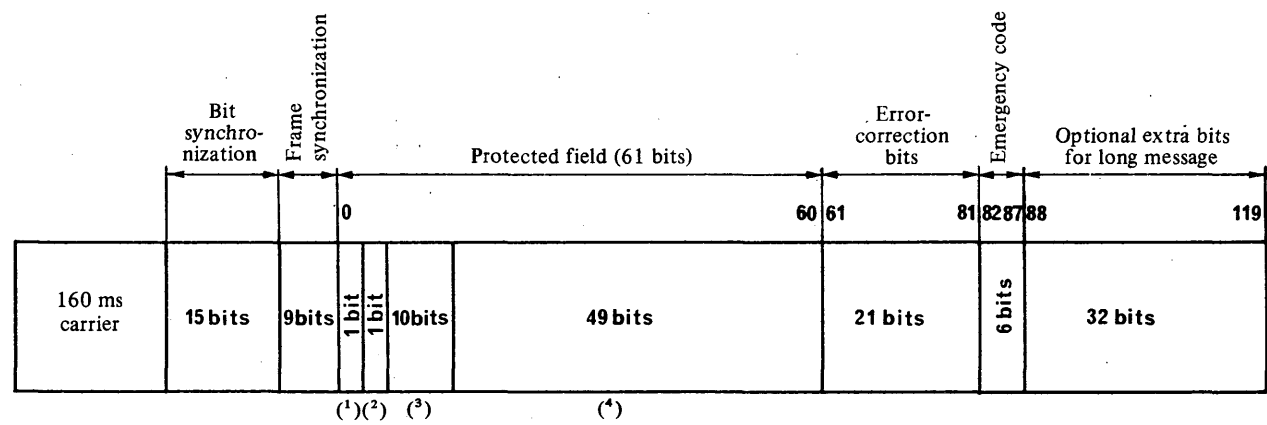


FIGURE 3 – Message format

- (¹) Format flag: “0” indicates short message
“1” indicates long message
- (²) Protocol flag
- (³) MID code (Maritime Identification Digit) (see § 2.2)
- (⁴) Data

Beacons may be coded either for a short message or for an optional long message format as described below:

- the short message includes a unique identification number which accommodates either the ship station identity number or an identity which meets the special needs of aeronautical or other users. The short message can provide additional information such as type of homing beacon, user type, and location of the EPIRB or other information as desired;
- the optional long message format provides all information necessary to meet the draft FGMDSS requirements, e.g. maritime users can report course, speed, nature of distress, and time of EPIRB activation in accordance with the IMO Sub-committee on Radiocommunications proposals for content of the distress message;
- the assignment of ship station identity numbers and country codes shall be in accordance with the relevant ITU Maritime Identification Digits (see Appendix 43 of the Radio Regulations), the relevant ICAO standard, or relevant national standards;
- administrations should note that any applications of data formats or options not defined by this Annex will not be decoded by operators of the COSPAS/SARSAT system. However, COSPAS/SARSAT partners are willing to consider proposals from administrations for other data formats.

The major bit fields are described as follows:

Bit field name	Bit field location
1. Bit synchronization	Preamble
2. Frame synchronization	Preamble
3. Protected field	Bit 0 to bit 60
4. Error-correction field	Bit 61 to bit 81
5. Emergency code field	Bit 82 to bit 87
6. Long message (optional)	Bit 88 to bit 119

1.1 The bit synchronization pattern consisting of a series of "1" shall occupy the first 15 bit positions.

1.2 The frame synchronization pattern consisting of 9 bits shall occupy bit positions 16 to 24. The frame synchronization pattern shall be "000101111".

1.3 The error-correction field is used with both the short message format and the long message format and is based on a (127 : 106) BCH code with the following generator polynomial:

$$g_5(x) = g_3(x) \cdot (7,4,3,2,0)$$

$$g_3(x) = g_1(x) \cdot (7,3,2,1,0)$$

$$g_1(x) = (7,3,0)$$

2. Protected field

The protected field consists of 61 bits (i.e. bit 0 to bit 60 inclusive) which are "protected" by application of the error-correction algorithm. The first bit (i.e. bit 0) is a format flag which shows whether the message is a short or a long format using the following coding:

0: short format

1: long format

The identification (ID) field, which begins at bit 1 after the format flag and ends at bit 60, has the following general structure:

TABLE II

Bits	Usage
1	Protocol flag
2-11	MID (see § 2.2)
12-60	Data field

2.1 Protocol flag

Bit 1 in the ID field is used to identify if the short message format is used for a programmed maritime position in the beacon (i.e. maritime/location protocol; bit 1 = 0) or for one of 8 possible user protocols (i.e. bit 1 = 1).

2.2 Maritime Identification Digit

Bits 2 to 11 in the ID field designate 3 decimal numeric characters expressed in binary notation with no offset. These codes are based on the Maritime Identification Digit (MID), assigned by the ITU from Appendix 43 of the Radio Regulations.

2.3 Maritime/location protocol

2.3.1 Short message

The maritime/location protocol has the following structure:

TABLE III

Bits	Usage
1	Protocol flag (= 0)
2-11	MID (see § 2.2)
12-31	20 bit ID (trailing 6 digits of MID number)
32-60	29 bit location

If bits 32 to 60 are all 1s, this indicates that no location has been entered or pre-programmed.

The MID for the maritime/location protocol is that of the country of vessel registration, and is coded in bits 2 to 11.

Bits 12 to 31 designate 6 decimal numeric characters expressed in binary notation and are based on the ITU MID system.

Bits 32 to 60 designate the following using binary notation:

TABLE IV

Bits	Usage
32-38	Latitude (degrees)
39-44	Latitude (min)
45	0: North, 1: South
46-53	Longitude (degrees)
54-59	Longitude (min)
60	0: East, 1: West

2.3.2 Long message (optional)

The long message is not in the “protected” field. At present, only one option exists for this protocol as shown in Table V below. These bits (88 to 119) follow the emergency code field and error-correction fields (see Fig. 3).

TABLE V – Maritime/location long message

Bits	Item	Usage
88-96	Course	Degrees true; range 359
97-101	Speed	Knots; range 32
102-104	Time of activation:	Day of week (000 = Sunday); range = 7 days
105-109		Hours; range = 23
110-114		Minutes (2 min increments); range = 58
115-119	Optional	National use ⁽¹⁾

⁽¹⁾ National option: it is desirable for administrations having alternative uses, to so advise the COSPAS/SARSAT partners and the appropriate SAR authorities (see § 1).

2.4 Identification of the eight different user protocols

The user protocols have the following structure:

TABLE VI

Bits	Usage
1	Protocol flag (= 1)
2-11	MID (see § 2.2)
12-14	User protocol type
15-58	Data field
59-60	Homing frequency

Bits 12 to 14 in the ID field designate one of 8 user protocols and are expressed as one octal character. This determines how the remaining bits in the data field are encoded/decoded. The 8 user protocols are as follows:

TABLE VII

Binary number	Octal character	User protocol type
000	0	Orbitography
001	1	Aviation
010	2	Maritime
011	3	Serialized
100	4	Spare (see footnote to Table V)
101	5	Spare
110	6	Spare
111	7	Test

Bits 15 to 58 are used to encode the actual identification of the beacon and are defined separately for each user protocol.

Bits 59 to 60 are used to indicate the homing signal for each user protocol (excluding orbitography beacons). The assignment of bits is as follows:

00: no homing transmitter

01: 121.5 MHz

10: maritime homing: VHF from Appendix 18 (see footnote to Table V)

11: other homing facility (see footnote to Table V)

2.4.1 Orbitography protocol (user protocol 000)

The orbitography protocol is for use by special system calibration beacons and is intended for use only by operators of the local user terminals.

2.4.2 Aviation protocol (user protocol 001)

The aviation protocol has the following structure:

TABLE VIII

Bits	Usage
1	Protocol flag (= 1)
2-11	MID (see § 2.2)
12-14	User protocol type (= 001)
15-56	Aircraft tail number
57-58	Spare (= 00)
59-60	Homing frequency

Bits 2 to 11 designate the country in which the aircraft is registered. However, it may also indicate the country to which an aircraft has been leased if the national authority in the leasing country requires this information within the country code.

Bits 15 to 56 designate the aircraft tail number (i.e. registration) which is encoded using the modified Baudot code shown in Table X. This code enables 7 characters ($6 \times 7 = 42$) to be encoded using 42 bits. This data will be right-justified with a Baudot space (letter), i.e. 100100, being used where no character exists.

2.4.3 Maritime protocol (see protocol 010)

The maritime protocol has the following structure:

TABLE IX

Bits	Usage
1	Protocol flag (= 1)
2-11	MID (see § 2.2)
12-14	User protocol type (= 010)
15-50	Call sign or MID (last 6 digits)
51-56	Specific EPIRB
57-58	Not used (= 00)
59-60	Homing frequency

Bits 2 to 11 designate the country of vessel registration.

Bits 15 to 50 designate the radio call sign of the 6 digit MID (i.e. the last 6 digits of the 9 digit number) using the modified Baudot code shown in Table X. This code enables 6 characters ($6 \times 6 = 36$) to be encoded using 36 bits. This data will be right-justified with a Baudot space (letter), i.e. 100100, being used where no character exists. If all characters are digits, the entry is interpreted as a MID number (trailing 6 digits).

Bits 51 to 56 will be used to identify specific EPIRBs on the same vessel (for the first float-free EPIRB, a Baudot zero, 001101, will be entered, other EPIRBs on the same vessel could be numbered consecutively using Baudot numbers 1 to 9).

2.4.4 Serialized protocol (user protocol 011)

The serialized protocol will permit the manufacturing of beacons whose ID will not change once entered. It will normally be used for small aircraft and vessels which normally stay within their national boundaries and non-registered users. Units will be identified by a data base giving specifics about the unit.

TABLE X – Modified Baudot code

Letter ⁽¹⁾	Code		Figure ⁽¹⁾	Code	
	MSB	LSB		MSB	LSB
A	1	1	(–) ⁽²⁾	0	1
B	1	0		0	1
C	1	0		0	1
D	1	0		0	1
E	1	0	3	0	1
F	1	0		0	1
G	1	0		0	1
H	1	0		0	1
I	1	0	8	0	0
J	1	1		0	0
K	1	1		0	0
L	1	0		0	0
M	1	0	9	0	0
N	1	0		0	0
O	1	0		0	0
P	1	0		0	0
Q	1	1	0	0	1
R	1	0	1	0	1
S	1	0	4	0	0
T	1	0	5	0	0
U	1	1		0	1
V	1	0		0	1
W	1	1		0	1
X	1	0	2	0	1
Y	1	0	/	0	1
Z	1	0	6	0	1
() ⁽³⁾	1	0			

MSB: most significant bit.

LSB: least significant bit.

- (¹) Letters/figures shift is shown by the most significant bit, i.e.:
1 = letters and
0 = figures.
- (²) Hyphen.
- (³) Space.

The serialized protocol has the following structure:

TABLE XI

Bits	Usage
1	Protocol flag (= 1)
2-11	MID (see § 2.2)
12-14	User protocol type (= 011)
15-18	Beacon type
19-38	Serial number
39-58	National use (see footnote to Table V)
59-60	Homing frequency

Bits 2 to 11 designate the country of beacon registration using the MID (see § 2.2).

Bits 12 to 14 serialized protocol (= 011).

Bits 15 to 18 will indicate the beacon type as follows:

0000: air (i.e. ELT)

0100: maritime (i.e., float-free EPIRB)

1000: survival (i.e., non float-free EPIRB)

1100: personal locator beacon.

Bits 19 to 38 will be a serial ID code number from 1 to 1 048 576 (i.e. 2^{20}) expressed in binary notation.

Bits 39 to 58 are for national use and control but will be made public when assigned.

2.4.5 Test protocol

The test protocol will be used for demonstrations, national tests, training exercises, etc. Mission control centres (MCCs) and data distribution centres (DDCs) will not forward these locations unless requested by the nation conducting the test.

3. Emergency code

The emergency code field consists of bits 82 to 87.

Bit 82 is a flag bit to indicate whether bits 84 to 87 are used for emergency code "1", or for other national use "0" (see footnote to Table V).

Bit 83 indicates if the beacon has been activated manually "0" or automatically "1".

3.1 Maritime users

When used for emergency code, bits 84 to 87 indicate the maritime emergency code in accordance with the IMO proposed nature of distress indications as shown in Table XII for all maritime distresses (i.e. maritime/location protocol and maritime protocol).

TABLE XII — *Maritime emergency codes in accordance with the IMO proposed nature of distress*

IMO indication	Binary code	Definition
1	0001	Fire/explosion
2	0010	Flooding
3	0011	Collision
4	0100	Grounding
5	0101	Listing, in danger of capsizing
6	0110	Sinking
7	0111	Disabled and adrift
8	0000	Undesignated (unspecified distress)
9	1000	Abandoning ship
10	1111	Test
	1001 to 1110	Spare which could be used in future for assistance desired or other information to facilitate the rescue if necessary.

If bits 84 to 87 are all zeros, then this indicates that no emergency code has been entered or pre-programmed.

3.2 Non-maritime users

When bit 83 is used to indicate emergency codes for non-maritime protocols (e.g. aviation, serialized or other spares), the bits 84 to 87 are used as shown in Table XIII.

TABLE XIII — *Non-maritime emergency codes*

Bits	Usage ⁽¹⁾
84	No fire "0" or fire "1"
85	No medical help "0" or medical help required "1"
86	Not disabled "0" or disabled "1"
87	Spare "0" ⁽²⁾

⁽¹⁾ When no use is intended for this field, bit 82 is set to "1" and bits 84 to 87 are all set to "0".

⁽²⁾ See footnote to Table V.

4. Long message (optional)

For maritime/location protocol see § 2.3.2. For all protocols except maritime/location (protocol flag = 1), the optional long message format permits additional information to be included in the message as follows:

TABLE XIV

Bits 88-89	Bits 90-119
00	Latitude/longitude
01	Spare (see footnote to Table V)
10	Spare
11	Spare

For the latitude/longitude message, bits 90 to 119 inclusive are decoded as follows:

TABLE XV

Bits	Usage
90-96	Latitude (degrees)
97-102	Latitude (min)
103	0: North; 1: South
104-111	Longitude (degrees)
112-117	Longitude (min)
118	0: East; 1: West
119	Even parity bit applied to bits 88-118

If bits 90 to 118 are all "1", then this indicates that no location has been entered.

REPORT 919-1 *

**PERFORMANCE OF A LOW ALTITUDE POLAR-ORBITING
SATELLITE EPIRB SYSTEM**

(Study Programme 17B/8)

(1982-1986)

1. Introduction**1.1 Background**

The COSPAS/SARSAT** programme is an international cooperative effort between the United States of America, Canada, France (SARSAT) and the USSR (COSPAS). Norway, the United Kingdom, Finland, Bulgaria and Denmark are also participating in this programme, and discussions are under way for the participation of Brazil and additional countries.

The programme has the following objectives:

- first, to support the existing search and rescue activities by providing position determination for aircraft emergency locator transmitters (ELTs) and maritime emergency position-indicating radio beacons (EPIRBs) transmitting at 121.5 MHz;
- second, to demonstrate the advantages of a new system operating at 406 MHz, which provides better performance and which better satisfies users' requirements of global coverage and identification;
- third, to promote the development of an international operational system as soon as possible.

A summary description of the system is given in Report 761, and details are provided in [USSR, *et al.*, 1984a]; therefore, they are not repeated in this Report.

The Cospas-1 (C1), -2 (C2) and -3 (C3) satellites were launched on 30 June 1982, 25 March 1983, and 21 June 1984, respectively. Sarsat 1 (S1), the first satellite carrying the SARSAT payload, was launched on 28 March 1983. It lost attitude stability and was placed out of operation in June 1984, but it was successfully reactivated in May 1985. Sarsat-2 (S2) was launched in December 1984. Sarsat-3 (S3) is planned to be launched in 1986. The initial launches started an engineering measurement effort and a demonstration and evaluation (D and E) effort. The purpose of the engineering measurements was to determine that the design was functioning as expected. The purpose of the D and E programme was to demonstrate the 406 MHz system performance and the system's capability for providing effective assistance to search and rescue (SAR) operations.

The engineering measurements consisted of well controlled 121.5 MHz and 406 MHz engineering tests and they continue to be performed with each new satellite launched. The D and E programme demonstrated 121.5 MHz and 406 MHz system performance in a more realistic user environment. The D and E programme was concluded in July 1984. However, additional measurement data is being continually acquired. Thereafter, the D and E data will be referred to as the "environmental" data to differentiate it from the engineering data. Preliminary results of the programme have become available in several reports (see References).

It must be noted that the 406 MHz COSPAS/SARSAT sub-system has just entered its operational phase and is continually improving its system performance. On the other hand, the 121.5 MHz sub-system has already demonstrated its operational performance in a number of successfully resolved real distress situations.

1.2 Objective of the Report

The objective of this Report is to present a consolidation of preliminary results taken from various engineering measurement and D and E reports and papers describing the 406 MHz system performance and environmental tests performed by all the COSPAS/SARSAT participants.

General test results of the 121.5 MHz system are also presented to give the user an idea of COSPAS/SARSAT operational capabilities and a basis from which to compare the effectiveness of the 406 MHz system.

* The Director, CCIR, is requested to bring this Report to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

** COSPAS: Kosmicheskaya Sistemya Poiska Avariynykh Sudov (Space System for Search of Distressed Vessels); SARSAT: Search And Rescue Satellite-Aided Tracking system.

1.3 *Scope of the Report*

In researching the various reports of test results provided by the participating countries, it was found that there were variations in the methods and formats in performing the tests and in recording the results. Accordingly, it was determined necessary to use only those results that were based on performance parameters with similar definitions and where the sample sizes of the collected data were known.

The countries whose data is used in this Report are:

- the COSPAS/SARSAT partners: the United States of America, Canada, France and the USSR; and
- the COSPAS/SARSAT investigators: Bulgaria, Norway, and the United Kingdom.

The reports used are listed in the References. The time period for the reported test results spans from 1 February 1983 to 31 August 1985.

Additional tests are planned for both the floating EPIRBs and the end-to-end performance assessment. The floating EPIRB tests will further investigate location probability for various conditions, including high sea states; the end-to-end tests will continue to investigate system performance using a four-satellite constellation with reduced susceptibility to interference. The results of these tests will be reported when complete, which is estimated to be in 1986.

2. **Measured performance of the 406 MHz system**

This section focuses on the measured performance of the COSPAS/SARSAT system using the 406 MHz experimental beacons.

2.1 *Introduction*

The purpose of the engineering measurements and the environmental tests was to determine the ability of the COSPAS/SARSAT system to detect, identify, and locate 406 MHz experimental beacons operating in maritime and inland environments. This was accomplished mainly by the evaluation of the following parameters for single-pass data:

- beacon-detection probability,
- beacon-location error,
- ambiguity resolution,
- beacon-location probability,
- capacity,
- homing range at 121.5 MHz and at 406 MHz,
- notification time.

During the period reported, the COSPAS/SARSAT system underwent:

- the continuation of ground system development;
- addition of the C3 and S2 satellites to the space segment;
- implementation of new operating procedures; and
- improvements of on-board satellite equipment.

For these reasons, the test results reflect a changing system. They afford a basis for preliminary evaluation of the parameters listed above with continuing improvements expected.

The tests fell into two categories; engineering tests and environmental tests.

Engineering tests are defined as closely controlled technical tests established to evaluate the degree to which the system design goals have been met. Environmental tests are reasonably controlled field tests designed to evaluate the impact of environmental factors (such as sea state, terrain, and weather) in a more operational mode.

Engineering tests were run under very good conditions in which the environment was stable and known. The true location of each beacon was accurately known to within approximately 0.50 km, output power was controlled, and beacon elevation angles to the spacecraft were accurately computed.

Environmental tests, on the other hand, were performed under a wide range of conditions that were not precisely recorded nor controlled. For example, beacon true locations were estimated and frequently fell outside 0.5 km error, output power measurements were not usually taken, and elevation angles were not usually recorded; however, with a sufficient sample size, this data can be expected to characterize the operational system.

2.2 Description of the tests

The tests were carried out under conditions and at locations selected by the participating nations. Generally, beacons were activated in sufficient time for them to warm up prior to data being taken to ensure that beacons were operating within specifications. Elevation angles from the beacons to the satellites were selected to allow message locations to be computed. To give a representation of what could occur during a beacon activation under real circumstances, a range of environmental conditions were selected. Such inland environments included flat and mountainous terrain, wet and dry weather, high to low altitudes above mean sea level, varying ambient temperatures, etc. Maritime tests were generally performed at low sea states with the EPIRBs on the decks of ships and/or floating. The beacons employed were newly developed 406 MHz ELTs and EPIRBs designed to meet the international specification for experimental beacons called for in the COSPAS/SARSAT 406 MHz ELT/EPIRB specification [Canada, *et al.*, 1982].

In order to cross-reference the various test results provided in this Report, to the originating country, the following list should be used:

<i>Series</i>	<i>Country</i>
A	Bulgaria
B	Canada
C	France
D	Norway
E	USSR
F	United States of America
G	United Kingdom

2.2.1 Beacon-detection probability

Beacon-detection probability is defined as the probability of detection by a local user terminal (LUT) (see Note) of at least one beacon message with a correct code protected section for the first tracked satellite.

Note. — A local user terminal is the COSPAS/SARSAT receiving earth station.

2.2.1.1 Test description

2.2.1.1.1 On-land tests

The C-series engineering test results were obtained in June 1985 by the Toulouse LUT during the Sarsat-1 and Sarsat-2 comparative performance tests. A local orbitography beacon and a reference beacon, placed on the roof of a building, were used during these tests.

The E-series environmental test results were obtained during January-February 1985 tests [CSSC, 1985a]. One test beacon (an industrial prototype) was placed on the roof of the Moscow LUT. The beacon was powered by internal batteries. During the 30-day test period the temperature varied between 0 °C and -24 °C.

The F-series engineering test results were obtained in August 1985 during simultaneous testing of two on-land and one on-deck field test beacons and a number of floating EPIRBs. The on-land test beacons were placed on top of two buildings, one of which was located at the Atlantic Marine Center near Norfolk, Virginia, and the other at NASA/Goddard Space Flight Center in Greenbelt, Maryland. Both of these beacons, as well as the on-deck beacon and the floating EPIRBs, transmitted at full power.

2.2.1.1.2 On-deck tests

The F-series engineering test results were obtained in August 1985 as mentioned in the preceding sub-section. A field-test beacon was used with the antenna placed on the bridge of a ship, which was stationed off the coast of Norfolk, Virginia.

2.2.1.1.3 Floating tests

The C-series environmental test results were obtained in April and June 1985 during the tests of three tethered and two free-floating EPIRBs, respectively [CSSC, 1985b]. These tests were conducted in the south-western Atlantic Ocean coastal region of France (near Bordeaux) during low sea-state conditions. In these tests, only those satellite passes were tracked whose elevation angles exceeded 5°; also, only the local (regional) mode was used.

The F-series engineering tests for floating EPIRBs were conducted in August 1985 off the coast of Norfolk, Virginia, where wave heights of up to 5 feet (1.5 m) were encountered. The data reported for the 6 EPIRBs were collected simultaneously with the on-land and on-deck engineering tests.

2.2.1.2 Test results

The measured beacon-detection probability is shown in Table I. The engineering test results indicate an overall value of this parameter to be 0.999, with somewhat lower results for environmental tests, 0.98; the measured cumulative beacon-detection probability thus being 0.99. These results were achieved with the use of the short message type with a protective BCH code. If the long message had been used, lower results would have been achieved due to the absence of correcting code for the last 32 bits of information.

2.2.1.2.1 On-land tests

In the C-series engineering tests, the beacon-detection probability for 66 passes of Sarsat-1 and 67 passes of Sarsat-2 was measured to be 1.0. Likewise, in the F-series engineering tests, it was also measured to be 1.0 for 246 possible detections.

In the E-series environmental tests, the beacon-detection probability for 262 passes of Cospas-2 and 253 passes of Cospas-3 was measured to be 0.98.

2.2.1.2.2 On-deck tests

The on-deck F-series engineering tests yielded a 0.99 beacon-detection probability for 130 possible detections and show essentially the same results as the on-land beacon and the floating EPIRB F-series engineering data.

2.2.1.2.3 Floating tests

In the F-series engineering tests, the beacon-detection probability was measured to be 1.0 for 260 possible detections.

In the E-series environmental tests, the beacon-detection probability for numerous passes of Cospas-2 and -3, and Sarsat-1 and -2 satellites was measured to be 0.98.

TABLE I — Beacon-detection probability

Beacon	Series	Engineering tests		Environmental tests		Cumulative	
		Probability	No. of possible detections	Probability	No. of possible detections	Probability	No. of possible detections
On-land	C	1.0	266	—	—	1.0	266
	E	—	—	0.98	515	0.98	515
	F	1.0	246	—	—	1.0	246
Sub-total		1.0	512	0.98	515	0.99	1027
On deck	F	0.99	130	—	—	0.99	130
Floating	C	—	—	0.98	377	0.98	377
	F	1.0	260	—	—	1.0	260
Sub-total		1.0	260	0.98	377	0.99	637
Total		0.999	902	0.98	892	0.99	1794

2.2.2 Location error

Location error is defined as the difference between the location calculated by the system using measured Doppler frequencies and the actual location of the radio beacon as reported by the field personnel.

One should be aware that measurement of location error during engineering tests is expected to be more precise than that during environmental tests because the actual beacon locations could be more accurately determined. The ELT actual locations often are more accurately determined than the actual locations of the EPIRBs. Hence, confidence in the actual beacon positions obtained during environmental on-land ELT tests is generally higher than EPIRB tests run at sea.

2.2.2.1 *Test description*

2.2.2.1.1 *On-land tests*

The B-series results were obtained from a single test in which two experimental beacons were placed on the roof of a building and powered by an external source [Canada, 1985a].

The C-series engineering tests provided a large number of measurements and were taken in an area where there is considerable interference at 406 MHz [USSR *et al.*, 1984b; Castetbert, 1984a; France, 1984a].

The C-series environmental tests were conducted at airports located throughout the world [CSSC, 1985c].

The D-series engineering test results were obtained from a single beacon transmitting via the S1 satellite [Hovmork, 1984a].

The D-series environmental tests included placing 406 MHz beacons at 16 different sites on land and in the water, including former aircraft and ship accident sites [Hovmork, 1984b].

The E-series engineering test results were obtained from two separate tests [USSR, *et al.*, 1984c]. One test used five beacons activated simultaneously with internal lithium batteries; the second test used a single beacon powered from an external source.

The F-series engineering tests were conducted at varying power levels to obtain threshold data concurrent with location accuracy [Westinghouse, 1985].

The F-series environmental tests were conducted over a 1-year period [NASA, 1984a; NASA, 1985a].

The G-series tests were run using three LUTs for data comparison [United Kingdom, 1985].

A joint G-series and C-series engineering test was held [Department of Transport, 1984; USSR *et al.*, 1984b] to allow comparison between the two LUTs.

2.2.2.1.2 *On-deck tests (all environmental)*

A-series tests involved both ship-mounted and floating EPIRBs [USSR *et al.*, 1984d].

B-series tests were quite extensive and were conducted inland and on open ocean [Canada, 1985b].

C-series tests involved stationary and moving vessels [USSR *et al.*, 1984b; CSSC, 1985d].

E-series tests involved several different ships [USSR *et al.*, 1984e].

F-series tests [NASA, 1984b; NASA, 1985b] may have had some procedural problems early in the testing which were corrected during later tests. The effect on the results is unknown.

2.2.2.1.3 *Floating tests (all environmental)*

B-series tests [Canada, 1985b] utilized only tethered EPIRBs.

C-series tests were conducted both inland and in several different sea states [CSSC, 1985d; USSR *et al.*, 1984b].

F-series tests were conducted using both tethered and free-floating EPIRBs [NASA, 1984c; NASA, 1985b].

G-series tests were conducted using data collected from three different LUTs [United Kingdom, 1985].

2.2.2.2 *Test results*

The location-error test results are shown in Table II and are described below. Graphs depicting the data are included in Annex I.

TABLE IIa – Location error measured during engineering tests of land beacons *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
B	2.2	675	1-2	675	2-4	675	2-4	675
C	3.6	3733	0-1	3682	1-2	3682	5-10	3682
D	1.6	23	0-1	23	5-6	23	6-7	23
E	1.8	66	1-2	66	3-4	66	5-6	66
F	3.2	89	2.0	89	6.3	89	7.7	89
G	3.5	136	0-2	136	5-10	136	5-10	136
Sub-total	3.4	4722	0-1	4671	2-3	4671	5-10	4671

* Location error is measured between true location and the correct-side solution.

TABLE IIb – Location error measured during environmental tests of land beacons *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of data points	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
C	2.5	961	0-1	961	1-5	961	5-10	961
D	3.1	149 ⁽¹⁾	1-2	149 ⁽¹⁾	7-8	149 ⁽¹⁾	10-15	149 ⁽¹⁾
F	5.8	260	—	—	—	—	—	—
Sub-total	3.2	1370	0-1	1110	1-5	1110	5-10	1110

* Location error is measured between true location and the correct-side solution.

⁽¹⁾ Includes data from floating EPIRBs.

TABLE IIc – Location error measured during environmental tests of on-deck beacons *

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
A	7.6	38 ⁽¹⁾	1-2	38 ⁽¹⁾	10-20	38 ⁽¹⁾	30-50	38 ⁽¹⁾
B	4.5	92 ⁽²⁾	2-3	92 ⁽²⁾	9-10	92 ⁽²⁾	16-17	92 ⁽²⁾
C	3.5	327	1-2	146	4-9	146	4-9	146
E	3.5	82 ⁽¹⁾	1-2	82 ⁽¹⁾	4-7	82 ⁽¹⁾	7-11	82 ⁽¹⁾
F	8.5	130	—	—	—	—	—	—
Sub-total	4.8	669	1-2	358	5-10	358	10-20	358

* Location error is measured between true location and the correct-side solution.

⁽¹⁾ Includes data from floating EPIRBs.

⁽²⁾ Data excludes global mode where both regional and global mode data were available.

TABLE II d — *Location error measured during environmental tests of floating beacons **

Series	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
B	3.8	258 ⁽¹⁾	1-2	189	7-8	189 ⁽¹⁾	14-15	189 ⁽¹⁾
C	3.0	395	1-2	284	4-5	284	5-10	284
F	8.5	256	—	—	—	—	—	—
G	4.1	90	1-2	90	5-10	90	15-20	90
Sub-total	4.7	999	1-2	563	5-10	563	5-10	563

* Location error is measured between true location and the correct-side solution.

⁽¹⁾ Data excludes global mode where both regional and global mode data were available.

TABLE II e — *Location error summary*

Test type	Average (mean) error (km)	No. of locations	50th percentile (median) error (km)	No. of locations	90th percentile error (km)	No. of locations	95th percentile error (km)	No. of locations
Engineering tests	3.4	4722	0-1	4671	2-3	4671	5-10	4671
Environmental tests	4.0	3038	1-2	2031	5-10	2031	5-10	2031
Total	3.7	7760	0-1	6702	3-4	6702	5-10	6702

2.2.2.2.1 On-land results

The mean-location error measured during the engineering tests was 3.4 km for 4722 locations; the 50th, 90th, and 95th percentile ranges were 0-1 km, 2-3 km, and 5-10 km respectively for 4671 locations.

The mean-location error of the environmental tests was 3.2 km for 1370 locations; the 50th, 90th, and 95th percentile ranges were 0-1 km, 1-5 km, and 5-10 km respectively, for 1110 locations. The environmental tests show similar accuracy to the engineering test results.

2.2.2.2.2 On-deck results

The mean-location error for the environmental tests was 4.8 km for 669 locations; the 50th, 90th, and 95th percentile ranges were 1-2 km, 5-10 km, and 10-20 km respectively, for 358 locations. While it is possible that degradation from the on-land result may have occurred, it is more likely that the less accurate knowledge of the ship locations at the time of the satellite passes is the reason for the small discrepancy between the on-deck and the on-land results.

2.2.2.2.3 Floating results

The mean-location error for the environmental tests was 4.7 km for 999 locations; the 50th percentile range was 1-2 km, the 90th percentile range was 5-10 km, and the 95th percentile range was 10-20 km for 563 locations. Degradation from the on-land results was expected; however, the lack of knowledge of the true location of the beacons during the time of the satellite passes also had an effect on the result.

2.2.2.2.4 Other data

Several sets of on-deck and floating series tests were not included in the evaluation of the mean location error because the conditions of the tests were operationally invalid (e.g. a moving ship or lost floating EPIRBs) and were inappropriate to combine with the other tests.

2.2.3 Ambiguity resolution

For each real signal, the Doppler position location estimate generates two solutions that are mirror images about the satellite sub-track. Ambiguity resolution is defined as the ability of the system to select the "true" rather than the "mirror" position location as part of the location determination process. The rotation of the Earth introduces a non-symmetrical effect that provides an indication of the true position location. The system uses the non-symmetrical effect to assign each solution a probability of its being the true solution. Therefore, the performance measure of ambiguity resolution is the percentage of beacon location messages for which the system correctly assigns the higher probability of the true solution.

2.2.3.1 Test description

Ambiguity resolution was generally recorded during the same tests as the location error. With the exception of those tests in which ambiguity resolution was not reported or as listed below, all of the tests are described in § 2.2.2.1.

C-series floating environmental tests [CSSC, 1985e] were conducted in low sea states.

2.2.3.2 Test results

Test results are noted in Table III and are described below.

TABLE III – Ambiguity resolution

Beacon location	Series	Engineering tests		Environmental tests		Cumulative	
		Probability	No. of locations	Probability	No. of locations	Probability	No. of locations
On-land	B	0.97	675	—	—	0.97	675
	C	0.98	831	—	—	0.98	831
	D	0.87	23	0.84	149 ⁽¹⁾	0.84	172
	E	0.82	66	—	—	0.82	66
	F	0.94	410 ⁽²⁾	0.92	260	0.94	670
Sub-total		0.96	2005	0.89	409	0.95	2414
On-deck	B	—	—	0.87	92	0.87	92
	C	—	—	0.98	372	0.98	372
	E	—	—	0.95	82 ⁽¹⁾	0.95	82
	F	—	—	0.93	130	0.93	130
Sub-total				0.95	676	0.95	676
Floating	B	—	—	0.91	243 ⁽³⁾	0.91	243
	C	—	—	0.91	234	0.91	234
	D	—	—	0.89	45	0.89	45
	F	—	—	0.81	256	0.81	256
	G	—	—	0.92	90	0.92	90
Sub-total		—	—	0.88	868	0.88	868
Total		0.96	2005	0.91	1953	0.93	3958

⁽¹⁾ Includes data from floating EPIRBs.

⁽²⁾ Tests were performed by varying the beacon output from 22 dBm to 37 dBm. The actual number of tests run at nominal beacon e.i.r.p. (37 dBm) is unknown.

⁽³⁾ When both regional and global mode data were available, the regional mode was used. The B-series on-deck data and the floating data would have been 0.97 for 92 locations and 0.99 for 214 locations, respectively, if the global mode had been used.

2.2.3.2.1 *On-land tests*

The 0.96 probability of correct ambiguity resolution obtained during the engineering tests was very good. In addition, the F-series test results indicated that there was no correlation between ambiguity resolution and either the spacecraft or the satellite pass direction (ascending or descending).

As expected, the environmental ambiguity resolution result (0.89) is degraded relative to the engineering results. Some of the reasons are as follows: the elevation angle for one of the test series was either below 10° or above 82° , which made Doppler detection extremely difficult; and the time of closest approach for another of the test series was of the order of 4 min, which is critical if the signal is partially obstructed. Further testing is required for a full understanding of the degraded performance.

2.2.3.2.2 *On-deck tests*

The 0.95 probability of correct ambiguity resolution obtained during on-deck environmental tests appears to be higher than would be expected when compared to other environmental results.

2.2.3.2.3 *Floating tests*

The probability of correct ambiguity resolution obtained during the floating EPIRB tests was 0.88. The result appears to be comparable to the on-land environmental result.

2.2.4 *Beacon-location probability*

Beacon-location probability is defined as the probability of detecting and decoding at least four individual message bursts during a single satellite pass so that a Doppler curve-set estimate can be generated by the LUT. Location probability, as defined here, is not the end product but results in two ambiguous positions.

2.2.4.1 *Test description*

Most of the beacon-location probability results were generally obtained during the same tests as the location error and ambiguity resolution and are described in § 2.2.2.1. The F-series engineering tests were described under the beacon-detection probability, § 2.2.1.1. The remainder of the tests are noted below.

The B-series on-land engineering tests [King, 1984] were very extensive and included elevation angles below 10° .

The C-series floating environmental tests [CSSC, 1985e] were conducted using tethered and free-floating EPIRBs.

2.2.4.2 *Test results*

Table IV summarizes the measured beacon-location probabilities determined from engineering and environmental tests. The data in this table refers to the two possible locations due to ambiguity. The August, 1985 F-series engineering tests showed better results. All problems with faulty beacons and operational procedures have been eliminated during these tests.

2.2.4.2.1 *On-land tests*

The beacon-location probability measured during on-land engineering and environmental tests has been found to be 0.86 and 0.90, respectively.

2.2.4.2.2 *On-deck tests*

The on-deck engineering beacon measurements, undertaken during the F-series August 1985 tests, resulted in 0.98 beacon-location probability.

The on-deck environmental beacon-location probability test result was comparable to the on-land environmental test data and was found to be 0.87.

TABLE IV — *Beacon-location probability**

Beacon location	Series	Engineering tests		Environmental tests		Cumulative	
		Probability	No. of possible locations	Probability	No. of possible locations	Probability	No. of possible locations
On land	B	0.82	822 ⁽¹⁾	—	—	0.82	822
	C	0.84	61	0.94	362	0.92	423
	D	—	—	0.91	164 ⁽²⁾	0.91	164
	E	0.90	73	—	—	0.90	73
	F	0.95	350	0.86	302	0.91	652
Sub-total		0.86	1306 ⁽¹⁾	0.90	828	0.88	2134
On deck	B	—	—	1.0	25	1.0	25
	C	—	—	0.87	634	0.87	634
	E	—	—	0.80	51	0.80	51
	F	0.98	130	—	—	0.98	130
Sub-total		0.98	130	0.87	710	0.89	840
Floating	B	—	—	0.84	403 ⁽³⁾	0.84	403
	C	—	—	0.88	377	0.88	377
	D	—	—	0.94	34	0.94	34
	E	—	—	0.76	54	0.76	54
	F	0.99	260	0.77	331 ⁽⁴⁾	0.87	591
	G	—	—	1.0	9	1.0	9
Sub-total		0.99	260	0.83	1208	0.86	1468
Total		0.89	1696	0.86	2746	0.87	4442

* This data was obtained without resolving the ambiguity.

⁽¹⁾ If only data above 10° elevation angle is considered, the probability becomes 0.93/617 for B-series and 0.93/1101 sub-total.

⁽²⁾ Includes data from floating EPIRBs.

⁽³⁾ When both regional and global mode data were available, the regional mode was chosen. The B-series floating data would have been 0.84/476 if the global mode had been used.

⁽⁴⁾ This data includes procedural errors in determining elevation angles and from some faulty beacons.

2.2.4.2.3 Floating tests

The engineering measurements for floating EPIRBs, obtained during the August, 1985 F-series tests, resulted in 0.99 beacon-location probability, a similar value to the on-land and on-deck data for that series.

Some degradation in environmental beacon-location probability from the engineering test data was expected. The cause of such a degradation to a value of 0.83 has been determined, at least for the F-series tests, to have been caused by use of some intermittent beacons and from less stringent accounting of data.

2.2.4.3 Beacon-location probability as a function of beacon output power

The beacon-location probability reduction is a quantitative measure of the system's ability to process beacon signals at reduced signal levels. The test described below measured that value of the beacon e.i.r.p. at which the beacon-location probability decreases by 10% from its value for a nominal power beacon.

2.2.4.3.1 Test description

A B-series engineering test on land was conducted during the September-November, 1983 test period to measure the beacon-location probability as a function of beacon output power [King, 1985]. A total of 482 satellite passes of C2 and S1 satellites were tracked by the Ottawa LUT. The test was conducted by operating two 406 MHz beacons collocated with the Ottawa LUT. One beacon was used as a reference and always operated at the nominal power output of 37 dBm (5 W), while the other beacon had selected fixed attenuators inserted in the antenna cable. Each beacon transmitted from a separate, but similar, quarter-wave monopole antenna (with ground plane) mounted on the roof of a one-storey building. The beacons transmitted at 50 s intervals, but staggered by 25 s so as not to have simultaneous transmissions.

2.2.4.3.2 Test results

Table V provides the data obtained during the above B-series tests. The test results indicate that for those satellite passes whose maximum elevation angle exceeded 10° (i.e. passes preferred for optimum system operation), a 13 dB beacon power reduction resulted in a 9% reduction in beacon-location probability. However, when all passes are considered (i.e. including those passes below 10° elevation angle), the equivalent power reduction was measured to be 6 dB.

TABLE V — Beacon-location probability as a function of beacon output power

Maximum elevation angle of pass	Attenuation level of nominal e.i.r.p. (dB)	Total No. of locations		Relative location probability ⁽¹⁾ (attenuated/nominal)
		Nominal power beacon	Attenuated power beacon	
> 10°	0	51	51	1.00
	3	55	54	0.98
	6	96	94	0.95
	9	100	91	0.94
	13	44	40	0.91
> 0°	0	57	57	1.00
	3	70	63	0.90
	6	116	104	0.90
	9	122	101	0.83
	13	54	41	0.76

⁽¹⁾ Actual beacon-location probability data for this test is not known.

2.2.5 Capacity

Capacity is defined as the ability of the system to simultaneously process beacons that are in a common field of view of the spacecraft during a single pass. The 406 MHz system is designed to be capable of processing 90 beacons simultaneously in the field of view of the satellite. Verification of this capability was attempted using Cospas-2, Sarsat-2, and a special test facility located in France. In 1984 and 1985, these tests demonstrated that with interference present, the 406 MHz on-board processor could process more than 90 simulated beacon transmissions simultaneously [Castetbert, 1984b; CSSC, 1985f].

2.2.6 Homing range

Homing-range capability is measured in terms of the distance (relative to height) from an airborne homing device to a 406 MHz beacon using the latter's low power 121.5 MHz homing signal. Figure 1a shows the test results in terms of homing range as a function of aircraft height above the beacon's terrain.

Some tests were conducted using an existing aircraft 121.5 MHz homer which was modified to respond directly to the 406 MHz burst signal. Performance data for these flight trials is shown in Fig. 1b.

Figures 1a and 1b illustrate that if search and rescue aircraft are used, the homing range of 10 km is sufficient to find 95% of 406 MHz satellite EPIRBs, as shown in Table IIe.

The maritime homing test results are presented in Report 1036.

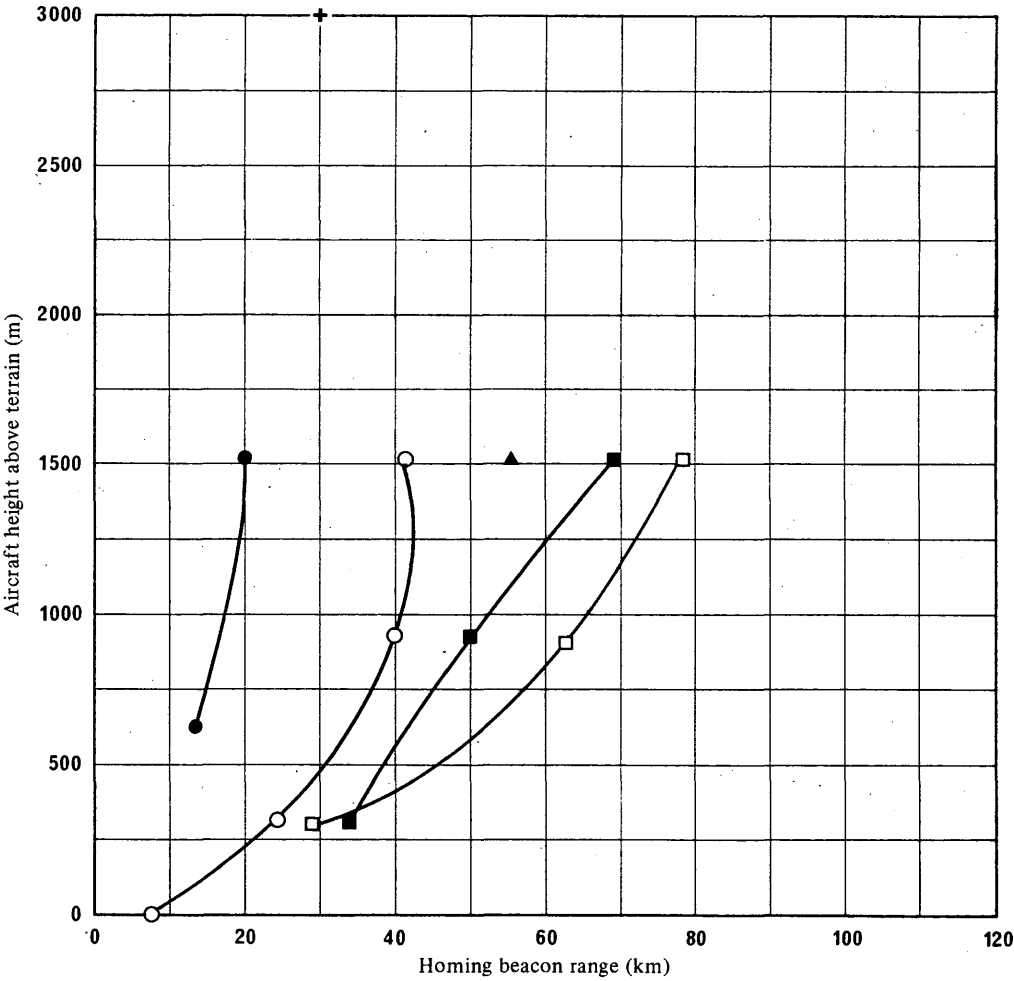


FIGURE 1a – Homing test results using 121.5 MHz, 20 mW transmitter*

* This was a 20 mW 121.5 MHz homing transmitter placed in a 406 MHz beacon

Sea test data

- USCG homer
- ▲ UK/French SAR
- + USSR Black Sea

Land test data

- USAF A homer
- USAF B1 homer
- USAF B2 homer

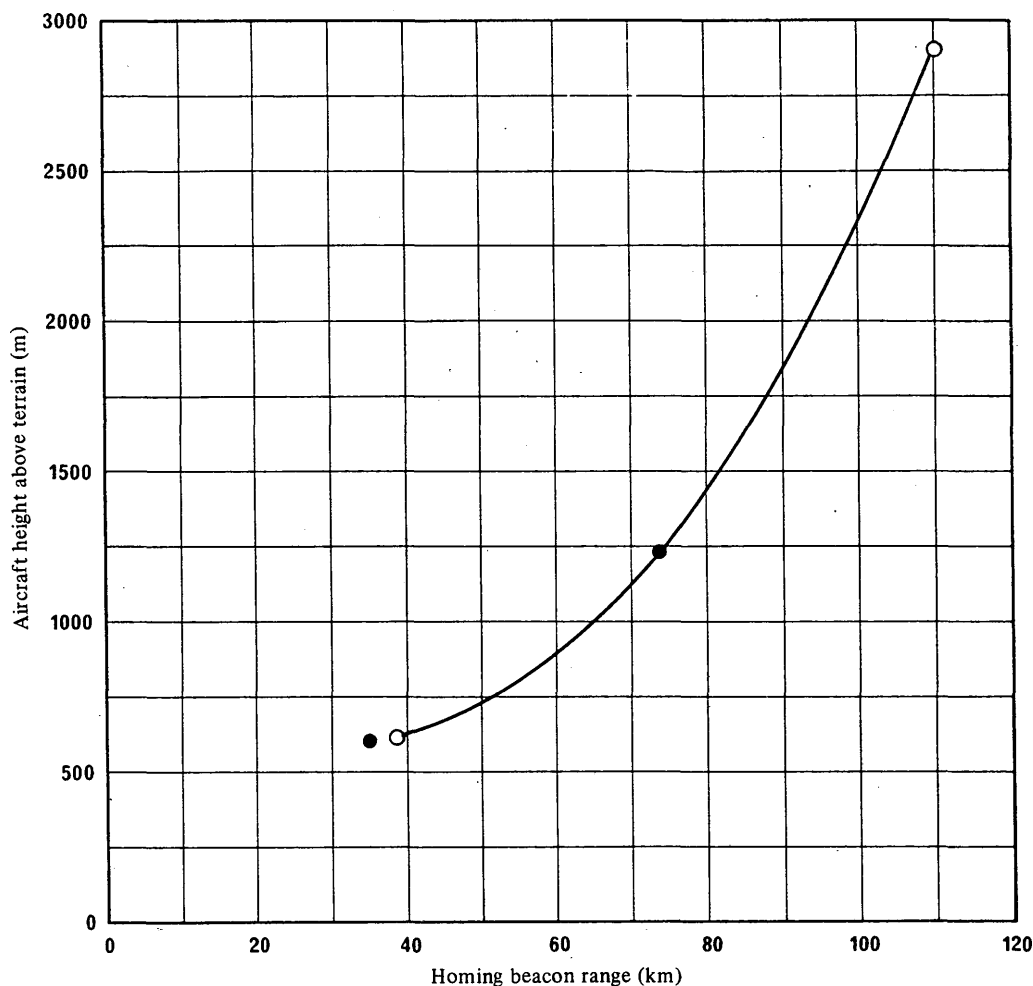


FIGURE 1b – Homing test results using COSPAS/SARSAT 406 MHz, 5 W/burst signal

Canadian modified DF 301 E homer

- Land test data
- Sea test data

2.2.7 Notification time

For the purpose of this Report, notification time is defined as the time period between activation of a radio beacon and the time when a valid alert message is received by the mission control centre (MCC) responsible for relaying the message to the rescue coordination centre (RCC). In the regional (real-time) mode, notification time includes the time period from beacon activation to the time of the establishment of a common field of view between the beacon and the spacecraft, and the LUT and the spacecraft; all processing time by the LUT; and all communications handling times to receipt of the message by the MCC.

In the global (stored) mode, notification time includes the time period from beacon activation to the time of line-of-sight contact with the spacecraft; the time period between receipt of the alert message by the spacecraft (including storage and processing) and its dump to the ground station; and all LUT communications handling/processing times from beacon activation to receipt of the alert message by the MCC.

The limited results presented in Table VI were obtained by B-, C-, and E-series tests [Canada, 1985b; USSR *et al.*, 1984f; France, 1984b; CSSC, 1985e]. Notification times depend on the number of satellites, the latitude of distress locations, the distribution of LUTs over the world, and the varying satellite positions with time. All of the above tests were performed with beacons and LUTs at northern mid-latitudes of about 45° N, and the results presented are mean values of both regional and

global modes. In the future, additional computer simulations and tests to verify the simulations may be performed to determine notification time as a function of additional latitudes, global and regional modes, and varying beacon-LUT-spacecraft geometries. The results of this additional effort will be reported in detail and will not be averaged.

TABLE VI – Mean notification time*

Beacon location	Series	Time (min)	No. of locations
On land	B	77	2
	C	114	51
	E	90	44
Sub-total		102	97
On deck	C	87	279
Floating	C	98	89
Total		92	465

* From one to three satellites were used with beacons and LUTs located at an approximate latitude of 45° N.

3. 406 MHz interference

Figure 2 shows the areas over which the COSPAS/SARSAT satellites are affected by interfering signals at 406 MHz [USSR *et al.*, 1984b]. The interference situation was raised during the 1983 World Administrative Radio Conference for Mobile Services (WARC MOB-83), and a Resolution to protect the 406.0-406.1 MHz frequency band was included in the Final Acts of the Conference (Resolution No. 205). With this Resolution, the WARC MOB-83 requested the International Frequency Registration Board (IFRB) to organize a monitoring programme in this frequency band and requested administrations to take all necessary actions to eliminate unauthorized transmissions.

In addition, using both Cospas-I and the SAR repeater (SARR), the SARSAT partners developed specific analysis programmes for locating interfering signals. Some interfering signals have well-characterized spectral components where the frequency variation due to the Doppler shift can be identified. It is therefore possible to determine the position of the interfering source using a positioning technique similar to the technique used for ELT/EPIRBs. A description of this method was submitted to Study Group 1 (see Report 979).

So far, several unauthorized transmission sources have been located and were removed from the SAR frequency band. Other sources are being pursued through bilateral contacts. Most of the interfering transmitters were found to be used for low-rate data links. Such use of the 406 MHz band was authorized prior to the WARC-79. The signal levels received by the satellites from these unauthorized transmissions are comparable to the signal levels from 406 MHz EPIRBs. It is expected that the IFRB actions and the bilateral actions will, in the near future, allow the elimination of most of the interfering signal sources.

4. Measured performance at 121.5 MHz

Although this Report is intended to show the results of the D and E phase at 406 MHz, it is important to mention the results of the concurrent and related D and E tests at 121.5 MHz. The primary relevance of these results is the fact that the 121.5 MHz is presently the most commonly used frequency world-wide for the support of search and rescue operations and is used in distress beacons of general aviation and maritime communities world-wide. Although the capabilities of the 121.5 MHz beacons are not expected to be nearly as good as the new experimental 406 MHz beacons undergoing development, the results of the D and E phase have already shown that the use of low Earth-orbiting satellites in conjunction with a distress beacon system does substantially improve SAR capabilities. As of 31 August 1985, the 121.5 MHz system has provided position locations and alert notifications that contributed to the rescue of 474 distress victims (238 aviation, 217 maritime, and 19 terrestrial) involved in real distress cases. In some of these cases, the 121.5 MHz COSPAS/SARSAT system was the only notification source; and, in more cases, the COSPAS/SARSAT system was the first notification source.

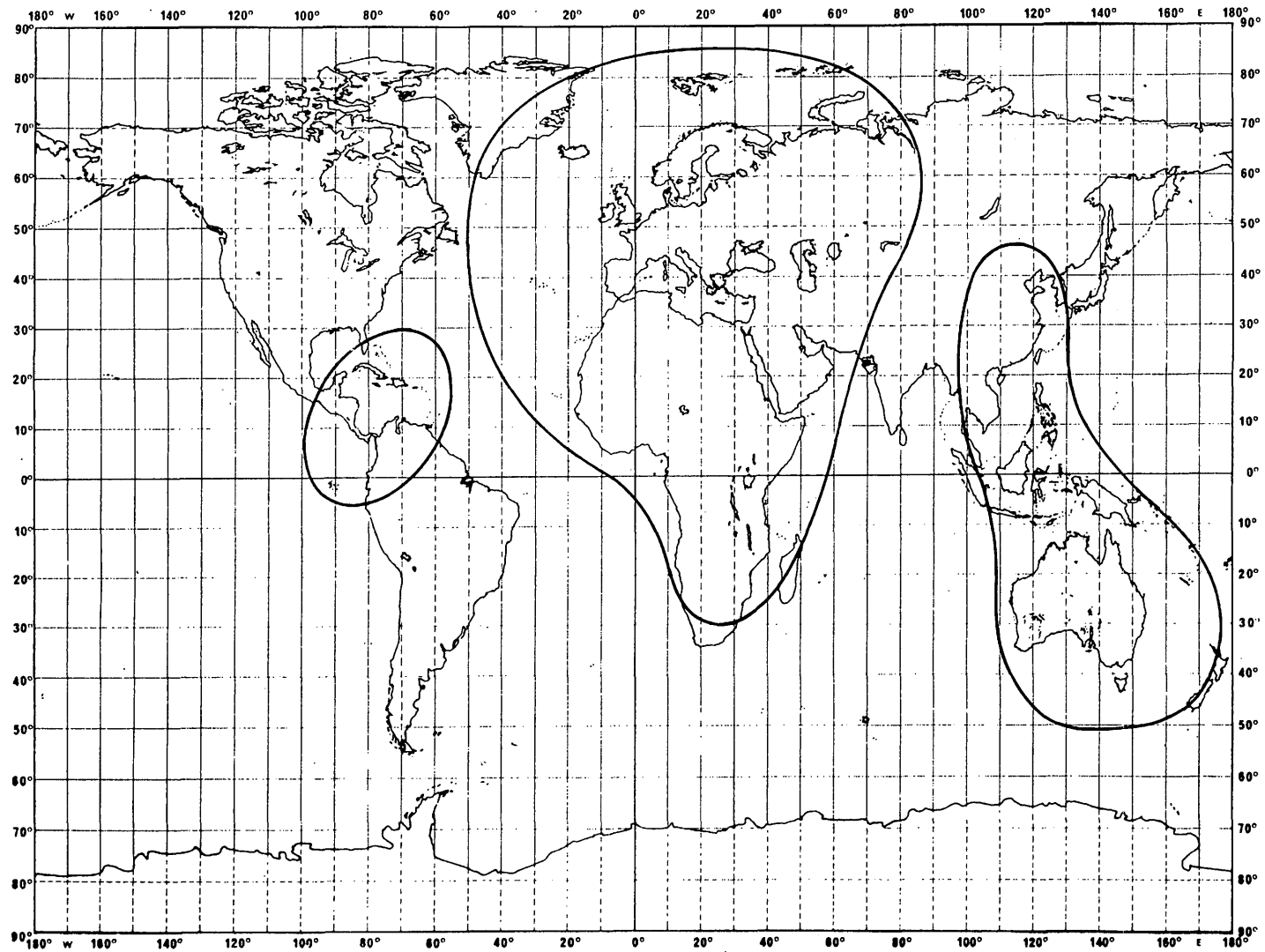


FIGURE 2 – Areas affected by interference

It is generally accepted by participants in the COSPAS/SARSAT project that the 406 MHz system is expected to provide to the SAR community, support that is far superior to that of the current 121.5 MHz system. To give the user an understanding of the performance of the 121.5 MHz system, the general SARSAT participants' results of environmental tests performed at this frequency during the period of February, 1983 to February, 1984 inclusive are presented in Table VII. The results are shown for tests on land and at sea. The tests on land were performed by the participating countries in nearly all possible environmental conditions. (These conditions ranged from desert to mountains, to dense forest from -40°C to $+55^{\circ}\text{C}$ from clear weather to thunderstorms, to blizzards and various combinations of other extremes. It must be noted that these tests used known, good ELT configurations, i.e. coherent signal (see Note), nominal signal strength, good power source, good antenna, and compatible geometry. The environmental sea tests were performed in much the same manner as the land tests. The primary variable in the sea tests was the sea state. There also existed the inherent problem of not knowing the exact location while at sea. These two conditions may explain the reasons why the sea-test results do not compare well with the land tests.

Note. — In this context, the definition given to a coherent signal is one with a spectrum containing a clearly identifiable constant frequency component; an incoherent signal has no predominant carrier component in its spectrum.

TABLE VII — *Measured performance of the 121.5 MHz system*

Performance parameter	Measured performance
Mean location error ⁽¹⁾	
Sea tests (km)	23.4
Land tests (km)	17.2
Location probability	
Sea tests (%)	76
Land tests (%)	91
Ambiguity resolution	
Sea tests (%)	72
Land tests (%)	73
Number of orbits	
Sea tests	174
Land tests	139
Number of locations	
Sea tests	189
Land tests	166

⁽¹⁾ Location error is measured between true location and the correct-side solution, i.e. disregarding ambiguity.

By comparing the results of 121.5 MHz tests shown in Table VII with the results of 406 MHz tests shown in Tables II to IV, one can see that performance of the 406 MHz system exceeds that of the 121.5 MHz system in location error and in ambiguity resolution, though there appears to be no significant improvement in performance in location probability over the coherent 121.5 MHz beacons used in the test.

The contributions already made by the 121.5 MHz system in supporting SAR operations are significant, even using distress beacons of unknown operating condition, many of which have neither coherent nor stable frequency characteristics. One should expect greatly improved support of SAR operations using the 406 MHz system with its improved performance and additional message information and identification.

A major improvement expected of the 406 MHz system over the 121.5 MHz system is the reduction of false alarms. This subject is addressed in § 5 below.

5. Problem areas at 121.5 MHz

5.1 False alarm resolution

False distress alarms have existed since emergency beacons came into use. False alarms are defined here as the transmission of a signal by an emergency beacon when it is not in a distress situation. (Short test transmissions following specified procedures are allowed and do not cause false alarms.) With the advent of satellite-aided detection of operational 121.5 MHz beacons, many previously undetected false alarms began to be detected because of the COSPAS/SARSAT demonstrated ability to detect very weak distress beacons. The SAR forces have always adopted procedures to continue their effectiveness in spite of false alarm problems, both before and after satellite support. The demonstrated extraordinary ability of the COSPAS/SARSAT satellites to detect even very weak beacons has the unfortunate consequence of capturing, in addition to distress signals, all the false alarms. Despite this present situation of intensity of false alarms at 121.5 MHz, the SAR forces remain responsive to the distress cases. Clearly, future operational systems require improvements for minimizing the false alarm rate.

One of the most positive steps in eliminating false alarms can come from the implementation of 406 MHz beacons that have unique identification, specifications for satellite compatibility, and elimination of 121.5 MHz beacon weaknesses. The 406 MHz beacon unique identification code will eliminate unnecessary searches for many false alarms by allowing communication checks based on data derived from the ID code. The satellite compatibility improvement of the 406 MHz beacon will eliminate falsely generated alerts in the ground system that were due to noise and modulation peculiarities that cause problems in the current 121.5 MHz system. The 406 MHz specifications and the voluntary 121.5 MHz specification for the ELT crash sensor will provide a more reliable system than currently provided by the 121.5 MHz beacons and will also reduce the false alarms. In the United States of America, changes to 121.5 MHz beacon specifications, and pilot and mariner education programmes are under way to reduce the false alarm problem with the present beacons.

6. Preliminary conclusions

The COSPAS/SARSAT system is an excellent example of international cooperation to establish technical and operational compatibility between two completely independent space systems. The project, a synthesis of the Soviet COSPAS and the Canada/France/United States SARSAT project activities, joined because of common technical and humanitarian objectives, has been successful despite its short period of existence. While the detailed evaluation of the performance of the COSPAS/SARSAT search and rescue satellite system continues, some of the following anticipated benefits of the system are being realized:

- saving of lives;
- improved response to distress calls from maritime, aeronautical, and land-mobile stations;
- more efficient use of SAR resources.

In summary, the COSPAS/SARSAT demonstration and evaluation phase indicates the following:

- COSPAS/SARSAT is contributing to quicker detection and location of people in distress, thus relieving human suffering and enhancing the protection of property;
- the SARSAT and COSPAS systems have demonstrated that all inter-operability requirements were achieved;
- experimentation and operational use at 121.5 MHz have been successful. As of 31 August 1985, the system has provided alert and location data in 194 distress incidents world-wide, in which 474 survivors were rescued;
- experimentation at 406 MHz has demonstrated the benefits of using beacons designed for satellite detection. Benefits include global coverage (in the global mode), beacon identification, and improved location probability and improved accuracy over the present 121.5 MHz beacon performance.

7. Summary and outlook

The environmental and engineering test data presented in this Report demonstrate that the COSPAS/SARSAT system has successfully met all its objectives. It has been used operationally at 121.5 MHz since 1982, and additional operations at 406 MHz were initiated in July 1985. The successful demonstration was accomplished even though during much of the demonstration and evaluation phase fewer than the specified four satellites were in orbit. In addition, other portions of the system, such as signal processing techniques and algorithms, continued to undergo improvements.

The in-orbit satellite configuration is now as intended. More LUTs are being added, including the first one in South America. A plan for a system of regional data distribution centres for the world-wide distribution of distress data has been developed and will be implemented over the next few years.

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ANNEX I

COSPAS/SARSAT SYSTEM
LOCATION-ERROR HISTOGRAMS

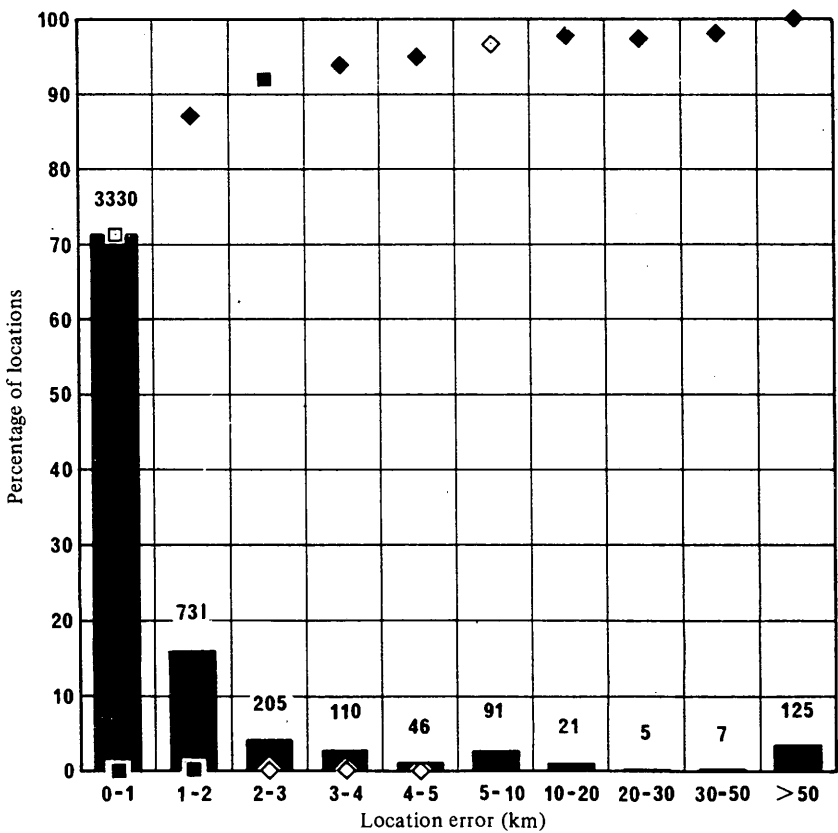


FIGURE 3 – Location error measured during engineering tests of land beacons as a function of percentage of locations
(Total of all data where the distributions were reported: 4671 locations)

- Group percentage
- 50% mark
- 90% mark
- 95% mark
- Cumulative percentage

The number of locations per group is indicated above each column.

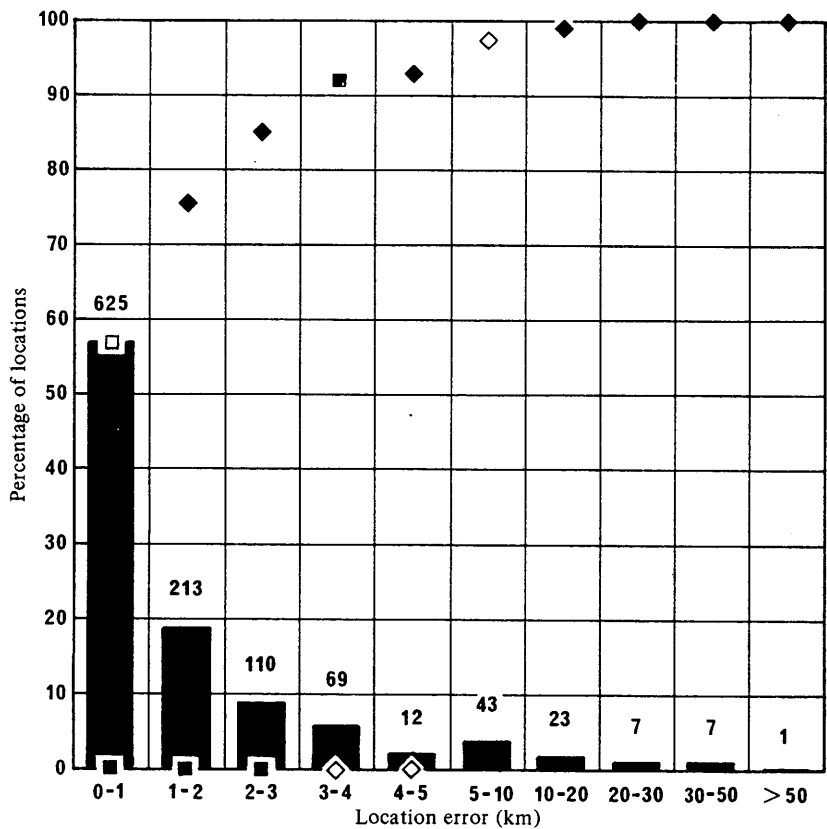


FIGURE 4 – Location error measured during environmental tests of land beacons as a function of percentage of locations
(Total of all data where the distributions were reported: 1110 locations)

- Group percentage
- 50% mark
- 90% mark
- 95% mark
- Cumulative percentage

The number of locations per group is indicated above each column.

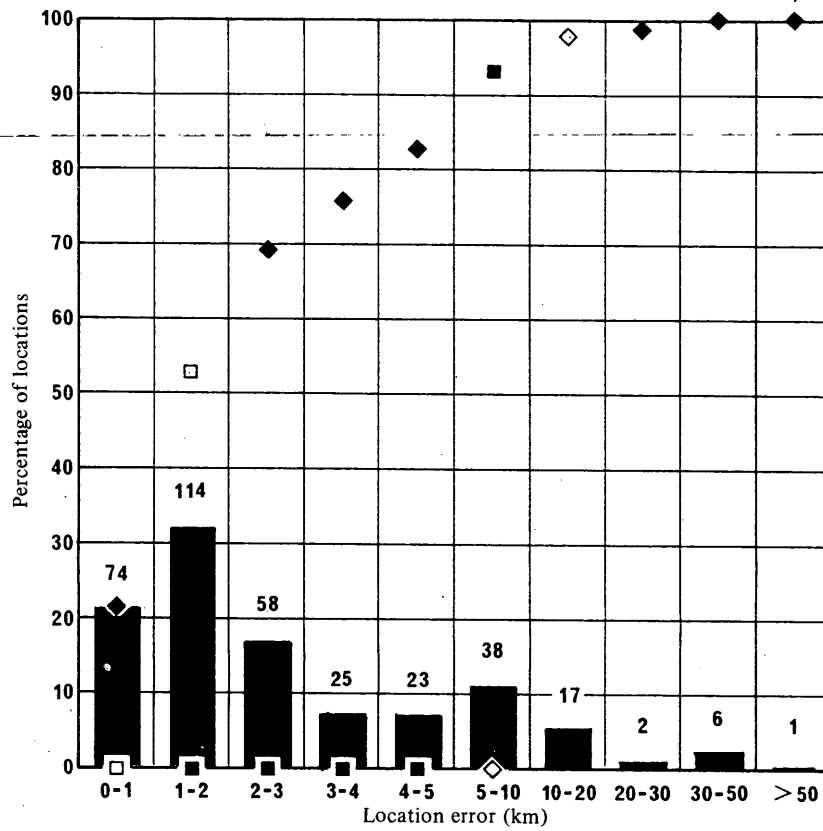


FIGURE 5 – Location error measured during environmental tests of on-deck beacons as a function of percentage of locations

(Total of all data where the distributions were reported: 358 locations)

- Group percentage
- 50% mark
- 90% mark
- ◇ 95% mark
- ◆ Cumulative percentage

The number of locations per group is indicated above each column.

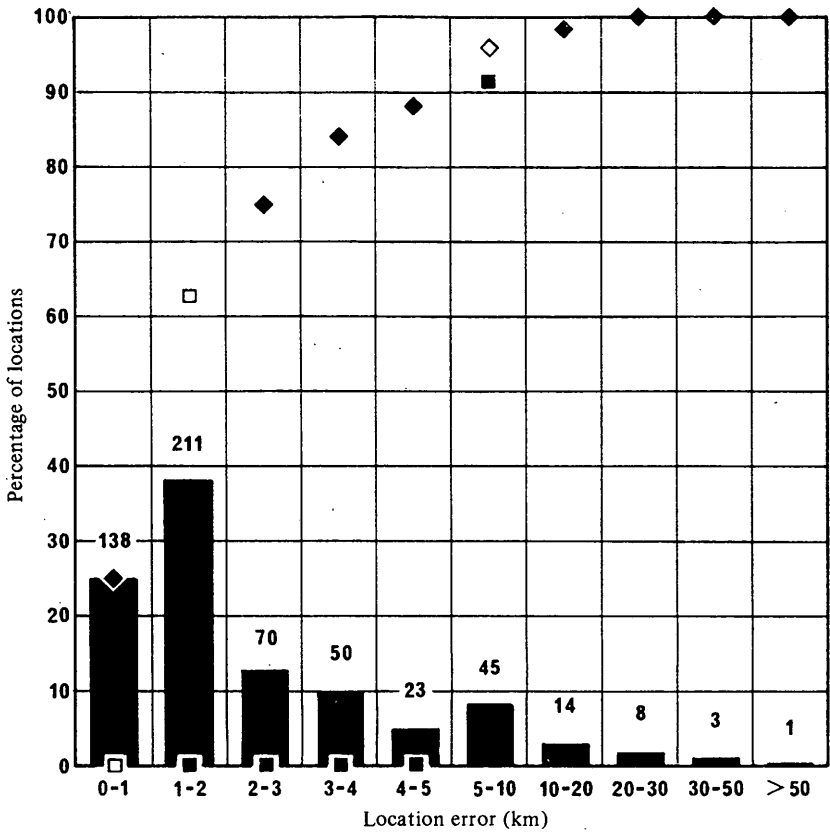


FIGURE 6 – Location error measured during environmental tests of floating beacons as a function of percentage of locations

(Total of all data where the distributions were reported: 563 locations)

- Group percentage
- 50% mark
- 90% mark
- 95% mark
- Cumulative percentage

The number of locations per group is indicated above each column.

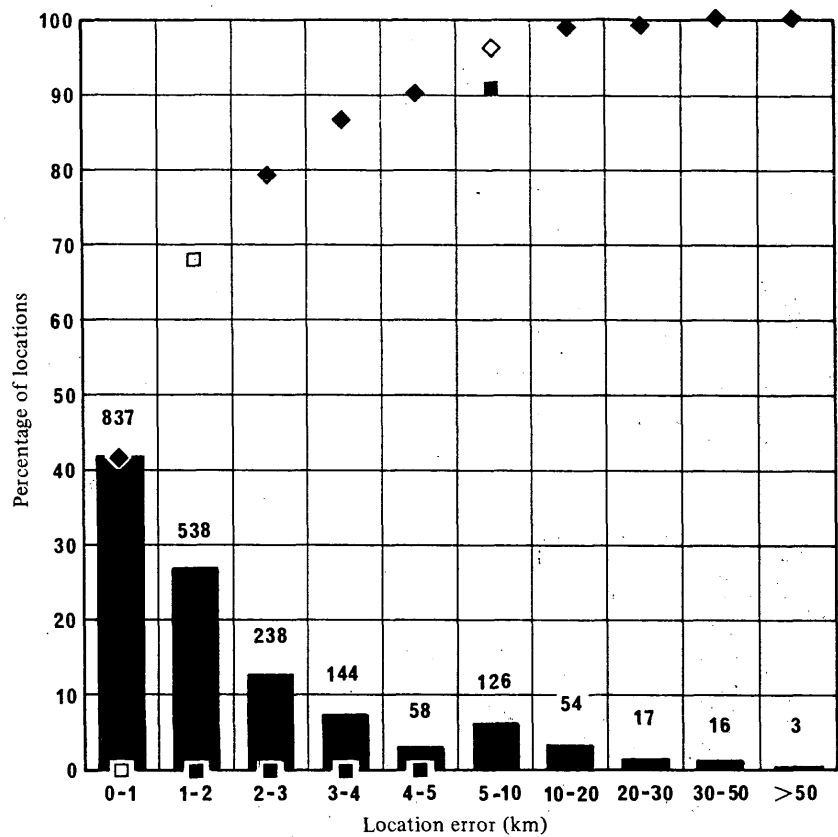


FIGURE 7 – Location error measured during environmental tests of all beacons as a function of percentage of locations

(Total of all data where the distributions were reported: 2031 locations)

- Group percentage
- 50% mark
- 90% mark
- ◇ 95% mark
- ◆ Cumulative percentage

The number of locations per group is indicated above each column.

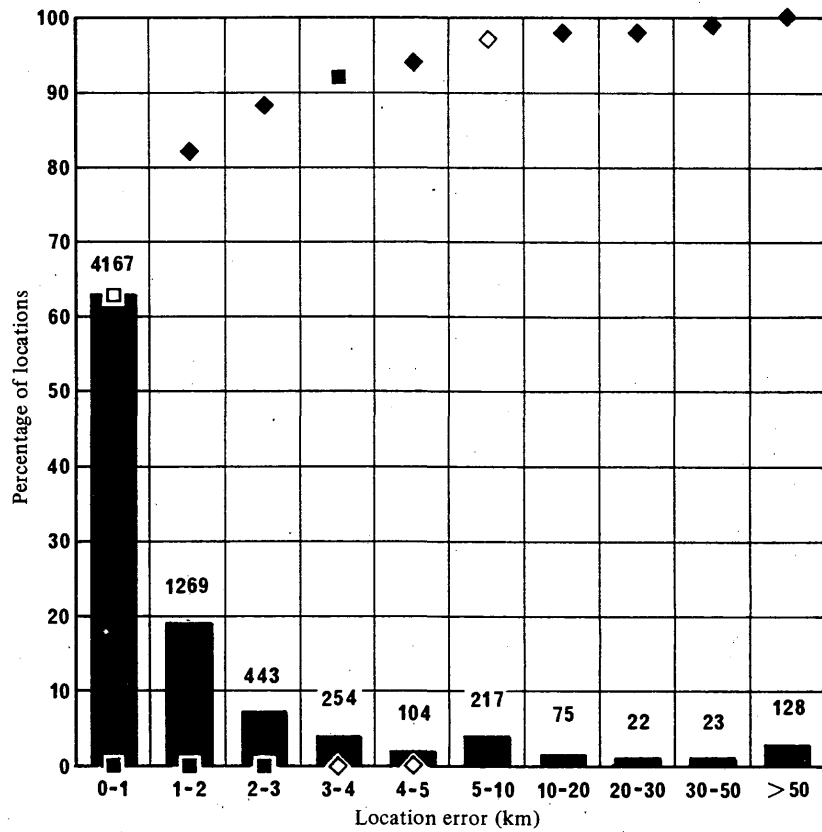


FIGURE 8 – Location error measured during all tests of beacons
as a function of percentage of locations

(Total of all data where the distributions were reported: 6702 locations)

- Group percentage
- 50% mark
- 90% mark
- ◇ 95% mark
- ◆ Cumulative percentage

The number of locations per group is indicated above each column.

REPORT 762-2

EFFECTS OF MULTIPATH ON DIGITAL TRANSMISSION OVER LINKS
IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The effects of multipath propagation on digital transmission have been theoretically analyzed and experimentally evaluated.

The theoretical analysis performed by Japan results in a prediction of error rate performance for two-phase coherent PSK and two-frequency non-coherent FSK modulations.

The theoretical analysis carried out by the United States gives the error rate for differential coherent phase-shift keying (DCPSK); the results of United States experiments with the ATS-6 satellite determine the range of multipath values used in the theoretical model. The calculated error rate is compared with measurements made using a laboratory channel simulator.

The tests performed in 1975 by France with the ATS-6 satellite have made it possible to obtain curves representing the bit error ratio for two-phase PSK digital transmission for different satellite elevation angles.

In tests performed in 1979 by the Federal Republic of Germany with the aid of the Marisat tracking beacon, the amplitude and phase response of the satellite-to-ship multipath signal was recorded on-board ship for various receiving antennas and elevation angles. The recordings were used to control a laboratory channel simulator (the stored channel principle) to determine the fading margin for various data transmission methods. The amplitude response was statistically evaluated and compared with theoretical models.

2. Theoretical analyses**2.1 Rice-Nakagami or m -distribution****2.1.1 General**

This work assumes that the amplitude distribution of the sea-reflected signal follows the m -distribution function and derives the probability distribution for the fading amplitude [Nakagami, 1960]; this distribution is also known as the Rice-Nakagami distribution and is general enough to describe most fading phenomena including Rayleigh fading.

An example of the m -distribution using " m " as a parameter is shown in Fig. 1. It should be noted that this figure represents one-sided Gaussian fading when $m = \frac{1}{2}$ and Rayleigh fading when $m = 1$, where m is the inverse of the normalized variance of the reflected signal amplitude squared.

2.1.2 Probability of error

The probability of error, $p(p, C/M, m)$, corresponding to the Rice-Nakagami distribution has also been derived [Mizuno *et al.*, 1975] for the cases two-phase coherent PSK and two-frequency non-coherent FSK. In this notation p is the energy per bit-to-noise power density ratio (E/N_0) at the demodulator, and C/M is the direct signal-to-multipath signal power ratio.

2.1.3 Results of calculations

Figures 2 to 4 illustrate the bit error ratio characteristics calculated using the analytic methods referenced above.

Figure 5 shows the relation between direct signal-to-multipath signal power ratio and the equivalent degradation value of carrier-to-noise power ratio. The equivalent degradation value is the difference in the E/N_0 values required to obtain a bit error ratio of 10^{-5} in the presence of thermal noise, between the case when a sea-reflected signal exists and the case when no reflected signal exists. In other words, it corresponds to the fading margin to be assigned for multipath interference for the particular modulations discussed.

The following can be concluded from Fig. 5:

- When C/M is constant, the degradation due to the multipath effect increases as m decreases.
- When the fading is deep or m is smaller than 1, the equivalent degradation value of E/N_0 for the two-phase coherent PSK is larger than that for the two-frequency non-coherent FSK.
- For a given m , the required margin necessary to achieve a bit error ratio (BER) of 10^{-5} , represented as a degradation of E/N_0 in Fig. 5, increases as C/M decreases. For a C/M of 12 dB and $m = 1/2$, which corresponds to a Gaussian scatter process for the multipath, an increase in signal of about 11 dB is required to give the same bit error ratio for a two-phase coherent PSK receiver as is obtained in the presence of thermal noise alone. It may also be noted in this case that a small decrease in the direct signal to multipath ratio, C/M , produces a large increase in required margin.

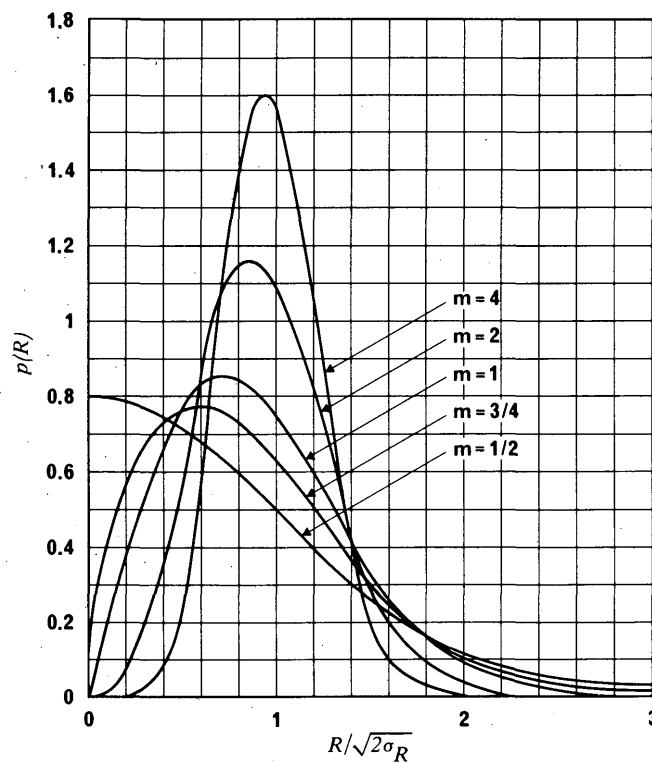


FIGURE 1 — m -distribution

R : amplitude of the reflected signal
 σ_R : r.m.s. value of the reflected signal

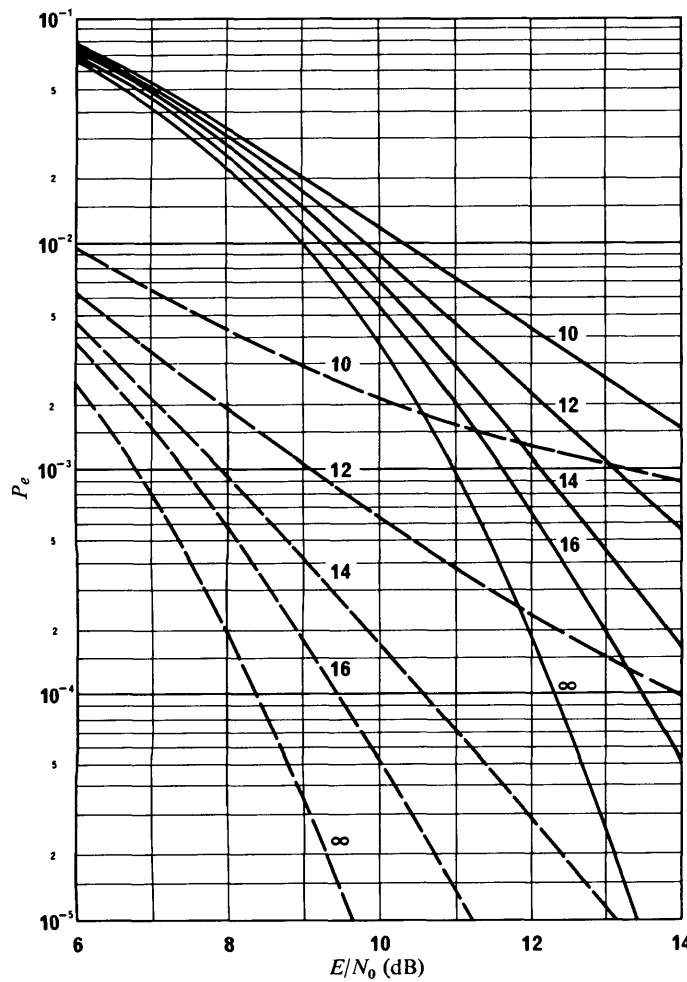


FIGURE 2 — Error probability for the two-phase coherent PSK and the two-frequency non-coherent FSK ($m = 1/2$) (Parameter is C/M , in dB)

----- 2CPSK
 ————— 2NFSK

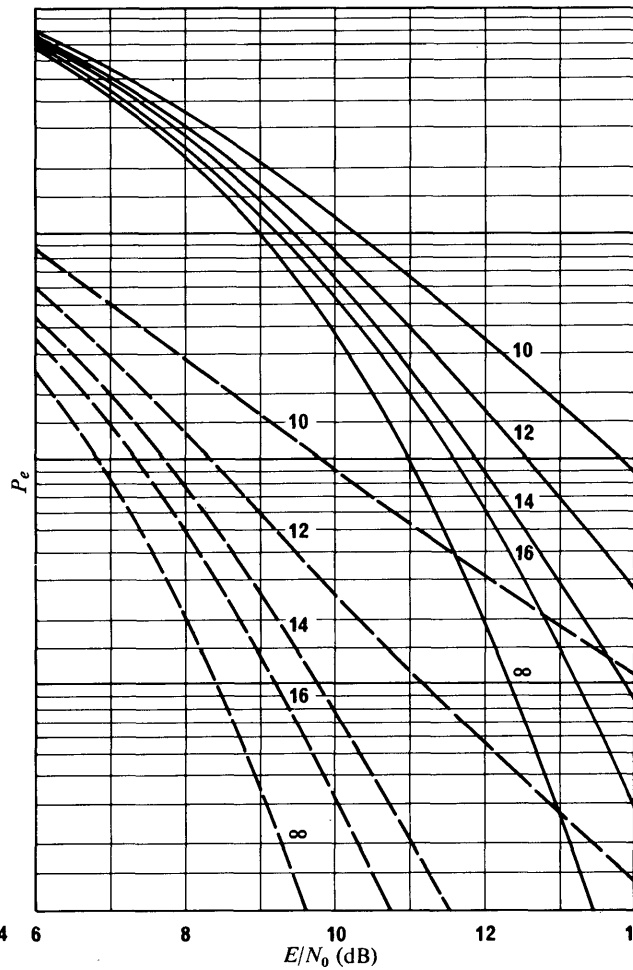


FIGURE 3 — Error probability for the two-phase coherent PSK and the two-frequency non-coherent FSK ($m = 1$) (Parameter is C/M , in dB)

----- 2CPSK
 ————— 2NFSK

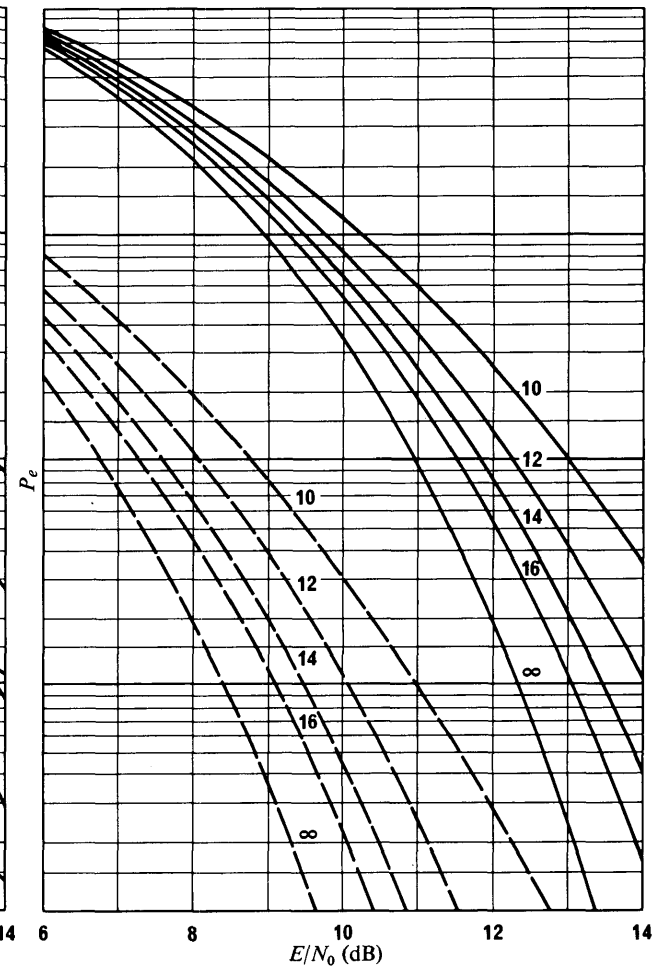


FIGURE 4 — Error probability for the two-phase coherent PSK and the two-frequency non-coherent FSK ($m = 4$) (Parameter is C/M , in dB)

----- 2CPSK
 ————— 2NFSK

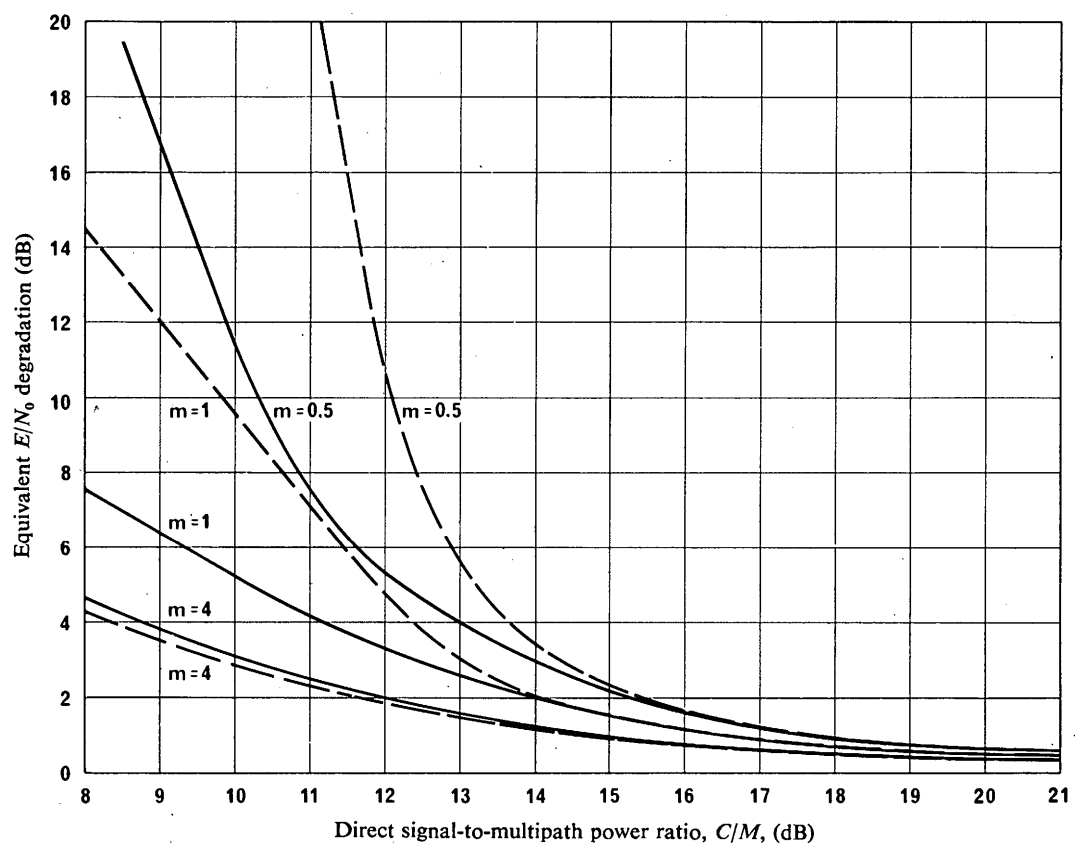


FIGURE 5 — Equivalent degradation of E/N_0
($BER = 10^{-5}$)

--- 2CPSK
— 2NFSK

2.2 Modestino-Mui analysis

2.2.1 General

The maritime satellite channel can be modelled as shown in Fig. 6. This model is based on previous analytical studies [Salwen, 1972].

The channel model of Fig. 6 can accommodate either specular or diffuse multipath reflection conditions. As the multipath becomes more specular in nature, the mean-square multipath power (M) tends to increase while the bandwidths of the in-phase and quadrature components of the complex envelope which characterize the multipath envelope tend to zero.

The data collected during the ATS-6 maritime satellite tests support the conclusion that the reflected multipath is diffuse. In particular, it was found that the multipath energy arrives from a broad region on the ocean's surface rather than from the multipath specular reflection point.

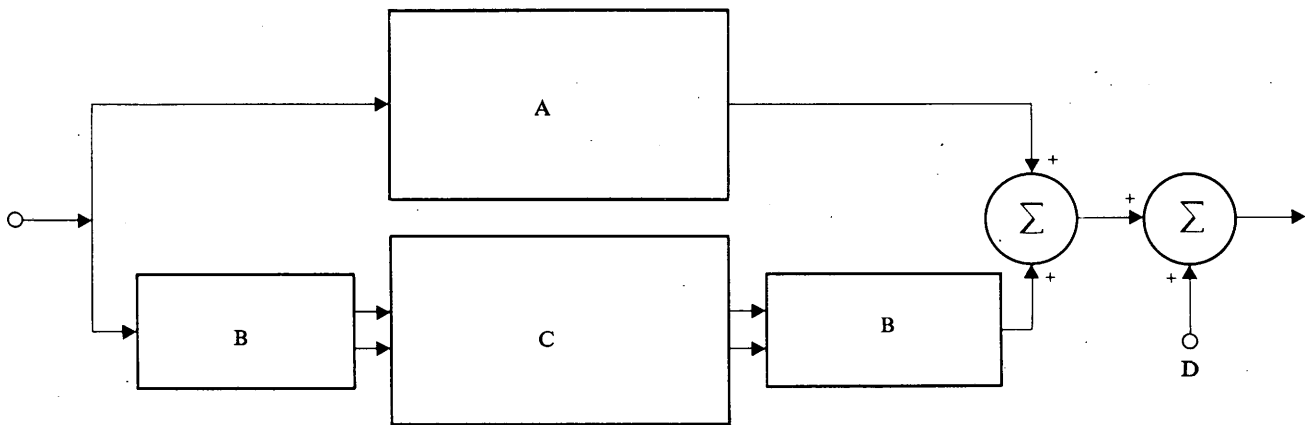


FIGURE 6 — Channel model representative of a satellite-ship link

- A: direct path (constant complex gain factor)
- B: quad hybrid
- C: multipath (time varying complex gain factor)
- D: $n(t)$ (noise)

2.2.2 Probability of error

The probability of bit error for a coherent PSK system in which there is a slowly varying carrier tracking error and a slowly fading amplitude (the fade is slow relative to the bit rate), has been derived [Modestino and Mui, 1976] for the case of two-phase coherent PSK. Their results are extended to the DCPSK case by noting that the probability of bit error for DCPSK is approximately $2P_b$ when $P_b \ll 1$.

2.2.3 Results of calculations

Figure 7 shows the expected value of the probability of bit error for DECPSK as a function of C/N_0 and C/M which are obtained by digital computer solution of the theoretically derived expression [Modestino and Mui, 1976]. The curves shown in Fig. 7 assume a 15 dB signal-to-noise ratio in the carrier tracking loop. At that level, carrier tracking errors have very little effect on probability of bit error.

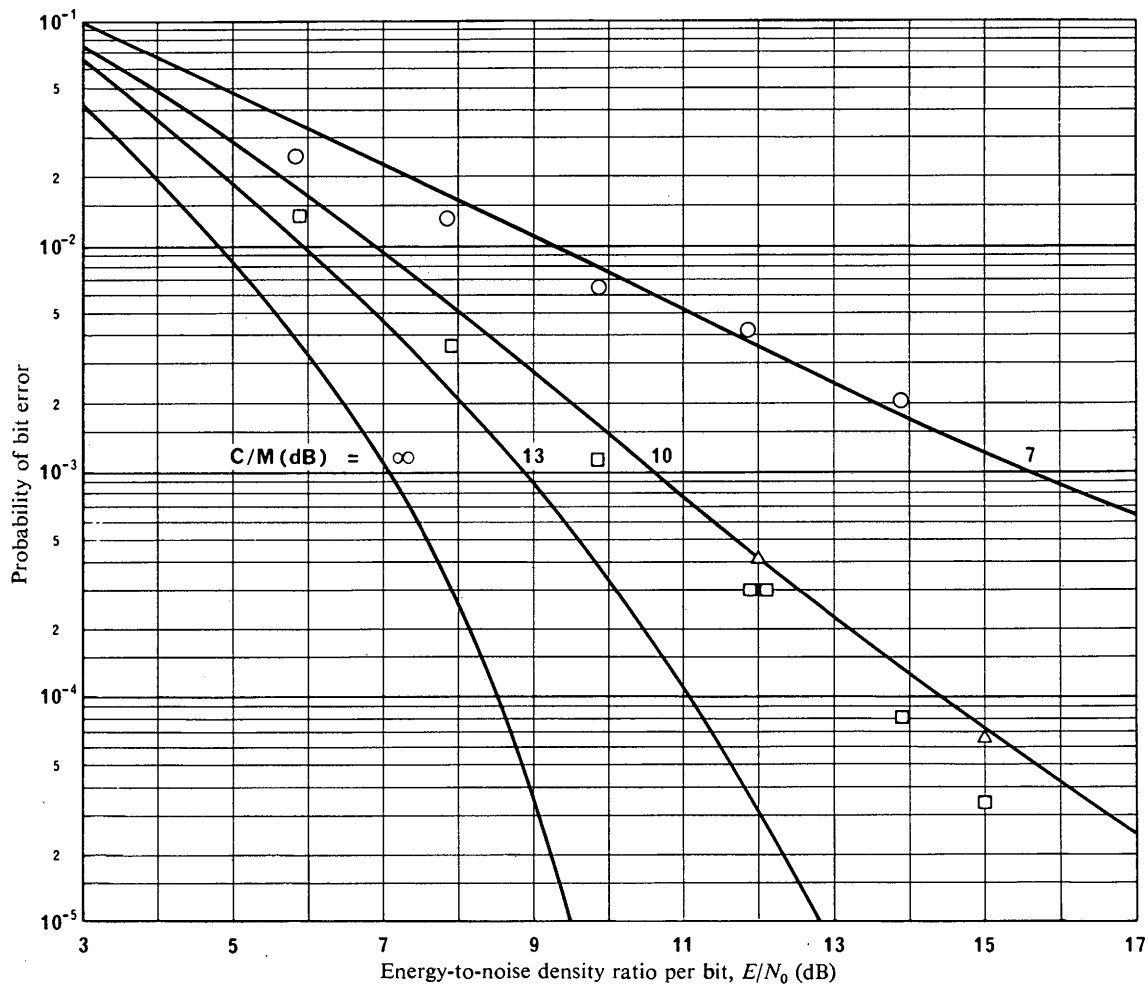


FIGURE 7 - Performance of DCPSK modem at 1200 bit/s in multipack with simulator

Notes:

- Solid curves are theoretical results with Doppler spread (fading rate) much less than bit rate.
- Simulator data :
 - $C/M = 8$ dB
 - △ $C/M = 10$ dB
 - $C/M = 11$ dB

3. Experimental results

3.1 Tests performed by United States with ATS-6 and with channel simulator

3.1.1 Tests performed by United States with ATS-6

Figure 8 shows the observed multipath power, relative to the power in the direct path signal for data collected during the ATS-6 tests. The relative multipath power is in the range from 5.7 dB to 8.8 dB. These values exclude antenna discrimination effects but do include polarization discrimination effects. The actual C/M ratios observed, including the antenna directivity factor, were typically 10 dB or greater. However, in some cases, C/M ratios as low as 6 dB were measured [Engels *et al.*, 1976].

Table I summarizes the averaged multipath data collected at low elevation angles during the ATS-6 maritime satellite tests. The ship antenna has a 35° beamwidth.

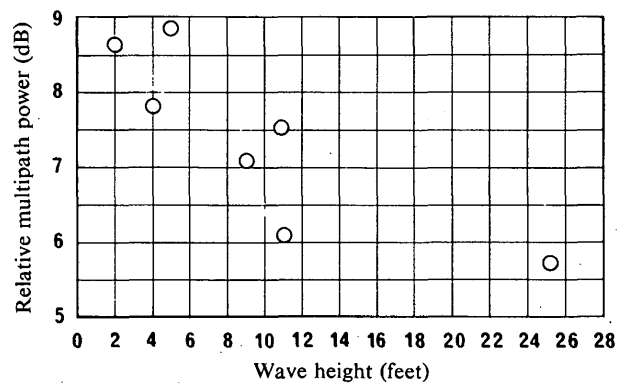


FIGURE 8 — Dependence of relative multipath power on sea surface wave height

TABLE I — ATS-6 Multipath data

Satellite elevation (°)	Sea condition (peak to through) (m)	Date	C/M (dB)	-20 dB linewidth (Hz)
8.2	2.4-3.0	13 November, 1974	10.02	4.5
8.3	7.5	14 November, 1974	8.65	5.35
8.4	3.0-3.6	15 November, 1974	9.1	4.55
16.9	1.2	19 November, 1974	14.2	5.5
16.9	3.3	20 November, 1974	14.76	3.75
17.0	1.5	21 November, 1974	16.2	4.47
17.0	0.6	31 March 1975	15.65	3.35

3.1.2 Tests performed by United States with channel simulator

The analysis outlined in § 2.2 was tested experimentally using a DCPSK modem and a laboratory channel simulator; the results obtained are superimposed on the theoretical results in Fig. 7. [Salwen and Duncombe, 1975; Salwen, 1975]. There is close agreement between theoretical and experimental data. The experimental results of Fig. 7 are for the best modem tested in an extensive laboratory test effort [Salwen and Duncombe, 1975]. The performance of other DCPSK modems tested was substantially worse under simulated multipath conditions.

The margins required to achieve 10^{-4} and 10^{-5} error rates can be derived for a DECPSK modem based on the results shown in Fig. 8. These margins are shown in Table II.

TABLE II – C/N_0 margins

C/M (dB)	Margin (dB) for $P_e = 10^{-4}$	Margin (dB) for $P_e = 10^{-5}$
13	2.5	3.2
11	5.3	7.4
10	5.5	9
8	—	30 (estimated)

Under the best conditions, a 5 dB margin would permit 10^{-5} error rate performance when C/M was on the order of 12 dB. However, in most cases a larger margin would be required in order to allow for other performance degradation factors such as:

- antenna pointing error,
- ionospheric losses,
- atmospheric losses,
- modem performance degradation (in presence of multipath).

3.2 Tests performed by France with the ATS-6 satellite

3.2.1 Type of transmission

A two-phase PSK 19.2 kbit/s digital channel transmitted through the ATS-6 satellite was received on board a ship operating off the Azores. A pseudo-random sequence transmitted on this channel was compared with an undisturbed sequence in order to determine the bit error ratio.

3.2.2 Ship antenna

The antenna used was a quadhelix antenna with a maximum gain of about 20 dB and a half power beamwidth of 14° . The height of the antenna above the sea was about 20 m. The antenna was stabilized to about 1° , using a vertical reference and the ship's gyrocompass.

3.2.3 Sea conditions

The measurements were carried out under rough sea conditions corresponding to a mean peak-to-peak wave height of about 3 m.

3.2.4 Results obtained

Figure 9 shows the bit error ratio curves for two-phase coherent PSK as a function of the E/N_0 expressed in dB, for elevation angles of 5° , 10° , 15° and 20° . It also shows the theoretical curve for the performance in presence of thermal noise only.

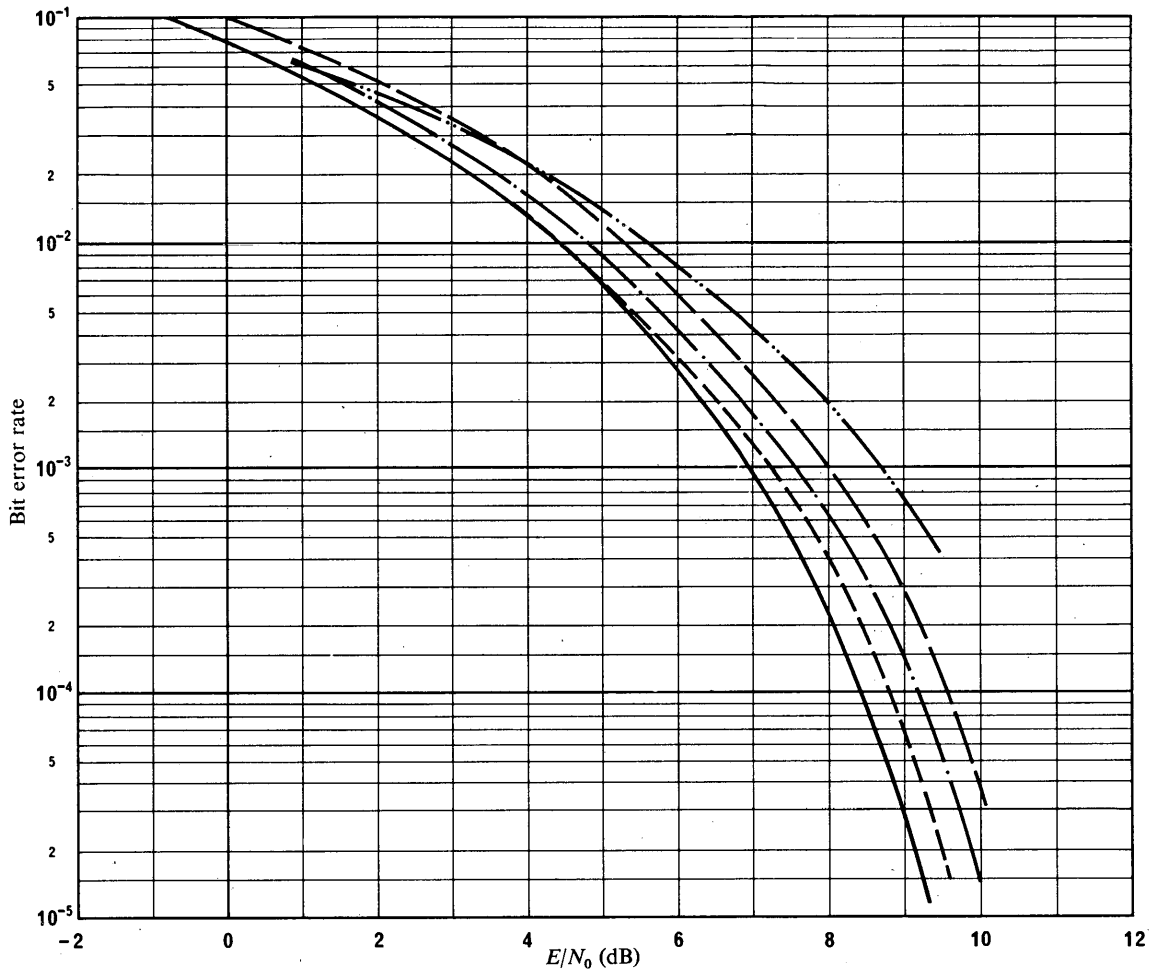
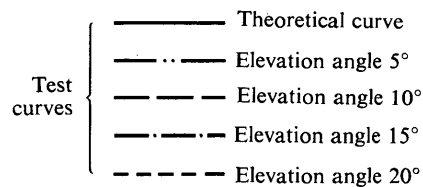


FIGURE 9 — Effect of the elevation angle on the error / rate



3.2.5 Comparison of experiment and theory

In order to directly compare the experimental and theoretical results, it is necessary to have a knowledge of m and the direct signal to multipath ratio.

Using the parameters given in the example of 2.1, a theoretical system margin of 11 dB is required, assuming no antenna discrimination. For a satellite elevation of 5°, both the direct and reflected signals will arrive within the main beam of the high gain antenna of the experiment. Extrapolating the 5° curve of Fig. 9, the measured degradation in E/N_0 for a bit error ratio of 10^{-5} is approximately 2.5 dB.

Substantial multipath discrimination in addition to that given by the antenna must have contributed to give this low value. The assumption made above regarding practical values for m and C/M require validation by further experiment.

3.3 Tests performed by the Federal Republic of Germany with MARECS and with the stored channel method

3.3.1 Description of the stored channel methods

Communication to and from ships via geostationary satellites is complicated by both multipath propagation at the sea's surface and antenna tracking requirements. In the case of the relatively large antennas used up to now, very little degradation was caused by fading occurring at elevation angles greater than 5° . Smaller antennas, in view of their broad beamwidth, do not require accurate tracking but lead to greater degradation. Limited information was available on the deterioration of the transmission quality to be expected due to multipath propagation. As it is extremely difficult to reproduce fading under realistic conditions, the stored channel principle was employed. During field trials the signal response of the channel with respect to amplitude and phase was recorded on board ship and evaluated at a laboratory. The channel was modelled as shown in Fig. 10. The correlations between the model's parameters and the various antenna types, sea conditions and elevation angles were also determined at the laboratory. By using the recorded fading to control a channel simulator it is possible to accurately reproduce the signal amplitude and phase response of the fading.

The addition of noise permits a comparison between various modulation and coding methods at a variable signal-to-noise ratio. At the laboratory, the bit error ratios and the required fading margin of various transmission methods were determined for various sea conditions and elevation angles (0° - 28°) with different antennas and tracking mechanisms [Schweikert *et al.*, 1980].

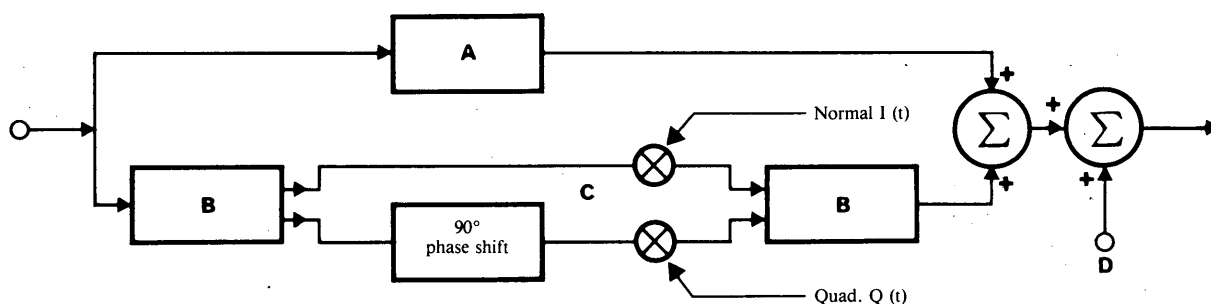


FIGURE 10 – Channel model representative of a satellite-ship link

- A: direct path (constant complex gain factor)
- B: quad hybrid
- C: multipath (time varying complex gain factor, normal and quadrature component)
- D: $n(t)$ (noise)

3.3.2 Field trials with standard C antennas

Field trials were performed from January to March 1983 on board the RV "Gauss" of the "Deutsches Hydrographisches Institut DHI". Four different antennas with gains ranging from 3 dB to 14 dB and three receivers were used, in parallel, to receive a CW-signal transmitted from Villafranca (Spain) earth station via the Atlantic Ocean Marecs satellite. The power of the CW-signal was the equivalent power of at least ten FM voice channels (e.i.r.p. 28 dBW). The baseband normal and quadrature components from the three receivers were recorded on board the ship for elevations between 4° and 30° and sea states between 1 m and 6 m wave height (open-sea conditions). Three 80-hour periods of recordings were made [Hagenauer *et al.*, 1984].

3.3.3 Statistical evaluations and channel model

In the laboratory, all the tapes were digitized and a broad variety of statistical evaluation took place on a mainframe computer. The results [Hagenauer *et al.*, 1984] of these evaluations show the following:

- the standard C-maritime channel can be modelled by a Rice-Nakagami fading model with a direct signal of power C and a diffuse scattered signal of mean power M . No significant reflected specular components have been observed;
- the Rice-Nakagami parameter C/M at the edge of satellite coverage (5° elevation) is 8 to 9.5 dB for all antennas and increases with elevation depending on the antenna (see Fig. 11);
- the influence of sea state is insignificant compared to elevation;
- the range of power fluctuations (fading range) at 5° elevation angle is:
 - 14 dB for 98%
 - 19 dB for 99.8%
- the fading bandwidth at 5° elevation angle (width of power density spectrum) is approximately:
 - 0.5 to 1 Hz (3 dB bandwidth)
 - 5 Hz (20 dB bandwidth) (see Fig. 12);
- average duration of a fade at -3 dB to -5 dB thresholds below average signal power is approximately 0.1 s;
- fading and connection time statistics are available and give a sufficient description of the channel in the time domain. Figure 13 gives some significant results;
- Doppler offsets (see Note) with this medium-size ship (1600 tons) were found to be of the order of ± 10 Hz with a rate of 1 Hz/s.

Note. – It should be noted that Doppler offsets observed by a ship are a function of the relative velocity of the satellite with respect to the ship and the coast earth station (see Report 214).

3.3.4 Tests of 2-PSK modems with uncoded data transmission

3.3.4.1 Modems

Four different 2-PSK modems have been tested for the maritime channel. To ensure comparability, the channel data rate was fixed at 1200 bit/s and differential encoding was used for phase ambiguity resolution.

The modems tested were:

- (a) coherent Costas receiver,
- (b) coherent tuned filter receiver,
- (c) DCPSK receiver,
- (d) Costas/AFC receiver.

3.3.4.2 Bandwidths

For all receivers, the filter and loop bandwidths have been optimized either by computer simulation during design or by on-line optimization during testing.

For synthetic Rayleigh fading receiver (a) performed best at high S/N (35 dB) and receiver (d) gave best performance at low S/N (20 dB). Contrary to the theoretical curves which assume perfect phase synchronization, the performance curves levelled out to a BER of 10^{-4} at S/N of 35 dB due to phase variations.

3.3.4.3 Receivers

For the stored channels receiver (d) performed best because it was able to track phase and frequency variations on the link. The fading margins are shown in Table III. The next best receiver was the (c) receiver.

3.3.4.4 Conclusions

In conclusion, the measured results on modem performance via the stored channel, showed that probably the most appropriate choice among those tested was a combined coherent Costas/AFC or a differential coherent (DPSK) receiver. If FEC is used, the selection of the receivers is less critical, because at channel error rates of 5×10^{-3} to 10^{-2} the receiver performance differs only by 1 dB. The results given in Table III apply only to the modems tested. It may be noted that use of FEC and/or other techniques would reduce the required margin and therefore reduce the required satellite and ship-earth station e.i.r.p. (see Report 921).

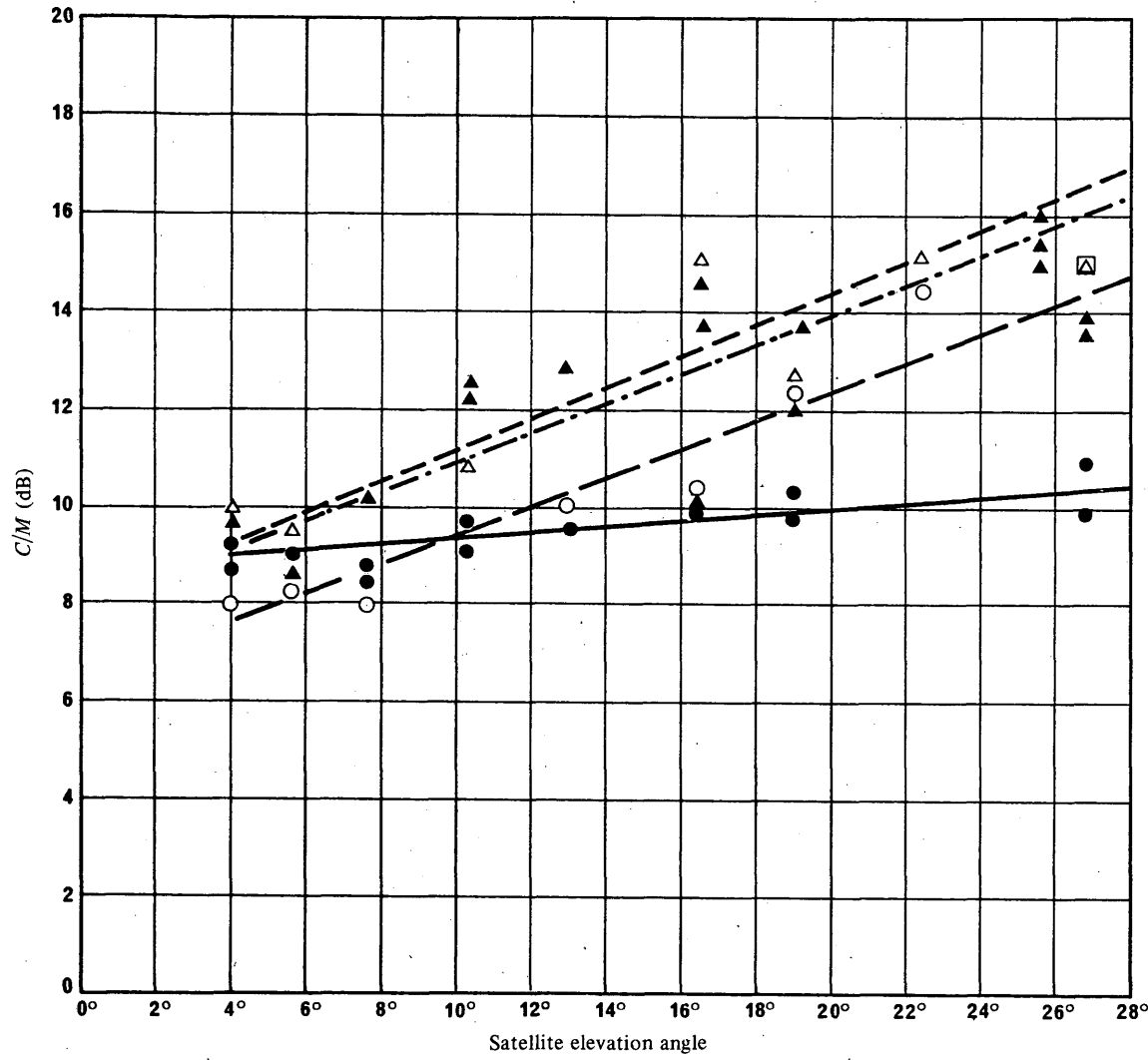
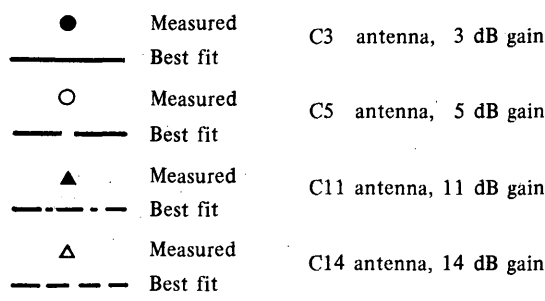


FIGURE 11 – Direct-to-multipath signal power ratio C/M in dB as a function of satellite elevation angle



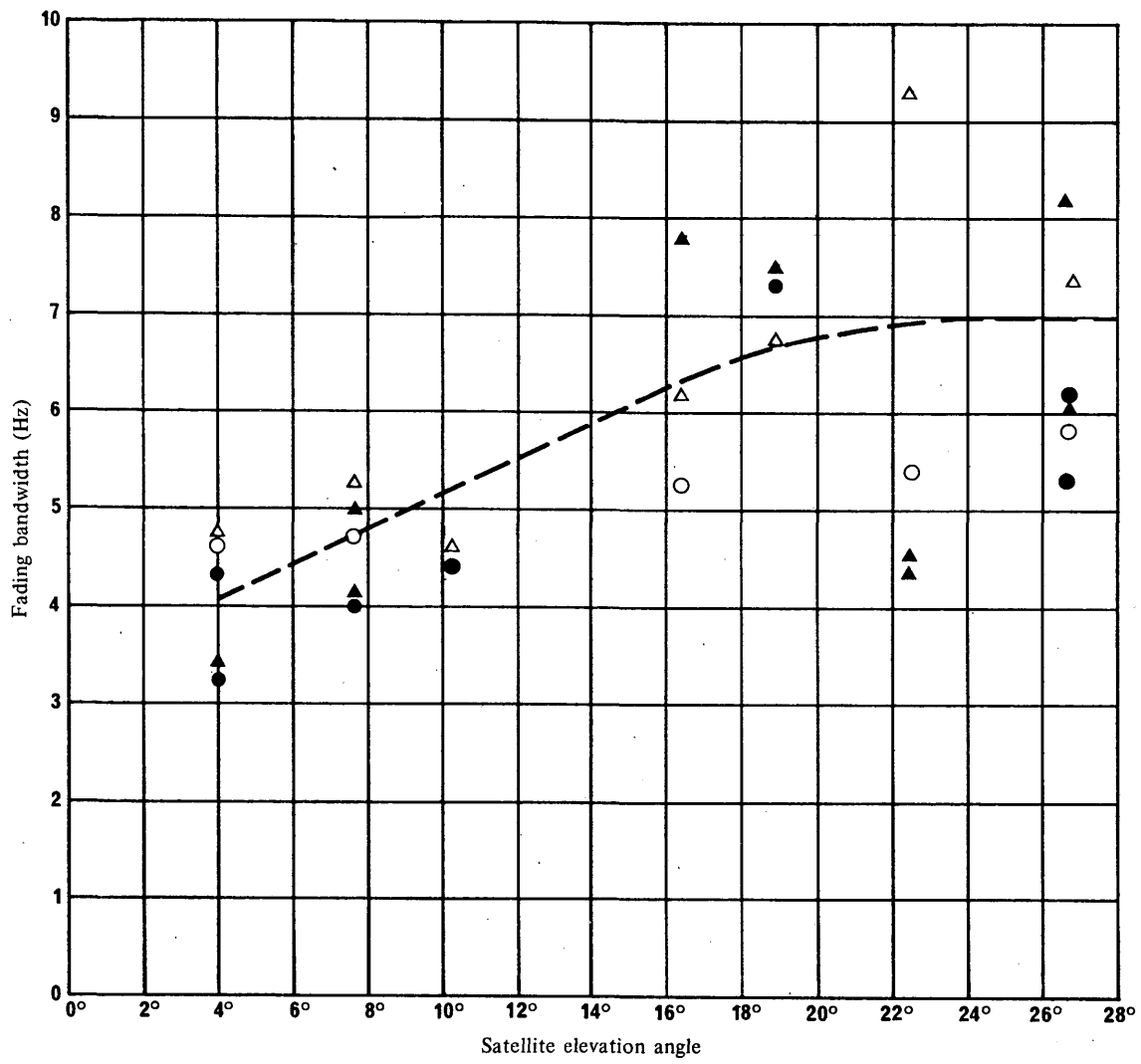


FIGURE 12 – The 20 dB fading bandwidth in Hz as a function of satellite elevation angle

- C3 antenna, 3 dB gain
- C5 antenna, 5 dB gain
- ▲ C11 antenna, 11 dB gain
- △ C14 antenna, 14 dB gain

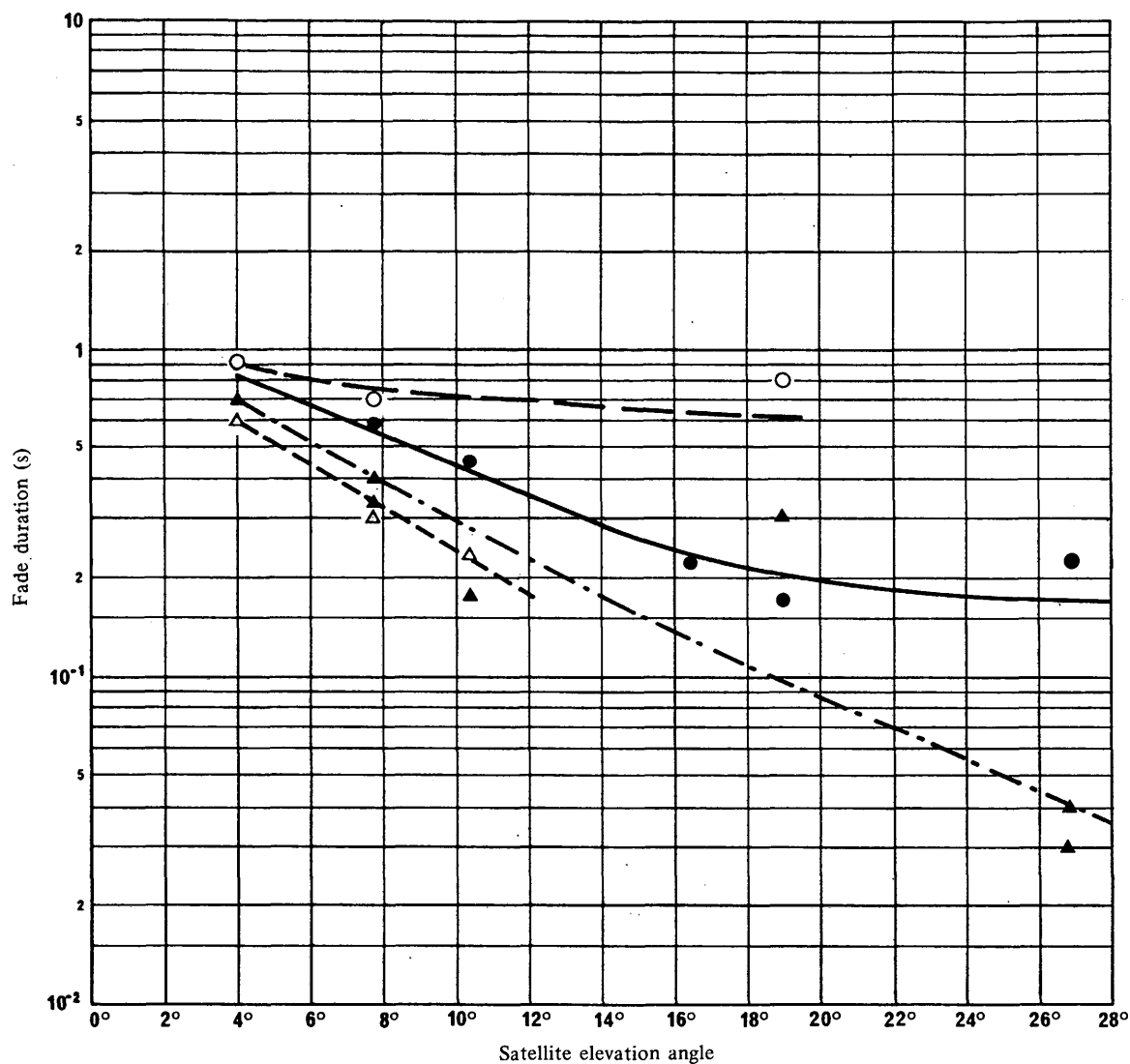


FIGURE 13 – Maximum duration of fades (5 dB below mean power) in 99.9% of time as a function of satellite elevation angle

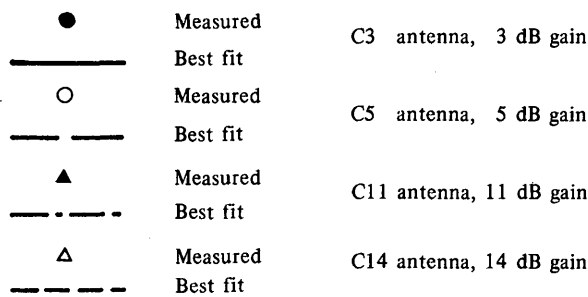


TABLE III — Required E_b/N_0 and fading margin for different antennas and elevation angles
(Costas/AFC 2-PSK receiver)

Antenna gain (dB)	Elevation angle (degrees)	Required E_b/N_0 faded (dB)		Required E_b/N_0 non-faded (dB)		Required long-term fade margin (dB)	
		BER = 10^{-4}	BER = 10^{-5}	BER = 10^{-4}	BER = 10^{-5}	BER = 10^{-4}	BER = 10^{-5}
3	4	19	25	10	11	9	14
	19	14	18	10	11	4	7
5	4	20	30	10	11	10	19
11	4	18	33	10	11	8	22
	19	12	14	10	11	2	3

Note. — The antennas used in these measurements were unstabilized and satellite pointing was carried out by hand.

4. Conclusions

The effect of the sea-reflected multipath interference on the received bit error ratio characteristics of binary coherent PSK and non-coherent FSK signals was theoretically examined by Japan assuming that the amplitude distribution of sea-reflected signals follows the m -distribution. The m -distribution can deal with almost all types of fading phenomena caused by specular reflected signals or by Gaussian reflected signals. The methods outlined and the figures shown in § 2.1 are useful in estimating the fading margin, although the value of m and C/M must be determined by experiments.

Theoretical analysis and experimental data obtained by the United States with ATS-6 using a 35° beamwidth shipboard antenna indicate that a margin of 5 dB will make possible a $P_e = 10^{-5}$ when $C/M = 12$ dB under ideal conditions. It is likely that under realistic conditions, a 5 dB margin will allow for $P_e = 10^{-5}$ when C/M is greater than about 14 dB. This multipath level (or less) was typically obtained when the elevation angle to the satellite was equal to one half the antenna beamwidth (or more).

The experimental curves given in Fig. 9 obtained by France with ATS-6, illustrate the effect of multipath upon the bit error ratio with the 20 dB gain antenna used. The test curves deviate from the thermal noise curve by a value (in dB) which increases as the elevation angle decreases, as theory predicts. The average additional power requirements due to multipath over that required for no multipath for a bit error ratio of between 10^{-3} and 10^{-4} are found to be the following:

- elevation angle 5° : 2 dB,
- elevation angle 10° : 1 dB,
- elevation angle 15° or more: 0.5 dB approximately.

The performance of the two-phase PSK digital modulation was significantly aided by the discrimination achieved by the 20 dB stabilized antenna.

The stored channel principle was used in the tests performed by the Federal Republic of Germany with MARECS in 1983. A comparison between the transmission of data via satellite and via the recorded channel at the laboratory as well as an evaluation of the amplitude statistics confirmed the usability of the stored channel and the Rice-Nakagami fading model.

The following values were found to be typical for a standard B antenna at 5° elevation:

- $C/M = 9$ dB,
- a fading margin of 8 dB in the case of 2-PSK-modulated data transmission and a bit error ratio of BER = 10^{-4} .

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REPORT 763-2*

SIGNAL LEVEL VARIATION DUE TO MULTIPATH EFFECTS AND BLOCKAGE BY SHIP'S SUPERSTRUCTURE IN MARITIME MOBILE-SATELLITE SERVICE LINKS

(Study Programme 17A/8)

(1978-1982-1986)

1. Introduction

The effect of multipath interference caused by sea-reflected signals is one important factor to be considered in establishing maritime satellite communication systems.

The fading characteristics depend on:

- frequency;
- angle of elevation;
- sea surface condition, especially wave height and slope (wind is an important factor);
- the shipborne antenna pattern;
- satellite and shipborne antenna axial ratio;
- the angular orientation of the polarization ellipses for the satellite and shipborne antennas;
- the shipborne antenna pointing error;
- the superstructure of the ship;
- the height of the antenna above the sea.

A theoretical estimate based on the model presented in Report 884 is given in order to predict values of fading as a function of the satellite elevation angle, sea state and antenna gain.

* The Director, CCIR, is requested to bring this Report to the attention of Study Group 5.

Results are given of radio-link experiments carried out across the Norwegian fjord, Lysefjorden, in terms of measurement of sea reflection coefficients and spectra.

Results are also given of experiments carried out in Japan, in terms of fading due to coherent and incoherent components and of fading as a function of elevation angle.

Shipborne experiments were carried out off the Azores by France in 1975 by means of the ATS-6 satellite. From the results of these tests, some suggested values for multipath carrier fade are given; results are also given for observed fluctuations and corresponding spectra. Tests were also carried out by others (see Report 598 (Kyoto, 1978)).

A computer simulation has been made to establish the fading resulting from reflection from a ship's superstructure. Results are given of this simulation. Attenuation factors for blocking due to column type structure are also given.

In a low G/T ship earth station using a passive antenna stabilizer, shipborne antenna pointing error due to random ship motion should also be considered. Experimental results and statistical analyses on this topic are given in Report 921.

2. Theoretical estimation of multipath fading

2.1 General

The purpose of the theoretical model is to provide for data on fading resulting from the effect of multipath for various parameter values. The theoretical estimation is based on a model presented in Report 884.

Account has not been taken of antenna polarization discrimination, although at low elevation angles this discrimination can have a significant effect on the characteristics of the received signal due to the polarization sense reversal at elevation angles greater than the Brewster angle (around 6° at 1.5/1.6 GHz over sea paths, see Report 1008). Neither has account been taken of fluctuations due to the atmosphere; their effect is significant when the effects due to the sea are negligible, in other words at high elevation angles.

In general, multipath fading due to sea reflection is caused by the interference between direct and reflected waves. Reflected waves coming from the sea surface are composed of a coherent component (specular reflection component) that varies with the height of antenna and an incoherent component (diffused component) that fluctuates with the motion of the sea waves. The coherent component is predominant under calm sea conditions, whereas the incoherent component is predominant under rough sea conditions.

In practice, the fading depth for $p\%$ of the time is approximately given by the sum of the coherent fading Fd_{max}^c and the incoherent fading Fd^i according to the following expression (see also Report 884):

$$Fd(p\%) = Fd_{max}^c + Fd^i(p\%)$$

The temporal amplitude variation of the frequency spectrum can also be obtained based on the model mentioned above and the assumption that ocean waves have the nature of gravity waves [Karasawa and Shiokawa, 1984a and b].

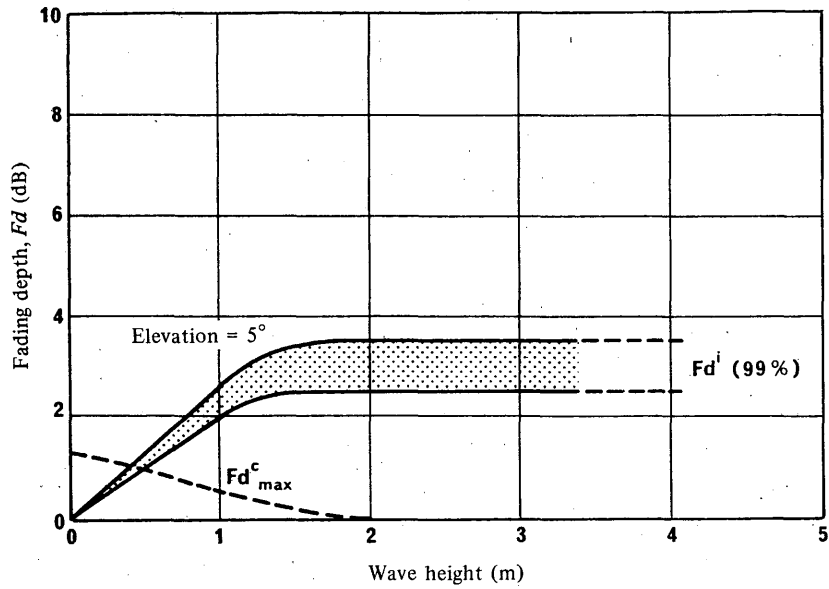
2.2 Estimated fading depth

Fading depths for 99% of the time calculated at 1.5 GHz are given in Fig. 1 for antenna gains of 24 and 14 dB as a function of the wave height. The shaded area covers the practical range of the sea wave slope between 0.04 and 0.07. From the results it may be deduced that the fading depth due to the coherent component decreases with increasing wave height monotonically, while the fading depth due to the incoherent component increases gradually with increasing wave height and then reaches a peak value.

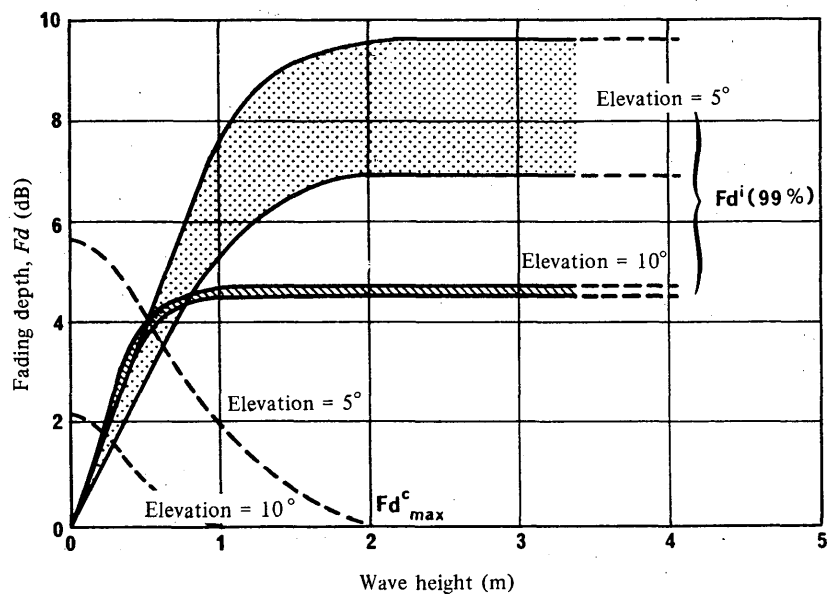
Figure 2 shows the fading depth for antenna gains of 24, 20, 15 and 8 dB as a function of elevation angle, with a fully developed incoherent component, due to wave heights of about 1.6-3.2 m.

2.3 Estimated fading spectrum

The frequency spectrum bandwidth of temporal amplitude variations increases with increasing wave height and elevation angle. According to the calculations, taking the antenna height variation due to the ship motions (rolling/pitching) into account, the frequency corresponding to the spectral power density of -10 dB relative to the flat portion of power spectrum (hereafter denoted as -10 dB spectral bandwidth) ranges from 0.3 Hz to 5 Hz when the significant wave height is from 0.5 m to 5 m, the elevation angle is from 5° to 10° , and the ship velocity is less than 30 knots.



(a) Antenna gain: 24 dB



(b) Antenna gain: 14 dB

FIGURE 1 – Fading depth as a function of the wave height

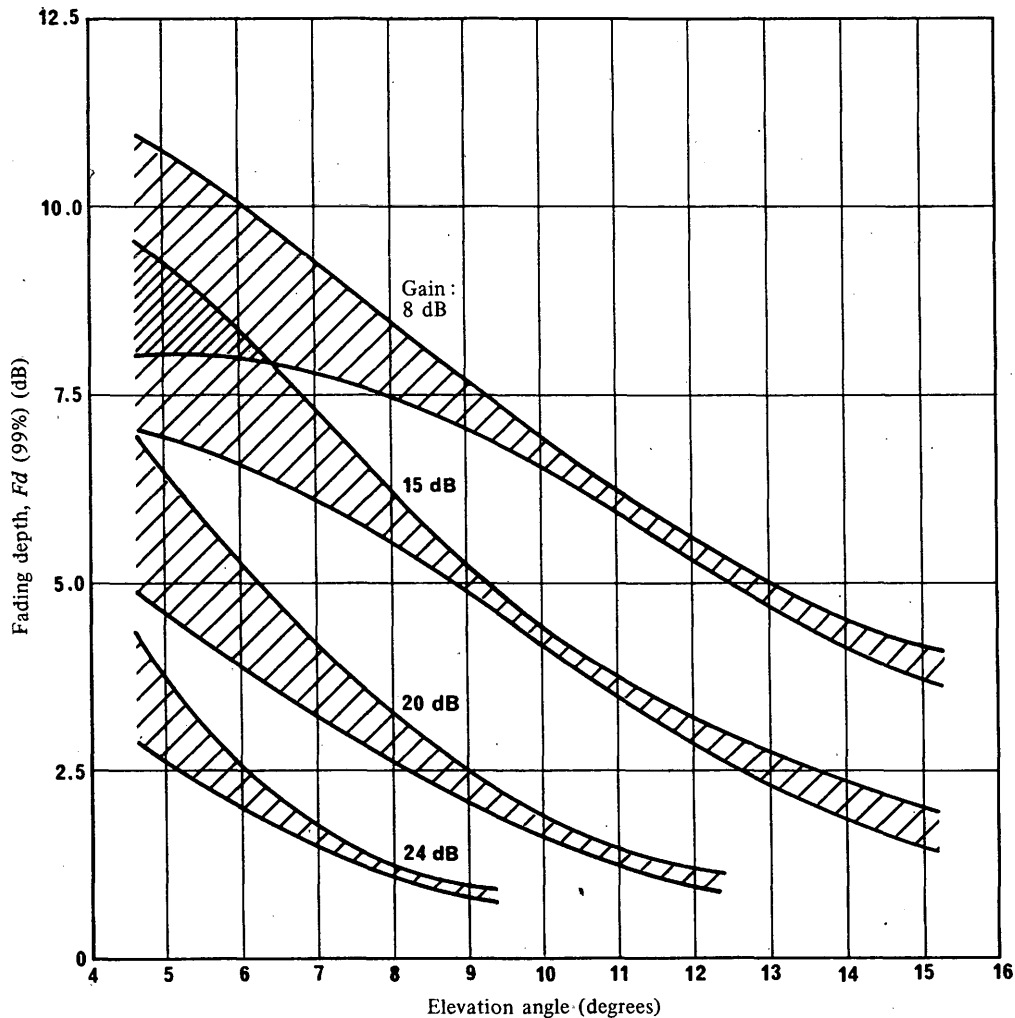


FIGURE 2 – Fading depth for 99% of the time as a function of elevation angle with wave height from 1.6 m to 3.2 m

Figure 3 shows the power spectra multipath fading at 1.5 GHz caused by sea surface reflections for the three cases having wide spectral bandwidth, in conditions which correspond to a significant wave height of 5 m and an elevation angle of 10° . In this figure, case a is when the antenna is set on a fixed platform, such as an oil-drilling vessel or a ship at anchor. For case b the ship velocity is 20 knots without antenna height variation due to ship motions, while case c is with fairly large antenna height variation due to ship motions typical of small ships. Figure 3 indicates that the -10 dB spectral bandwidth is not more than 3 Hz when the receiving antenna is on board a ship sailing without antenna height variation due to ship motion (rolling/pitching). This value amounts to 5 Hz at most under the conditions where there are large antenna height variations due to ship motion. The influence of ship motion on the frequency spectrum also, of course, depends on the place of installation of the ship antenna, as well as the magnitude and the period of ship motion.

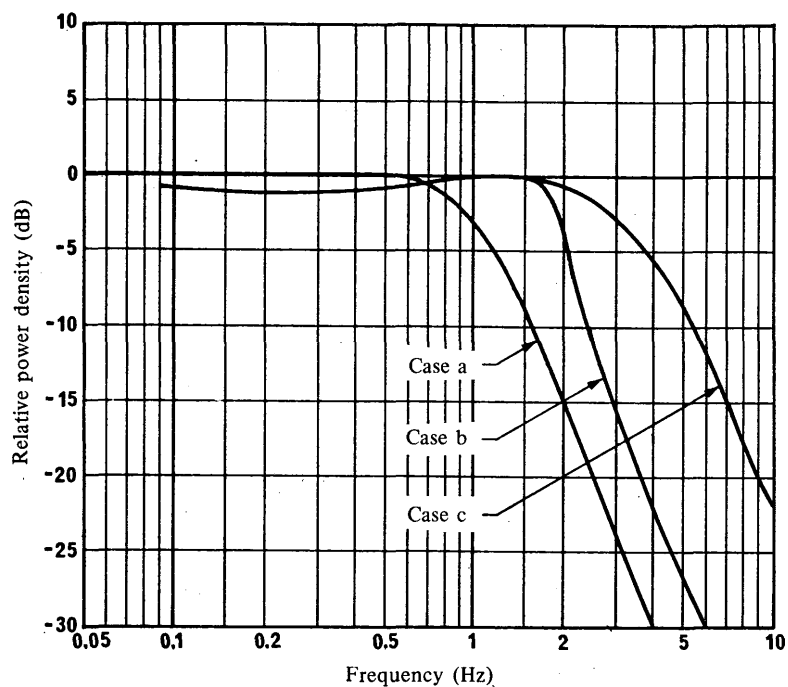


FIGURE 3 – Power spectra of multipath fading at 1.5 GHz caused by sea surface reflection for three cases having wide spectral bandwidth

- Case a : receiving on a fixed platform
- Case b : receiving on board a ship sailing at 20 knots without ship motions (rolling/pitching)
- Case c : receiving on a board a ship sailing at 20 knots with considerably large ship motions

Wave height : 5m
 Elevation angle : 10°
 Antenna gain : 13 dB

3. Experiments on sea reflection signals

3.1 Radio-link experiments across a fjord

3.1.1 General

Measurements of sea reflected signals were carried out using an experimental link set up across the Norwegian fjord, Lysefjorden.

The fjord is to a large extent shielded from wind, and no peak-to-peak wave heights greater than 50 cm were observed during the measurement period.

If the height of the antenna above the sea is varied, the received signal (V_{tot}) will pass through positions giving maximum and minimum constructive interference. The corresponding signals are V_i (max) and V_i (min).

From a signal analysis of V_i (max), V_i (min) and V_i^2 (max), the coefficients for coherent (R) and incoherent (D) reflection are determined.

3.1.2 Measurement set-up

Figure 4 shows the terrain profile of the transmission path. The equipment consisted on the transmit side of a transmitter with a 1 m parabolic antenna having a directivity of approximately 20 dB with circular polarization and on the receive side of an 0.75 m antenna with linear polarization and receiving and recording equipment.

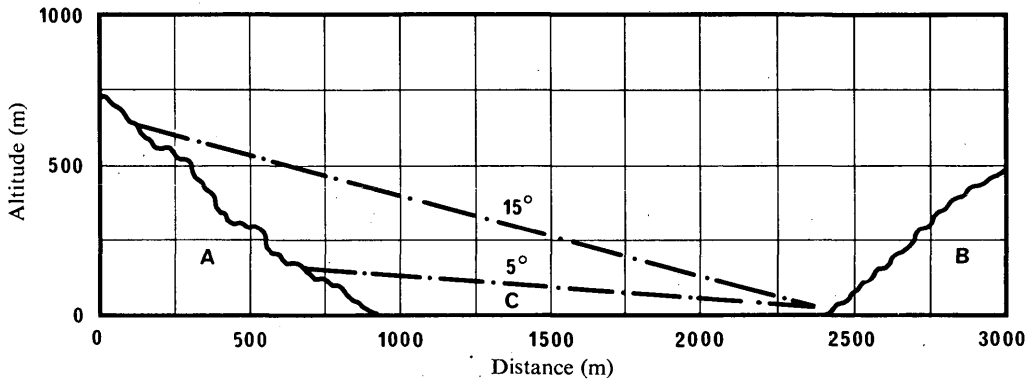


FIGURE 4 – *Terrain profile of measurement path
(experiments across a fjord)*

A: Transmit side
B: Receive side
C: Sea level

The location of the receive equipment was kept fixed while the location of the transmitter was varied in order to obtain different angles of incidence. The measurements were performed for four different elevation angles: 5°, 7.5°, 9.5° and 15°.

The mean height of the receive antenna was approximately 15 m above the sea level. It was mounted on a telescopic mast which permitted a continuously variable height over a range of 1.5 m.

The wave height was determined visually using binoculars and a clearly marked pole approximately 50 m from the shore. No significant difference between the sea structure in the close vicinity of the pole and in the rest of the fjord was observed.

For a given polarization, the antenna was set to the positions of maximum and then minimum constructive interference. For each position, short recordings of the signal were made. The complete measurement cycle lasted 6 to 7 min, a period short enough to ensure negligible influence from the tide and still provide statistically stationary surface conditions. The dipole feed of the antenna was then mechanically rotated 90° and similar records were made for the orthogonal polarization.

A recording was also made of the interference pattern along the mast for each polarization. As the phase centre of the antenna remained unchanged during the rotation, the recordings include the phase difference $\Delta\phi$ between vertical and horizontal polarization.

A double set of measurements was made. In the first set, the receive antenna pointing direction was kept in the horizontal plane. In this case both the direct and the coherently reflected signals were received with equal gain by the antenna. In the second set, the antenna pointed towards the transmitter and since the antenna radiation pattern was known, it was possible to accurately determine the ratio of the direct to the reflected signal. The coherent reflection coefficients were calculated for both cases.

3.1.3 Measured results

Table I A and B show measured coherent reflection coefficients (R) for four different elevation angles and for a number of calm sea states. In general there was good agreement between the two sets of measurements.

Table II A and B list the weighted r.m.s. incoherent reflection contributions (D) relative to the direct signal.

TABLE 1 – Measured coherent reflection coefficients
(The phase angle of the vertical polarization coefficient shown is relative to the phase angle
of the corresponding horizontal polarization coefficients

A. Horizontal polarization coefficients*

Wave height (peak- to-peak) (cm)	Elevation angle		7.5°	9.5°	15°
	5°				
0-1			0.95		
1-5	0.92			0.93	0.93
5-10	0.94		0.91	0.89	0.86
10-15	0.89		0.93	0.81	0.92
15-20	0.80		0.90		0.89
20-25				0.80	0.89
40-50	0.82				

B. Vertical polarization coefficients*

Wave- height (peak- to-peak) (cm)	Elevation angle		7.5°	Relative phase angle	9.5°	Relative phase angle	15°	Relative phase angle
	5°							
	Absolute value	Relative phase angle	Absolute value	Relative phase angle	Absolute value	Relative phase angle	Absolute value	Relative phase angle
0-1			0.11	167°			0.39	
1-5	0.10	75°			0.21		0.38	158°
5-10	0.10	67°	0.14	160°	0.17	140°	0.39	
10-15	0.10	51°	0.14		0.19	155°		
15-20	0.11	92°	0.14	120°			0.27	177°
20-25					0.17		0.32	169°
40-50	0.12	68°						

* Measured coherent reflection coefficients
The value given in A is the ratio of received coherent field strength of the reflected signal to the received direct signal for horizontal polarization, $R_H = |E_{RC}/E_D|_H$.
A. Horizontal polarization: $P_H = R_H \exp(j \psi_H)$.
B. Vertical polarization: $P_V = R_V \exp(j \psi_V)$, $R_V = |E_{RC}/E_D|_V$.
Absolute value: R_V ; relative phase angle $(\psi_H - \psi_V)$.

TABLE II – Weighted relative r.m.s. incoherent reflection contributions

A. Horizontal polarization coefficients*

Wave-height (peak-to-peak) (cm)	Elevation angle							
	5°		7.5°		9.5°		15°	
	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna
0- 1								
1- 5	0.04				0.03		0.02	
5-10	0.08	0.07			0.10		0.02	
10-15			0.10		0.12		0.03	
15-20	0.11	0.09	0.18	0.11				0.04
20-25							0.07	0.06
40-50	0.14	0.13						

B. Vertical polarization coefficients *

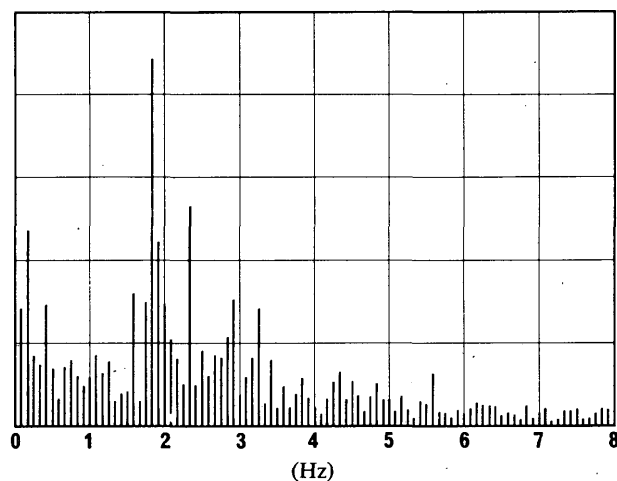
Wave-height (peak-to-peak) (cm)	Elevation angle							
	5°		7.5°		9.5°		15°	
	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna	horiz. antenna	elevated antenna
0- 1								
1- 5	0.02				0.03		0.02	
5-10	0.02	0.02		0.04	0.04		0.03	
10-15			0.05		0.06		0.04	
15-20	0.06	0.05		0.10				0.04
20-25							0.07	0.05
40-50	0.07	0.08						

* Weighted relative r.m.s. incoherent reflection coefficients
The value given in A and B is the ratio, *D* of the incoherent field strength r.m.s. level of the reflected signal to the received direct signal for horizontal and vertical polarization respectively. $D = \frac{(E_{RD}^2)^{1/2}}{E_D}$.

The two pointing directions for the receiving antenna (horizontal and elevated) give different values for D . In order to compare the two cases, the value obtained for the horizontal case is multiplied by $g(\psi)/g(0)$, where $g(\psi)$ is the antenna gain function and ψ the angle between the (elevated) antenna axis and the direction to the point of coherent reflection. This is equivalent to treating the incoherent reflected signal as coherent, with the same fixed angle of incidence. In general, the results obtained in this manner are not equal, as would be the case if the coherent reflections were from an infinite surface. However, from the number of measurements made (Table II) the differences are not significant, indicating that the dominant contributions arise from a central area in the vicinity of the specular point of reflection.

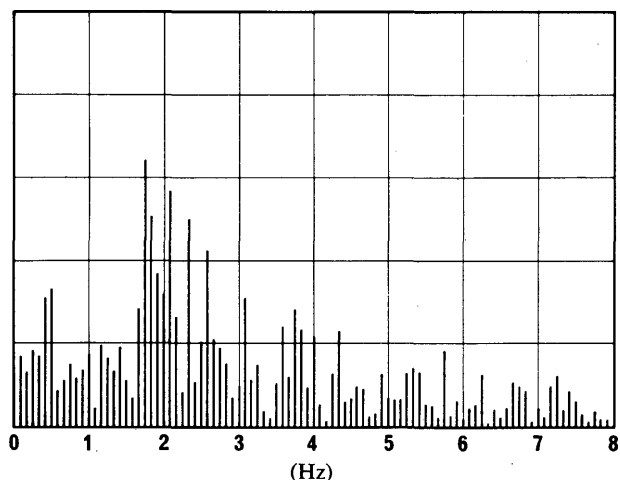
For small wave heights a certain regularity of the sea wave structure was present in the fjord and was clearly visible with the unaided eye. In general, care should be taken when selecting a statistical model for incoherent reflections.

The frequency spectrum of the incoherently reflected signal is shown in Fig. 5. The regularity of the wave structure, especially for the case of horizontal polarization, is observable by the peak of the spectrum at 2 Hz.



Frequency spectrum of incoherently reflected signal

Elevation angle: 5°
Wave height: 40-50 cm peak-to-peak
Horizontal polarization



Frequency spectrum of incoherently reflected signal

Elevation angle: 5°
Wave height: 40-50 cm peak-to-peak
Vertical polarization

FIGURE 5 – Frequency spectrum of incoherently reflected signal
(both curves measured in the same linear scale)

3.2 Field experiments in Japan

3.2.1 General

Results of three experiments carried out in Japan are given. One is the fading depth due to the coherent component under the calm sea condition, the second is that due to the incoherent component, and the third is fading depth obtained by a shipborne experiment.

3.2.2 Fading depth due to the coherent component

3.2.2.1 Measurement set-up

Experiments were carried out by using terrestrial links set up across a bay. The terrain profile of the measurement path is given in Fig. 6. Main characteristics of the measuring system were as follows:

Date: February 1977

Place: Tago Bay, Nishi-Izu, Shizuoka, Japan

Elevation angle: 5°, 7°, and 9°

Frequency: 1643.0 MHz

Polarization: right-hand circular

Wave height: 10-20 cm peak-to-trough, measured by a pole in the sea.

Antenna for transmitting: 0.6 m parabolic

Antenna for receiving:

Antenna (m)	Gain (dB)	Beamwidth (degrees)
1.2 parabolic	23.7	11.5
0.6 parabolic	17.6	18.2
0.4 short backfire	14.0	28.8
0.2 length helical	10.6	45.2

For the experiments of fading depth, due to the coherent component, the height pattern was measured for each antenna (see Fig. 7).

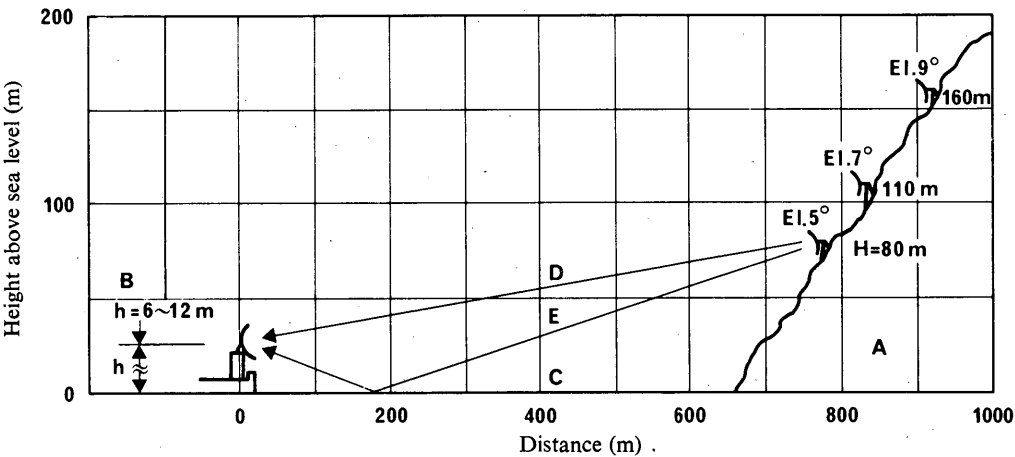


FIGURE 6 – Terrain profile of measurement path (experiments in Japan)

- A: transmitting side
- B: receiving side
- C: sea level
- D: direct wave
- E: reflected wave

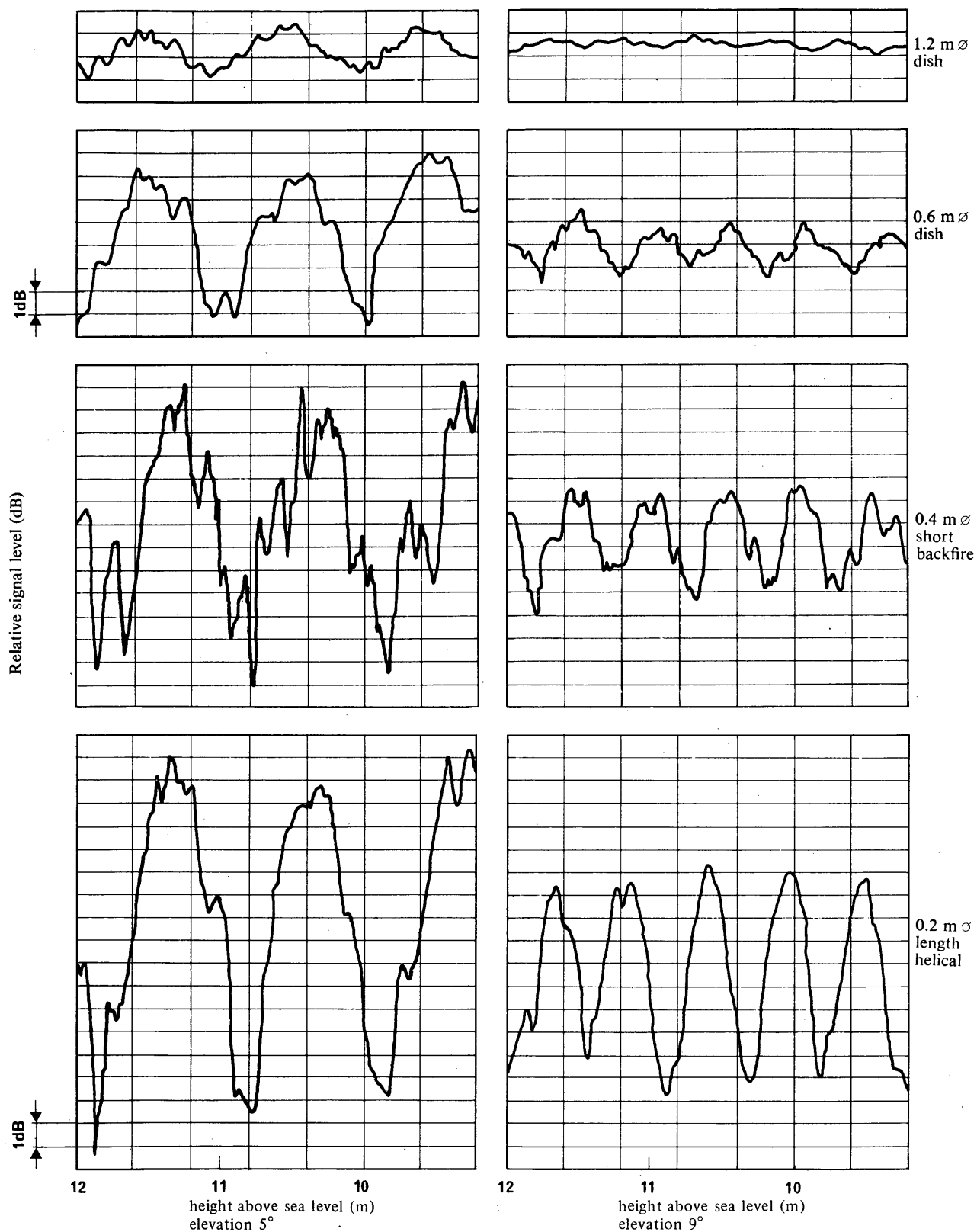


FIGURE 7 – Examples of heigth pattern

3.2.2.2 Measured results

The variation of the reflected component is caused by the vertical movement of the antenna. The measured and calculated fading depth of the coherent component is shown in Table III.

TABLE III — Measured and calculated fading depth of reflected coherent component (dB)

Antenna	Elevation angle					
	5°		7°		9°	
	measured (dB)	calculated (dB)	measured (dB)	calculated (dB)	measured (dB)	calculated (dB)
1.2 m Ø dish	0.8	1.67	0.6	0.26	0.24	0.08
0.6 m Ø dish	3.8	3.90	1.8	1.97	1.0	0.57
0.4 m Ø short backfire	5.5	5.96	4.8	3.89	2.4	2.43
0.2 m length helical	6.5	6.65	7.4	4.86	4.9	3.37

The difference between measured and calculated values is in the range of ± 1 dB, except for the helical antenna, for which Table III shows a maximum difference of 2.54 dB at 7° elevation angle (that is just above the Brewster angle).

3.2.3 Fading depth due to the incoherent component

3.2.3.1 Measurement set-up

Two experiments were carried out at an elevation angle of 5°. The first trial was done using a terrestrial link across Wakasa Bay, while the second trial was carried out on the coast-line of Echizen Cape by receiving the Marisat IOR 1.5 GHz common TDM carrier signal. Main characteristics of the measuring system were as follows:

	First trial	Second trial
Date:	November, 1980	February, 1983
Place:	Wakasa Bay	Echizen Cape
Frequency:	1540 MHz	1538 MHz
Polarization:	Right-hand circular	Right-hand circular
Elevation angle	5°	5°
Antenna for transmitting:	1.2 m parabolic	—
Antenna for receiving	1.2 m parabolic (gain: 24 dB) 0.4 m SBF (gain: 14 dB)	1.2 m parabolic 0.4 m SBF

In both experiments, the height of sea waves was measured precisely by using a wave rider buoy.

3.2.3.2 Measured results

Data of fading depth for 99% of the time normalized by the level for 50% of the time are given in Fig. 8 as a function of the wave height. In the experiments, the height of the antennas was fixed at the maximum and minimum points of the height pattern given by the effect of the coherent component.

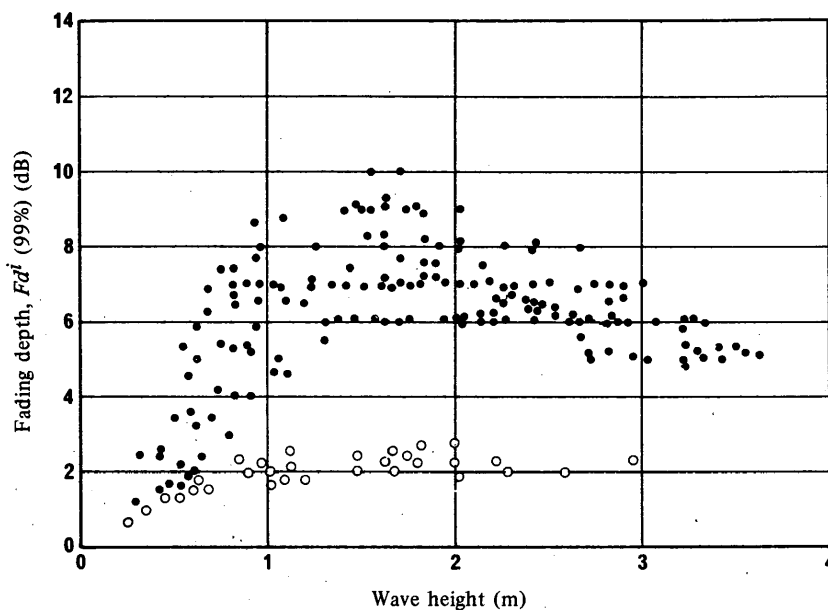


FIGURE 8 – Fading depth due to the incoherent component as a function of the wave height

Elevation angle: 5°

- Gain: 14 dB
- Gain: 24 dB

Figure 8 indicates that the maximum value of fading depth due to the incoherent component, appears at a wave height of around 1.6 m for the antenna with 14 dB gain whereas little dependency on the wave height can be seen for the antenna with 24 dB gain with wave heights between 0.8 m to 3.2 m.

3.2.4 Shipborne experiment

3.2.4.1 Measurement set-up

Measurements of 1.5 GHz multipath fading were made by using a low G/T ship terminal on board a ferryboat (9000 gross tonnage) cruising in the North Pacific Ocean near Japan. The main characteristics of the measuring system were as follows:

Date: January, 1983

Frequency: 1541.5 MHz (beacon signal from Marisat satellite)

Polarization: right-hand circular

Elevation angle: 5°-9°

Wave height: 0.3-3.2 m

Antenna for receiving: 33 cm SBF (gain: 13.5 dB)

In this experiment, pointing error due to ship motion (rolling/pitching) was kept within 3° by using a stabilized mount system with rolling/pitching compensation.

3.2.4.2 Measured results

Data of fading depth for both 99% and 90% of the time are shown in Fig. 9 together with the theoretical curves.

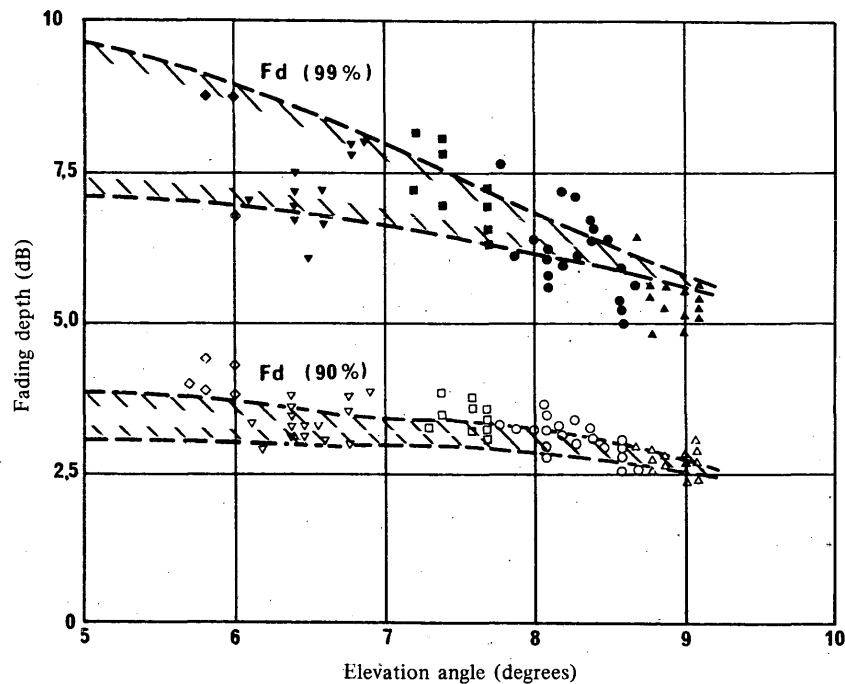
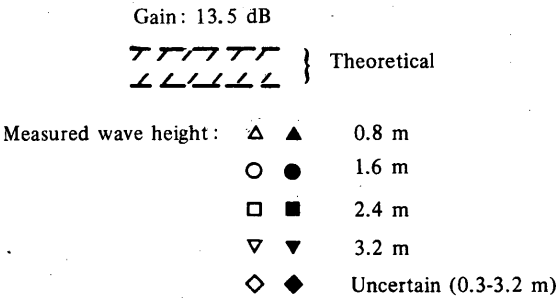


FIGURE 9 – Fading depth as a function of elevation angle (shipborne experiment)



As can be seen from this figure, the fading depth increases with decreasing elevation angle, and the measured results agree well with theoretical ones for wave heights from 0.8 m to 3.2 m.

3.3 Shipborne experiments with ATS-6 off the Azores

3.3.1 General

Tests carried out in 1975 by means of the ATS-6 satellite provided experimental results on the multipath effects in the case of reception on board a ship cruising off the Azores of a pure continuous wave emitted by the satellite. Results given in this section are those obtained by France; those obtained by others with ATS-6 are in Report 598 (Kyoto, 1978).

3.3.2 Ship antenna

The ship station antenna used for receiving the signals from the satellite was of the quadrihelix type with a maximum gain of about 20 dB and a half power beamwidth of 14°. The antenna's radiation diagram is shown in Fig. 10. Appropriate design features were incorporated in order to reduce the level of the first side lobe. The height of the antenna above the sea was about 20 m. The antenna was stabilized to about 1°, using a vertical reference and the ship's gyrocompass.

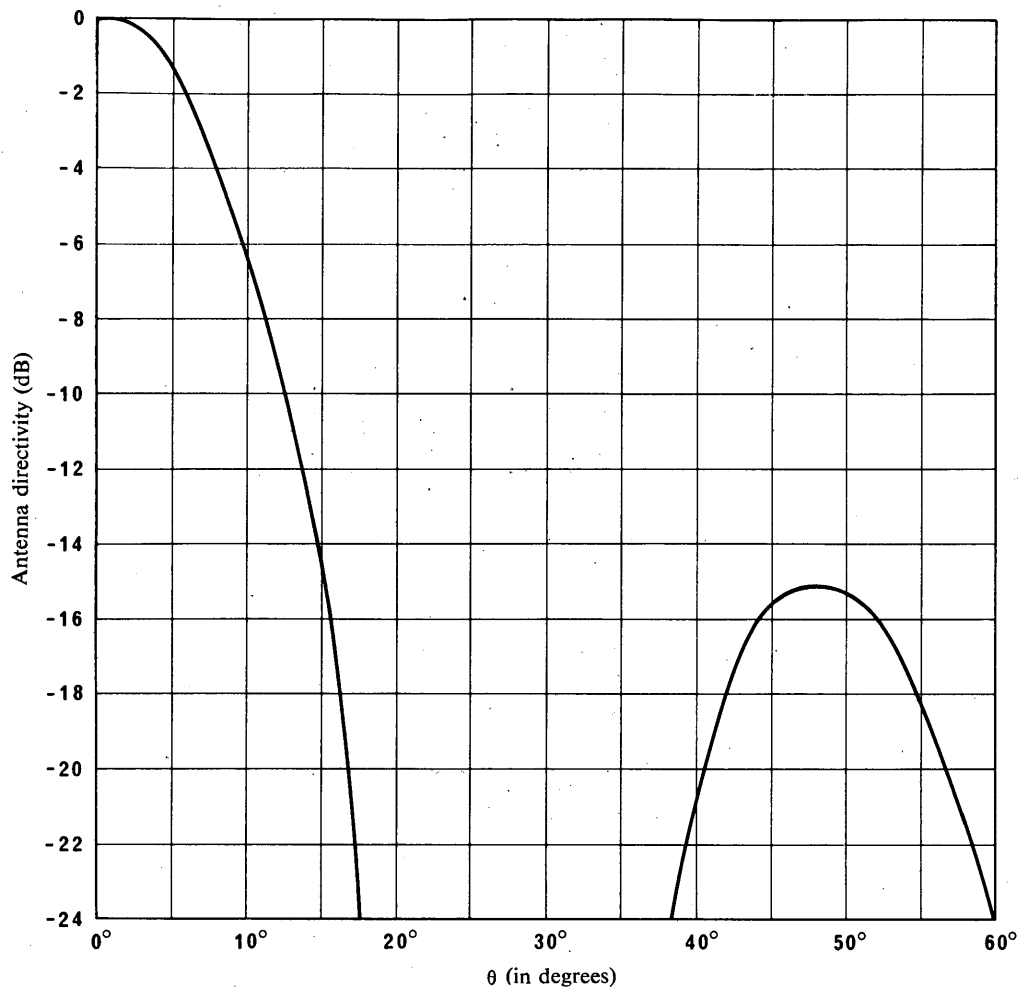


FIGURE 10 – Ship station antenna diagram
($G = 20$ dB)

3.3.3 Sea conditions

Two different states were observed, “rough sea” and “smooth sea”. They corresponded to a mean peak-to-peak wave height of about 3 m and 30 cm respectively.

3.3.4 Results obtained

3.3.4.1 Signal level fluctuation

3.3.4.1.1 Classification

The fluctuations observed can be classified into three categories in increasing order of periods and amplitudes:

- *Noise*
Low amplitude fluctuations, similar to thermal noise, with periods of less than one second;
- *Intermediate fluctuations*
Medium amplitude fluctuations with periods between about 1 and 3.5 s;
- *Interference*
Large-amplitude fluctuations, with very marked maxima and minima, with periods varying between about 3.5 and 10 s.

3.3.4.1.2 Variations in time

Fig. 11 gives an example of the fluctuations observed for different angles of elevation in the rough sea conditions and Fig. 12 an example of the fluctuations observed for a given angle and elevation (10° in the case considered) and two different sea conditions.

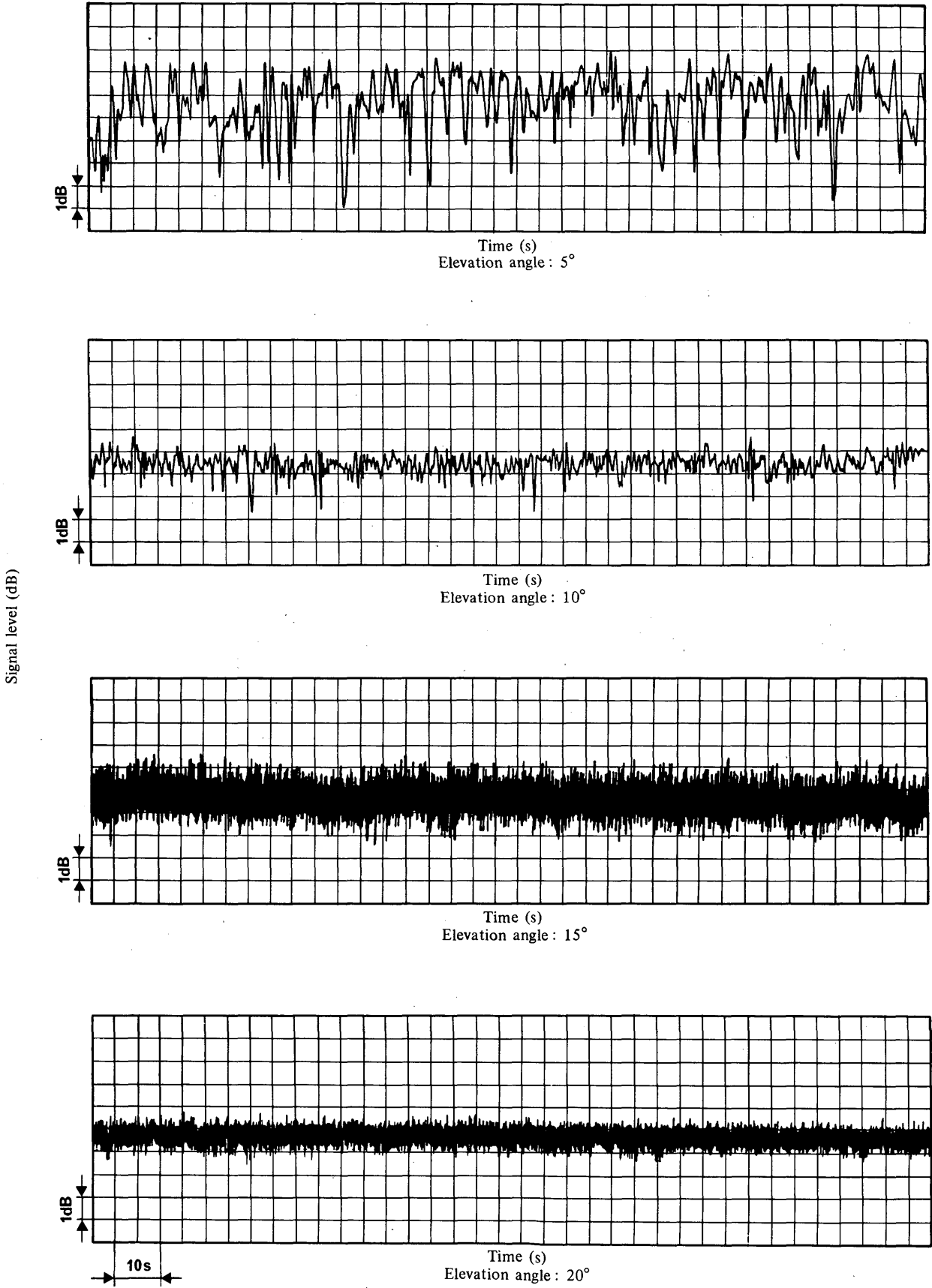


FIGURE 11 – CW signal level fluctuations observed with a rough sea

Time (1 s/mm)

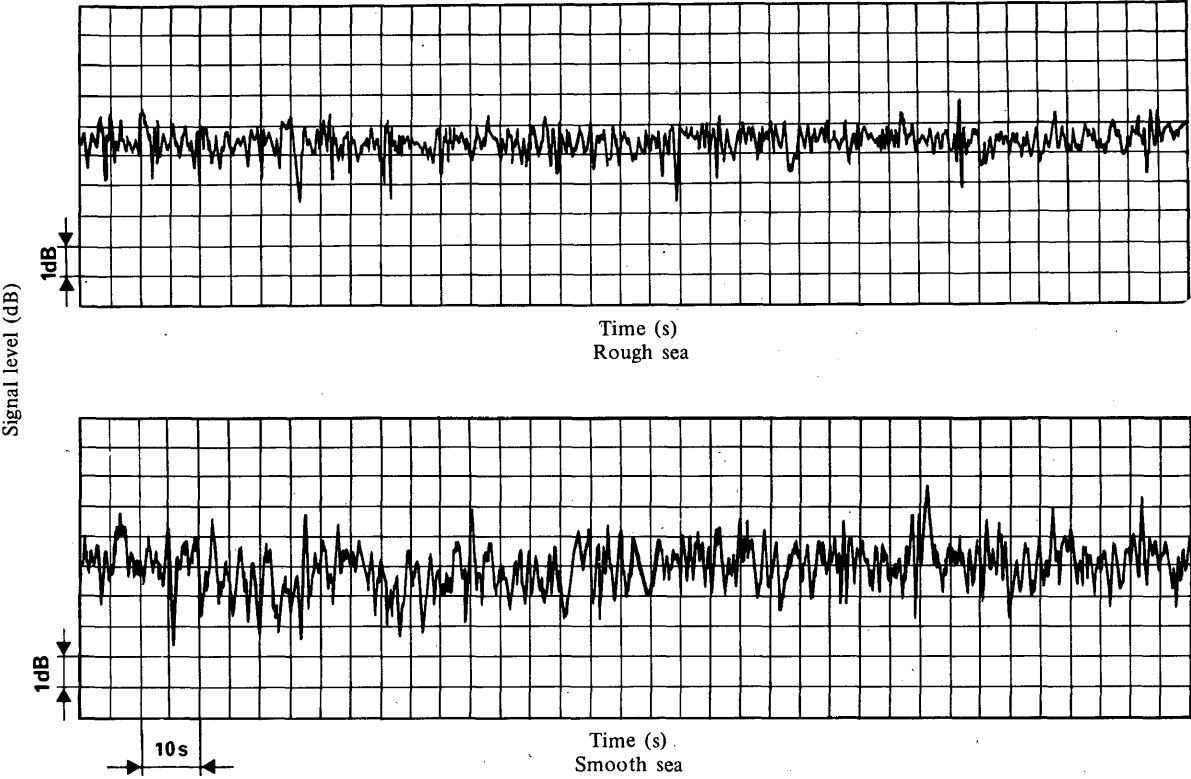


FIGURE 12 – CW signal level fluctuations observed with two states of sea (elevation: 10°)

Time (1 s/mm)

These figures reveal the types of fluctuation indicated in Table IV:

TABLE IV – Fluctuations observed

State of the sea	Elevation angle			
	5°	10°	15°	20°
Rough sea	Interference Intermediate fluctuations	Intermediate fluctuations	Noise	Noise
Smooth sea		Interference Intermediate fluctuations		

In general, it can be seen:

- that higher level of interference may be found at low elevation angles;
- that the amplitude of the interference increases as the wave height diminishes for a given elevation angle.

3.3.4.1.3 Spectral analysis

Figure 13 shows the spectral analysis of the fluctuations observed in the case of a rough sea for different angles of elevation. It will be noted from this figure that the spectrum undergoes substantial modifications when the elevation angle increases, changing from an interference and intermediate fluctuation spectrum (with high amplitude values for frequencies less than 1 Hz) to a uniform noise spectrum. Figure 14 gives the spectral analysis of the fluctuations observed with an elevation angle of 10° and two different states of the sea. It will be seen that on passing from a rough to a smooth sea, the fluctuations tend to concentrate towards the lower frequencies while the amplitude increases. On Figs. 13 and 14, the abscissae show the scale of frequencies (1 Hz/4 cm).

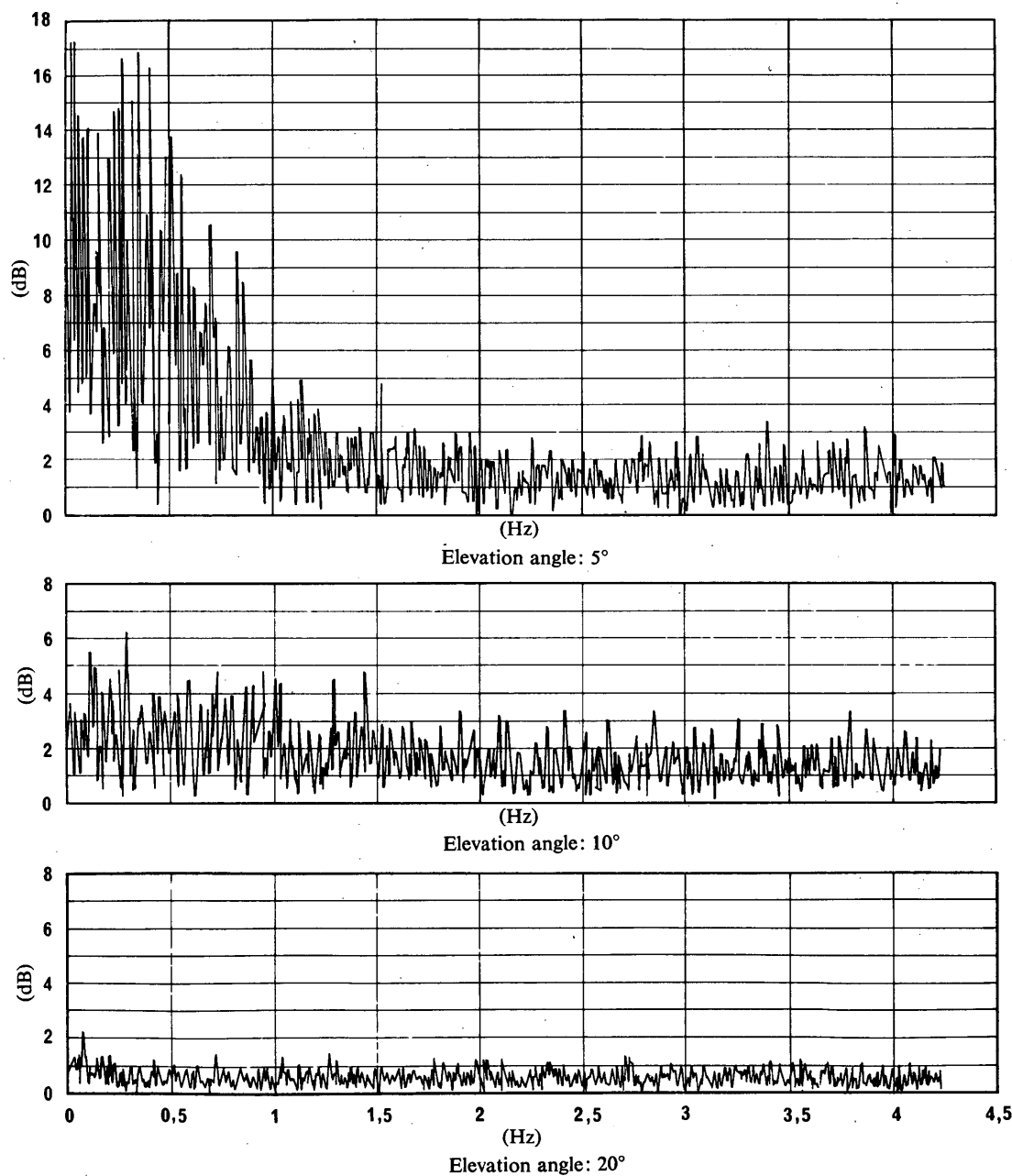


FIGURE 13 – Spectra of fluctuations observed with a rough sea

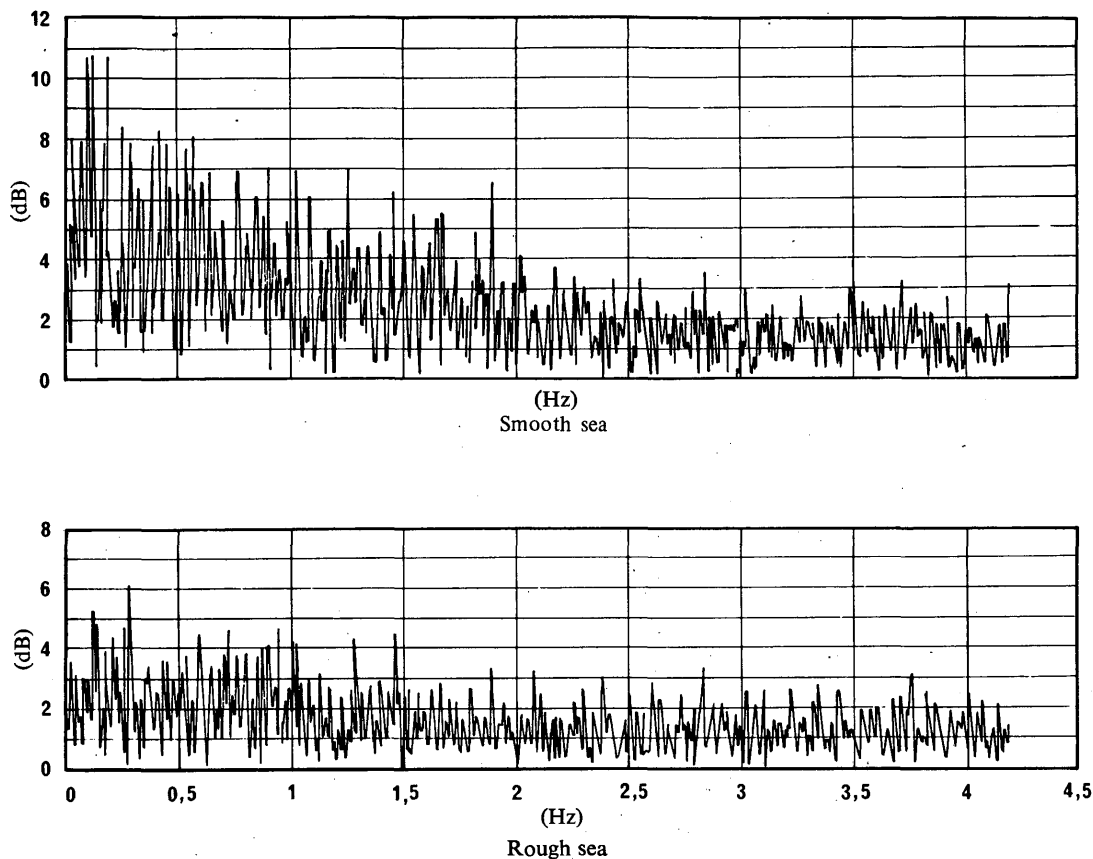


FIGURE 14 – Spectra of fluctuations observed with two states of sea
(elevation angle: 10°)

Figure 15 gives a schematic representation of the changes in the fluctuation spectrum when the elevation angle or the roughness of the sea diminishes. In this figure, it can be seen how, starting from a uniform spectrum, one arrives at an interference spectrum, passing *via* successive spectra in which the intermediate fluctuations are larger and larger; the same types of fluctuation are found in Table IV with the frequency bands corresponding to the information given in § 3.3.4.1.1.

3.3.4.2 Carrier multipath fading

3.3.4.2.1 Definition

A carrier fade at $p\%$ is defined as the difference, in dB, between the mean value of the signal received and a value such that the level received is higher during $p\%$ of the time.

The fade values corresponding to p equal to 95% and 99% were determined for rough and smooth sea.

3.3.4.2.2 Values obtained

Fade level values were obtained by computer processing of measured results. These are shown in Fig. 16. Averages of these figures are shown in Table V.

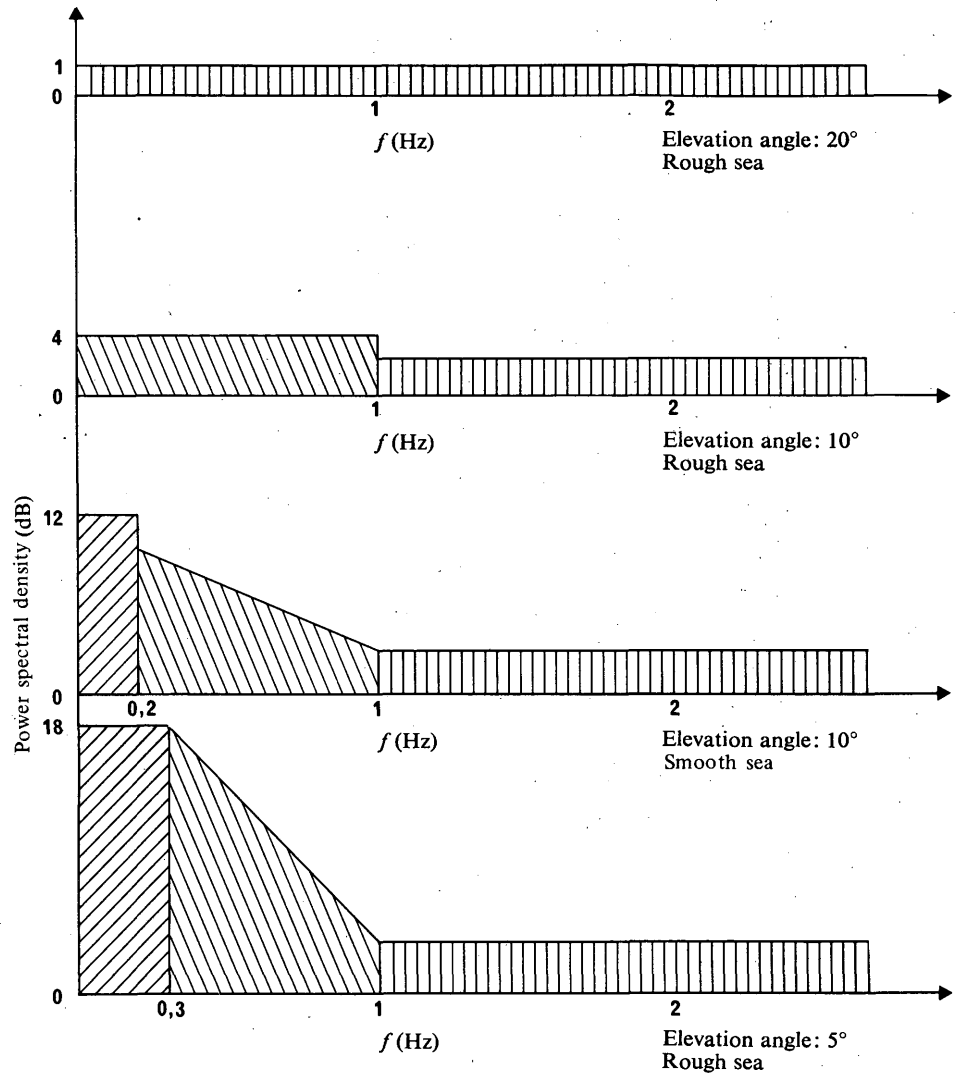


FIGURE 15 – Changes in the fluctuations spectrum with elevation angle and state of sea

-  Interference
-  Intermediate fluctuations
-  Noise

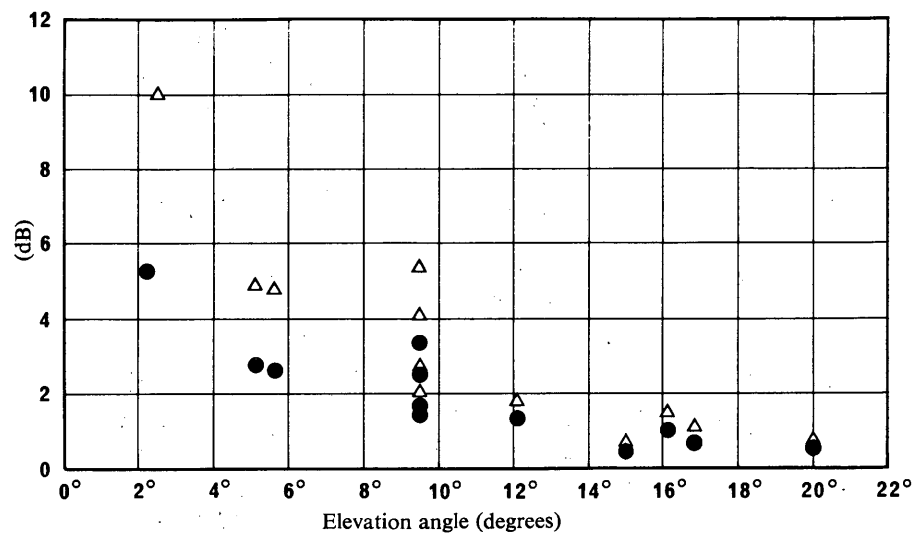


FIGURE 16 – *Carrier multipath fade*
(experimental values obtained with ATS-6)

- Carrier fade at 95%
- △ Carrier fade at 99%

TABLE V – *Carrier multipath fade (in dB)*
(20 dB antenna gain)

State of the sea	Elevation angle (°)	Multipath carrier fade (dB)	
		at 95%	at 99%
Rough sea	5	2.7	4.8
	10	1.7	2.8
	20	0.5	0.6
Smooth sea	10	3.2	5.4

4. Summary of multipath fading statistics

Table VI gives a summary of theoretical estimations and measured results of multipath fading depths contained in this Report. The table also shows some results of measurements carried out using an experimental low *G/T* ship earth station (see Annex II to Report 921).

TABLE VI — *Theoretical and measured multipath-fading statistics for 99% of the time*

Antenna gain (dB)	Elevation angle (degrees)	Wind force (knots)	Wave height (m)	Fade depth (dB)		Source notes
				Theoretical	Measured	
3	4	35			12	(1)
	8	27			13	
	19	20			10.5	
5	4	35			14	(1)
	8	27			14	
	19	20			8	
11	4	35			11	(1)
	8	27			10	
	19	20			6.5	
14	5		1.5-3.2	7-9		(2) (3)
14	5		1.5-3		6-10	(4)
13.5	6		0.3-3.2		7-9.5	(5)
13	4		4.5		7.2	(6)
14	10		1.5-3	4.5-5		(2) (3)
13.5	9		0.8-1.6		4.5-5.5	(5)
13	10		3.5		6.2	(6)
20	5		1.6-3.2	5-7		(3)
20	5		3		4.8	(7)
24	5		1.6-3.2	2.5-4		(2) (3)
24	5		1.6-3.2		1.5-3	(4)
20	10		1.6-3.2	1.5-2		(3)
20	10		3		2.8	(7)
24	10		1.6-3.2	1		(2) (3)

(1) [Hagenauer *et al.*, 1984].

(2) Report 884, Fig. 4.

(3) Report 763, Fig. 2.

(4) Report 763, Fig. 14.

(5) Report 763, Fig. 15.

(6) Report 762, Fig. 11.

(7) Report 763, Table V.

The figures shown in Table VI indicate that the theoretical model is borne out well by experimental results.

5. Prediction of influence from ship's superstructure

5.1 Reflections from ship's superstructure

Reflections from the ship's superstructure, which are mainly coherent with the direct signal, will cause fading in the received signal.

The fading depth depends on a number of parameters:

- shape of the ship;
- location of the ship antenna;
- antenna directivity and side lobe level;
- axial ratio and orientation of the polarization ellipse, both for the satellite and the ship antenna;
- elevation and azimuth angle.

An oil tanker of approximately 230 000 tons deadweight (see Fig. 17) was chosen as a sample ship for a computer prediction of ship reflections. This type of ship was expected to give strong reflections because of its large open deck space in front of the antenna. The reflecting surface on the ship deck was modelled as a set of plane surface elements with infinite conductivity. The on-axis axial ratio of the ship antenna was assumed to be 1 dB and that of the satellite antenna to be 2 dB.

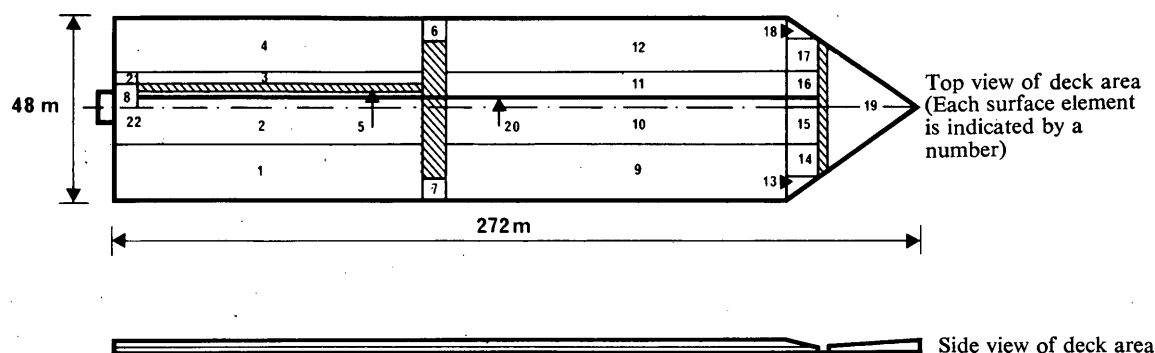


FIGURE 17 – Diagram of tanker used for simulation of ship's reflectors

In Fig. 18 the signal levels predicted by the computer are presented as a function of the elevation angle for two values of assumed directivity, 20 dB and 24 dB. The effect of antenna pointing error is shown, corresponding to a loss of 1 dB. The corresponding pointing angle errors are -5.4° in elevation for the 20 dB antenna and -3.4° for the 24 dB antenna.

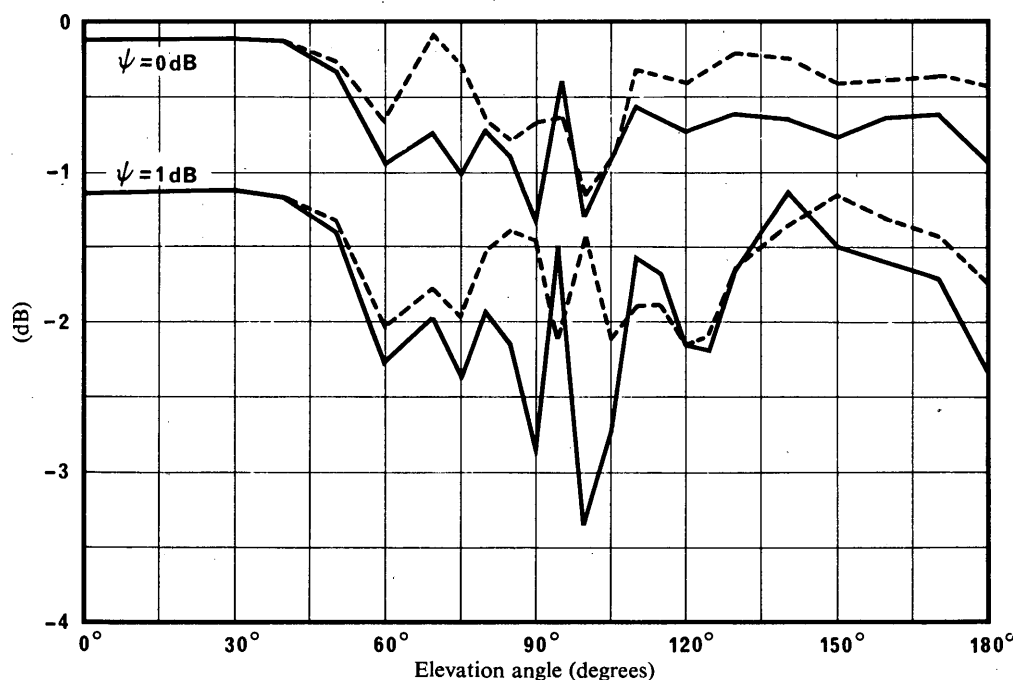


FIGURE 18 – Computer predicted fading depth versus elevation angle for an oil tanker of 230 000 tons deadweight (ψ = pointing loss)

———— 20 dB directivity
----- 24 dB directivity

The variations within the elevation angle range 9° to 11° are caused by interference between reflections from the various parts of the deck.

For this particular example, the predicted multipath effect from a ship's superstructure:

- decreased to zero when the ship heading was more than 14° off the bearing of the satellite,
- changed less than one dB when the height of the antenna above the deck varied.

5.2 Blocking by ship superstructures

Blocking is caused by ship superstructures such as the mast and various types of antennas. The geometry is shown in Fig. 19. Attenuation due to blocking depends on various parameters such as diameter of column, distance between antenna and column and size of antenna. Based on experimental data reported so far, attenuation due to blocking caused by a column type structure can be obtained.

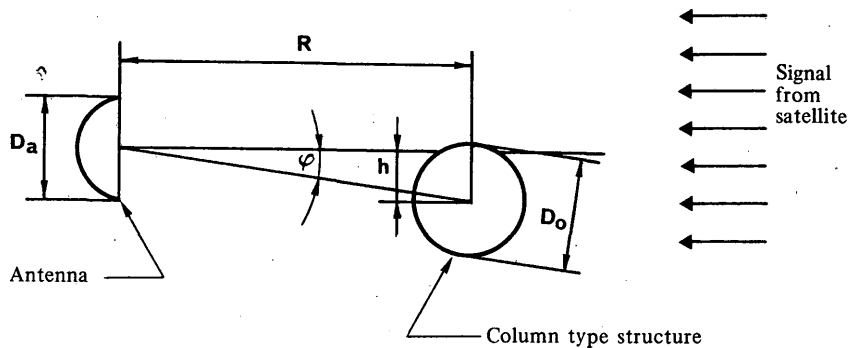
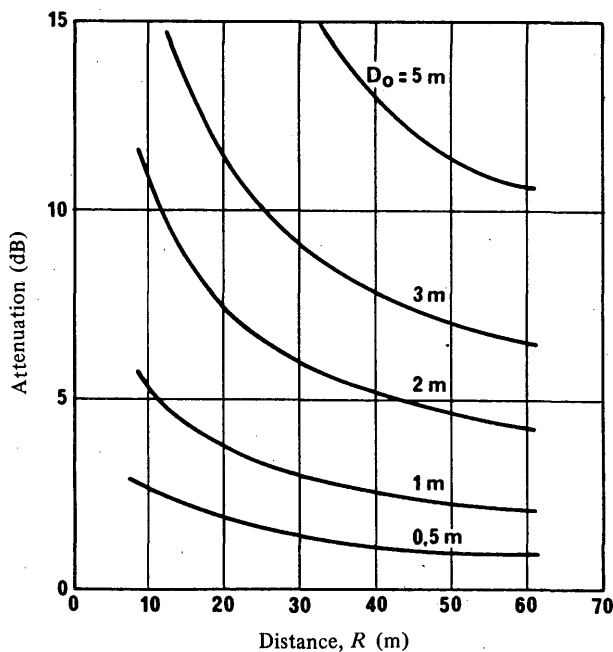
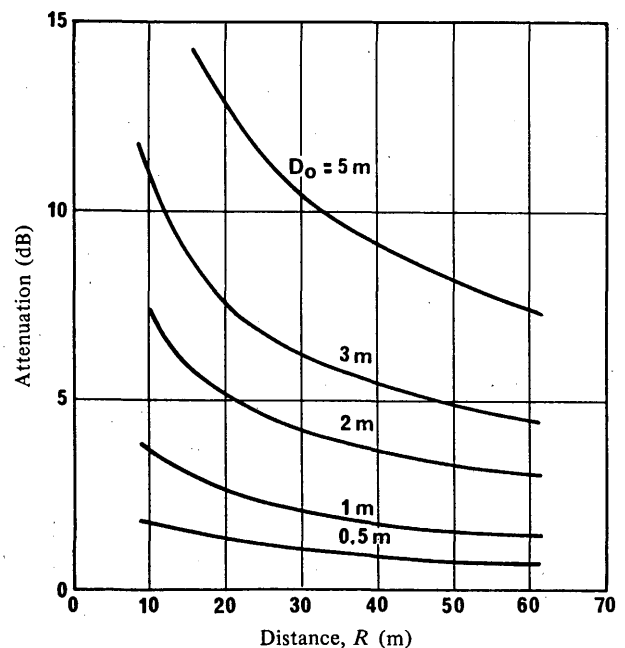


FIGURE 19 – Geometry of blocking

Estimated attenuation due to blocking caused by a column-type structure is given in Fig. 20 for antennas of 20 dB and 14 dB gain.



(a) Antenna gain: 20 dB



(b) Antenna gain: 14 dB

FIGURE 20 – Estimated attenuation due to blocking

6. Conclusions

The results obtained by the theoretical model given in § 2 enable fading due to the multipath effect to be predicted for a wide range of parameter values. It has been shown that fading due to the coherent component, namely height pattern fading, decreases with increasing wave height monotonically, while fading due to the incoherent component increases gradually with increasing wave height and reaches a peak value at around a wave height of 1.6 m. Fading depth generally increases with decreasing elevation angle and antenna gain.

For low elevation angles the coherent (specular) component of the reflection may predominate while the incoherent (diffuse) component dominates for higher elevation angles.

The experimental results described above show that the multipath effect increases with decreasing satellite elevation angle and antenna gain. Maximum fading depth containing both coherent and incoherent components appears at wave heights around 1.6 m and the dependency of fading depth on wave height is small at wave heights ranging from 0.8m to 3.2 m.

Experimental measurements of multipath fading depths are typically within 1 dB of those given by theoretical estimations. Therefore it can be concluded that the theoretical model is borne out well by measured results.

Reflections from the superstructure of a large oil tanker were studied. The results show that fades of the order of one dB may be expected for antenna gains in a range of 20 to 24 dB, assuming small pointing errors and for the antenna aligned along the axis of the ship. Blocking by the ship superstructure was also studied. Attenuation due to blocking by a column-type structure is presented as functions of distance, diameter of a column and size of antenna.

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CCIR Documents

Report 884.

REPORT 764-2

**INTERFERENCE AND NOISE PROBLEMS FOR MARITIME MOBILE-SATELLITE
SYSTEMS USING FREQUENCIES IN THE REGION OF 1.5 AND 1.6 GHz**

(Study Programme 17A/8)

(1978-1982-1986)

1. Introduction

Operational maritime mobile-satellite systems will employ at least frequencies in the region of 1.5 and 1.6 GHz for the satellite-to-ship and ship-to-satellite links respectively. This Report gives results of a theoretical investigation of the potential interference to a maritime mobile-satellite system from different sources and of the interference caused to other systems from the maritime mobile-satellite systems at such frequencies [Haakinson and Kimball, 1974; Haakinson, 1974]. Results of practical electromagnetic (EM) noise measurements in harbours and on-board ships at sea are summarized [Clarke *et al.*, 1974]. Finally, consideration is given to other sources of noise at these frequencies such as extra-terrestrial noise and receiver noise temperature.

2. Interference to maritime satellite systems**2.1 Interference from radar altimeters**

Radar altimeters can interfere with the shipboard satellite receivers when aircraft with operating altimeters are in the shipboard antenna beam. It is understood however that the number of radar altimeters operating in this band is diminishing. Radar altimeter operation may be restricted to the high end of the allocated band to reduce the chances and duration of interference.

2.2 Interference from aeronautical satellite systems

An aircraft transmitter of an aeronautical satellite system is not expected to cause interference to a maritime satellite system shipboard terminal, even while radiating into the main beam of the shipboard antenna [Haakinson, 1974].

2.3 Interference from out of band radar emissions

The AN/SPS-29 air search radar used by US government ships can be considered a potential radio-frequency interference problem. This EM noise source can be suppressed by the insertion of a simple commercially available RF coaxial filter at the transmitter. Similarly the interference from 10 cm surface search radar can also be suppressed with a simple commercially available waveguide filter located at the transmitter output. There was no evidence of Band 9 noise originating from 3 cm surface search radars used by government and merchant ships.

2.4 Interference from existing shipborne communications equipment and associated high voltage insulators

HF ship transmitter emissions may lead to interference in satellite channels of ship earth stations. Results of theoretical and experimental assessment of this effect are published in Annex I of this Report. Further experimental data and study are required.

3. Potential interference from shipboard maritime satellite transmitters**3.1 Interference to aeronautical satellite systems**

One study has shown that interference from a shipboard transmitter of a maritime satellite system may occur only when the aircraft satellite receiver is within 4 nautical miles of the ship and is within the main beam of the maritime satellite transmitter [Haakinson, 1974].

3.2 Interference to collision avoidance systems

Spurious emissions from shipboard transmitters are potentially capable of interference to experimental collision avoidance systems. Limits on spurious emission should be established to eliminate insofar as practicable the source of interference.

3.3 *Out-of-band interference to other radiocommunication services*

Satellite ship terminal transmitters may generate intermodulation, harmonic and other forms of spurious emissions which could cause harmful interference to other services operating above, between and below the 1.5 and 1.6 GHz maritime mobile satellite service bands. Limits on spurious emissions from satellite ship terminals should be determined which would eliminate insofar as practicable such interference. Studies on the values of limits should recognize practical equipment limitations.

3.4 *In-band interference to the fixed service*

In accordance with the provisions of No. 727 and 730 of the Radio Regulations, the band 1540 to 1660 MHz is also allocated to the fixed service to certain Administrations in Regions 1 and 3.

The potential interference from shipborne transmitters to the fixed service is under study (see Report 917, Annex I).

4. **Electromagnetic compatibility**

An in-harbour and at-sea electromagnetic compatibility survey was made on board the *American Alliance* for a maritime satellite shipboard terminal operating in the 1500 to 1600 MHz band [RCA, 1974].

4.1 *Field strength*

Measurements of field strength 1 m from the radar transmitter cabinets in the storage room showed that the cabinet radiation was not excessive.

Field-strength measurements at the above deck locations showed levels that were either equivalent to or less than the levels measured in the storage room.

Radar interference to the shipboard terminal was influenced by the relative location of the antennas. On the *American Alliance*, the separation between the maritime satellite antenna and the radar Band 9 antenna was 9.2 m, and for the Band 10 antenna it was 7.4 m. Closer spacing might justify the requirement for an additional low pass filter.

4.2 *Interference to radars*

The test for shipboard satellite terminal interference to the Band 9 and Band 10 radars as installed on the *American Alliance* showed that this should not be a problem with 15 W power from the shipboard satellite transmitter. One 1.2 m (4 feet) diameter parabolic dish reflector, containing a right-hand circular polarization feed, was used. The antenna gain was 24 dB at 1559 MHz.

5. **Extra-terrestrial noise**

Table I summarizes the effects of extra-terrestrial radio noise sources on a system at 1500 MHz.

6. **Atmospheric noise from absorption**

An absorbent medium, such as oxygen and water vapour in the atmosphere, emits thermal noise that can be described in terms of apparent sky temperature. Report 714 gives a summary of available information. At 1600 MHz the temperature varies from 80 K to 2 K between elevation angles from 0° to 90°. At a 10° elevation angle the sky temperature is about 10 K. (See also § 5.2 of Report 714.)

7. **Noise of satellite ship terminal receiver**

The noise temperature of a satellite ship terminal receiver will depend mainly on the type of pre-amplifier stage and the feeder loss between the antenna and pre-amplifier. Typically the pre-amplifier would be mounted immediately behind the antenna to minimize feeder loss. In such a configuration a transistor pre-amplifier can provide a receiver noise temperature of the order of 225 K and an uncooled parametric amplifier of the order of 55 K.

8. **Man-made noise**

Data have been recorded in harbour and at sea for approximately ten different classes of ships [Clarke *et al.*, 1974]. All of the significant electromagnetic noise sources of Band 9 (1535 to 1660 MHz) which were measured were determined to be broadband in character relative to the link bandwidths contemplated for future maritime mobile-satellite system design. The broadband noise was intermittent and generally having a duration much shorter than a typical message element envisaged for a maritime satellite system.

TABLE I – Extra-terrestrial radio source characteristics at 1500 MHz

Source		Sun	Moon	Jupiter	Casseopeia	Galactic centre
Source size (steradians)		1.35×10^{-4}	1.07×10^{-4}	Point source	Point source	1.9×10^{-3} ($2.6 \times 1.4^\circ$)
Power flux-density (W/(m ² ·Hz))		9.3×10^{-21}	–	–	2.2×10^{-23}	
Apparent temperature (K)		10^5	250	2×10^3	–	162
Antenna temperature (K)	20 dB Antenna gain	107	0.21	< 1	0.24	15
	10 dB Antenna gain	11	2.1×10^{-2}	< 10^{-1}	2.4×10^{-2}	7
	3 dB Antenna gain	2	2.1×10^{-3}	< 2×10^{-2}	4.8×10^{-3}	2 (estimated)

The predominant sources of serious Band 9 electromagnetic noise were found to be associated with electrical equipment operating intermittently in ports or in close proximity. This noise is generally broadband in character. A high percentage of these intermittent sources originated as broadband impulsive noise from ignition circuits associated with dockside and shipboard unloading apparatus. The same noise category was frequently evident for automobiles and trucks on highways and bridges adjacent to harbours, ports and canals. Also evident at ports is a component of city ambient noise which varies in amplitude from port to port, and also depends upon the time of the day. This noise varies in magnitude by 20 dB depending on whether it is measured on a normal working day or on weekends and holidays, when it is lower in magnitude. Occasionally evident while near or in port were radio-frequency interference noise power density levels 20 to 30 dB above the ambient receiver noise power density level for a 3 dB noise figure receiver. This increase in apparent ambient noise level may seriously affect link thresholds. Beyond radio line-of-sight of any port, radio-frequency interference should not affect receiver sensitivity especially for new ships.

8.1 Interference from automobiles on an expressway

The peak amplitude of the noise emanating from the Brooklyn Expressway with heavy traffic was recorded to be about –150 dB(mW/Hz) within Band 9. For this test, a 20 dB gain horn antenna was used, oriented in the direction of the noise source. Under certain operating conditions, man-made noise from automobile traffic may impair receiver sensitivity level [Clarke *et al.*, 1974].

8.2 Ship-yard

Extremely high peak amplitudes of noise of –141 dB(mW/Hz) were recorded from the Boston Navy Yard which was in full operation at the time. This noise is a combination of city ambient noise and of broadband electromagnetic noise from industrial equipment. A 20 dB gain horn antenna was used, oriented in the direction of the noise source. Under certain operating conditions ship-yard noise may impair receiver sensitivity levels in Band 9 [Clarke *et al.*, 1974].

8.3 Dockside noise

Broadband impulsive noise, originating from combustion engine ignition circuits used with dockside unloading apparatus, was found to exist at all ports. The recorded peak amplitude of the noise at Narragansett Bay, 5 miles from Portsmouth, Rhode Island (USA), is about -137 dB(mW/Hz) within the maritime mobile-satellite receive band. Noise levels of -150 dB(mW/Hz) have been recorded from ships' cranes. A 20 dB gain horn antenna was used, oriented in the direction of the noise sources.

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ANNEX I

EFFECT OF SHIPBORNE HF TRANSMITTER OPERATION ON SHIP EARTH STATION

1. Theoretical aspects

A criterion for identifying the extent to which the HF transmitter emissions can affect the ship earth station operation is the susceptibility threshold of the ship earth station receiver. The threshold of susceptibility is assumed to be receiver sensitivity level calculated for the corresponding frequencies, f_{SR} , which are capable of producing spurious responses and may be represented by the following expression:

$$f_{SR} = \frac{pf_{LO} \pm f_{IF}}{q} \pm \frac{B_R}{2q} \quad (1)$$

where:

- f_{LO} : local oscillator frequency, MHz,
 f_{IF} : first intermediate frequency, MHz,
 B_R : 3 dB bandwidth at the first intermediate frequency, MHz,
 p, q : harmonic number of local oscillator and interfering signal, respectively ($p, q = 0, 1, 2 \dots$, etc.).

The receiver spurious response susceptibility threshold at the receiver input, $P_R(f_{SR})$, can be expressed as:

$$P_R(f_{SR}) = P_R(f_{OR}) + I \log \frac{f_{SR}}{f_{OR}} + J \quad (2)$$

where:

- $P_R(f_{OR})$: receiver fundamental sensitivity, dBm,
 f_{OR} : receiver fundamental frequency, MHz,
 I, J : constants for characterizing receiver off-tune rejection, in dB/decade and dB respectively.

The interference signal power produced by HF transmitter emissions at ship earth station receiver input, $P_I(f_{SR})$, is determined for transmitter fundamental harmonics in accordance with the following equation:

$$P_I(f_{SR}) = P_T(f_{OT}) + A \log n + B - L_c \quad (3)$$

where:

- $P_T(f_{OT})$: fundamental power, dBm,
 n : harmonic number of transmitter frequency (f_{OT}) relative to receiver spurious response frequency (f_{SR}), $n = f_{SR}/f_{OT}$,
 A, B : constants for characterizing transmitter harmonic emission levels, in dB/decade and dB respectively,
 L_c : coupling loss, in dB, including propagation, receiver antenna and transmitter antenna effects.

In more detail, L_c can be expressed as:

$$L_c = 10 \log \eta_{af} + 20 \log \frac{\lambda}{4\pi r} + 10 \log \gamma + 10 \log \beta + 10 \log G(\theta, \phi, \lambda) + 10 \log \eta_f \quad (4)$$

where:

- η_{af} : transfer constant of transmitter antenna feeder link;
 λ : wave length (for corresponding harmonic) (m);
 r : distance between SES antenna and HF transmit antenna (m);
 $G(\theta, \phi, \lambda)$: SES receiver antenna gain referred to azimuth, θ , and elevation, ϕ ;
 η_f : receiver feeder efficiency;
 β, γ : constants for characterizing the effects of antenna polarization mismatch and of physical obstructions.

Equations (1) and (2) were applied to calculate receiver susceptibility threshold for spurious response frequencies most close to HF transmitter operating frequencies. Initial data used in the calculation were as follows:

$f_{OR} = 1538 \text{ MHz}$	$f_{LO} = 1351 \text{ MHz}$
$f_{IF} = 187 \text{ MHz}$	$P_R(f_{OR}) = -139 \text{ dBm}$
$B_R = 8.5 \text{ MHz}$	$I = -20 \text{ dB decade}$
$P = 0$	$J = 80 \text{ dB}$

Results of the calculation are shown in Table II.

TABLE II — Spurious response susceptibility thresholds

q	$f_{SR} \text{ (MHz)}$	$P_R(f_{SR}) \text{ (dBm)}$
8	23.37 ± 0.53	-22.6
10	18.70 ± 0.42	-20.7
11	17.00 ± 0.39	-19.9
5	37.40 ± 0.85	-26.7
7	26.71 ± 0.61	-23.8

The spurious response frequencies as given in Table II are the first IF sub-harmonics of ship earth station receive system.

Using equation (3), interference power of spurious response frequencies was calculated and compared with the obtained values of receiver susceptibility threshold. The calculation was performed for those HF transmitter frequencies, f_{OT} , which are capable of producing interference at the receiver spurious response frequencies. It was assumed that $P_T(f_{OT}) = 1500 \text{ W}$, $A = -70 \text{ dB/decade}$ (see Note), $B = -20 \text{ dB}$, and free space loss over a distance of 10 m was used for L_c .

Note. — The value of A in future calculations can be taken as -60 dB/decade without impairing the quality of reception.

Results of the calculation are shown in Table III.

TABLE III — *Spurious response interference power*

$f_{OT}(\text{MHz})$	n	$P_I(f_{SR}) \text{ (dBm)}$	$P_I(f_{SR})/P_R(f_{SR}) \text{ (dB)}$
4.670 ± 0.1062	5	-27.0	- 4.4
6.2333 ± 0.1417	3	- 9.5	+11.2
17.00 ± 0.3864	1	+24.7	+44.6
8.50 ± 0.1932	2	+ 3.6	+23.5
12.4666 ± 0.2833	3	-15.5	+11.2
13.3571 ± 0.3035	2	- 0.3	+23.5

TABLE IV — *Interference power at SES receiver fundamental frequency ($P_I(f_{OR})$)*

$f_{OT} \text{ (MHz)}$	n	$P_I(f_{OR}) \text{ (dBm)}$	$P_I(f_{OR})/P_R(f_{OR}) \text{ (dB)}$
6.2 to 13.2	248 to 124	-102 to 82	-11 to 9

The above interference values are for only the first sub-harmonics of the ship earth station IF. It should be noted that equations (2) and (3) do not take into account non-linearities in active receiver or transmitter components that can affect the relative susceptibility or emission levels for different harmonics.

2. Experimental results

During the experimental period, $(I + N)/N$ levels were measured to identify the effect of HF transmitter emissions. Interference was produced by the HF transmitter emissions at the frequencies selected within the band shown in Table III. Noise levels and interference-plus-noise levels were determined for 20 kHz bandwidth in the first IF channel of the ship earth station.

The ship earth station antenna was directed towards the HF transmit antenna located at 8.6 m distance. The transmitter was operating in A1A emission mode, the emitted power being 1.5 kW.

Shown in Table V are results of processing of measured $(I + N)/N$ values.

TABLE V — *Mean $(I + N)/N$ vs HF transmitter operating frequency*

$f_{OT}(\text{MHz})$	4.68	6.23	8.35	12.51	13.2	16.75
$(I + N)/N \text{ (dB)}$	0	20	18	23	17	16

The measured interference in Table V does not compare directly with the calculated interference in Table III. Any inconsistency is due to a number of factors not taken into account in calculating Table III values, e.g. frequency dependent effects on L_c . Further information on predicting spurious responses can be found in Reports 522 and 524.

The interference in the receive channel was narrowband in nature, with its level dependent upon directing the ship earth station antenna towards HF transmit antenna.

Throughout the experiment period, the effect of HF transmitter emissions on the quality of telephone and telex message reception was examined at $f_{OT} = 12.502$ MHz which causes interference at the receive frequency 1537.75 MHz (satellite channel). Values of $(I + N)/(C + N)$ were determined.

No troubles were experienced with reception of reference telex messages with $(I + N)/(C + N) \leq -1$ dB. It should be noted that this ratio may reach 15 dB at low elevation angles.

The quality of telephone message reception was judged to be satisfactory, with $(I + N)/(C + N) \approx 2$ dB, where:

- I : interference signal level,
- N : noise,
- C : wanted carrier signal level.

Should the $(I + N)/(C + N)$ value measured in the first IF channel be equal to or exceed 5 dB, the telephone channel was completely blocked due to the interference.

REPORT 765

EFFICIENT UTILIZATION OF THE ALLOCATED FREQUENCY BANDS FOR THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978)

1. Introduction

The frequency spectrum is a precious resource. The efficiency of frequency spectrum utilization can be enhanced by employing frequency re-use techniques, careful frequency assignment and other methods of maximizing the traffic-carrying capacity of available frequency bands. Once the methods of using the frequency allocation have been decided upon, it may be very difficult to change them later. Since some of the techniques which maximize frequency spectrum utilization have a great effect on both satellite and ship-board terminal design, it is necessary to study this subject at the initial stage of the maritime mobile-satellite service.

2. Channel requirements

The traffic forecast for a world-wide maritime satellite service has been considered by the IMO Panel of Experts on Maritime Satellites and has been presented in the Report to the Governments [IMO, 1974].

The analysis has shown that the number of equivalent telephone channels required on a world-wide basis will "most probably" exceed 150 channels after about 13 years of operation, and a further increase in the channel requirements is likely to occur also in the later stages of development. Therefore, the system must be planned in such a way that it can accommodate more than 150 channels in order not to limit the growth of the service. Since a 7.5 MHz allocation divided into 50 kHz channels equates to 150 channels, it is clear that the techniques to improve the efficiency of the frequency band must be considered.

3. Methods for efficient utilization of the allocated frequency bands

The following methods should be considered individually or in combination, in order to obtain an efficient utilization of the frequency band:

- frequency re-use through orthogonal polarization;
- minimization of channel spacing for a given signal bandwidth;
- re-use of frequencies through geographical or angular separations;
- frequency off-set;
- modulation methods resistant to interference.

3.1 *Frequency re-use through orthogonal polarization*

The use of orthogonal polarizations, as conditioned by cross channel interference, is affected by the obtainable cross polarization discrimination of the various antennas in the communications link and by depolarization phenomena encountered along the signal path.

Signal depolarization may be due to various effects, the most important of which are:

- ship motions,
- ship superstructure reflection,
- multipaths,
- satellite rotations.

These problems must be studied carefully and to the extent possible by means of experiments, keeping in mind the different types of ships' antennas (gains going from 0 dB to above 20 dB) which are expected to be used for the various communication services.

More generally, the performances of linear polarized systems, as opposed to circularly polarized systems, should be studied in this respect.

3.2 *Minimization of channel spacing for a given signal bandwidth*

This is limited by:

- the frequency error of individual carriers;
- the allowable inter-channel interference;
- the intermodulation introduced by the satellite transponder;
- the effect of filters on the spectrum of the transmitted signal.

3.2.1 *Frequency errors of individual carriers*

The main sources of frequency errors are due to Doppler shift and instability of the local oscillators in the shore station, in the satellite and in the ship terminal.

Doppler shift in a maritime satellite system is caused by the relative motion of the satellite with respect to a shore station and by the movement of ships relative to the satellite.

In the case of the shore station/satellite component of Doppler, the precise value will be different at each shore station location. However, it is possible, by a suitable adjustment of a particular shore station transmit or receive frequency, to compensate completely for the Doppler component at that shore station arising from satellite motion.

In the case of the ship/satellite component of Doppler, the frequency error is obviously different for each ship. There is no known simple or economic way for this component of Doppler shift to be compensated.

Table I indicates the frequency error resulting from some assumed values of frequency stability for shore station satellite and ship station equipment with an assumed 50 kHz channel separation plan. The values of frequency stability are considered feasible without incurring substantial economic penalty.

Frequency errors can be reduced in several ways, such as:

- the use of higher stability local oscillators,
- the use of spectrum centring pilots.

Higher stability oscillators may have considerable impact on the system cost, particularly as far as satellite transponders are concerned. This solution does not reduce Doppler shift.

Spectrum centring pilots can be used in two ways:

- (a) in connection with automatic frequency control (AFC) in the receivers. Only one pilot signal is required to control all receivers. In fact, the whole frequency band comprising both the pilot and the communication channels is shifted in frequency but remains properly spaced. This method could be used in either the ship-to-shore or shore-to-ship direction, but the application of this technique to the latter case is not preferred since it would unduly complicate the ship terminal equipment;
- (b) by measuring the frequency of the pilot signal after transmission through the satellite. The information is used to adjust the frequencies of the transmitted carriers at the shore station so that the carriers are received at their nominal frequencies. This method may be used in the shore-to-ship direction.

TABLE I – Typical frequency errors

Channel separation	50 kHz			
Guard band	8 kHz			
Frequencies (MHz)	1500 or 1600/ 4000 or 6000		1500 or 1600/ 11 000 or 14 000	
Transmitting oscillator (Note 1) Up-link J Satellite (Note 2) Doppler shift I Ship (Note 3) Satellite oscillator (Note 4) Down link J Satellite (Note 2) Doppler shift I Ship (Note 3) Receiving oscillator	Frequency errors (maximum)			
	Shore-to-ship (kHz)	Ship-to-shore (kHz)	Shore-to-ship (kHz)	Ship-to-shore (kHz)
	±0.18	±0.24	±0.435	±0.24
	±0.46	±0.12	±1.1	±0.12
	-	±0.07	-	±0.07
	±4.5	±2.4	±13.0	±10.1
	±0.11	±0.3	±0.11	±0.89
	±0.07	-	±0.07	-
	±0.12	±0.23	±0.225	±0.35
Total error (maximum)	±5.44	±3.36	±14.94	±11.77
Required information bandwidth (depending on modulation method used)	25-35 kHz			

Note 1. – Frequency stabilities quoted for ship terminals and shore stations assume use of quartz crystal oscillators in continuously running ovens requiring periodic correction to offset aging effects. The periodic correction for shore stations is assumed to be monthly and for ship terminals six to twelve months. On this basis a frequency stability of $\pm 3 \times 10^{-8}$ for shore stations and $\pm 1.5 \times 10^{-7}$ for ship stations would seem to be feasible.

Note 2. – Satellite orbital inclination ± 3.0 degrees and zero eccentricity or a combination of lower inclination and some eccentricity.

Note 3. – Ship speed 50 km/h.

Note 4. – Satellite frequency stability $\pm 10^{-6}$ over the satellite lifetime.

The advantages of spectrum centring pilots are:

- the stability requirements of the satellite transponder can be reduced without affecting the channel spacing of the received signals;
- where method (b) is used in the shore-to-ship direction, individual ship receivers need not be equipped with AFC;
- the component of Doppler shift due to the motion of the satellite relative to the shore station may be compensated; for ships not too distant from the particular shore station which has been specially compensated for Doppler on a 1.6 GHz satellite-to-shore link, there will also be some compensation for Doppler arising from satellite movement relative to the ship. Doppler error arising from movement of the ship itself would, of course, remain uncompensated.

From the figures given in Table I it can be deduced that whatever the choice for the shore-to-satellite and satellite-to-shore frequency bands, the net residual frequency error can be reduced to less than ± 1.5 kHz by means of spectrum centring pilots, (limited only by residual Doppler error in the 1.6 GHz band and errors from ship oscillator instability).

Further study is required on the ways in which spectrum centring pilots could be implemented.

3.2.2 *Inter-channel interference*

The inter-channel interference depends on the voice processing method, the modulation technique used and the performance objectives chosen. As yet, no general rules have been established concerning the required width of the guardband.

3.2.3 *Intermodulation*

If hard limiting is used in the satellite transponder, the amount of intermodulation distortion may become excessive. In such situations, a channel spacing such as the Babcock spacing must be employed, which leads to inefficient utilization of the frequency band. Therefore, in order to achieve efficient utilization of the frequency spectrum, the best possible carrier-to-intermodulation-noise ratio performance at the satellite transponder is desirable. However, with present technology, satellite power amplifier efficiency reduces with increasing linearity. Techniques such as pre-distortion, constant gain control and feed-forward, which improve linearity without significantly reducing efficiency, are under investigation.

The intermodulation distortion also depends on the modulation technique and on whether voice activation is used. When voice activation is used, the average intermodulation distortion would be reduced by an amount approximately equal to the voice activation advantage. If voice activation is not used, the actual intermodulation will depend on the spectrum of an idle channel. In FM systems, the idle channel will consist of a pure carrier, unless an energy dispersal technique is used, whereas for the Delta M/PSK systems the idle channel will be modulated by the idle pulse pattern of the Delta encoder, thus resulting in energy dispersal of the RF signal.

3.2.4 *The effect of filters on the spectrum of a signal*

In FM systems, the bandwidth of the transmitted spectrum can be approximated to the Carson rule bandwidth. Truncation of higher order sidebands would not add any appreciable distortion as long as the truncating filters are symmetric.

In digital systems, transmit filters can be designed such that the spectrum width is restricted to less than 1.2 times the Nyquist bandwidth.

The filter problems have been treated by several authors [Lavean and Palmer, 1974; Assal, 1974; Lopriore and Lundquist, 1974; Muratani *et al.*, 1974].

3.3 *Re-use of frequencies through geographical or angular separations*

World-wide coverage (excluding polar regions) can be provided by various arrangements of geostationary satellites. The minimum requirement is for three satellites employing global beam antennas (17° beamwidth). Other possibilities exist. Four satellites provide greater possibilities for frequency re-use than using three satellites. A system which provides for radiodetermination would use more than four satellites. With each of the above possibilities, spot beams (i.e. beamwidths less than 17°) may be employed to provide the necessary coverage. However, the use of spot beams leads to operational complexities and, unless adaptive spot beams are used, to loss of flexibility.

3.3.1 *Frequency re-use in different areas*

3.3.1.1 *Three geostationary satellites*

3.3.1.1.1 *Full re-use*

In this case, each radio frequency can be used in all three ocean areas regardless of whether or not the same frequency is being used simultaneously in an adjacent area. The main constraint is the co-channel interference introduced by the second satellite in the overlap areas. An important parameter here is the relative antenna gain of the ship terminal in the direction of the interfering satellite. This gain cannot be reduced below a certain limit determined by the antenna design and the unpredictable reflections from the superstructure of the ship. Moreover, the individual e.i.r.p.-variation of carriers transmitted by different satellites may require large margins to protect against severe degradations. Further study is required on such aspects as antenna performance, satellite transponder design, statistical distribution of interfering signal levels due to variation of earth station e.i.r.p. and statistics on sea states.

3.3.1.1.2 *Limited re-use*

Channels may be assigned for use in overlap areas only. The number of channels so required depends on the expected traffic to and from ships in these areas.

Co-channel interference may have a significant influence on the system performance only when the angle of elevation is low. Therefore, special frequency assignment is essential only in those parts of the overlap area where the satellite is seen under low angles of elevation.

The number of ships in these zones of the overlap area of the Atlantic and the Indian satellites may be about 7% of the total number of ships in the area covered by the Atlantic satellite alone [Thompson, 1970].

In this case, the number of channels obtainable with partial re-use is 93% of that obtained by full re-use.

One disadvantage concerning limited re-use is that the area of operation of the ship must be known.

3.3.1.1.3 *Globally controlled access*

A combination of the above methods may be used to prevent a channel from being used simultaneously by two satellites covering the same overlap area.

The channels must then be assigned on request from each shore station on a world-wide basis. The channel assignment must be done over one or more service channels common to all shore stations.

Such an approach would seem more practical if there was "control by a single routing centre" as described in Report 596 (Kyoto, 1978).

If the traffic peaks are not likely to occur simultaneously in all three ocean areas, this method may be nearly as efficient as full re-use. The technical and operational problems involved, however, need further study.

3.3.1.1.4 *Zone configuration method*

In the zone configuration method the available channels are divided into groups (G_1 , G_2 , etc.). The surface of the Earth is divided into zones (Z_1 , Z_2 , etc.).

Figure 1a shows an example of a zone configuration giving an effective world-wide channel capacity of 450 channels which is a frequency re-use factor of 3. It should be noted that in this example of zone configuration, satellite spot beams would need to be employed (see § 3.3.2).

3.3.1.2 *Four geostationary satellites*

The use of four geostationary satellites together with the zone configuration method offers a significant frequency re-use factor. Figures 1b and 1c show examples which give an effective world-wide channel capacity of 300 and 600 channels respectively, corresponding to a frequency re-use factor of 2 and 4. The example in Fig. 1c requires the use of satellite spot beams (see § 3.3.2). The economic implications of using four satellites instead of three is an important factor that needs to be considered.

If, in the initial stage of a world-wide maritime satellite service, a three-satellite arrangement is chosen, it would remain possible to extend to a four-satellite arrangement using a zone configuration method at a future time.

3.3.2 *Use of spot beam antennas in the same or in different areas*

The use of multiple satellite antennae giving spot beam coverage can significantly increase the number of available channels. However, for high channel capacity, unless adaptive spot beams are used, it is desirable to have frequency re-use between spot beams within the same global coverage area. It has been shown [Phillips and Temple, 1975] that the manner in which spot beams are arranged can affect the re-use rate. In Fig. 2a no frequency re-use is possible between any beams within the global coverage area. However, the zone configuration methods as discussed in § 3.3.1.2 can take advantage of such a spot beam arrangement. In Fig. 2b some re-use may be possible between beams 5 and 2, 1 and 4 etc., although isolations may not be sufficient depending on attainable discrimination between beams. The possibility exists of utilizing additional discrimination such as that provided by frequency interleaving in order to obtain sufficient isolation between channels, a possibility which may be worth further study.

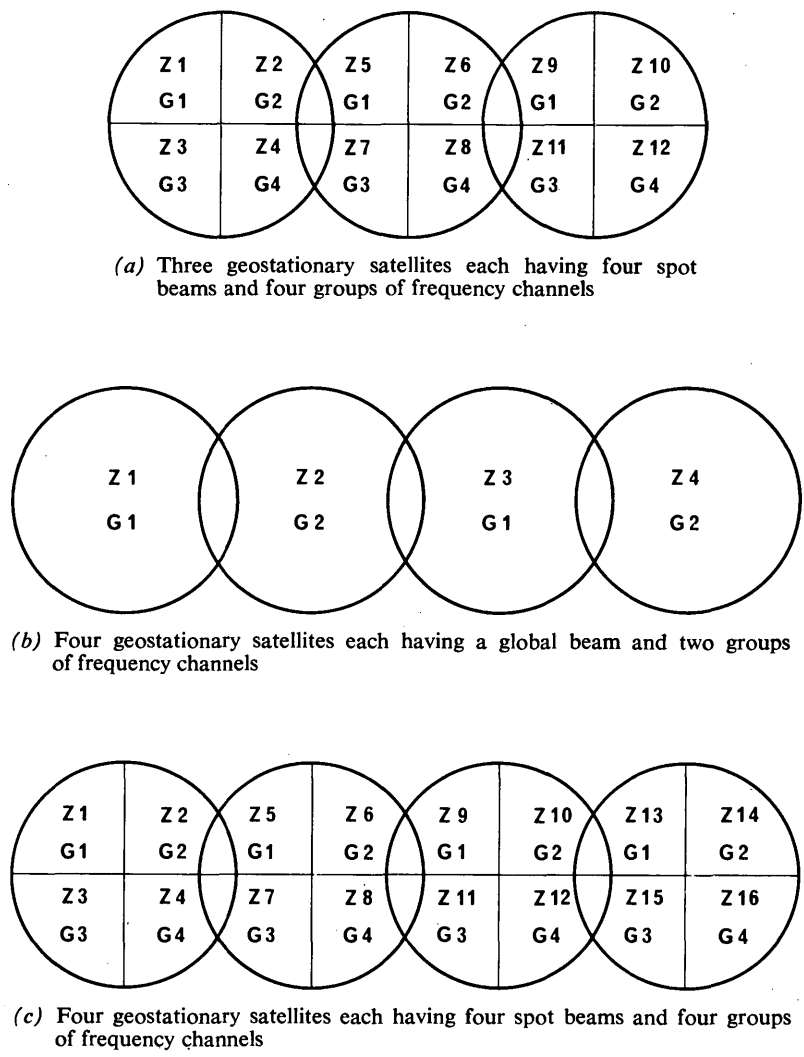


FIGURE 1 — Example of zone configuration

3.4 Frequency off-set

It is possible to make more efficient use of the available spectrum by arranging the carriers so that their spacing is some fraction of the actual channel bandwidth. In this way, a large proportion of the energy from one channel will fall into the edge of the adjacent channel. The amount of discrimination that can be achieved needs to be determined experimentally for different frequency off-sets. Frequency interleaving is a particular case of a frequency off-set arrangement where the frequency of a carrier is off-set by one-half of the channel bandwidth from another carrier.

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3.5 Modulation methods resistant to interference

The immunity of the modulation system to interference is an important factor in efficient spectrum utilization. For example, a four-phase PSK signal has approximately the same resistance to interference as a two-phase PSK signal but needs only slightly more than one-half the bandwidth required for two-phase PSK. A higher than four-phase PSK signal is less resistant to interference than four-phase PSK. Studies on modulation techniques should consider the aspect of resistance to interference.

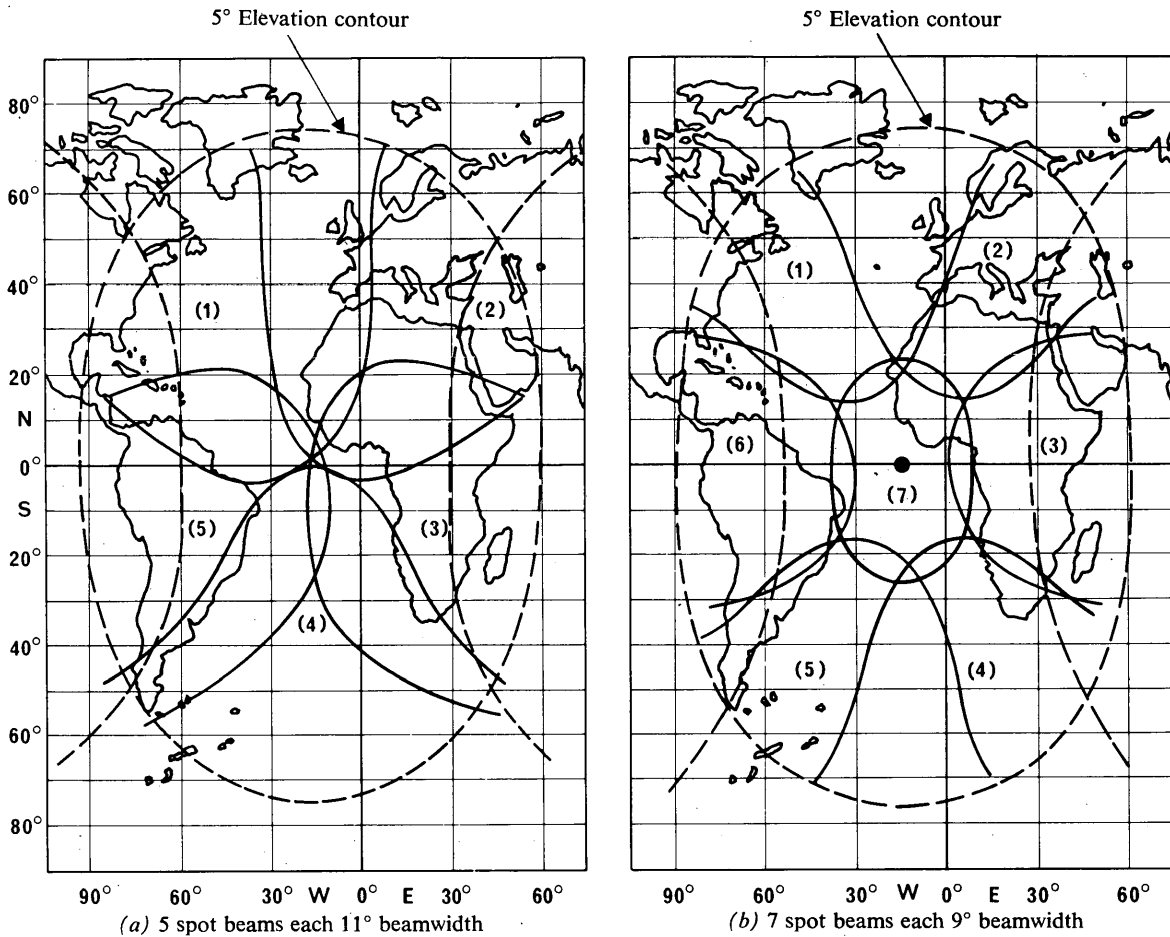


FIGURE 2 — Some examples of practical spot beam coverage arrangements

4. Other considerations

4.1 Frequency tuning flexibility of the ship earth station

All techniques of frequency re-use require ships' terminals to tune to specific channels under particular circumstances. Implementation of these techniques is facilitated if ships' terminals are able from the outset to tune to any channel in the allocated 8.5 MHz bandwidth.

4.2 Antenna radiation patterns

Some frequency re-use techniques discussed above require good side lobe suppression of the ship terminal antennas. Studies are required on what practical performance is achievable, taking into account the effect to the ship structure. Administrations are urged to submit data on measurements to the CCIR related to the different types of antennas which are expected to be used in the maritime mobile-satellite service.

For a satellite with multi-spot beam antennas, similar considerations apply.

4.3 Permissible interference levels

The allowable noise power on the hypothetical telephone reference circuit will include a contribution from inter-channel interference.

The larger the value allowed from this contribution the greater will be the overall frequency re-use factor. This will, however, involve a trade-off between the various noise contributions from the satellite link and the terrestrial network.

4.4 *Sub-synchronous satellites*

The Report of the IMO Panel of Experts calls for coverage of all ocean areas, including the polar regions, as the long-term objective. A geostationary satellite which radiates channels across all of the allocated band may inhibit sub-synchronous polar orbiting satellites from radiating whilst in the beam of that geostationary satellite. This may have adverse operational consequences in the zone where a ship's angle of elevation to a geostationary satellite is between 0 and 5°, i.e. where it may be preferable to use a sub-synchronous satellite. This requires further study.

4.5 *Assignment of telephony and telegraphy channels to shore and ship stations*

The pre-assignment of telephony channels to shore stations would quickly exhaust the available frequency spectrum. The most efficient use of the frequency spectrum is accomplished when all telephony channels are available for use by all shore stations and ship stations. Public correspondence telephony channels, therefore, should be allocated on an automatic demand assigned basis. Since access channels may be pre-assigned to earth stations there may be an advantage to a limited pre-assignment of telegraphy channels to shore stations, e.g. multiplexed with the access channels (see Report 596 (Kyoto, 1978)).

5. Conclusions

The prospective traffic demand in a maritime mobile satellite system and the available frequency spectrum of only 8.5 MHz in each direction of transmission will make it necessary to consider special techniques to improve the efficiency of use of the frequency band.

This Report indicates a number of areas in which further study is required before any decision on feasibility or the desirability of employing the various techniques available can be taken. However, conclusions can be drawn on some aspects of the studies undertaken so far:

5.1 The use of polarization discrimination or ship antenna side-lobe discrimination in frequency re-use techniques will need to take into account all the antenna sizes that are expected to be used for the various communication services.

5.2 The use of four geostationary satellites instead of three to provide world-wide coverage offers a technically simple solution to increasing the frequency spectrum re-use; however, the extra capital cost and operational complexity may be a disadvantage.

5.3 Ship terminals should be able from the outset to tune to any channel in the allocated 8.5 MHz bandwidth.

5.4 It would assist the introduction of some frequency re-use techniques for provision to be made in the design of ship terminals to enable information on the ship's area of operation to be passed to shore stations.

5.5 The assignment of channels automatically on demand between ship and shore stations is the preferred channel assignment concept. However, for telegraphy a limited pre-assignment of channels to shore stations may be desirable.

5.6 Some form of frequency error reduction technique would appear to be desirable to minimize the effects of the frequency instability of local oscillators in the satellite and shore stations. In particular the use of spectrum centring pilots would appear worth further study.

5.7 A frequency stability of $\pm 1.5 \times 10^{-7}$ for ship stations quartz crystal local oscillators in continuous running ovens would seem feasible providing it is shown to be practicable to re-calibrate the oscillators approximately every 6 to 12 months. Some practical experience would be desirable on this point.

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REPORT 766-1 *

**FEASIBILITY OF FREQUENCY SHARING IN THE 1215-1240 MHz BAND
BETWEEN THE NAVSTAR GPS AND TERRESTRIAL RADIOLOCATION AND
RADIONAVIGATION SYSTEMS**

(Question 17/8)

(1978-1986)

1. Introduction

This Report refers to Question 17/8, DECIDES 5, i.e. "Is the sharing of frequencies with other systems feasible, and if so, what other systems and under what circumstances?". The Question is addressed for the radionavigation-satellite system, NAVSTAR global positioning system (NAVSTAR GPS), which provides accurate timing and position determination via two satellite-to-Earth transmission channels. This Report addresses the feasibility of this system sharing the 1215-1240 MHz band with terrestrial stations.

A more thorough description of the NAVSTAR GPS system and the rationale behind the selection of frequencies is presented in Annex I.

2. Frequency sharing considerations

The frequency band 1215-1240 MHz is presently allocated on a primary co-equal basis to the radiolocation and radionavigation-satellite services in all three regions. Thus the feasibility of sharing with these stations has been given primary emphasis. Detailed consideration has also been given to other allocated services, i.e. fixed, mobile and radionavigation.

3. NAVSTAR GPS sharing with the radiolocation and radionavigation services

The radiodetermination services presently operating in the 1215 to 1240 MHz radiolocation band are almost exclusively P0N and XXX type emissions with duty cycles between 10^{-2} and 10^{-3} .

3.1 Interference to the NAVSTAR GPS

The NAVSTAR GPS receiver is designed to operate in a pulsed environment. High-speed, rapid-recovery front-end limiters are used to prevent high-energy pulses from damaging the receiver. In addition, intermediate-frequency clipper circuits essentially maintain the peak pulse voltages at the same level as peak noise bursts.

* The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO).

The modulation structure and system logic are such that the system is essentially invulnerable to normal radar signals. The pseudo-random phase-shift signal with a bit rate in excess of 10 MHz is compressed to an information bandwidth of 50 Hz. This provides an extremely large protection ratio against all types of interference of narrower bandwidth than the GPS emissions. Results of various studies have shown that a system of this type, once synchronized, can function satisfactorily in a pulsed environment which has a duty cycle much higher than any operational environment [USA, 1976].

3.2 Interference from the NAVSTAR GPS to the radiolocation and radionavigation services

The signal transmitted from the GPS satellite is of uniform power flux density over the visible portion of the Earth and will appear as a noise-like signal over a band of approximately 20 MHz. The majority of radars operating in the 1215 to 1240 MHz band have IF bandwidths much less than 20 MHz and consequently will receive a noise-like signal with a flat spectral power density over the receiver band pass. The amplitude of this signal will be a function of the radiolocation receiver antenna gain in the direction of the satellite and the impact upon the operation of the radiolocation system will be dependent upon the ratio of this signal amplitude to the receiver noise spectral power density or to the receiver threshold.

The antenna gains and receiver noise figures for the radiolocation equipment operating in the 1215 to 1240 MHz band will vary over a wide range depending upon the system mission. It will be convenient here to utilize the concept of the antenna gain/temperature ratio (G/T) in assessing the impact of the NAVSTAR GPS signal upon the radiolocation systems.

3.3 Radar sensitivity

Virtually all radars operate very near their noise level in order to maximize the detectability of the system. There is normally a threshold level established between 5 and 15 dB above the noise level, chosen to optimize the trade-off between suppressing noise peaks and other anomalous responses (false alarms) and detecting the desired signals. Interference power from well below the noise level up to just below the threshold level manifests itself as an increasing number of false alarms. The interference power level at the radar receiver input is given by:

$$(I)_{dB} = (SPFD)_{dB} + (A_e)_{dB} + (B)_{dB} \quad (1)$$

where

$(I)_{dB}$ means $10 \log I$,

I : interference power in watts,

$SPFD$: GPS satellite spectral power flux-density at earth surface ($W/(m^2 \cdot Hz)$),

A_e : effective antenna aperture of the ground receiving antenna in the direction of the satellite,

B : ground receiver bandwidth in Hz,

$$A_e = \frac{G\lambda^2}{4\pi} \quad (2)$$

where

G : ground receiving antenna power gain,

λ : GPS wavelength = 0.2444 m,

$$(I/N)_{dB} = (I)_{dB} - (kTB)_{dB} \quad (3)$$

where

k : Boltzmann's constant = 1.38×10^{-23} joule K^{-1} ,

T : receiver noise temperature (K),

B : receiver noise bandwidth (Hz),

I/N : interference to receiver noise ratio that would produce noticeable degradation.

From equations (1), (2) and (3) we have:

$$(G/T)_{dB} = -205.4 + (I/N)_{dB} - (SPFD)_{dB} \quad (4)$$

where:

$(G/T)_{dB}$: maximum ratio of gain of ground antenna to receiver noise temperature for which limiting interference to noise ratio will not be exceeded.

The power flux-density from the satellite L2 signal (see Annex I) in a full capability GPS has been determined to be $-200.0 \text{ dB(W/(m}^2 \cdot \text{Hz))}$. This value includes a margin allowing for satellite ageing, signal fading, etc. Substituting this value into equation (5):

$$(G/T)_{\text{dB}} = (I/N)_{\text{dB}} - 5.4 \quad (5)$$

The value of I/N will vary with the type of radar and some of its basic circuits. For a value $I/N = 0 \text{ dB}$, the false alarm rate for a simple PPI radar with no clutter, jamming or interference suppression circuits would be degraded from 10^{-n} to $10^{-n/2}$ if the G/T in the direction of the NAVSTAR GPS satellite exceeded -5.4 dB [Barton, 1965]. The range of acceptable values of I/N might extend from -10 dB for very sensitive systems to values exceeding $+20 \text{ dB}$ for systems with automatic clutter suppression and anti-jamming circuits.

For the remainder of this discussion, a value of 0 dB will be assumed for I/N .

3.4 Variation in G/T

In the band 1215 to 1240 MHz, the antenna sizes range from 1.8 m (6 feet) to 12 m (40 feet) or 15 m (50 feet) for a range of gains 19 dB to 35 dB. Noise figures range from a few dB to $+15 \text{ dB}$. The G/T for the main beam illumination of the satellite is given below for three representative systems:

- a small transportable radar with a 3 metre antenna and a 9 dB noise figure would have a G/T of -10 dB ,
- a large search radar with a 15 metre antenna and a 5 dB noise figure would exhibit a $+10 \text{ dB } G/T$,
- space tracking systems with phased-array antennas of 30 metres and noise figures as low as 1.5 dB have a G/T as high as $+26 \text{ dB}$.

Considering the above examples, it appears that small transportable radars could operate with little or no observable degradation while the larger systems might find compatible co-channel operations difficult.

4. Sharing with the fixed and mobile services and other CW type stations

The Radio Regulations are footnoted to indicate that certain countries have allocated the band to fixed and mobile services. Stations in these services usually operate via modulating a CW carrier, or as high duty cycle, pulsed system (PCM).

4.1 Interference to the NAVSTAR GPS

In the previous discussion of interference to the NAVSTAR GPS system it was found that the system was essentially invulnerable to radar type pulsed signals due to their low duty cycle and to the S/I improvement due to the NAVSTAR GPS modulation/demodulation process. This is not so, however, with continuous wave systems.

The NAVSTAR GPS system modulation techniques provide a substantial processing gain to S/N or S/I input levels. However, much of the improvement is required to overcome receiver noise and to allow the use of small omnidirectional antennas and the use of low-cost equipment. The absolute interference power levels which can be tolerated for narrow band or continuous wave signals is not large and has been estimated between -90 and -100 dBm at the NAVSTAR GPS receiver input [USA, 1977].

Meeting these interference limits would place untenable constraints upon these services. For example, a 1-watt transmitter with an omnidirectional antenna could cause interference to a NAVSTAR GPS user out beyond the line-of-sight. For aircraft operations this could be greater than 160 km (100 miles).

4.2 Interference from the NAVSTAR GPS to the fixed and mobile stations

Power flux-density limitations on the Earth's surface have been specified for space stations operating in the fixed satellite service which share frequencies with the fixed service. These are stated in Recommendation 357 for frequency bands from 1.7 to 23 GHz. Extrapolation of these data to a lower frequency, i.e. 1.2 GHz, would indicate that a power flux-density of $-156 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ would suffice for NAVSTAR GPS sharing with the fixed and mobile services. The stated NAVSTAR GPS L2 requirement of $-164 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ should cause no problems. Such services are unlikely to be degraded unless high gain antennas are used, as for tropospheric scatter systems.

5. Conclusion

5.1 *Sharing with the radiolocation and radionavigation services*

There are radiolocation systems which can operate on a frequency sharing co-equal basis with the NAVSTAR GPS. However, certain radar equipments with large antenna could suffer interference from NAVSTAR GPS signals.

5.2 *Sharing with the fixed and mobile services*

The power flux-density of the NAVSTAR GPS signal at the Earth's surface appears to be sufficiently low to preclude interference to these services.

Transmissions of the fixed or amateur service stations can cause degradation to the NAVSTAR GPS system over very large areas.

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ANNEX I

TECHNICAL CHARACTERISTICS OF THE NAVSTAR GLOBAL POSITIONING SYSTEM

1. NAVSTAR GPS system

1.1 *System description*

The United States Government has developed a satellite system, the NAVSTAR global positioning system (NAVSTAR GPS), for the radiodetermination services. This system provides accurate timing and position determination in three dimensions anywhere on or near the surface of the Earth. The system consists of 18 operational satellites and three in orbit spares (10 900 nautical miles, 12-hour orbits) evenly spaced in three orbital planes such that a given point on the Earth has 4 to 7 satellites visible at all times. Each satellite transmits the same two frequencies for navigational signals. These navigational signals are modulated with a predetermined bit stream, containing coded ephemeris data and time, and having a sufficient bandwidth to produce the necessary navigation precision without recourse to two-way transmission or Doppler integration.

1.2 *Frequency requirements*

The frequency requirements for the NAVSTAR GPS system are based upon an assessment of user accuracy requirements, space-to-Earth propagation delay resolution, multipath suppression, and equipment cost and configurations. Two channels were selected for NAVSTAR GPS operations: 1575.42 MHz (L1) and 1227.6 MHz (L2) [USA, 1976]. The L1 channel resolves a user's location to within 150 m. A second signal transmitted on both L1 and L2 channels, provides the necessary frequency diversity and wider bandwidth for increased range accuracy for Earth-to-space propagation delay resolution and for multipath suppression to increase the total accuracy to 15 m.

Telemetry and maintenance signals from US based control facilities to the satellite and return are accommodated in the allocated telemetry band in the US.

2. CCIR guidance

The development of such systems has been under careful study of the CCIR for a number of years. There have been four Study Programmes, 25 Reports and two Recommendations generated for the purpose of tracking the progress of development and keeping the community aware of the potential spectral requirements of the final system configurations. Recommendation 361 was formulated and provides the following guidance.

- bands 8, 9, or 10 be used,
- narrowband signals be used where feasible,
- it is preferred that telemetry and control be accomplished on radiodetermination frequencies,
- experimentation be carried out on different bands and using different techniques.

3. Conformance to Recommendation 361

Below is a summary of the various aspects of the NAVSTAR GPS system.

3.1 *Operating frequency*

Primary operation (L1) is in a segment of the 1215-1240 MHz band allocated to radiolocation and radionavigation-satellite (space-to-Earth).

3.2 *Emission bandwidth*

While the emission from any given satellite cannot be labelled narrowband, the fact that the wideband signal serves a large number of users for 24 hour continuous service, provides range accuracy of 15 metres, and provides multipath suppression while generating low power flux densities on the Earth indicates that the system is an efficient user of the RF spectrum. Further study should be carried out to determine the feasibility of reducing the bandwidth.

3.3 *Telemetry functions*

The NAVSTAR GPS is a passive system. There is no need for a navigational up link. Therefore, spectrum is conserved by placing telemetry and housekeeping functions in bands allocated for such use.

3.4 *Development*

The GPS is the result of over 15 years of study and experimentation of a wide variety of competitive systems in an attempt to optimize the configuration of a navigational satellite system.

REFERENCES

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REPORT 768-1

PERFORMANCE MONITORING OF SHIP EARTH STATIONS IN THE MARITIME MOBILE-SATELLITE SERVICE

(Study Programme 17A/8)

(1978-1982)

1. Introduction

The effect of performance variation or malfunction in ship earth station equipment is potentially severe in terms of disruption of a satellite communications network.

In addition such disruption can cause secondary but nonetheless important problems in the international telephone and telex networks to which the system is connected.

It is thus important that adequate monitoring and supervisory arrangements are made for the maritime mobile-satellite service so that the potentially harmful effects of ship earth station malfunction are minimised.

The solution to the problem contains two basic requirements:

- (a) the need to ensure that high reliability and consistency of performance is achieved,
- (b) the need to ensure that speedy indication of fault conditions is given so that correction or removal of the fault condition can be quickly effected.

Consideration is given here mainly to the ship earth station monitoring aspects covered by item (b), although it is recognized that item (a), which includes maintenance aspects, could also have an effect on monitoring requirements.

2. Call set-up and clear-down

The call set-up procedures usually involve a simple exchange of appropriate signals largely conducted over the out-of-band signalling channel. This does not prove that the communications link is established or that it is of satisfactory quality. Thus the signalling procedures should include arrangements for "in-band" continuity checks by exchange of signals prior to connection of a call. In the event of lack of confirmation of continuity, the call should be cleared prior to notification of call connection. Although it may appear desirable that a check of quality be made prior to the establishment of a call, this is not, in practice, considered to be essential since it is likely to be an unusual occurrence for the quality to be poor, following a continuity check. A good judge of whether or not the quality is acceptable is of course the user.

So that the absence of a clearing signal does not result in a circuit being held open unnecessarily, both shore and ship stations should be designed so that the connection is released if an interruption is noted on the receive side which exceeds a pre-determined short time interval.

3. Effect of malfunction

Ship earth station faults may cause problems of congestion due to faulty signalling protocols and may cause calls to remain connected after they should have been cleared or, interference problems resulting from the presence of unstable radiated carriers. In addition, if the ship earth station misinterprets signalling instructions, it could be caused to transmit on the wrong frequency or to pick up the wrong time slot on the (TDMA) telex carrier. As a result, interference may be caused to one channel or many channels, depending on the actual fault. Since these faults would result in reduced availability of service, all possible precautions should be taken to minimise the risk of them occurring. In addition measures to enable a faulty terminal to be closed down, if necessary, should be built into the system.

4. Supervision and control

If proper arrangements for supervisory indications are made, the effects of faults can be reduced and speedy detection and correction facilitated. To this end supervisory facilities included in the coast earth station (CES) design should be as complete as possible and should enable an indication to be given of failure of a channel to release after the clearing signal has been given. In addition it is desirable that the CES be able to send alarm signals over the signalling channel to alert the ship in the case of an identifiable ship earth station fault.

In the event that normal release does not occur and the ship earth station (SES) is causing serious disturbance, it should be possible to force-release the SES and close its transmitter down. This action should cause an alarm signal to be raised on board ship. It is then necessary to design the SES so that it can be re-activated by the ship staff after the fault condition has been rectified. This demands the establishment of shipboard checking facilities and procedures to enable checkout to be done prior to re-energizing the transmitter.

5. Monitoring functions

In addition to supervisory functions it is desirable that the SES be designed to carry out certain monitoring functions to ensure it does not radiate if fault conditions are present.

Examples of these monitoring functions and the parameters to be measured are as follows:

- transmitted power level;
- revertive check (desirably at RF) that correctly paired transmit and receive frequencies have been selected;
- length of TDMA and Random Access bursts.

It is desirable that "loop back" facilities be available at the ship installation to permit measurement of certain SES parameters at a land based monitoring station. This may facilitate speedy rectification of faulty ship equipment.

It is possible to envisage a system of automatic polling of SESs in order to ensure, on a routine basis, that all SESs are satisfactorily operational. However, care must be taken with such routines since they may interfere with normal communication. This facility would require the provision of fairly complex software at the CES which could not be regarded as normal provision. It could conceivably form part of a communications system monitoring facility.

On board ship it is desirable to incorporate in the SES design self-checking facilities. It is preferable that these self-check arrangements be manually activated otherwise they may interfere with normal communication functions.

REPORT 1047

SHIP EARTH-STATION ANTENNA SYSTEM CHARACTERISTICS

(Study Programme 17A/8)

(1986)

1. Introduction

Consideration is given in this Report to the characteristics of potential ship earth station (SES) antenna systems envisaged for future maritime satellite systems described in Report 921.

Report 921 considers potential new ship earth-station systems and their applications, and in particular new concepts denoted by standard B, standard C and their possible variants. Various types of antenna systems for such applications have been studied by [Heckert, 1972], and Table I indicates preferred antenna types for the gain range 3-18 dBi.

This Report concentrates, at present, on medium gain antennas in the range of 10 to 15 dBi.

One of the primary requirements for such ship antennas is simplicity, i.e. small size, light weight and simple configuration.

A short back-fire (SBF) antenna is the most attractive candidate for gain in the range of 12 to 15 dBi. It has very desirable characteristics of high efficiency and simplicity of configuration. The conventional short back-fire antenna consists of two planar reflectors of different diameters, the main reflector and the sub-reflector separated by one-half wave length. They act as a shallow leaky cavity resonator with the radiation beam normal to the sub-reflector. The antenna, originated by Ehrenspeck [Ehrenspeck, 1965], is fed by a crossed dipole antenna at the midpoint between the two reflectors and provides a useful gain of 10-15 dBi.

TABLE I — Preferred antenna types

Gain range (dBi)	Antenna type	Pointing azimuth (Az)/ elevation (El)	Stabilisation	Remarks
0-3	Hemispherical coverage: – quadrifilar helix – turnstile	No	No	Suited for low bit rate data terminals
4-6	a) Optimized for a given elevation sector with toroidal pattern: – conical spiral – turnstile on ground plane – quadrifilar helix on ground plane – microstrip patch b) Full elevation range, partial in azimuth: – cylindrical array of 5 to 8 antennas or 5 dB antenna mounted on azimuth mount	No Yes in Az by switching Yes in Az	No No No	Need to change antenna for other coverage zones, or with a manual elevation adjustment Highest affordable gain without stabilisation
7-10	Helix: – horn – plana array of 4 crossed dipole archimedian spirals – microstrip patches, etc.	Yes in Az and El	Yes (simple gravity?)	No requirement on accurate pointing/stabilisation
11-15	Short back-fire: – array of 8/16 elements as above	Yes in Az and El	Yes	Can be made simple and inexpensive
16-22	Parabola: – array of 16/24 elements as above	Yes in Az and El	Yes	Accurate pointing/stabilisation needed

2. Antenna designs

2.1 Modified short back-fire antenna (SBF)

This antenna provides desirable characteristics of high efficiency and is simple in construction [Shiokawa *et al.*, 1983].

Figure 1 shows the construction details of the modified SBF antenna (diameter: 0.4 m). As can be seen from this figure, the antenna has dual small reflectors and a large reflector with a step configuration. The former plays a role in improving the frequency characteristics of VSWR, the latter plays a role in improving the radiation characteristics of the conventional SBF antenna. There is an improvement of about 1 dB in antenna gain and 0.3 dB in axial ratio over that of the conventional SBF.

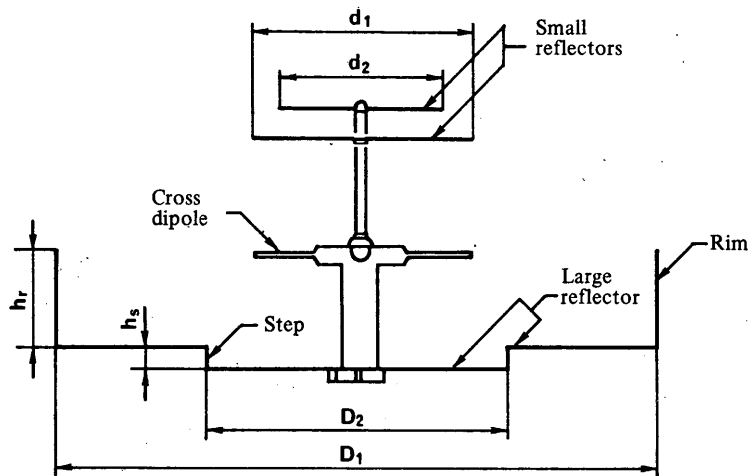


FIGURE 1 – Configuration of modified short back-fire antenna

Dimensions (mm):

$D_1 = 400$	$D_2 = 270$
$h_s = 20$	$h_r = 50$
$d_1 = 95$	$d_2 = 85$

Table II summarizes the performance characteristics of the modified SBF antenna.

TABLE II

Frequency coverage (MHz)	Receive: 1535-1543.5 Transmit: 1636.5-1645
Antenna gain (dBi)	15.5
Beamwidth at -3 dB (degrees)	Receive: 33 Transmit: 32
Axial ratio (dB)	About 1.0 (transmit band) About 0.85 (receive band)

2.2 Improved short back-fire antenna (SBF)

Figure 2 shows the improved short back-fire antenna with crossed dipole feed [Ohmori *et al.*, 1983]. Frequency bandwidth becomes about 9% of the centre frequency for VSWRs under 1.5 : 1 by using a conical main reflector. Moreover by adding a second, smaller reflector in front of the main sub-reflector, the VSWR characteristics can be further improved, that is better than 1.5 : 1 for around 20% of the centre frequency, almost without degrading other electrical characteristics. The main electrical characteristics are shown in Table III in comparison with a conventional SBF antenna.

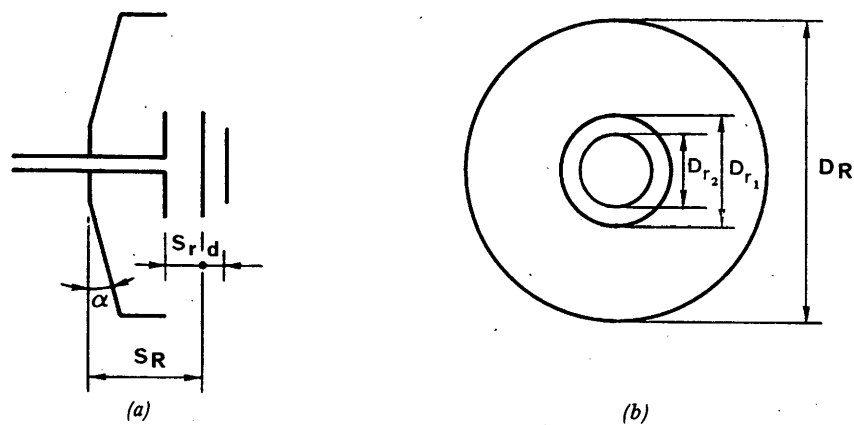


FIGURE 2 – Two views of an improved SBF antenna

(a) Cross section

- $\alpha = 15^\circ$
- $d = 0.09 \lambda$ (18 mm)
- $S_r = 0.29 \lambda$ (57 mm)
- $S_R = 0.66 \lambda$ (129 mm)

(b) Front

- $D_R = 2.05 \lambda$ (400 mm)
- $D_{r_1} = 0.46 \lambda$ (90 mm)
- $D_{r_2} = 0.41 \lambda$ (80 mm)

TABLE III

	Conventional SBF antenna	Improved SBF antenna
Antenna gain (dBi)	14.3	15
Beamwidth (degrees)	34	34
First side-lobe level (dB)	-21.0	-22.5
Axial ratio (dB)	1.28	1.1
Aperture efficiency (%)	65	76
Frequency bandwidth for VSWR under 1.5 : 1 as percentage of centre frequency	3	20

2.3 Spiral feed short back-fire antenna (SBF)

The conventional SBF antenna feed comprises a hybrid and crossed dipoles to obtain circular polarization.

The planar spiral is an alternative feed arrangement which is lower in cost and mechanically simpler to implement. Of the two possible spirals, the equi-angular and the archimedian, the equi-angular is preferred due to its compactness and ease of manufacture using printed circuit board (PCB) techniques.

Figures 3 and 4 provide the mechanical details of a SBF antenna utilizing such a planar spiral feed.

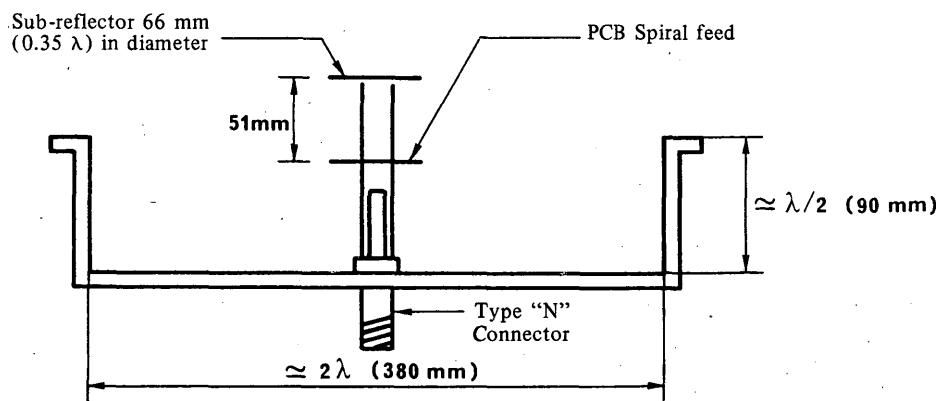


FIGURE 3 – Cross section of complete assembly

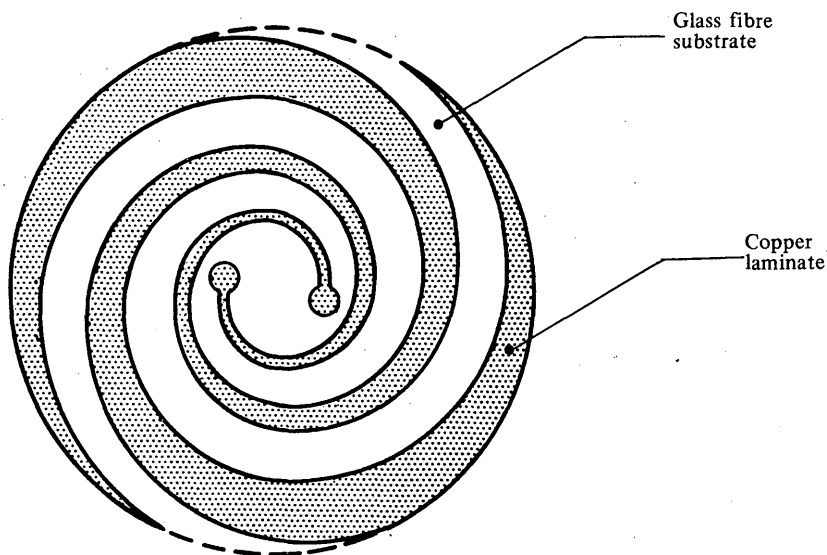


FIGURE 4 – Glass fibre PCB equi-angular spiral
(76% of actual size)

Table IV provides the electrical performance characteristics of the antenna.

Experimental results using this antenna system are described in Annex II to Report 921, and the radiation pattern is given in Report 922.

TABLE IV

Frequency coverage (MHz)	Receive: 1535-1543.5 Transmit: 1636.5-1645
Gain (dBi)	13
Beamwidth (degrees) – at –3 dB	Receive: 47 Transmit: 38
– at –0.5 dB	Receive: 18 Transmit: 14
Axial ratio (dB)	Better than 6 (transmit band) Better than 3 (receive band)
Impedance (Ω)	50
VSWR	Better than 1.5 : 1

3. Fading reduction technique

For low G/T SESs the effect of multipath fading due to sea surface reflection will be more severe at lower elevation angles since the antenna beamwidth is wider than that of current standard A SES antenna [Karasawa and Shiokawa, 1984]. For a low G/T SES, the fading reduction method, as well as the antenna, should be simple in configuration, light in weight and inexpensive. With these considerations in mind the polarization shaping method (see Report 1048) was chosen for use with the antennas described in § 2.1 and 2.2. This method is suitable for cross-dipole fed antennas and requires a cross-dipole rotator and variable phase shifter.

4. Antenna mount

For the current standard A SES, the 4-axis El/Az/Y/X mount with a step track function is most desirable because of its high stabilization capability and pointing accuracy. In the case of a low G/T SES a 2-axis mount with a programme track function slaved to the navigation equipment may be desirable from the economic and construction viewpoints. Between the 2-axis mounts (El/Az and Y/X), the El/Az mount may be preferable because the Y/X mount has both a large pointing error due to gimbal-lock, and multipath fading effects at low elevation angles.

In this type of mount, the arm which supports the El-axis is U-shaped. Furthermore, the El-axis is mounted near the central axis of the antenna to easily maintain the weight balance of the antenna, LNA, diplexer etc. Accordingly, the weight load on the Az-axis is decreased resulting in a reduction of size and weight to the conventional El/Az mount. In addition, in order to achieve good pointing accuracy from the El/Az mount, the following should be considered:

- reduction of the pointing errors due to gimbal-lock at a high elevation angle of around 85° ;
- reduction of the pointing errors due to the rewind operation of the Az-axis.

In the newly developed antenna mount shown in Fig. 5, the El/Az mount is controlled by using a microprocessor with input signals from the ship's navigation equipment and a pitching/rolling sensor. A newly developed control algorithm was adopted in order to improve the pointing error [Shiokawa *et al.*, 1983]. Figure 6 shows examples of the pointing errors measured using the new El/Az mount. In this figure, the amplitudes of rolling and pitching are 30° and 10° , and the period of rolling and pitching are 5 and 3 s, respectively. Although the pointing errors of the conventional El/Az mount at a high elevation angle ($El = 85^\circ$ and $Az = 90^\circ$) are about 30° due to the gimbal-lock and more than 30° due to the re-wind operation, the pointing errors of the new El/Az mount are less than 11° at the same pointing direction ($El = 85^\circ$ and $Az = 90^\circ$) as shown in Fig. 6. The degradation of the pointing accuracy due to the gimbal-lock completely disappears and the error due to the re-wind operation is greatly reduced. Additionally, the pointing errors of the new El/Az mount at a low elevation angle ($El = 10^\circ$ and $Az = 90^\circ$) are less than 3° .

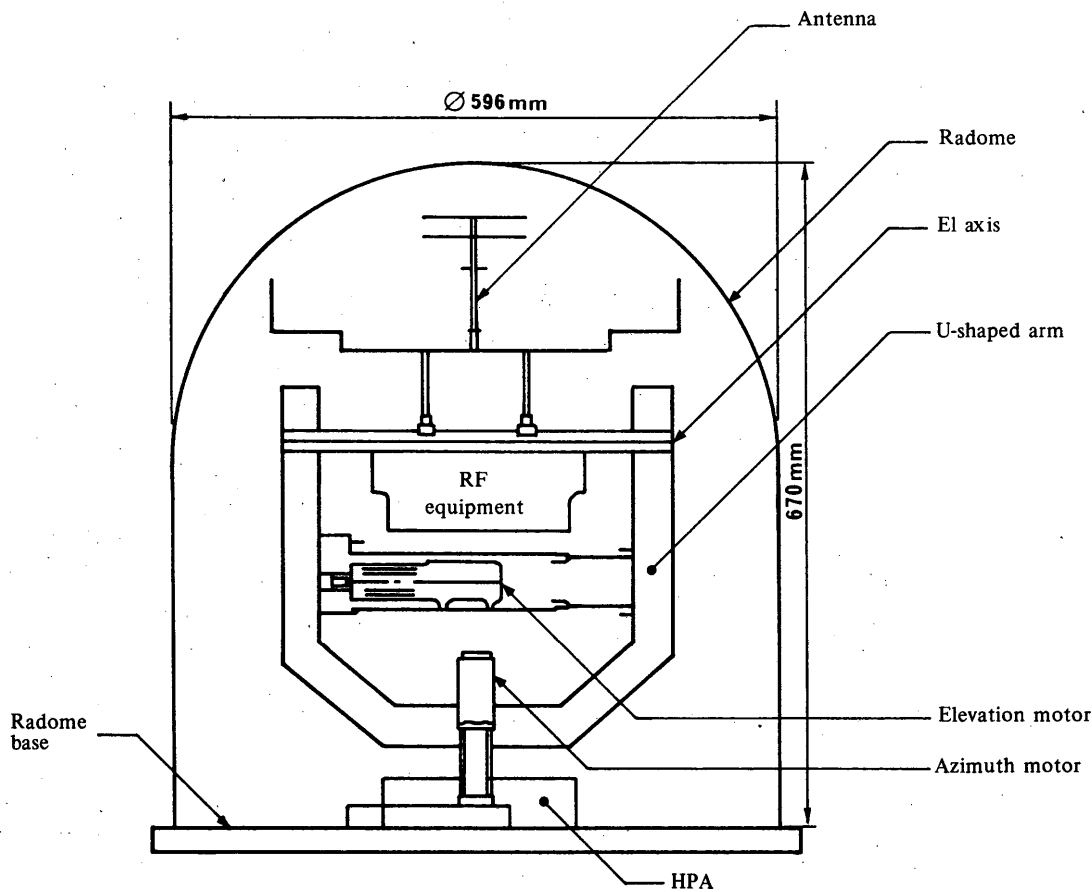


FIGURE 5 – Configuration of newly developed antenna mount for a small antenna system

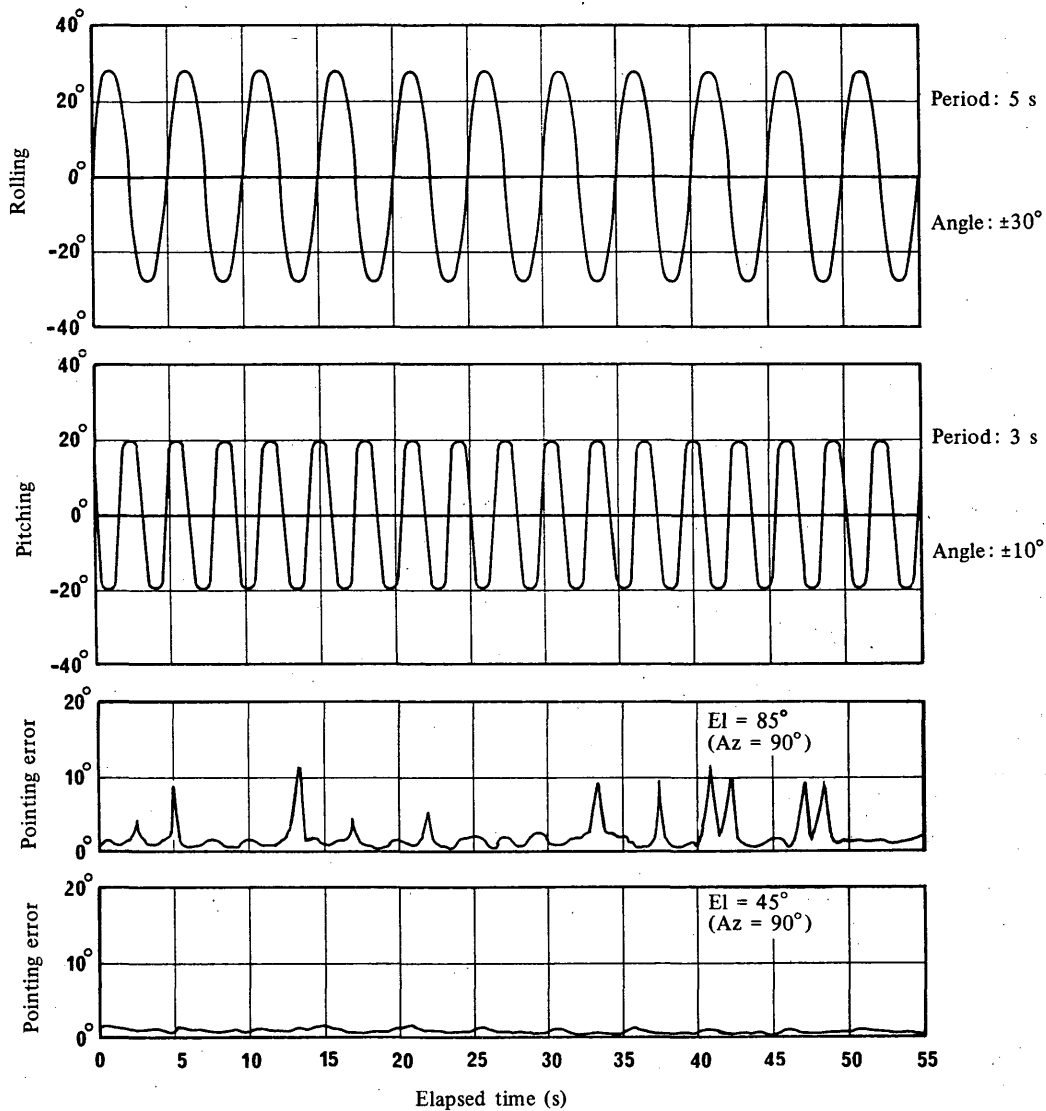


FIGURE 6 – Pointing error of newly developed Az-El mount

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RECOMMENDATION 496-2*

**LIMITS OF POWER FLUX-DENSITY OF RADIONAVIGATION TRANSMITTERS
TO PROTECT SPACE STATION RECEIVERS IN THE FIXED-SATELLITE SERVICE
IN THE 14 GHz BAND**

(1974-1982-1986)

The CCIR,

CONSIDERING

- (a) that Earth-to-space transmissions of the fixed-satellite service share the band 14-14.3 GHz with the radionavigation service;
- (b) that the World Administrative Radio Conference, Geneva 1979, has asked the CCIR to study the criteria for frequency sharing in this band (Recommendation No. 708, § 2.12);
- (c) that the Radio Regulations (No. 856) require that the use of this band by the radionavigation service shall be such as to provide sufficient protection to space stations in the fixed-satellite service;
- (d) that, in the band 14-14.3 GHz, sufficient protection for geostationary satellites in the fixed-satellite service can be obtained by limiting the power flux-density produced at the geostationary satellite orbit by stations of the radionavigation service;
- (e) that some kinds of radionavigation device, such as small ship radars and motor vehicle collision avoidance devices, although generally of comparatively low power, may be used in very large numbers;
- (f) Report 560,

UNANIMOUSLY RECOMMENDS

1. that in order to provide sufficient protection to space station receivers of the fixed-satellite service, the following limits should apply:

1.1 that where the value of D , as defined below, is less than 2×10^{-4} , the maximum value of the peak power flux-density produced at any point in the geostationary-satellite orbit by any radionavigation transmitter in the band 14-14.3 GHz should not exceed $-150 \text{ dB(W/m}^2\text{)}$ in any 1 MHz band;

1.2 that where the value of D , as defined below, exceeds 2×10^{-4} the maximum value of peak power flux-density produced at the geostationary satellite orbit by any radionavigation transmitter should not exceed

$$-187 - 10 \log D \quad \text{dB(W/m}^2\text{)} \quad (1)$$

in any 1 MHz band, where D is the estimated geographical density of radionavigation transmitters per km^2 simultaneously active in any 1 MHz band, taking into account future needs and averaged over the territory of the administration concerned or over an area of 10^6 km^2 , whichever is less.

REPORT 920-1

**MARITIME SATELLITE SYSTEM PERFORMANCE
AT LOW ELEVATION ANGLES**

(Study Programme 17A/8)

(1982-1986)

1. Introduction

Maritime satellite system performance at low elevation angles is affected by, *inter alia*, a number of propagation factors. The results of tests performed by Japan, the USA and the U.S.S.R. are described in this Report, and a preliminary assessment of the system performance at low elevation angles is given.

* This Recommendation should be brought to the attention of Study Group 4.

2. Japan tests

2.1 Background

In June 1976, measurements of 1.5 GHz multipath fading were made by Japan over a period of 2 days using a MARISAT ship earth station on board the Kurama-Maru (51 000 gross tonnage) receiving the signal from the Atlantic Marisat satellite. The received TDM signal (1537.75 MHz) was continuously recorded on a pen-recorder during the course of cruising off Mauritius, the elevation angle being 0° to 10° .

2.2 Main characteristics of the measuring system

Main characteristics of the measuring system used are as follows:

- Antenna gain : 24.2 dBi (1.2 m parabolical antenna)
- Beamwidth : 10°
- G/T : $-4 \text{ dB(K}^{-1}\text{)}$
- Tracking : step track
($0.5^\circ/\text{step}$; integration time = 30 s)
- Accuracy of roll/pitch compensation : within $\pm 1^\circ$
- Received C/N : about 16 dB
- Speed of pen-recorder : 5 mm/min

2.3 Environmental conditions

Environmental conditions at the time of measurement are summarized as follows:

- State of sea : very rough sea
- Wind scale : 6-7
- Motions of ship : roll : 13.0° p-p maximum
9.9° p-p average
pitch : 2.5° p-p maximum
- Ship speed : 24-26 knots

2.4 Measured data

In Fig. 1, estimated values of fading depth are shown as a function of elevation angle and percent of time. Here, the fading depth is defined as the difference between each reading of the signal level on the pen-recorder paper for specified time percentages and the level that occurred most frequently (C/N of about 16 dB).

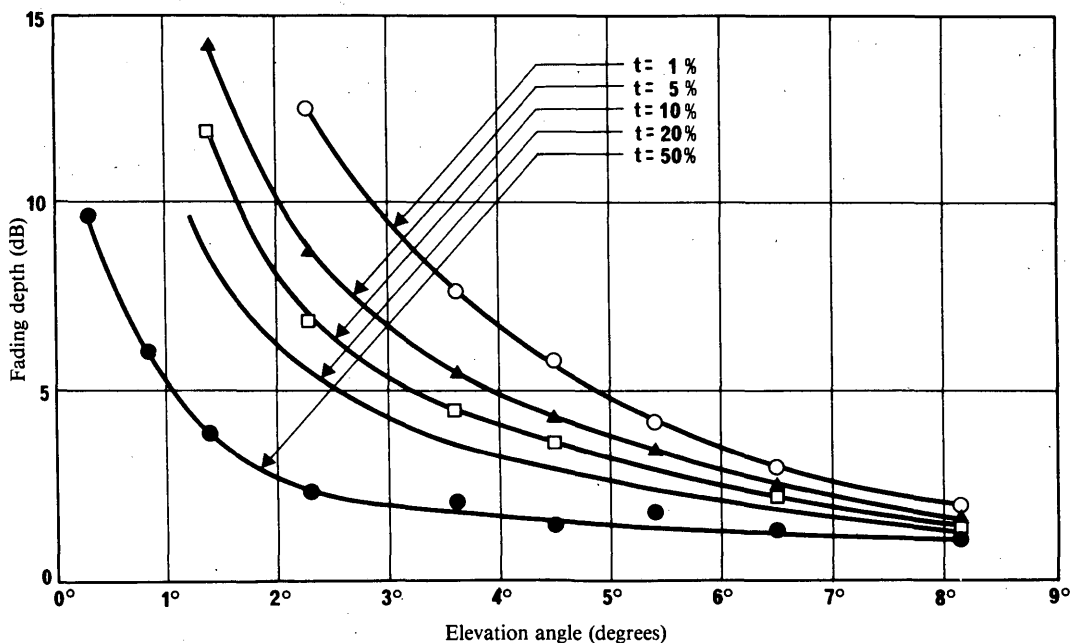


FIGURE 1 – Estimated values of fading depth as a function of elevation angle

2.5 Experimental results

The experiment by Japan has indicated that approximately 4 to 5 dB of signal margin would be required to overcome multipath fading for 99% of the time at an elevation angle of 5°.

3. USA tests

3.1 Background

In October 1978, an experiment to determine the extent of degradation of satellite-to-ship and ship-to-satellite signals at low elevation angles in the bands 1.5/1.6 GHz was performed by the USA using the Atlantic Marisat satellite. A MARISAT ship earth station having a G/T of $-4 \text{ dB(K}^{-1}\text{)}$ was used on-board the S.S. Mobile AERO, an 18 600-ton oil tanker, while on route from Norfolk, Virginia to Texas City, Texas, with elevation angles changing from 17° to 0°. Baseline measurements were made during the initial portion of the trip. On a straight line sailing from Tampa, Florida to Texas City, Texas on a heading of 274°, the elevation angle from the ship earth station to the satellite decreased steadily from 11° to 0.3° at an average rate of 0.3° per hour. During this 40 h period the experiment was conducted without interruption.

3.2 Data collection

The equipment block diagram of the measurement set-up at the ship earth station is shown in Fig. 2. An IDS-1310A data test set was used to generate either 2400 bit/s or the 1200 bit/s data for input to a DPSK modem (ICC-24LSI) or an FSK modem (GDS1200ES), respectively. The input/output point was at the data jack on the ship earth station console (VOICE/DATA). A 600 ohm variable attenuator, not shown in Fig. 2 was inserted at the data jack for the purpose of adjusting the interface level between the console and the modem. The block size for each transmit/receive test could be either 10^6 or 10^7 bit/s, taking either 7 or 70 min to complete for 2400 bit/s tests, and taking twice as long for 1200 bit/s tests. Besides direct readings from the data test set, a printer was also employed to record the bit error ratios [Fang *et al.*, 1981].

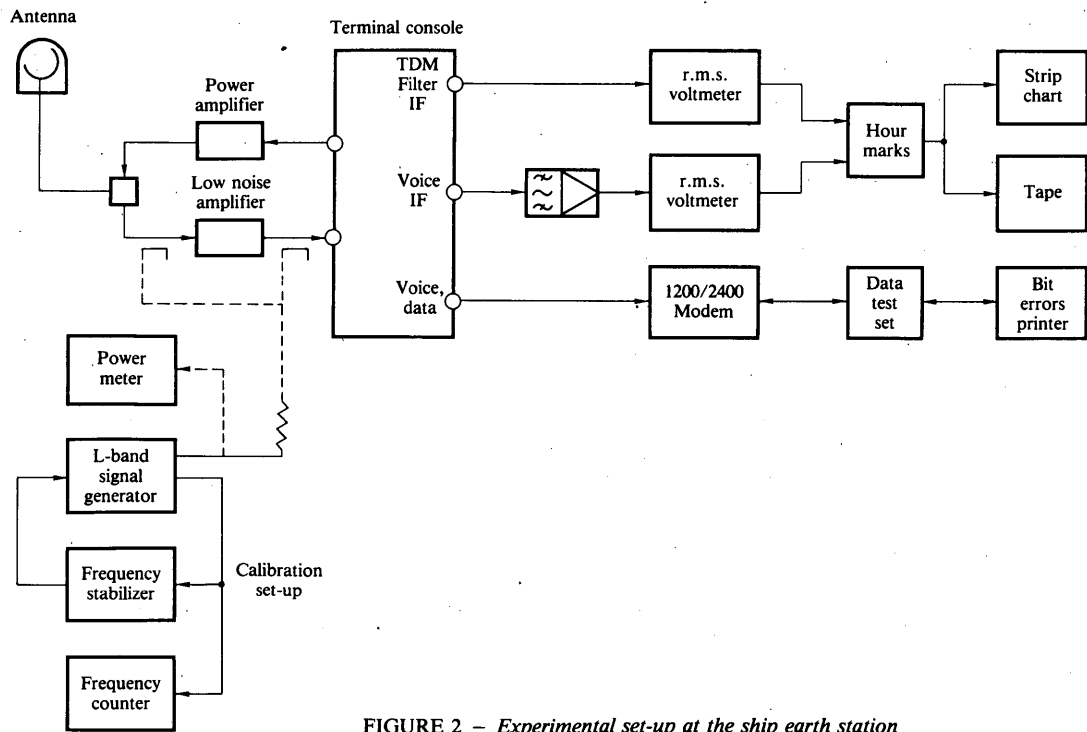


FIGURE 2 – Experimental set-up at the ship earth station

3.3 *Test conditions*

Signal degradations on the received TDM carriers due to atmospheric and sea surface anomalies cannot be assessed until the carrier level shifts due to the effect of demand assignment of telephone calls are resolved. To achieve this, the signal levels were measured during the earlier period of the experiment when the elevation angles were above 10° . The distribution of telephone traffic was not uniform over a 24 h period for any given day. The busy time for ship/shore and ship-ship voice communications via the Atlantic Marisat satellite was generally concentrated in early morning hours, between 0330 and 0530 EST (Eastern Standard Time) and in late morning hours, between 0830 to 1130 EST.

Throughout the entire experiment period, the weather was mild. The sky was either clear or cloudy but it never rained. The windspeed was generally under 15 knots (28 km/h).

The highest sea state during the experimental period was 4, corresponding to a wave height of about 1.2 m (4 feet), which was considered relatively calm. The sea surface was, nevertheless, fairly rough from the point of view of the microwave propagation experiment. This is because at L-band, the wavelength is about 0.2 m, which is only $1/6$ of the peak amplitude of the sea waves at sea state 4.

3.4 *Experimental results*

3.4.1 *Carrier-to-noise characteristics*

Since the satellite-to-ship TDM and voice carriers are amplified by a common 1.5 GHz TWT, a redistribution of RF powers occurs whenever there is a change in telephone traffic. This is a further cause of the carrier level shifts.

Although such carrier level shifts occur on both TDM and voice carriers, the extent of the shifts is not the same. TDM carrier levels which were continuously available were measured to determine the 1.5/1.6 GHz band C/N variation as a function of elevation angle. (In actuality $(C+N)/N$ was measured in all cases. It is understood that $(C+N)/N$ is implied for measured data where C/N is written.) In addition, the voice carrier levels were measured during times of voice communication or of transmitting and receiving digital data, for the correlation of voice channel C/N and the bit error ratio of the digital signals.

There are two principal differences between the performance at high and low elevation angles:

- mean C/N levels decrease as the elevation angle decreases, and
- peak-to-peak fluctuations of C/N increase with respect to its mean, as the elevation angle decreases.

At extremely low elevation angles, i.e., below 2° , the mean C/N reductions and peak-to-peak C/N fluctuations are so severe that it is impossible to identify the shifts of carrier levels due to the effect of simultaneous telephone traffic.

3.4.2 *BER versus C/N*

For an ideal bit error ratio measurement, the signal C/N should remain at a fixed level, i.e., with little or no variation while the digital data are being transmitted. The BER observed over a block size of 10^6 or 10^7 bits then provides a true measure of probability of errors with a high degree of confidence. Furthermore, if such an ideal measurement can be repeated at different elevations angles, the effect of elevation angle on BER can be readily assessed.

Unfortunately, such an ideal situation never existed during the shipboard tests. First of all, the number of telephone calls changed the C/N level from time to time. Even during a 7 min period, which was the minimum time period required for relaying a block of 10^6 bits at 2400 bit/s rate, the number of simultaneous telephone calls often changed 4 to 5 times. Furthermore, signal fluctuations were severe at low elevation angles. These fluctuations sometimes caused the C/N to fall below the threshold level required to maintain the synchronization of the digital transmission. As a result, an instantaneous drop of C/N below threshold level due to signal fluctuations would generate very large numbers of errors over a prolonged period of time. Even though C/N recovered readily to a respectable level, it took some time for synchronization to be restored.

In order to overcome these difficulties in the data analysis effort, each digital data transmission test was divided into a number of subtests based on the occurrence of sudden shifts of C/N levels. In one 3 min period, the C/N variation about the mean was 2 to 4 dB, which caused a loss of synchronization;

while in the following 9 min period, the C/N varied over a 1.0 to 4.0 dB range, giving a BER of 28×10^{-4} with no loss of synchronization. The irregularity is due to the fact that the occurrences of either bit errors and loss of synchronization were random events. Statistical regularities were observable only when an adequate sample size was available, which was not always the case in the subdivisions. Furthermore, the peak-to-peak fluctuations of voice C/N sometimes exceeded 5.0 dB or more. A determination of BER in reference to a fixed value of C/N was not meaningful in such instances. The degradation of BER for elevation angles below 5° was even more serious.

The BER data for elevation angles above 5° were generally much more manageable. This was because the mean C/N was higher and peak-to-peak fluctuations of C/N were less severe, reducing markedly the possibility of synchronization loss. The results of measured BER versus the range of C/N variations during the measurement are presented in Figs. 3 and 4 for the cases of 2400 bit/s DPSK transmission at elevation angles between 5° to 11° , and between 11° and 15° , respectively; and in Fig. 5 for the case of 1200 bit/s FSK transmission at elevation angles between 5° and 11° . Also shown in the figures are curves of BER versus the mean C/N which best fit the data. The gross pattern of the BER fitting curves do follow a general class of error functions, which is consistent with theoretical predictions.

3.4.3 *Multipath measurements*

Measurements of the multipath fading depth were made by observing the level of the time division multiplex signal transmitted from the MARISAT coast earth station located at Southbury, Connecticut. Reduced data for two cases (2.4° and 5.7° elevation angles) are presented in Fig. 6.

3.4.4 *Major findings*

Major propagation effects at low elevation angles that have significant system impact include multipath interference, polarization reversal, group time delay, Doppler shift and direction of transmission. Multipath and polarization effects which were identified in the experiment are discussed.

At low elevation angles, multipath interference due to sea surface produces two results: degradation of mean C/N and enhancement of peak-to-peak fluctuations of the C/N with respect to its mean. Although both are complicated effects, they can be evaluated to a first order using a simple two-component specular reflection model, which appears to be adequate for engineering applications for elevation angles of 5° and above. This model predicts a mean C/N drop of about 2.0 dB at an elevation angle of 5° from that at a 10° elevation angle. The maximum fade level due to fluctuations at 5° elevation will be less than -6.5 dB for 99% of the time while at 10° elevation, the fluctuation level is less than -4.5 dB for the same percentage of time. The fading statistics measured during these tests indicate that about 4 to 5 dB of link margin would be required for 99% of the time for a ship earth station having a G/T of $-4 \text{ dB(K}^{-1}\text{)}$ operating at an antenna elevation angle as low as 5° .

There is a polarization reversal effect from the sea surface reflection. To a first order, the cross-polarized wave can be treated as a co-channel interference to the co-polarized signal, and it is a main contributor to C/N degradation at low elevation angles.

Additional signal degradation due to blockage caused by the presence of structures in front of the MARISAT ship earth station antenna may be significant. In one specific instance at 11° elevation angle, an 18 in radar mast was observed to cause a worst case received signal degradation of about 8 dB. For design considerations, the degradation can be estimated by using a simple geometric-optics model based on the Fresnel zone blockage concept.

Due to the degradation of the mean C/N and the severity of peak-to-peak C/N fluctuations with respect to their mean at elevation angles less than 5° , 2400/1200 bit/s digital data transmission through a voice channel is not reliable. Above 5° , however, a relationship between BER and C/N is available as predicted by theoretical studies and it follows a general class of error functions. For example, at 5° elevation angle, a C/N of about 8 dB with the 2400 bit/s test modem was found to produce a BER of 2×10^{-4} or better about 50% of the time. Data transmission measurements over the FM voice channel indicated that BERs of the order of 10^{-4} to 10^{-5} were achieved at 5° elevation, with data rates of up to 2400 bit/s. The relationship itself is independent of elevation angle; however, the confidence level of the relationship decreases as elevation angle decreases.

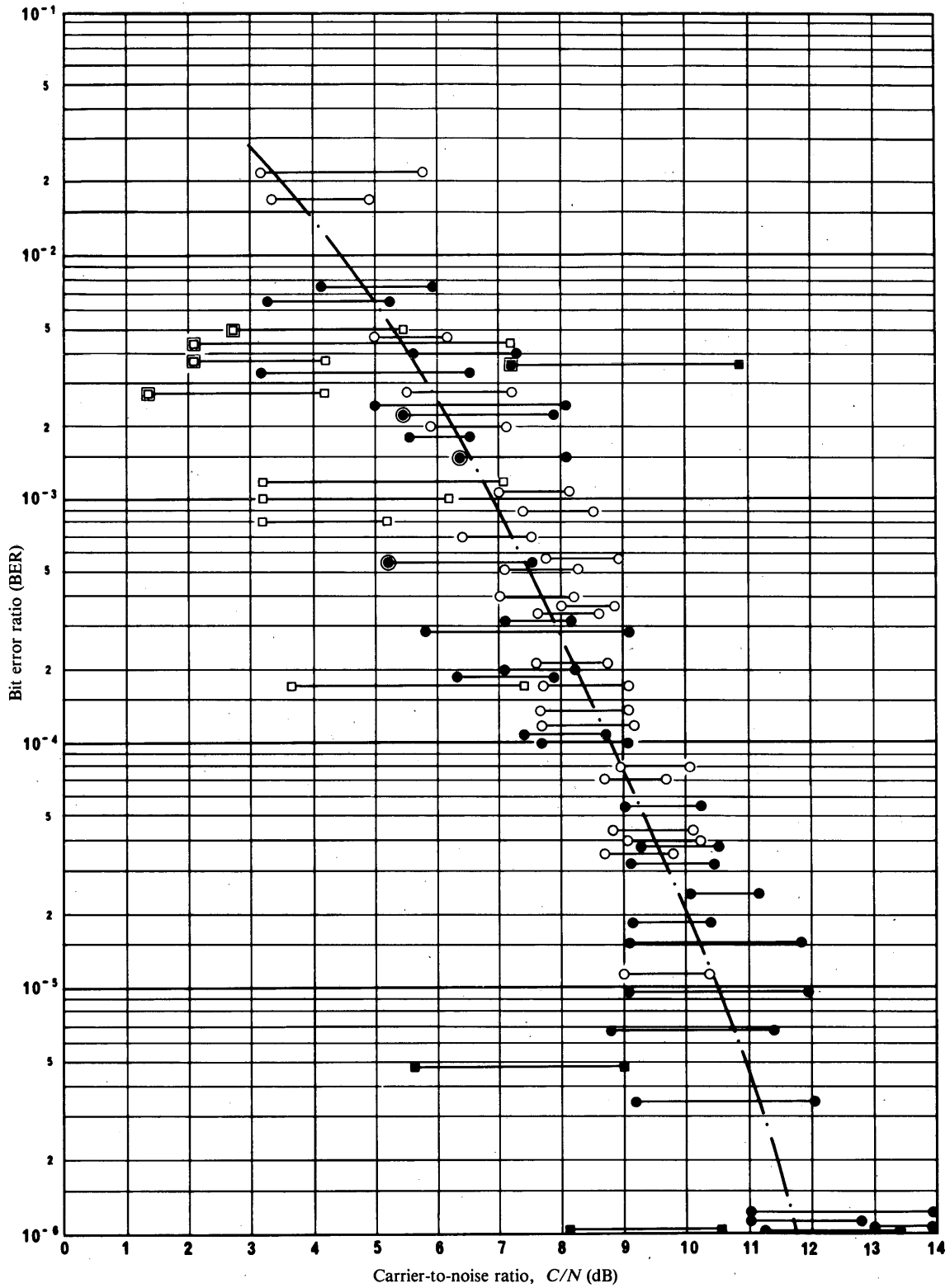


FIGURE 3 — MARISAT 2400 bit/s DPSK data transmission measurement at elevation angles between 5° and 11°

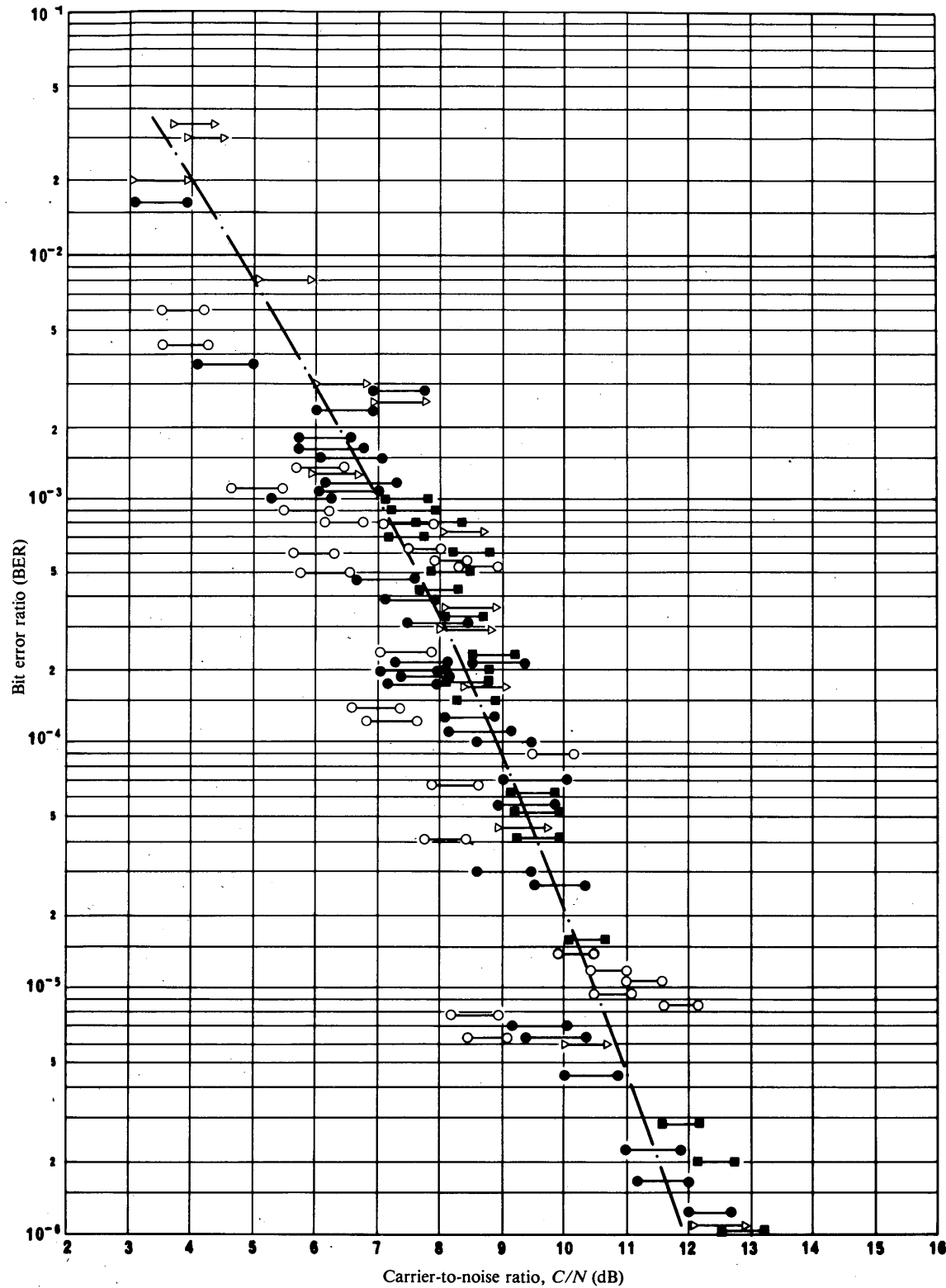


FIGURE 4 - MARISAT 2400 bit/s DPSK data transmission measurement at elevation angles between 11° and 15°

Data test runs	Elevation
9-32	14°-15°
33-38	15°-14°
39-49	14°-13°
50-64	13°-11°
- - - -	fitting curve

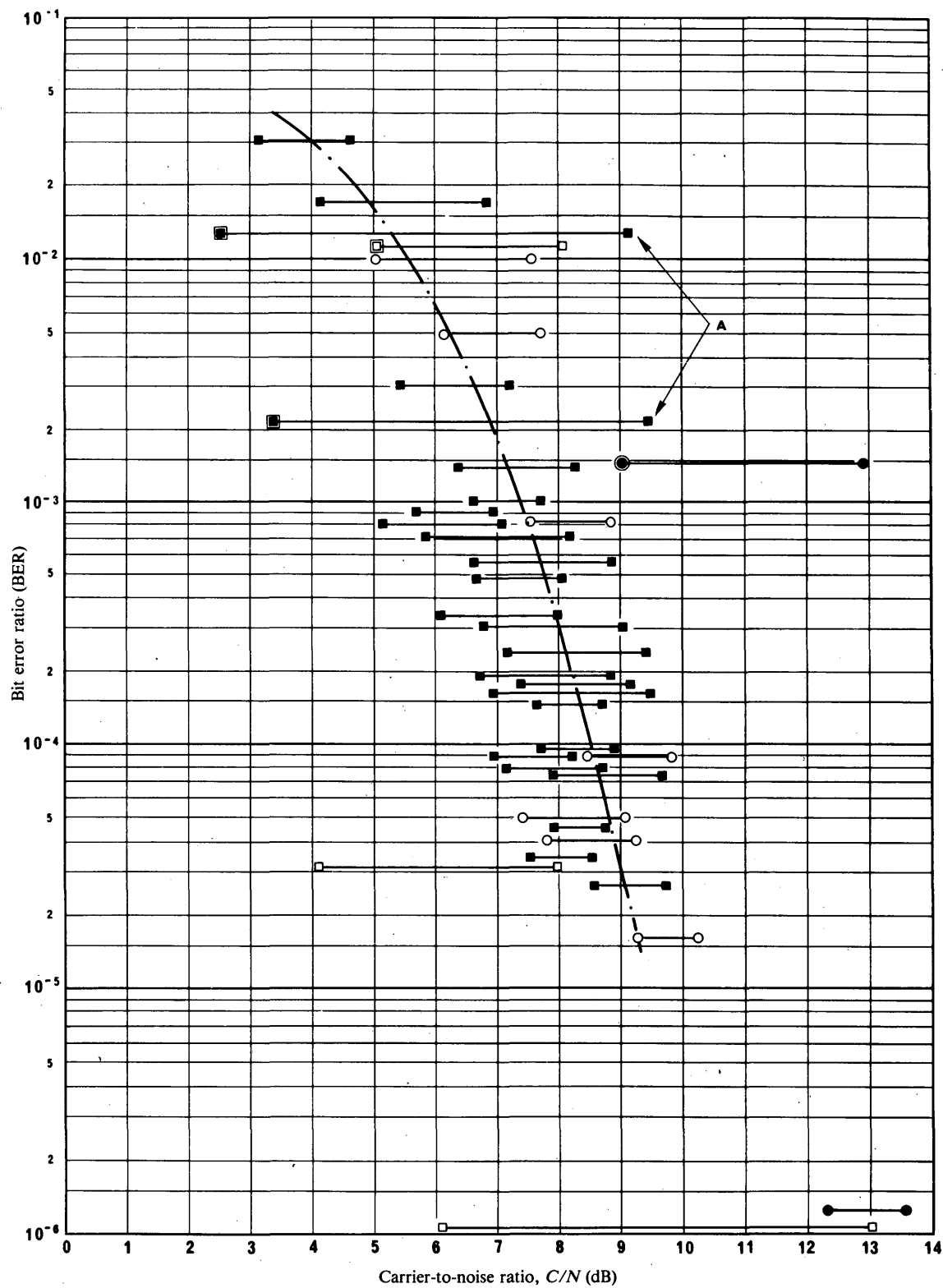


FIGURE 5 – MARISAT 1200 bit/s FSK data transmission measurements at elevation angles above 5°

Test	Elevation angle
■ — ■ 66	11.2°
○ — ○ 67,68	11°
● — ● 77	8.4°-7.6°
□ — □ 81	6.0°-5.0°
— · — fitting curve	
■ □ ● lost sync	
A	radar mast blockage

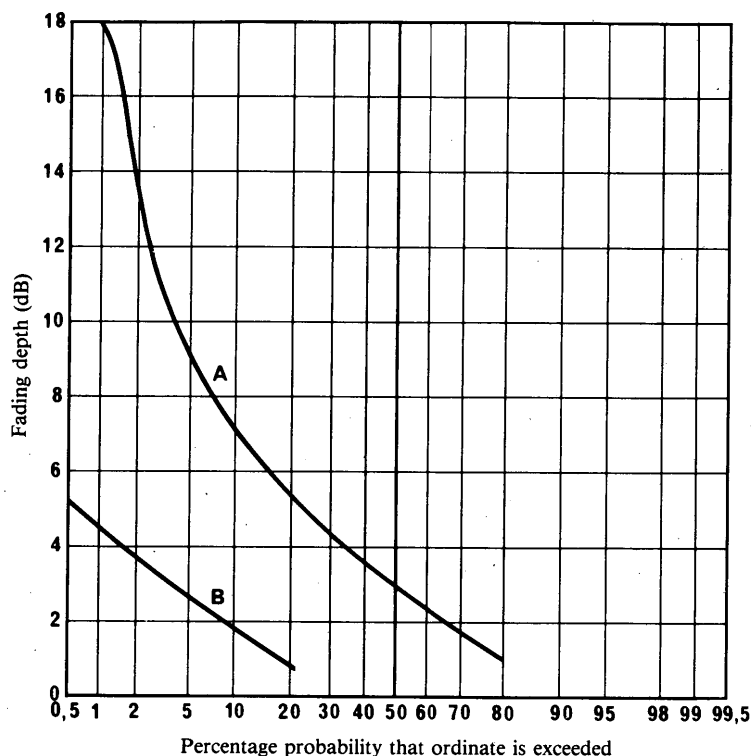


FIGURE 6 - *Measured multipath fading statistics*

Curves A: elevation angle 2.4°

B: elevation angle 5.7°

An ionospheric scintillation event was observed on 10 October, 1978, at a location where the geomagnetic latitude is approximately 35° N. On that occasion, at an elevation angle of about 11° , signal fluctuations of unusual structure were observed to increase from about 2 dB to about 4.5 dB peak-to-peak. Since the probability of occurrence of such events increases drastically during the equinox periods in the regions near the geomagnetic equator, it implies that ionospheric scintillation events will be observed more frequently and will be more pronounced than those reported above. This implies further that ionospheric scintillation is likely to be a significant impairment for ships operated in the tropics.

At extremely low elevation angles, link C/N was observed to vary by more than 15 dB over a very short time period (see Fig. 6).

4. U.S.S.R. tests

4.1 Background

Experiments were performed by the U.S.S.R. on board the M/V "Magnitogorsk" (220 m length, 25 000 grt deadweight) over the period November 1979-February 1980. The objective of the tests was the collection and processing of experimental data pertaining to MARISAT system performance at low elevation angles. When the ship was operating near the Bay of Biscay and within the Gulf of Mexico, communication tests were conducted via Marisat satellites over the Indian and Atlantic Oceans respectively.

The M/V "Magnitogorsk" is equipped with a ship earth station of $-4 \text{ dB(K}^{-1})$ G/T which was employed for establishing communication and making tests.

4.2 Test conditions

The measurements were conducted under normal operation of shipborne equipment in the absence of failures of satellite or shorebased equipment.

To evaluate the system performance at low elevation angles, the data used was obtained over the periods for which the ship earth station was not affected by operation of other shipborne radio aids. Therefore no allowance is made for the possible effect of these aids in the given results.

Concerning the effect of propagation conditions, variations on a satellite-to-ship link (1.5 GHz) only were estimated. Propagation conditions on a shore-to-satellite link were believed to be stable. The ship-satellite-shore direction was not examined during the tests.

Account was taken of the effect of variations in satellite loading levels (i.e. number of simultaneously operating channels) on C/N values. Variations of C/N at the first IF were then assumed to be due to propagation conditions at low elevation angles.

Measurements were carried out mainly on telex channels. A limited amount of data was obtained for telephone channels. In evaluating performance of the telephone channels at low elevation angles, the changes in signal levels in the telephone channels were assumed to be proportional to the relevant changes observed at the time in the telex channels. The validity of this assumption was confirmed by a series of measurements taken for the telephone and telex channels at 3° elevation angle.

4.3 Weather effect

During the test period, the effects of weather conditions on quality of communications via satellite were studied. The data obtained indicated that, during drizzle and rainstorm conditions, degradations of the mean C/N of about 1.5 dB and 2 dB respectively were observed.

Environmental conditions encountered were mostly favourable, so that the ship rolling and pitching did not exceed 3°-5° and 2°-3°, respectively. Such disturbances are too small to evaluate their effect on quality of satellite communications at low elevation angles.

4.4 Experimental data

The total number of readings processed was about 2500. Elevation angles ranged from 3° to 14°.

Experimental data were divided into two groups, each being handled separately.

The first group comprised measured C/N values on telex channels in the absence of operating telephone channels.

The second group comprised measured C/N values with both telex and telephone channels being active.

Graphic presentation of experimental and measured values of C/N ratio in accordance to the first and the second groups mentioned above is given in Figs. 7 and 8 respectively. Because of the limited data for telephone channels, the r.m.s. deviations from mean C/N of telephone channels were assumed to correspond to those of telex channels at the same elevation angles.

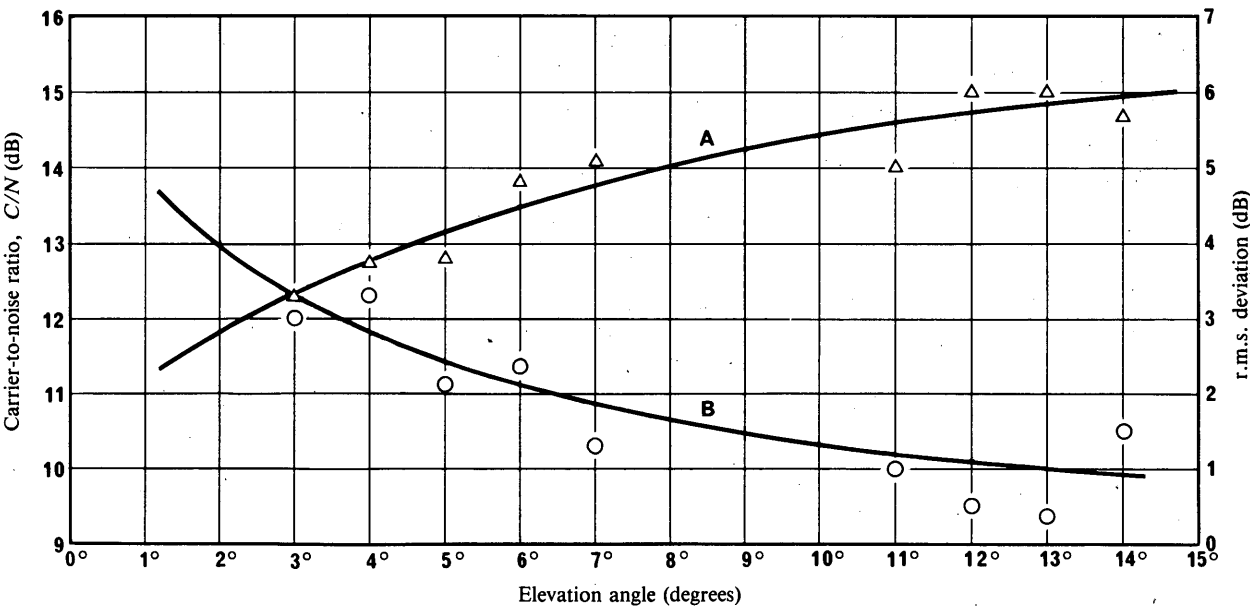


FIGURE 7 – Received carrier-to-noise ratio (C/N) and root mean square deviation (r.m.s.) from mean C/N of telex channels at different elevation angles (no active telephone channels)

○, Δ: experimental data
Curves A: C/N
B: r.m.s. deviation

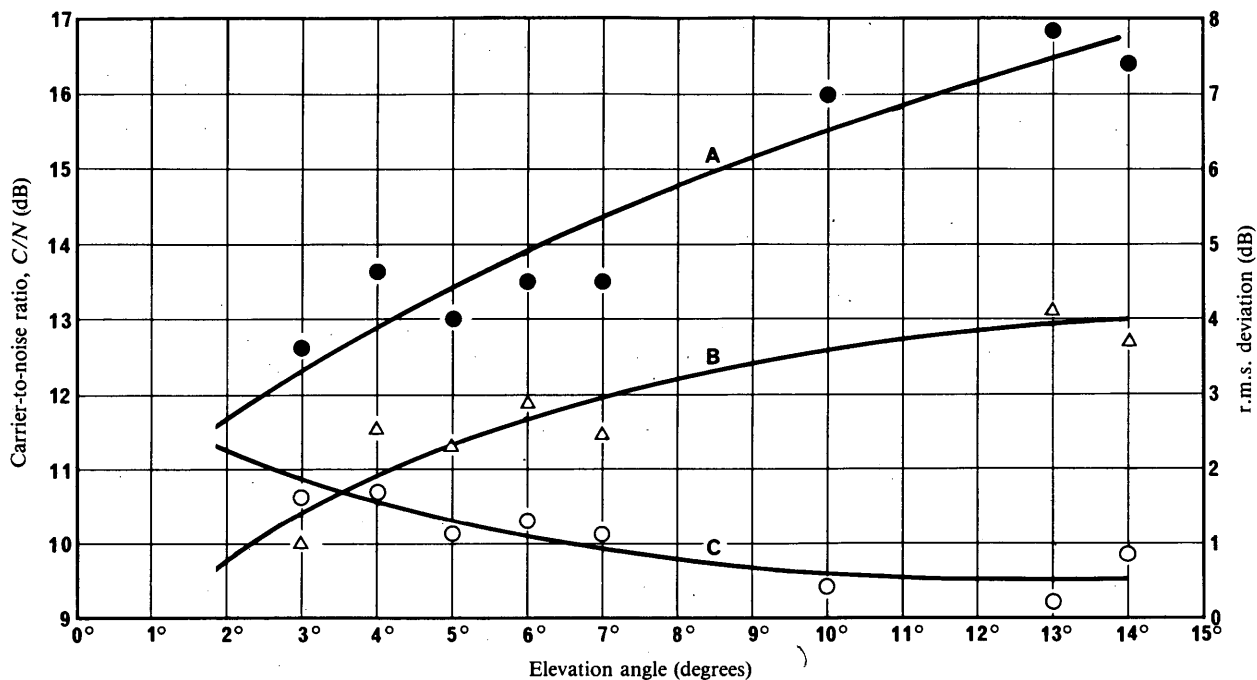


FIGURE 8 - C/N and r.m.s. deviation from mean C/N in case of simultaneous operation of telex and telephone channels at different elevation angles

○, ●, △: experimental data
 Curves A: C/N of telephone channel
 B: C/N of telex channel
 C: r.m.s. deviation

4.5 Minimal values of elevation angles for telephone and telex services

In order to determine minimal values of elevation angles, certain threshold values of C/N for telephone and telex channels were assumed. The criterion for telex channel quality was assumed to be a BER of 10^{-5} for 99% of the time. A speech intelligibility of 99% was adopted as the criterion for telephone channels.

The best-fit curves shown in Figs. 7 and 8 were used to determine areas of marginal values of C/N (99% probability) in telex and telephone channels for various levels of satellite loading and different elevation angles.

Shown in Figs. 9, 10 and 11 respectively are the areas of marginal values of C/N for:

- telex channels in the absence of telephone channel loading in the satellite;
- telex channels with telephone channels in operation;
- telephone channels.

The threshold values of C/N are plotted with an allowance being made for possible degradation due to precipitation.

4.6 Experimental results

From analysis of Figs. 9 to 11 it can be determined that the required quality of communications of telex channels can be achieved, given certain conditions of external disturbances, if the elevation angle exceeds 4.5° .

A speech intelligibility of 99% for telephone channels can be achieved for at least 99% of the time when the elevation angle exceeds 12.5° . At lower elevation angles, rainstorms may degrade the communication quality, e.g. at 10° elevation angle, intelligibility will be 98% for isolated words and 92% for isolated syllables; at 8° elevation angle the intelligibility drops to 88%.

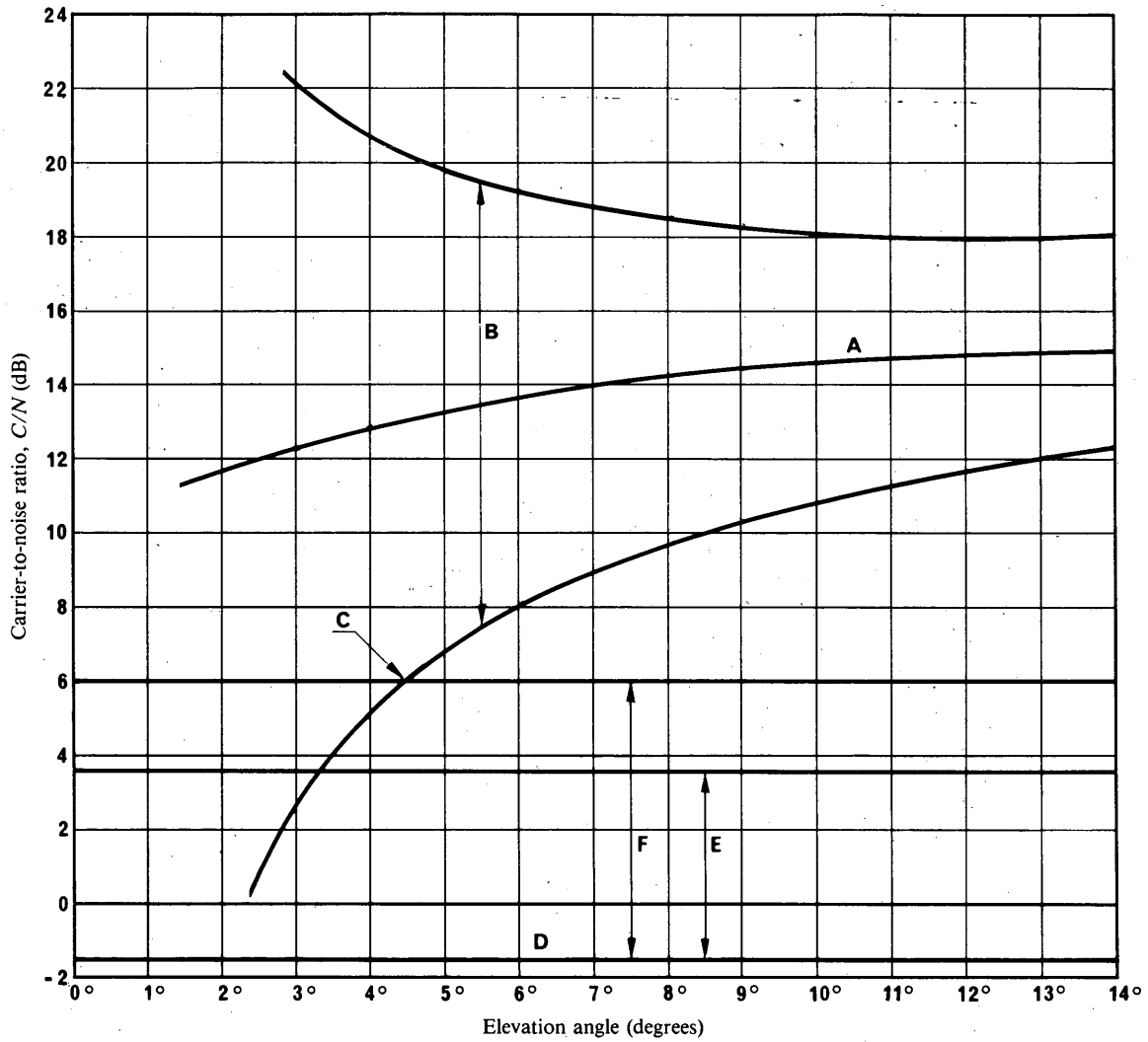


FIGURE 9 – Area of marginal values of C/N of telex channels at various elevation angles
(no telephone loading in the satellite)

- A: mean C/N
- B: C/N marginal value area
- C: critical value of elevation angle
- D: threshold C/N for telex channel (-1.5 dB)
- E: drizzle, 5.25 dB maximum degradation
- F: rainstorm, 7.5 dB maximum degradation

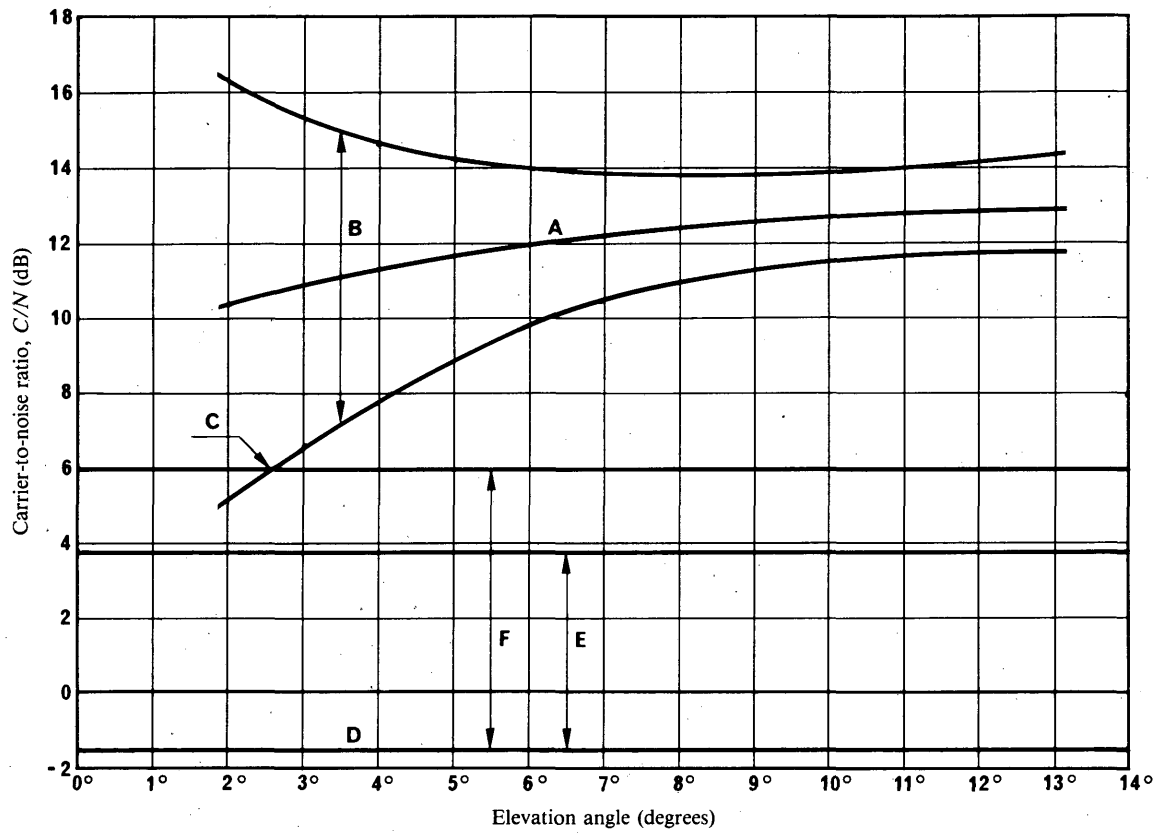


FIGURE 10 – Area of marginal values of C/N of telex channels at various elevation angles (active telephone channels)

- A: mean C/N
- B: C/N marginal value area
- C: critical value of elevation angle
- D: threshold C/N for telex channel (-1.5 dB)
- E: drizzle, 5.25 dB maximum degradation
- F: rainstorm, 7.5 dB maximum degradation

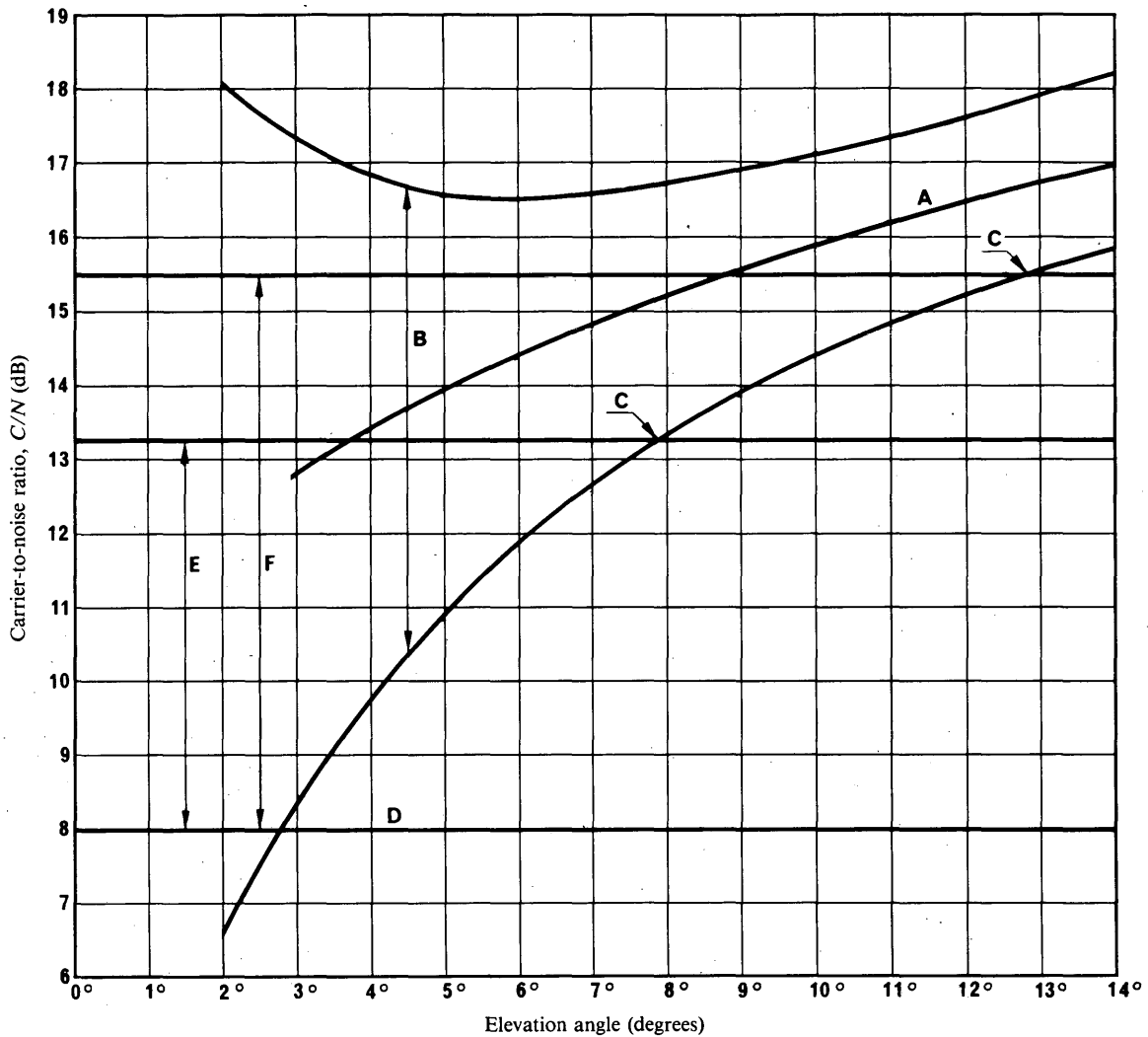


FIGURE 11 – Area of marginal values of C/N of telephone channels at various elevation angles

- A: mean C/N
- B: C/N marginal value area
- C: critical value of elevation angle
- D: threshold C/N (8 dB)
- E: drizzle, 5.25 dB maximal degradation
- F: rainstorm, 7.5 dB maximal degradation

4.7 Background (new tests)

Experiments were performed by the USSR on board the M/V "Michael Kalinin" (122 m length, 4980 grt deadweight) over the period 26 May-14 July, 1984. The objective of the tests was the determination of Inmarsat satellite telex channel performance at low elevation angles. The ship was cruising on the Baltic Sea, North Sea, Bay of Biscay and Mediterranean Sea. During the tests, C/N levels were measured in the coverage areas of the Atlantic Ocean Marecs-A satellite and the Indian Ocean Intelsat-V satellite, with elevation angles changing from 7° to 46° and from 4° to 16°, respectively.

4.8 Environmental conditions

Environmental conditions throughout the experiment period may be summarized as follows:

- Weather : clear, sunny, no precipitation
- Wave height : 1-2m
- Motions of ship : roll : 1-2° with a period of about 20 s
pitch: 0 average

4.9 Main characteristics of the equipment used

Main characteristics of the equipment used were as follows:

4.9.1 Standard A ship earth-station (Volna-S)

- Antenna height : 15 m above the sea
- Beamwidth : 10°
- G/T : -4 dB(K⁻¹)

4.9.2 Test receiver and recorder

- Receiver : Selective microvoltmeter SMV-8
- Recorder response : 0-150 Hz

4.10 Experimental results

The results of processing statistical data obtained for the Atlantic and Indian Ocean regions are shown in Figs. 12 and 13, respectively.

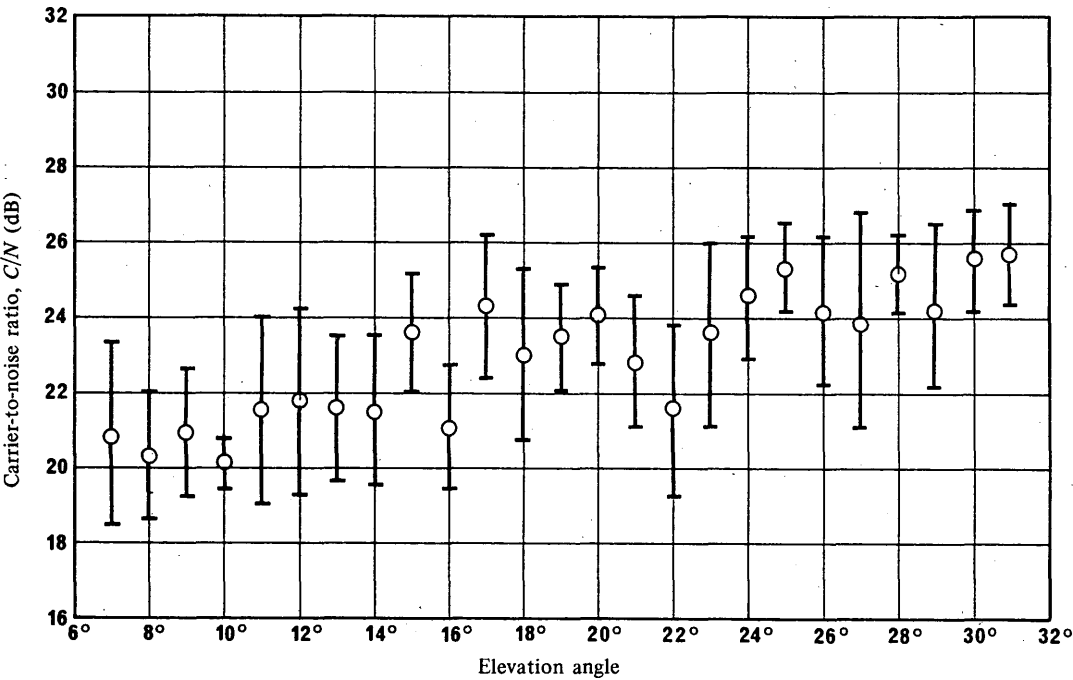


FIGURE 12 – Atlantic Ocean data

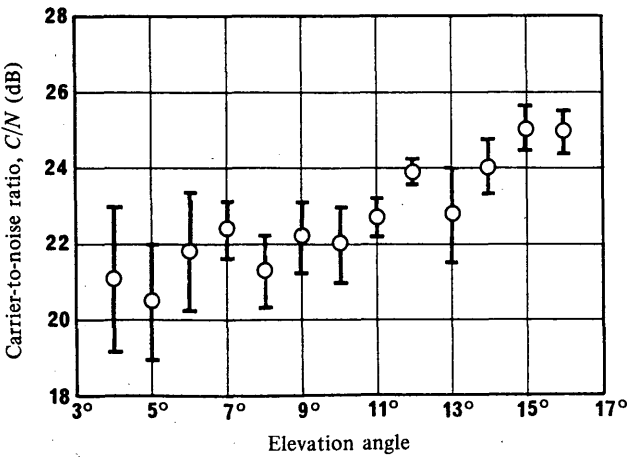


FIGURE 13 – Indian Ocean data

Examination of the results showed that mean C/N levels were 21-22 dB at elevation angles of 5-6°, with the C/N variations about the mean being 4-5 dB for 95% of the time. The experimental data was extrapolated (see Note) to determine the C/N values and their variations for lower elevation angles for the same percentage of time. The estimated values of C/N are 20.5, 20.3, 20 and 19.5 dB for elevation angles of 4°, 3°, 2° and 1°, respectively, with the C/N variations ranging from 3.6 dB for a 4° elevation angle to 5.5 dB for 1° elevation. Calculations were also made to obtain the C/N variations for 99% of the time. The estimated C/N variations are 5.5, 6, 7.5 and 8 dB for elevation angle of 4°, 3°, 2° and 1°, respectively. Estimation was made of minimal C/N occurring in the worst case of degradation due to precipitation referred to in Figs. 9 and 10. The minimal C/N values were found to be 8.0, 7.0, 5.5 and 3.0 dB at elevation angles of 4°, 3°, 2° and 1°, respectively. Shown in Table I is BER performance calculated for the estimated minimum C/N .

Note. — Validation of the extrapolation method will be provided for a future meeting of Study Group 8.

TABLE I

Elevation angle (degrees)	Minimum C/N (99% of the time) (dB)	BER ⁽¹⁾ (99% of the time)	Minimum C/N (99% of the time) (dB)	BER ⁽¹⁾ (99% of the time)
4	8.0	3×10^{-3}	12.5	1×10^{-6}
3	7.0	7×10^{-3}	11.3	2×10^{-5}
2	5.5	3×10^{-2}	10.0	2×10^{-4}
1	3.0	6×10^{-2}	9.0	8×10^{-4}

⁽¹⁾ BER values include anticipated degradation of 2 dB due to hardware design and operational factors.

5. Conclusion

Minimum elevation angles from ship-to-satellite were determined at which the satellite communication system is still capable of providing the needed quality of communications. Sufficient communication quality can be achieved at elevation angles of about 5°. It should be recognized, however, that the values obtained are of preliminary nature, since the analysis was limited. Further study of ship earth station performance at low elevation angles is required.

REFERENCES

FANG, D. J., TSENG, F. T. and CALVIT, T. O. [January, 1982] Elevation angle propagation measurement of 1.5 GHz satellite signals in the Gulf of Mexico. *IEEE Trans. Ant. Prop.*, Vol. AP-30, 1.

REPORT 921-1

SYSTEM ASPECTS OF FUTURE SHIP EARTH STATIONS

(Study Programme 17A/8)

(1982-1986)

1. Introduction

This Report addresses a number of technical aspects related to system and communications channel characteristics for potential future ship earth station standards, in particular the trade-offs between system requirements for efficient space segment capacity utilization and the user requirements for small, compact shipborne equipment.

The present maritime satellite communication system is designed to operate with ship earth stations having a G/T of $-4 \text{ dB(K}^{-1}\text{)}$. For a number of technical and other reasons, it is assumed that new ship earth-station standards introduced in the future will be characterized by generally lower G/T and perhaps smaller antenna size, as summarized in Table I below in the case of the INMARSAT system.

TABLE I — *Summary of existing and potential INMARSAT ship earth-station characteristics*

Ship earth-station standard	Antenna gain (dBi)	G/T (dB(K ⁻¹))	Service capability
A	21 to 24	-4	Full range of public correspondence
B	21	-4	Full range of public correspondence and dedicated digital data-based services
B variant	12 to 15	-13 to -10	(Under study)
C	2	around -23	Low data-rate messages

In the shore-to-ship direction for the same type of modulation, it would be possible to provide the same channel quality for a low G/T ship earth station as for a $-4 \text{ dB(K}^{-1}\text{)}$ G/T ship earth station, by increasing the satellite e.i.r.p. per channel. However, this approach would reduce the channel capacity of the system, since maritime satellite communication systems are power-limited, at least in the foreseeable future.

In the ship-to-shore direction, the same channel quality could be provided by increasing the power from a low G/T ship earth station, but this would result in a radiation hazard and the possibility of increased interference to other maritime satellites.

Therefore, it is necessary to consider more efficient modulation and coding techniques which can provide channels at the lower values of carrier-to-noise density ratio (C/N_0).

The new concepts denoted in Table I by standard B and standard C are envisaged as providing transmit and receive capabilities based on digital modulation and coding techniques, whereas the current standard A system uses FM analogue modulation for telephony. In both cases a new access control and signalling system is envisaged, separate from the existing system and with different channel characteristics which are expected to provide enhanced signalling efficiency and capacity. In the standard B system, demand assignment of channels is based on forward TDM links which may be used for centralized or distributed access control within each network. Such links, coupled with ship earth-station request (random access) and response (TDMA) signalling channels, also enable adaptive power control and satellite spot-beam identification procedures to be implemented. In the standard C system, communications and signalling information are combined in forward TDM and return random access links, using ARQ techniques.

Variants of the new concepts are also under investigation. Annex I describes a digital ship earth-station development similar to the envisaged standard B system with G/T values of $-10 \text{ dB(K}^{-1})$ and $-4 \text{ dB(K}^{-1})$. Annex II describes the performance of a low G/T ship earth-station ($G/T = -13 \text{ dB(K}^{-1})$) with a 2400 bit/s vocoder channel. Annex III discusses the concept of a very low G/T ship earth station ($G/T = -29 \text{ dB(K}^{-1})$) for operation in a receive-only mode for the reception of shore-to-ship distress alerts, as well as meteorological and navigational warnings. Annex IV presents experimental results on the forward error correction (FEC) as a means of multipath fading compensation. Annex V describes a statistical evaluation method for a passive antenna stabilizer.

Annex VI describes a communication system concept which relies on an adaptive coding scheme suitable to data-only mobile earth stations (e.g. maritime, aeronautical, and land mobile with a G/T of $-24 \text{ dB(K}^{-1})$). A detailed description of the coding scheme is given in Report 509, Annex II. The communication system under consideration is based on TDM in the forward link and CDMA in the return link.

2. Standard B system

2.1 System concept and service aspects

The eventual introduction of a standard B system is assumed to represent a means of providing a successor to INMARSAT standard A ship earth stations for the full range of public correspondence services, including the following:

- telephony, based on digital modulation, coding and speech processing techniques, including voice-band data;
- circuit-switched data for low-speed services (up to around 9.6 kbit/s), including telegraphy, teletex and facsimile;
- higher speed circuit-switched and packet data up to 16 kbit/s.

In addition to the above basic services, it is also assumed that the standard B system would continue to provide the other capabilities available with standard A, such as telephone and telex distress alerting, ship-to-shore high-speed data at 56 kbit/s and multi-channel operation.

It is expected that the main service requirement in terms of space segment utilization will continue to be telephony. The introduction of digital techniques would provide the opportunity for saving in satellite power and bandwidth, or a reduction in ship earth-station G/T and e.i.r.p. requirements, or a combination of both.

In order to maintain the telephone channel subjective quality currently provided by standard A (see Recommendation 547), it is assumed that a design objective for standard B would be to provide good quality telephony under nominal conditions at least equivalent (subjectively) to the standard A companded FM system, with acceptable voice quality under adverse propagation conditions at low satellite elevation angles. Furthermore it is assumed that the satellite e.i.r.p. required to meet these objectives would be comparable to that required for standard A. By applying voice activation and power control on forward links, the average satellite e.i.r.p. per channel would be further reduced to less than that required for standard A.

A digital implementation of ship earth-station equipment would support a wide variety of data services. The definition of the telegraphy and signalling systems is under study by INMARSAT.

2.2 Voice coding techniques

Report 509 indicates that digital modulation and voice coding techniques could provide the required voice quality more efficiently than analogue modulation. The application of efficient digital voice coding methods would serve to reduce bandwidth requirements which, coupled with forward error correction (FEC) would also reduce the value of carrier-to-noise density ratio (C/N_0) which determines the satellite power requirement in the shore-to-ship direction, the most power-limited link in the system. Such techniques would also serve to minimize ship earth-station e.i.r.p. requirements in the ship-to-shore direction. It is expected that the continuing development of LSI circuit technology will enable the necessary digital techniques to be realized in a cost-effective manner.

One conclusion to be drawn from the comparison of available voice coding techniques is that the required speech quality objectives could be achievable with 16 kbit/s voice coding rate and a bit error ratio (BER) of around 10^{-2} to 10^{-3} , using adaptive-predictive coding (APC) or sub-band coding (SBC) as the voice coding method. This would also provide the opportunity to achieve a reduction in channel spacing to 20-25 kHz, depending on the modulation and FEC coding technique adopted.

Currently available information suggests that the subjective speech quality obtainable with lower rate vocoder techniques is not yet sufficient for the desired quality objectives, and that further study and development is required in this area. However, these systems demonstrate a useful potential for reductions in satellite power and bandwidth requirements at coding rates around 9.6 kbit/s or less, and could thus be applied to future maritime and perhaps other mobile satellite communications services.

2.3 Modulation techniques

Report 509 considers various digital modulation techniques which are potentially applicable to standard B, and compares the resultant BER performance characteristics, bandwidth utilization efficiency and hardware complexity.

For shore-to-ship transmissions, filtered 4-PSK would be an efficient modulation technique but because of its varying amplitude characteristics, a linear (class A) amplifier at the ship earth station would be required for ship-to-shore transmissions. However, offset 4-PSK modulation with smaller amplitude variation, would be compatible with existing (class C) amplifiers, and could be used with only minor degradations in spectral efficiency and BER performance.

2.4 FEC techniques

The application of FEC to digital channels for voice transmission to and from ship earth stations would enable the value of C/N_0 required to meet the BER criterion derived from the speech quality objective to be reduced significantly, irrespective of the type of voice coding techniques adopted (see Report 708).

Figure 1 shows the C/N_0 requirement for 2-PSK or 4-PSK channels at various bit rates, without FEC and with FEC. For practical applications, an additional 1 to 2 dB should be included for implementation margins, although more recent developments suggest that implementation margins less than 1 dB may be appropriate in the future. It is obvious from the figure that FEC techniques are very effective in reducing the value of C/N_0 for a given bit rate.

Rate 1/2 convolutional coding (constraint length $k = 7$) with soft decision Viterbi decoding has been widely used in satellite systems and is thus a well-proven technique; implementation in VLSI is available. Coding gains achievable in practice are close to theoretical predictions: around 3.8 dB at 10^{-3} output BER and 5.2 dB at 10^{-5} BER.

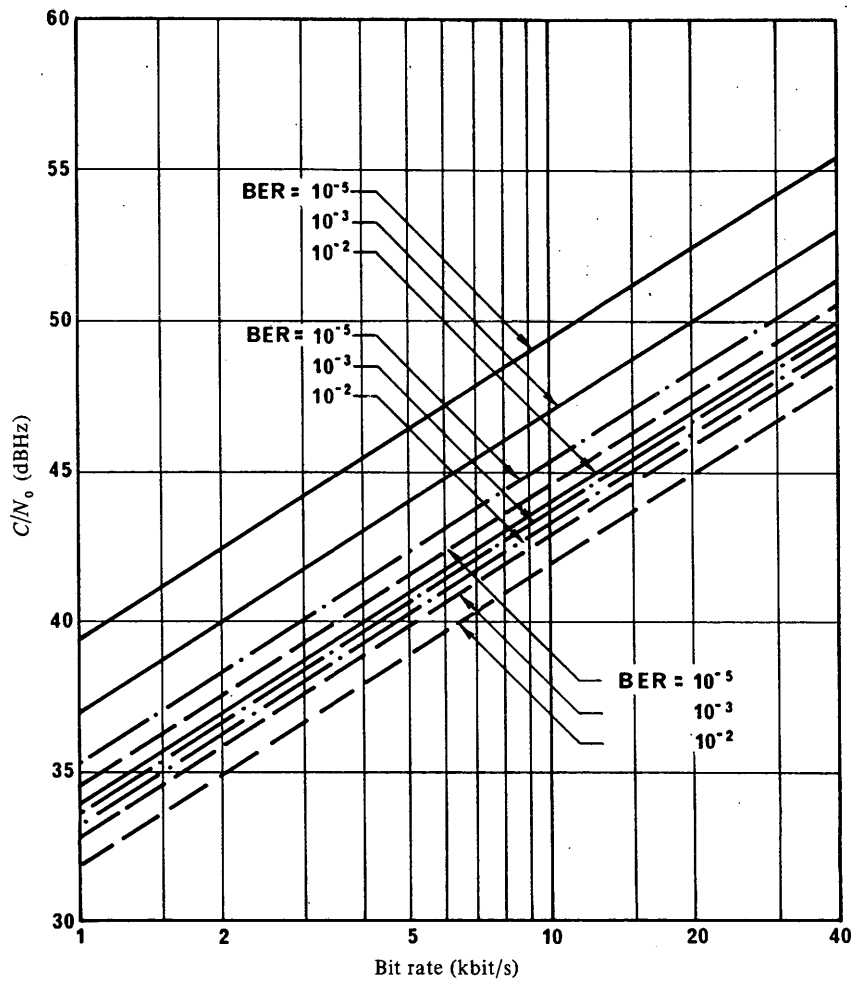
Rate 3/4 coding with Viterbi decoding is not currently as widely applied as rate 1/2 FEC, and requires more complex processing. Practical coding gains are of the order of 2.8 dB at 10^{-3} output BER and 4.3 dB at 10^{-5} BER (i.e. about 1 dB less than rate 1/2), but the bandwidth expansion factor is reduced significantly (i.e. 1.8 dB less than rate 1/2).

The complexity of rate 3/4 coding can be significantly reduced by applying "punctured" coding techniques to the basic rate 1/2 code. This requires deletion of 2 bits in every 6 coded bits in the rate 1/2 coded data stream, transmission of the remaining 4 bits at rate 3/4, and insertion of 2 additional bits at the receiver prior to rate 1/2 Viterbi decoding. Another potential application is the implementation of codecs with flexible coding rates switchable between rate 1/2 and rate 3/4. BER performance with punctured coding is only marginally inferior to non-punctured techniques, requiring 0.2 dB additional E_b/N_0 at 10^{-5} BER and essentially no degradation at 10^{-3} BER.

It may be concluded that rate 3/4 FEC offers significant advantages for a standard B system, providing efficient spectral efficiency and good power utilization. Rate 1/2 FEC could be appropriate to a more power-limited system, where 1 dB savings in satellite and ship earth-station e.i.r.p. requirements could be achieved at the expense of less efficient bandwidth utilization.

3. Standard C system concept

The ship earth-station characteristics inherent in standard A and the envisaged standard B concept may not be optimum for smaller vessels which constitute a large proportion of the maritime community, in particular where voice-grade communications are not required and where space for equipment installation is limited.

FIGURE 1 – C/N_0 as a function of bit rate

- : Without FEC
- : With FEC, rate 1/2 convolutional coding ($k = 7$), 8-level soft decision Viterbi decoding
- · - : With FEC, rate 3/4 punctured convolutional coding, 8-level soft decision Viterbi decoding
- ($C/N_0 = E_b/N_0 + 10 \log R$, where R = information bit rate)

The standard C concept could enable satellite communications facilities to be extended to such vessels, by means of a relatively simple, compact ship earth station providing message-based capabilities at a channel rate of 600 bit/s. The ship earth station would be characterized by an unstabilized and unsteered antenna system. Potential applications for the system include both-way distress alerting, reception of safety messages, transmission of meteorological data, public correspondence and ship polling, with the following message services:

- text in the appropriate alphabet selected by the user;
- graphics and facsimile;
- information and control instructions for user peripherals such as voice-synthesis equipment.

In view of the projected low G/T of the standard C ship earth station, efficient modulation and coding techniques need to be adopted in order to minimize satellite and ship earth-station e.i.r.p. requirements. The choice of technique should also be compatible with anticipated antenna characteristics, channel bit rates and system efficiency.

For typical ship motion characteristics currently applied to standard A designs, the maximum antenna gain for an unstabilized standard C antenna would be of the order of 2 dBi. In the shore-to-ship direction a satellite e.i.r.p. of 20 dBW could then support a channel bit rate of 600 bit/s; an increase in e.i.r.p. would enable higher bit rates to be achieved. In the ship-to-shore direction, practical limitations on ship earth station transmit amplifiers cause the channel rate to be restricted to around 600 bit/s.

At these bit rates an efficient modulation technique would be 2-PSK, with rate 1/2 convolutional coding as the basic FEC technique to improve the system margin. For the ship-to-shore direction, sensitivity to potential interference could be minimized by the use of block coding, linked with an inner convolutional code. In both cases the fading margin due to multipath effects would be significantly reduced by means of interleaving, which would disperse error bursts into a random pattern correctable by FEC, as opposed to improving the antenna discrimination. This would incur transmission delays of up to 20 s, and would thus result in an inability to provide real-time communications such as telephony in the future, although such a capability for small ship earth stations is envisaged for a standard B variant, e.g. as described in Annexes I and II.

Measurements of FEC performance with antenna systems of the standard C type are reported in Annex IV, as a means of compensating for multipath fading effects. These measurements show that it will be necessary to use FEC with interleaving in order to improve channel error performance on faded data links of a standard C system with continuous transmissions.

As an alternative to FDMA/2-PSK modulation in the ship-to-shore direction, the use of code division multiple access (CDMA) may provide some advantages which are further discussed in Annex VI.

The use of FEC in a maritime satellite link is mainly necessary to combat multipath effects at low elevation angle. This leads to the implementation of a communication system with protocols and coding overheads that are more powerful than necessary for much of the time. Furthermore, a coding scheme that is efficient in a multipath environment may exhibit reduced efficiency under non-faded conditions. One way to minimize the protocol and coding overheads when the link is good and still be able to cope with the most unfavourable link conditions is to use an adaptive coding scheme (see Annex VI).

4. Link budget considerations

4.1 *Multipath fading characteristics*

The currently envisaged standard B and, in particular, standard C ship earth-station concepts indicate a general trend towards smaller antenna systems which, in view of their reduced directivity, would be more susceptible than standard A to multipath fading effects.

Figure 2 shows a simple multipath fading model derived from theoretical considerations and from measurement data (see Annexes I and II to this Report, and Reports 884 and 763). The model is based on antenna directivity for gains in the range 7-25 dBi, and shows fade margins (99% of the time under Rice-Nakagami fading conditions) for "moderate" sea states at 5° and 10° elevation. Also shown is the potential advantage provided by the application of multipath fading reduction (polarization shaping technique) to the antenna system, as described in Report 1048.

4.2 *Pointing/tracking error characteristics*

Pointing/tracking errors for a passively-stabilized ship earth-station antenna, due to ship motion, have been studied in Japan. Experimental results and a statistical analysis of the measurement data are given in Annex V. This information could be used to determine link budget losses for representative antenna systems.

4.3 *Link budget examples*

Example link power budgets for a voice channel BER objective of 10^{-3} are shown in Table II for a standard B ship earth station (case 1: $G/T = -4 \text{ dB(K}^{-1}\text{)}$) and the standard B variant system (case 2: $G/T = -10 \text{ dB(K}^{-1}\text{)}$) operating through an Inmarsat second-generation satellite. In the latter case, the potential link quality (C/N_0) improvements due to multipath fading reduction (polarization shaping) are also indicated.

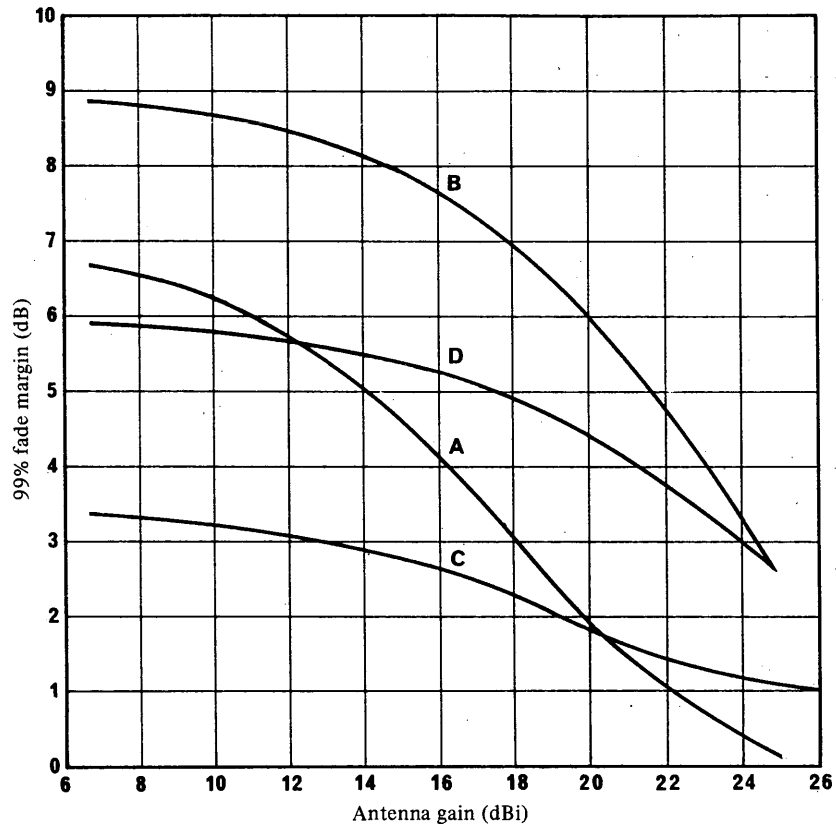


FIGURE 2 – Multipath fading characteristics (99% time Rice-Nakagami fading)

Curves A: 10° elevation angle

B: 5° elevation angle

C: 10° elevation angle with multipath fading reduction (polarization shaping)

D: 5° elevation angle with multipath fading reduction (polarization shaping)

TABLE II — Example link budgets for digital voice-grade ship earth stations
Coast earth-station elevation angle: 5°
Ship earth-station elevation angle: 10°

Shore-to-ship link		
Ship earth-station standards	Case 1	Case 2
Shore-to-satellite (6.42 GHz):		
– CES nominal e.i.r.p. (dBW)	52.0	60.0
– free-space path loss (dB)	200.9	200.9
– atmospheric absorption (dB)	0.4	0.4
– satellite G/T (dB(K ⁻¹))	–14.0	–14.0
– up-path C/N_0 (dBHz)	65.3	73.3
– Satellite C/IM_0 (dBHz)	60.5	68.5
Satellite-to-ship (1.54 GHz):		
– satellite nominal e.i.r.p. (dBW)	13.0	21.0
– free-space path loss (dB)	188.4	188.4
– atmospheric absorption (dB)	0.2	0.2
– SES G/T (dB(K ⁻¹))	–4.0	–10.0
– down-path C/N_0 (dBHz)	49.0	51.0
Overall unfaded C/N_0 (dBHz)	48.6	50.9
Fading loss (dB)	2.0	4.4 (2.7)
Overall faded C/N_0 (dBHz)	46.6	46.5 (48.2)
Ship-to-shore link		
Ship earth-station standards	Case 1	Case 2
Ship-to-satellite (1.64 GHz):		
– SES nominal e.i.r.p. (dBW)	31.0	26.0
– free-space path loss (dB)	188.9	188.9
– atmospheric absorption (dB)	0.2	0.2
– satellite G/T (dB(K ⁻¹))	–12.5	–12.5
– up-path C/N_0 (dBHz)	58.0	53.0
– satellite C/IM_0 (dBHz)	69.0	69.0
Satellite-to-shore (4.20 GHz):		
– satellite nominal e.i.r.p. (dBW)	–7.4	–2.4
– free-space path loss (dB)	197.2	197.2
– atmospheric absorption (dB)	0.4	0.4
– CES G/T (dB(K ⁻¹))	32.0	32.0
– down-path C/N_0 (dBHz)	55.6	60.6
Overall unfaded C/N_0 (dBHz)	53.5	52.2
Fading loss (dB)	2.0	4.4 (2.7)
Overall faded C/N_0 (dBHz)	51.5	47.8 (49.5)

Note. — Values in parentheses for Case 2 show the case using multipath fading reduction technique.

Although these example link budgets are not strictly in accordance with the method described in Report 760, they do indicate that digital modulation and coding techniques provide the opportunity for significant savings in satellite and/or ship earth-station transmit power requirements compared to the existing standard A system.

5. Areas for further study

Further study is required on the following aspects:

- speech quality objectives for the potential standard B variant ship earth station system ($G/T = -10 \text{ dB(K}^{-1}\text{)}$);
- interconnection with the terrestrial networks;
- telegraphy and signalling arrangements;
- further development and subjective assessment of possible coding techniques, particularly at bit rates around 9.6 kbit/s and below;
- effects of increased multipath fading, with particular regard to modulation and coding methods;
- effects of ship motion on ship earth-station antenna performance characteristics.

ANNEX I

PERFORMANCE CHARACTERISTICS OF A DIGITAL VOICE-GRADE SHIP EARTH STATION

This Annex presents an example concept of a ship earth station employing efficient digital communication technologies, and its performance characteristics based on the results of a field experiment using two types of antenna system (medium-gain and high-gain).

1. System design

The digital ship earth-station system described here has been designed to be used in the INMARSAT system and therefore to operate in the SCPC mode at carrier spacings of 25 kHz.

Table III shows the basic parameters of the telephone signal transmission channel of the digital ship earth-station system [Hirata *et al.*, 1984]. The system employs 16 kbit/s adaptive-predictive coding for voice coding [Yatsuzuka *et al.*, 1983], rate $\frac{1}{2}$ convolutional coding/soft decision Viterbi decoding [Viterbi, 1971] and 4-PSK. The transmission bit rate is 36 kbit/s which results from the 32 kbit/s coded data and 4 kbit/s additive data for system synchronization and control.

TABLE III – Major parameters of the digital communications channel

Information bit rate	16 kbit/s
Voice coding	APC (adaptive predictive coding)
FEC	Rate 1/2 convolutional coding ($k = 7$)/8-level soft decision Viterbi decoding
Modulation TX filter RX filter	4-PSK Square-root raised-cosine Nyquist filter with 30% roll-off Third-order Butterworth ($BT = 1$)
Transmission bit rate	36 kbit/s
Carrier spacing	25 kHz (minimum)
Operation mode	Voice activation operation in shore-to-ship direction

Figure 3 shows the functional block diagram of the digital communications unit for the system. In addition to the APC codec, the FEC codec and the modem, a speech detector which performs voice activation in the shore-to-ship direction is used in the coast earth-station, and a noise generator is provided in the ship earth-station to provide a more natural listening environment. Voice activation will allow efficient use of satellite power in the satellite-to-ship direction.

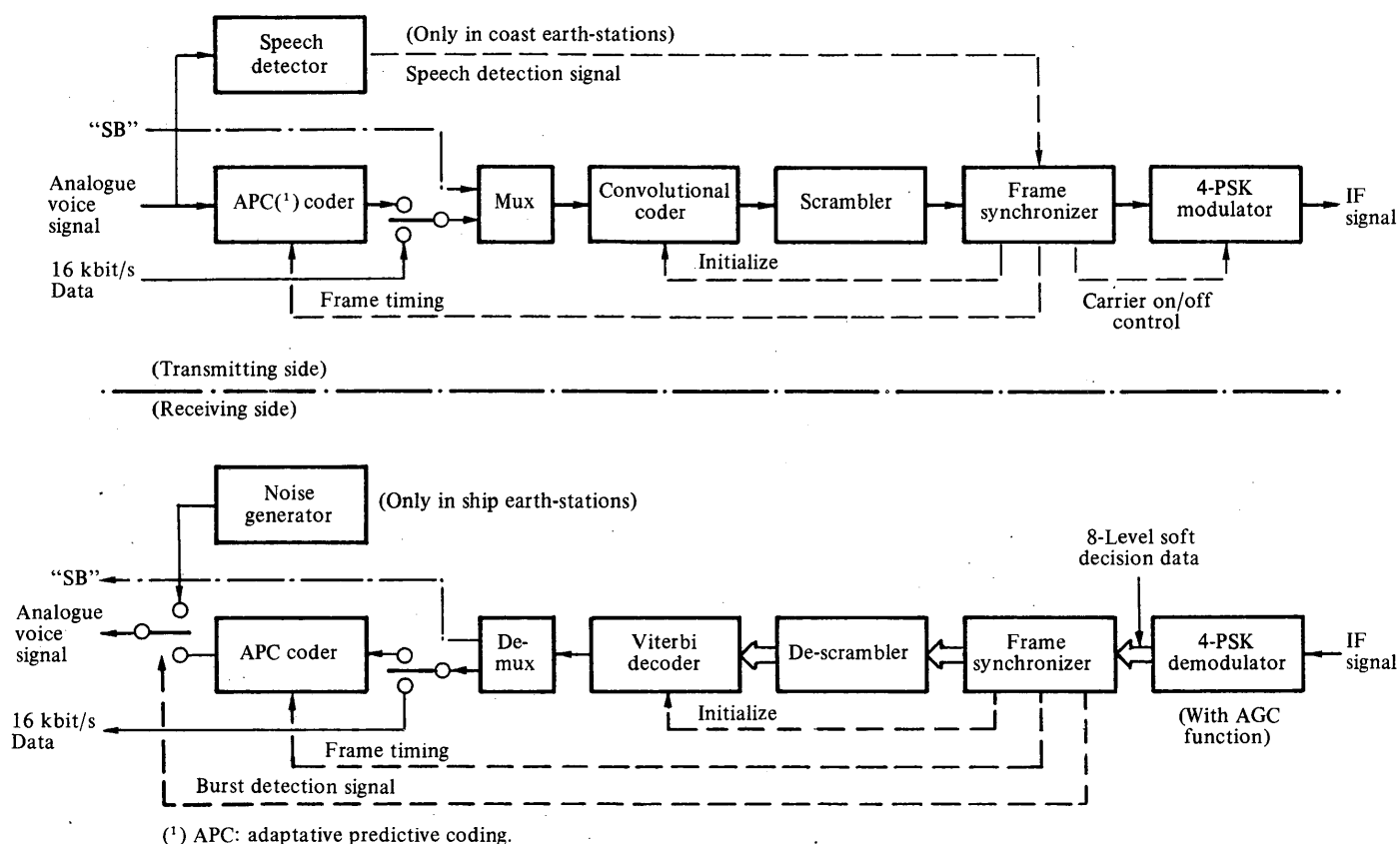


FIGURE 3 – Functional block diagram of communications unit

2. Results of field experiment [Kashiki *et al.*, 1985]

A field experiment has been carried out using the Inmarsat satellite over the Indian Ocean (Intelsat-V MCS-A). The ship earth-station equipment was installed on a moving vessel which weighed 701 tons.

Two types of ship earth stations were tested in the experiment; one employing a high gain antenna and the other a medium gain antenna. The high gain antenna was an 85 cm diameter parabolic antenna with a gain of 20 dBi and provided a G/T of $-4 \text{ dB(K}^{-1}\text{)}$, as for current INMARSAT standard A ship earth stations. The medium gain antenna was a 40 cm diameter modified short back-fire antenna with a gain of 15 dBi and provided a G/T of $-10 \text{ dB(K}^{-1}\text{)}$. Table IV shows the major parameters of the high and medium gain antennas.

TABLE IV — Major parameters of high gain and medium gain antennas

	High gain antenna	Medium gain antenna
Antenna type	85 cm diameter parabolic	40 cm diameter modified short back-fire
G/T (dB(K ⁻¹))	-4	-10
e.i.r.p. (dBW)	up to 31	up to 26
Antenna gain (dBi)	20.5	15
Antenna -3 dB beamwidth (degrees)	14	32
Antenna axial ratio (beam centre) (dB)	1.8	1
Transmitter output power (W)	15	20

The long-term bit error ratio (BER) which is an average BER over a period of more than 10 min was measured. Figs. 4a to 4d show the long-term BER as a function of either satellite e.i.r.p. or ship earth-station e.i.r.p. at an elevation angle of around 10°. For the system using the high gain antenna, the BER performance at an elevation angle of around 5° is also indicated. The BER performance for the system using the medium gain antenna, was obtained when fading reduction based on polarization shaping [Shiokawa and Karasawa, 1982] was carried out in the antenna equipment. Broken lines in the figures indicate the BER performance which was measured in a land-based experiment where the multipath fading effect does not exist when the elevation angle of the antenna is 9°. Satellite e.i.r.p. was derived from a calibration curve against up-link e.i.r.p. as determined by land-based measurements.

For the BER performance at an elevation angle of 10°, the following observations are made:

- in order to achieve a long-term BER of 10^{-5} for the system employing the high gain antenna, a value of 15 dBW would be required for the 1.5 GHz satellite e.i.r.p. in the shore-to-ship link. This is 3 dB less than that required for the INMARSAT standard A system. In the ship-to-shore link, a ship earth-station e.i.r.p. of 25 dBW would be required;
- in the system which employs the medium gain antenna equipped with the fading reduction unit, a fading impairment of approximately 3 dB would be required to be taken into account in the link budgets. In order to achieve a long-term BER of 10^{-5} , a 1.5 GHz satellite e.i.r.p. of 21 dBW would be required in the shore-to-ship link, and the ship earth-station e.i.r.p. of 26 dBW would be required in the ship-to-shore link;
- the performance of the ship-to-shore link will be improved when the second-generation Inmarsat satellite with a higher 1.5 GHz (L-band) G/T and a higher transponder gain than the Intelsat-V satellite/MCS, is used. In this case, a long-term BER of lower than 10^{-6} would be achieved with the ship earth-station e.i.r.p. of 26 dBW even in the system employing the medium gain antenna. The improvement can also be used for reducing the ship earth-station e.i.r.p. requirement.

In conclusion, the experimental results have demonstrated that digital technologies such as forward error correction and voice coding are effective in the development of a system employing a medium gain antenna as well as a high gain antenna.

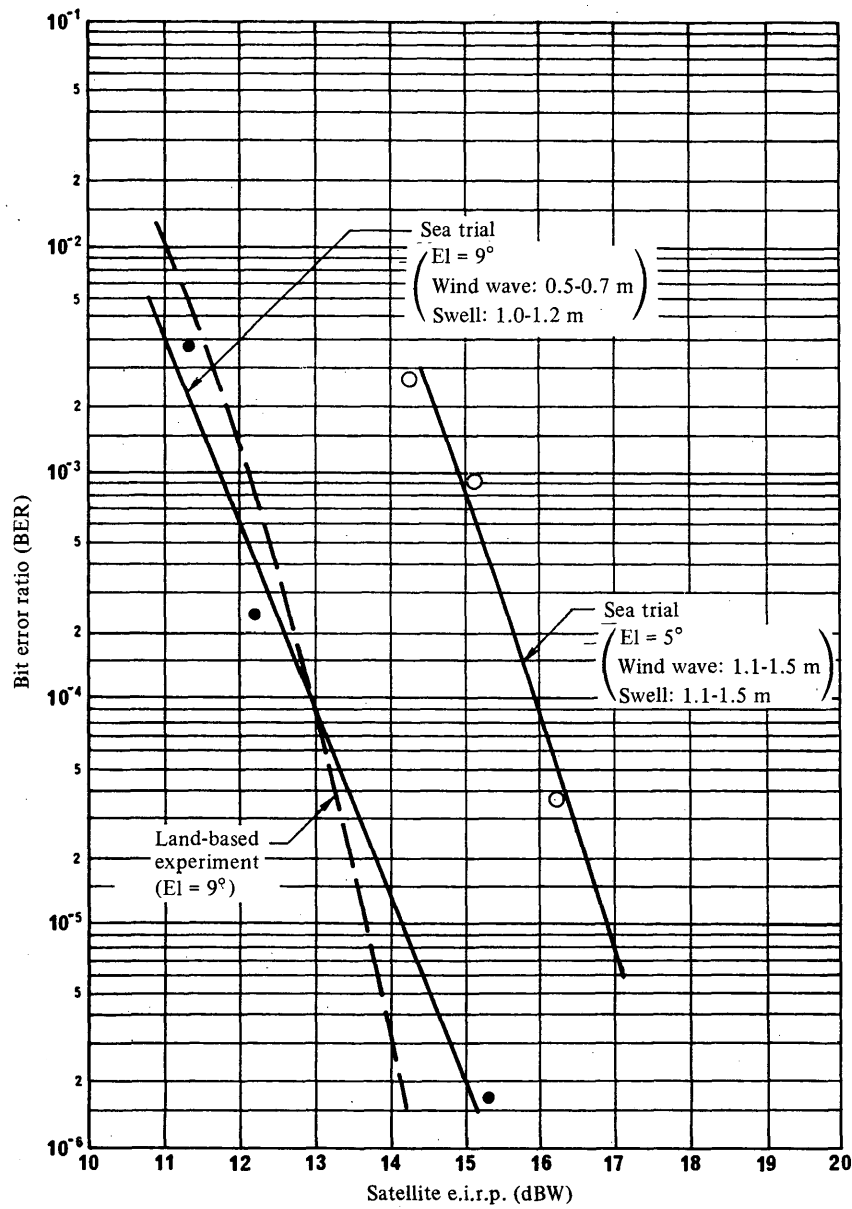


FIGURE 4a — Long-term BER as a function of satellite e.i.r.p. in shore-to-ship link of the system employing high gain antenna

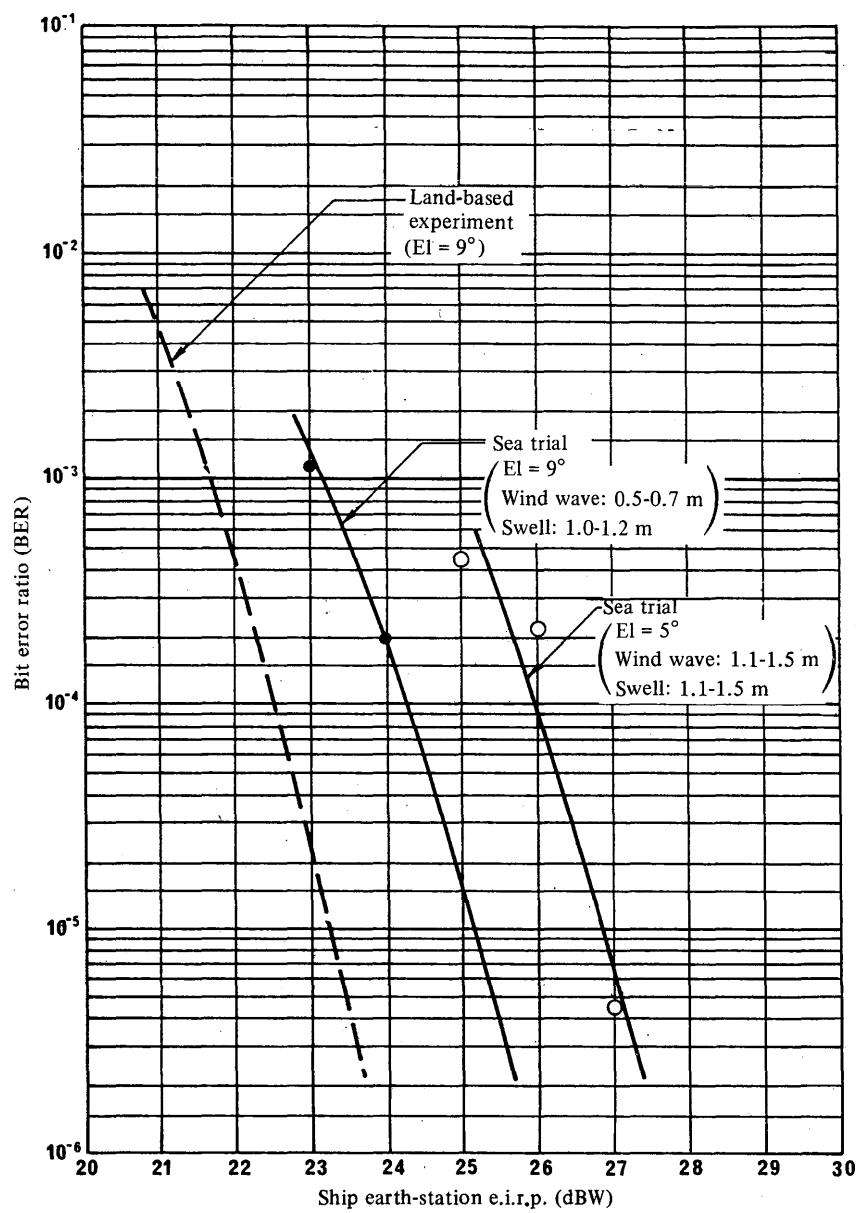


FIGURE 4b – Long-term BER as a function of ship earth-station e.i.r.p. in ship-to-shore link of the system employing high gain antenna

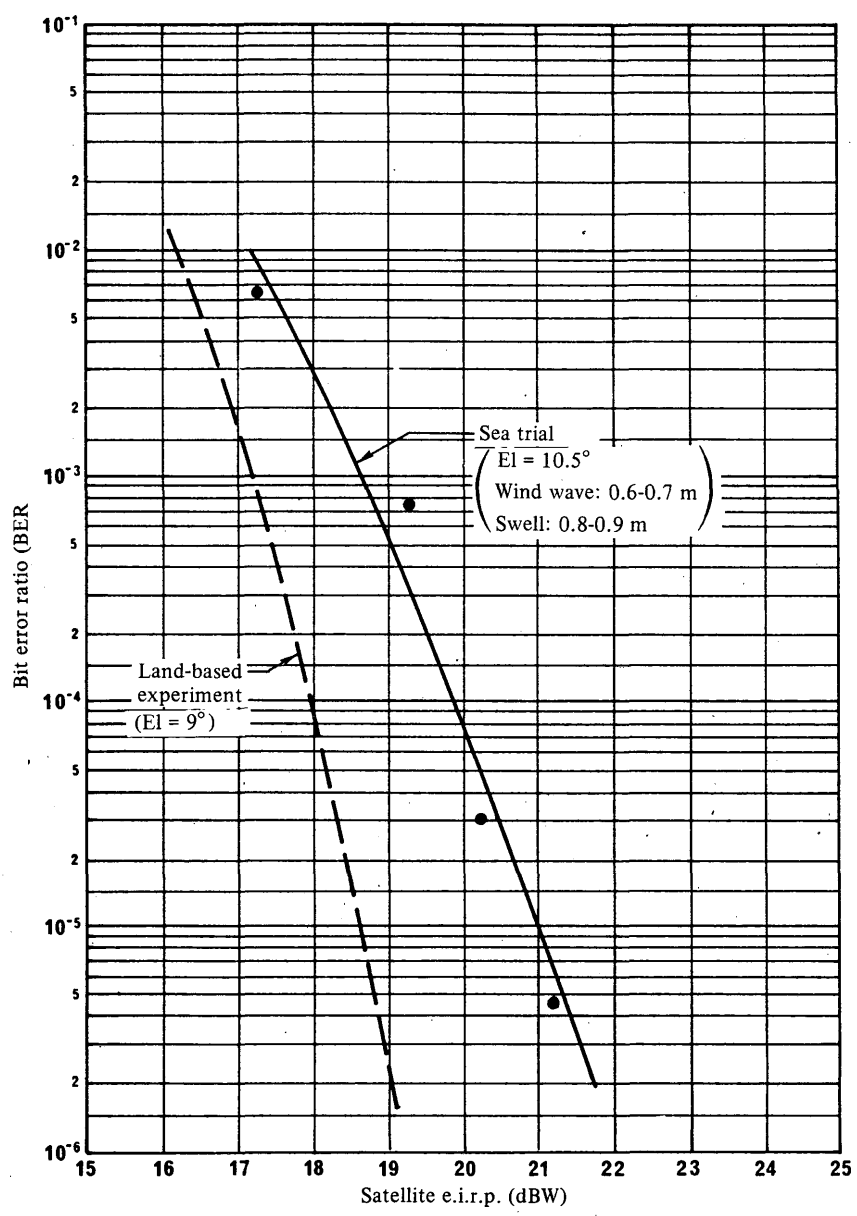


FIGURE 4c — Long-term BER as a function of satellite e.i.r.p. in shore-to-ship link of the system employing medium gain antenna

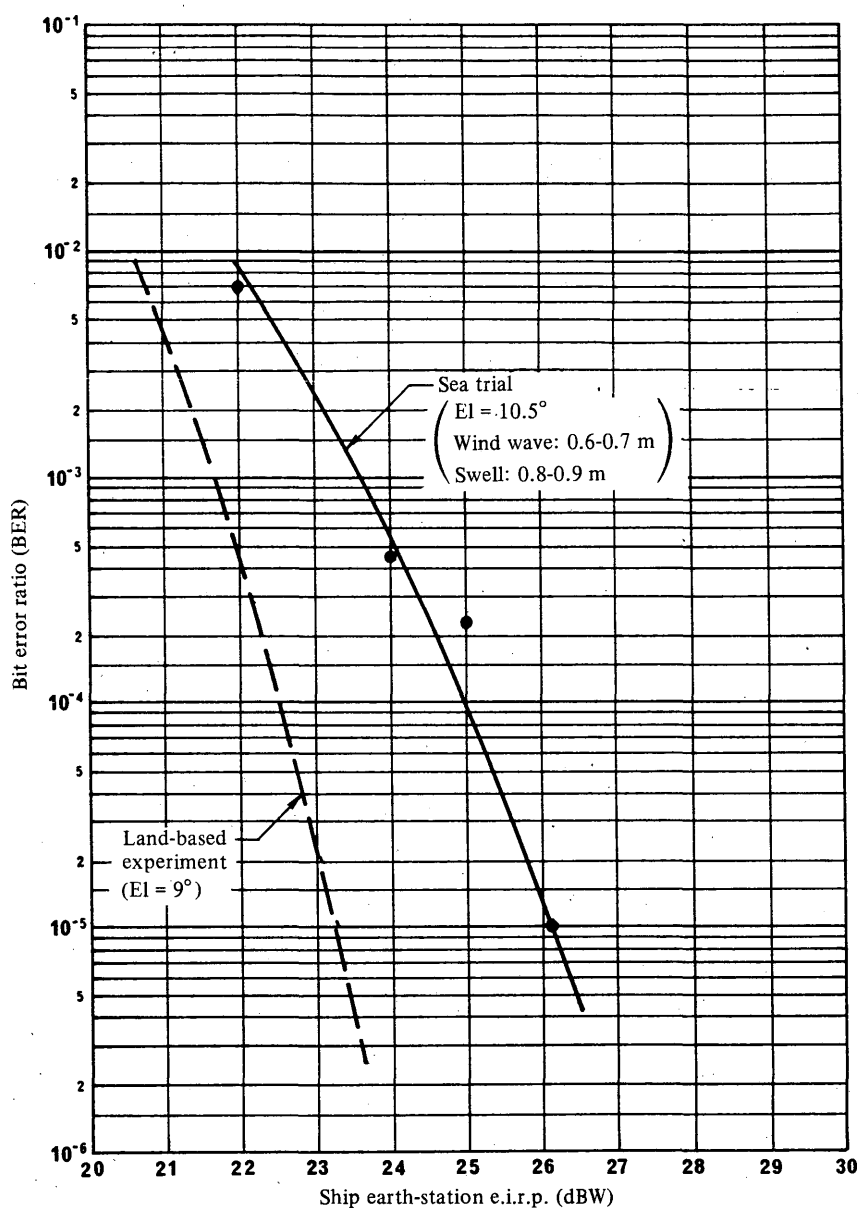


FIGURE 4d – Long-term BER as a function of ship earth-station e.i.r.p. in ship-to-shore link of the system employing medium gain antenna

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ANNEX II

PERFORMANCE OF AN EXPERIMENTAL LOW G/T SHIP EARTH STATION

1. Introduction

This Annex presents some results from tests carried out with an experimental low G/T SES ($-13 \text{ dB(K}^{-1}\text{)}$) of the standard B type which uses a wide beamwidth antenna and digital modulation techniques.

These tests were aimed at demonstrating the practicability of this type of SES, and at evaluating its performance at a bit rate of 2400 bit/s (suitable for vocoded speech operation [Holmes, 1982] over the present generation of maritime satellites both in conditions prevailing at high elevation angles, essentially unfaded, and in the multipath fading conditions prevailing at low elevation angles.

The tests therefore consisted of two distinct parts:

- land-based tests, with transmissions in the 6 GHz-1.5 GHz direction, via the INMARSAT Atlantic Ocean Region (AOR) satellite Marecs-A, to establish the base-line performance of the SES over an actual satellite link;
- tests using the “stored channel method” to evaluate the performance of the modulation system (modem) in different fading environments and so determine the link margins available for 2400 bit/s (vocoder) operation.

This work was performed jointly by the United Kingdom Home Office (now the Department of Trade and Industry), British Telecom International (BTI) and the German Aerospace Research Establishment (DFVLR).

2. Tests using the Marecs-A satellite

Land-based tests were conducted during the last quarter of 1982 using Marecs-A and the British Telecom International Coast Earth Station (CES) at Goonhilly Downs, Cornwall. The low G/T SES was also sited at the CES, giving an elevation angle to the satellite of 29° i.e. effectively unfaded conditions. Measurements were made in the 6 GHz to 1.5 GHz band (shore-to-ship) direction of transmission. A repeated 511 bit pseudo-random sequence was transmitted over the link at 2400 bit/s and measurements were made of BER for different values of carrier-to-noise density ratio (C/N_0), the BER being evaluated over 10^6 bits. The C/N_0 at the SES was varied by adjusting the e.i.r.p. of the CES. The equipment configuration used during these tests is shown in Fig. 5.

3. Tests using the stored channel method

The stored channel simulator was driven by pre-recorded tapes. These tapes can be produced synthetically, by using theoretical fading models or by recording actual measurements of satellite transmissions. The technique is described in [Hagenauer and Papke, 1980] and was previously used in the multipath tests carried out by the Federal Republic of Germany (see Report 762).

In order to have available appropriate recordings for the modem tests, the wide beamwidth SES antenna was mounted (unstabilized) on board the German Research Vessel RV GAUSS, and during March 1983, tape recordings were made at elevation angles between 25° and 4° from high level (28 dBW) CW transmissions from Marecs-A.

Two signals representing the amplitude and phase variations of the multipath signals were recorded during each test.

These recorded tapes as well as synthetic tapes generated by the DFVLR were used to assess the modem performance under non-fading (Gaussian) as well as under fading (Rice-Nakagami and Rayleigh) conditions.

Table V gives details of the RV GAUSS and summarizes the sea and wind conditions prevailing during the recording of the test tapes. For further details see [Hagenauer *et al.*, 1984].

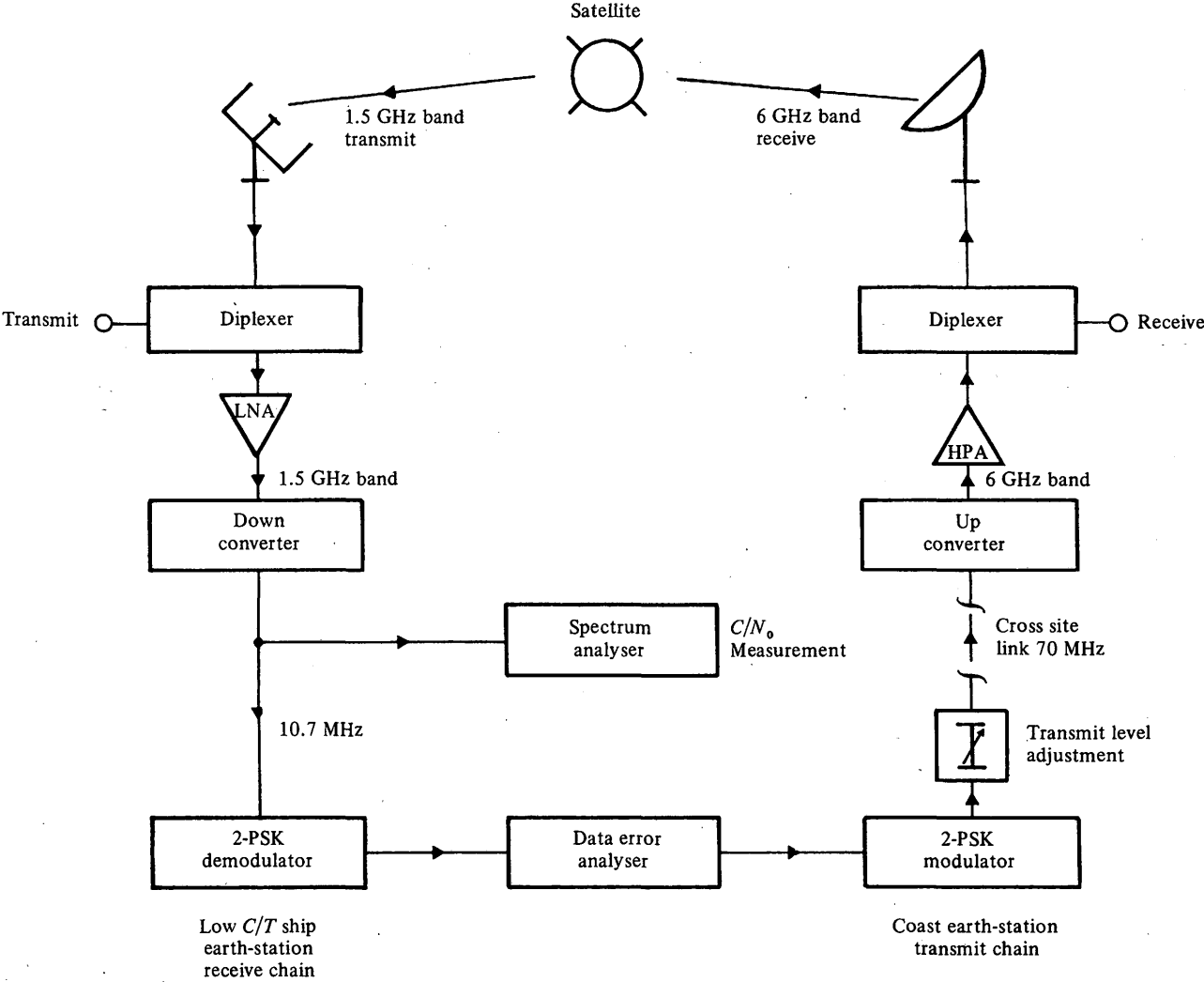


FIGURE 5 – Equipment configuration for test in the shore-to-ship direction of transmission

TABLE V

Ship RV GAUSS Length: 68.86 m Width: 13.09 m Grt: 1599 t			
Satellite		Marecs A Atlantic Ocean Region 26° W	
Test Tape No.	1	2	3
Elevation angle (degrees)	26	10	4
Wave height (m)	< 1	3.5	4.5
Wind force (knots)	< 5	26	35
Measured C/M (carrier to multipath) (dB)	16.5	11	10
Antenna height above sea surface: 12 m			

As in the land-based tests, measurements were made of BER as a function of C/N_0 . The equipment configuration used during these tests is shown in Fig. 6.

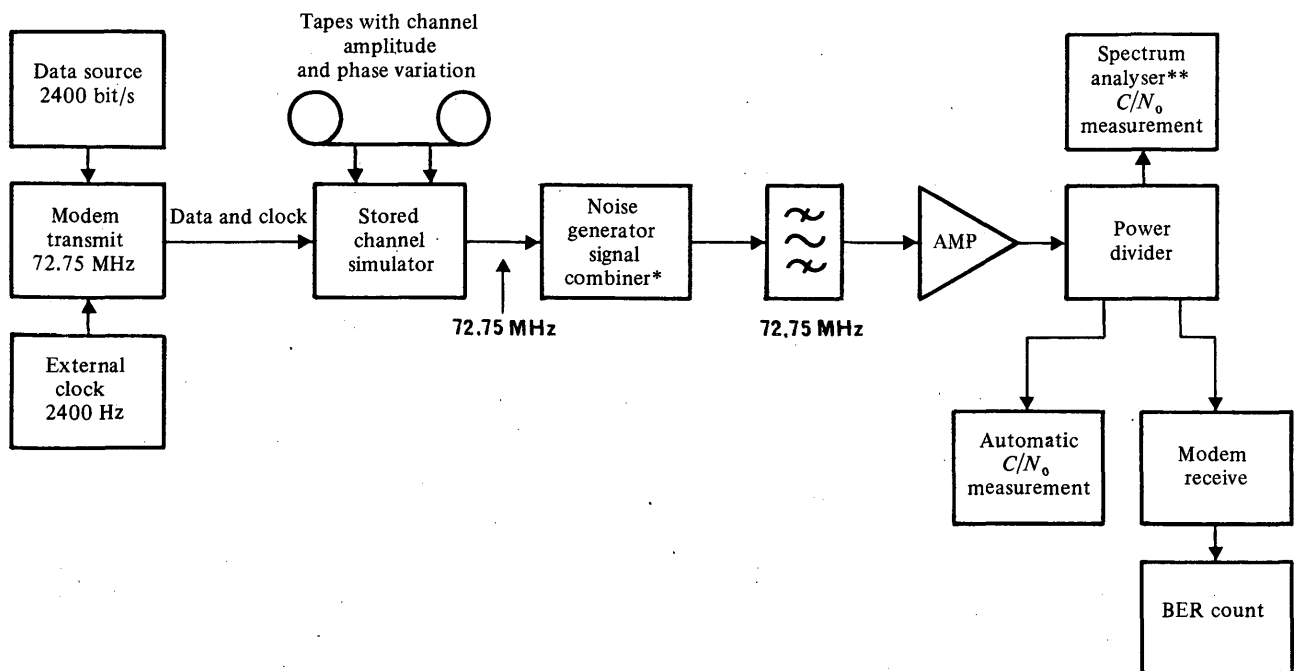


FIGURE 6 – Equipment configuration for test, using the stored channel simulator

* The noise generator and signal combiner have the capability to vary the signal and noise independently, allowing the value of C/N_0 to be set for each series of BER measurements.

** The spectrum analyser shown here is similar to the one employed during the land-based tests for C/N_0 measurements. It was used here for comparison with the automatic C/N_0 measurements. In all cases the results obtained from the two methods of measurement were within ± 0.5 dB of each other.

4. SES hardware

A full description of the SES hardware is given in [Mecrow *et al.*, 1983]. The main component parts relevant to this Report are the SBF antenna (see § 2 of the main Report and Annex I to Report 922) and the two phase PSK modem. The modem employs a residual carrier modulation technique (deviation ± 1 rad) with the data Manchester-encoded [Subramaniam, 1978].

5. Test results

5.1 Land-based tests

The results of the land-based tests are shown in Figs. 7 and 8. In Fig. 7, BER as a function of C/N_0 is plotted as curve D. Throughout the measurements, short-term variations of up to 1.5 dB were observed in the carrier level received from the satellite. This was due to variations in satellite loading which was an average of 12 channels during the tests. Measurements of C/N_0 were therefore made by taking an average of at least 10 measurements over a period of about 2 min before and after each test run. The resulting accuracy of C/N_0 measurements is estimated to be within ± 1.5 dB. The scatter of the results shown in Fig. 7 at low values of C/N_0 is thought to be due to the dominance of varying intermodulation products occurring in the satellite transponder.

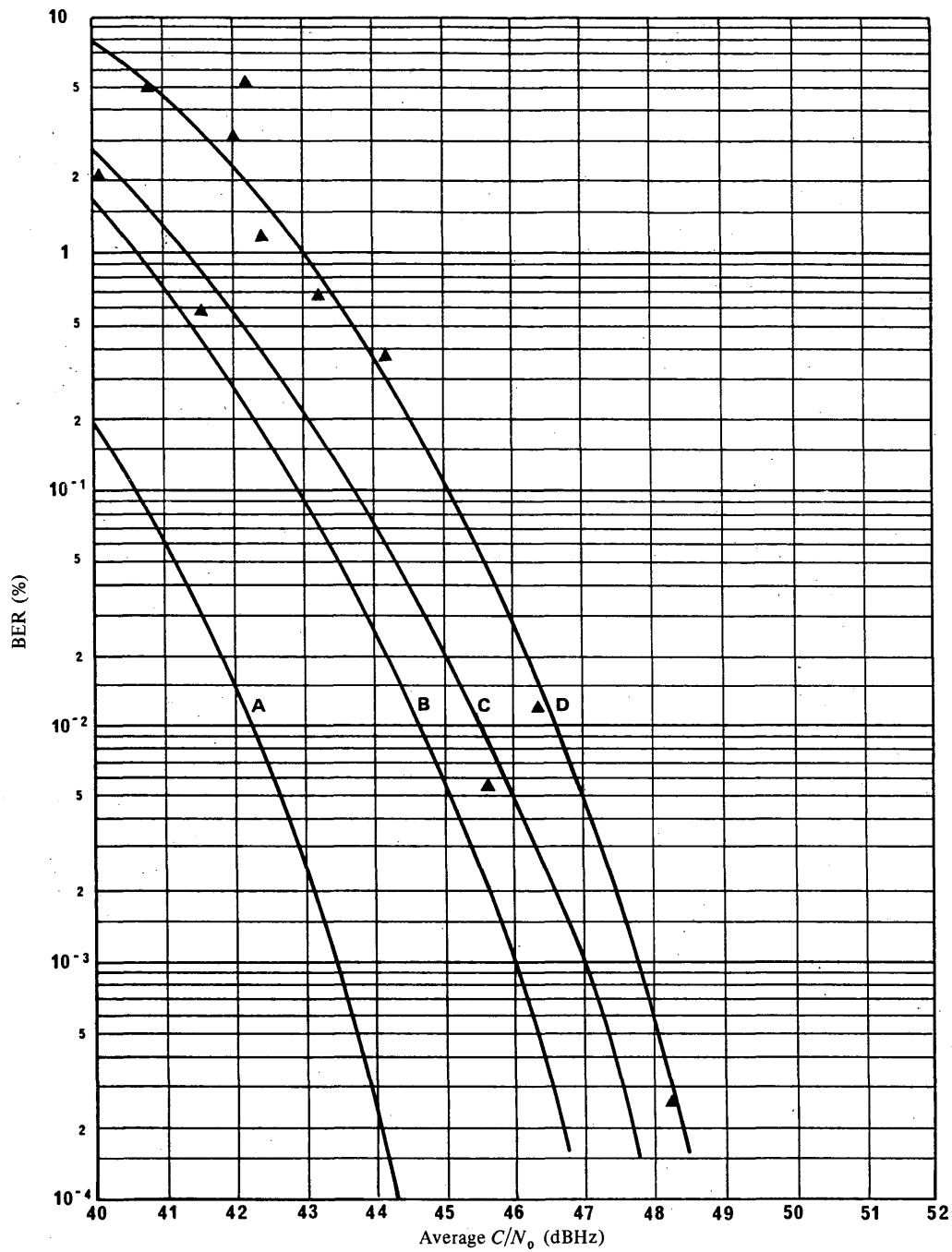


FIGURE 7 – Measurements of percentage BER for different values of C/N_0 at 2400 bit/s in an effective unfaded (Gaussian) channel

Curves A: theoretical curve for CPSK

B: back-to-back performance of the modem with the addition of Gaussian noise

C: channel simulator results using a recorded tape (1), elevation angle = 25° , $C/M = 16.5$ dB

D: $\blacktriangle$ results of satellite tests carried out at Goonhilly in the shore-to-ship direction

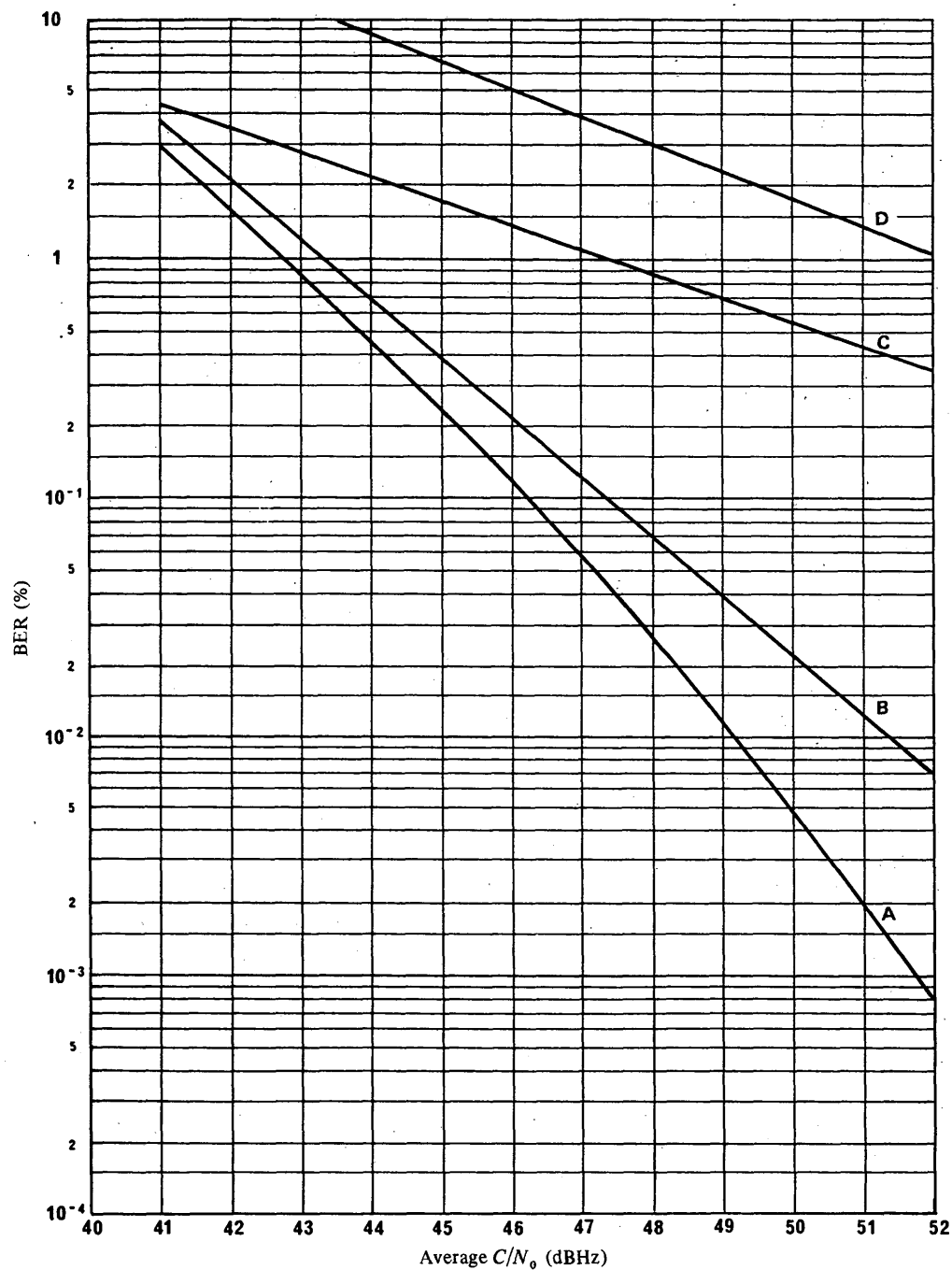


FIGURE 8 – Measurements of percentage BER for different values of C/N_0 at 2400 bit/s in a fading (Rice-Nakagami and Rayleigh) channel

- Curves A: recorded tape (2), elevation angle = 10° , C/M = 11 dB
 B: recorded tape (3), elevation angle = 4° , C/M = 10 dB
 C: synthetic fading (equivalent Rice-Nakagami), C/M = 6 dB
 D: synthetic fading (equivalent Rayleigh), C/M = 0

5.2 Stored channel (simulator) tests

The results of the stored channel (simulator) tests are shown in Figs. 7 and 8.

Figure 7 curve C shows the performance of the modem in an effectively unfaded (Gaussian) channel using the channel simulator and a tape recording (tape 1) made on the RV GAUSS at an elevation angle of 26° with a measured carrier-to-multipath power ratio (C/M) of 16.5 dB.

For comparison, Fig. 7 also shows: curve A, the theoretical performance of CPSK in an unfaded channel, curve B, the back-to-back performance of the modem with the addition of Gaussian noise and in curve D, the results of the land-based tests carried out at Goonhilly. As mentioned in § 5.1, the effects of intermodulation product must be borne in mind when comparing the Goonhilly results with other measurements.

Figure 8 curves A and B show the modem performance in fading Rice-Nakagami conditions obtained using tape recordings (tapes 2 and 3) made on the RV GAUSS at elevation angles of 10° and 4° with a C/M of 11 dB and 10 dB respectively. Curves C and D show the modem performance using synthetic tapes equivalent to a Rice-Nakagami channel with a C/M of 6 dB and a Rayleigh channel with a C/M of 0.

6. Discussion of results

In considering the implications of these results for an operational low G/T system it is assumed that the satellite e.i.r.p. per voice channel is as provided by the present generation of maritime satellites, and a BER of 2% is taken as the criterion (vocoder operation) for assessing the link margins which would be required to provide 99% availability in multipath fading environments.

Considering first the curves in Fig. 7, the modem performance in an effectively Gaussian channel, some difference can be seen between the results obtained via the satellite link and those from the channel simulator. At worst the difference is about 1.5 dB at the lower values of C/N_0 . This is within the measuring accuracy that was attributed to the land-based tests (see § 4.1) and allowances must be made for the fitted curve due to the scatter of results which was obtained at low values of C/N_0 and the possibility of bit errors being introduced by the CES high power amplifier (HPA) and satellite transponder. In general it is considered that the two sets of results compare favourably and that a C/N_0 value of about 41 dBHz can be taken as that required for a BER of 2% in unfaded conditions.

Measured SES C/N_0 as a function of CES e.i.r.p., shows that a C/N_0 of 50 dBHz was measured at the SES for a CES e.i.r.p. of 55 dBW. The e.i.r.p. of 55 dBW, measured at Goonhilly CES (during its pre-operational phase) was found to be the e.i.r.p. required to provide the satellite power at 1.5 to 1.6 GHz (measured by Southbury NCS, United States of America) equivalent to that provided for an INMARSAT standard A SES voice channel. However, this figure of 50 dBHz would be reduced by about 4 dB under full satellite loading (30 channels compared to the average of 12 observed during the tests), and by a further 1.4 dB for edge of coverage (EOC) conditions (elevation angle 5° as compared to the 29° at which the measurements were made). Taking these factors into account the available unfaded C/N_0 at edge of coverage (EOC) would be 44.6 dBHz.

Table VI shows the modem C/N_0 required for 2% BER performance under various fading conditions and indicates the link margins available when compared to the calculated EOC C/N_0 available.

It should be noted that although the wide beamwidth SES antenna was mounted unstabilized on the RV GAUSS, and wave heights of up to 4.5 m were experienced, the measured C/M value did not drop below about 10 dB.

7. Conclusions

It is concluded that with a link of an average C/N_0 of > 44 dBHz this experimental low G/T ship earth station ($G/T = -13$ dB(K $^{-1}$)) could support 2400 bit/s vocoded speech, with a BER not greater than 2% for 99% of the time in all but the worst-case theoretical fading conditions. Under such conditions, fade reduction or forward error correction (FEC) techniques could be applied, although this would add to SES equipment complexity and cost.

Furthermore from the experimental results obtained with this wide beamwidth (47° at 3 dB) unstabilized antenna under realistic fading conditions at edge of coverage, it may also be concluded that only minimal requirements for antenna elevation pointing are necessary. This would significantly reduce the complexity and cost of above deck equipment.

TABLE VI

Fading conditions	Measured C/N_0 required for 2% BER (dBHz)	Calculated available C/N_0 at EOC (dBHz)	Link margin (dB)
<i>Tape 2:</i> $C/M = 11$ dB elevation angle 10°	41.6	44.6	3
<i>Tape 3:</i> $C/M = 10$ dB elevation angle 4°	42	44.6	2.6
$C/M = 6$ dB (synthetic Rice-Nakagami)	44.2	44.6	0.4
$C/M = 0$ (synthetic Rayleigh)	49.6	44.6	-5

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ANNEX III

THE SHORE-TO-SHIP DISTRESS ALERTING CHANNEL (SHOSAC)
USING RECEIVE-ONLY SHIP EARTH STATIONS

1. Introduction

Today, there exist a number of proposals for maritime distress alerting systems using float free Emergency Position-Indicating Radio Beacons which transmit via satellite (satellite EPIRB). As a necessary complement to these ship-to-shore alerting systems, IMO requested for its "Future Global Maritime Distress and Safety Systems" that the shore-based Rescue Coordination Centre (RCC) should be enabled to quickly and effectively contact ships in the immediate vicinity of the vessel in distress, for which a simple and reliable radio link, a shore-to-ship alert channel, is required.

Therefore, it is proposed to connect even those vessels which do not possess an INMARSAT communications ship earth station by employing an inexpensive receiver operating at low bit rates via satellite. Ships could be addressed individually or selectively as a group in a certain area. The link could be used for distress alerting as well as for navigational and meteorological warnings.

2. System definition

The system must be inexpensive to own and operate; therefore, one possible solution, as described here, is to provide an omnidirectional antenna. In order to reduce sea surface multipath effects, the polarization should be circular. Since this service is in the shore-to-ship direction only, the ship terminal is a Receive-Only Ship Earth Station (ROSES). The operational bandwidth of the equipment should include the frequency band 1544 to 1545 MHz which is limited to distress and safety operations by footnote 728 of the Radio Regulations. The operational satellites Marisat and first phase INMARSAT space segments INTELSAT V-MCS and MARECS do not include this 1 MHz band. The second generation INMARSAT space segment is expected to use this band.

The small antenna gain of ROSES, in conjunction with an inexpensive (uncooled) receiver and a limited satellite power, allows only a very narrowband SHOSAC-transmission, i.e. a very low bit rate. Assuming that a SHOSAC would be allocated the same effective isotropically radiated satellite power (e.i.r.p.) as the public correspondence voice carrier then this value would be about 18 dBW which corresponds to the present MARECS and INTELSAT V-MCS e.i.r.p.

One predominant problem is the signal acquisition, especially for phase shift keyed (PSK) modulation, as opposed to non-coherent frequency shift keyed modulation (FSK). In this context, the accuracy and stability of the carrier frequency radiated from the spacecraft is of importance. As an example, the frequency inaccuracy value of the INMARSAT system after automatic compensation at the coast earth station is around ± 800 Hz (after the ship earth station demodulator) or 1600 Hz peak-to-peak. In § 5, a frequency inaccuracy of 2 kHz peak-to-peak has been assumed, to take into account residual compensation errors.

3. Suitable modulation and coding techniques

As the ROSES antenna is relatively small, it could therefore be mounted on a high point of the vessel. The link between a ROSES antenna and the satellite should therefore experience reduced multipath effects and little path blockage compared to a link between a buoy and a satellite.

Signal fades can be largely compensated by using forward error correcting codes (FEC). A possible alternative technique would be time diversity but this is considered less suitable for this particular application.

Both PSK and FSK are considered here as possible modulation methods. PSK requires continuous carrier acquisition but this is not required by FSK. However, PSK is around 4 dB more efficient than FSK.

Further information on certain aspects of system design are required; for example, oscillator phase noise, acquisition vs tracking loop bandwidth and effects of multipath.

4. Link budget

The link budget shown in Table VII is based on INTELSAT V-MCS and MARECS figures. It is assumed that SHOSAC e.i.r.p. allocation is that of a voice carrier. The multipath fade assumed is 6 dB; the FEC coding gain assumed here amounts also to 6 dB. It is further assumed that degradation on the up-path would have negligible effect on the overall C/N_0 .

The FEC coding gain assumed in the budget is a coarse approximation and needs further refinement. In the study presented here a BCH block code and a Rayleigh-channel are assumed.

5. Acquisition and tracking

Four alternative proposals are discussed which include coherent and non-coherent systems. To avoid mutual intra system interference in the overlapping areas, adjacent satellites transmit the SHOSAC on different carrier frequencies which the ROSES must be equipped to acquire and track. Suitable transmit carrier frequencies offset by, for example 5 kHz, could be achieved at coast earth stations.

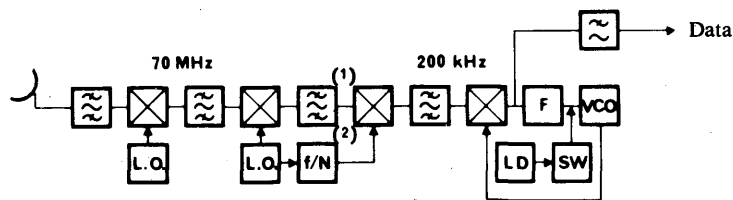
TABLE VII — SHOSAC link budget calculation

	Units	MARECS/ INTELSAT V-MCS	
Satellite e.i.r.p. (5° elevation)	dBW		18.0
Free space loss (1 544 MHz; 5° elevation)	dB		188.5
Antenna gain; ship earth station	dB		1
System noise temperature (1 000 K)	dBK		30
Boltzmann's constant	dB(W/HzK)		-228.6
Multipath fade	dB		6
C/N_0 down path	dBHz		23.1
		PSK	FSK
C/N_0	dBHz	23.1	23.1
Required E_b/N_0 (BER = 10^{-4})	dB	8.3	12.3
FEC improvement approx. (code rate = $1/2$)	dB	6	6
Modem losses	dB	2	2
Available bandwidth	dBHz	18.8	14.8
Assumed information bit rate 32 and 16 bit/s		15.1	12.1
Margin	dB	3.7	2.7
Transmitted bit rate	bit/s	64	32
Transmission time for 500 information bits	s	15.6	31.2

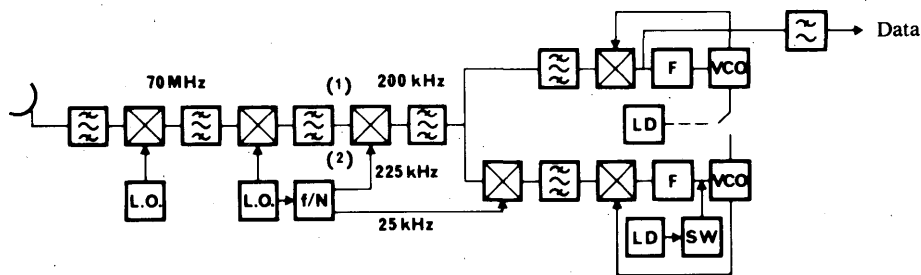
A second intermediate frequency (IF) of 200 kHz has been adopted for which cost effective filters and voltage controlled oscillators (VCO's) with bandwidths of a few kilohertz are readily available commercially. Furthermore, it is assumed that, at the beginning of each transmission, the carrier remains unmodulated for between 1 and 10 s, thus allowing the ROSES to acquire lock.

Four different methods of acquisition and demodulation considered to date are as follows and as illustrated in Fig. 9:

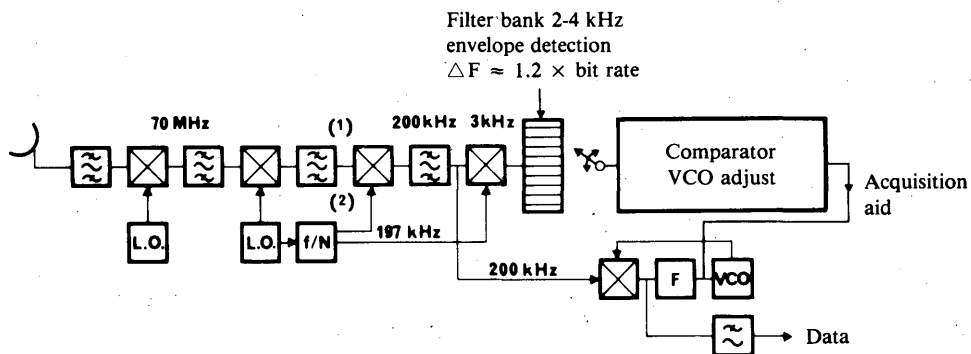
- BPSK with phase-locked loop (PLL) for acquisition and demodulation (see Fig. 9a);
- BPSK with aided PLL for acquisition using a beacon receiver (see Fig. 9b);
- BPSK with non-coherent acquisition and coherent demodulation (see Fig. 9c);
- BFSK with non-coherent acquisition and non-coherent demodulation (see Fig. 9d).



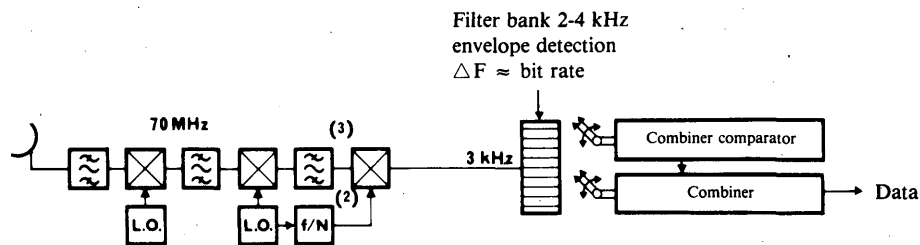
a) Coherent acquisition, coherent demodulation



b) Aided acquisition, coherent demodulation



c) Incoherent acquisition aid, coherent demodulation



d) Incoherent acquisition and demodulation

FIGURE 9 – Four different methods of acquisition and demodulation

LD: Lock detector
 SW: sweep
 F: filter
 L.O.: local oscillator
 f/N: frequency divider
 VCO: voltage controlled oscillator

	(1)	(2)	(3)
AOR	195	5	8 kHz
IOR	190	10	13 kHz
POR	185	15	18 kHz

A preliminary analysis of these system alternatives has been carried out and is summarized in Table VIII:

TABLE VIII

Method	(a)	(b)	(c)	(d)
Modulation	PSK	PSK	PSK	FSK
Acquisition time (s)	10	1	1	1
Information bit rate (bit/s)	32	32	32	16
Transmission time for a message of 500 bits, incl. acquisition time (s)	26	17	17	32

Method (a) requires the least complex implementation, but requires a longer transmission time compared to methods (b) and (c). Methods (b) and (c) appear attractive as far as transmission time is concerned. Method (b) requires a beacon, whereas method (c) requires a more elaborate receiver design. If multipath effects severely degrade the performance of PSK, it could be necessary to use FSK with non-coherent demodulation (method (d)).

6. Selective broadcast

One of the requirements of the Future Global Maritime Distress and Safety System is selective addressing of shore-to-ship alerts to concise ocean area. IMO is presently developing such a subdivision (SAR-plan).

As an example, with the earth subdivided into areas of 120 nautical miles squared, there would be about 3000 sea areas which could be sequentially numbered giving a 12 bit binary area code. Several of these areas may be combined at the expense of another few bits in order to address larger areas for other safety purposes such as navigational and meteorological warnings.

7. Summary

SHOSAC offers the possibility of contacting ships in given areas from a coast earth station via satellite, even if the ships are not equipped with INMARSAT ship earth stations.

Both coherent and non-coherent modulation schemes and the respective implications on acquisition and tracking are discussed and typical bit rates and transmission times have been estimated. Multipath effects can be largely compensated by use of FEC.

Additional studies are required on those aspects indicated in § 3 of this Annex.

ANNEX IV

FORWARD ERROR CONTROL (FEC) AS A MEANS OF MULTIPATH FADING COMPENSATION

The performance of coded DECPSK transmission over the standard C maritime channel was measured by means of the DFVLR channel-simulator test set-up with a modem of new design using a COSTAS-loop combined with an AFC loop (automatic frequency control), in order to recover carrier and data of the DECPSK signal [Hagenauer *et al.*, 1984]. The BER was evaluated for convolutionally and block coded transmission over synthetic channels (Rayleigh-channel, Rice-Nakagami-channel with $C/M = 6.3$ dB) as well as for a representative selection of stored standard C channels recorded on the ship "Gauss" (C/M between 8 dB and 14 dB). The set of stored channels includes the worst case of 4° elevation angle for all tested antennas C3, C5, C11, C14 and the 19° elevation test for antennas C3 and C11 (standard C antennas with gains in decibels as indicated). See Report 762 and [Hagenauer *et al.*, 1984].

The realized coding schemes were:

- Viterbi decoding of convolutional codes of rate 1/2, constraint length 7, with and without channel state information (fading depth information from AGC is used in the decision-making process in the FEC decoder); decoder realized in hardware;
- Reed-Solomon codes (15 : 9 : 3), Berlekamp-Massey decoder realized in software on-line in a main-frame computer [Lutz, 1984].

Interleaving was used with different interleaver sizes. The self-synchronizing de-interleaver was realized in a microprocessor.

An example of the performance of FEC with a Viterbi decoder, for the 11 dB antenna (C11), is shown in Fig. 10. The measurements show that with rate 1/2 convolutionally coded transmission at an elevation angle of 4° a BER of 10^{-5} can be achieved with E_b/N_0 in the range from 12.5 dB to 15.5 dB corresponding to a net coding gain of 18.5 to 20.5 dB.

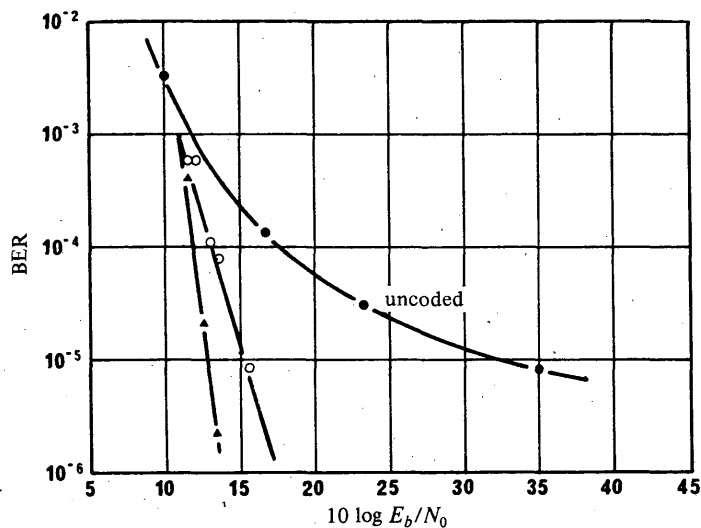


FIGURE 10 – Measured performance of interleaved Viterbi decoding (C11 antenna, 4° elevation)

Channel: stored, C11, 4° elevation

Modulation: binary DECPSK

Modem: COSTAS/AFC

Data rate: channel 1200 bit/s
inform. 545 bit/s

Interleaver size: 60 × 80

Decoder: Viterbi rate 1/2
constraint length 7

Decoder mode:

○ YH, AN

▲ YH, AH

YH: variable for decisions/hard decisions

AN: no channel state information

AH: hard decision on channel state

Antenna:

C11: standard C type with 11 dB gain

Measurements with a 3 dB antenna showed that at an elevation angle of 19° a BER of 10^{-5} requires an E_b/N_0 of 9.5 to 10.5 dB; the corresponding net coding gain is between 4.5 and 7.5 dB [Hagenauer *et al.*, 1984].

For rate 1/2 block code transmission over stored channels, necessary E_b/N_0 values ranged from 12 dB to 18 dB which correspond to net coding advantages from 6 dB to 17 dB. Compared to convolutional codes the realized simple block coding scheme was somewhat inferior, but it can be concluded that equivalent results will be achieved by using more powerful block coding. A comparison between block and convolutional codes is shown in Table IX.

TABLE IX — Comparison of block and convolutional codes with respect to interleaver volume, decoding effort and measured E_b/N_0 for BER = 10^{-5} at 1200 bit/s channel rate (COSTAS/(AFC) modem)

Channel	Code ⁽¹⁾	Interleaver volume (bit/s)	Decoding effort operations/infobit ⁽²⁾	Measured E_b/N_0 for BER = 10^{-5} (dB)
Rayleigh synthetic 1 Hz	Block	48·60 = 2880	8.3	27
	Convolutional	48·60 = 2880	128	22.5
C3 antenna 4° elevation stored	Block	48·60 = 2880	8.3	17
	Convolutional	80·60 = 4800	128	13.2
C3 antenna 19° elevation stored	Block	48·60 = 2880	8.3	12
	Convolutional	80·60 = 4880	128	10.5

⁽¹⁾ Block code: Reed-Solomon (RS) code (15 : 9 : 3), hard-decision decoding.
Convolutional code: rate 1/2, constraint length 7, YHAH Viterbi decoding.
⁽²⁾ 1 operation for RS decoding means 1 multiplication + 1 addition in GF (2^4) (GF: Galois field).
1 operation for Viterbi decoding means 1 addition + 1 table look-up of fixed point numbers.

It can be concluded that under the worst-case conditions (hemispherical antenna C3, 4° elevation angle) the mean E_b/N_0 to achieve 10^{-5} BER has to be in the range of 13 dB to 17 dB. The lower value can be achieved with more sophisticated Viterbi-decoding and an interleaving delay of 4 s. For the upper E_b/N_0 value a fairly simple Reed-Solomon decoder with interleaving delay of 2.4 s can be used. Compared to uncoded transmission, net coding advantages of 9 dB to 13 dB have been achieved. These results show that it is necessary to use FEC on standard C satellite data communication systems with continuous transmission to compensate for the multipath effects.

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ANNEX V

METHOD OF STATISTICALLY EVALUATING SHIP MOTION INFLUENCE
ON MARITIME MOBILE SATELLITE COMMUNICATIONS

1. Introduction

A shipborne antenna system mounted on a passive gravity-stabilized platform was recently studied for low G/T ship earth stations such as INMARSAT standard C [Sandrin and Carpenter, 1983]. In such cases, the received signal level is randomly affected by the antenna off-beam gain because the antenna motion may be directly influenced by random ship motion. Therefore, the performance of such an antenna system mounted on a passive stabilizer should be statistically evaluated as the received signal level fluctuation margin.

This Annex describes a method of statistically evaluating passive antenna stabilizer performance for obtaining the fluctuation margin of the received signal level due to antenna off-beam gain changes on the basis of experimental results and statistical analysis [Sato *et al.*, 1984].

2. Evaluation of ship motion influence

The experimental area was near Japanese waters. The vessel used for the experiment was in the 200-ton class. Roll motion analysis is discussed here because this mode is a dominant ship motion. Roll was measured with a vertical gyroscope.

A typical recording of a series of instantaneous roll motions (X) for a period of 5 min is shown in Fig. 11. The measured cumulative probability distribution (CPD) of (X) is shown in Fig. 12. This is the probability that (X) does not exceed a specified level (X_s). The coordinates in Fig. 12 are scaled so that the Gaussian CPD appears as a straight line. It is found that the measured values agree well with a zero-mean Gaussian distribution. The Gaussian CPD is expressed as follows:

$$p(X < X_s) = (1 + \operatorname{erf}(X_s / \sqrt{2} \sigma_s)) / 2 \quad (1)$$

where:

σ_s : standard deviation of ship motion; and

$\operatorname{erf}(x)$: error function.

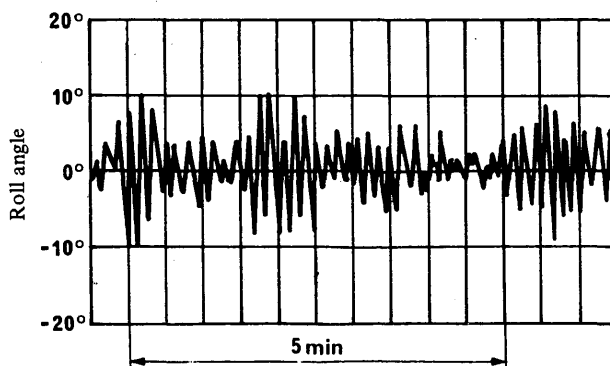


FIGURE 11 – Typical ship roll motion recording

Ship speed: 10 knots

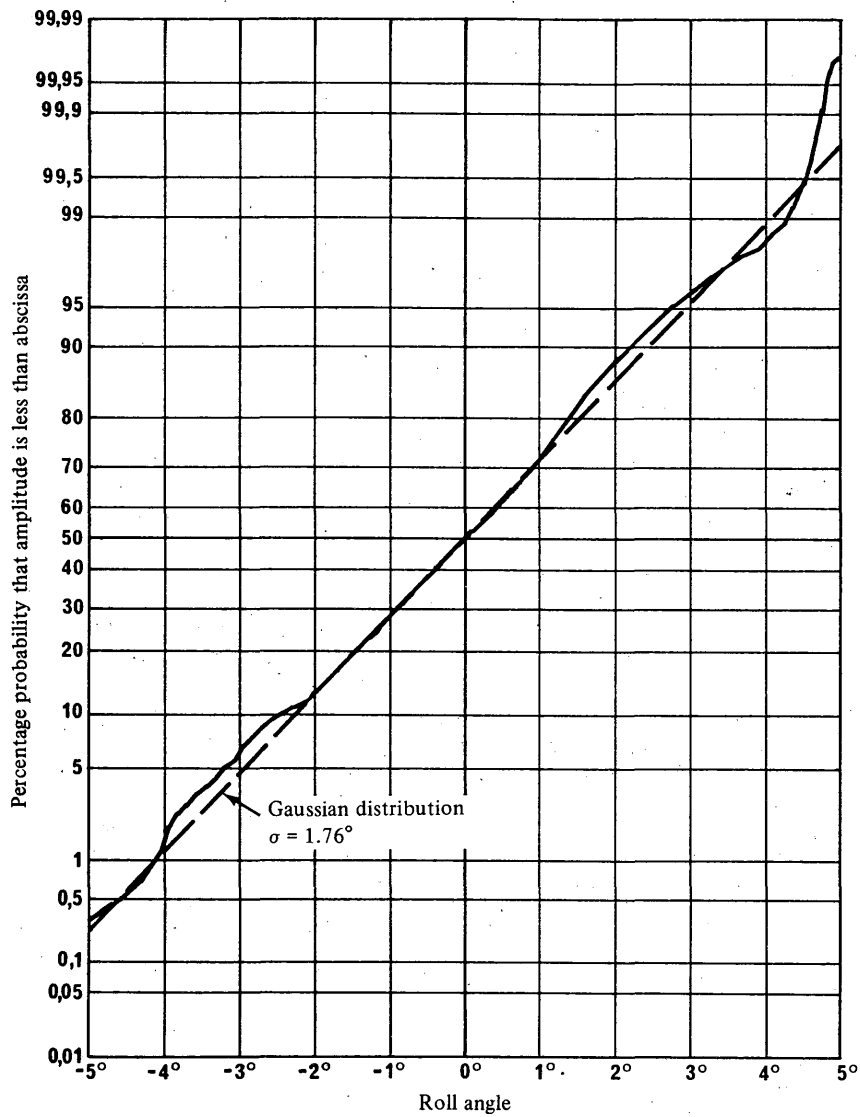


FIGURE 12 – Measured cumulative probability distribution of instantaneous roll motion

— : Measured values
- - - : Calculated values
Wave height: approximately 1 m

The passive gravity stabilizer illustrated in Fig. 13 was studied as a means of suppressing the shipborne antenna fluctuation due to such random ship motion. Measured stabilizing effects of the passive stabilizer when the ship motion is Gaussian distributed are shown in Fig. 14. It is shown that antenna motion is considerably suppressed, and that the stabilized antenna motion approximates to a Gaussian distribution with zero mean.

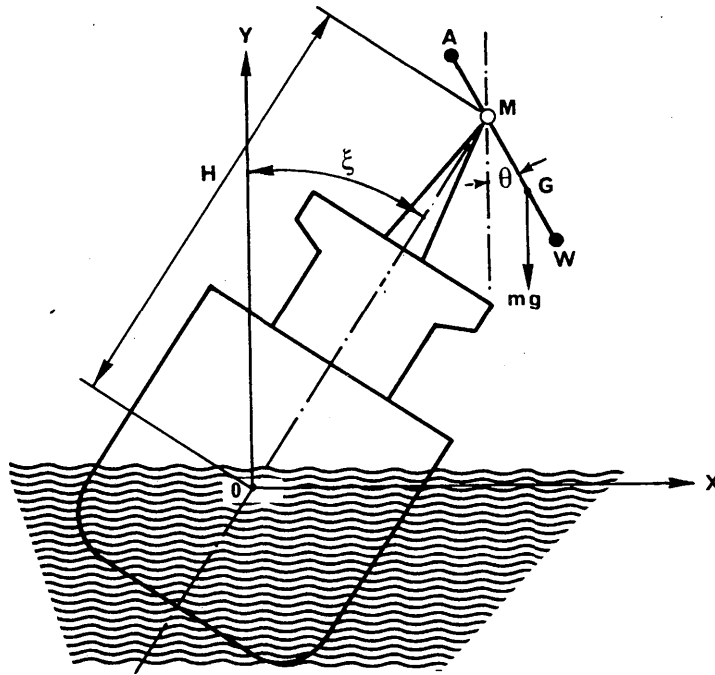
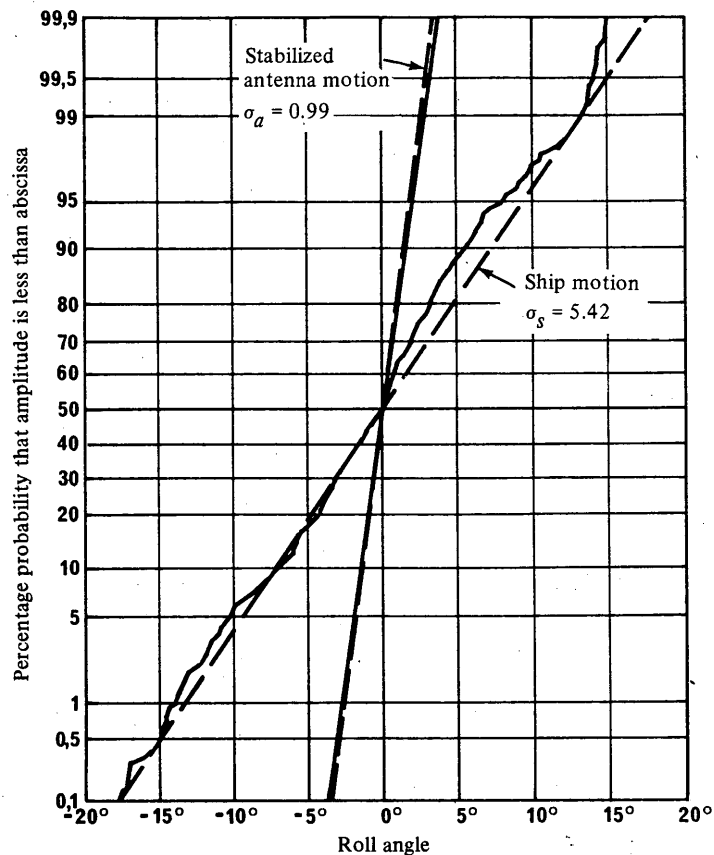


FIGURE 13 – Configuration of passive gravity-stabilizer

- A: antenna
- W: counterweight
- M: universal joint
- G: centre of gravity

FIGURE 14 – *Measured stabilized antenna motion*

— : Measured values
 - - - : Calculated values
 Wave height: approximately 5 m

If p_1 denotes the probability of CPD for the stabilized antenna motion over a short interval of time, the maximum antenna motion angle, X_a , can be calculated by the following relation from equation (1):

$$X_a = \sqrt{2} \sigma_a \cdot \text{erf}^{-1}(2p_1 - 1) \quad (2)$$

where:

σ_a : standard deviation of the stabilized antenna motion; and

$\text{erf}^{-1}(x)$: inverse function of the error function.

For example, for $p_1 = 99\%$: $X_a = 2.4 \sigma_a$. The antenna directivity at X_a (degrees) from the beam centre is equivalent to the maximum received signal level reduction due to antenna motion with a stabilizer at the probability p_1 within a short interval of time. The relationship between standard deviation σ_s and σ_a depends on the design of the passive stabilizer.

The long interval distribution for the standard deviation of ship motion, σ_s , should be determined to evaluate the received signal level fluctuation margin for designing a link budget.

It is well known that the envelope of Gaussian variations with zero mean is Rayleigh distributed. A measured CPD of the roll motion envelope for half amplitude, R , within a short interval of time is shown in Fig. 15. The coordinates in Fig. 15 are scaled so that the Rayleigh CPD appears as a straight line. The short interval CPD of R agrees well with the Rayleigh distribution. The root mean square of R , (R_{rms}) for the Gaussian random process with zero mean and standard deviation σ_s is expressed as follows:

$$R_{rms} = \sqrt{2} \sigma_s \quad (3)$$

Therefore, the long interval distribution of σ_s can be evaluated by the long interval distribution of R_{rms} .

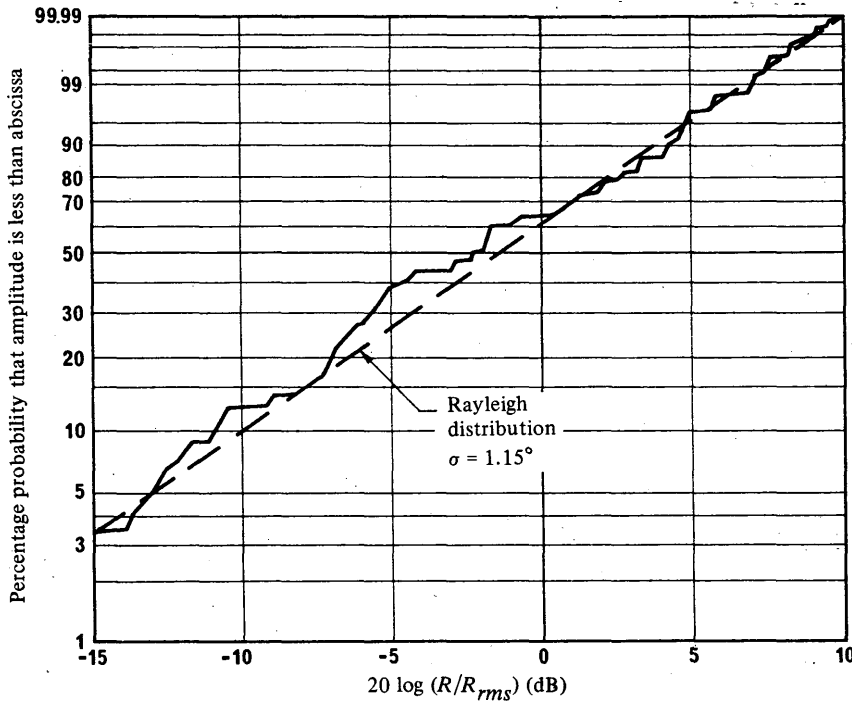


FIGURE 15 – Measured cumulative probability distribution of roll amplitude envelope within short interval of time

— : Measured values
 --- : Calculated values

The long interval distribution of R_{rms} has been studied for a long time and it has been approximated by a log-normal distribution [Jasper, 1956]. However, according to recent studies of long interval distribution during a season, it is known that a Weibull distribution agrees better with measured values for a wider range of probability than a log-normal distribution [Nishinokubi and Kawashima, 1976]. Nevertheless, the long interval distribution of R_{rms} should be studied further. Here a Weibull distribution is assumed in discussing the statistical evaluation method.

The Weibull distribution is employed in the field of ship stress technology. The probability distribution function is expressed as follows:

$$p(x) = q(x/k)^{q-1} \cdot \exp(-(x/k)^q)/k, \quad x > 0 \quad (4)$$

where q and k are experimentally determined parameters. The CPD function is then given by:

$$p(R_{rms} < R_0) = 1 - \exp(-(R_0/k)^q) \quad (5)$$

Using equations (3) and (5), the maximum standard deviation of ship motion σ_{s0} related to $R_{rms} = R_0$ for $CPD = p_2$ can be expressed as follows:

$$\sigma_{s0} = R_0/\sqrt{2} = k(-1n(1 - p_2))^{1/q}/\sqrt{2} \tag{6}$$

According to experimental evaluations of ship roll motion (wave heights around 1 m), during the winter season near Japanese waters, the values of parameters q and k are approximately 1.9 and 5, respectively [Nishino-kubi and Kawashima, 1976]. The long interval CPD of R_{rms} is then shown in Fig. 16, where the coordinates are scaled so that log-normal CPD appears as a straight line. For example, for $P_2 = 99\%$ the maximum standard deviation of ship motion σ_{s0} can be estimated to be less than about 8° during the season of severest ship motion.

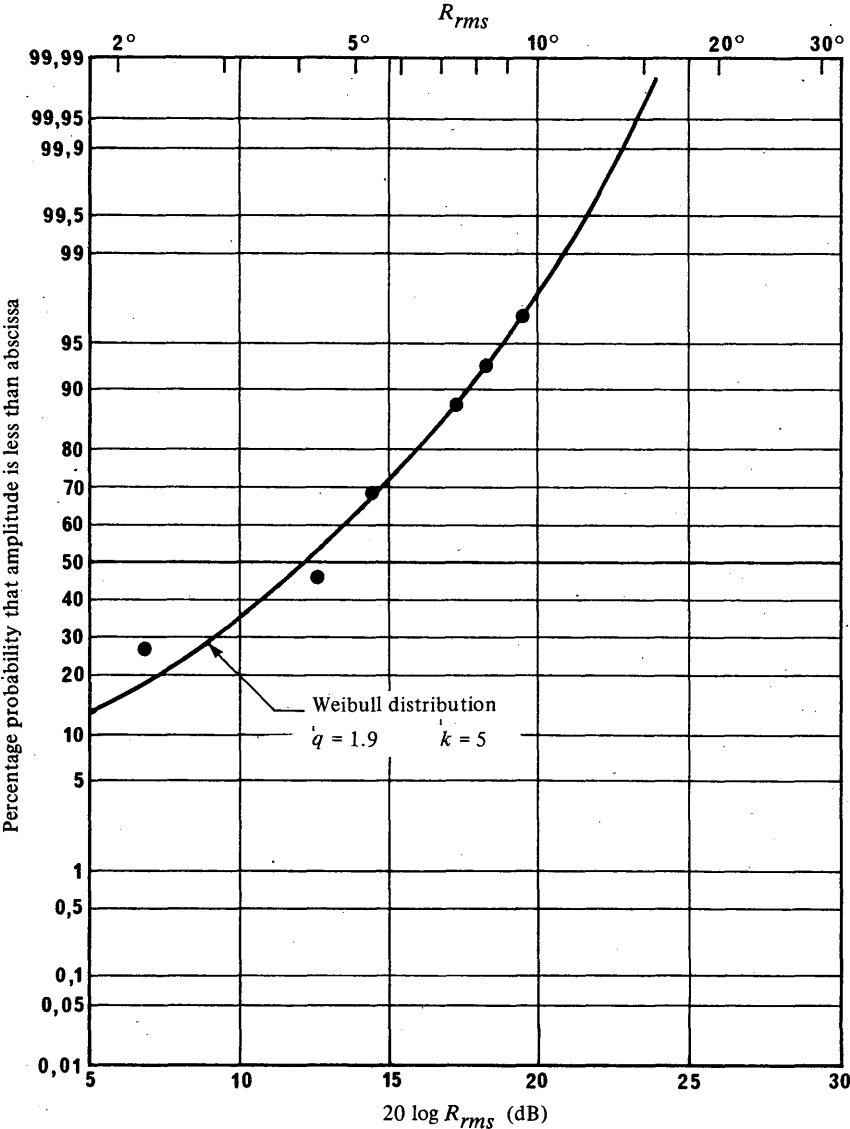


FIGURE 16 – Measured cumulative probability distribution of root mean square of roll amplitude envelope during winter season near Japanese waters

●: Measured values
Wave height: 5-10 m

The maximum standard deviation of the stabilized antenna motion is σ_{a0} . The relation between σ_{a0} and σ_{s0} is experimentally determined, and is dependent on the design of the passive stabilizer. The resultant reduction of the received signal due to antenna off-beam gain change, may then be regarded as the fluctuation margin for designing a maritime mobile satellite communication link budget.

3. Conclusion

Passive stabilizer performance for the development of a low G/T ship earth station requires statistical evaluation. The fluctuation margin of received signal level due to random antenna motion can then be estimated by the instantaneous and long interval cumulative probability distribution functions of ship motion, antenna directivity and stabilizer performance.

A statistical treatment for passive stabilizer performance will be useful in designing a shipborne antenna system and link budget for a future maritime mobile satellite communication system using simple low G/T ship earth stations.

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ANNEX VI

A DATA-ONLY COMMUNICATION SYSTEM FOR MOBILE SATELLITE SERVICES

1. Introduction

This Annex describes data-only communication system, named PRODAT, potentially suitable for application in the fields of the three mobile satellite services, i.e. aeronautical-, maritime- and land-mobile satellite services. The PRODAT system is currently being implemented by the European Space Agency as part of the PROSAT programme which is a test and demonstration programme relating to future mobile satellite communication services. The PRODAT system design is based on the experimental data that were gathered during the first phase of the PROSAT programme. The system will be used during the second phase to perform demonstrations and long-term evaluation of data-only communication services suitable for low G/T mobile earth stations in the three fields of application mentioned above.

The PROSAT phase 1 experiments demonstrated that the aeronautical, maritime and land mobile satellite "channels" are different. However, at system, level their behaviour is very similar: the channel is good for most of the time, but under certain conditions (e.g. low elevation angle or environment in the land mobile case) it can be very bad. In order to minimize the protocol and coding overheads when the channel is good and still be able to cope with most of the unfavourable conditions, it is necessary to find a communication system which adapts itself to the channel characteristics. This is one of the basic design criteria that has been used to define the PRODAT system. The coding and ARQ schemes used in PRODAT for both forward and return links are well adapted to the propagation conditions that low G/T PRODAT mobile earth stations ($G/T = -24 \text{ dB(K}^{-1}\text{)}$) will have to face.

2. PRODAT system

2.1 Satellite link

2.1.1 Forward link

The forward link is a digital link from a network management system to mobile stations through the satellite. The data to be sent to mobiles are multiplexed according to a time division multiplexer scheme (TDM).

The main characteristics of the forward TDM are:

Signalling rate:	1500 Bd
Frame duration:	1.098 s
Data rate (per channel):	46 bits

The coding is based on short block GF (2^4) Reed-Solomon codes and message redundancy is introduced following an automatic repeat request (ARQ) scheme.

2.1.2 Return link

The return link is a digital link from mobile stations to the network management system through the satellite. The data from mobile stations are transmitted according to a code division multiple access (CDMA) scheme.

The main characteristics of the return CDMA are as follows:

Number of codes:	32
Signalling rate (per channel):	300 Bd
Data rate (per channel):	150 bits
Chip code length:	889

The coding is organized in a way similar to that of the forward link.

2.2 Communication functions

The PRODAT system will provide the following functions:

- transmitting of messages from fixed user to mobile user and *vice versa*, and from mobile-to-mobile users;
- transmitting of messages to multiple mobile users;
- dialogue between a fixed user and a mobile user;
- request/reply function;
- periodic polling of mobile stations;
- paging.

Each user will not necessarily have access to all functions.

For the purpose of PROSAT phase 2 demonstrations, the network management system will provide interfaces to the public data network, public telephone and telex networks.

2.3 Coding scheme and ARQ function

The PRODAT system is based upon the use of a bi-dimensional coding scheme and the implementation of an ARQ scheme.

The information is organized in “blocks”, each block being a set of extended RS (16 : 12) code vectors (vertical coding). Each code vector occupies a TDM slot. The symbols of the code vectors are elements of the Gallois Field GF (2^4) containing 4 signalling bits each. The vertical coding is used to correct random errors. A detailed description of the coding scheme is given in Report 509, Annex II.

2.4 Return link CDMA

The selected access scheme in the return link is CDMA. The modulated signal is spread using a 127 Gold code tiered by a 7 bit Barker sequence. The modulation by the spreading code is 2-PSK, and the chip rate is 266.7 kHz. The maximum cross correlation peak is less than -13 dB (with respect to the autocorrelation peak) and the mutual interference degradation less than 2 dB.

The advantages that CDMA will provide are as follows:

- improved protection against interfering signals;
- improved efficiency in the performance of the random access channel (two signals spaced by one or two chips can be distinguished);
- better efficiency of the return data link with respect to TDMA (no need for guard times to avoid signal garbling);
- spreading of intermodulation products in the return transponder of the satellite (hence the possibility of accommodating higher signal dynamics or improving the link performance);
- improved frequency re-use capability for satellite multi-beam antennas; and
- less peak power than for TDMA in the ship earth-station transmitter.

2.5 Channels

The following channels are provided in the forward TDM frame:

- S0: unique work
- S1: signalling channel (access)
- S2: sub-multiplex for backward sub-channel (acknowledgement)
- S3: signalling channel (access)
- D001-017: data channels (17)

In the return link 30 CDMA codes are used, each code being associated to a particular channel:

- RA1: random access call channel
- D051-062: data channels (12)
- D101-117: backward sub-channels (17)

Backward sub-channels are used to transmit acknowledgement messages.

2.6 Synchronization (return link)

Transmissions on any particular channel, except the random access channel, occur once the channel is assigned to a given mobile station. Therefore only one mobile station is transmitting during the assignment period in a particular channel.

3. PROSAT phase 2 programme

The PRODAT system is being developed in the frame of the second phase of the PROSAT programme. All procurements relating to PRODAT (ground facilities, mobile earth stations for aeronautical, maritime and land mobile satellite applications) have already been initiated. The PRODAT trials and demonstrations are expected to start by April, 1987. This will involve up to 16 mobile earth stations including 3 maritime terminals, 7 aircraft terminals and 6 land mobile terminals.

REPORT 922-1

REFERENCE RADIATION PATTERN FOR SHIP EARTH-STATION ANTENNAS

(Study Programme 17A/8)

(1982-1986)

1. Introduction

Consideration is given in this Report to the reference antenna pattern for ship earth stations to be used in assessing interference between ship earth stations and either terrestrial stations or space stations of different satellite systems sharing the same frequency bands.

The objective of this Report is to present actual measurement of antenna patterns taken on a test range and show that these measured patterns are well below the reference pattern proposed by other Study Groups and defined by the WARC-79.

2. Existing reference radiation patterns

Reference radiation patterns have been developed in various Study Groups of the CCIR; Report 390 and Report 391 in Study Group 4, Report 771 in Study Group 8 and Report 614 in Study Group 9. These Reports give a reference radiation pattern for antennas with diameter less than 100λ , as stated below.

$$\begin{aligned}
 G &= 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi & \text{dB} & \quad \text{for } 100 \frac{\lambda}{D} \leq \varphi < \varphi_1 \\
 G &= G_1 & \text{dB} & \quad \text{for } \varphi_1 \leq \varphi
 \end{aligned}$$

where:

D : antenna diameter	} expressed in the same unit
λ : wavelength	
φ : angle from beam centre, in degrees	

In Report 391, G_1 is taken to be -10 dB. On the other hand, in Report 614, G_1 is taken to be 0 dB. For values of φ less than $100 \lambda/D$, WARC-79 has defined the following reference radiation pattern for interference calculations:

$$\begin{aligned}
 G &= G_{\max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 & \text{dB} & \quad \text{for } 0 < \varphi < \varphi_m \\
 G &= 2 + 15 \log \frac{D}{\lambda} & \text{dB} & \quad \text{for } \varphi_m \leq \varphi < 100 \frac{\lambda}{D} \\
 \text{where, } \varphi_m &= \frac{20\lambda}{D} \sqrt{G_{\max} - 2 - 15 \log \frac{D}{\lambda}} & & \quad \text{(degrees)}
 \end{aligned}$$

and $G_{\max}$ = maximum gain of the antenna relative to isotropic.

These equations assume the case of a circular paraboloidal reflector antenna, which might not be relevant for some kinds of antennas which could be used in the future for ship earth stations. Therefore, the use of this kind of pattern should clearly be restricted to the case of circular paraboloidal reflector antennas. Moreover, the above Reports have not specifically considered the question of the applicability of these equations to very small values of D/λ ; therefore, for antennas of such diameter as small as 4λ , the value of G_1 must be carefully established taking into account measured radiation patterns.

3. Measured antenna patterns

All production designs of ship earth stations manufactured to date for use in the MARISAT system have employed a parabolic reflector antenna having a diameter of between 1.2 and 1.3 m with a G/T of -4 (dBK $^{-1}$). This value of G/T is the current requirement for INMARSAT Standard-A ship earth stations.

Figures 1 and 2 present measured antenna patterns for 1.3 m antenna for transmit and receive frequencies, respectively. Figures 3 and 4 present measured antenna patterns for 1.2 m antenna for transmit and receive frequencies, respectively. Figure 5 presents measured antenna pattern for 0.8 m antenna for receive frequencies.

In submitting information on measured radiation antenna patterns, the following guidelines should be adopted:

- for each antenna diameter, only two Figures should be presented, one for transmit band and one for receive band, which should include all available data for this type of antenna;
- only the peaks of the side lobes measured over the appropriate frequency band and antenna pattern cut should be plotted, for any angle from beam centre;
- the reference radiation pattern as described in § 5 should be included in all Figures;
- the Figures should be one-sided (right-hand) with measured peaks from both sides superimposed;
- the caption of the vertical axis should read “Gain relative to isotropic (dB)” with a scale of 2 dB/cm;
- the caption of the horizontal axis should read “Angle from beam centre (degrees)” with a linear scale of $10^\circ/8$ mm;

Figures 1 to 5 in this Report have been prepared using these guidelines.

4. Effect of reflection due to sea and ship's superstructures

Considerations have been given to the concept that the design objectives and the reference radiation pattern for interference studies may be defined separately, because the reference radiation pattern should include the effect of local reflections from the sea and ship's superstructure.

However, it is very difficult to estimate quantitatively such effects, which may be of the order of several dB, because the directions of reflected waves vary in accordance with the ship movement. Moreover, the time probability of the interference caused by such reflected side lobes is very difficult to assess. Further study is needed to clarify the effect of such reflections.

5. Reference radiation pattern for ship earth stations

Based on the above and using a conservative approach, it may be reasonable to adopt the following reference radiation pattern for the antennas of ship earth stations:

$$\begin{aligned}
 G &= G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 & \text{dB} & \quad \text{for } 0 < \varphi < \varphi_m \\
 G &= 2 + 15 \log \frac{D}{\lambda} & \text{dB} & \quad \text{for } \varphi_m \leq \varphi < 100 \frac{\lambda}{D} \\
 G &= 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi & \text{dB} & \quad \text{for } 100 \frac{\lambda}{D} \leq \varphi < \varphi_1 \\
 G &= 0 \text{ dB} & & \quad \text{for } \varphi_1 \leq \varphi
 \end{aligned}$$

$$\text{where: } \varphi_m = \frac{20\lambda}{D} \sqrt{G_{max} - 2 - 15 \log \frac{D}{\lambda}} \quad (\text{degrees})$$

$$\varphi_1 = 120 \left(\frac{\lambda}{D} \right)^{0.4} \quad (\text{degrees})$$

and where other variables are defined in § 2.

This pattern has been indicated on Figs. 1 to 6.

6. INMARSAT side lobe performance requirement

Based on the measured radiation patterns of paraboloidal antenna with diameters between 0.8 m and 1.2 m, the following expression has been determined as the performance requirement for the sidelobe envelope of INMARSAT Standard-A ship earth stations:

$$\begin{aligned}
 G &= 8 & \text{dB} & \quad (16^\circ \leq \varphi \leq 21^\circ) \\
 G &= 41 - 25 \log \varphi & \text{dB} & \quad (21^\circ < \varphi \leq 57^\circ) \\
 G &= -3 & \text{dB} & \quad (\varphi > 57^\circ)
 \end{aligned}$$

where G is the antenna gain relative to isotropic at an angle φ from beam centre.

The INMARSAT antenna pattern is illustrated in Fig. 6, together with the reference radiation pattern derived from § 5, for 1.2 m antenna diameter (24 dB maximum gain).

7. Conclusion

Based on the measured radiation patterns of ship earth stations, it is proposed to adopt provisionally the reference radiation pattern for interference studies as given in this Report, for the circular paraboloidal reflector antennas of D/λ higher than 4 to be used for ship earth stations. In order to assure the suitability of this reference radiation pattern, administrations are invited to study further and submit measured radiation patterns of ship earth stations of various sizes, using the guidelines delineated in § 3.

To take into account that antennas other than parabolic may be used for ship earth stations, it would be desirable to examine additional measured radiation patterns, and administrations are invited to submit such information on various antenna types and sizes, using the guidelines delineated in § 3.

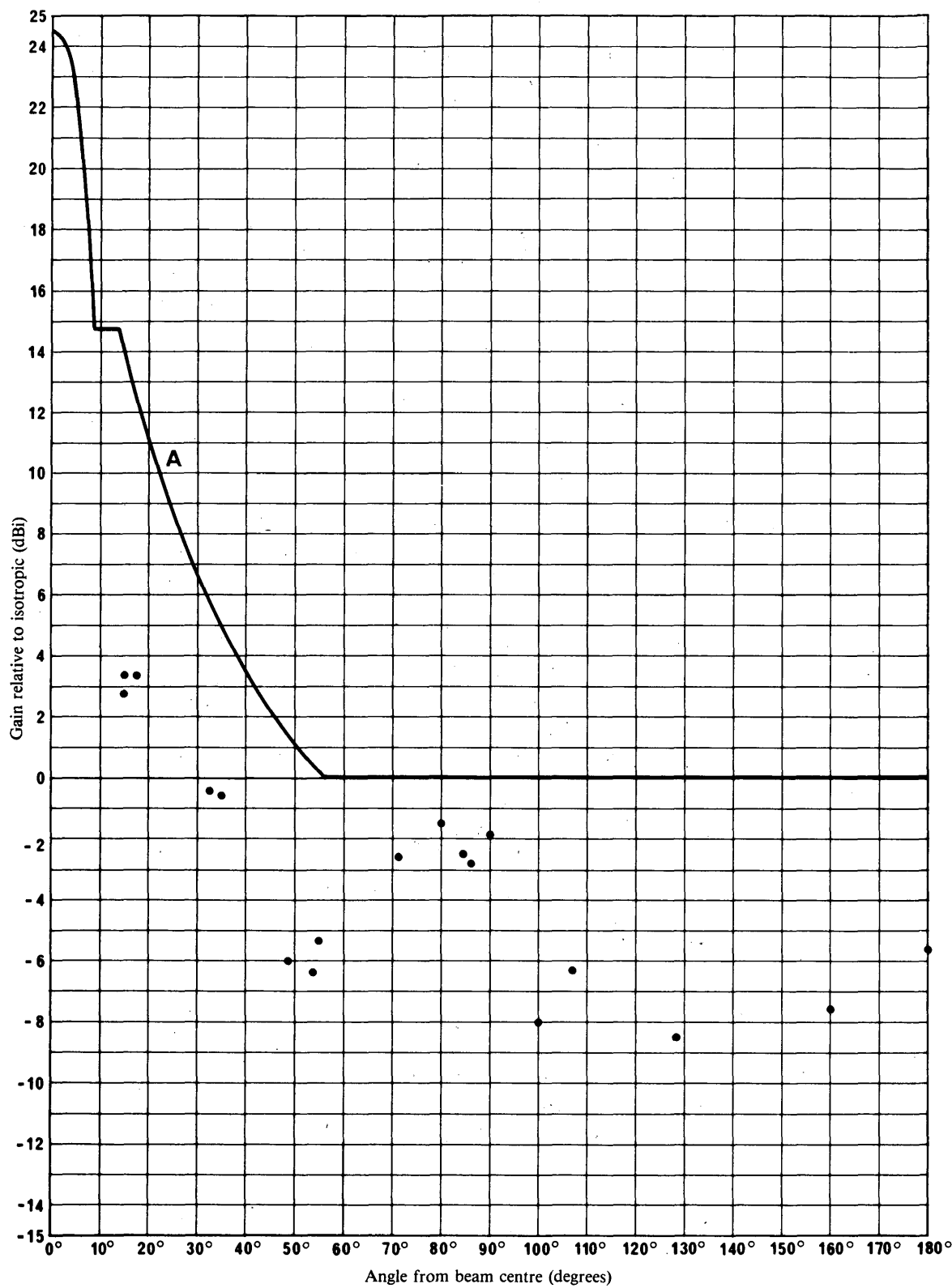


FIGURE 1 – Measured antenna pattern for a ship earth station antenna

Type of antenna: circular parabolic
Frequency band: 1636.5-1645 MHz (transmit)
Diameter: 1.3 m

●: maximum gain: 24.6 dBi Polarization: RH circular Manufacturer: UK
A: reference radiation pattern

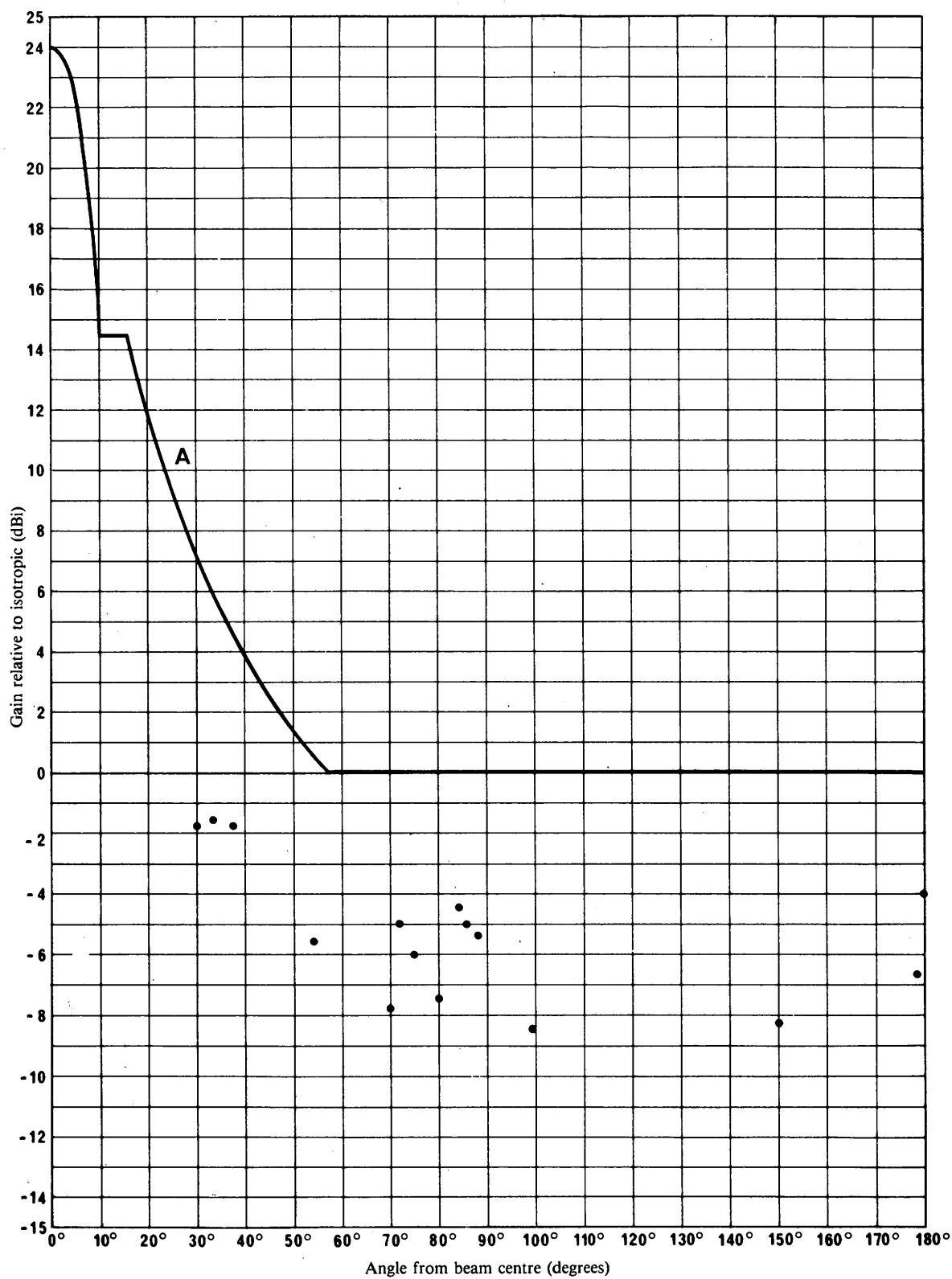


FIGURE 2 – Measured antenna pattern for a ship earth station antenna

Type of antenna: circular parabolic
Frequency band: 1535-1543.5 MHz (receive)
Diameter: 1.3 m

● : maximum gain: 24 dBi Polarization: RH circular Manufacturer: UK
A: reference radiation pattern

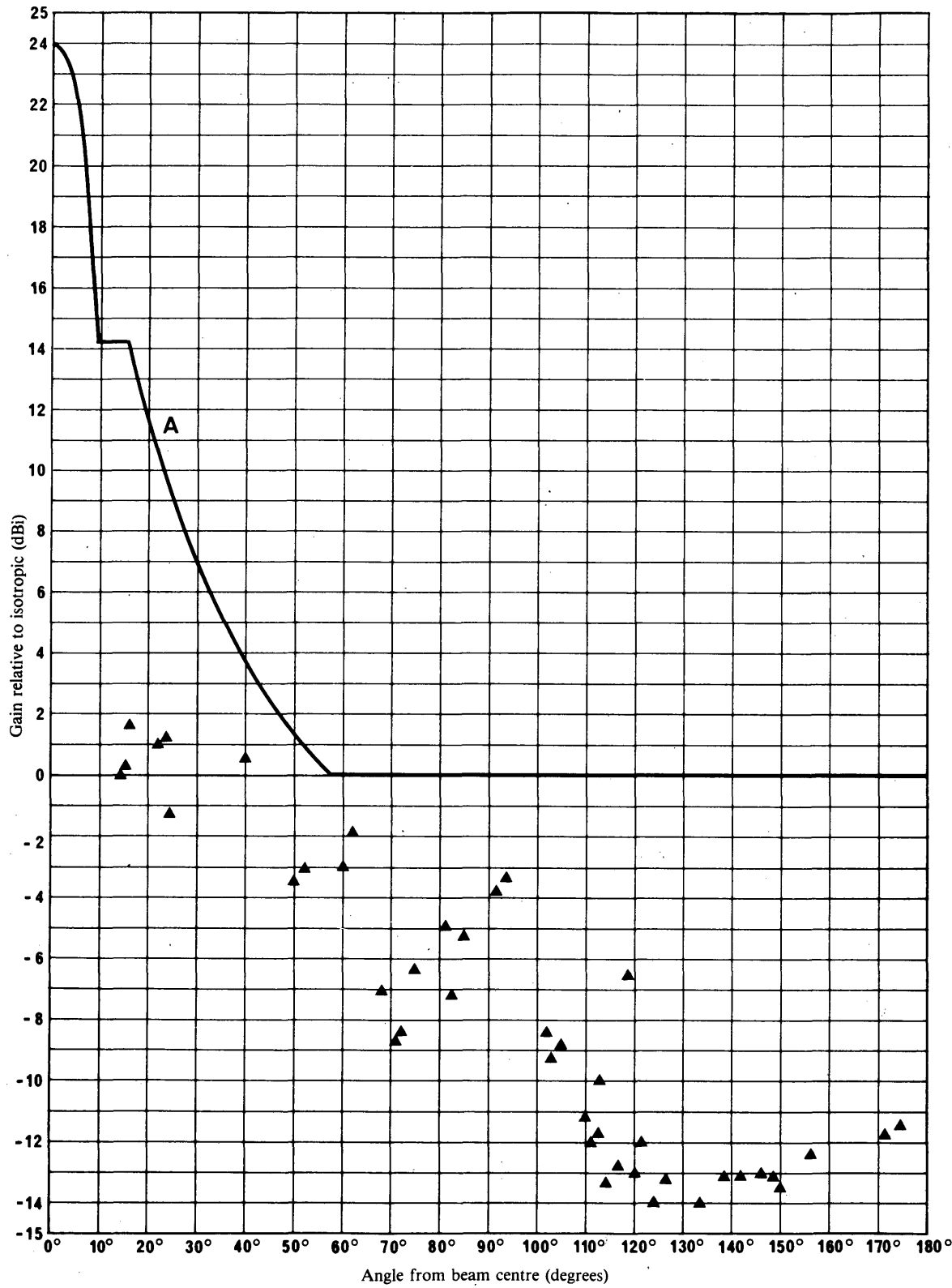


FIGURE 3 – Measured antenna pattern for a ship earth station antenna

Type of antenna: circular parabolic
Frequency band: 1636.5-1645 MHz (transmit)
Diameter: 1.2 m

▲: maximum gain: 24 dBi Polarization: RH circular Manufacturer: USA
A: reference radiation pattern

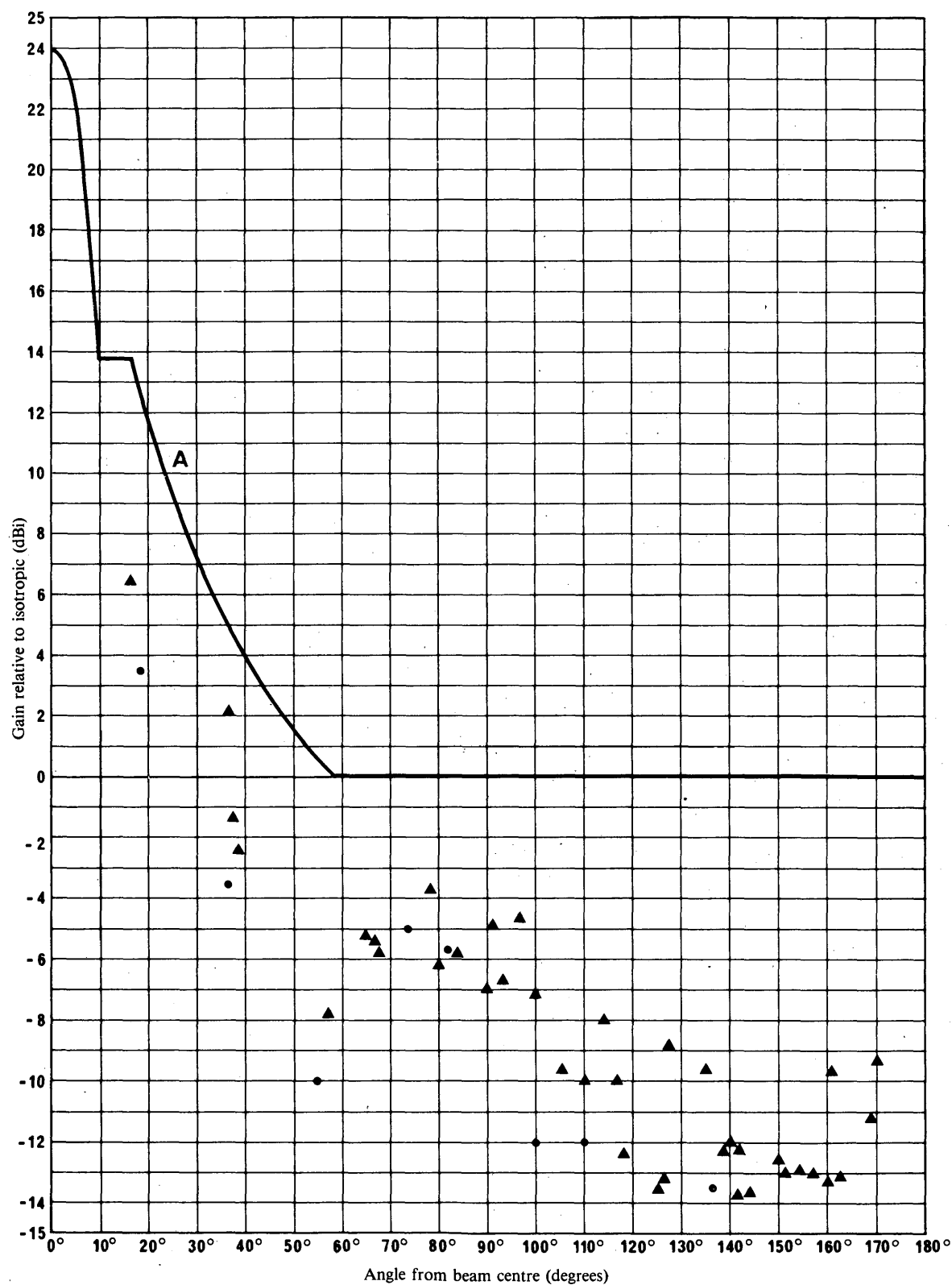


FIGURE 4 – Measured antenna pattern for a ship earth station antenna

Type of antenna: circular parabolic
Frequency band: 1535-1543.5 MHz (receive)
Diameter: 1.2 m

● : maximum gain: 23.9 dBi	Polarization: RH circular	Manufacturer: Japan
▲ : maximum gain: 23.5 dBi	Polarization: RH circular	Manufacturer: USA
A: reference radiation pattern		

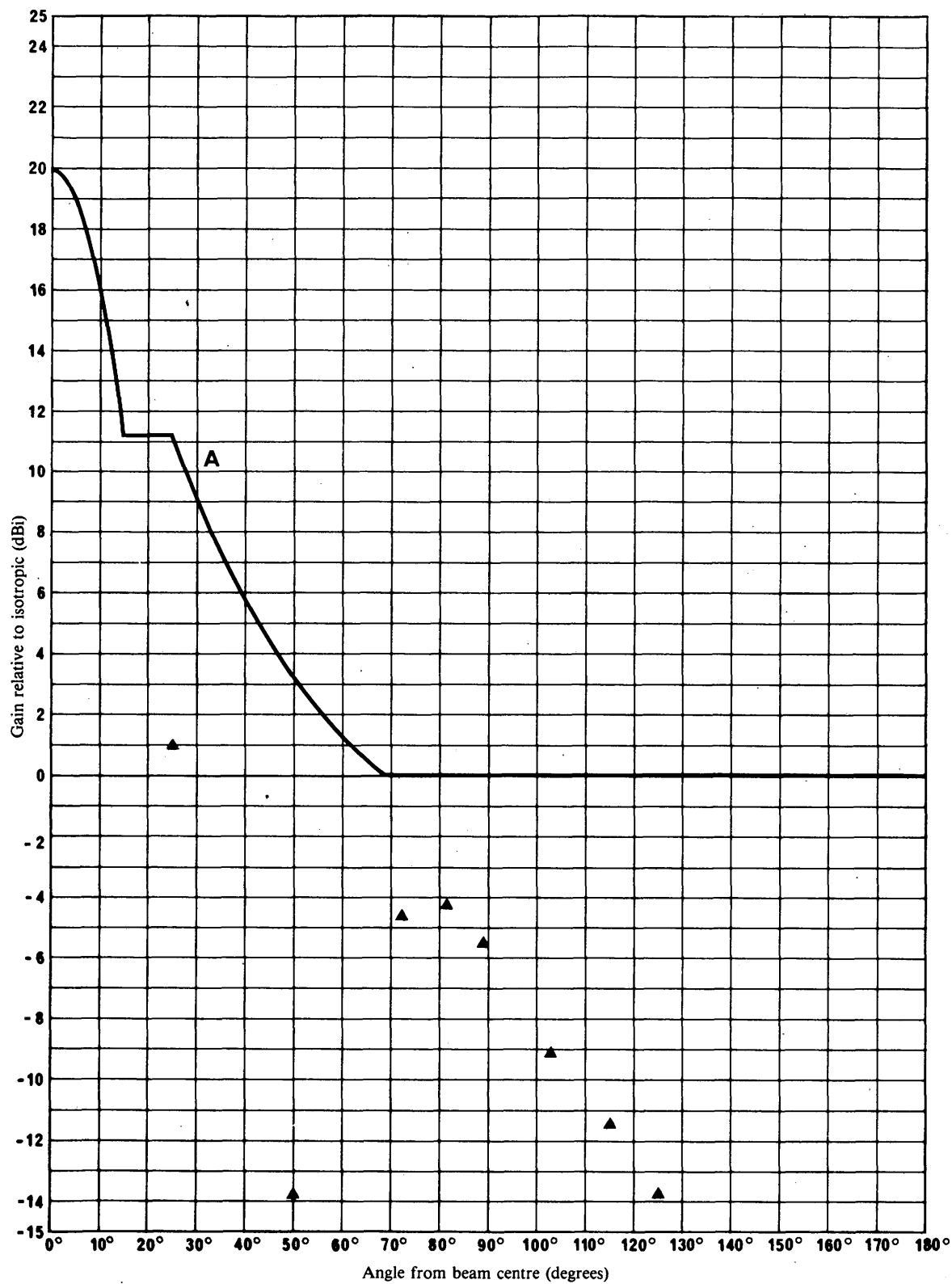


FIGURE 5 – Measured antenna pattern for a ship earth station antenna

Type of antenna: circular parabolic
Frequency band: 1535-1543.5 MHz (receive)
Diameter: 0.8 m

▲: maximum gain: 20 dBi Polarization: RH circular Manufacturer: Japan
A: reference radiation pattern

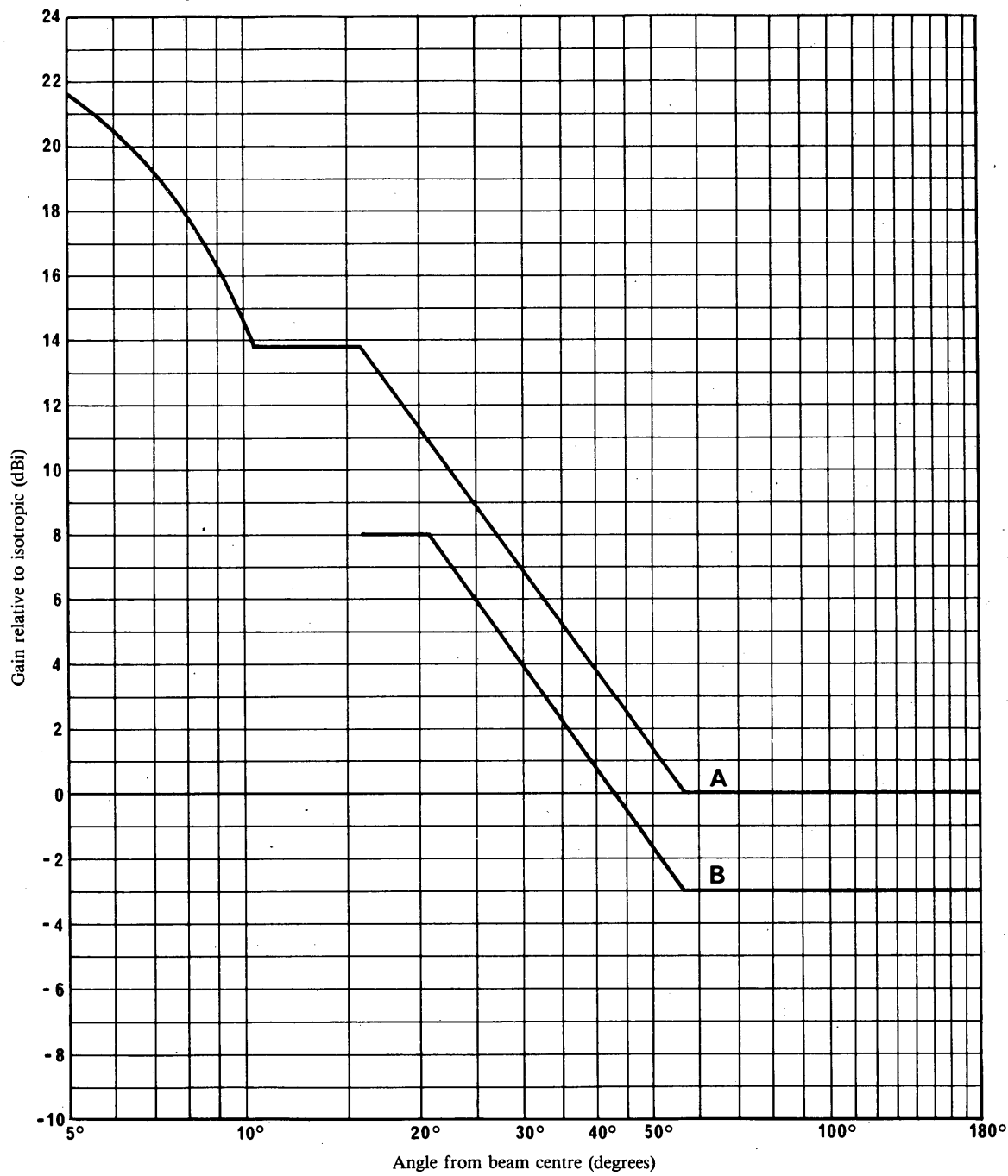


FIGURE 6 – INMARSAT antenna side lobe envelope for Standard-A ship earth stations

A: reference radiation pattern (1.2 m antenna diameter, 24 dBi maximum gain)
B: INMARSAT pattern

ANNEX I

A SMALL LOW-COST ANTENNA FOR USE WITH LOW *G/T* SHIP EARTH STATIONS

This Annex provides the measured radiation patterns of an antenna of simple design using an equi-angular spiral feed and low cost construction with a gain of 13 dBi and a beamwidth wide enough to obviate the need for a sophisticated stabilization system. The side-lobe performance compares favourably with the INMARSAT requirements for a standard A antenna (Figs. 7 and 8). Although the antenna was primarily designed for use with a low *G/T* ship earth station it could well have other applications in the mobile satellite service.

A fuller description of this type of antenna is given in Report 921.

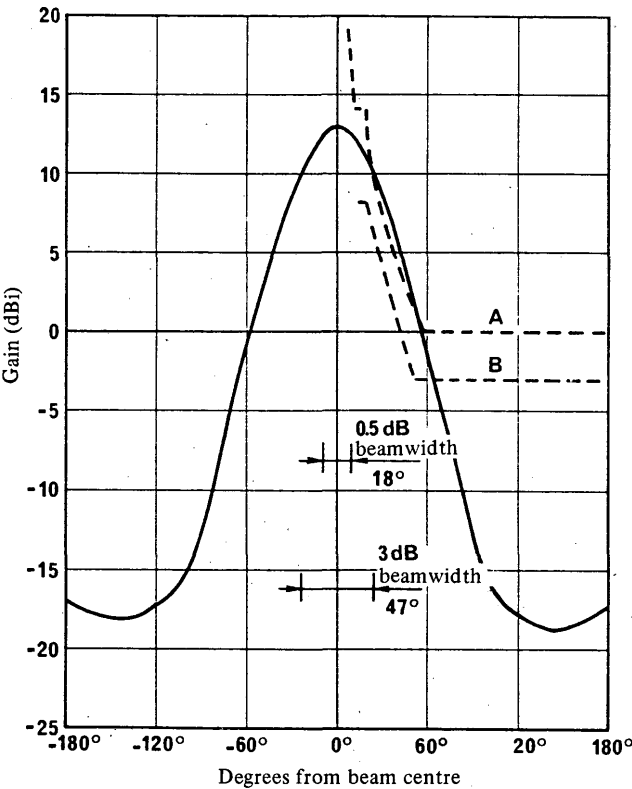


FIGURE 7 – Measured radiation pattern from a short back-fire antenna

Type of antenna: short back-fire
Diameter: 0.4 m
Frequency band: 1535–1543.5 MHz
Maximum gain: 13 dBi
Polarization: RHC
A: CCIR reference pattern
B: INMARSAT reference pattern

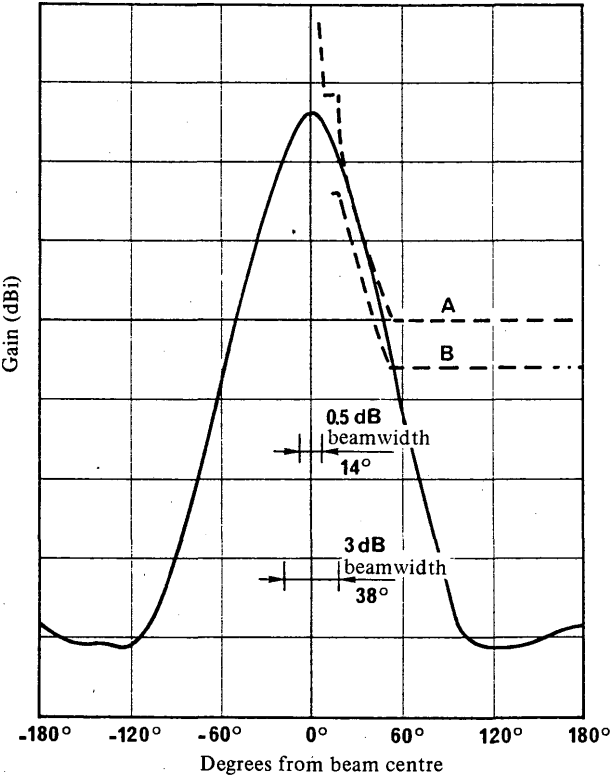


FIGURE 8 – Measured radiation pattern from a short back-fire antenna

Type of antenna: short back-fire
Diameter: 0.4 m
Frequency band: 1636.5-1645 MHz
Maximum gain: 13 dBi
Polarization: RHC
A: CCIR reference pattern
B: INMARSAT reference pattern

REPORT 1048

FADING REDUCTION TECHNIQUES APPLICABLE TO SHIP EARTH-STATION ANTENNAS

(Question 17/8 and Study Programme 17A/8)

(1986)

1. Introduction

For low G/T systems, the effect of multipath fading due to sea surface reflection is a severe problem, especially at low elevation angles as pointed out in § 5 of Report 921. This Report surveys possible fading reduction techniques for low G/T ship earth-station antennas and presents field experimental results on the reduction effects. The antennas reported in these tests are described in more detail in Report 921.

2. Survey on fading reduction techniques

The following methods are possible as fading reduction techniques applicable to low G/T ship earth-station antennas:

- diversity method,
- polarization method,
- pattern shaping method,
- maximum level tracking method,
- beam offset method.

2.1 Diversity methods

Diversity techniques such as space, polarization and frequency diversity have already been used practically in radiocommunication systems subject to severe fading. The space diversity technique needs two or more antennas, while other diversity techniques can be effected using a single antenna. In any case, the fading reduction effect largely depends on the correlation of signals with different properties, such as frequencies, polarization and time difference. Figure 1 shows the principle of space diversity with a switch and stay algorithm [Kozono and Yoshikawa, 1981]. As is seen in this figure, the diversity output results in $R(t)$, when signal levels through antenna 1 and antenna 2 are $r_1(t)$ and $r_2(t)$, respectively. With this technique, the greatest reduction effect is expected when the correlation of the signals between the two antennas is lowest. In practice, it may not be possible to set up the antennas with the optimum spacing of a half wavelength.

Frequency diversity can produce a good reduction effect when the path difference between the direct and reflected waves is greater than one wave length of the difference frequency between two frequencies used. Assuming that the height of the ship antenna is 15 m, the elevation angle is 5° and the frequency separation is 15 MHz, which is the maximum separation with the current 1.6 GHz band maritime mobile satellite service allocations, then, at the most, the path difference is only 0.14 wave length of the difference frequency. Therefore, frequency diversity does not seem practicable at this stage, because of the limited separation of the two frequencies. However, if the frequency band were to be widened in the future, this method could be applicable.

2.2 Polarization method

For reflections from the sea surface at 1.64/1.54 GHz, the horizontally linear polarized wave is almost perfectly reflected, while the vertically polarized wave is reflected with fairly large attenuation at incident angles, with respect to the horizontal plane, of less than 10° . Furthermore, the phase angle of a vertically polarized wave undergoes a continuing change as the elevation angle increases, whereas the phase of a horizontally polarized wave remains unchanged at all but the highest elevation angles. Above around 6° elevation angle, the phase and amplitude relationship between the horizontal and vertical components of an incident circularly polarized wave is such that upon reflection it becomes elliptical and reversed in its sense of rotation, with its major axis nearly horizontal. (An elevation angle of around 6° is the Brewster angle at 1.5/1.6 GHz over sea paths; for more information see Report 1008.) Accordingly, if the polarization ellipse of a shipborne antenna, in the direction of the reflected wave, could be adjusted so that it always stays orthogonal to that of the reflected wave, the reflected wave can be suppressed. This principle [Shiokawa and Karasawa, 1982] can be easily applied to cross dipole fed antennas such as a short back-fire antenna. For instance, if it is arranged that the cross dipole elements are inclined by 45° with respect to the horizontal line, and the phase is adjusted by a phase shifter inserted in one of the ports of the short back-fire antenna feed as shown in Fig. 2a), the axial ratio of this antenna can be arbitrarily controlled. In this case, the major axis of the polarization ellipse is always vertical as shown in Fig. 2b).

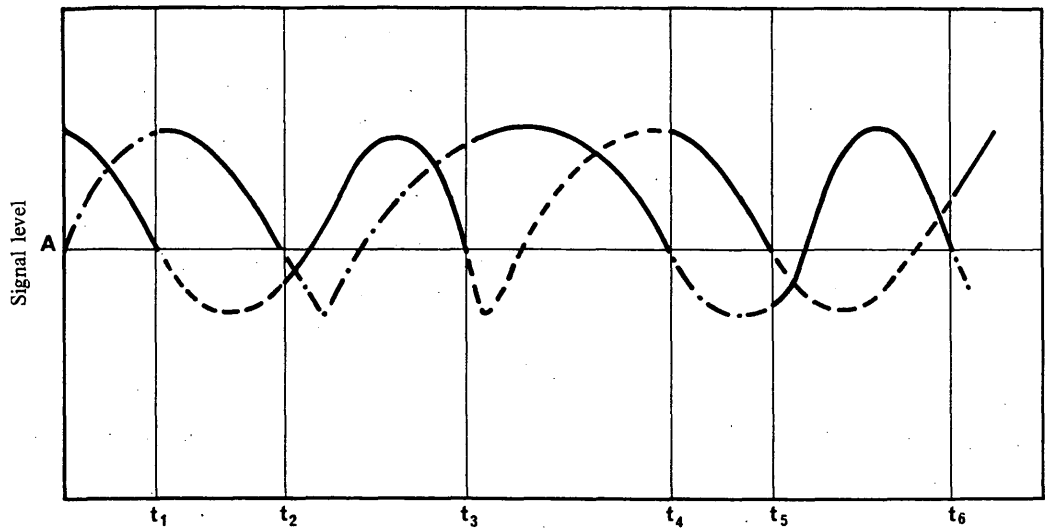
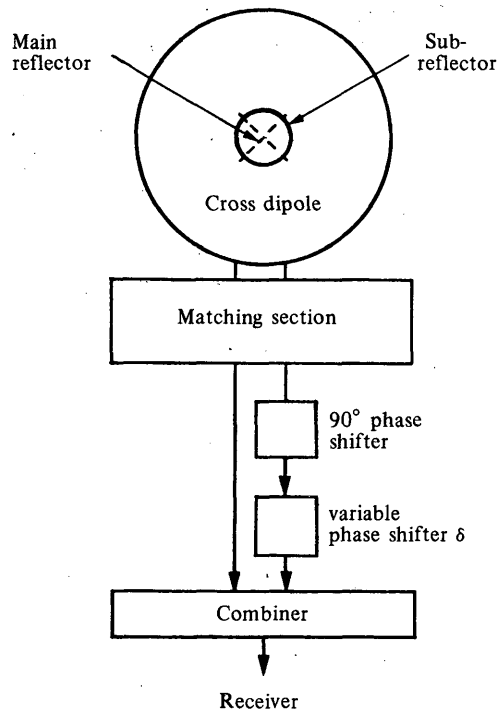


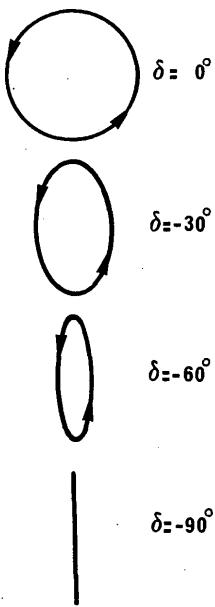
FIGURE 1 – Principle of switch and stay algorithm

— · — · — $r_1(t)$
- - - $r_2(t)$
— $R(t)$

Note.— The input to the receiver is switched to the serial from which the output is rising when the input of the selected antenna falls below a pre-determined level “A”.



a). Block diagram



b) Polarization ellipse of ship antenna

FIGURE 2 – Short back-fire antenna with polarization method (A)

Recently, another reduction technique applying a polarization method has also been proposed [Ohmori and Miura, 1983]. This method (polarization method (B)) makes use of the polarization characteristics of the sea-reflected wave and of the electrical characteristics of a hybrid combiner. This method is based on the difference of reflection coefficients of sea surface, as in the case of circular polarization, for cross-polarized as against co-polarized waves. In this case it is noticed that the amplitude of the cross-polarized circular component is greater than that of the co-polarized component when the elevation angle is greater than about 6° . Accordingly, by making the amplitudes of both reflected components equal and setting the phase difference to be out of phase ($\pm 180^\circ$) with each other, it should be possible to get a direct wave without fading. In this method, a phase shifter (which is pre-programmed to optimize the phase shift at a particular elevation angle) and a power combiner are added to the ordinary circular polarized antenna equipment as shown in Fig. 3, where the direct and the reflected co-polarized components are put out on terminal T3 and the reflected cross-polarized component is put out on terminal T4. Although this method has a few disadvantages such as an increase of insertion loss due to the 3 dB power combiner loss and the increase of thermal noise temperature due to the attenuator, a large reduction effect is expected, especially when the fading is very severe.

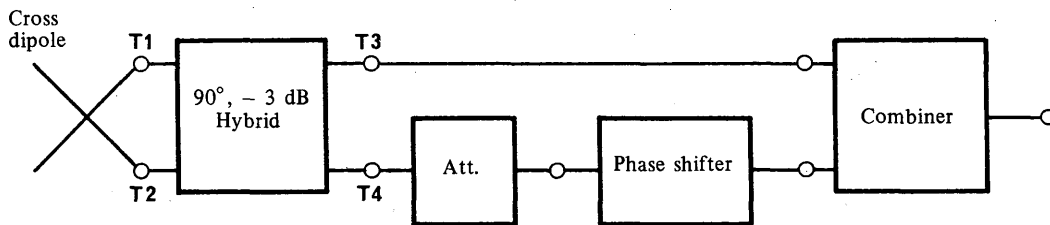


FIGURE 3 – Configuration of polarization method (B)

2.3 Pattern shaping method

It is possible to suppress the reception of a reflected signal by using a shaped pattern antenna which has low gain radiation characteristics in the direction of the sea-reflected wave. This method may be realized by an antenna array or a shaped reflector antenna. Figure 4 shows an example of the radiation pattern of a shaped pattern antenna [Ohmori *et al.*, 1980]. The radiation pattern is shaped so as to be flat in the main beam and to be suppressed in other directions. This antenna is expected to have a good reduction effect when the reflected waves come from directions away from the main beam. The shaped pattern antenna, however, has the disadvantage that the aperture efficiency of the antenna is in general comparatively low.

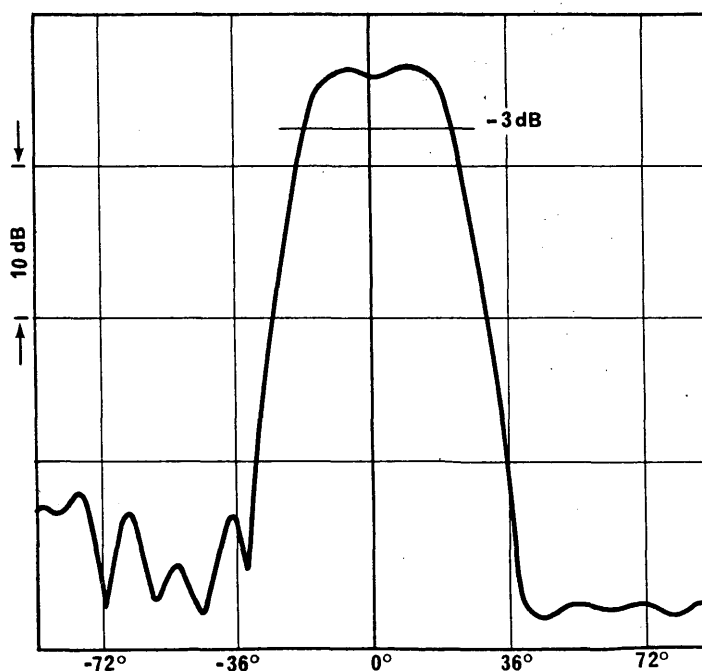


FIGURE 4 – Radiation pattern of shaped pattern antenna

Gain: 16 dBi (1.54 GHz)

2.4 Maximum level tracking method

If the radiation characteristics of an antenna in the direction of the reflected wave are controlled so that the received signal intensity is always maintained at a higher level, the fading could be substantially suppressed. This principle [Shiokawa and Karasawa, 1982] can be easily applied to an antenna array. The phase of a variable phase shifter inserted in the feed circuit for each antenna element is varied by a small amount by changing its control voltage in order to see whether the resultant signal level increases or not. The phase has to be adjusted at a rate sufficiently fast to track the speed of the fading. If the signal level increases, the control voltage is allowed to change continuously in the same direction. If not, the polarity of the control voltage has to be reversed to control the variable phase shifter in the opposite direction. Fading can be reduced by repeating this operation. Figure 5 shows a block diagram illustrating an example of this method applied to a quad-helix antenna.

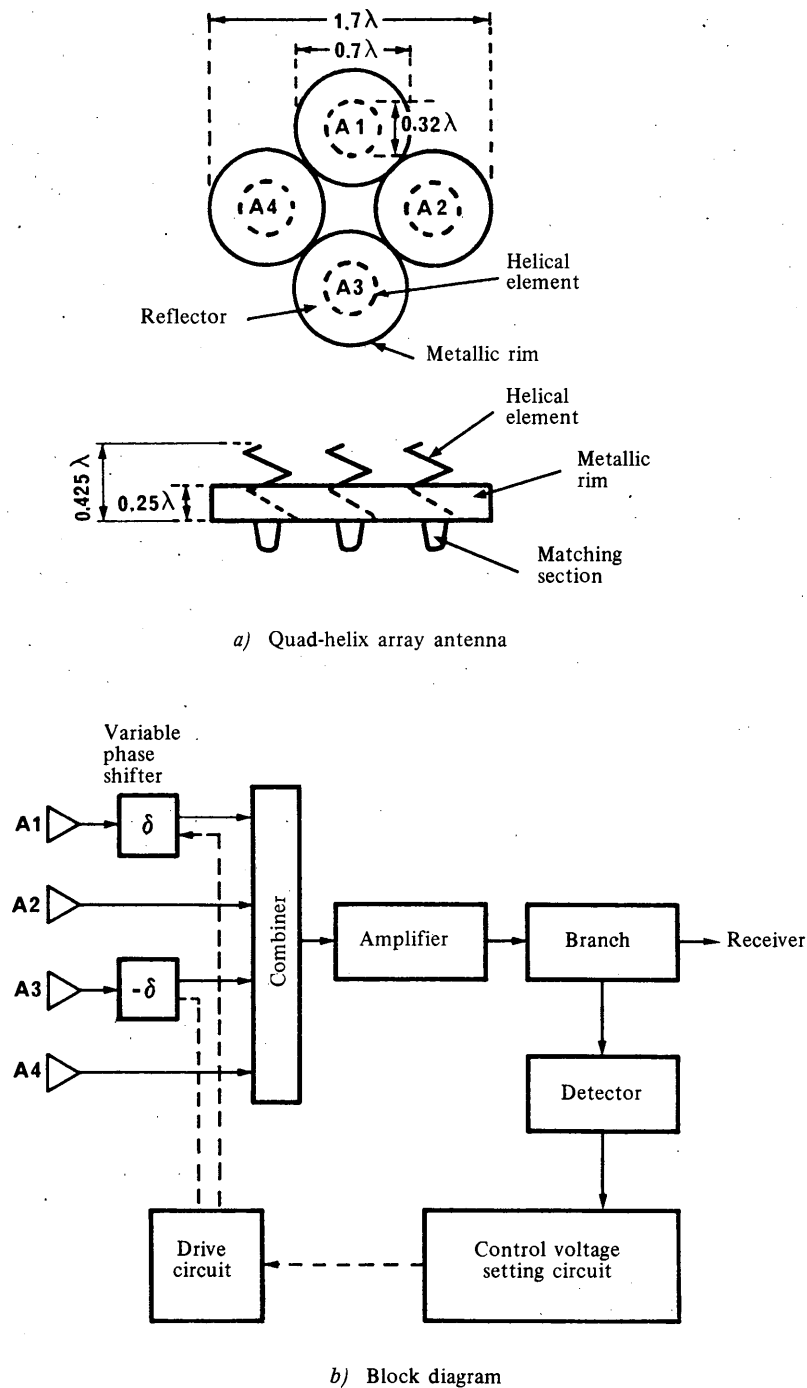


FIGURE 5 – Quad-helix antenna with maximum level tracking method

2.5 Beam offset method

If the beam axis of a ship antenna could be varied slightly with satellite direction, fading due to sea reflection could be suppressed by the general characteristics of the ship antenna so that the degradation of antenna gain in the direction of the reflected wave would be generally greater than the boresight error. This is achieved by utilizing a program tracking antenna system. It would also be possible to reduce the fading by the polarization characteristics of the ship antenna. Figure 6 shows the measured polarization ellipse of the short back-fire antenna [Yamada *et al.*, 1981]. From this figure, if the cross-dipole is arranged to be inclined by 45° with respect to the horizontal line, the major axis of the polarization ellipse in the vertical plane is nearly vertical and the degradation of axial ratio becomes bigger as the angle, with respect to the beam centre, becomes larger. On the other hand, the major axis of the sea-reflected wave is nearly horizontal, in the case of an elevation angle lower than about 10° , as shown in § 2.2. Therefore, the relation between both polarization ellipses approaches more closely the orthogonal condition (see § 2.2) compared to the case where beam offset is not applied.

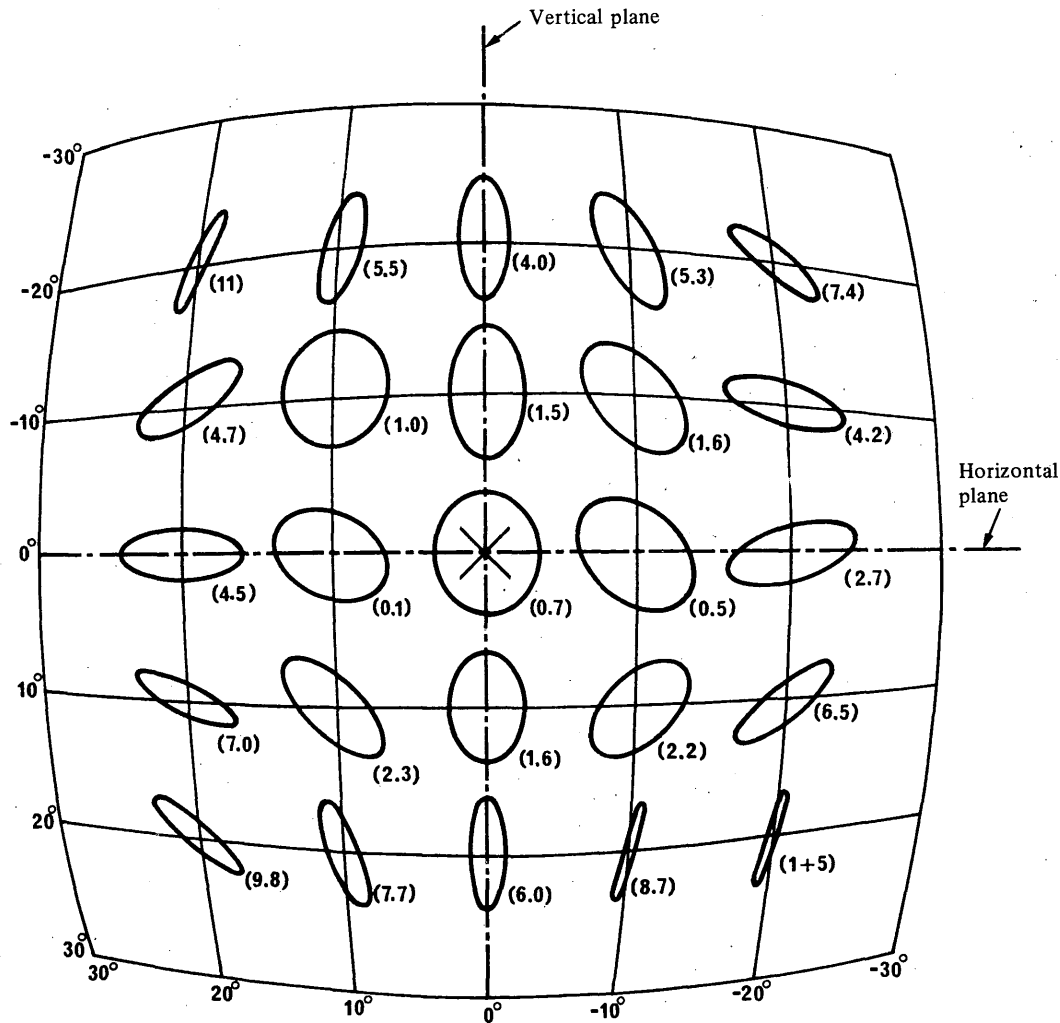


FIGURE 6 – Polarization ellipse of short back-fire antenna
(antenna gain: 12 dBi)

3. Field experimental results on reduction effects

3.1 Space diversity

A space diversity experiment [Kozono and Yoshikawa, 1981] applying the switch-and-stay algorithm was carried out by setting up two 20 cm diameter short back-fire antennas on a small vessel under conditions with wave heights of about 1 to 1.5 m. These antennas were located with a 3 wavelength separation in the vertical direction. Figure 7 shows the space diversity effect obtained by a simulation in which the switching operation has been carried out by computer. From this figure, it can be noticed that the cumulative time distributions through each branch are nearly equal to each other and these distributions almost correspond to a I_0 distribution with C/I of 6.25 dB. It is also noticed that the fading depth of about 8 dB at an elevation angle of 9° can be reduced to about 5 dB in the case where the threshold level is -5 dB.

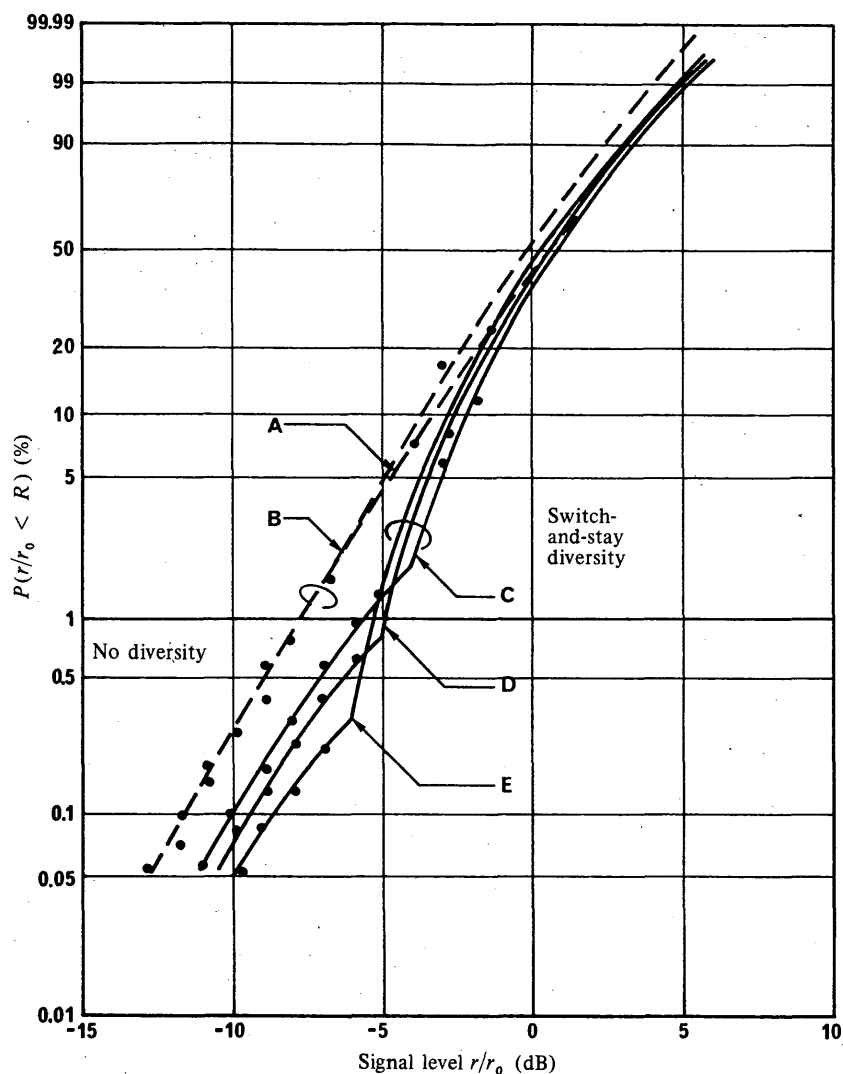


FIGURE 7 – Fading reduction effect of space diversity method

Frequency : 1.5 GHz
 Short back-fire antenna
 Antenna separation : $\Delta h = 0.6$ m

Curves A : branch 1
 B : branch 2
 C : $S = -4$ dB
 D : $S = -5$ dB
 E : $S = -6$ dB
 S : threshold level

3.2 Polarization method

For polarization method (A), field experiments [Shiokawa and Karasawa, 1982] have been made using a short back-fire antenna with an aperture diameter of 33 cm, which was located on the deck of a ferry receiving signals from the Marisat satellite. This antenna had a gain of about 13.5 dBi, an axial ratio of about 0.7 dB without fading reduction and a beamwidth of about 38° . Figure 8 shows the cumulative time distribution of the fading reduction effect for a wave height of about 70 to 80 cm corresponding to "rough" sea conditions. It can be seen that the fading depth corresponding to 99% of the time is decreased from 5.1 dB to 2.5 dB by the use of this fading reduction technique. However, there is a polarization loss of about 1 dB.

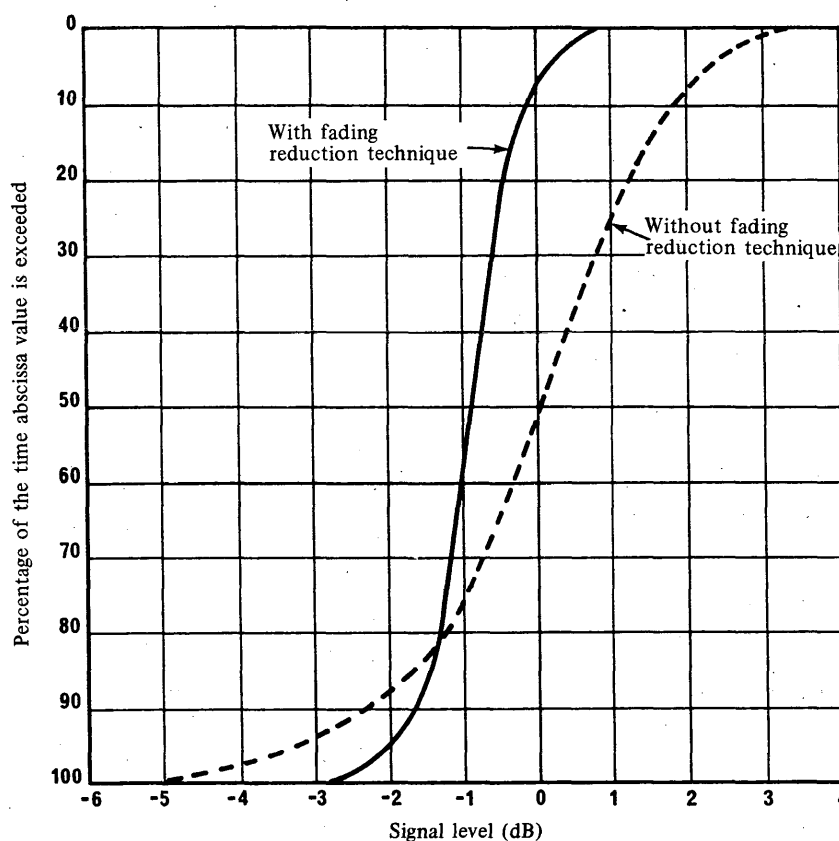


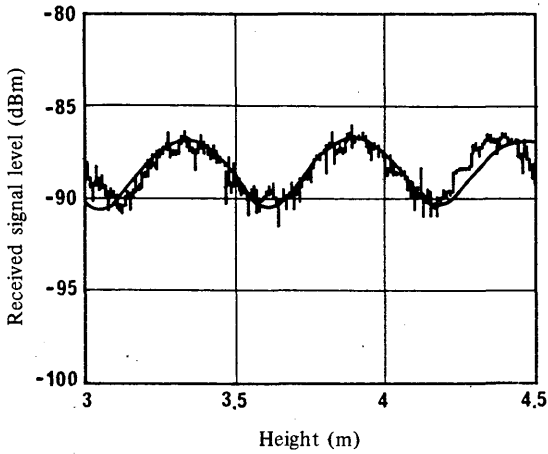
FIGURE 8 – Fading reduction effect of polarization method (A)

Elevation angle: 11.2°
Wave height: 70-80 cm

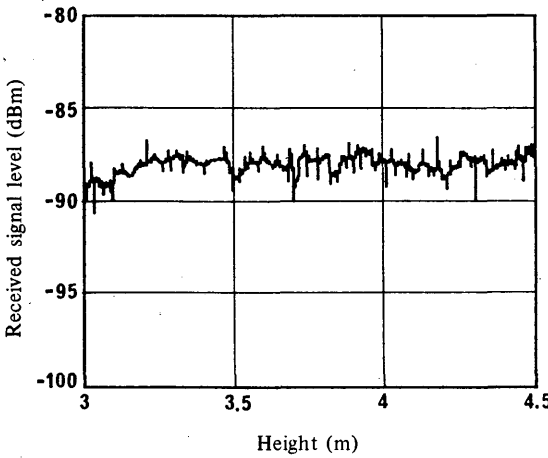
For polarization method (B), experiments [Ohmori and Miura, 1982] have also been performed on the sea shore receiving pilot signals from Inmarsat with elevation angles of about 10° . The antenna used in these experiments was a short back-fire antenna, with electrical characteristics which were almost the same as those of the experiments for polarization method (A). Figures 9a) and 9b) show height-gain patterns of the ordinary short back-fire antenna where the value of additional attenuator was fixed at infinity and the short back-fire antenna with fading reduction technique, respectively. The results show that the spatial fading (height-gain pattern fading) is almost completely eliminated.

3.3 Maximum level tracking method

A field experiment [Shiokawa and Karasawa, 1982] has been carried out on a beach to receive a signal from a signal source on a hill separated by a bay. In this experiment, a quad-helix antenna was used. This antenna was composed of four elements of two-turn helices as shown in Fig. 5a) and had a gain of about 13 dBi and an axial ratio of about 1.0 dB [Shiokawa *et al.*, 1981]. The elevation angle was 7.5° and the wave height was 15 to 20 cm corresponding to "moderate" sea conditions. The receiving antenna was fixed at the minimum point of the height pattern to evaluate the worst case where the received signal level is least. Figure 10 shows the cumulative time distribution of the received signal intensity. The fading depth of about 11 dB corresponding to 99% of the time has been reduced to about 7.5 dB.



a) Without fading reduction technique
40 cm short back-fire antenna



b) With fading reduction technique
Reduction short back-fire antenna

FIGURE 9 – Fading reduction effect of polarization method (B)

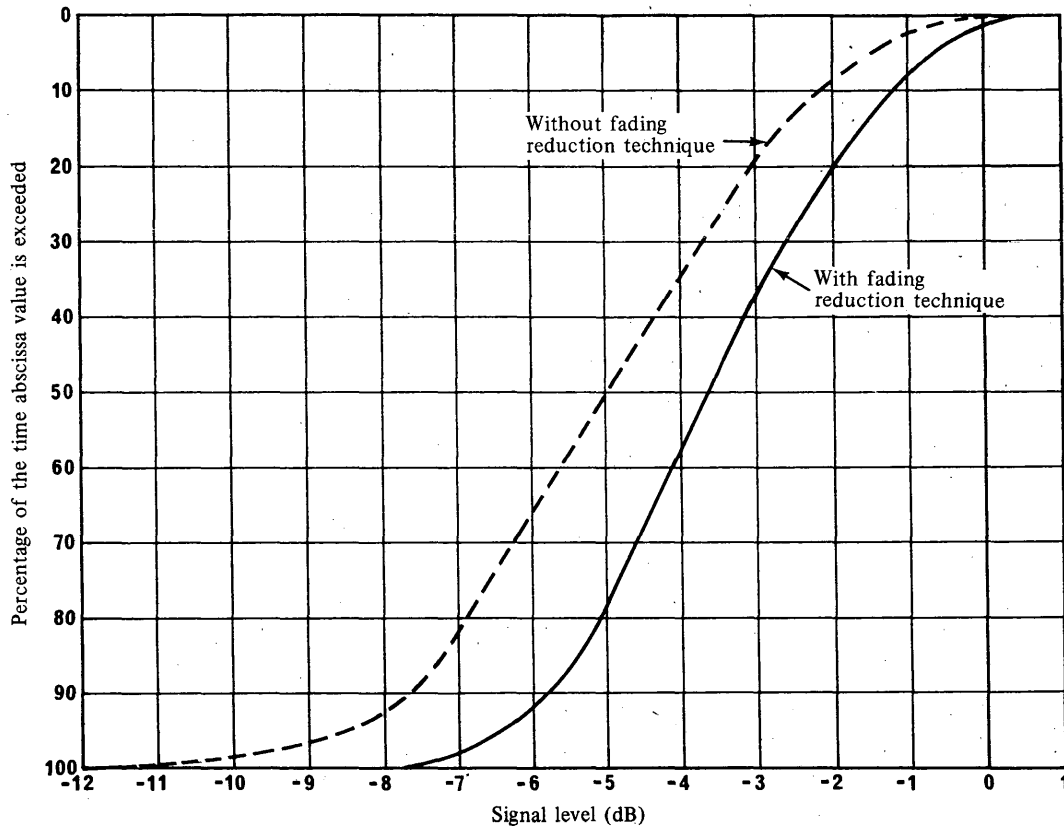


FIGURE 10 – Fading reduction effect of maximum level tracking method

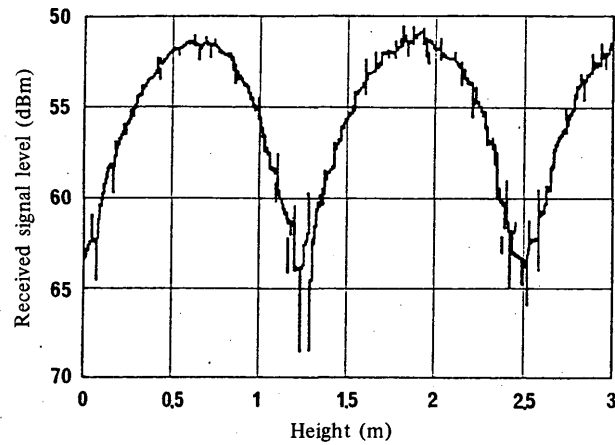
Elevation angle: 7.5°
Wave height: 15-20 cm

3.4 Pattern shaping method and beam offset method

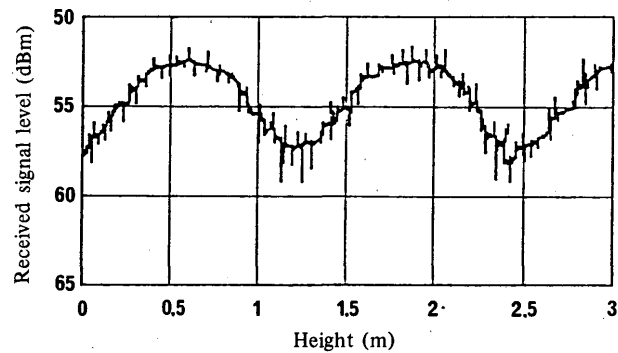
Field experiments [Ohmori *et al.*, 1980] were performed on the sea shore to confirm the fading reduction effect of a combined reduction method using both the pattern shaping method and beam offset method. In this experiment, the shaped beam antenna which is presented in § 2.3 was used. Figure 11 shows the experimental results against height, Fig. 11a) is for the case of an ordinary antenna with antenna gain of about 16 dBi and Fig. 11b) is for the case of a shaped pattern antenna with a beam offset of 15° . From this figure, it can be seen that the reflected waves are fairly well suppressed.

4. Conclusion

Some fading reduction techniques have been surveyed and experimental field results for the reduction effects have been presented. It is concluded that the adoption of fading reduction techniques is very effective for enabling significant signal degradation due to sea surface reflection to be avoided, especially for low G/T ship earth-station antennas.



a) Without fading reduction technique



b) With fading reduction technique

FIGURE 11 – Fading reduction effect of pattern shaping method and beam offset method

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REPORT 923-1

DESIGN OF FREQUENCY PLANS FOR SATELLITE TRANSMISSION OF SCPC CARRIERS USING NON-LINEAR TRANSPONDERS

(Study Programme 17A/8)

(1982-1986)

1. Introduction

In satellite communication systems, a number of SCPC carriers are transmitted via a single satellite transponder. For efficient use of satellite power, the transponder would be operated in the non-linear region, in which case intermodulation noise affects signal quality.

The intermodulation products falling into the frequency slots of occupied signal channels could be reduced by suitably positioning the channels within the available bandwidth. Babcock spacing [Babcock, 1953] is a typical example of this approach where the signal channels are completely free from third-order intermodulation noise. However, such an intermodulation-free frequency plan would not necessarily be desirable because of its inefficient use of available bandwidth, especially where a large number of channels have to be accommodated. For example, in order to accommodate 20 channels, it would be necessary to utilize a bandwidth more than 10 times the width of a plan using adjacent frequency slots [Hirata and Yasuda, 1976]. Hence, bandwidth-efficient frequency plans need to be developed, and one approach is to allow some intermodulation products to fall into the signal channels, but only to the extent that the degradation of signal quality can be acceptable.

A reasonable and effective approach to realize such an idea is to minimize the number of the third-order intermodulation products falling into the worst signal channel [Hirata, 1978]. The worst signal channel here means a specific signal channel into which the largest number of the third-order intermodulation products fall. This Report discusses the assignment of frequencies based on this approach, which is referred to hereafter as intermodulation-minimum frequency assignment.

2. Equal level SCPC carriers

2.1 Relationship between assigned bandwidth and intermodulation products

It is difficult to determine theoretically intermodulation minimum frequency plans. However, the attainable minimum number of intermodulation products falling into the worst affected signal channel can be estimated by the theoretically derived lower bound.

Figure 1 shows the theoretically derived lower bounds of the number of the $(f_1 + f_2 - f_3)$ type of the third-order intermodulation products falling into the worst signal channel as a function of the assigned bandwidth with a parameter of the number of signal channels to be accommodated. In this Figure, the number of intermodulation products, which is proportional to the intermodulation noise power, is normalized against the number produced in the worst signal channel in a plan using adjacent frequency slots. The result is then expressed in decibels. For convenience, the latter plan is referred to hereafter as minimum equal-spacing. The assigned bandwidth is also normalized by that required for the minimum equal-spacing plan. This Figure implies that the number of intermodulation products falling into the worst signal channel could be reduced to about one half compared to the case of minimum equal-spacing when the total frequency bandwidth occupied is 50% wider than that required for minimum equal-spacing.

2.2 Intermodulation-minimum frequency plan

Intermodulation-minimum frequency plans have been obtained for practical application by computer calculation. For a small number of signal channels, the optimum solution can be obtained by examining all possible combinations. Table I shows the results obtained where the number of signal channels K is 10.

For a large number of signal channels, the quasi-optimum solution, which may not be optimum but would be considered very close to optimum, can be obtained by an iterative approach [Okinaka *et al.*, 1982]. Table II shows the obtained results where K is 20 in IIa and 40 in IIb, respectively.

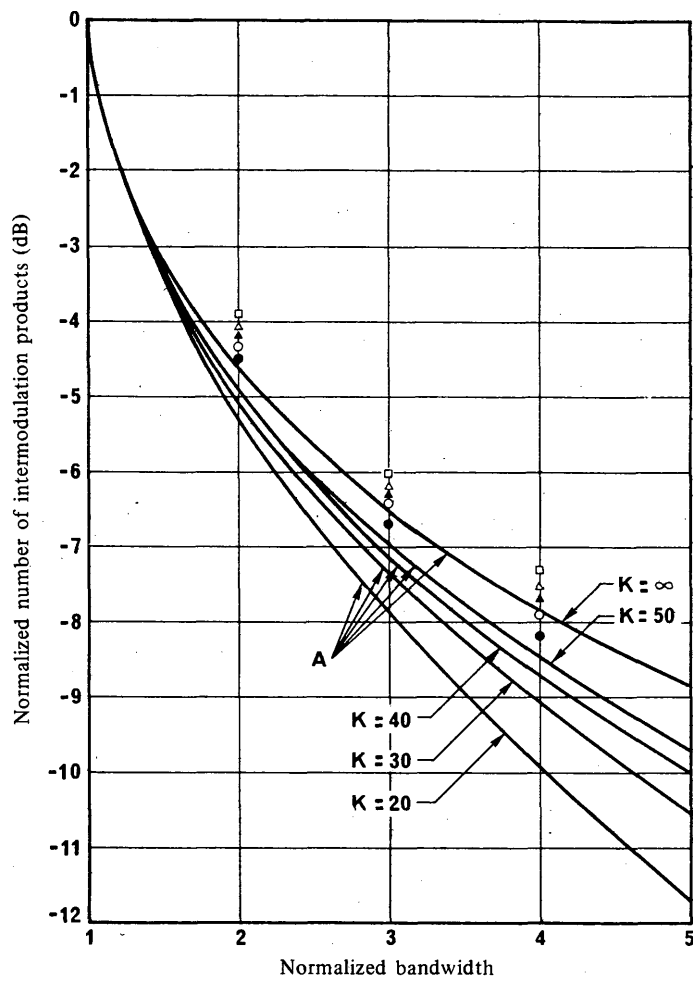


FIGURE 1 – Relationship between the number of intermodulation products falling into the worst signal channel and the assigned bandwidth

Obtained results:

- : K = 20
- : K = 30
- ▲: K = 40
- △: K = 50
- : K = 100
- A: lower bounds
- K: number of signal channels

TABLE I — Optimum intermodulation-minimum frequency plans (number of signal channels, $K=10$)

Number of frequency slots	Normalized bandwidth	Normalized number of IM products (dB)	Assigned frequency slots
11	1.1	-1.0	1, 2, 3, 4, 5, 7, 8, 9, 10, 11
12	1.2	-1.7	1, 2, 3, 4, 6, 7, 9, 10, 11, 12
13	1.3	-2.4	1, 2, 3, 4, 6, 7, 10, 11, 12, 13
14	1.4	-3.0	1, 2, 3, 4, 6, 7, 10, 12, 13, 14
15	1.5	-3.5	1, 2, 3, 4, 7, 8, 11, 13, 14, 15
16	1.6	-3.9	1, 2, 3, 4, 7, 10, 12, 14, 15, 16
17	1.7	-4.3	1, 2, 3, 4, 7, 10, 12, 14, 16, 17
18	1.8	-4.7	1, 2, 3, 5, 7, 10, 13, 16, 17, 18
19	1.9	-5.2	1, 2, 3, 5, 9, 12, 14, 17, 18, 19
20	2.0	-5.4	1, 2, 3, 6, 8, 12, 15, 18, 19, 20
21	2.1	-5.7	1, 2, 3, 5, 10, 14, 15, 18, 20, 21

The normalized number of intermodulation products shown in Tables I and II are plotted in Fig. 1. Comparing them with their lower bounds, it is observed that the number of intermodulation products falling into the worst signal channel in the intermodulation-minimum frequency plans can be estimated effectively by using the lower bound curve for $K = \infty$ shown in Fig. 1.

3. Multi-level SCPC carriers

In future satellite systems it may be desirable to operate with several standards of mobile earth stations having different G/T values. One possibility would be to transmit signals destined to the various mobile earth station standards with different satellite e.i.r.p. levels. Even within systems that operate with a single mobile earth station standard, different satellite carrier power levels may be used for different services.

However, accommodation of large numbers of carriers of mixed power levels in a single non-linear satellite transponder by placing the carriers in arbitrarily-selected channel assignments could easily lead to situations where intermodulation noise from certain relatively higher-power channels would render several relatively lower-power channels unusable.

A carefully developed frequency plan, resulting in a distribution of intermodulation noise among channels in such a way as to be proportional to the carrier power of the channel could prevent such a situation.

This section briefly describes several frequency plans for multi-level carriers.

3.1 Mixed level frequency plan alternatives

One type of frequency plan capable of easily accommodating mixed level carriers assigns carriers to channels selected from a set of equally spaced channels using a Babcock spacing [Babcock, 1953; Edwards *et al.*, 1969]. Resultant assigned channels are totally free of third-order intermodulation noise and could consequently be used for carriers of any power level. However, Babcock plans are generally impractical, unless the number of required carrier assignments is small, due to the inefficient use such plans make of the available bandwidth.

TABLE II – *Quasi-optimum intermodulation-minimum frequency plans*

a) $K = 20$

Number of frequency slots	Normalized bandwidth	Normalized No. of IM products (dB)	Assigned frequency slots
40	2	−4.5	1, 2, 3, 5, 6, 7, 10, 16, 17, 19, 24, 26, 27, 32, 34, 36, 37, 38, 39, 40
60	3	−6.7	1, 2, 3, 6, 9, 12, 13, 19, 22, 27, 32, 41, 43, 47, 54, 55, 56, 58, 59, 60
80	4	−8.2	1, 2, 3, 4, 8, 11, 16, 28, 30, 41, 45, 52, 57, 61, 62, 70, 73, 76, 79, 80
100	5	−9.5	1, 2, 3, 5, 10, 17, 29, 31, 42, 45, 48, 65, 67, 80, 85, 89, 90, 96, 98, 100

b) $K = 40$

Number of frequency slots	Normalized bandwidth	Normalized No. of IM products (dB)	Assigned frequency slots
80	2	−4.2	1, 2, 3, 4, 5, 6, 7, 8, 10, 13, 16, 18, 22, 24, 25, 27, 28, 32, 35, 39, 43, 45, 46, 48, 52, 61, 62, 64, 65, 66, 70, 71, 72, 74, 75, 76, 77, 78, 79, 80
120	3	−6.3	1, 2, 3, 4, 5, 6, 7, 8, 12, 15, 17, 22, 31, 32, 34, 39, 45, 55, 57, 65, 67, 70, 77, 78, 82, 88, 91, 96, 97, 100, 105, 109, 111, 112, 113, 116, 117, 118, 119, 120
160	4	−7.6	1, 2, 3, 5, 7, 8, 10, 13, 20, 21, 25, 30, 31, 37, 40, 45, 56, 58, 66, 70, 71, 72, 79, 92, 104, 108, 115, 117, 126, 132, 136, 145, 148, 151, 152, 154, 156, 158, 159, 160
200	5	−8.7	1, 2, 3, 4, 6, 9, 10, 13, 20, 26, 32, 38, 45, 54, 58, 71, 75, 83, 85, 86, 104, 106, 117, 128, 132, 144, 146, 161, 164, 175, 176, 184, 185, 190, 192, 194, 195, 198, 199, 200

Improved efficiency at the expense of third-order intermodulation products falling in assigned channels can be achieved with "multiple Babcock" plans. For example, in the case of a two-level system, such plans are formed by placing two identical Babcock plans side by side in frequency, but separated by an amount approximately equal to the bandwidth of one of the identical plans, which are referred to hereafter as a "double Babcock" plan. The penalty paid for the increased carrier density is some third-order intermodulation products falling on assigned channels. It can be shown that, in an " n " carrier plan, precisely $(n/2) - 1$ third-order products fall on each of the assigned channels when all carriers are active. Since such a plan still provides a substantial reduction in the number of third-order products within each assigned channel over that which could be obtained with uniform or random channel spacings, intermodulation performance may be sufficiently good to operate with mixed level carriers.

If required, performance of the "double Babcock" plan can be improved for any selected assigned channel by deleting its "twin" assigned channel in the opposite half of the plan. When this is done, the selected channel becomes totally free of third-order intermodulation products. Consequently these improved channels may be used for carriers either lower or higher in power than other channels of the plan. Although the bandwidth efficiency of this plan is better than that of a Babcock plan, it still utilizes bandwidth inefficiently and is useful only when small numbers of assignable channels are required.

More bandwidth-efficient plans can be achieved at the expense of higher levels of intermodulation noise falling into carrier channels. Two methods, "dedicated zone method" and "interleaving method", which achieve a significant improvement in bandwidth utilization efficiency while at the same time providing low intermodulation noise power in carrier channels, have been suggested [Okinaka *et al.*, 1982].

In the "dedicated zone method", a dedicated frequency band is provided within the available bandwidth for carriers of each power level, and the carriers are placed within the dedicated frequency band exclusively usable by them. If the dedicated frequency bands are properly placed within the whole bandwidth, the band for lower level carriers could be free from the intermodulation products caused by higher level carriers. If it is possible to separate the two dedicated bands by an unassigned band, the possibility of intermodulation products caused by higher level carriers falling into the dedicated frequency band for lower level carriers could be further reduced.

In the "interleaving method", the carrier of i th level is placed only on the (M_{j+i}) numbered frequency slots, where M represents the number of carrier levels, i an integer between one and M , j an integer between zero and $(B/M - 1)$, and B the number of the whole assignable frequency slots. In this method, the intermodulation products caused by three carriers of a certain power level necessarily fall into the frequency slots for carriers of the same power level, thus the intermodulation products caused by higher level carriers would not fall into the frequency slots for lower level carriers. In the case of a dual-level system, for example, the "interleaving method" leads to an "odd-even" plan, where high power carriers are placed on even-numbered slots and lower power carriers on odd-numbered slots.

In the case of a dual-level system, the third-order products created may be classified into one of 8 categories shown in Table III. The Table also shows the approximate relative powers of each product type assuming that the ratio of low power to high power carriers is equal to " r ". The advantage gained with plans based on the "dedicated zone method" and the "interleaving method" is that the more powerful intermodulation products of category 1 do not fall in frequency slots where the lower power carriers are placed. In many cases, the "dedicated zone method" may provide larger reduction in the number of the intermodulation products falling into channels of the lower level carriers than the "interleaving method".

Actual frequency plans can be obtained by the following procedure. First, the positions of the lowest level carriers are determined within the frequency slots for them by using the iterative approach [Okinaka *et al.*, 1982]. Then, the positions of the next low level carriers are determined within the frequency slots for them by the iterative method, where the worst carrier-to-intermodulation noise power ratio (C/IM) among all carriers already placed is maximized. This procedure is repeated on a level-to-level basis until the positions of carriers of all levels are determined.

TABLE III — Categories and relative powers of the third-order intermodulation products and channels into which the products may fall for a dual-level frequency plan

Product category	Product type	Relative power	Channels into which the products may fall	
			Dedicated zone method	Interleaving method
1	$f_h + f_h - f_h$	1	For H carriers	For H carriers
2	$f_h + f_h - f_l$ $f_h + f_l - f_h$	r	For L carriers	For L carriers
3	$f_h + f_l - f_l$ $f_l + f_l - f_h$	r^2	For H and L carriers	For H carriers
4	$f_l + f_l - f_l$	r^3	For H and L carriers	For L carriers
5	$2f_h - f_h$	1/4	For H and L carriers	For H carriers
6	$2f_h - f_l$	$r/4$	Unused slots	For L carriers
7	$2f_l - f_h$	$r^2/4$	For H and L carriers	For H carriers
8	$2f_l - f_l$	$r^3/4$	For H and L carriers	For L carriers

Note 1. — f_h is used to indicate a frequency slot for a high-power carrier and f_l to indicate a frequency slot for a low-power carrier.

Note 2. — r is the ratio of low-power to high-power carrier powers.

Note 3. — H carrier is used to indicate a high-power carrier and L carrier to indicate a low-power carrier.

3.2 Typical performance of a dual-level plan

In order to compare two assignment methods for the multi-level systems, the C/IM improvement has been calculated for typical examples of two-level and three-level systems. The C/IM improvement means the amount of improvement in the worst C/IM compared with that for the frequency plan where the lowest-level carriers are equally spaced, and where the number of carriers are chosen so as to maintain the same output power in the satellite transponder. For the two-level system, it is assumed that ten carriers with a certain level and ten carriers with 10 dB higher level share a transponder. For the three-level system, it is assumed that ten carriers with a certain level (L), ten carriers with 7 dB higher level, and ten carriers with 10 dB higher level than L share a transponder. Furthermore, a normalized bandwidth of three is assumed for both cases.

Table IV summarizes the performance of the obtained frequency plans. The Table implies that the “dedicated zone method” could provide better C/IM in the lower power carrier channels than the “interleaving method”.

4. Conclusions

It has been shown that the number of third-order intermodulation products falling into a channel slot can be substantially reduced by the use of a carrier assignment plan encompassing an assigned bandwidth greater than that for the minimum equal-spacing plan. It was also shown in Fig. 1 that the normalized number of intermodulation products depends on the number of carriers as well as the normalized assigned bandwidth, and that spectrum efficiency decreases with the number of carriers.

TABLE IV — Comparison of performance of multi-level frequency plans based on the "dedicated zone method" and the "interleaving method"

Number of carrier levels	Level of carriers (dB)	C/IM improvement (dB)	
		Dedicated zone method	Interleaving method
2	0	5.2	3.2
	10	5.2	5.3
3	0	3.2	2.8
	7	3.4	2.8
	10	6.2	5.1

Note. — C/IM improvement means the amount of improvement in the worst C/IM compared with that in the frequency plan where the lowest level carriers are equally spaced, and where the number of carriers is chosen so as to maintain the same output power in the satellite transponder.

In the case where carriers with multiple power levels must be transmitted, improved carrier-to-intermodulation noise power ratio performance for the lower power carriers can be achieved by the "dedicated zone method". With a proper selection of channel assignments using a procedure such as that suggested in this Report, substantial improvements in low power carrier C/IM can be achieved with a small sacrifice in high power carrier C/IM.

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REPORT 1049 *

CONTROL OF PASSIVE INTERMODULATION PRODUCTS

(Question 17/8)

(1986)

1. Introduction

This Report deals with the subject of passive intermodulation and emphasizes the importance of careful consideration of the relevant mechanisms applying to satellite design and system operations that cause such intermodulation effects.

2. History

Passive intermodulation products (PIMs) were initially observed at HF radio stations where high level transmitted signals produced intermodulation which caused interference to communications receivers. The intermodulation was found to be due to oxidation of the iron bolts used to fix the transmitting antennas together (rusty bolt effect). Latterly, the phenomenon has been identified as occurring in maritime satellites at 1.5 GHz where similar electrical conditions to those at the HF radio stations occur, i.e. high level transmitted signals and very low level received signals.

It seems that a necessary condition for production of passive intermodulation products, is that a difference of signal level of around 130 dB should exist between transmitted and received signals. Such conditions occur in maritime satellite antenna feeds both in the satellites and at the shore stations. However, passive intermodulation has only been noted as occurring in satellites and attention to the differences of construction between these two areas may yield conclusions as to its fundamental cause.

3. General

Intermodulation is a phenomenon that occurs in non-linear devices. If two or more signals are transmitted through such devices, further signals are generated whose frequencies and levels are a function of the frequencies and levels of the wanted signals at the input to the device.

Intermodulation products commonly cause adjacent-channel interference and, in the case of multiple carrier systems, interference throughout the radio channel bandwidth.

The level of intermodulation products is determined not only by the voltage transfer characteristic of the device but also by the bandwidth of its response. Thus in the case of active devices, where the bandwidth is limited, the level of intermodulation products having frequencies outside the bandwidth of the device is commonly negligible. In the case of passive devices (e.g. waveguide) the bandwidth constraint is much less and products may also be generated after transmission of the wanted signals through filters intended to suppress intermodulation products and/or reduce spurious or noise power at receive frequencies. Where systems have more than about 150 dB gain, it is possible for passive intermodulation products to be generated at the output, which are of sufficient level to make the system unusable because of interference to the system input signal.

4. Generation of passive intermodulation products (PIM)

It is believed that the most dominant mechanisms in the generation of PIMs are:

- semi-conductor effects of surface oxide layers;
- micro-discharges due to metal defects;
- non-linearities associated with carbonization at metal surfaces and deposition of other contaminants;
- the non-linearity of all ferro-magnetic materials, including stainless steel, nickel-plating and all ferrite components.

It also appears that PIM is far more likely to occur in a vacuum than under ambient pressure conditions.

* This Report should be brought to the attention of Study Groups 1 and 4.

In practice the non-linearities in passive devices, responsible for the generation of PIM, are a result of the summation of many different micro-currents. Microscopically, all surfaces are highly irregular and moreover they have an oxide layer several angstroms thick on their surfaces. Where contact occurs between surfaces, the oxide layer affects the impedance at the contact point. The oxide and voice regions generate a displacement current and the relative magnitude of this current to the conduction current determines the non-linearity of the junction.

5. Experimental investigations by :

5.1 Nuding

Nuding [1974] of AEG-Telefunken carried out an experimental investigation of PIM produced in a waveguide using RF powers up to 1000 W in the 2 GHz band. With powers in the range 0-500 W the amplitudes of the third-order intermodulation products were found to vary as the third power of the applied RF power, i.e.:

$$Nk = \alpha N^3 \tag{1}$$

where:

- Nk : amplitude of an intermodulation product of the third order;
- N : RF signal power (same level for both test signals);
- α : constant which depends on the degree of non-linearity of the device.

The experimental results of Nuding indicate that for two RF carriers, N_1 and N_2 , of equal power up to 500 W, the PIM signal power levels obey the law of equation (1), i.e. αN^3 . Third, fifth and seventh order PIMs (k_3, k_5, k_7) vary in amplitude with respect to the carrier power in the same manner. Also, for a fixed RF carrier level the difference in amplitude between 3rd and 5th orders is approximately equal to the difference between 5th and 7th orders, i.e. $\alpha = \beta$ (see Fig. 1).

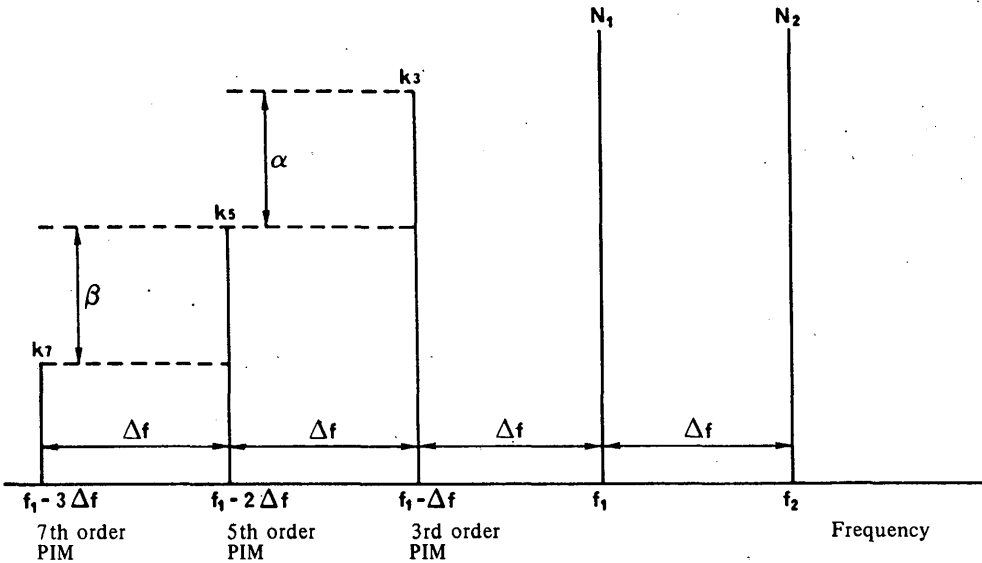


FIGURE 1 – Passive intermodulation product levels

Table I below gives some values quoted in Nuding’s paper, or extrapolated from his results.

TABLE I

Carrier power, N (W)	Average change in power per order (dB)	PIM power level (dBm)		
		3rd order	5th order	7th order
200	34 ⁽¹⁾	-60	-94	-128 ⁽¹⁾
250	33 ⁽¹⁾	-56	-90	-122 ⁽¹⁾
1000	20	-45	-66	-86

⁽¹⁾ Extrapolated.

5.2 Cox

Earlier experimental work by Cox [1970] used a 1 W power source and frequencies around 6.0 GHz. However, because of the low power used the results may not be directly transferable to that which would happen at higher powers. As an example he found that a loose waveguide flange could give rise to third-order PIMs as high as -25 dBm for 1 W carrier power, and -50 dBm for fifth-order PIMs. Flexible waveguide gave third-order products in the range -55 dBm to -110 dBm.

One of the conclusions in Cox's paper is that PIM generation is essentially independent of changes in transmitter frequency separation. On this basis it is likely that results can be extrapolated to other frequency bands.

Another observation of Cox was that loose metal-to-metal surfaces exposed to RF fields such as waveguide joints or tuning screws, generated strong but erratically changing PIM levels. For one circulator for example, a third-order PIM product was measured at -65 dBm with up to 20 dB variations. Tightening of screws which held the circulator together reduced the same PIM level to -90 dBm steady, a reduction of 25 dB.

5.3 Chapman *et al.*

Chapman and colleagues [Chapman *et al.*, 1976] measured a third-order PIM at -80 dBm with two equal power test signals of frequencies 7.9 and 8.05 GHz and a total power of 5 kW. They concluded that third-order PIM varies by about 3 dB for each dB variation of total power. Regarding the higher order PIMs they found that the level reduced by between 10-20 dB per order for a typical feed assembly with 1000 W total applied power. They recommended that tuning screws be eliminated to remove the most significant cause of PIM products.

6. Variation of PIM with increasing order

Nuding's conclusion on the variation of PIM levels with increasing order gives extremely low results for the thirteenth order and higher orders. Nuding's conclusion was that the decrease in PIM power per odd order was -34 dB, however other authors have quoted lower figures; for example [Roorsey *et al.*, 1973] gives a figure of -8 dB per odd order and others about -10 dB per odd order. In addition the third-order power level obtained by others is significantly lower than those obtained by Nuding. The following table gives a comparison between various figures for the third-order PIM level and the rate of decrease per odd order.

It is probable that in going from third to fifth order and from fifth to seventh order the PIM power level does drop by around 34 dB but for higher orders the change is less as different mechanisms come into effect. Nuding's results do indicate that the variation is less with increased carrier power.

TABLE II

	Authors		
	Nuding [1974]	Roorsey <i>et al.</i> [1973]	Chapman <i>et al.</i> [1976]
3rd order PIM power level (dBm)	-60	-85	-82
Variation per increased odd order (dB)	-34	-8	-10

7. Minimization of PIM product levels

PIM minimization should be part of overall satellite design philosophy and thus at the outset the materials used for waveguides and filters etc., should be carefully selected to reduce it. A concerted effort to overcome these problems could also be made by component and system designers as well as assembly and testing personnel.

A number of general design guidelines exist which, if properly employed, can help to minimize the problem. These are as follows:

- if possible, frequencies chosen for the up-link should be such as to ensure that PIM products from the satellite transmitter are outside the satellite receiver carrier bands;
- the satellite design should be optimized to limit the sources of passive intermodulation (non-linear passive devices) to a minimum;
- the use of high-Q resonant circuits should be kept to a minimum in appropriate areas. For example, hybrid filter designs for band-stop filters could be used instead of band-pass filters;
- the use of mechanical contacts in appropriate areas should be minimized;
- the RF current density in transmission lines and resonators should be kept to a minimum e.g. by increasing the dimensions of transmission lines and resonators;
- care should be taken in the design of mechanical components in appropriate areas;
- care should be taken in fabrication and cleaning procedures to avoid contamination at critical interfaces;
- the use of metals which readily oxidize should be avoided, e.g. aluminium;
- good electrical conductivity should be ensured by using high contact pressures and smooth surfaces at flanges.

These steps should be followed, preferably in the order shown above until sufficient linearity is reached, or the PIM level is below the maximum permissible level. Clearly the latter steps are progressively more difficult and costly.

Experience has shown that metallic interfaces are the most likely sources of system non-linearity. This does not mean that an acceptable low level PIM system cannot exist without junctions but a junction can be linear only if it is tight, smooth, flat and clean. These are of course relative terms and are somewhat inter-related in that non-smooth surfaces can be made smooth by sufficient pressure. In general, it is good practice either to make contact surfaces smooth and tighten them until satisfactory contact is achieved or to braze joints using high quality methods and materials.

8. Conclusions

Passive intermodulation products (PIMs) only cause problems where a common signal path exists for transmitted and received signals having a level difference of about 130 dB since the level of PIMs is generally about 150 dB below the signals causing them. In addition, because a necessary condition for their production is that the material used for the transmitting elements should exhibit non-linear properties e.g. due to oxides etc., it is more likely that PIM occurs where metals such as aluminium are used. Since the use of such materials predominantly occurs where mass is a constraint it is more likely to occur in satellites than at ground terminals. In addition, at ground terminals better waveguide flange joints are generally achievable using higher flange pressures etc.

A general conclusion is that where mass is not a constraint it is not difficult to suppress PIMs by attention to good mechanical construction and use of appropriate non-oxidizing metals wherever possible.

The treatment of passive intermodulation as considered in this document is largely obtained from material not directly related to maritime satellites. Nevertheless observation of the dominant mechanisms as detailed in § 3 and the design guidelines as given in § 6 should ensure that occurrence of passive intermodulation is minimized.

Because of the importance of this subject and the fact that problems due to this cause exist in maritime satellites currently in service, administrations and other participants are encouraged to contribute more information on this subject particularly with regard to the design of maritime satellites and operation of maritime satellite systems. Relevant information with regard to satellites currently in service is requested.

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REPORT 1050 *

TECHNICAL AND OPERATIONAL CONSIDERATIONS FOR A RADIODETERMINATION SATELLITE SERVICE IN BANDS 9 AND 10

(Study Programme 17A/8)

(1986)

1. Introduction

Satellite systems operating in the radiodetermination satellite service (RDSS) could provide radionavigation and radiolocation functions to aeronautical, maritime and land based mobile users. This Report presents a system concept for an RDSS system. Further description and a frequency sharing analysis for the system planned to be implemented by the United States of America is given in Annex I.

2. Background and applications

Previous tests (see Report 770) have demonstrated the feasibility of providing radiocommunications and radiodetermination to mobile service users via geostationary satellites. Report 509 presents a discussion of the use of pseudo-random noise (PN) code ranging systems for high precision distance measurement as used in the RDSS.

* This Report should be brought to the attention of Study Groups 2, 4, 7 and 9.

It now appears to be feasible to develop an operational system using low average power transmitters, near omnidirectional user antennas and multiple access methods using inexpensive user transmitter/receivers (transceivers). Annex I describes an example of a radiodetermination system which is designed to provide the capability of precision positioning, navigational information and radiolocation for terrestrial, maritime and airborne users. Such a system would employ a minimum of two geostationary satellites using bi-lateral techniques.

3. Link requirements

A general system concept addressed in this Report implies four separate Earth-space links. These are: user-to-satellite link, satellite-to-control centre link, control centre-to-satellite link and satellite-to-user link. These links enable a "closed-loop" system to be implemented whereby the propagation delay, in relation to the reference signal transmitted by the master control earth station, relayed through the geostationary satellites, is determined at the master earth station. The position of the user is then computed at the master station and the position information is transmitted in a digital message back to the user.

Because of the requirement for low user transmit powers, and the fact that most applications will require near omnidirectional low-gain user antennas, the preferred frequency bands for this service are in the 0.3-6 GHz range in order to avoid excessive atmospheric transmission losses. This is especially true on the user-to-satellite and satellite-to-user links.

3.1 *Satellite-to-user link*

The down link to the user transceiver is provided by the satellite having the best viewing angle of the service area. The function of this link is to provide timing references to the user which can be used in initiating position determination requests and to transmit control commands, data messages, and calculated user position information to the user. Transmissions occur sequentially over a single 16.5 MHz channel. Several independent systems can operate on the same 16.5 MHz channel, provided that the satellite signals are modulated by appropriately selected PN codes.

From a technical standpoint, in order to permit successful operations with receivers on the ground having omnidirectional antennas, frequencies in the 400 MHz to 3 GHz range would be preferred for this link. Annex I examines the 2400-2500 MHz portion of the spectrum for this link.

3.2 *User-to-satellite link*

The function of the user up link is to transmit position requests and messages to the central earth station from the user transceiver. User transmissions can occur only at specific times determined by the synchronization timing marks in the down-link signal to the user. The user up link is received by each of the RDSS satellites. Interference effects from multiple simultaneous user transmissions are avoided by a code division multiplexing technique.

The preferred up link frequency band is approximately in the 300-2000 MHz frequency range primarily to avoid the probability of excessive signal degradation due to atmospheric anomalies that occur at higher frequencies, and to permit the use of low-cost technology. Frequency sharing with certain services may be possible depending on the transmission characteristics of the other services. Annex I examines the 1610-1626.5 MHz band for this link.

3.3 *Links between the central control station and the satellite*

The up-link provides communications between the central earth station and the single satellite with the best viewing angle for the RDSS service area. The function of this link is to provide timing synchronization, control messages, and calculated user positions for the entire system. The up-link transmission consists of individual data streams for each user reception area, multiplexed on a single channel.

Each of the satellites within the system transmits a down-link signal to the central earth station. This transmission consists of the signals received by the satellite from each of its user-to-satellite beams. These individual signals are frequency multiplexed onto a single transmission from each satellite.

These feeder links would be expected to share bands available for other links in the fixed satellite service and would thus be subject to appropriate coordination requirements. Atmospheric losses greater than about 2 dB are considered unacceptable, hence the RDSS feeder links should operate in appropriate bands below about 7 GHz.

4. Frequency sharing considerations

The frequency bands deemed best for an RDSS application should be selected, *inter alia*, to minimize potential interference. Any use of these bands would, of course, have to be shared with other allocated services. The characteristics of this type of service, i.e. mobile, low average power user transmitter, near omnidirectional user antenna, etc. do not make it an easy service with which to share frequencies.

Annex I discusses the frequency sharing potential in these bands based upon the system characteristics provided in that Annex.

5. Summary

This Report presents initial information describing link requirements, and frequency sharing information, concerning the concept of a radiodetermination satellite system whose design objective is to provide low-cost position information to aeronautical, maritime and land mobile users.

Further study is necessary on sharing considerations including electromagnetic compatibility of RDSS with other services, as well as studies on the effects of multipath and on probabilistic system performance.

ANNEX I

CHARACTERISTICS AND SHARING ASPECTS OF A PROPOSED RADIODETERMINATION-SATELLITE SERVICE SYSTEM BEING DEVELOPED IN THE UNITED STATES OF AMERICA

1. System description

1.1 General system concept

A radiodetermination satellite service (RDSS) system is being developed in the United States of America to provide position and navigation information and a limited digital message capability to users with small, low cost transceivers (see Note). The system is intended to be used for maritime, aeronautical and land mobile applications. It will use code and time division techniques to achieve electromagnetic compatibility with other RDSS systems.

Note. — The United States of America has provided advanced publication information on this system to the IFRB under the name USRDSS.

This proposed RDSS system is designed to operate in two different accuracy modes. Higher accuracy would be obtained by determining the location of the user (i.e. an aircraft, ship or land-based vehicle) by first determining the distance of the user from two geostationary satellites. This bi-lateration information would then be used in conjunction with a digitized terrain map of the surface of the Earth (or, in the case of an aircraft, with data from the aircraft's altimeter) to calculate the location of the system user. In the event that accurate terrain data or altimeter data is not available, a second method would be employed which utilizes the data from a third satellite to provide tri-lateration information. The third satellite data could also be used to verify the bi-lateration calculations. In the first mode of operation, the accuracy over the United States of America is expected to be of the order of 5-10 m. The second, or tri-lateration, mode is expected to yield position accuracies of 50-100 m over the United States of America. Because of geometric considerations, the system accuracy is latitude dependent, being more accurate at higher latitudes with the United States of America than near the equator.

The communications links and equipment of the proposed RDSS system could also be used simultaneously for relaying short digital messages between the system users via the satellites and the central earth station. A general description of overall system operation is contained in [O'Neill, 1985].

1.2 Link description

The planned RDSS will use 8 spot beams for coverage of the continental United States of America for its user links and a single broader beam antenna for its feeder links. Four frequency bands have been allocated for the operation of the system as follows:

- user-to-satellite: 1610.0-1626.5 MHz;
- satellite-to-user: 2483.5-2500.0 MHz;
- central earth station-to-satellite: 6525.0-6541.5 MHz;
- satellite-to-central earth station: 5117.0-5183.0 MHz.

Because of the potential use of the system for safety of human life applications, low power constraints and limited antenna gains of the user transceiver, the frequency bands proposed for both the satellite-to-user and user-to-satellite links were selected to avoid major losses due to atmospheric attenuation. System performance is further enhanced by automatic re-transmission of signals that are not acknowledged.

The proposed RDSS uses a spread-spectrum modulation with a chip rate of 8.192 Mbit/s. Such a modulation would, unless filtered, have relatively high levels of out-of-band emissions. The interference effects of the users will be mitigated by filtering the RDSS user transmissions. The degree of filtering required is undergoing further study. The baseband data rate will be about 16 kbit/s for the user-to-satellite link, and 64 to 128 kbit/s per beam for the satellite-to-user link.

1.2.1 *Forward link*

The forward link originates in the central earth station in the form of an 8.192 MHz clock signal and eight data streams, one for each of the eight satellite-to-user antenna beams. Each data stream has a data information rate of 64 kbit/s, which results in a 128 kbit/s transmission bit rate by the use of $\frac{1}{2}$ rate forward error-correction convolutional encoding. Each data stream consists of user addresses, beam number information, framing information and messages directed towards the user. These data streams are multiplexed into a single 8.192 Mbit data stream. This signal is transmitted to the satellite in the frequency band 6525.0-6541.5 MHz using a 7.5 m parabolic dish antenna. Link characteristics for the forward link are provided in Table I.

After being received in the satellite, the signal is applied to a baseband demodulator which recovers the timing pulses and data streams in the original signal. The baseband information is passed to a beam demultiplexer which routes each data stream to the appropriate beam. Pseudo-random (PN) code modulators impose unique PN codes on each of the data streams, synchronizing the code to the clock signal. This signal is then up-converted, filtered and supplied to the power amplifier serving the appropriate down-link antenna beam for transmission to the user in the 2483.5-2500.0 MHz frequency band. The transmission is received by the RDSS user through a near-omnidirectional antenna.

The satellite transmission has a frame structure. Each frame is numbered and consists of 98 560 chips at a rate of 8.192×10^6 chips/s. This results in a frame duration of approximately 12 ms (1540 transmission bits, 770 data information bits). Each frame is identified so that it can serve as a time epoch for replies from the user transceivers. Data transmission is organized in frames, with each frame containing a short synchronization segment for rapid acquisition. These data frames are addressed to a particular user and consists of data packets.

A link budget giving the performance of the link for a 10^{-5} bit error ratio (BER) after coding is summarized in Table II. As shown in the table, the major noise sources include thermal noise, noise generated by system users located in other antenna beams of the system coupling into the antenna beam being considered, and noise generated by users of other systems of the same general type operating in the same service area.

1.2.2 *Return link*

The return link originates in the user transceiver. User transceivers are locked on to the continuous outbound data stream from the central station. Based on the need of the user to obtain a position determination, the user will initiate a request at a precisely defined time mark relative to receipt of a frame reference.

Data originating with the user consists of position determination requests and messages. These are transmitted from the user through its near-omnidirectional antenna to the geostationary RDSS satellites in the 1610.0-1626.5 MHz frequency band. The signals received by each beam are then applied to a linear transponder which produces two times four contiguous 16.5 MHz channels occupying the 66 MHz wideband 5117.0-5183.0 MHz. Each of these two groups is transmitted to the central earth station in a frequency re-use mode using two orthogonal linear polarization. Characteristics for the return links are provided in Table III.

TABLE 1 — Forward link characteristics

Central earth station transmit	
Frequency band (MHz)	6525.0-6541.5
Input power to antenna (dBW)	21.5
Antenna gain (dBi)	51.5
Polarization	Linear
Off-axis pattern	32 — 25 log θ (Recommendation 465)
Satellite receive	
G/T (dB(K ⁻¹))	1.0
Antenna:	
Gain (edge of coverage) (dBi)	29.0
Beamwidth (half-power) (degrees)	5.6
Polarization	Linear
Satellite transmit (per beam) ⁽¹⁾	
Frequency band (MHz)	2483.5-2500.0
Input power to antenna (dBW)	19.8
Antenna:	
Gain (edge of coverage) (dBi)	33.8
Beamwidth (half-power) (degrees)	2.2
Polarization	RHC
User receive	
G/T (nominal towards satellite) (dB(K ⁻¹))	— 26.8
Antenna:	
Gain ⁽²⁾ (nominal towards satellite) (dBi)	1.0
Beamwidth (half-power) (degrees)	70
Polarization	RHC

⁽¹⁾ Eight separate beams on each satellite cover the service area.

⁽²⁾ User antenna gain will vary between 1 and 3 dBi.

TABLE II — *Link budgets for forward link*

Central earth station-to-satellite (6533.25 MHz)	
e.i.r.p. (dBW)	73.0
Free space path loss (dB)	200.2
Atmospheric loss (dB)	1.4
Satellite G/T (minimum) (dB(K ⁻¹))	-1.5
C/N_0 (up link) (dBHz)	98.5
Satellite-to-user (2491.75 MHz)	
e.i.r.p. (minimum) (dBW)	53.6
Free space loss (dB)	191.8
Atmospheric loss (dB)	0.7
User G/T ⁽¹⁾ (dB(K ⁻¹))	-26.8
C/N_0 (thermal) (dBHz)	62.9
C/I_0 (adjacent beams) (dBHz)	71.1
C/I_0 (three other systems) ⁽²⁾ (dBHz)	63.8
$C/(N_0 + I_0)$ (down link) (dBHz)	60.0
$C/(N_0 + I_0)$ (total link) (dBHz)	60.0
Information data rate (64 kbit/s) (dB(bit/s))	48.1
E_b/N_0 received (dB)	11.9
E_b/N_0 required ⁽³⁾ (dB)	9.8
Margin (dB)	2.1

⁽¹⁾ Assumes 1 dBi user antenna gain towards satellite and an elevation angle of 20°.

⁽²⁾ Assumes three other systems of the same type operating in the same service area.

⁽³⁾ Includes 4.6 dB needed to achieve a BER of 10^{-5} , with coding, 2 dB of modem implementation loss and 3.2 dB of system margin.

TABLE III — *Return link characteristics*

User transmit	
Frequency band (MHz)	1610.0-1626.5
Input power to antenna (dBW)	16
Antenna:	
Gain (nominal towards satellite) (dBi)	1
Polarization	LHC
Satellite receive	
G/T (edge of coverage) (dB(K ⁻¹))	1.0
Antenna:	
Gain (edge of coverage) (dBi)	29.0
Polarization	LHC
Satellite transmit	
Frequency band (MHz)	5117.0-5183.0
Input power to antenna ⁽¹⁾ (dBW)	17.1
Antenna:	
Gain (minimum) (dBi)	25.2
Beamwidth (degrees)	5.8
Polarization	Linear
Central earth-station receive	
G/T (minimum) (dB(K ⁻¹))	29.4
Antenna:	
Gain (dBi)	49.4
Beamwidth (half-power) (degrees)	0.6
Polarization	Linear

(¹) Per four channels transmitted using a single polarization. Each channel originates in a single up-link beam.

The earth-station receiver demodulates user data bursts. The wideband spread spectrum characteristics of the user bursts enable the receiving system to make time of arrival measurements accurate to a few nanoseconds, by delay locked discriminator techniques. The user data is also demodulated and then routed to the central computer. There are 8 channels per satellite, and 3 active receiving satellites; therefore the receiving system will have 24 similar receivers. Each receiver will have several (at least 20) demodulation modules to allow reception of many overlapping user bursts.

When the reply signals from a user are received at the central earth station, it must know exactly at what time the user transmission originated in order to make the appropriate range calculations. This is done by including in the transmission the forward frame number corresponding to the time at which the user initiated the transmission.

The link budget summarizing performance for the return link is presented in Table IV. As shown in the table, the major noise sources include: thermal noise; noise generated by four other system users operating in the same satellite antenna beam coverage area; noise generated by system users located in other antenna beam coverage areas coupling into the antenna beam being considered; and noise generated by users of other systems of the same general type operating in the same service area.

TABLE IV — *Link budgets for return link*

User-to-satellite link (1618.25 MHz)	
e.i.r.p. ⁽¹⁾ (dBW)	17.0
Free space loss (dB)	189.0
Atmospheric loss (dB)	0.7
Satellite G/T (nominal) (dB(K ⁻¹))	1.0
C/N_0 (thermal) (dBHz)	56.9
C/I_0 (other users, in-beam) (dBHz)	65.1
C/I_0 (adjacent beam users) (dBHz)	70.3
C/I_0 (three other systems in same service area) (dBHz)	58.4
$C/(N_0 + I_0)$ (up link) (dBHz)	54.1
Satellite-to-central earth station (5150.0 MHz)	
e.i.r.p. ⁽²⁾ (dBW)	42.3
e.i.r.p. per user signal (dBW)	18.3
Free space loss (dB)	198.1
Atmospheric loss (dB)	1.4
Earth station G/T (dB(K ⁻¹))	29.4
C/N_0 (down link) (dBHz)	76.8
C/N_0 (total link) (dBHz)	54.1
Information data rate (16) (dBHz)	42.0
E_b/N_0 received (dB)	12.1
E_b/N_0 required ⁽³⁾ (dB)	10.0
Margin (dB)	2.1

⁽¹⁾ Assumes 1 dBi user gain at an elevation angle of 20°.

⁽²⁾ This e.i.r.p. is used to transmit four channels of a single polarization, each channel consisting of the signal from a single up-link beam.

⁽³⁾ Includes 4.6 dB needed to achieve a BER of 10^{-5} , 2 dB implementation loss and 3.4 dB system margin.

1.2.3 *Probabilistic performance measures*

It is difficult to represent link performance as a single set of equations due to the number of variables present at any particular time, such as the number of users transmitting, their location etc. Therefore, parameters can only be chosen to model the system at a specific point in time. To analyze the performance of the system over time, a computer program can be used to simulate system operation and determine the probability of achieving certain levels of performance for individual users and for the system as a whole. Further study is being performed in this area.

1.2.4 *Positioning accuracy*

Positioning accuracy is determined by the magnitude of the ranging error, the error in determining the user's altitude above mean sea level and the geometrical relationship between the satellites and the users. Variations in propagation delay will be largely compensated for by using data from a network of 300 transceivers at fixed, known locations.

Ranging accuracy of the system is a function of the signal-to-noise (S/N) ratio in the synchronizing circuit. The minimum uncoded S/N ratio for operation of the communications channel is 4.6 dB. The synchronizer has 6 dB more processing gain than the communications channel, so that the minimum S/N in the synchronizer is 10.6 dB. This produces an r.m.s. ranging error of approximately 5 ns, applying the equation of Report 509. Since the ranging error occurs both in the user and central earth-station receivers, the resultant r.m.s. range error is 7 ns for the round trip, or approximately 1 m r.m.s. error in distance between the satellite and the user.

Altitude above sea level can be computed from the terrain map stored in the computer or, in the case of aircraft, from the aircraft altimeter. Either of these methods introduces further errors into the position calculations. The positioning accuracy is approximately twice the total ranging plus data-base error due to the geometrical relationship between the satellites and the surface of the Earth. For example, a 1 m ranging error and 5 m terrain map error would result in a positioning error of 12 m. Within the United States of America, this position error is expected to be approximately 5 to 10 m.

In the lower accuracy mode, triangulation is performed using three geostationary satellites rather than two satellites and a model of the Earth's surface. This eliminates one source of error but, because of this different geometrical relationship, positioning accuracy is much worse, 30 to 50 times the total ranging error. A 1 m error in ranging results in positioning accuracy of 30 to 50 m.

1.2.5 *Multipath effects*

An estimate for required fade margin of 2 dB was developed, based on the user antenna radiation pattern and an elevation angle to the satellite of 20° . This, however, does not consider the possible effect on multipath performance due to mounting a basically two-dimensional near-omnidirectional antenna on a flat surface such as the top of a vehicle. It also does not address the possibility of a reduced need for multipath fade margin in a system utilizing very short messages that are automatically re-transmitted if not acknowledged. More study is required in this area.

1.3 *System capacity*

1.3.1 *User-to-satellite link*

The use of spread-spectrum modulation in conjunction with the "Aloha" (see Report 741) type random access method on the user-to-satellite link yields a system which acts quite differently than a non-spread Aloha system. In a non-spread Aloha system, two messages being received simultaneously (a "collision"), usually results in the loss of one or both messages. In a spread Aloha system, such as planned for the RDSS, a number of messages may be received simultaneously, but still be received correctly, if they are transmitted using different pseudo-random-noise modulation codes with good cross-correlation characteristics. If two signals using the same PN code collide in the receiver, it may still be possible to decode both messages, provided that there are two decoders available for that PN code and the two signals are slightly offset in time. The RDSS signal processing ground station is to be designed to operate with an average collision rate in the user-to-satellite link of approximately 10 signals within each of the 8 beams. All signals will still be received with good signal-to-noise ratios with up to 32 simultaneous user transmissions per beam from all RDSS systems operating in the coverage area.

1.3.2 *Satellite-to-user link*

On the satellite-to-user link, messages would be addressed to specific users (or groups of users) and transmitted sequentially at an approximate rate of 350 position fixes per second in each antenna beam, assuming a message packet length of 128 bits.

2. **Frequency sharing analyses in the United States of America**

This section discusses the frequency sharing potential of RDSS systems presented by the United States of America based on the initial system characteristics described in § 1. Sections 2.1 to 2.4 discuss sharing with other services (inter-service sharing) while § 2.5 discusses sharing between RDSS systems (intra-service sharing). It is recognized that the frequencies for use by a radiodetermination satellite service, as planned in the United States of America, may present difficulty in some parts of the world.

2.1 *User-to-satellite link (1610-1626.5 MHz)*

Allocations in this band include radionavigation (primary), fixed (primary footnote in several Region 1 countries), fixed (secondary footnote in several Region 3 countries) and radioastronomy (secondary, Radio Regulation No. 734).

2.1.1 *Aeronautical radionavigation service*

Coordination of an RDSS system with other users of the band would be required under Article 14 of the Radio Regulations. However, considering that users of this band are typically mobile and individual users presumably have extremely low duty cycles, it is expected that interference between users will be transient and could be handled using operational techniques commonly used in mobile services, such as re-transmitting an interfered-with signal. Additional information and study is required.

2.1.2 *Radioastronomy service*

The radioastronomy service uses the band 1610.6-1613.9 MHz for observations of a hydroxyl line (Radio Regulation No. 734). Due to the extreme sensitivities required by radioastronomy receivers, it would not be possible to perform observations of this line when a transmitting RDSS user is within the line-of-sight of an observatory. In order to protect these valuable observations, a plan for coordinating RDSS and radioastronomy usage of this frequency band has been developed in conjunction with radioastronomers in the United States of America. The plan calls for RDSS users to restrict their transmission to the first 200 ms following the one second time markers of coordinated universal time (UTC) whenever the transmitter is located in a specific area surrounding a radioastronomy observatory.

The effect of these restrictions is to increase the response time to user transmissions slightly since the transmissions can occur only within certain periods of time, and to increase the integration time for radioastronomy observations of the hydroxyl line. These restrictions, however, permit two apparently incompatible services to utilize the same frequency band with acceptable operational complexities.

2.1.3 *Fixed service (Radio Regulation No. 730)*

Radio Regulation No. 730 provides for an additional allocation to the fixed service in several countries, primarily in Region 1. Frequency sharing between RDSS and fixed service systems in this up-link band depends upon the relative locations of the receiving satellite, the service area in question and the fixed service systems.

2.1.3.1 *Interference to fixed service systems*

RDSS users may cause sporadic interference in a fixed service system when operating in the vicinity of a fixed service system receiver. The interference would consist of short bursts of noise, approximately 20 ms long. A single user would generate such a burst of interference at intervals ranging from once per minute for certain aircraft to several times a day for some land-based users and so would have an extremely low duty cycle.

The area within which a fixed service receiver could receive interference from an RDSS user will vary depending on the location, receiver noise and antenna gain of the receiving system but, in general, would extend to the horizon.

2.1.3.2 *Interference to RDSS satellites*

Two potential interference situations exist for interference from fixed service systems to an RDSS satellite, depending upon whether or not the fixed service system is in the service area of the satellite. For fixed service systems located within the RDSS service area, interference effects are reduced by antenna discrimination of the fixed service system. For fixed service systems located outside of the RDSS service area, interference is reduced by antenna discrimination of both the fixed service system and RDSS satellite antennas.

In the absence of any antenna discrimination between the systems, the interference power level received by an RDSS satellite from a typical 2 W fixed service system transmitting through a 32 dBi antenna would be about 16 dB above the carrier power level of the desired RDSS user signals. The carrier to total interference ratio necessary to protect the RDSS satellite from interference is approximately 0 dB which makes the interference equivalent in power level to the emissions of a single RDSS user. A level 4 dB lower than this appears to be appropriate as a single-entry interference criteria. This level is achieved by a single interferer if 21 dB of discrimination is provided by the two antennas.

For fixed systems located outside of the RDSS service area, the RDSS satellite antenna will have significant levels of discrimination towards the fixed station transmitter. The entire 21 dB of discrimination is achieved in the RDSS satellite antenna if it is pointed more than 7.6° away from the fixed station location. Additional discrimination is provided if the fixed station antenna is not pointed directly towards the RDSS satellite.

For fixed service systems located within an RDSS service area, all discrimination between the two systems must be obtained from the fixed service system antenna discrimination. A typical 32 dBi fixed service system antenna would provide 21 dB of discrimination at an off-axis angle of 12°. Considering, however, that a fixed service system is generally pointed relatively close to the horizon and that an RDSS satellite would be visible considerably above the horizon within its service area, fixed service transmitters located within an RDSS service area should not represent an interference problem.

2.2 *Satellite-to-user link (2483.5-2500.0 MHz)*

The 2483.5-2500.0 MHz band is part of the 2400-2500 MHz band designated for industrial, scientific and medical (ISM) applications by Radio Regulation No. 752. Radio services operating within this band must accept harmful interference which may be caused by these applications.

Also, the band is allocated to radiolocation and fixed and mobile service users. The following sections discuss frequency sharing of the RDSS with ISM, fixed and mobile systems.

2.2.1 *Sharing with ISM operations*

Due to the large number of microwave ovens in use today, this section concerns potential interference to RDSS user receivers from microwave oven emissions in the 2400-2500 MHz band. Previous studies have indicated that interference to the RDSS system from microwave ovens should not pose a serious operational problem. The effect of possible interference from microwave ovens operating in close proximity to an RDSS user would be to cause a modest increase in a user's re-transmit rate.

2.2.2 *Sharing with fixed and mobile service system*

2.2.2.1 *Interference to RDSS*

Due to the omnidirectional characteristic of the user receive antenna, the RDSS users are susceptible to interference from nearby fixed and mobile service transmissions. In fact, the potential for interference is quite high if fixed or mobile service transmitters are within line-of-sight of the user receivers.

There appear to be few fixed and mobile service assignments in the 2484-2500 MHz band. As a means, therefore, of expanding the use of the spectrum to include RDSS operations, it may be necessary to re-assign fixed and mobile service users to slightly different frequencies within the allocated frequency band. In countries where extensive use of this band for fixed and mobile service use is not made, re-assignment such as this may be desirable in order to utilize RDSS type services.

2.2.2.2 *Interference to fixed and mobile service systems*

The proposed RDSS space station will produce a maximum pfd level on the Earth's surface of $-139.0 \text{ dB(W/m}^2\text{)}$ in 4 kHz. The CCIR has determined limits of power flux-density at the Earth's surface to protect fixed service systems in the 1.7 to 2.5 GHz frequency band of -154 to $-144 \text{ dB(S/m}^2\text{)}$ in a 4 kHz band, varying with the angle of arrival of the emission. Considering that pfd limits were developed based on a 2500 km 60 hop radio-relay system while the actual users of this band in the service area of the proposed system use only 1 or 2 short hop systems, the spread-spectrum RDSS satellite emissions at 2491.75 MHz should have little effect on existing terrestrial systems. Outside of the RDSS service area, the pfd produced at the surface of the Earth will decrease rapidly due to the discrimination provided by the high gain, 38.8 dBi, RDSS satellite antenna.

2.2.3 *Sharing with the radiolocation service*

Because of the great diversity of terrestrial radiolocation stations, it is difficult to make a definitive statement as to the feasibility of sharing between the radiodetermination satellite service and the radiolocation service. Inter-system interference will be a function of system power and sensitivity, antenna gains, relative system locations, pulse length, pulse repetition frequencies and types of received signal processing, among other factors. In general, the radiolocation systems that would be most likely to produce or receive interference would be those systems which have a high antenna gain towards the RDSS satellites and which are located near the service area of an RDSS system, and therefore are near the main beam of the RDSS satellite. This occurs when a low elevation angle RDSS service area contains radiolocation stations or is adjacent to an area containing radiolocation stations. The satellite emissions would appear to the terrestrial radiolocation system from a single point in the sky. Depending upon the signal processing used in the radiolocation receiver it may be possible to process out a recognizable signal of the type emitted by the RDSS.

The high power terrestrial radiolocation service transmitters will cause interference in RDSS users operating in the vicinity of the radiolocation site. It may be possible, however, for RDSS users to operate in this area if the radiolocation transmitter antenna scans the horizon so that emissions in the direction of the RDSS user are periodically low. In the case of the RDSS users, only a relatively short period of interference-free transmissions is necessary to establish a link to the satellite. By utilizing these interference-free periods, it may be possible to achieve effective communications in these areas.

2.3 *Satellite-to-central earth station (5117-5183 MHz)*

The 5117-5183 MHz band is allocated under Footnote 797 to the fixed-satellite service and the inter-satellite service, for use as feeder links serving the aeronautical radionavigation and/or aeronautical mobile (R) service, subject to agreement obtained under the procedure set forth in Article 14. This band is also allocated on a world-wide basis to the aeronautical radionavigation service with use by the international microwave landing system (MLS) (Radio Regulation No. 796) taking precedence. MLS equipment, however, is being developed and distributed only in the 5030-5090 MHz portion of the spectrum.

2.3.1 *Interference to MLS receivers*

The portion of the MLS that could operate in this band is a mobile receive-only station used on board aircraft for final approach and landing at major airports. Indications are that the system would have a noise temperature near 2600 K and a receive antenna gain of about 3 dBi.

Using these hypothetical characteristics and a maximum RDSS satellite power flux-density of $-139 \text{ dB(W/m}^2\text{)}$ in a 4 kHz band, a noise-to-interference ratio in excess of 30 dB is obtained. This value would be sufficient to protect the MLS receivers and thus there should be no sharing difficulties encountered in this band.

2.3.2 *Interference to RDSS central earth station*

Any potential interference to the central earth station from MLS transmitters would be controlled via proper earth-station site selection and coordination so as to avoid airport facilities utilizing MLS systems.

2.4 *Control earth station-to-satellite (6525-6541.5 MHz)*

This link, operating as a feeder link in a fixed satellite service band, would be the subject of normal coordination with other satellite systems (see Appendix 29 to Radio Regulations) and terrestrial stations (see Appendix 28 to Radio Regulations).

2.5 *Sharing within the RDSS service*

The use of pseudo-random-noise codes by the RDSS system to produce the spread-spectrum modulation of the user-to-satellite signals enables a large number of users to access the satellite simultaneously. The same process is also effective for extracting signals from interference generated by other RDSS systems in the same service area, provided the signals are modulated by pseudo-random-noise codes that have good cross-correlation characteristics. Gold codes, for example, are a class of codes that have these characteristics and can be readily generated in large numbers. This method of coordination through the use of Gold codes permits an RDSS system to operate with other RDSS systems in the same area. The noise contributions of three such systems is shown in Tables II and IV. For systems serving different areas, sharing is further enhanced by the antenna discrimination provided by the high gain RDSS satellite antenna.

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SECTION 8G: LAND MOBILE-SATELLITE SERVICE AND MOBILE-SATELLITE SERVICE

Reports

REPORT 770-2

**TECHNICAL AND OPERATING CONSIDERATIONS FOR
A LAND MOBILE-SATELLITE SERVICE OPERATING IN BAND 9**

(Question 47/8)

(1978-1982-1986)

1. Introduction

Definitions (Radio Regulations Nos. 27, 29, 31, 35, 73) adopted at the WARC-ST in 1971 anticipated the needs of a mobile-satellite service, separate from the fixed-satellite service, and provided space counterparts of conventional land mobile, maritime mobile, and aeronautical mobile services. Subsequently, considerable progress has been made toward establishing maritime mobile and aeronautical mobile-satellite services in bands allocated for these purposes in 1971. These space services augment and extend the capabilities provided by non-space means, overcoming line-of-sight limitations, and overcoming the uncertainties of ionosphere-dependent propagation.

The purpose of this Report is to explore the operational utility of satellites in the land mobile service, to present information on the probable technical characteristics of certain types of land mobile-satellite systems, and to employ these characteristics in a preliminary assessment of sharing between such a land mobile-satellite service and other services in the vicinity of 1 GHz.

2. Background

In the United States, and in some other countries, frequencies in the vicinity of 900 MHz have been allocated domestically for use by the land mobile service. In the USA in particular, the intent is to develop a nationwide land mobile service which is both a mobile extension of the public telephone services and a substantial augmentation of the Public Safety, Industrial, and Land Transportation Radio Services.

The application of space systems could increase the capacity, capability and versatility of these land mobile systems and services, particularly for covering large geographical areas with a single system, for assuring communications during emergencies and natural disasters, and for extending service to remote and isolated areas.

Because they are intended to be complementary, the technical characteristics of land mobile and land mobile-satellite systems should be compatible. That is, the technical characteristics should allow inter-operability between the systems where appropriate, and they should facilitate frequency sharing under mutually agreed circumstances.

3. Potential applications

Three possible roles for the land mobile-satellite service are experimental, operational, and emergency use. The first of these is a prelude to the others, in that it would permit experimentation in close collaboration with the land mobile service. The purposes of such experiments would be twofold: first, to identify operational services for which satellites may provide a logical and cost-effective alternative, supplement or augmentation for the land mobile service, and second, to establish criteria for possible sharing between the land mobile-satellite service and the land mobile service in rendering these services.

Operationally, the land mobile-satellite service may prove to be the most effective means for dependable coverage into rural and isolated areas. Satellites could either provide geographical extensions of conventional land mobile services (as in the case of aeronautical and maritime satellite services beyond line-of-sight of land masses); or satellites could provide new services not now possible with existing facilities because of line-of-sight limitations of the land mobile service at VHF and UHF.

Another application is a satellite data communication system for vehicles. Preliminary market surveys in Europe have indicated considerable interest in reliable communication for long distance road transports. From these market contacts, it appears that a dispatch system* based on two-way telex and data transmission would satisfy the essential needs. Excluding voice transmission enables a considerable reduction to be made in the system C/N_0 . The basic system elements conceived are:

- dispatch centres working through the public telex and data networks;
- a land earth station;
- a satellite transponder; and
- mobile earth stations.

Practical experiments in the concept envisaged in this system would be of great value in finalizing the details. Such a communication system could find wider use, for example finding roaming subscribers in land mobile radio systems. For the time being there is no suitable frequency allocation for the land mobile-satellite service in Region 1. At the WARC-79 an allocation was made for land mobile-satellite communication within the 900 MHz band in Regions 2 and 3. In Region 1, however, only Sweden and Norway have an allocation. Consequently, a Region 1 system will only be possible if a suitable frequency allocation is made at a future competent conference. One possibility could be integration with another system using low G/T earth stations.

Annex IV describes and provides the results of voice communication and position location experiments conducted in the United States using the ATS-6 experimental geostationary satellite.

4. Technical characteristics

The transmission quality objectives for a system in the land mobile-satellite service would be similar to the transmission quality objectives of a land mobile system. For example, for a mobile telephone service, the transmission quality objective would be that there is a 0.90 probability of obtaining a voice circuit which 75% of the subscribers rate as circuit merit 4; and a 0.90 probability of obtaining a voice circuit which 90% of the subscribers rate as circuit merit 3.

A concept definition study [Anderson and Milton, 1979; Anderson, *et al.*, 1981] for a land mobile-satellite system to provide mobile radiotelephone service to about 200,000 subscribers located primarily in rural areas of the contiguous 48 states in the United States has been completed. The satellite consisted of 69 beam multi-beam antenna system featuring a beamwidth of 0.5° between the 3 dB points. There were 111 channels per beam and with a frequency re-use factor of 3, this yielded a total of 333 channels. The total occupied bandwidth was 10 MHz in both the satellite-to-mobile and mobile-to-satellite directions of transmission. For operation in the 800 MHz band, the space station antenna would be about 42 m in diameter and the prime power would be about 12 kW. Operation in the 1550-1650 MHz bands would decrease the antenna diameter to 21 m, but increase the prime power to 48 kW.

Annexes I and II to this Report present the principal technical characteristics of the land mobile and land mobile-satellite services which are pertinent to the feasibility of sharing between these services. The material is drawn largely from these sources:

- Annex I of Report 631 contains summary information on the characteristics of a land mobile service used in Japan.
- Report 358 summarizes information from numerous sources on protection ratios applicable to sharing in the land and maritime mobile services at VHF and UHF. Much of this information is "service-independent" and can be applied, with proper attention to the particular geographical considerations, to analyze sharing between land mobile and land mobile-satellite systems.

* For the purpose of this text, "dispatch system" has the meaning: a radio system used to control the operation of a fleet of mobiles, such as aircrafts, taxis, police, etc.

- In the United States, experiments are being planned for a nation-wide public radiotelephone system designed on a cellular basis [Addeo, 1976; Fisher, 1976].
- The technical characteristics for a land mobile-satellite service are being developed by the US National Aeronautics and Space Administration, based on an authoritative sampling of the public service community [NASA/GSFC, 1976, 1977].

Annex V to this Report presents the results of a measurement programme carried out in Canada in the 806-890 MHz band and at 1542 MHz to characterize the excess path-loss statistics for land mobile satellite systems.

Annex VI similarly presents the results of a measurement programme to characterize the depolarization of the signal received at the mobile station using a low-gain antenna.

5. Sharing considerations

The technical characteristics given in Annex I and II are employed in Annex III to examine a number of specific aspects of sharing between the land mobile and land mobile-satellite services. In particular, the annexes contain data on minimum values of signals to be protected, protection ratios, power flux-density limitations, and coordination distances. It is emphasized, however, that the coalescence of these parameters into detailed sharing criteria is not possible until the potential for use of satellites becomes more clearly defined, and until further experimentation with proposed land mobile systems provides more data on minimum desired signals and other factors which will influence sharing.

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ANNEX I
CHARACTERISTICS OF THE LAND MOBILE SERVICE NEEDED
TO EXAMINE SHARING POSSIBILITIES

1. General

Technical characteristics from three sources are examined. Maximum allowed interference levels to protect the three systems are found to be nearly identical.

2. Characteristics of Japanese land mobile system to operate at about 800 MHz

In Annex 1 of Report 631, a preliminary evaluation of the feasibility of sharing between the broadcasting-satellite service and the terrestrial mobile service in the 800 MHz band is provided. The permissible limits of power flux density produced on the surface of the Earth are based on worst-case co-channel interference, no account being taken of the advantage of channel interleaving.

The limits of interfering power flux-density produced on the surface of the Earth by a satellite to protect a high grade service are given as:

- 133 dB(W/m²) in a 16 kHz band at the receiving antenna of a mobile station,
- 146 dB(W/m²) in a 16 kHz band at the receiving antenna of a base station which correspond to field strengths of 12.8 and -0.2 dB(μV/m), respectively.

The following base station characteristics were assumed:

Channel spacing	25 kHz
Receiver bandwidth	16 kHz
Receiver noise factor	10 dB
Improvement factor	12 dB
Antenna gain	15 dB
Protection ratio	18 dB
Polarization discrimination	3 dB.

3. Field strength and protection ratios in the mobile service

Report 358, gives the minimum field strength to be protected as:

$$E_{min} = -41 + d + 20 \log f \qquad \text{dB}(\mu\text{V}/\text{m}) \qquad (1)$$

where:

- d = multipath degradation (dB)
 - = 10 dB for mobile receiver in motion
 - = 21 dB for base station receiver (mobile transmitter in motion)
 - = 0 dB for base station receiver (stationary hand-held portable transmitter)
- f = frequency in MHz.

At 860 MHz the minimum field strength and corresponding power flux densities to be protected are:

27.7 dB(μV/m) or -118.1 dB(W/m ²)	for mobile receiver in motion
38.7 dB(μV/m) or -107.1 dB(W/m ²)	for base station receiver (mobile transmitter in motion)
17.7 dB(μV/m) or -128.1 dB(W/m ²)	for base station receiver (stationary hand-held portable transmitter).

According to Table 1 in Report 358, the RF protection ratio is a function of the modulation parameters and difference in frequency between the desired and interfering carriers. However, the RF protection ratio is bounded by 8 and 17 dB. Taking into account a 3 dB polarization isolation and a conservative value of 17 dB for the RF protection ratio (assumes co-channel interference), the permissible interfering field strength and corresponding power flux-density is:

13.7 dB(μV/m) or -132.1 dB(W/m ²)	for mobile receiver in motion
24.7 dB(μV/m) or -121.1 dB(W/m ²)	for base station receiver (mobile transmitter in motion)
3.7 dB(μV/m) or -142.1 dB(W/m ²)	for base station receiver (stationary hand-held portable transmitter).

4. Characteristics of a cellular public radiotelephone system planned for use in the United States of America

Channel spacing	30 kHz
Receiver bandwidth	30 kHz
Modulation (FM voice)	12 kHz deviation
(FM 10 kbit data)	8 kHz deviation
Transmitting antenna gain	
(base station)	10 dBi (or 7.9 dBd)
(mobile station)	3 dBi (or 0.9 dBd)
e.i.r.p. (base station)	20 dBW (erp = 17.9 dB)
(mobile station)	13.8 dBW (erp = 11.7 dB)
Receiving antenna gain	
(base station) (60° sector)	17 dBi (14.9 dB)
(mobile station)	4.1 dBi (2.0 dB)
Typical base station height	150 m
Receiver sensitivity (12 dB, SINAD)	
(base station)	−146 dBW (0.71 μV (e.m.f.))
(mobile station)	−143 dBW (1.0 μV (e.m.f.))

The minimum desired power flux-density may be determined from:

$$\rho = \frac{4\pi P}{\lambda^2 G_r} \quad \text{W/m}^2$$

where:

P : minimum desired signal power (watts)

λ : wavelength (metres)

G_r : receive antenna gain relative to isotropic

Based on the 12 dB SINAD receiver sensitivity, the minimum desired power flux density and corresponding field strength at 860 MHz is:

- −142.9 dB(W/m²) or 2.9 dB(μV/m) for the base station,
- −127.0 dB(W/m²) or 18.8 dB(μV/m) for the mobile station.

Taking into account a 3 dB polarization isolation and an assumed 8 dB RF protection ratio, the permissible interfering power flux density and corresponding field strength is:

- −147.9 dB(W/m²) or −2.1 dB(μV/m) for the base station,
- −132.0 dB(W/m²) or 13.8 dB(μV/m) for the mobile station.

5. Summary

Values of permissible interfering power flux density and corresponding field strength are summarized in Table I.

TABLE I – Summary of permissible interfering power flux-density and corresponding field-strengths

Interfered with station	Report 631-1		Report 358-3		Cellular	
	dB (W/m ²)	dB (μV/m)	dB (W/m ²)	dB (μV/m)	dB (W/m ²)	dB (μV/m)
Base station	−146.0	−0.20	−142.1	+3.7	−147.9	−2.1
Mobile station	−133.0	+12.8	−132.1	+13.7	−132.0	+13.8

ANNEX II

CHARACTERISTICS OF THE PROPOSED LAND MOBILE-SATELLITE
SERVICE NEEDED TO EXAMINE SHARING POSSIBILITIES

1. General

Services offered by the proposed land mobile-satellite service will include voice and data. In order to reduce experimental and development costs, for an initial system, transmitting and receiving equipments are assumed similar to those planned for the land mobile cellular system described in § 4 of Annex I, with the addition of:

- a low-noise receiving pre-amplifier (4 dB, NF) to provide -152 dBW receiver sensitivity (12 dB, SINAD),*
- a transmitting power amplifier (100 W maximum).

Three earth station types are contemplated:

- mobile, roof-mounted, approximately 0.3 m square to allow mobile operation without antenna tracking for satellite elevations above 25°,
- transportable,** approximately 1 m diameter, pointed toward satellite with ± 8° accuracy,
- base station, approximately 2 m diameter, pointed toward satellite with ± 4° accuracy.

2. Earth station characteristics

Antenna gain	(mobile)	3.5 dBi
	(transportable)	16.5 dBi
	(base)	22.5 dBi
E.i.r.p.	(mobile)	17.8 dBW
	(transportable)	17.8 dBW
	(base)	17.8 dBW
Antenna discrimination in the horizontal plane (25° minimum elevation angle)		
	(mobile)	0.6 dB
	(transportable)	12.4 dB
	(base)	22.5 dB
Receiver sensitivity (12 dB SINAD)		-152 dBW
Protection ratio		8-17 dB

The minimum required power flux densities at the edge of the service area are determined by:

$$\rho = \frac{C}{N_T} \frac{4\pi kTB}{\lambda^2 G_r} \quad \text{W/m}^2$$

where:

- $\frac{C}{N_T}$: nominal operating received carrier-to-thermal noise ratio (10 dB assumed),
- k : Boltzmann's constant (J/K),
- T : operating noise temperature (438 K corresponding to 4 dB noise figure),
- B : noise bandwidth (28 kHz),
- λ : wavelength (0.35 metres $\approx$ 860 MHz),
- G_r : receiver antenna gain.

Because of the propagation uncertainties associated with the use of low gain mobile antennas, a margin of 8 dB has been assumed.

* SINAD is an abbreviation for the ratio between signal-plus-noise-plus-distortion to noise-plus-distortion.

** In this Annex, a transportable station is an earth station in the land mobile-satellite service which may be moved from location to location for temporary use at each location.

Substituting the appropriate values in the above equation yields median pfd values of:

- 123.1 dB(W/m²) for the mobile station,
- 136.1 dB(W/m²) for the transportable station,
- 142.1 dB(W/m²) for the base station.

3. Tentative space station characteristics

Antenna gain (7 m diameter)*	33 dBi
Receiving system noise temperature	1200 K
Transmitter power per channel (mobile)	9.9 dBW
Transmitter power per channel (transportable)	–3.1 dBW
Transmitter power per channel (base)	–9.1 dBW

ANNEX III

SHARING POSSIBILITIES

1. General

This Annex is provisional and presents a parametric analysis of worst-case sharing possibilities between the land mobile service and the proposed land mobile-satellite service (desired and interfering signals are frequency-modulated and co-channel). No account has been taken of the potential of channel interleaving and spread spectrum or other modulation techniques to reduce mutual interference.

The analysis examines the use of spot-beam satellite antennas as a means of providing coverage to a specific geographical area and to protect terrestrial systems. The geographical separation required between terrestrial stations of the land mobile service and those of the proposed land mobile-satellite service (LMSS) are plotted as a function of the satellite system characteristics.

From the material presented, it is concluded that *co-channel* sharing in the same service area would present formidable design constraints upon the proposed land mobile-satellite service. It is recognized, however, that the development of high-gain, spot-beam satellite antennas along with the use of channel interleaving offers the possibility of reducing these constraints to manageable proportions in the foreseeable future, but a further evaluation of these possibilities is required.

2. Use of spot beams to protect receiving stations in the land mobile service from satellite emissions

A comparison of the power flux density limits listed in Table I of Annex I with those required by a land mobile-satellite service (see Annex II) indicates the following values of additional isolation needed for co-channel operation:

<i>To protect</i>	<i>Land Mobile-Satellite Station</i>		
	<i>Mobile</i>	<i>Transportable**</i>	<i>Base</i>
Land mobile base station	24.8 dB	11.8 dB	5.8 dB
Land mobile mobile station	9.9 dB	–3.1 dB	–9.1 dB

Co-channel operation in a common geographical area is, in general, not feasible, although the use of spot-beam satellite antennas will allow adjacent area operation.

In order to determine the limits of this adjacent area, Figs. 1-3 show the required off-axis angle from the satellite main beam needed to reduce the interfering pfd to a range of specified values, plotted as a function of satellite antenna gain (see Report 810).

* Spot-beam space station antenna gains as high as 50 to 60 dB may be practical within the time frame of WARC-1979 allocations.

** In this Annex, a transportable station is an earth station in the land mobile-satellite service which may be moved from location to location for temporary use at each location.

Figure 4 depicts a typical coverage area and interference zone as seen from a satellite in geostationary orbit. This example assumes a main beam pfd of $-123 \text{ dB(W/m}^2\text{)}$ to serve a mobile station. From Fig. 1, an off-axis angle of 0.9° would reduce the interfering pfd to $-133 \text{ dB(W/m}^2\text{)}$, the permissible interfering level into a land mobile service mobile station, given a satellite antenna gain of 45 dBi. The 0.9° radius defining the interference area is shown by the dashed circle on Fig. 4. The coverage area of the satellite is shown as the solid circle of 1° diameter (3 dB satellite antenna beamwidth from the top of Fig. 1).

3. Protection of receiving base stations in the land mobile service from proposed land mobile-satellite service earth station emissions

The required geographical separation needed between transmitting stations in the proposed land mobile-satellite service and a receiving base station in the land mobile service is shown on Fig. 5 (derived from curves in CCIR Recommendation 370) as a function of LMSS station e.i.r.p.

The relation between required LMSS station e.i.r.p. and the gain of the satellite receiving antenna is given in Fig. 6.

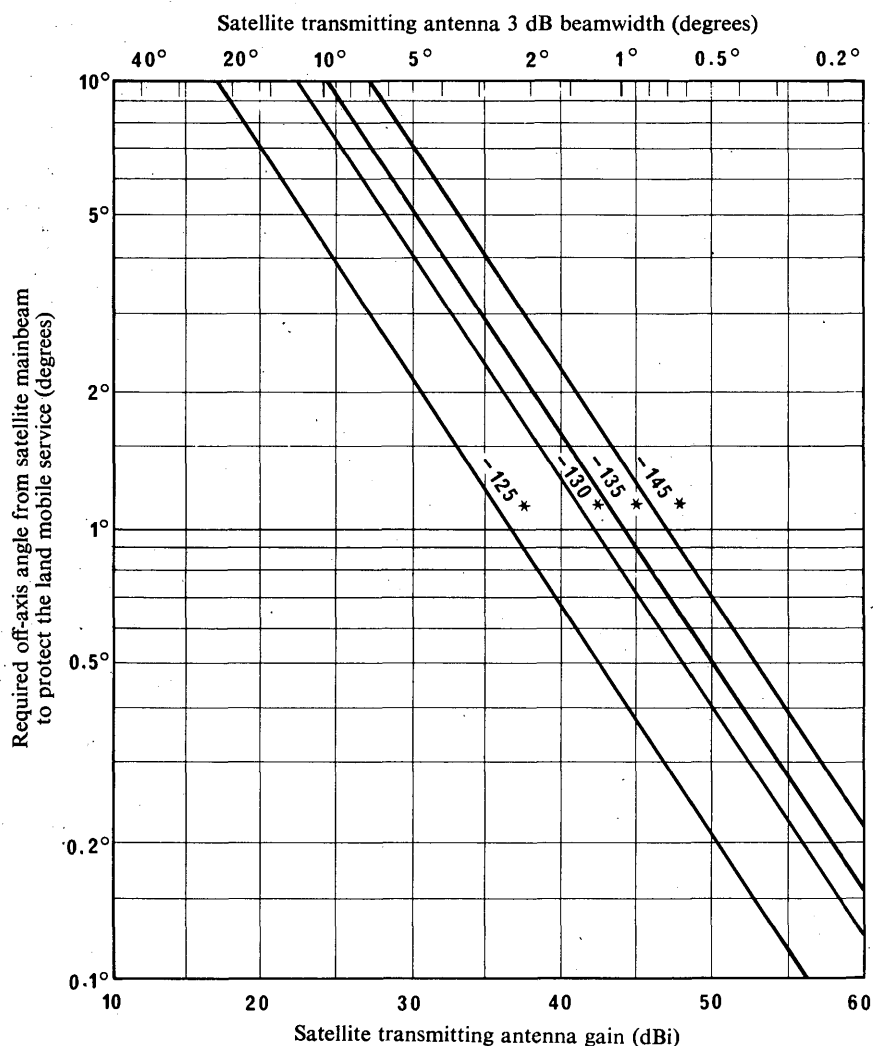


FIGURE 1 — Off-axis angle to protect the land mobile service from satellite transmissions to land mobile satellite service mobile stations

Note. — For pfd at Earth in the mainbeam = $-123 \text{ dB(W/m}^2\text{)}$
 (yields 18 dB (C/N) at LMSS mobile station)
 where: $G = 3.5 \text{ dBi}$, noise factor = 4 dB, $b = 28 \text{ kHz}$.

* Permissible incident pfd ($\text{dB(W/m}^2\text{)}$).

4. **Protection of terrestrial receiving stations in the proposed land mobile-satellite service from land mobile service base station emissions**

Fig. 7 (derived from curves in CCIR Recommendation 370) shows the required geographical separation required between a land mobile service base station transmitter and a receiving station in the proposed land mobile-satellite service as a function of LMSS station receiving antenna gain for two conditions:

- for $(I/N) = 0$ dB; assumes that the satellite e.i.r.p. is adjusted to provide an 18 dB (C/N) for each earth station gain value, and
- for $(C/I) = 18$ dB (desired signal pfd = -123 dB(W/m²)); assumes that satellite e.i.r.p. is fixed at the value required to serve a mobile receiver of 3.5 dBi gain.

5. **Protection of space station receivers in the proposed land mobile-satellite service from emissions in the land mobile service**

Further study is required of the technical and operating constraints to protect space station receivers from emissions of stations in the land mobile service.

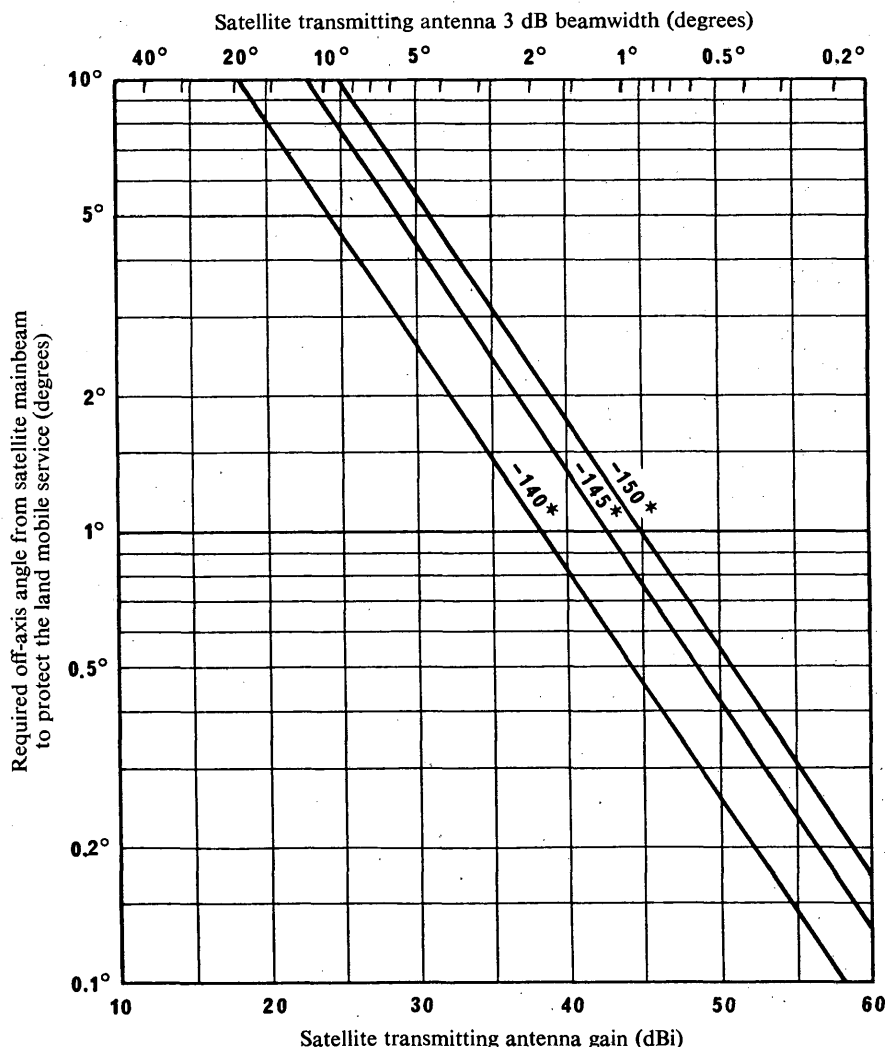


FIGURE 2 — *Off-axis angle to protect the land mobile service from satellite transmissions to land mobile satellite service transportable stations*

Note. — For pfd at Earth in the mainbeam = -136 dB(W/m²)
(yields 18 dB (C/N) at LMSS transportable station)
where: $G = 16.5$ dBi, noise factor = 4 dB, $b = 28$ kHz.

* Permissible interference pfd (dB(W/m²)).

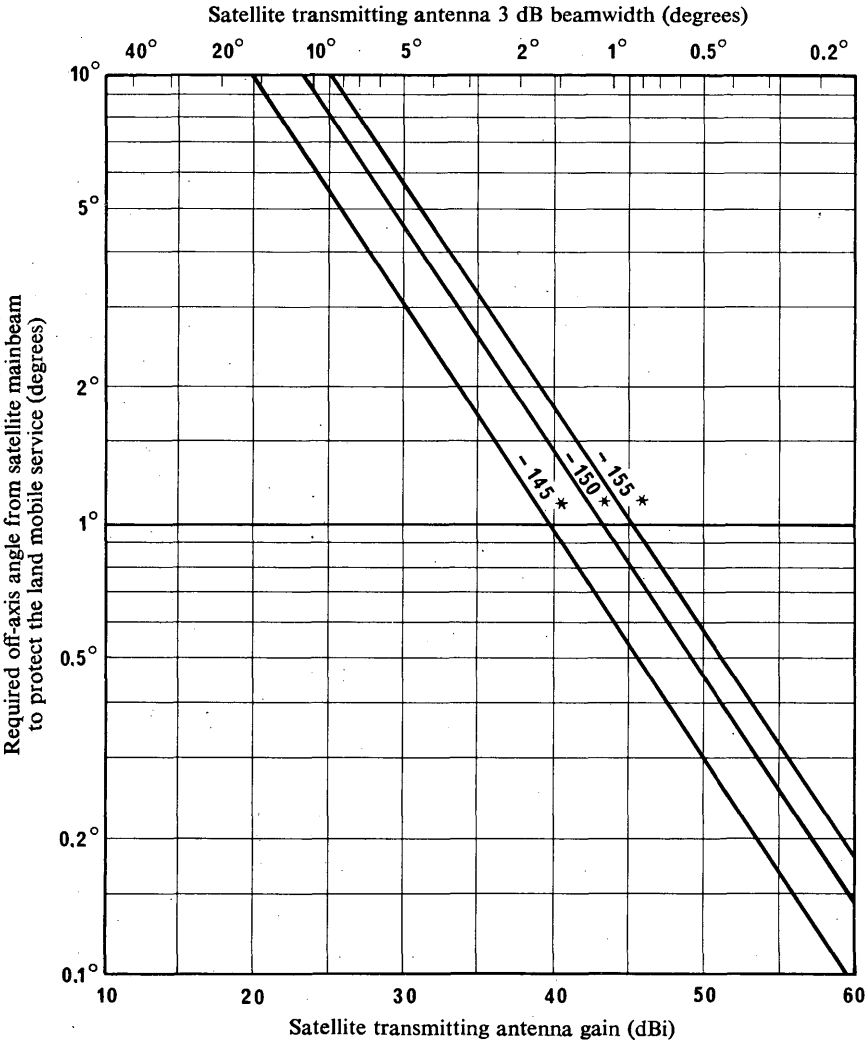


FIGURE 3 — Off-axis angle to protect the land mobile service from satellite transmissions to land mobile satellite service base stations

Note. — For pfd at Earth in the mainbeam = $-142 \text{ dB(W/m}^2\text{)}$
(yields 18 dB (C/N) at LMSS base station)
where: $G = 22.5 \text{ dBi}$, noise factor = 4 dB, $b = 28 \text{ kHz}$.

* Permissible incident pfd ($\text{dB(W/m}^2\text{)}$).

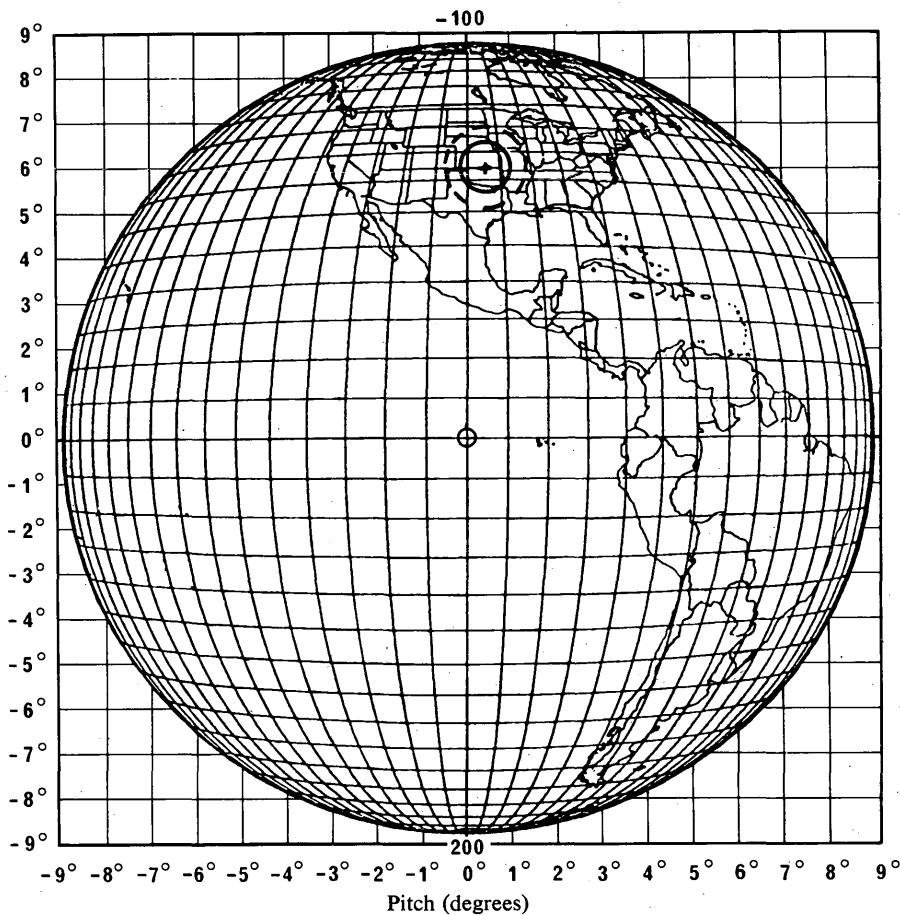


FIGURE 4 — Land mobile satellite service coverage area and co-channel interference area (45 dBi satellite antenna gain)

———— Coverage area
- - - - Interference area

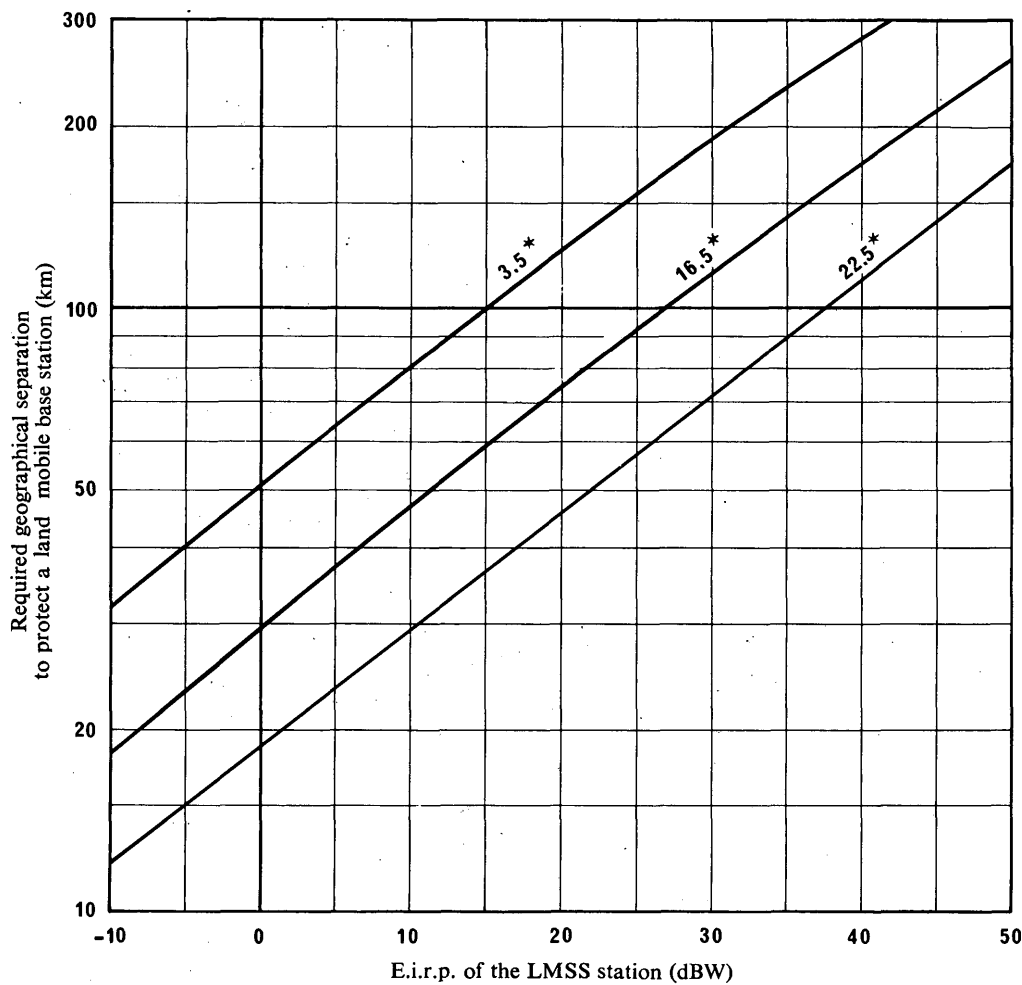


FIGURE 5 — Geographical separation needed to protect a base station in the land mobile service from land mobile satellite service station emissions

Note. — For an interference pfd = -146 dB(W/m²) at the land mobile base station, 10% of the time, 50% of the locations, $h_1 = 150$ m, $h_2 = 3$ m, $\Delta h = 50$ m, suburban propagation path.

* LMSS transmitting antenna gain (dBi).

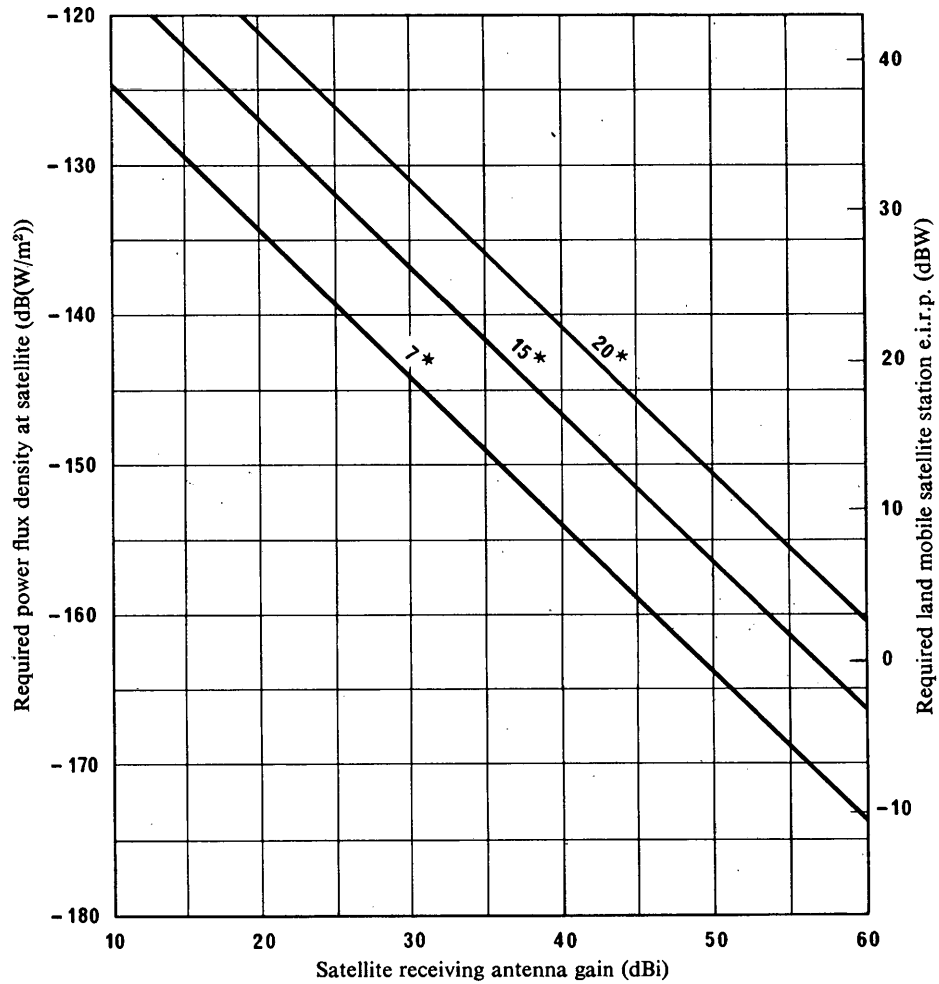


FIGURE 6 — Relation between required land mobile satellite service station e.i.r.p. and satellite receiving antenna gain

Note — For $(C/N) = -18$ dB at satellite receiver in a 28 kHz bandwidth.

* Satellite noise factor (dB).

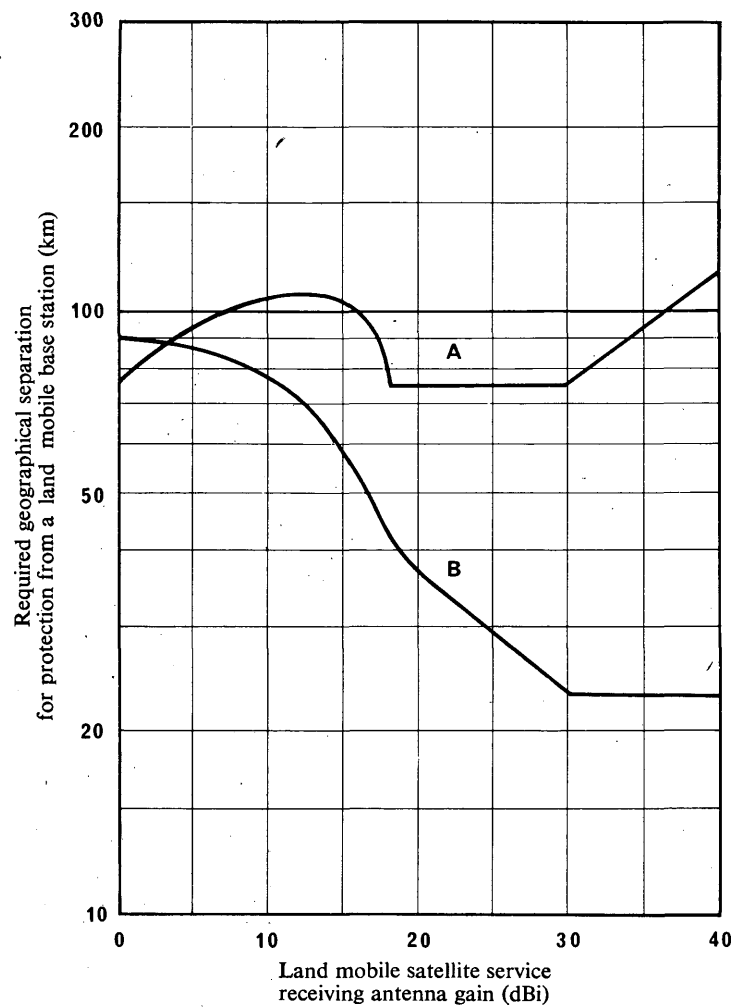


FIGURE 7 — Geographical separation required to protect receiving land mobile satellite service stations from land mobile service base station emissions

Curves A: For $I/N = 0$ dB at LMSS receiver (noise factor = 4 dB)
 B: For $C/I = 18$ dB at LMSS receiver (desired signal pfd = -123 dB(W/m²))

ANNEX IV

MOBILE VOICE COMMUNICATION AND POSITION LOCATION EXPERIMENTS

1. Introduction

This Annex describes the results of two experiments to demonstrate the feasibility of and obtain data on the reliability of land mobile-satellite systems to provide voice communications and automatic vehicle position location services. These experiments were conducted in the United States using the experimental geostationary satellite ATS-6 positioned at 140° W longitude. In both experiments, signals in the 1650 MHz band were received by ATS-6 using the on-board 9.1 m diameter antenna, processed, and transmitted to Earth in the 1550 MHz band. Transmission parameters adopted for both experiments were the same as those in common use by terrestrial mobile systems, i.e., narrow-band frequency modulation with 2.5 kHz baseband, 5 kHz peak deviation of 15 kHz radio frequency bandwidth [Anderson, *et al.*, 1981].

2. Voice communications experiment [General Electric, 1980a]

Five trucks of a long distance trucking company were equipped with commercial radios built for operation in the 806-890 MHz mobile band. Each radio transmitter drove a varactor frequency doubler that delivered 12 W to the antenna at the L-band frequency of ATS-6 (1550-1650 MHz). The antennas for satellite communications were specially built. They were 75 cm in height, 2 cm in diameter, and were mounted on the truck cab roof. The antennas were of the Wheeler type, with eight half-wave sections in a vertical line phased to produce a pattern that is omnidirectional in azimuth with directivity in the vertical plane from 4° to 19° elevation for reception and from 11° to 28° for transmission between the -3 dB points. The linearly polarized antennas had a maximum gain of 7.3 dB, a net gain of 4.3 dB when used with the circularly polarized satellite.

A base station was installed at the Staunton, Virginia offices of the trucking company. The base station radio was supplemented with a frequency doubler and signal down converter like those used in the trucks. The antenna was a 1.2 m diameter paraboloid mounted on the roof of the one storey building. Its gain was 20 dB. The trucks and base station were equipped with touchtone signalling and sub-audible squelch control to provide selective calling to the individual trucks and automatic identification with digital display of the origin of each received signal.

Communications between the trucks and base station were relayed through an earth station laboratory near Schenectady, New York, where all signals were recorded for later analysis of their quality and reliability. The procedure involved a two-hop mode through the satellite, hence a one-half second propagation time between truck and base station. The delay was not noticeable in the simplex mode of operation.

Signal relay through the laboratory assured strong signals to the trucks and base station because the laboratory received the signals from the satellite on a 9.1 m diameter antenna and retransmitted them through a 1.8 m diameter antenna with a power of 13 W. The satellite power was shared between the simultaneous laboratory and truck or base station signals. Transmission frequencies and received signal-to-noise ratios are shown in Table II.

The satellite beam (1.5° pencil) was centered at 35° N. latitude, 87° W. longitude, near Nashville, Tennessee, during the test periods. The trucks moved through the area extending from New Jersey westward to Nebraska, and Georgia northward to Michigan.

The signal levels of Table II were achieved when there was a clear path between the trucks and the satellite. Trees, buildings, overpasses, and terrain features between the trucks and the satellites interrupted the communications. Most interruptions were very short so they did not affect the understanding of the messages. The drivers were quick to recognize when their communications would be cut out by intervening objects. Table III indicates the reliability of the communications as a function of the geographical characteristics of the service area. Elevation angles from the trucks to the satellite were between 9° and 23° , with the lower angles in the mountainous and forested areas of the eastern states.

TABLE II — Transmission frequencies and received signal-to-noise ratios

	Transmit frequency MHz	Receive frequency MHz	IF S/N	Audio output S/N
Trucks and Base Station	1655.050	1552.000	26 dB	> 30 dB
Earth Station Laboratory	1652.010	1550.050	18 dB	24 dB

TABLE III — Truck signals received at earth station laboratory (poorest link, signals better in truck, see Table II)

Truck location	Approximate elevation	Total time on (s)	Q4 (s)	Q5 %	Q3-Q1 (s)			
					Overpass	Hills, mountains	Trees	Other
Open Plains	19°	2481	2407	(97)	35	8	2	29
Appalachian Western Foothills	15°	344	313	(91)	0	31	0	0
Appalachian Mountains	14°	1037	881	(85)	9	88	59	0
Eastern Piedmont	13°	1219	1107	(91)	9	51	39	13
Southern Piedmont ⁽¹⁾	18°	279	153	(55)	2	0	124	0

(1) Near beam edge

Signal Quality Definitions

- Q5: clearly understood, no perceptible noise
- Q4: clearly understood, perceptible noise
- Q3: mostly understood, noisy
- Q2: poorly understood, much noise
- Q1: signal present, not understood

Propagation characteristics are very different for satellite links as compared with terrestrial links. The differences enable communications via the satellite to be conducted with the same transmitted power and receiver sensitivity as the terrestrial communications. The vehicle antenna for the satellite link can be approximately the same size as the vehicle antenna for terrestrial links, although the antenna used with the satellites should be circularly polarized and have an elevated pattern that discriminates against ground reflections (Report 925).

The truck experiment confirmed that there was virtually no multipath fading with an antenna having the recommended pattern. One or two dB multipath fading was observed briefly as a truck approached or receded from an obstruction such as an overpass.

Obstructions, including trees, in the direct path between vehicle and satellite caused a complete drop out of the signal. Table III presents results typical of the truck experiment. The shadowing due to hills, trees and building would be less for a satellite at higher angles of elevation. Outside urban areas, the shadowed regions are usually small, fixed in location, and readily anticipated by the user.

3. Position location experiment [General Electric, 1980b]

One of the truck mobile units and the base station unit were modified for a position location experiment with a towboat on the Mississippi River. A mobile unit was installed on a towboat and a base station was installed at the Davenport, Iowa, office of the towing company.

The earth station laboratory near Schenectady tracked the towboat as it proceeded along the Mississippi. One line-of-position for a position fix was made by active tone-code ranging through the ATS-6 satellite. The other line-of-position was derived from passive reception of timing signals from the GOES satellite of the National Oceanic and Atmospheric Administration. Tone-code ranging interrogations were transmitted from the laboratory every 3 s, alternately to the towboat and fixed base station, resulting in a position fix for the towboat every 6 s during a tracking exercise. The position fixes of the fixed base were compared in the computer with its true position to derive corrections for errors in the independent predictions of satellite positions.

An experimental tone-code and data responder was connected between the transmitter and receiver on the towboat and the base station communication equipments. A satellite-controlled clock was added to each unit to receive time signals from GOES at one second intervals. Time "tick" outputs of the clocks were connected to the responders. The laboratory also was equipped with a satellite-controlled clock.

The tone-code ranging signals that produced the ATS-6 lines-of-position consisted of 1024 cycles of a 2.4414 kHz tone frequency modulated on the 1650 MHz band carrier with a deviation of 5 kHz so that the signal was limited to a 15 kHz bandwidth. The tone frequency and deviation were selected for compatibility with narrowband frequency modulation used for commercial mobile radio. The tone was followed by a 30 bit digital address in which a binary "zero" was transmitted as a suppressed audio cycle and a binary "1" was transmitted as an audio cycle. The responder units matched locally generated 2.4414 kHz tones to the received-tone phase, averaging over 256 cycles of the received tone to determine its phase. When the received code matched the code wired into the responder's correlator, it recognized that it was the interrogated unit and produced an output signifying the time-of-arrival of the signal. It then stopped the counter that was counting time since the last GOES tick, turned on its transmitter, transmitted the tone burst, its address code, its internal time delay measurement, and the count in the GOES interval counter.

Figure 8 presents results that are typical of all the results during the two 5 h test periods. The data was taken when the towboat was stopped in Lock 19 at Keokuck, IA; an accurately known location. The position fixes shown in Fig. 8 were recomputed after equipment recalibration. The recomputation was from the punched tape records of data made during the test. The real time results were displaced 3.7 miles toward GOES and 0.25 miles away from ATS-6 because there was not sufficient time to calibrate the equipment time delays accurately before deployment of the equipment. All of the fixes in Fig. 8 are clustered within ± 0.1 nautical mile of the true ATS-6 line-of-position, but are scattered over ± 1.5 and ± 2.2 nautical miles of the true GOES line-of-position. The difference in precision is due to the difference in bandwidths and signal-to-noise ratios of the ATS-6 and GOES ranging signals. If the GOES signals had the same bandwidth and the signal strength as the ATS-6 signals, the GOES precision would approximate that of ATS-6 and the fixes would be in a small cluster.

4. Conclusions

The experiments demonstrated that good quality voice bandwidth communications can be relayed through geostationary satellites with mobile radio equipments that are similar in cost and construction to present-day commercial mobile radios. A circuit added to the voice communication equipment can enable a fixed earth station to determine a line-of-position of the vehicle. If the vehicle carries a receiver that can measure the time-of-arrival of a signal from a second satellite, the fixed earth station can determine a second line-of-position, and hence position locate the vehicle.

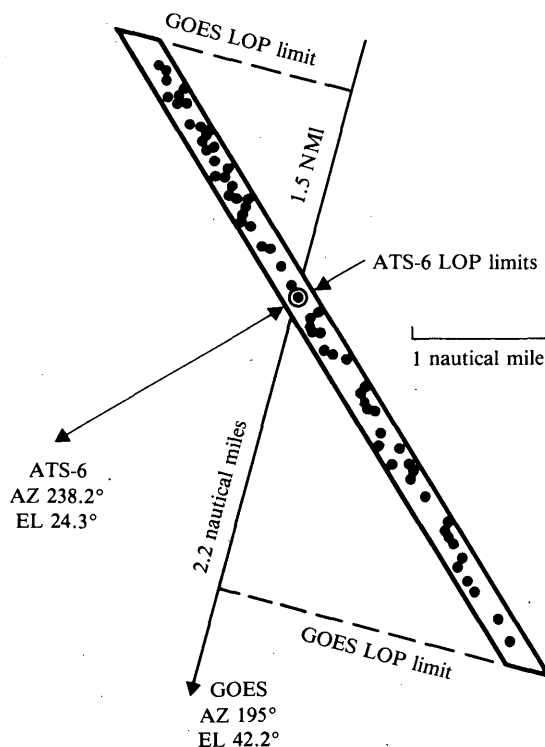


FIGURE 8 - Geometry of fix determination

LOP: line-of-position

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ANNEX V

PROPAGATION MEASUREMENTS FOR LAND MOBILE SATELLITE SYSTEMS

1. Introduction

This Annex presents the results of a measurement programme carried out in Canada in the 806-890 MHz band and at 1542 MHz to determine the excess path-loss statistics for land mobile satellite systems. In the first case a satellite source was simulated by using a helicopter to carry a transmitter and antenna, while in the second case INMARSAT's Marecs-A satellite was used as the source.

2. Description of experiment methodology

2.1 In order to gather digitized signal-strength samples and to make analogue tape-recordings of signal amplitude and phase, a mobile data-collection system was designed and installed in a converted "minibus". A full description of the equipment has been published previously [Butterworth and Matt, 1983].

2.2 For the tests at 870 MHz, where a helicopter-borne source was used, a test area was chosen where the terrain was relatively flat and was crossed by a series of straight, parallel roads. During the measurements, the helicopter flew above a road parallel to that taken by the test vehicle and moved along at the same speed, to keep a near-constant bearing and elevation from the test vehicle. Readings were taken for each 5 cm travelled by the vehicle, corresponding to an interval of about one-eighth of a wavelength. The antennas used to receive the signal were an omni-azimuth conical log-spiral for some of the measurements as well as a circularly-polarized crossed drooping-dipole turnstile for others. Right-hand circular polarization was radiated from the source.

2.3 To collect data at 1542 MHz, INMARSAT's Marecs-A satellite, located at 26° W longitude, was used. INMARSAT made 28 dBW spacecraft e.i.r.p. available during off-peak hours. Use of 300 Hz bandwidth resulted in adequate dynamic range for the measurements, giving an unfaded signal-to-noise ratio of 20 dB.

Signal strength samples were taken for each 2.5 cm travelled by the vehicle. Additional details of the methodology can be found in [Huck *et al.*, 1983].

3. Measurement results

3.1 The routes chosen for the 870 MHz measurements passed through a rural area which is 35% woodland, the rest being cleared land. Figure 9 shows the terrain and the routes taken. Readings taken at 15° elevation in completely open terrain, with no nearby trees or power lines, showed a cumulative distribution which was modelled closely by the Rice-Nakagami distribution. The value of the Rice-Nakagami parameter K (multipath/constant component ratio) for best fit to the data samples, was in the range -10 to -14 dB.

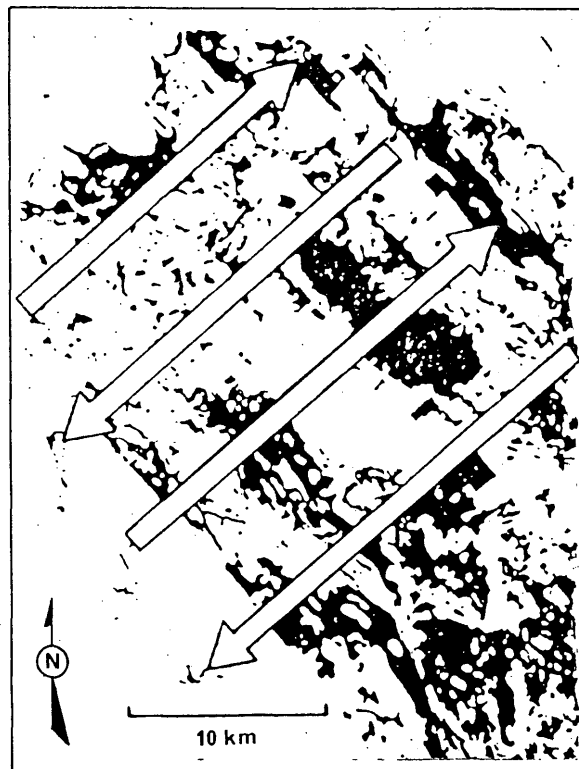


FIGURE 9 – Map showing the routes followed for 870 MHz measurements
(Woodlands (shown dark) constitute 35% of the land area)

3.2 Figure 10 shows the distribution functions obtained for measurement runs made in summer conditions along the routes of Fig. 9. One-third of these routes ran through wooded areas. The measurements were repeated with the helicopter at various heights, to provide source elevation angles of 5° , 15° and 20° at the receiving antenna. During the measurements at 5° elevation, in addition to the rapid fading due to diffuse multipath propagation, slow fading of about 8 dB fade depth was observed in areas of open terrain. It was inferred that the slow fading was due to specular reflection. The effect was not observed at higher elevation angles.

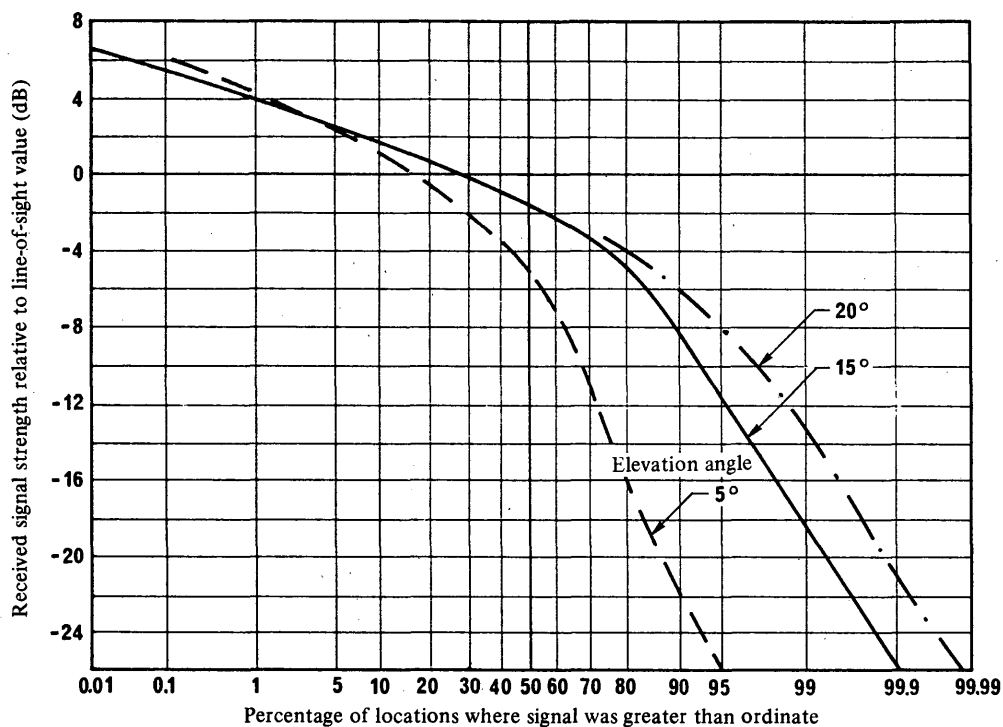


FIGURE 10 – Distribution functions of data recorded at 870 MHz for various elevation angles

3.3 Similar general procedures were followed for the measurements at 1542 MHz, where the elevation angle to the source was fixed at about 20° . Recordings were made along a number of different routes, including those used at 870 MHz. The recordings were made in the same period (June 1983 significant foliage) as the 870 MHz measurements. Figure 11 shows examples of the cumulative distribution obtained for measurements along several types of terrain other than that shown in Fig. 9.

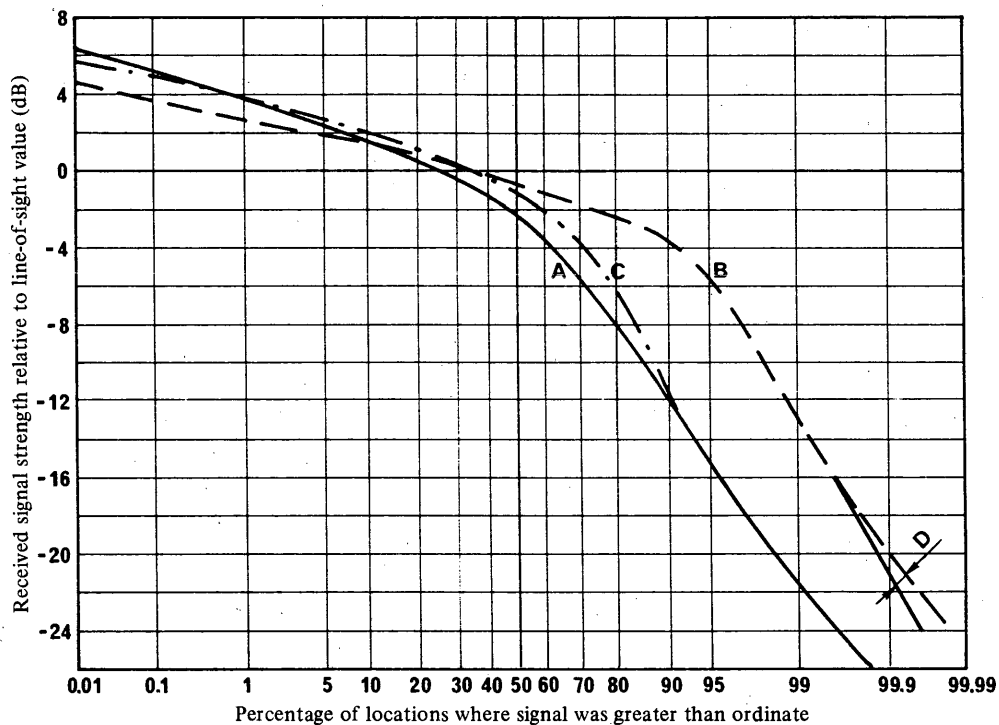


FIGURE 11 – Distribution functions of data recorded at 1542 MHz for various types of terrain

- A: suburban data
- B: rural/farmland
- C: rural/forested
- D: effect of receiver noise

4. Comparison of results at 870 MHz and 1542 MHz

A direct comparison is possible between the data taken at the two frequencies. Measurements were made over routes in the test area of Fig. 9, 35% woodland and cleared land, at 870 MHz and 1542 MHz. The antenna types used for both frequencies were circularly polarized crossed drooping-dipole/turnstile with similar radiation patterns and with the signal source at the same elevation angle of 20°. Figure 12 shows this comparison. Much as would be expected, due to the increasing foliage attenuation with frequency (as shown in Report 236, Fig. 2) the excess path loss at 1542 MHz is significantly greater than the loss at 870 MHz, for area coverage in the region of interest, i.e. above 90%.

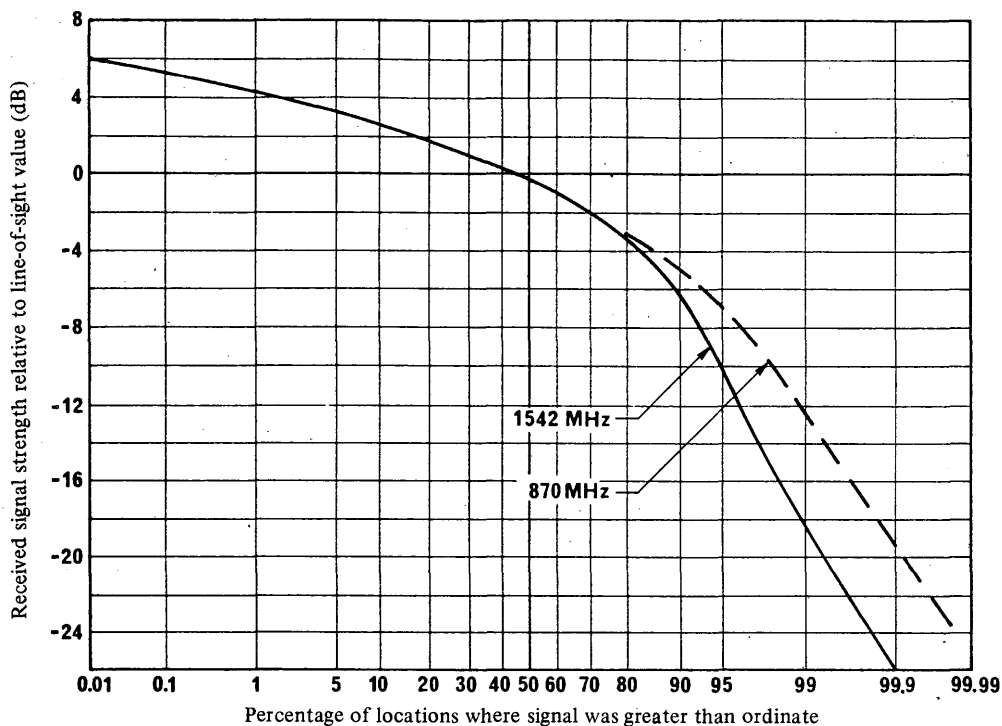


FIGURE 12 – Comparison of 870 MHz and 1542 MHz data recorded in the same test area as shown in Fig. 9 with the same antenna type and a signal source elevation angle of 20°

5. Conclusions

Although these results have been obtained in a limited number of suburban and rural areas, they should provide a useful indication of the link margin requirements for a land-mobile satellite system.

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ANNEX VI

DEPOLARIZATION MEASUREMENTS USING A LOW GAIN ANTENNA FOR MOBILE STATIONS

1. Introduction

1.1 This Annex presents the results of a measurement programme carried out in Canada to characterize depolarization effects for mobile stations using low-gain antennas. The measurements were made at a frequency of 870 MHz using a helicopter to carry a suitable signal source, as described in Annex V.

1.2 Although high levels of polarization discrimination are achievable in fixed Earth-space links using high-gain antennas, lower values are to be expected in mobile links due to pick-up of random polarized multipath signals by low-gain vehicle antennas and due to random scattering of the direct signal by shadowing obstacles such as roadside trees. The purpose of this programme was to characterize the depolarization in statistical terms.

2. Description of equipment and procedures

2.1 A helicopter was used to carry a transmitter and an antenna. The general procedures and the routes followed were as described in Annex V.

2.2 The helicopter used to carry the signal source was equipped with a small transmitter feeding a back-fire quadrifilar helix antenna. The antenna was mounted on the end of a boom extending from the side of the helicopter. The antenna radiation was right-hand circularly polarized (RHCP), with the left-circular component being at least 15 dB lower.

2.3 The mobile laboratory used to make the measurements was equipped with a cross-dipole (turnstile) antenna with an integral ground plane. The antenna assembly was mounted on the left side of the vehicle roof and was tilted with an elevation angle of 20°. For this antenna the cross-polar component was 20 dB below the co-polar component for angles up to 45° from boresight, which also corresponded to the approximate 3 dB beamwidth.

2.4 The RHCP and LHCP outputs from the antenna assembly were connected, with appropriate amplification and filtering, to the "reference" and "test" inputs of a network analyzer. In this way, readings of the difference (in decibels) between the RHCP and LHCP signal levels were recorded, under computer control, for every 5 cm travelled by the mobile laboratory.

3. Measurement results

3.1 The routes described in Annex V were traversed three times. In each case the helicopter flew at a different altitude so that data were recorded at elevation angles of 15°, 20° and 30° from the mobile laboratory. About one million data points were recorded at each angle. Figure 13 shows the cumulative distribution function of the RHCP/LHCP received signal ratio for the three elevation angles. The median value of the ratio increases with elevation angle as the scattering effect of roadside trees becomes less intrusive.

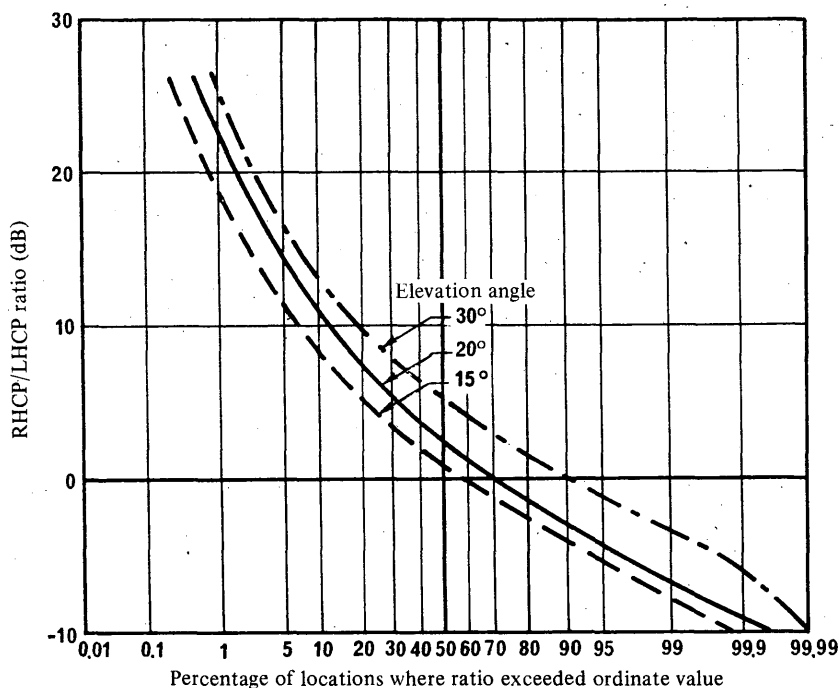


FIGURE 13 – The distribution functions obtained for three different elevation angles

3.2 Figure 14 shows the range of effects observed in individual data files of 130 000 readings. In conditions where the terrain was completely open, the median ratio at 30° elevation was as high as 10 dB. Under heavily-shadowed conditions at 15° elevation, the median ratio was 0 dB.

4. Conclusions

In order for polarization diversity to provide a useful enhancement in co-channel interference rejection, a reasonable co-polar to cross-polar signal ratio would have to be available over a large percentage of the service area. This was not found to be the case when using a low-gain vehicle antenna.

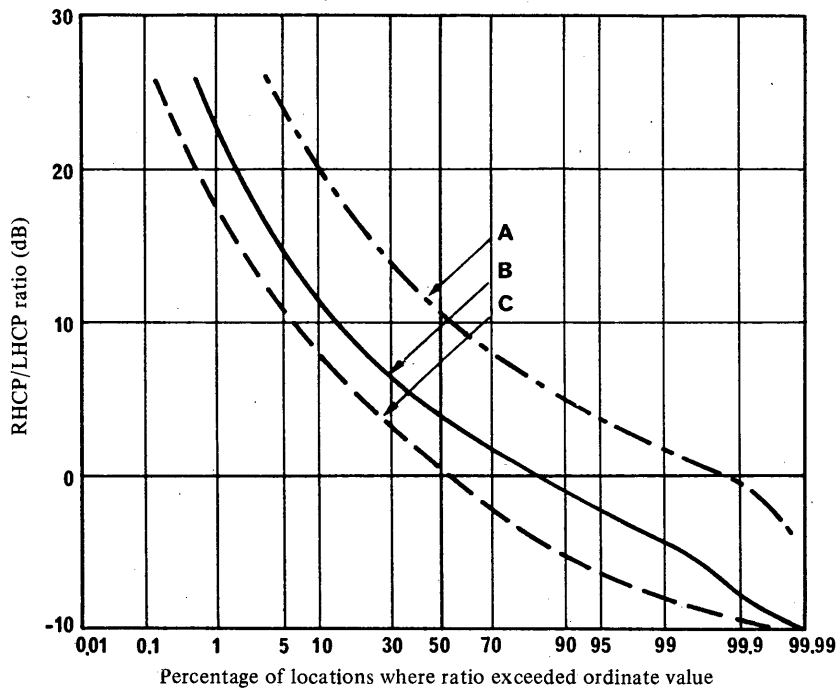


FIGURE 14 – Distribution functions for various degrees of shadowing

- A: No shadowing
- B: Moderate shadowing
- C: Heavy shadowing

REPORT 925-1

FACTORS AFFECTING THE CHOICE OF ANTENNAS FOR
MOBILE STATIONS OF THE LAND MOBILE-SATELLITE SERVICE

(Question 47/8)

(1982–1986)

1. Introduction

Report 770 describes the applications and technical characteristics of a potential land mobile-satellite system intended to extend the availability of mobile radiocommunication services routinely obtainable in urban areas into rural and remote areas. The mobile-satellite system would be compatible with the terrestrial mobile system in order to minimize user equipment costs. From this viewpoint it is desirable to use the same mobile station antenna and transceiver. Terrestrial mobile systems operating in the 800 MHz band (the band allocated by the World Administrative Radio Conference, 1979) are designed to operate with low cost, low gain omni-directional antennas on the mobile station. The use of such simple mobile station antennas, while desirable from cost and compatibility considerations, may impact on the land mobile-satellite space segment cost and on sharing with other services.

Omnidirectional antennas are susceptible to multipath, which in turn results in the carrier power received by the mobile station being a random variable. For a given grade of service, sufficient margins must be designed into the link to overcome the multipath fading. The resultant increase in the space station e.i.r.p. has a direct effect not only on the cost of the space station but also on the potential for interference to other terrestrial services. Similar multipath considerations also apply to the up link from the mobile station and result in a larger e.i.r.p. from the mobile station.

Interference between mobile stations in the land mobile-satellite service and stations (either base or mobile) in the mobile service is also a function of the gain characteristics of the mobile station antenna. The directivity of the land mobile-satellite earth station antenna will also have a direct influence on the efficient utilization of the geostationary orbit.

This Report summarizes a preliminary analysis of how the system link margins and interference to terrestrial mobile systems are affected by the gain characteristics of the mobile station antenna.

2. System link margins

This analysis focuses on the space-to-Earth path. A simple low cost omnidirectional antenna is assumed to be mounted on the roof of the mobile station.

2.1 Propagation modelling

The carrier power received by an antenna whose characteristics approximate those of an isotropic antenna is a function of the total electromagnetic field in which it is located. The total field is the vector sum of three major components. The direct line-of-sight component (when there are no obstructions), a specular multipath component (or components), and a diffuse multipath component. The multipath components result from the geometry and reflection characteristics of the environment. Their amplitude and phases will tend to be random variables yielding a received carrier power which is itself a random variable.

The conditions for both specular reflection and diffuse scattering in a rural environment may be determined from the scattering coefficient, ρ_s , for surfaces exhibiting random height variations with a Gaussian probability density function [Beckmann and Spizzichino, 1963]:

$$\rho_s = \exp \left[- \frac{1}{2} \left(\frac{4 \pi \sigma_h \sin \delta}{\lambda} \right)^2 \right] \quad (1)$$

where, σ_h is the r.m.s. height of the irregularities of the earth's surface (metres) δ the elevation angle, and λ the wavelength (metres).

The scattering coefficient is one term in the equation for the specular reflection coefficient, R_s :

$$R_s = \rho_s D R_0 \quad (2)$$

where D is the divergence factor, and R_0 the reflection coefficient of a plane smooth earth.

For antenna heights less than 3 m and an elevation angle greater than about 1.3° , the divergence factor will be greater than 0.77 and will rapidly approach unity with increasing elevation angle.

Similarly, the magnitude of the reflection coefficient for a plane smooth earth is close to unity except for vertically polarized waves at elevation angles in the vicinity of Brewster's angle [Beckmann and Spizzichino, 1963]. Consequently, the value of the scattering coefficient is a simple first order approximation of the magnitude of the specular reflection coefficient.

Equation (1) has been evaluated at 860 MHz for terrain irregularities corresponding to a Δh between 5 m and 50 m (Δh is defined in Report 239 as the difference between the 10% and 90% terrain contours. The corresponding r.m.s. height, σ_h , is given by $\Delta h / (1.82/\sqrt{2})$). For $\Delta h = 5$ m, the scattering coefficient is .0013 for an elevation angle of 3° , and rapidly decreasing. For $\Delta h = 50$ m, the scattering coefficient is .0013 for an elevation angle of only 0.3° . It may therefore be concluded on theoretical grounds that in rural areas, where the elevation angle is greater than 3° , the reflected energy is contained primarily in the diffusely scattered waves with a negligible amount of energy in the specularly reflected component.

The amplitude of the envelope of the diffusely scattered wave has been shown to be Rayleigh-distributed, whereas the phase is uniformly distributed over the interval $-\pi$ to $+\pi$ [Beckmann and Spizzichino, 1963]. The probability density function of the envelope of the vector sum of the diffusely scattered component and the line-of-sight component is given by the familiar Rice-Nakagami density function (Report 415 (Kyoto, 1978)):

$$p(r) = \frac{r}{\sigma^2} I_0 \left(\frac{E_0 r}{\sigma^2} \right) e^{-\frac{(r^2 + E_0^2)}{2\sigma^2}} \quad (3)$$

where, r is the instantaneous peak envelope voltage (a random variable), σ the root mean square envelope voltage of the multipath, I_0 the modified Bessel function of order zero, and E_0 is the peak envelope voltage of the line-of-sight component.

The probability that the envelope of the received signal exceeds a prescribed value, R_0 , is given by:

$$P(r \geq R_0) = \int_{R_0}^{\infty} p(r) dr \quad (4)$$

Substituting (3) into (4) yields an integral which cannot be evaluated analytically. However, it can be expressed in terms of a function commonly called the Marcum Q function:

$$P(r \geq R_0) = Q(\alpha, \beta) \quad (5)$$

where, $\alpha = E_0/\sigma$, and $\beta = R_0/\sigma$. The Marcum Q function has been tabulated (Report 415), [Marcum, 1950], computed by a simple algorithm [Brennan and Reed, 1965].

The value of the parameter α is a measure of the direct line-of-sight signal relative to the multipath signal at the input to the receiver. The amplitude of the multipath signal is a function first of the environment which produces it and secondly the gain of the antenna for the elevation and azimuth angles at which it arrives.

In urban areas where there are tall buildings with heights much greater than the antenna height, the multipath elevation angles could range up to 90° . However, in rural areas where diffuse scattering by rough ground will predominate, multipath elevation angles will tend to be less than 0° (Report 763), [Beckmann and Spizzichino, 1963]. By controlling the gain of the antenna in and below the horizontal plane, the effects of multipath, at least in rural areas, may be controlled.

The link margins required for specific values of diffuse scattering and shadowing (attenuation of the line-of-sight component due to foliage, an occasional building, etc.) may be obtained from equation (5). In the figures the ratio of the peak envelope voltage of the line-of-sight signal to the r.m.s. envelope voltage of the diffuse scattering component (α) has been varied over the range from 4 to 23 dB. In addition, line-of-sight signal fading due to shadowing up to 30 dB has been considered. The results are shown in Figs. 1 to 6.

The figures clearly demonstrate the deleterious effect of diffuse scattering in the absence of line-of-sight attenuation. As shown in Fig. 1 for $\alpha = 4$ dB, a 6 dB margin is required to ensure the received envelope is above a minimum value for 90% of the time, increasing to about 15 dB for 99% of the time. In contrast, as shown in Fig. 6, rejecting the diffuse scattering by 19 dB ($\alpha = 23$ dB) reduces the required margin to less than 2 dB to meet the minimum value for 99% of the time.

The figures also show that diffuse scattering may be used as the primary propagation mechanism in the presence of severe line-of-sight attenuation. Referring again to Fig. 1, it is seen that for an attenuation of the line-of-sight signal by up to 20 dB, the corresponding increase in the 90 percentile margin is about 4 dB, and about 5 dB for the 99 percentile margin.

Figures 2 to 6 illustrate that for a given attenuation of the line-of-sight signal the required margin increases with increasing rejection of the diffuse scattering component.

These figures indicate that there are substantial link margin trade-offs to be made on the basis of the amount of mobile antenna discrimination in the horizontal plan. These trade-offs depend on the link performance objective: 90 percentile, 95 percentile or 99 percentile; the percentage of locations which will experience line-of-sight attenuation; and the spatial attenuation probability density function.

Propagation measurements are needed in order to complete the mobile antenna design trade-offs which critically affect link design margins and potential interference to other services sharing the same frequency band.

2.2 Propagation measurements

Some very preliminary propagation measurements have been made in the United States. An experimental measurements program was conducted from 1977 to 1978 to characterize the space-to-Earth path to mobile earth stations which used low gain antennas approximating to an isotropic antenna [Hess, 1978; Hess, 1979].

Circularly polarized signals transmitted at 860 MHz and 1550 MHz from the NASA Applications Technology Satellite 6 (ATS-6) were received by a specially equipped mobile test van. Conventional, linearly polarized quarter-wave antennas were mounted on the van roof about 2.5 m above the ground. The amplitude of the received signal was encoded digitally and stored for later analysis.

The measurements were taken in urban, semi-urban, suburban and rural areas at elevation angles that varied between 19° and 43°. Direction of travel and side of the street relative to the direction to ATS-6 were also noted. A total of approximately 36 h of data were taken.

Analysis of the data showed there was a similarity between the major propagation characteristics exhibited by terrestrial paths and by Earth-space paths; namely, over small distances, of the order of several hundred wavelengths, the statistical variation of the received carrier power exhibits a rather constant local mean value: whereas, over large distances, of the order of kilometres, there is a statistical variation in the local mean value. No attempt was made to separate the effects of line-of-sight attenuation, specular reflection or diffuse scattering. The margin required to ensure that the received carrier power will be above a specified value for 90% of the time for an urban area may be estimated by:

$$M = 17.8 + 1.93 f - 0.052 \delta + K(7.6 + 0.053 f + 0.040 \delta) \quad (6)$$

and for a suburban/rural area by:

$$M = 12.5 + 0.17 f - 0.17 \delta + K(6.4 - 1.19 f - 0.05 \delta) \quad (7)$$

where, M is the margin (dB), f the operating frequency (GHz), δ the elevation angle (degrees) and K is the factor which relates the percentage of the locations for which the specified carrier power will be exceeded. Values for K are:

$$\begin{aligned} K(50\%) &= 0 \\ K(90\%) &= 1.3 \\ K(95\%) &= 1.65 \\ K(99\%) &= 2.35 \end{aligned} \quad (8)$$

These equations have been derived from a regression analysis of measured data taken at 860 MHz and 1550 MHz over a limited range of elevation angles (19° to 43°). Care must be taken in applying them to other frequencies and, in particular, to elevation angles greater than 43° and less than 19°.

From equation (6), margins between 18 dB (50% of the locations) and 39 dB (99% of the locations) are necessary in urban areas to ensure that the received carried power is above a specified value relative to the line-of-sight value for 90% of the time. These values apply to an operating frequency of 860 MHz and are almost independent (within 1 dB) of elevation angles between 20° and 40°. These margins indicate that the predominate propagation mode in urban areas will be diffuse scattering: the line-of-sight path will experience large attenuation in most of the locations. Because of this large margin, plus other factors such as cost, which is consequential to the margin, and efficient spectrum utilization, the feasibility of serving urban areas using space techniques is questionable.

The corresponding margins for 90% of the time in a suburban/rural environment at 860 MHz have been calculated using equation (7). The results are shown in Table I. According to [Hess, 1978], for the suburban/rural environment the 90 percentile temporal margins may be extrapolated to other percentages of time in the 50 to 95 percentile range. Within this range the data exhibited a sensitivity of about 0.1 dB/%. The 50% temporal margin shown in Table I is therefore 4 dB less than the 90% temporal margin.

It may be deduced from the values given in equation (8) and the form of equation (7) that the probability density function for the spatial margin, i.e., percentage of locations, is given by the normal density function:

$$p(m) = \frac{1}{\sqrt{2\pi} \sigma_m} e^{-\frac{[m - U_0]^2}{2\sigma_m^2}} \quad (9)$$

where, m is the margin (dB), U_0 the margin for 50% of the locations, and σ_m^2 the variance of the distribution. Values for U_0 and σ_m are obtained from equation (7) noting that the 50% temporal margin is 4 dB less than that given by equation (7). Consequently:

$$U_0 = 8.5 + 0.17 f - 0.17 \delta \tag{10}$$

$$\sigma_m = 6.4 - 0.19 f - 0.05 \delta \tag{11}$$

where the variables are the same as previously defined.

To test the hypothesis that the 0.1 dB/% temporal sensitivity observed by [Hess, 1978] is consistent with the model for a line-of-sight plus diffuse scattering channel, a fifth curve E has been added to Figs. 3, 4 and 5. This curve is given by:

$$X = - 0.1 (P-50) + b \qquad \text{dB} \qquad \text{for } 50\% \leq P \leq 95\% \tag{12}$$

where P is the probability expressed as a percentage, and b is a constant picked so that the curve will closely approximate curve A of the figures. The closeness of fit appears to be best in Fig. 4 where the maximum difference for a given probability is less than 1 dB.

It appears reasonable then to assume, based on the above analysis of empirical data, that the ratio of the peak envelope voltage of the line-of-sight signal to the r.m.s. envelope voltage of the diffusely scattered signal is of the order of 13 dB. Stated differently, the ratio of the line-of-sight signal power to the diffusely scattered signal power is of the order of 10 dB.

TABLE 1 — Link margins, 860 MHz suburban/rural environment

Elevation angle (degrees)	Percentage of locations (%)	50% temporal margin (dB)	90% temporal margin (dB)
20	50	5.2	9.2
	90	10.9	14.9
	95	12.5	16.5
	99	15.5	19.5
30	50	3.5	7.5
	90	8.6	12.6
	95	9.9	13.9
	99	12.7	16.7
40	50	1.8	5.8
	90	6.2	10.2
	95	7.4	11.4
	99	9.8	13.8

2.3 Summary

To a first order approximation, the space-to-Earth land mobile-satellite path for a suburban/rural environment may be modelled as a line-of-sight plus diffuse scattering channel. The statistics of the spatial variation of the received power of the line-of-sight component, expressed in dB, approximates the Gaussian density function. The mean is given by equation (10) and the square root of the variance, in dB, by equation (11).

The statistics of the temporal variation (movement by the mobile over a distance of several hundred wavelengths) closely approximate the Rice-Nakagami density function when the parameter α is 4.47 (13 dB).

This model applies primarily to a roof top mounted linearly polarized quarter-wave whip receiving a circularly polarized signal in the 800 MHz band.

3. Coordination considerations

The allocation to the mobile-satellite service in the 800 MHz band is shared with allocations to the mobile, broadcasting and fixed services. Coordination is to be carried out under the provisions of Article 14 of the Radio Regulations. The e.i.r.p. of the space station and the mobile station operating in the mobile-satellite service is a key parameter effecting the coordination. As shown in § 2, the link margins and therefore the e.i.r.p. of both the space station and the mobile station may be reduced by minimizing the gain of the mobile station antenna in and below the horizontal plane. Each dB reduction in the space-to-Earth link margin will facilitate coordination with the terrestrial services.

The e.i.r.p. in the horizontal plane of the mobile station antenna will govern the coordination distance between mobile stations and stations operating in the terrestrial services. Two advantages are gained here through the control of the antenna gain characteristics. First, the e.i.r.p. in the horizontal plane will be decreased as a result of the reduced antenna gain, and secondly, the transmitter power will be decreased because of the higher antenna gain for elevation angles above 20° , for example, and the smaller link margin.

The relative significance of controlling the gain in the horizontal plane may be shown by the following example. Assume that the space-to-Earth and the Earth-to-space paths are reciprocal so that identical space-to-Earth and Earth-to-space link margins are required. Assume further that the paths exhibit Rice-Nakagami fading with $\alpha = 13$ dB and that the margins are chosen such that the received signal is above a threshold value for 95% of the time. For an isotropic antenna, the required margin will be about 3 dB as shown in Fig. 4. For an antenna with 3 dBi gain in the upper hemisphere coupled with -10 dBi gain in and below the horizontal plane, the margin is reduced to less than 1.5 dB as shown in Fig. 6. (The figure for $\alpha = 23$ dB has been used rather than including another figure for $\alpha = 26$ dB for this specific example.)

It may be readily shown that the e.i.r.p. in and below the horizontal plane is 14.5 dB less for the case of hemispherical antenna compared to the case of the isotropic antenna.

A first order estimate of the relative coordination distance may be made using equation (1) from Report 567, viz:

$$E = 88 \sqrt{P} \frac{h_t h_r}{\lambda d^2} \quad (13)$$

where E is the median field strength ($\mu\text{V}/\text{m}$), P the effective radiated power of the transmitter in the horizontal plane (watts), d the distance between antennas (m), h_t the effective height of the transmitting antenna (m), h_r the effective height of the receiving antenna (m), and λ the wavelength (m). This equation is valid within the region where the field strength decreases monotonically with distances up to the radio horizon.

Assuming the protection criteria is given in terms of a permissible field strength, the relative separation distance for a hemispherical antenna compared to an isotropic antenna may be derived from equation (13) to be:

$$\frac{d_2}{d_1} = \left(\frac{P_2}{P_1} \right)^{1/4} \quad (14)$$

For P_2/P_1 equal to $1/28.2$ (-14.5 dB), the separation distance is reduced by a factor of 2.3 when using a hemispherical antenna compared to an isotropic antenna.

4. Conclusion

It has been shown that the mobile station antenna gain characteristics play a key role in determining the link margins required in mobile-satellite systems, and have a significant effect on the coordination distance to protect terrestrial systems from harmful interference from mobile stations in the mobile-satellite service.

Preliminary urban propagation measurements taken in the United States indicate that link margins of the order of 18 to 39 dB are required for 90% of the time in 50% and 99% of the locations, respectively. These margins are based on the use of a roof mounted, linearly polarized quarter-wave antenna.

In suburban/rural areas the measurements indicate that the space-to-Earth path may be modelled as a line-of-sight plus diffuse scattering channel. The spatial statistics, expressed in dB, approximates the Gaussian density function, whereas the temporal statistics are approximated by the Rice-Nakagami density function. These conclusions also apply primarily to a roof mounted, linearly polarized quarter-wave antenna.

It has also been shown that the mobile station antenna characteristics play a key role in determining the coordination distance to stations operating in the terrestrial services. In the example given, it was shown that the coordination distance could be reduced by a factor of 2.3 by the use of a mobile station antenna with -10 dBi gain in and below the horizontal plane.

The land mobile-satellite earth station antenna directivity also affects the geostationary-satellite orbit utilization efficiency. Additional study is required in order to quantify this specific aspect of the land mobile-satellite service.

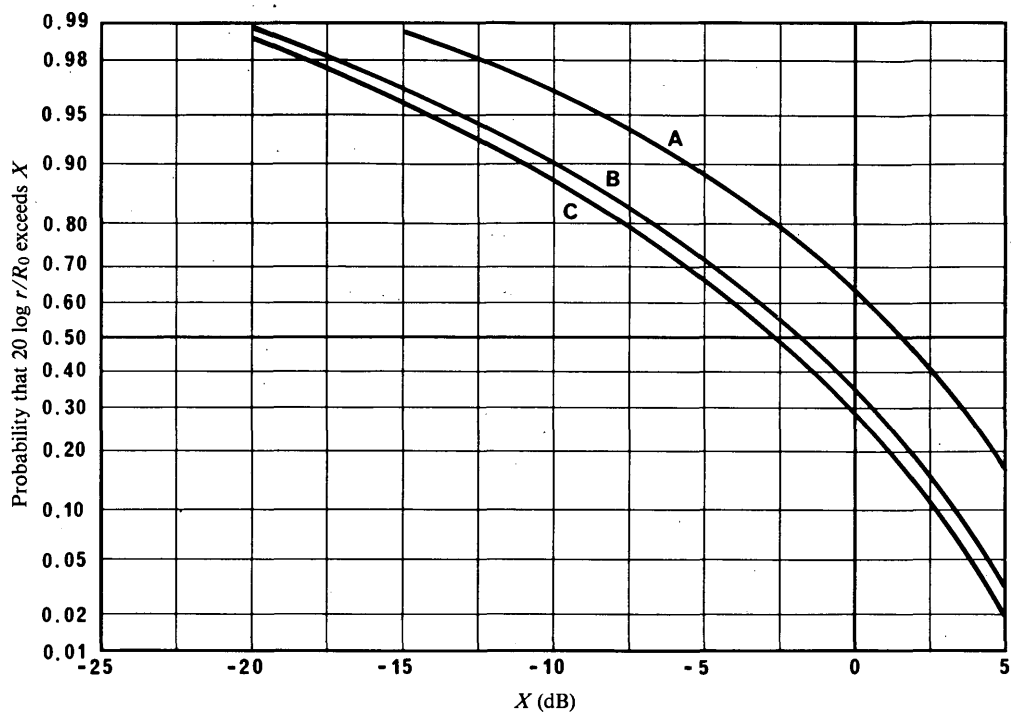


FIGURE 1 – Received carrier envelope
Distribution function: $\alpha = 4$ dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss

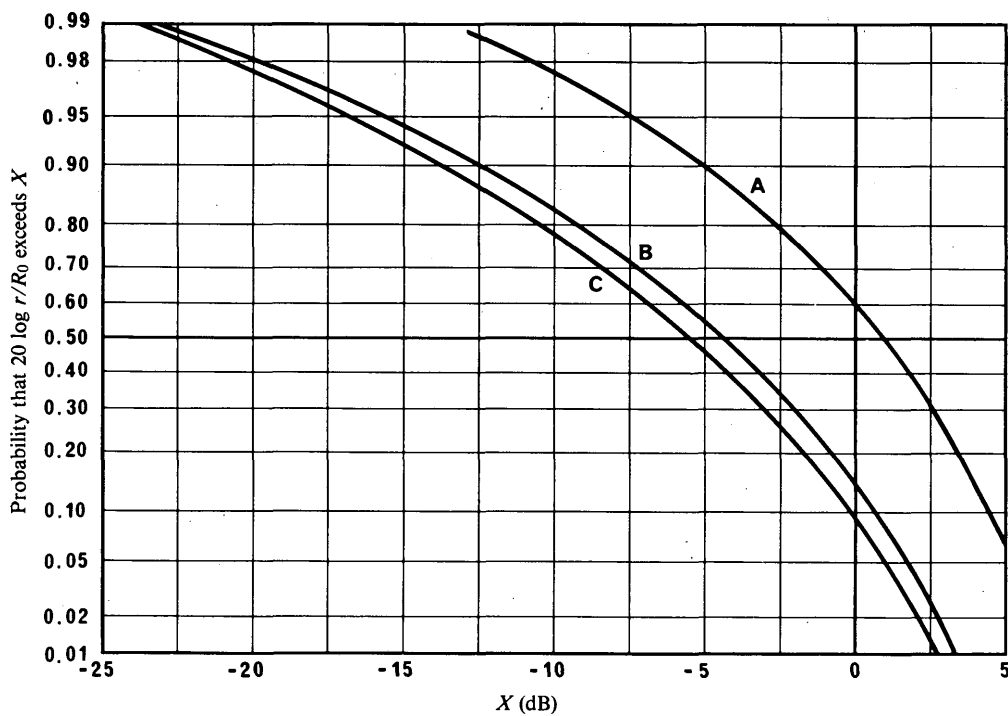


FIGURE 2 – Received carrier envelope
Distribution function: $\alpha = 7$ dB

Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 to 30 dB shadow loss

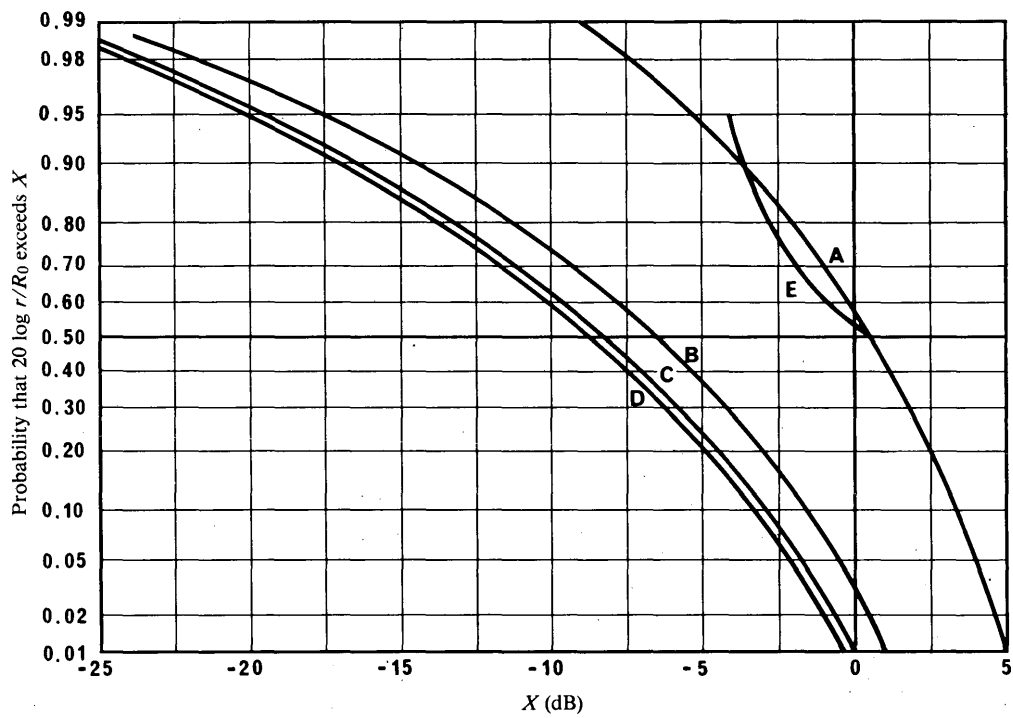


FIGURE 3 – Received carrier envelope
Distribution function: $\alpha = 10$ dB

- Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss
D: 30 dB shadow loss
E: 0.1 dB/% temporal sensitivity

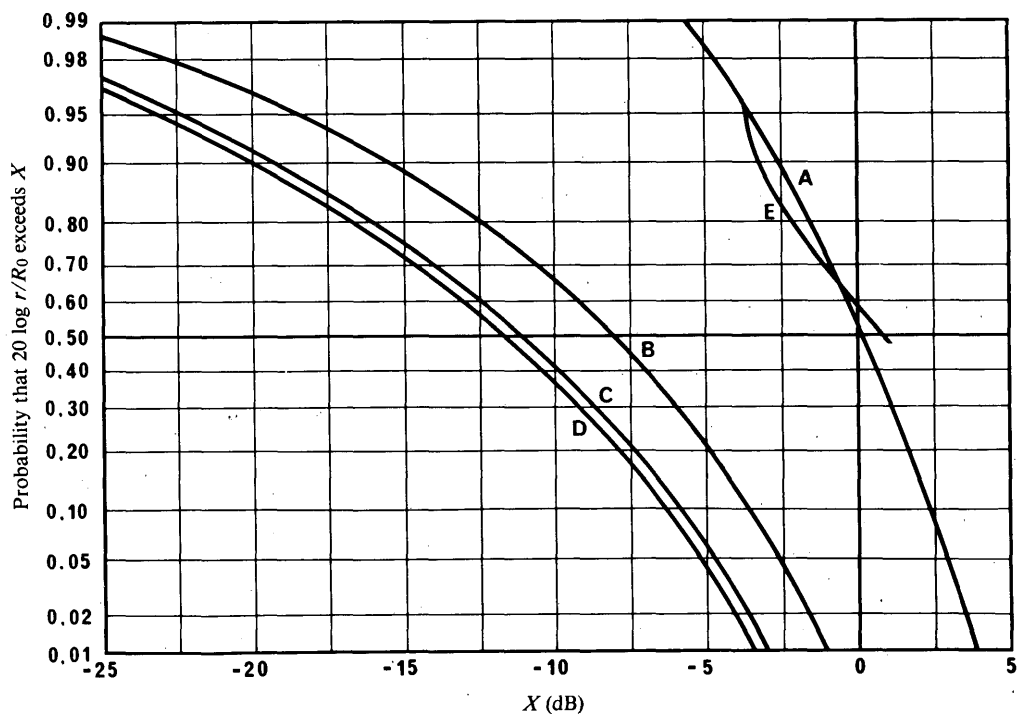


FIGURE 4 – Received carrier envelope
Distribution function: $\alpha = 13$ dB

- Curves A: 0 dB shadow loss
B: 10 dB shadow loss
C: 20 dB shadow loss
D: 30 dB shadow loss
E: 0.1 dB/% temporal sensitivity

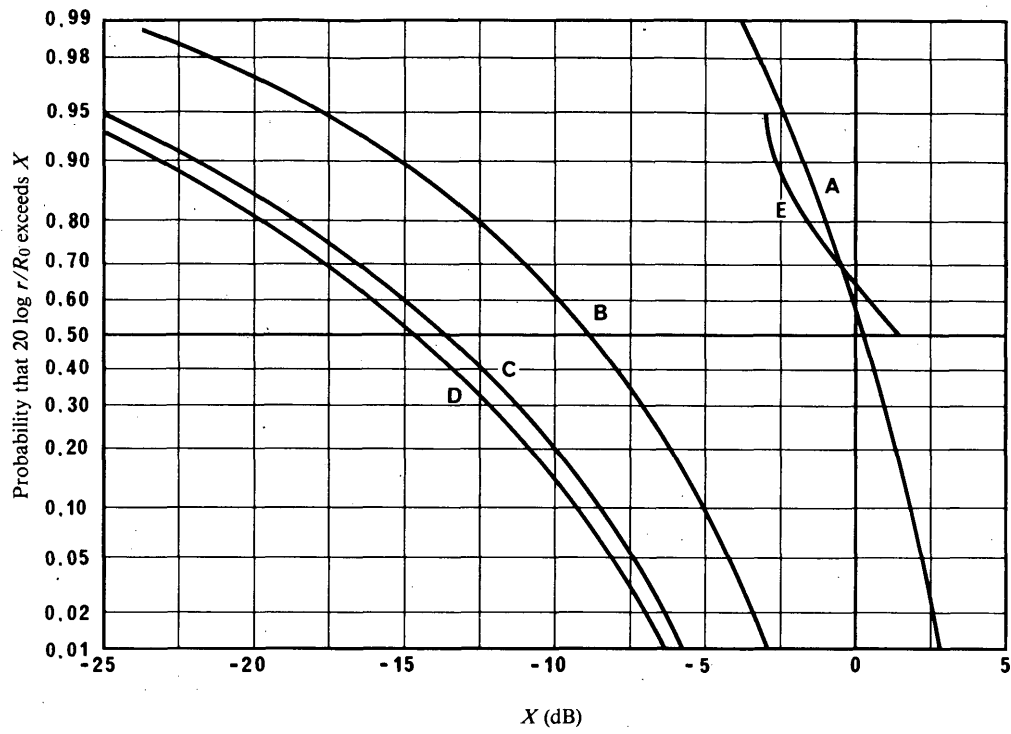


FIGURE 5 – Received carrier envelope
Distribution function: $\alpha = 16$ dB

- Curves A: 0 dB shadow loss
- B: 10 dB shadow loss
- C: 20 dB shadow loss
- D: 30 dB shadow loss
- E: 0.1 dB/% temporal sensitivity

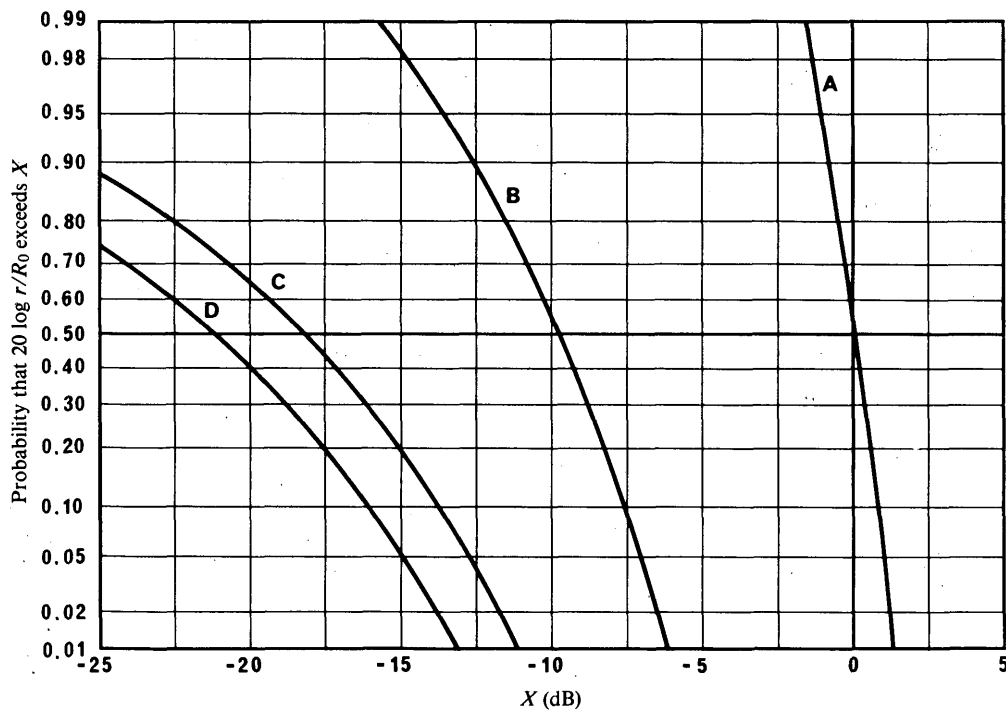


FIGURE 6 – Received carrier envelope
Distribution function: $\alpha = 23$ dB

- Curves A: 0 dB shadow loss
- B: 10 dB shadow loss
- C: 20 dB shadow loss
- D: 30 dB shadow loss

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REPORT 771-2

CONSIDERATIONS FOR THE MOBILE-SATELLITE SERVICE

(Question 32/8)

(1978-1982-1986)

1. Introduction

The purpose of this Report is to discuss factors relating to the characteristics of the mobile-satellite service. A mobile-satellite service is a service which might have earth stations on ships, on land, and on aircraft, all operating within the same system.

2. General considerations

A mobile-satellite system generally has many small, relatively inexpensive earth stations, with low to intermediate values of figure of merit (G/T), and satellites with relatively high values of e.i.r.p. and sensitivity.

2.1 Preferred ranges of frequencies for the mobile-satellite service

The practical lower limit on the frequency range might be determined by the antenna gain achievable with the small apertures that are suitable for mobile earth-station applications. Assuming that at least 3 dBi antenna gain is required (e.g. for a hemispheric radiation pattern), then the lower limiting frequency for a 1 m effective aperture is about 200 MHz. Report 504 and others address the influence of noise in the selection of frequencies.

The practical upper limit on operating frequency is affected by a number of factors. Above about 10 GHz, attenuation due to precipitation and molecular absorption generally increases with frequency; however, transmission windows exist between approximately 10 and 50 GHz, 80 and 110 GHz, 125 and 150 GHz and between 210 and 280 GHz (see Report 205). Availability objectives are a major factor in the use of frequency bands above about 10 GHz.

For a mobile-satellite system with high availability requirements, the optimum range of frequencies would be 200 MHz to 10 GHz. However, in identifying a preferred band, several factors in addition to propagation should be considered; for example, the maturity of the state-of-the-art, availability requirements, and operational constraints due to frequency sharing. For some applications, airborne earth stations could employ the millimetre wave bands to advantage, since present-day aircraft typically fly at altitudes above much of the attenuating atmosphere.

These considerations led to the allocation of a number of new bands for the mobile-satellite service at the WARC-79. These bands include 7250-7375 MHz, 7900-8025 MHz, 20.2-21.2 GHz, 30-31 GHz, 39.5-40.5 GHz, 71-74 GHz and 81-84 GHz which are co-equally shared with the fixed-satellite service and, except for the 20.2-21.2 GHz and 30-31 GHz band, with the fixed and mobile services. Additionally, the bands 43.5-47 GHz, 66-71 GHz, 95-100 GHz, 134-142 GHz, 190-200 GHz and 252-265 GHz were allocated to the mobile-satellite service, shared with the radionavigation-satellite, mobile and radionavigation services.

2.2 Characteristics of an earth station

An earth station in the mobile-satellite service is limited by such factors as: simplicity, ease of maintenance, size, weight and primary power. Where transportable equipment is employed, it should also have the capability for rapid, simple assembly and dismantling and be able to be compactly packaged.

The antenna type and dimensions are determined primarily by the operational factors appropriate to the type of mobile platform to be used. The required antenna pointing accuracy of mobile earth stations will generally increase with antenna gain. The difficulty of achieving this pointing accuracy increases with antenna mass. Although it is desirable to use small antennas, such factors as spectrum/orbit sharing and link performance tend to place a lower limit on antenna size for the new frequency bands allocated at the WARC-79.

In the 8/7 GHz band, an earth station in the mobile-satellite service might typically employ an air-cooled klystron or TWT having an output power in the range of 100 to 1000 W and an uncooled parametric amplifier having a noise temperature in the range of 100 to 200 K. Low-noise field effect transistor (FET) amplifiers are becoming competitive with the uncooled parametric amplifiers in terms of noise temperature and high-power transistor amplifiers offer a promising alternative to the klystron or TWT power amplifiers.

For the systems described in Annex I, the (G/T) s range from 7 dB(K⁻¹) to 26 dB(K⁻¹) for earth stations which may be used in the mobile-satellite service, while those which may be used in the fixed-satellite service vary from 18 dB(K⁻¹) to 39 dB(K⁻¹). This range is also typical for earth stations in the 6/4 GHz band. Maximum up-path e.i.r.p. densities vary from -3.6 dB(W/Hz) to 21 dB(W/Hz) for the mobile-satellite service and 11 dB(W/Hz) to 21 dB(W/Hz) for the fixed-satellite service. The maximum off-axis e.i.r.p. density for the Phase III system is $38 - 25 \log \theta$ dB(W/4 kHz) which is comparable to that of Recommendation 466 for the fixed-satellite service in the 6/4 GHz band. Earth-station reference radiation patterns conforming to Annex III of Appendix 29 to the Radio Regulations are used.

2.3 *Characteristics of a space station*

The implementation of a mobile-satellite system, which would serve a variety of mobile users simultaneously, necessarily involves a very flexible space segment — particularly if some degree of interconnection is desired between the different types of users. The disparity between the size and type of earth stations (for example, differences in (G/T) , etc.), and possibly different modulation and multiple access techniques employed by shipborne, airborne and land mobile users also adds to the need for flexibility in the space station.

Because of the lower antenna gains in the earth stations, there is generally a need to use higher gain satellite antennas. These antennas may be re-directable, mechanically or electronically, in order to serve the users in the desired coverage area. Signal regeneration may be used to reduce earth-station e.i.r.p. and G/T requirements.

For the systems described in Annex I, satellite antenna gains vary from 20 dB to 35 dB and are either mechanically steerable or electronically shaped. The maximum e.i.r.p. density for the Phase III system is -26 dB(W/Hz) which corresponds to a maximum power-flux density of -152 dB(W/(m² · 4 kHz)) at the Earth's surface. These values are also comparable to those of the 6/4 GHz band satellites.

2.4 *Other characteristics*

Several operational and technical factors affect the choice of modulation and access schemes (see Report 708). Modulation and multiple access techniques requiring time synchronization are more difficult to implement in mobile satellite systems than for fixed-satellite systems, particularly for earth stations on aircraft. However, time synchronization may be needed in order to achieve the desired system operational characteristics. Because mobile users may have low duty cycles, demand assigned multiple access may be used to achieve more efficient use of the space station.

Systems intended for a wide variety of applications might best be designed to permit several modulation types and multiple access schemes in order to optimize the utilization of the available satellite capacity. In the systems described in Annex I, bandwidth efficient modulations are generally used with links with high (G/T) earth stations and power efficient modulations used for low (G/T) earth-station links.

3. *Factors affecting frequency re-use*

The following are some of the most significant factors which affect frequency re-use within and among satellite networks in the mobile-satellite service.

3.1 *Satellite antenna discrimination*

Probably, the most limiting factor in terms of frequency re-use for satellite networks in the mobile-satellite service using the geostationary orbit results from the service area requirements. Maximum utility for this service is generally achieved by providing communications to earth stations located anywhere within the satellite visible area, thus the service area tends to be large, approaching the visible area. This in turn indicates that co-coverage conditions will normally exist between satellite networks and thus satellite antenna pattern discrimination will generally not provide significant isolation between networks.

Although a large service area implies a low-gain satellite antenna, (e.g. earth coverage), a higher gain steerable antenna may be used to compensate for the lower gains of the earth-station antennas as indicated in § 2.3. Thus, the up-path sensitivity can be considerably higher than implied by the service area. A lower gain satellite antenna might nevertheless be used for control channels (i.e. order wires).

Within a network there is the potential for frequency re-use in the mobile-satellite service by the use of multiple, independent narrow beams on the satellite, spaced to cover the service area. Where sufficient spatial discrimination exists between beams, frequencies may be re-used. The number of frequency re-uses is dependent on the side-lobe characteristics of each beam, the number of beams and the required isolation. The number of "apparent" frequency re-users can be quite significant. For example, with a hexagonal arrangement of beams where frequencies can be re-used in non-adjacent beams and with an equal user population in each beam, the "apparent" frequency re-use can be defined as the ratio of users served with frequency re-use to users served without frequency re-use. The potential "apparent" re-uses is about 2.3 for 7 beams and about 4.7 for 19 beams.

3.2 *Earth-station antenna discrimination*

Earth-station antenna discrimination is a primary factor in determining the frequency re-use between networks using the geostationary orbit. The lowest newly allocated frequency band indicated in § 2.1 is a part of the nominal 7/8 GHz band. At this frequency, significant earth-station antenna gains are needed for viable operations, probably 30 dBi or more (33 dBi for the systems described in Annex I). Low side-lobe levels are obviously desirable and emphasis needs to be placed on this aspect of earth-station antenna design. However, satellite spacing for co-coverage conditions may still be limited by main-lobe considerations; for instance the -20 dB relative gain point with a 30 dBi on-axis gain is about 6.5° off-axis.

3.3 *Orthogonal polarizations*

Orthogonal polarizations are commonly used in the fixed-satellite service to increase the network capacity and/or enable closer satellite spacing. The 6 dB isolation factor between satellites using orthogonal circular polarizations, as given in Appendix 29 to the Radio Regulations, could reduce satellite spacing by a factor of about 1.75. This is comparable to a factor approaching 2 for re-use by means of polarization discrimination on the same satellite. Practical antennas for mobile satellite systems may provide insufficient cross-polarization discrimination for intra-network frequency re-use at this time; however, polarization discrimination can nevertheless be used to achieve closer satellite spacing. Report 555 addresses the pertinent factors.

3.4 *Modulations*

In order to minimize satellite spacing requirements it is desirable to utilize modulation and multiple access techniques which minimize both radiated power densities and sensitivity to interference. This is generally accomplished by using digital modulations with efficient coding and energy dispersal techniques. Code division multiple access can provide a high degree of interference immunity. While these techniques are not particularly efficient in bandwidth utilization, they are effective in reducing satellite spacing requirements. Report 708 addresses relevant factors for fixed satellite systems, many of which pertain to mobile satellite systems.

4. *Sharing with other space services*

The factors which affect frequency re-use within the mobile-satellite service also affect the frequency re-use between networks in this and other space services. Of immediate interest is a portion of the nominal 8/7 GHz band in which a number of networks are in operation or being implemented and which is shared with the fixed-satellite service. The next band of interest is a portion of the nominal 30/20 GHz band in which mobile-satellite networks may become operational in the next decade and which is also shared with the fixed-satellite service.

Based on data published in IFRB Circulars to date, some basic factors which are common to a number of satellite systems using the 8/7 GHz band are:

- large service areas; i.e. approaching the visible areas;
- Earth coverage, hemispheric coverage and re-directable narrow-beam satellite antennas;
- capabilities for changing satellite antenna/transponder configurations;
- circular polarizations; no frequency re-use within a network;
- large differences in earth-station antenna sizes; the smallest are in the order of 1 to 3 m;
- relatively high maximum transmission gains (see Appendix 29 to the Radio Regulations), which, coupled with high up-path satellite antenna gains, result in relatively high up-path sensitivity.

These factors are consistent with satellite networks which could operate in either or both the fixed-satellite and mobile-satellite services.

Because of these factors, the minimum satellite spacing tends to be limited by up-path interference under co-coverage conditions and probably in the limit, by the main-lobe skirt selectivity of the small earth-station antennas. Generally, the characteristics of the mobile-satellite service will determine the minimum spacing from satellites in other services.

ANNEX I

CHARACTERISTICS OF THE UNITED STATES GOVERNMENT COMMUNICATION SATELLITE SYSTEM, PHASE II AND PHASE III

1. Introduction

This Annex describes the characteristics of the United States Government Communications Satellite System (USGCSS). The USGCSS employs geostationary satellites, operating in the 7/8 GHz frequency bands. The Phase III networks will operate in both the fixed-satellite service (FSS) and mobile-satellite service (MSS).

2. Satellites

The USGCSS Phase II satellites are spin-stabilized, with two steerable beam antennas, one narrow coverage (NC) and the other with area coverage (AC) footprints and two earth coverage (EC) antennas all on a de-spun platform. The antennas are cross-strapped to permit any antenna to receive and transmit via any other. Four transponders of different bandwidths are employed.

The USGCSS Phase III satellites are three-axis stabilized. The up-path antennas include an earth coverage horn and a multiple beam antenna (MBA). The down-path antennas include an earth coverage horn, two MBAs and a steerable parabolic reflector antenna. The MBAs are lens antennas employing multiple element phased array feed systems. The phase and amplitude of each element is adjustable by command. Any shaped beam pattern can be generated by these antennas between earth coverage to one narrow circular beam. Six transponders are used with the ability to change antenna/transponder configurations.

Transponder gains are adjustable in steps by telecommand for both the Phase II and Phase III satellites. Table I shows the principal characteristics of the Phase II and Phase III satellites. The G_2 and G_3 terms are satellite antenna receiving and transmitting gains, respectively, as defined in Appendix 29 to the Radio Regulations.

3. Earth stations

The USGCSS networks utilize a number of different types of earth stations. Table II shows some basic characteristics of these earth stations. An example of the flexibility provided by these earth stations can be seen from the features of the station with the 6.09 m diameter antenna:

- load and transport on 2.5 ton truck or transport aircraft;
- 12 to 24 hour erection on rough terrain (slopes up to 10°);
- safe antenna erection in 32 km/h winds;
- tracking error: 0.5 dB in 16 km/h winds;
- tracking error: 2.0 dB in 120 km/h winds.

Table III provides some additional information on USGCSS earth stations.

TABLE I — USGCSS satellite characteristics — Phases II and III

Satellite locations: Phase II (12° W, 60° E, 175° E, 135° W) Phase III (12° W, 60° E, 175° E, 135° W)						
Longitudinal tolerance: $\pm 0.5^\circ$						
Polarizations: right-hand circular up-path; left-hand circular down-path						
Satellite channel	Frequency up-path (MHz)	G_2 (δ) (max) (dB)	T_s (K)	G_3 (η) (max) (dB)	P_s (max) (dB(W/Hz))	Frequency down-path (MHz)
<i>USGCSS II</i>						
EC-NB/AC	7900-7950	20	1800	35/32	-62/-59	7700-7750
EC-EC	7975-8100	20	1800	20	-42	7250-7375
NB/AC-EC	8125-8175	35/32	5000	20	-42	7400-7450
NB/AC-NB/AC	8215-8400	35/32	5000	35/32	-62/-59	7490-7675
Beacon				20	-42	7250.1
Beacon				35/32	-62	7675.1
<i>USGCSS III</i>						
1	7975-8035	20-27.3	855	20-32	-46 to -58 ⁽¹⁾	7250-7310
2	8060-8120	20-27.3	855	34.6	-60.6	7335-7395
3	8145-8230	20-27.3	855	20-32	-46 to -58 ⁽¹⁾	7420-7505
4	8255-8315	20-27.3	855	20-32	-46 to -58 ⁽¹⁾	7530-7590
5	8340-8400	20.2	855	21	-47	7615-7675
6	7900-7950	20.2	855	21	-47	7700-7750
Beacon				21	-43	7600
Beacon				21	-43	7604-7058

⁽¹⁾ The product $P_s G_3 (\eta)$ will be ≤ -26 dB(W/Hz).

TABLE II — Characteristics of earth stations in USGCSS Phase III networks

Type	Service	Antenna (m)	G/T (dBK)	e.i.r.p. density (dB(W/Hz))		Side-lobe envelope ⁽¹⁾ (dB)
				On-axis	Off-axis ⁽¹⁾	
Fixed	FSS	18.28	39	21	-8 - 25 log θ	32 - 25 log θ
Fixed	FSS	12.19	34	21	-4 - 25 log θ	32 - 25 log θ
Relocatable	FSS or MSS	6.09	26	21	2 - 25 log θ	32 - 25 log θ
Relocatable	FSS or MSS	2.44	18	11	2 - 25 log θ	34 - 25 log θ
Shipborne	MSS	1.22	11	2	2 - 25 log θ	37 - 25 log θ
Airborne	MSS	0.84	7	-3.6	2 - 25 log θ	38.6 - 25 log θ

⁽¹⁾ Beyond first side-lobe to $\theta \leq 48^\circ$.

TABLE III – USGCSS characteristics – Phases II and III

Earth station antenna diameter (m)	18.28	12.19	6.09	2.44	1.22	0.84
Up-path on-axis gain (dB)	61	57	51	43	37	33
Down-path on-axis gain (dB)	60	56	50	42.4	37	33
Maximum power density (P_e) (dB(W/Hz)):						
Phase II: 7900 to 8100 MHz	-30	-26	-26 ⁽¹⁾	-28 ⁽¹⁾		
Phase II: 8125 to 8400 MHz	-40	-36	-30	-32		
Phase III: all channels	-40	-36	-30	-32	-35	-36.6
Maximum transmission gain (γ) (dB):						
Phase II: 7900 to 8100 MHz	-10.1	-10.1	-11.6	-13.8		
Phase II: 8125 to 8400 MHz	-14.6	-14.6	-16.1	-18.3		
Phase III: all channels	-6.9	-6.9	-8.4	-10.6	-13.3	-16.3
Associated link noise temperature (T) (K):						
Phase II: all channels	350	350	400	400		
Phase III: all channels	350	350	400	400	415	420
Minimum transmission gain (γ) (dB):						
Phase II: all channels	-30	-30	-30	-30		
Phase III: all channels	-30	-30	-30	-30	-36	-40
Associated link noise temperature (T) (K):						
Phase II: 7900 to 8100 MHz	177	177	277	327		
Phase II: 8125 to 8400 MHz	180	180	280	330		
Phase III: all channels	176	176	276	326	375	400
Equivalent down-path noise temperature (T_e) (K)	175	175	275	325	375	400

(1) Reference bandwidth: 16 kHz.

4. System characteristics

The USGCSS Phase III systems use only digital modulations, principally 2-PSK or 4-PSK. Convolutional coding with Viterbi decoding is used with satellite accesses involving earth stations with the smallest antennas, i.e. power efficient modulation.

Frequency division multiple access (FDMA) is the primary mode of accessing the satellites. Code division multiple access (CDMA) is also used for a small amount of traffic.

Table III provides some additional information on link parameters.

REPORT 772-2

**ORBITAL SPACING CONSIDERATIONS FOR A
MOBILE-SATELLITE SERVICE ***

(Question 32/8)

(1978-1982-1986)

1. Introduction

Question 32/8 addresses the technical and operating aspects of the mobile-satellite service, including the feasibility of sharing with other satellite services. Of particular interest is the spacing required between adjacent satellites.

The interference between adjacent satellite systems is a function of the earth station antennas sizes and the modulation schemes and other characteristics of these services rather than the location or motion of the earth stations. Physical size, weight and primary power are intrinsic constraints placed on earth stations intended for operation in the mobile-satellite service. These constraints result in physically small earth station antennas (as compared to those which may be used in the fixed-satellite service).

In this Report, inter-satellite spacing is calculated for geostationary satellites operating in the 8 and 7 GHz band. The spacing is determined parametrically as a function of allowable interference, mobile earth station antenna diameter and modulation type. The more general problem of inter-satellite spacing in any frequency band is treated in Annex I, wherein a method for determining required orbital spacing of geostationary space stations is developed.

2. Factors affecting orbital sharing

There are numerous factors affecting the general problem of optimum utilization of the geostationary orbit. These are discussed in Report 453. The factors bearing most heavily upon the problem of a general mobile-satellite service sharing the orbit with the fixed-satellite service are as follows:

- permissible interference levels;
- earth-station antenna gain characteristics;
- earth-station antenna pointing accuracy;
- satellite system inhomogeneity.

2.1 Permissible interference levels

The maximum permissible levels of interference in a geostationary satellite network in the fixed-satellite service caused by other networks of this service are specified in Recommendations 466 and 483 for frequency modulated FDM telephone and television. No criteria have been developed for adjacent satellite networks in a mobile-satellite service.

2.2 Antenna gain characteristics

Equipment operating in a general mobile-satellite service will utilize a wide range of antenna diameters. It can be expected that the antenna size will be determined by the system application. There are limiting factors on antenna size. In bands shared with terrestrial services, the power flux density (pfd) limitations will usually limit the minimum antenna size and data rate. In bands not shared with the terrestrial services, there is no limit to down link e.i.r.p. other than the state-of-the-art in spaceborne transmitter design and one might envision general mobile-satellite service requirements calling for extremely small antennas and correspondingly high transmitter power.

The amount of energy in the side lobes of the antenna must be controlled in order to use the geostationary orbit efficiently. These levels can be controlled by careful antenna design and selection of proper illumination functions. However, this sidelobe suppression is commonly achieved at the expense of reduced main beam gain and beam broadening. The limiting factor will then be a combination of beamwidth and pointing accuracy.

* The material contained in this Report is preliminary and has been drawn up by Study Group 8 only, without the benefit of consultation with Study Group 4. This Report should be brought to the attention of Study Group 4.

2.3 Antenna pointing accuracy

As the antenna diameter is decreased, the beam broadens. It becomes increasingly difficult to accurately centre the beam on the desired satellite. This fact coupled with the present limit on satellite station keeping places a limit on minimum antenna size (Recommendation 484). Thus, the minimum antenna size is a function of orbital spacing between satellites and the pointing accuracy of the earth-station antenna.

2.4 Satellite system inhomogeneities

Any large disparity in antenna sizes of earth stations utilizing the same satellite transponder will require the users of the smaller antennas to increase their transmitter power in order to maintain the desired down link signal strength. This, in turn, increases the e.i.r.p. in the side lobe region and therefore the potential for interference to both terrestrial systems and other space systems.

3. Equations for calculating inter-satellite spacing requirements

Equation 1, which is used to calculate the required satellite separations in the geostationary orbit, derives from Appendix 29 to the Radio Regulations. Figure 1 is a diagram of a given satellite system and an adjacent interfering satellite system. The parameter notation is similar to Appendix 29 with the parameters of the interfered-with system being unprimed and those of the interfering system being primed.

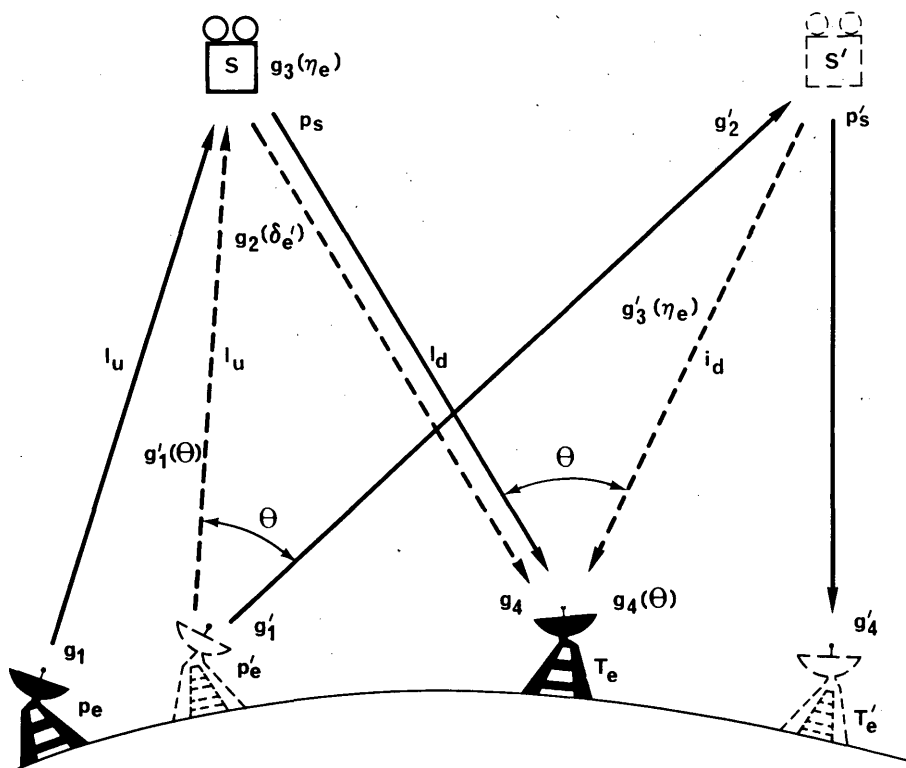


FIGURE 1 — Link diagram of desired and interfering systems

Note. — The symbols used in Fig. 1 are the same as those defined in Report 454 "Method of calculation to determine whether two geostationary-satellite systems require coordination".

The equation taking into account earth station, satellite, link and modulation parameters developed in [CCIR, 1974-78] and evaluated specifically for the 7 and 8 GHz band is:

$$\theta = \left\{ \frac{2}{\Delta T/T_e} \left(\frac{c/kT|_{req.}}{SF} \right) \left[\frac{(D'_{4L})^2}{(D'_4)^2 (D'_1)^3} + \frac{3}{D'_4} \right] \right\}^{0.4}$$

(1)

where

- θ :

is the resulting off-axis angle subtended by the interfering satellite on the earth station antenna;
θ is approximately the inter-satellite separation for geostationary satellites (degrees);
- $\Delta T/T_e$:

is the acceptable ratio of an equivalent interference noise temperature to the receive earth station thermal noise temperature. (This is not identical to the Appendix 29 definition);
- $c/kT|_{req.}$:

the required carrier-to-noise density ratio;
- SF :

total signal power divided by maximum signal power density; SF is a spectrum spreading factor;
- $D'_{1,4}$:

are the diameters of the earth station transmit, receive antennas in the interfering system (metres);
- $\left(\frac{D'_{4L}}{D'_4} \right)$:

inhomogeneity factor where D'_{4L} is the largest receive earth station antenna diameter in the interfering system (metres).

The assumptions embodied in equations 1 are:

- The adjacent satellites have earth coverage antenna patterns and the same receive noise temperatures. However, for a spot beam satellite antenna, the general results also apply when the antenna gains and coverage areas of the adjacent satellite are identical.
- The earth station side lobe reference patterns are as in Report 391.
- The ratio of up-path to down-path carrier-to-noise density is equal to or greater than 4, for both the mobile and fixed-satellite systems.
- The earth station noise temperatures are 300 K for mobile earth stations and 100 to 200 K for fixed earth stations.
- Satellite station-keeping errors are not taken into account.

The factor $\left(\frac{c/kT|_{req.}}{SF} \right)$ depends on the modulation type.

For FDM-FM, a threshold extension demodulator and 4 dB link margin are assumed. For phase shift keyed modulations, 4 dB link margin and 2 dB implementation loss are assumed. The values for $\left(\frac{c/kT|_{req.}}{SF} \right)$ are shown in Table I:

TABLE I

Modulation type	$\left(\frac{c/kT _{req.}}{SF} \right)$
QPSK	19.4 dB
QPSK coded rate ½	11.4 dB
FDM-FM	15 dB

It should be noted here that, in actual practice, this parameter will not be the same for both the fixed-satellite and mobile-satellite services. In this analysis, the same value is applied to both services in order to consider what would be the worst case.

Another important parameter is $\left(\frac{D'_{4L}}{D'_4}\right)^2$. This represents the degree of inhomogeneity within the interfering satellite system. In this analysis, it was assumed that a mobile earth station with a four metre antenna is always part of the interfering mobile network. This important parameter should be given careful consideration in planning any mobile network or the use of any one transponder in a satellite for any service.

An important feature of equation (1) is that the inter-satellite separation angle depends almost entirely on the characteristics of the interfering network, T_e being the only parameter of the interfered with network that is involved.

4. Inter-satellite spacing requirements of the general mobile-satellite service

For purposes of analysis herein, the fixed-satellite service (FSS) at 7 and 8 GHz is considered as containing earth stations whose antenna diameters are greater than 4 metres; 4 metres is a diameter equal to 100λ . Below this value, the earth station is considered as being "small". The mobile-satellite service (MSS) at 8 and 7 GHz is assumed to have earth station antenna diameters of 4 metres or less.

The ratio of equivalent interference noise to down link thermal noise, $\Delta T/T_e$, is an important parameter. T_e (earth station noise temperature) as used herein differs from the Appendix 29 definition which refers to the total link equivalent noise temperature. The value of T in the ratio $\Delta T/T$ of Appendix 29 is highly dependent upon individual link characteristics. The factor T_e was chosen for this analysis in order to provide a constant frame of reference. The $\Delta T/T_e$ parameter is arbitrarily assigned the following values: 2%, 8%, and 20% in order to cover a range of inter-satellite interference allowances.

Since the separation angles calculated for FSS interference into MSS are always smaller than those of equation (1), the latter will be used to calculate the separation angles between the satellites of the two services. These angles are plotted as a function of the interfering antenna diameter in Fig. 2. The effect of different modulations are shown in Fig. 3 for this case.

Antenna pointing accuracy is not taken into account in these analyses.

Satellite separations based on the parameters of an existing system are given in Annex II as a function of $\Delta T/T$ versus satellite separation (see Report 454).

5. Analysis of results

It should be emphasized that the examples presented here are for a limited set of parameter values and are given as an aid for efforts to plan future general mobile-satellite systems.

The inter-satellite spacing between fixed and mobile-satellite systems can be determined from Figs. 2 and 3. The characteristics of a general mobile service system are taken to correspond to a mobile to mobile inter-satellite separation of 10° . For 2 m antennas and FDM-FM modulation in the mobile system an inter-satellite spacing of about 13.5° for an interference allocation of $\Delta T/T_e = 8\%$ in the fixed system. A 1.5 m mobile earth station antenna and coded QPSK modulation would imply a spacing of 16° . These spacings are representative of the mobile earth stations accessing the same frequency as the fixed stations on the adjacent satellite.

The spacing requirements could be as much as 2 to 3 times as large as those shown in Figs. 2 and 3 if the mobile-satellite up link shared the same satellite transponder with a system using large antenna (> 10 m).

Modulation inhomogeneities have an effect on satellite space requirements as shown in Fig. 3. Modulation inhomogeneities of 7 dB affect the satellite spacing by a factor of about two. Considerably higher inhomogeneities than this currently exist in the satellite networks of the FSS in the case of FM-TV interference on single-channel-per carrier systems.

6. Summary

Equation (1) has been presented here for calculation of separation angle requirements between satellites in the mobile and fixed-satellite services for the 7/8 GHz band. Examples are provided which demonstrate the variability of these requirements over certain parametric ranges: antenna dimensions, interference criteria and modulation types.

Two parameters in equation (1) should be examined further to determine their effect on satellite spacing: the degree of inhomogeneity and the required carrier-to-noise ratios of the mobile-satellite system. In addition, the effect of earth station antenna pointing accuracy should be investigated.

Other aspects of system design will affect satellite spacing requirements and a set of favourable system trade-offs such as separated antenna spot beams, polarization diversity, one-way transmission links or relatively interference free signal/modulation combinations would tend to increase orbit utilization and lessen spacing requirements.

Equation (10) in Annex I can be used to determine required orbital spacing between geostationary space stations in any frequency band. This equation is more generally applicable than equation (1) since it embodies less restrictive assumptions.

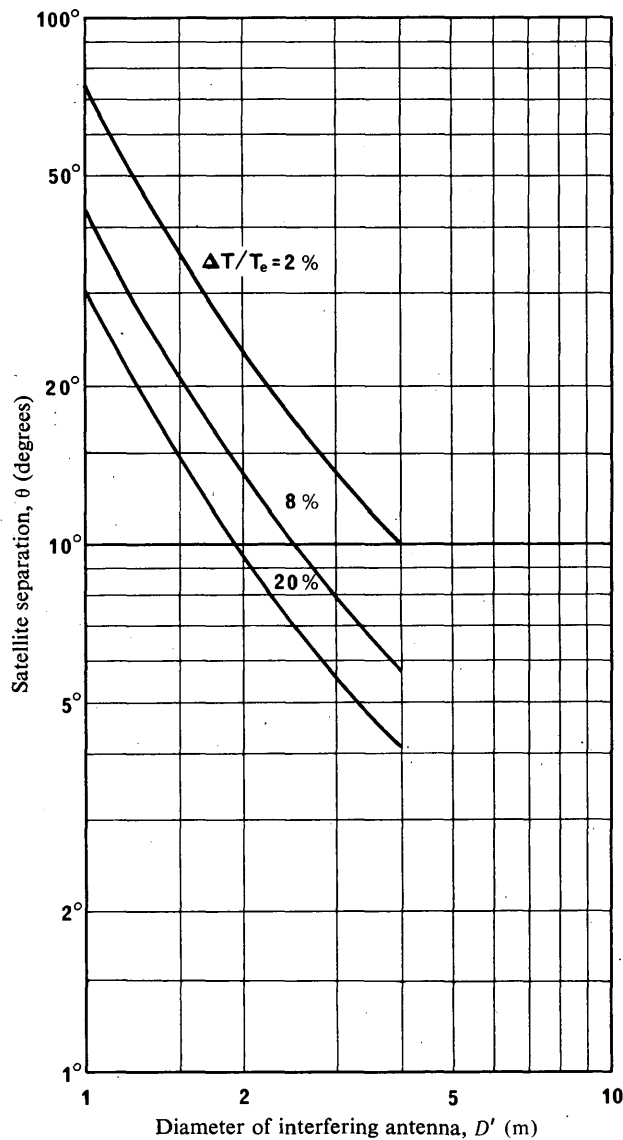


FIGURE 2 — Satellite spacing requirements based upon interference from the Mobile-Satellite Service to the Fixed-Satellite Service

(FDM-FM)

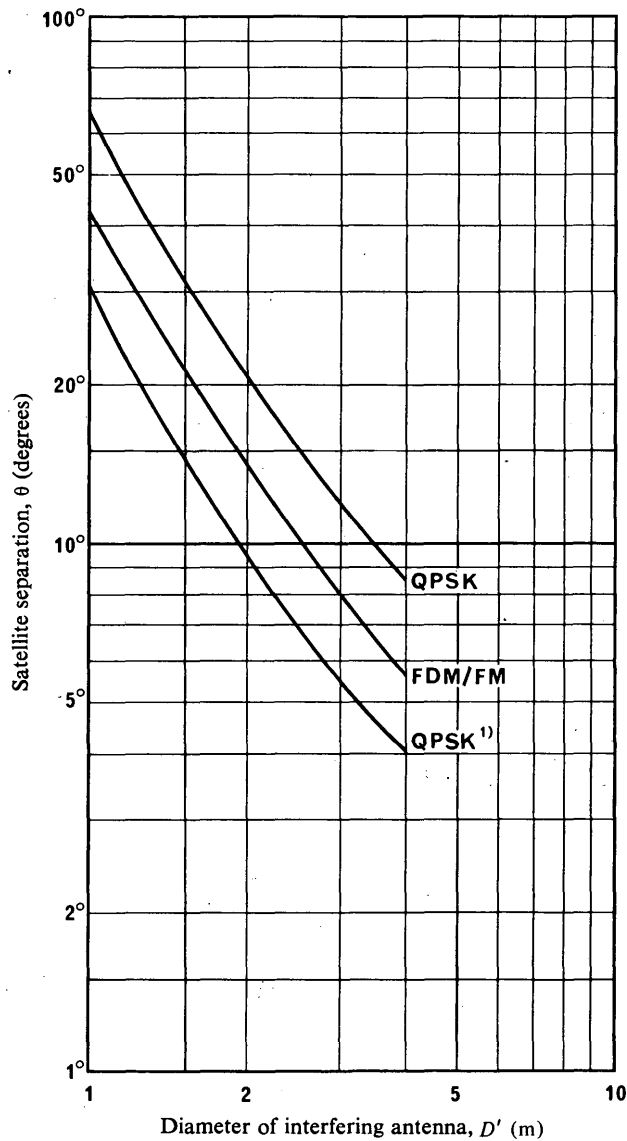


FIGURE 3 — Effect of modulation type on satellite spacing requirements based on interference from the Mobile-Satellite Service to the Fixed-Satellite Service
 $\Delta T/T_e = 8\%$

¹⁾ Coded rate 1/2

REFERENCE

ANNEX I

METHOD OF CALCULATION TO EVALUATE THE REQUIRED
ANGULAR SEPARATION BETWEEN INDEPENDENT GEOSTATIONARY
SATELLITE NETWORKS SHARING THE SAME FREQUENCY BANDS

Equation (1) in the body of the Report defines a method for calculating separation between satellite systems whose satellite antenna gains and coverage areas are identical. This Annex considers a more general situation, wherein adjacent satellites may be independent and therefore have different characteristics, including antenna gain and coverage area. The method of calculating required angular separation is based on the concept that a maximum permissible interference-to-thermal noise ratio may be specified in the system receiving interference. It can, therefore, be applied irrespective of the modulation characteristics of the satellite networks, and of the precise frequencies used.

In the method described in this Annex, the power level of each interference entry is determined parametrically at the earth station receiver of the system receiving interference. The summation of the interference entries is then compared with the equivalent link thermal noise power. From the resulting equation, the effect of each system parameter upon the interference-to-thermal noise ratio may be determined. For most cases, the equation may be solved directly for the required angular spacing, and used for evaluation or for a parametric analysis as a function of the satellite network parameters.

The geometry involved in the two systems is shown in Fig. 4. The symbols are defined in Table II. Referring to Fig. 4, the interfered with system up-path e.i.r.p. is given by the product of the earth station transmitter power (p_{et}) and earth station transmitting antenna gain (g_{et}):

$$e.i.r.p. = p_{et} g_{et} \qquad W$$

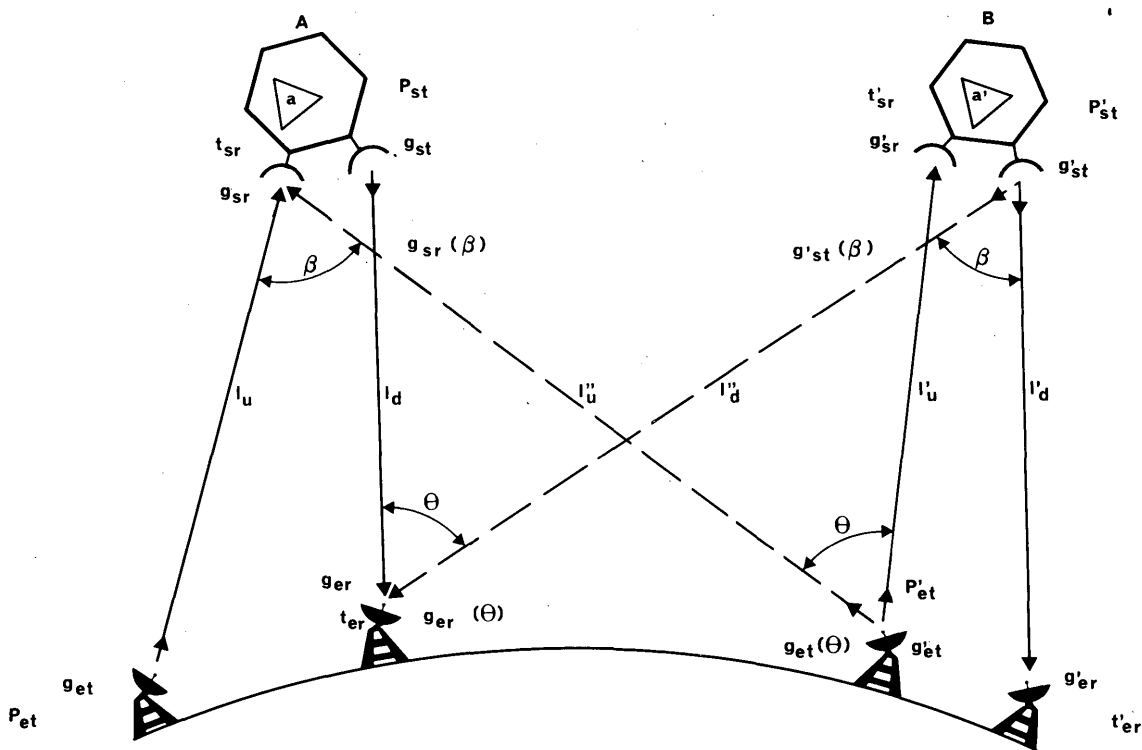


FIGURE 4 - Geometry to determine interference between satellite systems

- : desired path
- - - - : potential interference path
- A: interfered with satellite system
- B: interfering satellite system
- Note. - All symbols are defined in Table II

TABLE II — Definition of parameters used in Fig. 4

Note. — Primed (') or (") parameters refer to the interfering system.

p_{et} :	power delivered to the earth station transmitting antenna in the reference bandwidth, b ; W.
g_{et} :	power gain of the earth station transmitting antenna*.
g_{er} :	power gain of the earth station receiving antenna*.
p_{st} :	power delivered to the space station transmitting antenna in the reference bandwidth, b ; W.
g_{st} :	power gain of the space station transmitting antenna*.
g_{sr} :	power gain of the space station receiving antenna*.
t_{er} :	effective noise temperature of the earth station receiver (K).
t_{sr} :	effective noise temperature of the space station receiver (K).
a :	the ratio of power delivered to the space station transmitting antenna to the power available to the space station receiver.
b :	reference bandwidth (Hz).
θ :	off-axis angle from earth station antenna main beam (degrees).
β :	off-axis angle from space station antenna main beam (degrees).
l_u :	up-path basic transmission loss, power ratio.
l_d :	down-path basic transmission loss, power ratio.
$g_{er}(\theta)$:	power gain of earth station receiving antenna in the direction of the interfering space station*.
$g'_{et}(\theta)$:	power gain of the interfering earth station transmitting antenna in the direction of the interfered with space station*.
$g_{sr}(\beta)$:	power gain of space station receiving antenna in the direction of the interfering earth station*.
$g'_{st}(\beta)$:	power gain of the interfering space station transmitting antenna in the direction of the interfered with earth station*.

* Relative to an isotropic antenna.

Given the up-path basic transmission loss (l_u), the received signal level at the space station receiver is given by:

$$p_{sr} = p_{et} g_{et} g_{sr} / l_u \quad W$$

and the carrier-to-thermal noise ratio at the space station receiver is then:

$$c/n = p_{sr} / k t_{sr} b$$

The received signal power (p_{sr}) increased by the gain of the space station transponder (a) is then the power delivered to the space station transmitting antenna:

$$p_{st} = p_{sr} a \quad W$$

In this manner, the following levels may be determined at the *interfered with earth station receiver*:

— The desired carrier power:

$$c = \frac{p_{et} g_{et} g_{sr} a g_{st} g_{er}}{l_u l_d} \quad (2)$$

— The up-path interference power:

$$i'_u = \frac{p'_{et} g'_{et}(\theta) g_{sr}(\beta) a g_{st} g_{er}}{l'_u l_d} \quad W \quad (3)$$

— The down-path interference power (from an interfering satellite to the interfered with earth station receiver):

$$i'_d = \frac{p'_{et} g'_{et} g'_{sr} a' g'_{st}(\beta) g_{er}(\theta)}{l_u l''_d} \quad W \quad (4)$$

- Rebroadcast noise from the interfering space station:

$$n'_{ss} = \frac{k t'_{sr} b a' g'_{st}(\beta) g_{er}(\theta)}{l''_d} \quad W \quad (5)$$

- The earth station receiver noise:

$$n_{er} = k t_{er} b \quad W \quad (6)$$

- Re-broadcast noise from the interfered with system space station receiver:

$$n_{ss} = \frac{k t_{sr} b a g_{st} g_{er}}{l_d} \quad W \quad (7)$$

Where both satellite system space stations are in geostationary orbit, the above equations provide useful working relations, with negligible error, for most cases by assuming:

- All up-path and down-path transmission losses in a frequency band are equal:

$$l_u = l_d = l'_u = l'_d = l''_u = l''_d = l$$

- Off-axis angles from space station antenna mainbeams are sufficiently small to be neglected, so that:

$$g(\beta) = g$$

- The topocentric angular separation between two satellites (θ) as seen from any earth station is equivalent to the geocentric angular separation between the two satellites.

With these assumptions, the total interference-to-link noise ratio may be written using equations (3) through (7):

$$\frac{i_{total}}{n_{link}} = \frac{i'_u + i'_d + n'_{ss}}{n_{er} + n_{ss}} \quad (8)$$

and substituting equations (3) through (7):

$$\frac{i}{n} = \frac{\overbrace{p'_{et} g'_{et}(\theta) l^{-1} g_{sr} a g_{st} l^{-1} g_{er}}^{\text{Up-path interference}} + \underbrace{p'_{et} g'_{et} l^{-1} g'_{sr} a' g'_{st} l^{-1} g_{er}(\theta)}_{\substack{\text{Down-path} \\ \text{interference} \\ \text{e.i.r.p.}}} + \underbrace{k t'_{sr} b a' g'_{st} l^{-1} g_{er}(\theta)}_{\substack{\text{Rebroadcast noise} \\ \text{from interfering} \\ \text{satellite}}}}{k t_{er} b + \underbrace{k t_{sr} b a g_{st} l^{-1} g_{er}}_{\substack{\text{Earth} \\ \text{station} \\ \text{noise}}}} \quad (9)$$

Since, for most cases of interest, the earth-station antenna gain function may be written (for example, when $G(\theta) = 32 - 25 \log \theta$, $g(\theta) = 1585 \theta^{-2.5}$):

$$g(\theta) = \alpha \theta^{-2.5}$$

the equation (9) may be arranged as follows for convenient computation:

$$\frac{i}{n} = \frac{p'_{et} g'_{et} \left| \frac{\alpha'_{et} \theta^{-2.5}}{g'_{et}} l^{-1} g_{sr} a g_{st} l^{-1} g_{er} + l^{-1} g'_{sr} a' g'_{st} l^{-1} \alpha_{er} \theta^{-2.5} \right| + k t'_{sr} b a' g'_{st} l^{-1} \alpha_{er} \theta^{-2.5}}{k t_{er} b + k t_{sr} b a g_{st} l^{-1} g_{er}}$$

This equation may be used to calculate the interference-to-equivalent link noise ratio between any two satellite networks, where the parameters included in Table II are known. When the permissible i/n ratio is given, it is convenient to solve this equation for the satellite separation angle (θ), as follows:

$$\theta^{2.5} = \frac{n}{i} \frac{\begin{array}{c} \text{Up-path interference} \\ \text{Up-path e.i.r.p.} \\ p'_{et} g'_{et} \frac{\alpha'_{et}}{g'_{et}} l^{-1} g_{sr} a g_{st} l^{-1} g_{er} + p'_{et} g'_{et} l^{-1} g'_{sr} a' g'_{st} l^{-1} \alpha_{er} + k t'_{sr} b a' g'_{st} l^{-1} \alpha_{er} \end{array}}{\begin{array}{c} \text{Down-path interference} \\ \text{Down-path e.i.r.p.} \\ k t_{er} b \\ \text{Earth station noise} \\ \text{Interfered with satellite rebroadcast noise e.i.r.p.} \\ k t_{sr} b a g_{st} l^{-1} g_{er} \end{array}} + \frac{\begin{array}{c} \text{Rebroadcast noise e.i.r.p.} \\ k t'_{sr} b a' g'_{st} l^{-1} \alpha_{er} \end{array}}{\begin{array}{c} \text{interfered with link noise} \end{array}} \quad (10)$$

Using this equation, the required satellite separation can be calculated given the values of parameters in Table II. For the case where the c/n ratio of the interfering system is specified:

$$(c/n)' = \frac{p'_{et} g'_{et} l^{-1} g'_{sr} a' g'_{st} l^{-1} g'_{er}}{k t'_{er} b + k t'_{sr} b a' g'_{st} l^{-1} g'_{er}}$$

the separation becomes:

$$\theta^{2.5} = \frac{n}{i} \frac{\left(\frac{c}{n}\right)' \frac{k t'_{er} b + k t'_{sr} b a' g'_{st} l^{-1} g'_{er}}{l^{-1} g'_{sr} a' g'_{st} l^{-1} g'_{er}} \left| \frac{\alpha'_{et}}{g'_{et}} l^{-1} g_{sr} a g_{st} l^{-1} g_{er} + l^{-1} g'_{sr} a' g'_{st} l^{-1} \alpha_{er} \right| + k t'_{sr} b a' g'_{st} l^{-1} \alpha_{er}}{k t_{er} b + k t_{sr} b a g_{st} l^{-1} g_{er}} \quad (11)$$

and after re-arranging terms to simplify:

$$\theta^{2.5} = \frac{n}{i} \frac{\left(\frac{c}{n}\right)' (t'_{er} + t'_{sr} a' g'_{st} l^{-1} g'_{er}) \left(\frac{\alpha'_{et}}{g'_{et}} \frac{g_{sr}}{g'_{sr}} \frac{a g_{st} l^{-1} g_{er}}{a' g'_{st} l^{-1} g'_{er}} + \frac{\alpha_{er}}{g'_{er}} \right) + t'_{sr} a' g'_{st} l^{-1} \alpha_{er}}{t_{er} + t_{sr} a g_{st} l^{-1} g_{er}} \quad (12)$$

Using this equation, the impact on separation of each system parameter is easily determined.

ANNEX II

ORBITAL SPACING CONSIDERATIONS BASED ON PARAMETERS OF AN EXISTING NETWORK

The United States Government Communications Satellite System (USGCSS), Phase III networks will operate in both fixed-satellite service (FSS) and mobile-satellite service (MSS) with geostationary satellites utilizing the 7/8 GHz frequency bands.

The pertinent parameters relating to earth stations for performing worst-case $\Delta T/T$ calculations in accordance with Appendix 29 to the Radio Regulations, are given in Table III. For the satellite, the pertinent parameters are the maximum e.i.r.p. density of -26 dB(W/Hz) and the maximum satellite up-path antenna gains of 27.3 dB for the multiple beam antenna (MBA) and 20.2 dB for the Earth coverage (EC) antenna. It should be noted that the satellite transponder gains are adjustable by telecommand and are adjusted in accordance with the particular earth station connectivity in a transponder. Thus, the parameters given are derived from different potential connectivities. Additional information on USGCSS Phase III characteristics is given in Annex I to Report 771.

TABLE III — Characteristics of earth stations in USGCSS Phase III networks

Earth-station type	Service	Antenna size (m)	Off-axis e.i.r.p. density (dB(W/Hz)) ⁽¹⁾	Transmission gain, γ (dB)	Equivalent link temperature (K)
Fixed	FSS	18.28	$-8 - 25 \log \theta$	-6.9	350
Fixed	FSS	12.19	$-4 - 25 \log \theta$	-6.9	350
Relocatable	FSS or MSS	6.09	$2 - 25 \log \theta$	-8.4	400
Relocatable	FSS or MSS	2.44	$2 - 25 \log \theta$	-10.6	400
Shipborne	MSS	1.22	$2 - 25 \log \theta$	-13.3	415
Airborne	MSS	0.84	$2 - 25 \log \theta$	-16.3	420

⁽¹⁾ Beyond first side lobe to $\theta \leq 48^\circ$.

In computing $\Delta T/T$ the topocentric angle should be used but this requires knowledge of earth-station locations. Earth-station locations are not known in the mobile-satellite service. The combined effects of topocentric angle, range to the satellite and clear-air attenuation can be closely estimated for any earth-station location by using the geocentric angular separation, the satellite range to the nadir, and an additional loss factor in the Radio Regulations, Appendix 29 equations (1.6 dB for the 7/8 GHz band). The $\Delta T/T$ as a function of the geocentric angular separation between USGCSS Phase III satellites may then be computed.

For the worst case, with co-coverage and co-polarization the increases in noise temperatures due to up-path interference ($\gamma \Delta T_s$) are:

$$\gamma \Delta T_s = 47.6 - 25 \log \theta \text{ dB(K}^{-1}\text{) for MBA}$$

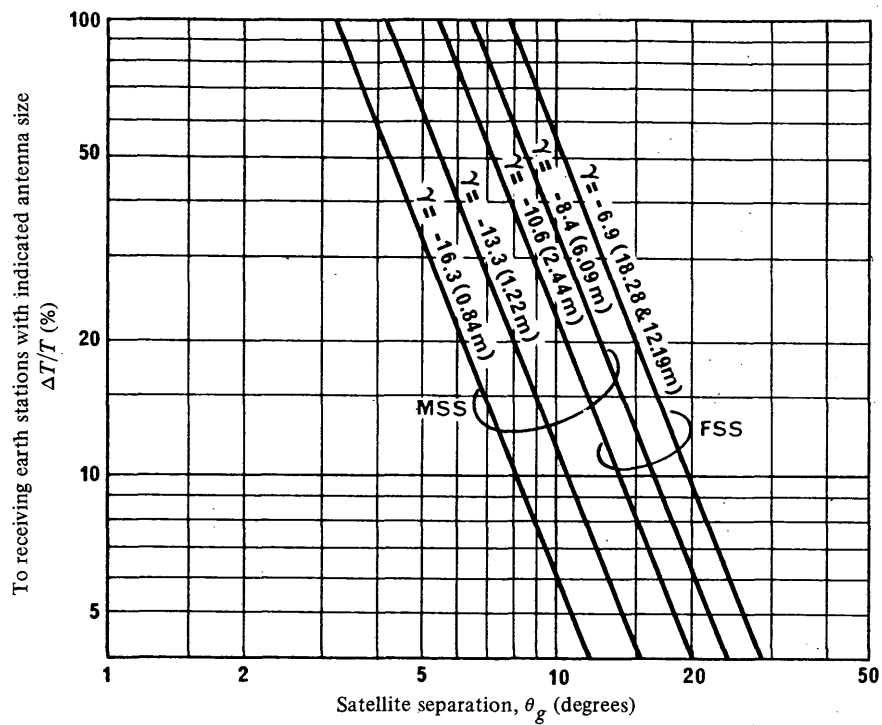
$$\gamma \Delta T_s = 40.5 - 25 \log \theta \text{ dB(K}^{-1}\text{) for EC}$$

for the 18.28 m antenna receiving earth station. Other earth stations receive less interference in proportion to their associated transmission gain, γ . The down-path increase in noise temperature (ΔT_e) is:

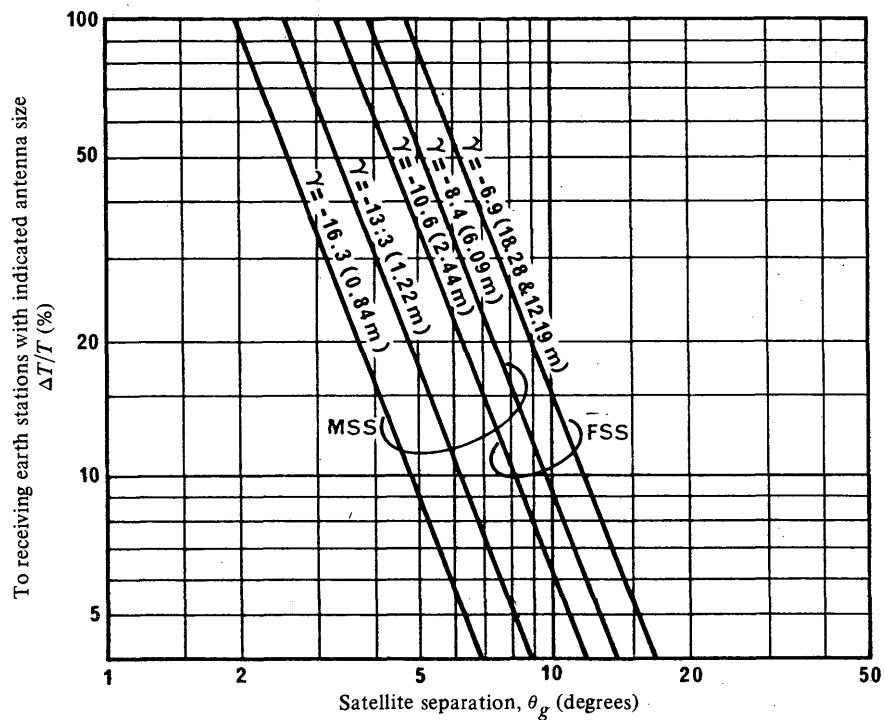
$$\Delta T_e = 32.0 - 25 \log \theta \quad \text{dB(K}^{-1}\text{)}$$

Thus, up-path interference is dominant for these cases and is computed using the maximum off-axis e.i.r.p. density of $2 - 25 \log \theta$ corresponding to the earth stations with the smaller antennas of Table III. If orthogonal circular polarization is used on the adjacent satellite, then these values would be 6 dB lower, using the factor given in Appendix 29 to the Radio Regulations for this case.

Figure 5 shows the worst-case values for $\Delta T/T$ for the co-coverage, co-polarization case with maximum MBA up-path satellite antenna gain. Figure 6 shows the worst-case values for $\Delta T/T$ when orthogonal circular polarization is used on the adjacent network. Figure 7 shows the same cases with the maximum earth coverage up-path antenna gain.

FIGURE 5 – Worst-case $\Delta T/T$ between USGCSS Phase III networks

Maximum MBS up-path antenna gain
 Co-polarization
 Co-coverage

FIGURE 6 – Worst-case $\Delta T/T$ between USGCSS Phase III networks

Maximum MBS up-path antenna gain
 Cross-polarization
 Co-coverage

The $\Delta T/T$ versus satellite spacing function in Figs. 5 and 6 for the 18.29 and 12.19 m earth stations represents a condition where it is possible to have accesses from earth stations with all antenna sizes in the same transponder i.e. from 0.84 to 18.29 m. This can be a case where earth stations operating in the MSS are linked to an earth station with a large antenna (base station) while at the same time links between earth stations with large antennas operating in the FSS could also be achieved. For links in the MSS involving a base station with a large antenna, the mobile-to-base links can be designed to tolerate larger levels of interference than the base-to-mobile links and thus reduce satellite spacing when only MSS is used in both networks. For earth stations with large antennas operating in the FSS, interference criteria would generally be more stringent, resulting in larger spacing requirements when one satellite network operates in the MSS and the other in the FSS.

It may be noted that using these values of antenna diameters in equation (1) in the body of this Report results in spacings about an order of magnitude greater than indicated in Figs. 5 and 6 for the same $\Delta T/T$. For equation (1) the same modulation is used for all links, complete connectivity is assumed (which represents the worst case) and the earth station rather than the link noise temperature is used. It is therefore, very general and each system needs to be considered on a case by case basis. For the case shown in Figs. 5 and 6 the link noise temperature is about twice the earth-station noise temperature for the earth stations with large antennas, coding is used for transmission and reception on links to earth stations with small antennas and the connectivity is limited.

Figure 7 shows $\Delta T/T$ versus satellite spacing for the up-path earth coverage satellite antenna. These functions are generally more indicative of USGCSS Phase III networks operating in the FSS only in a transponder.

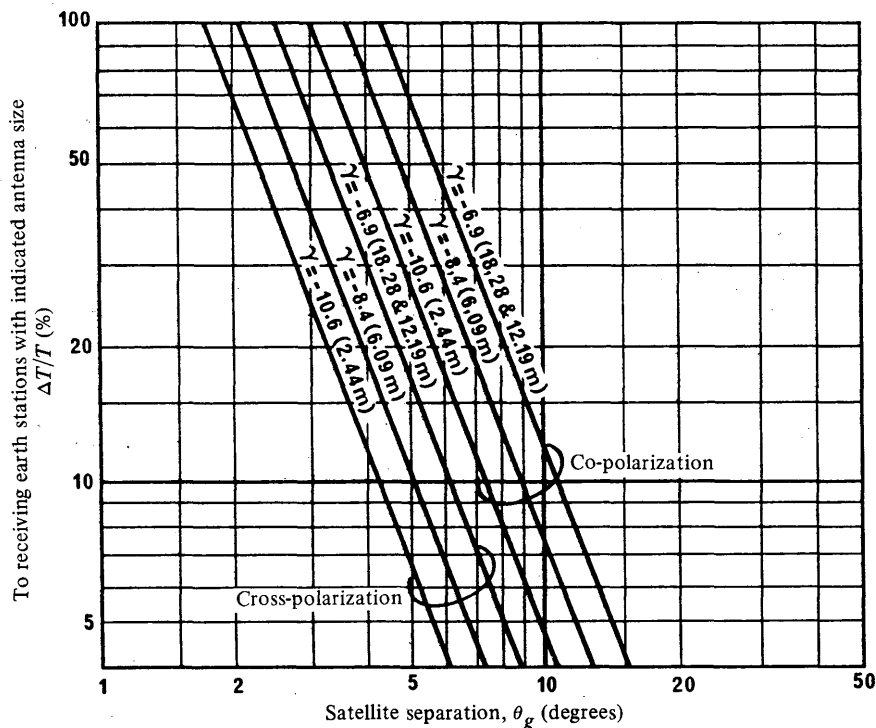


FIGURE 7 – Worst-case $\Delta T/T$ between USGCSS Phase III networks

Earth coverage up-path antenna
Co-coverage

Relationships between $\Delta T/T$, interference criteria and types of carriers are given in Report 455.

Finally, it should be noted that the functions shown in the figures apply only to USGCSS Phase III networks. Spacing between USGCSS Phase III satellites of other satellites or between other satellites operating in the 7/8 GHz band can be quite different. Also through the inter-satellite network coordination process, smaller angular separations than indicated by $\Delta T/T$ calculations may be achieved with mutually acceptable interference levels.

REPORT 773

**A CONCEPT OF COORDINATION AND PROTECTION CONTOURS FOR USE
IN THE COORDINATION OF MOBILE EARTH STATIONS***

(Question 32/8)

(1978)

1. Introduction

Reports 382 and 448 provide analytical methods for use in the coordination of fixed-satellite service earth stations and fixed service (terrestrial) stations. The use of these methods allow the fixed-satellite and fixed services to operate in the same frequency band without mutual interference. The concepts and interference calculations in Reports 382 and 448 can be used to determine whether stations in the mobile-satellite and fixed services can operate in the same frequency band without mutual interference.

This Report discusses the concept of the use of coordination contours in identifying potential mutual interference situations between mobile earth stations and terrestrial stations. If it is desired to operate both the mobile earth station and a terrestrial station within the coordination contour, detailed interference calculations are required in order to assess the probability of mutual interference.

The detailed interference calculations result in distances, referred to as protection distances, which indicate where the mobile earth station can operate without risking mutual interference. A technique is presented for graphically illustrating the protection distances.

2. Coordination contours

Coordination contours are calculated for worst case conditions, (i.e., those leading to the largest, most conservative contour). This requires careful consideration of the mobile earth station antenna radiation pattern, interference criteria, other sources of interference, and propagation mechanisms. The calculation of the maximum permissible levels of interference, minimum permissible basic transmission losses, and coordination distances may be performed in a manner similar to that of Reports 382 and 448**.

2.1 Coordination contour construction

Figure 1 shows an example of a coordination contour constructed around a mobile earth station service area. The coordination distances, the locus of which forms the coordination contour, are calculated in an incremental fashion around the perimeter of the mobile earth station service area. The coordination contour which results will be equivalent to a union of contours constructed for a mobile earth station located at any specific point within the service area.

The coordination contour calculations are performed for a mobile earth station intended to access a particular geostationary satellite; thus, the mobile earth station antenna main beam direction is uniquely determined for any possible mobile earth station location. If access to another satellite is desired, a new coordination contour must be calculated using the associated antenna gain-azimuthal relationship. The main beam path through Zone "A" of Fig. 1 will be approximately parallel, if the area of desired mobile earth station operation is suitably small. Furthermore, it can be observed that Zone "C" will grow larger, and Zone "B" will grow smaller, as the required mobile earth station elevation angle increases.

The propagation mechanisms involved in the operation of an airborne mobile earth station differ from those considered in Reports 382 and 448. Reports 715, 238 and Recommendation 528 provide the necessary propagation data for airborne considerations.

* The material contained in this Report is preliminary and has been drawn up by Study Group 8 only, without the benefit of consultation with Study Groups 4 and 9. The attention of Study Groups 4 and 9 should be drawn to this Report.

** These calculations must be performed for both cases of (1) receiving terrestrial stations (mobile earth station transmitting) and (2) the receiving mobile earth station (transmitting terrestrial stations) to afford protection from interference to either service.

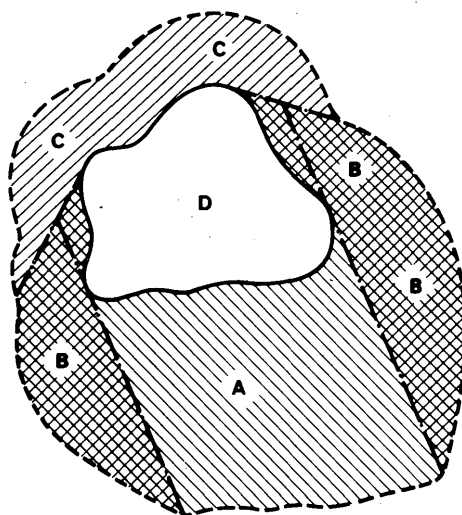


FIGURE 1 — *Coordination contour around a mobile earth station service area*

- Zone A: area transversed by earth station main beam paths in azimuths towards the satellite
- Zone B: area where the mobile earth station antenna gains will be less than the main beam gain and greater than the backlobe gain
- Zone C: area where backlobe earth station antenna gain (commonly -10 dBi) will be used
- Zone D: mobile earth station service area
- : coordination contour

3. Protection contours

Protection contours may be constructed around the terrestrial station(s) located within the coordination contour of a mobile earth station as shown in Fig. 2. A protection contour is the locus of the protection distances, which are the distances from a terrestrial station beyond which a mobile earth station can operate without causing or experiencing more than a permissible level of interference. Equations for calculating protection distances should account for frequency dependent rejection, propagation considerations, other transmitters which may contribute to the interference environment, and other factors which could affect the protection distances.

The protection contours are only applicable for access to the particular geostationary satellite considered for the coordination contour. Since frequency dependent rejection is incorporated in the calculations, a set of protection contours will normally only apply to a certain mobile earth station carrier frequency. However, the protection contours within a certain coordination contour may apply to several mobile earth station carrier frequencies if all carrier frequencies are considered and the protection distances of each terrestrial station reflect the worst case condition (e.g., the mobile earth station carrier frequency closest to that of the terrestrial station is used for the individual protection contours).

It can be seen that in many cases the protection contours will be small even though the mobile earth station and terrestrial station share the same frequency band. Figure 2 shows that the protection contour need not necessarily be calculated for all azimuths, (i.e., open contour) since only azimuths directed towards the desired area of mobile earth station operation are of concern. However, all azimuths from a terrestrial station located within the desired area of mobile earth station operation must be considered.

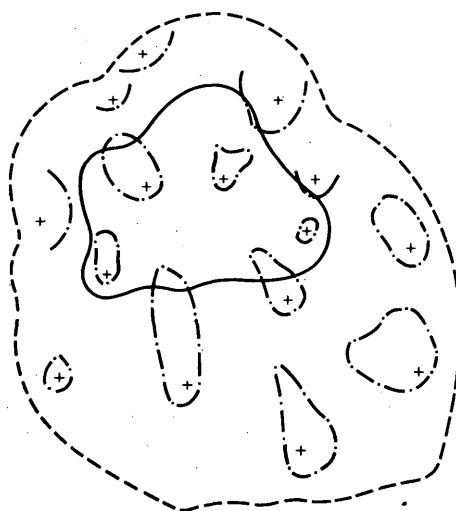


FIGURE 2 — Protection contours around terrestrial (fixed) stations

- Coordination contour
- Protection contour
- + Terrestrial (fixed) station
- Service area boundary

4. Conclusions

The calculation of protection contours and coordination contours could be extremely complex, particularly where the density of terrestrial stations is high, and would require the use of computer techniques.

The establishment of coordination contours provides a method for identifying potential interference situations. It should be noted that the methods in this Report are applicable to the frequency bands from 1 GHz to 40 GHz as in Reports 382 and 448. The calculation of coordination contours associated with airborne mobile earth station operation requires special consideration. Some consideration of this problem is set out in Annex I.

When a terrestrial station lies within the coordination contour of a mobile earth station, the protection contours specify the protection distances to be observed. Additionally, frequency planning for the mobile earth station may take place prior to calculating protection contours, in order to select the optimum mobile earth station operating frequencies, which in turn will yield the smallest protection contours.

The methods described herein will not preclude the expansion of the fixed service, since the contours can be recalculated to afford protection to new fixed stations. Clearly, the burden of calculation and coordination lies with the mobile-satellite service.

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- NG, H. J. [1977] Technical considerations of small fixed, mobile, and transportable satellite systems. Office of Telecommunications Report 77-115, United States Department of Commerce. (NTIS PB-266600).

CCIR Documents

[1974-78]: 8/344, 8/346, 8/349, 8/351 (USA).

ANNEX I

AIRBORNE MOBILE EARTH STATION COORDINATION AND PROTECTION CONTOURS

1. The airborne mobile earth station is capable of operation on the ground as well as throughout its flight path. While on the ground, the coordination and protection contours can be calculated as described in the text of this Report.

The concepts of coordination distance and interference calculations as described in Reports 382 and 448 need not be greatly altered for application to airborne earth station operation. The basic transmission loss model in Report 238 must be used. The coordination distances can be computed for the aircraft at a specific location and altitude. These distances are then used to define an area on either side of the proposed flight path, within which coordination is required. The distances on either side of the aircraft flight path must be recalculated periodically along the path to account for the change in earth station antenna pointing angle. In order to account for potential interference situations during take off and landing, a series of contours will have to be generated for a sequence of altitudes in the vicinity of airports.

Two other areas require special treatment:

- the earth station antenna pattern will not necessarily be described by the reference radiation patterns of Report 391, and
- the rain scatter mode of propagation may not be applicable to the high altitude aircraft.

All terrestrial stations identified as being located within the coordination contour must be considered, using more detailed calculations. If the detailed calculations (protection contours) require that the aircraft alter its flight path, the coordination contour around the new flight path must be constructed.

In order to determine the extent of the potential interference problems, an extensive test programme was conducted in the United States. One of the objectives of this programme was to determine the dynamic characteristics of the received interference level due in part to aircraft motion through the multi-lobed pattern of the terrestrial radio-relay system antenna.

2. Measurements

An airborne mobile earth station was flown for a total of 80 hours over pre-planned flight paths in the vicinity of five different point-to-point microwave systems (Table I). Interference power was measured continuously at the antenna output terminals of the microwave stations. The distribution of interference power versus time is plotted in Fig. 3. The abscissa is expressed as 1 minute mean power levels (dBW) at the antenna terminals of the terrestrial system. The ordinate is the amount of time during a flight that a given level on the abscissa was exceeded. Given allowances for variations in flight path configurations, i.e., not all worst case, and allowing an arbitrary rate of encounter (number of flights over a site), the interference power distribution over a longer period can be determined. Curve A of Fig. 4 presents the interference power density distribution over a 1 month period for three flights per day over a site with an airborne mobile earth station power of 1 kW.

Also plotted on Fig. 4 (Curve B) are the permissible interference power density levels of Report 382. This level is based upon the interference levels of Recommendation 357 as well as the equipment characteristics given in Report 382. Curve C on Fig. 4 is also based on Recommendation 357; however, the equipment characteristics are those of current FDM-FM radio-relay stations. Curve D is also based on Recommendation 357. This curve represents systems whose interference criteria and/or critical mission requirements are such that additional protection is required. The particular equipment characteristics used to generate Curve D are those of a wideband FM system transmitting radar video signals.

TABLE I – Test site characteristics

Site	Terrain	Transmission type	Fixed or mobile	Fade margin (dB)	Antenna
Site 1	Desert	Television	F	20 to 50	Dish (beam horizontal)
		High speed data	M		Dish (beam elevated)
Site 2	Average	FDM-FM (600 ch CCIR)	F	40	Dish
Site 3	Coastal	Radar RML-4	F	20	Periscope
		FDM-FM data RML-6	F	40	Midpath reflector

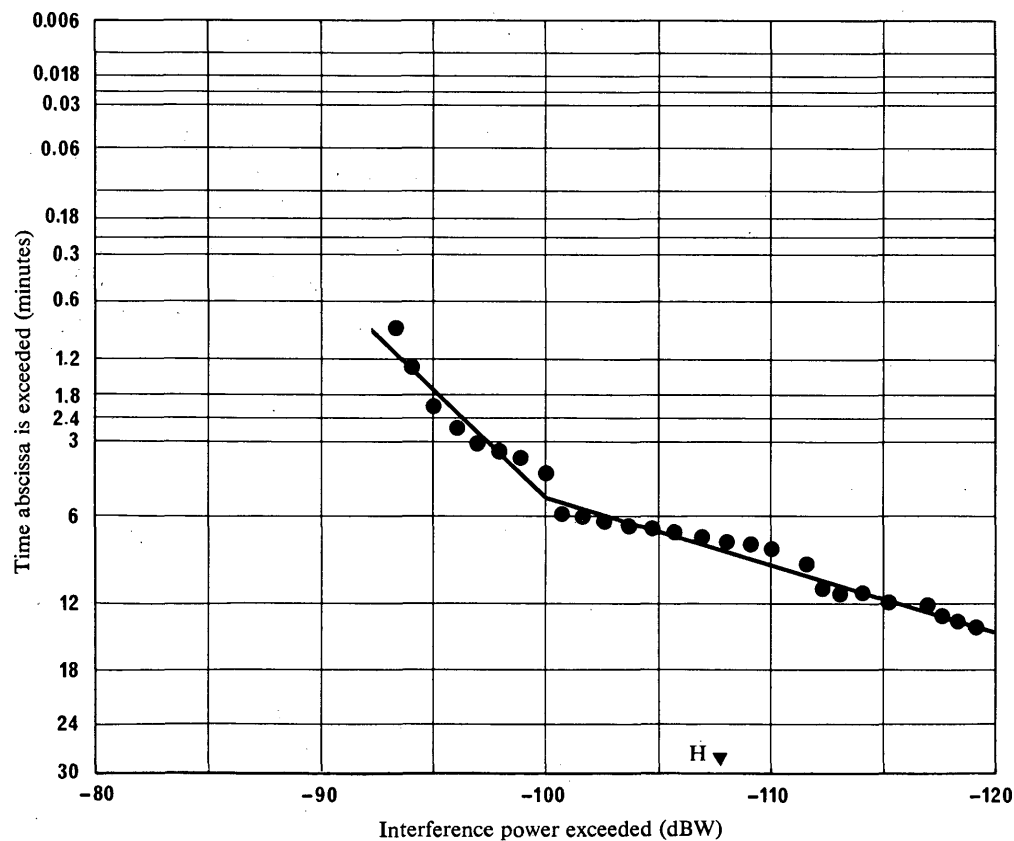


FIGURE 3 — Distribution of measured interference power (Worst-case 1 minute mean) for an airborne mobile earth station with radiated power of 1 kW

H: 1 hour mean

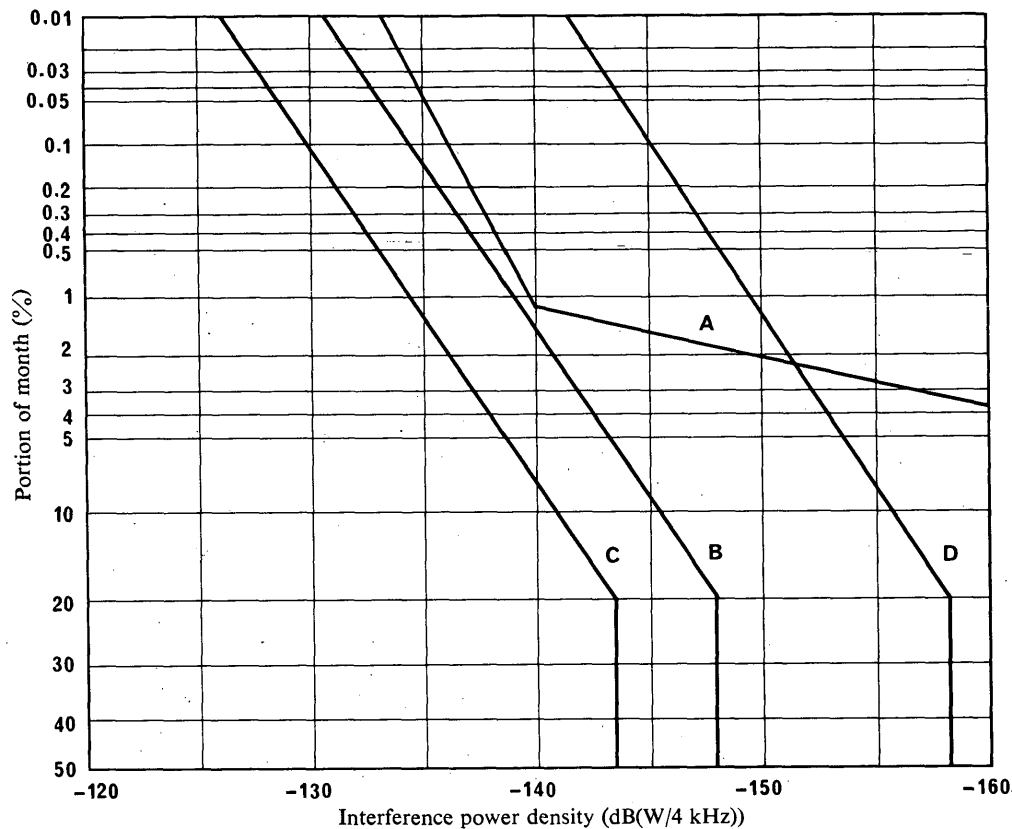


FIGURE 4 — Comparison of expected interference power density distribution (1 minute mean) with permissible interference power density levels for three different criteria

Curves A: expected interference power density distribution (1 minute mean)

B: permissible interference power density levels using equipment characteristics specified in Report 382

C: permissible interference power density levels using current equipment characteristics

D: permissible interference power density levels for broadband analogue terrestrial systems

3. Summary

Figure 4 shows that the extent to which airborne mobile earth stations and systems of the fixed service may share frequencies is dependent upon the operational requirements, quality, and type of service provided by the terrestrial systems.

In many cases, coordination between the airborne earth stations and terrestrial stations could be accomplished through an examination of the system performance characteristics of systems of the fixed service.

Figure 4 shows that there are systems requiring additional protection which must be provided by additional coordination through the generation of protection contours as described in the body of this Report. For such systems, these protection contours might cover a large area and thus the use of airborne earth stations could be difficult if not impossible in such areas.

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SECTION 8H: AERONAUTICAL MOBILE SERVICE, AERONAUTICAL
MOBILE-SATELLITE SERVICE AND RELATED SUBJECTS

Recommendations and Reports

RECOMMENDATION 441-1

**SIGNAL-TO-INTERFERENCE RATIOS AND MINIMUM FIELD STRENGTHS
REQUIRED IN THE AERONAUTICAL MOBILE (R) SERVICE ABOVE 30 MHz**

(Question 1/8)

(1966-1982)

The CCIR,

CONSIDERING

- (a) that the World Administrative Radio Conference, Geneva, 1979, in Recommendation No. 64, invited the CCIR to continue its study of signal-to-noise ratios and minimum field strengths;
- (b) that there are partial data relating to interference protection ratios and minimum field strengths required in certain documents of the ITU;
- (c) that the International Civil Aviation Organization (ICAO) has adopted standards and recommended practices for the best use of VHF frequencies and the aeronautical service and the avoidance of harmful interference,

UNANIMOUSLY RECOMMENDS

that the provisions made by the ICAO should be considered as adequate for the planning and protection of Aeronautical Mobile (R) Service frequencies above 30 MHz; the provisions are contained in Annex 10, Volume 1, Part II, § 4.1.5, to the Convention on International Civil Aviation.

REPORT 926*

**FACTORS THAT SHOULD BE CONSIDERED WHEN ESTABLISHING PROTECTION CRITERIA
FOR AERONAUTICAL SAFETY SERVICES**

(Question 62/8 and Study Programme 21A/8)

(1982)

1. Introduction

For the purposes of this Report, "electromagnetic noise" or "noise" is defined as all electromagnetic energy from both intentional and unintentional radiators, except from a desired signal for a specific system of interest.

Existing and proposed protection criteria, sometimes referred to as "maximum permissible interfering signals", "maximum permitted interfering field strengths", or "noise limits", are often stated in the following manner:

$N \mu\text{V/m}$ at 30 m for the frequency band 108 to 112 MHz

This type of statement may be insufficient in itself as it fails to consider a number of pertinent factors, some of which will be identified in § 2.

* The Director, CCIR, is requested to bring this Report to the attention of the International Civil Aviation Organization (ICAO) and the International Electrotechnical Commission (IEC), and Study Group 1.

2. Specific factors

2.1 The conditions for the field strength measurement of the interfering signal should be stated. Failure to specify the conditions for field strength measurements, such as the receiver bandwidth (e.g., 10 kHz, 100 kHz or 1 MHz, 3 dB, 6 dB, or effective impulse bandwidth), receiver detector characteristics, calibration techniques, type of antenna used, polarization and antenna height above ground, leaves the method of measurement open to interpretation; this could then result in erroneous conclusions and inability to compare with data obtained by other experts. Dissimilar characteristics of the many different types and makes of field strength meters widely used also prevent a direct comparison of data obtained by different experts. A recent survey of field strength meters used for the measurement of noise produced by power lines has shown a less than satisfactory correlation in some frequency bands.

2.2 Systematic and random measurement errors result from errors in instruments and their calibrating sources and from errors in test set-up and measurement procedures. Error problems also exist because electromagnetic interference problems are often probabilistic, rather than deterministic, in nature. The method of error analysis in the development of parameter limits becomes important where regulatory aspects must be considered.

2.3 Interference prediction techniques, noise models and communication system models are currently under development or refinement by a number of administrations, educational institutes, and industrial research organizations. A non-exhaustive list of noise measurement parameters and techniques used includes:

- average voltage (V_{avg}),
- root-mean-square voltage (V_{rms}),
- quasi-peak voltage (V_{qp}) (both CISPR and ANSI),
- peak voltage (V_p),
- impulsiveness ratio $V_d = 20 \log (V_{rms}/V_{avg})$,
- effective antenna noise factor (F_a),
- mean noise power (P_n),
- amplitude probability distribution (APD),
- noise amplitude distribution (NAD),
- average crossing rate (ACR).

Some of these parameters are useful principally as means of detecting the presence or absence of unwanted emissions from some area or object. Ideally, the emission or radiation parameter or measurement technique selected should correlate directly to how the noise is degrading the performance of a radio communication or navigation system.

2.4 A single protection ratio covering all noise sources within a fixed frequency band may not be realistic. Such a protection ratio may fail to take into account the characteristics of the noise (that is, whether the noise is continuous wave, Gaussian, random or impulsive). Noise sources may have to be broken down into groups such as power lines, industrial-scientific-medical apparatus and ignition systems, with protection ratios defined for each of these groups.

2.5 The time characteristic of the noise is an important consideration. Depending on the grade of service required, a noise source that exceeds the protection criterion only 0.5% of the time may have to be treated differently from a noise source that exceeds this criterion 95% of the time.

2.6 Protection criteria may be required to take into account variations in radio communication and navigation equipment performance. One approach may include the determination of susceptibility of radio communication and navigation systems to man-made noise and the establishment of parameters and levels that describe the noise that these systems can withstand without intolerable degradation in performance.

2.7 Where the sources of noise are manufactured in quantity, control of their radio frequency emission limits may be effected by statistical sampling tests (e.g. CISPR test method). Such tests may only give guarantees that a certain proportion of the manufactured items conform to a stated limit. A detailed examination of the statistical sampling test may therefore be necessary to establish whether the statistical guarantees are compatible with the particular protection required. Annex I gives such an examination of the CISPR statistical method.

2.8 For the protection of aeronautical safety services it may not be realistic to formulate protection ratios based on field strength measurements made at or near ground level when, in the real world, aircraft fly over noise sources. An examination of available literature has shown that in some cases, noise levels at a given distance measured laterally from a noise source are lower than those measured at the same distance above the noise source. In addition, aircraft in flight could be subjected to noise from many possible sources; although the noise produced by one source may be of little consequence, the effect of many such sources could be significant. It should be noted that aircraft in flight regularly experience unwanted signals that are not detected by ground monitoring.

Considering the mobility of aircraft and the large viewing area to which aircraft are exposed, together with the variability and uncertainty of assessing and controlling harmful interference to safety of life services, the impracticability becomes obvious of accurately accounting for all of the signal characteristics of the unwanted signal sources that aircraft may encounter. Nevertheless, these factors must be accommodated if the high reliability of civil air transport is to be maintained. One method of accommodating these factors is by including a compensation in the form of a margin added to the protection ratios.

2.9 The protection of radio communication and navigation systems might be better achieved by a combination of protection criteria in a prescribed critical area around a site. This would assist in land-use planning around airports and around off-airport radio communication and navigation facilities. In regard to protection of aeronautical radiocommunication and/or navigation facilities at airports, attention is drawn to the coordination procedure presented in Report 929.

3. Conclusion

In order to safeguard aeronautical safety of life services, it is essential to establish adequate protection criteria from unwanted signals. However, the formal derivation of such protection criteria is considerably complicated by factors which introduce significant uncertainties. Some of these factors have been presented in this Report.

ANNEX I

AN EXAMINATION OF THE CISPR (INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE) STATISTICAL TEST PROCEDURES FROM THE VIEWPOINT OF INTERFERENCE PROTECTION TO THE AERONAUTICAL SERVICES

1. Introduction

1.1 The CISPR has published much valuable work on the methods of measurement of radio frequency energy and corresponding recommended limits of radiation from various types of equipment which may cause interference [CISPR, 1975a and b; 1976 and 1977]. Some of these equipments are manufactured in quantity, and in these cases the CISPR recommends a statistical sampling method for checking compliance with corresponding RF radiation limits. This Annex is a first assessment, in statistical terms, of the potential interference to aeronautical services from equipments whose RF radiation limits are measured by the CISPR statistical method.

2. The CISPR statistical testing method

2.1 Full details of the method recommended and a comprehensive exposition of its mathematical derivation are available in CISPR publication 13 [CISPR, 1975b]. In essence two choices are offered: either taking measurements from a relatively small sample of the production run or from one item only.

In the latter case the value measured must be at least 2 dB more stringent than the CISPR recommended limit for the particular equipment type. Only if the item does not meet this more stringent limit is the sampling method obligatory.

In the sampling method, compliance with the CISPR limits is judged by measuring the variable interference attribute (e.g. field strength radiated in a particular band) in accordance with the test procedure and measuring instrument characteristics laid down (e.g. typically using a quasi-peak detector on a test site).

Depending on the sample size, and with the set of results to hand, (typically 5 to 12 values of field strength expressed in dB relative to 1 $\mu\text{V/m}$), the mean and the standard deviation of these values is calculated. These values are, in turn, substituted in the formula:

$$\bar{X} + KS < L$$

where

$\bar{X}$: arithmetic mean of measured levels from the items;

S: standard deviation of the same measured levels;

- L : appropriate CISPR permissible limit; and
- K : factor depending on the sample size (n);
- K : given in Table I:

TABLE I

Sample size (n)	3	4	5	6	7	8	9	10	11	12
K	2.04	1.69	1.52	1.42	1.35	1.30	1.27	1.24	1.21	1.20

- 2.2 If the sample results satisfy the relationship given above then the whole production of the item is classified as “meeting the CISPR limit”.
- 2.3 Clearly, the factor K is very important and the CISPR references show that K is based on the assumption that the production output exhibits a normal distribution and that the “consumer’s risk” is that there shall be an 80% confidence that 80% of all the production items shall be below the CISPR limit.
- From the viewpoint of the degree of protection offered to an interfered with service it is important to note that the consumer risk, in turn, means that 20% of the items must be assumed to radiate RF energy greater than the CISPR limit – how many and how much greater will depend on the parameters of the particular distribution in practice, which depends on the manufacturer’s design decisions. For example purposes two hypothetical cases are given below in Table II:

TABLE II

CISPR limit = L dB	Case a)	Case b)
Production line mean value (manufacturer’s choice) (dB)	$(L - 5)$	$(L - 1)$
Corresponding standard deviation required to meet CISPR “80%/80%” consumers’s risk exactly (dB)	5.95	1.2
Resulting approximate radiation level exceeded by 5% of items (dB)	$(L + 5)$	$(L + 1)$
Resulting approximate radiation level exceeded by 0.5% of items (dB)	$(L + 10)$	$(L + 2)$

- Thus, in both of these hypothetical cases the production line would “meet the CISPR limit” and yet a wide variation of higher radiation levels would exist.
- 2.4 Further examination also shows that the factor K is very sensitive to changes in the percentage values chosen for the consumer’s risk. Table III gives examples of the variation of K for more stringent risk values. It is evident that such changes might have important economic repercussions for the manufacturers of the items being tested.

TABLE III — CISPR statistical sampling method
(Source: Biometrika Tables for Statisticians)

K (80%/80%)	2.04	1.69	1.52	1.42	1.35	1.30	1.27	1.24	1.21	1.20
K (95%/95%)	—	5.13	4.19	3.70	3.39	3.18	3.02	2.83	—	—
K (99.5%/99.5%)	—	17.25	11.77	9.37	8.01	7.15	6.56	6.12	—	—

3. Statistical requirements of the aeronautical services

It is clearly difficult to assess the probability of actual harmful interference occurring in practice from a knowledge of the statistical probabilities of certain manufactured items exceeding certain radiation limits.

However it is pertinent to note that some aeronautical services are designed to meet statistical targets which are extremely stringent and several orders higher than the values implied by a consumer's risk of "80%/80%" (see Report 927). There is therefore some justifiable doubt whether the current CISPR consumer's risk is acceptable in these cases and further study is required on this matter.

4. Specific areas of concern

To assist in further study some particular points of concern have been identified, as follows:

4.1 The use of a statistical test method based on a small number of samples and a simple statement of "consumer's risk" does not provide strong practical control over the range of actual radiation limits likely to be met in practice, possibly in significant quantities. As § 2 shows, a significant proportion of equipments manufactured to meet a CISPR limit could exceed the actual limit value by quite a high margin.

In practice, commercial pressures may lead a manufacturer to adopt a tighter specification than the CISPR consumers' risk indicates, in order to give the manufacturer better assurance that his products will be accepted when tested by sampling. However this possible factor cannot easily be taken into account by the aeronautical community.

4.2 The ability, as an alternative within the CISPR test method, to assess compliance with the CISPR limit by testing only one item from a production series — albeit to a 2 dB more stringent level — offers statistically no guarantee of protection to any consumer at any level of consumer's risk. There would therefore seem to be a strong need for the justification of this alternative to be re-examined.

4.3 There would appear to be a basic need for justified aviation protection requirements to be stated as precisely and fully as possible, including statistical criteria where applicable.

4.4 The most difficult area of investigation would seem to be the *practical* conversion of limits established by § 4.3 above into corresponding limits for the testing of production items by the CISPR sampling test method.

4.5 Following on from § 4.1 above it would seem to be important to examine if it would be possible to limit the actual use of equipment which emits radiation above certain levels (higher than the relevant CISPR limit). It should be noted here that in view of the stringent statistical requirements referred to in § 3 the prime aim may need to be to prevent interference from occurring rather than to seek to identify and remove the interference after it has occurred.

5. Conclusions

This Annex indicates some specific areas of concern in relation to the use of the CISPR statistical test method in cases where very high protection from interference is required, e.g. aeronautical radionavigation.

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- CISPR [1975a and 1976] Publications 11 and 11A. Limits and methods of measurement of radio interference characteristics of industrial, scientific and medical radio-frequency equipment (excluding surgical diathermy apparatus).
- CISPR [1975b] Publication 13. Limits and methods of measurement of radio interference characteristics of sound and television receivers.
- CISPR [1977] Publication 16. CISPR specification for radio interference measuring apparatus and measurement methods.

REPORT 927-1 *

GENERAL CONSIDERATIONS RELATIVE TO HARMFUL INTERFERENCE FROM THE VIEWPOINT OF THE AERONAUTICAL MOBILE SERVICES

(Questions 1/8 and 62/8 and
Study Programme 21A/8)

(1982-1986)

1. Background

The ITU definition of "harmful interference" is contained in Radio Regulation No. 163 as follows:

"Harmful Interference: interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with these Regulations."

The term "harmful interference" is not generally definable in a precise quantitative manner and therefore an assessment of harmful interference must be construed in the light of the nature of the operations and the safety environment. This leads directly to the conclusion that the determination of quantitative threshold levels of harmful interference for the various aeronautical mobile radiocommunication services requires the examination of the appropriate safety criteria.

2. Aviation safety criteria

A prime basis of aviation safety is the *statistical* assessment of performance criteria and failure rates. The following statistical "failure rates" may have been used as criteria by some civil aviation administrations in the international aeronautical community:

- the air traffic systems which ensure separation between aircraft flying *en route* are designed to reduce the chances of mid-air collisions to a level no greater than 2 in 10^8 ; and
- the certification of aircraft automatic landing equipment by many civil aviation administrations requires that the control system in each aircraft be demonstrated statistically to have a failure rate no greater than 1 in 10^7 landings.

In light of the above, it is evident that for aeronautical mobile radiocommunication services, the required interference protection ratios will be very much influenced by the statistical characteristics of the particular service. For instance, a radionavigation aid providing the sole guidance to an aircraft during automatic landing requires very high protection from harmful interference. Indeed, it would follow that the statistical probability of harmful interference in such cases needs to be more stringent than 1 in 10^7 . In comparison it may be possible to identify other aeronautical systems which do not require this same degree of protection. § 5 of this Report examines this aspect further for the various aeronautical systems.

The above points lead directly to the thought that whilst it may be possible to quantify a signal level for unwanted harmful interference which would permit safe operation of a particular type of radio service, the promulgation of such a level without an associated description of its assumed nature and statistical variation could be of little value and could have serious implications. This would apply particularly to those environments where there are a multitude of potential interfering sources, possibly of more than one type, and where the aggregate harmful interferences at any particular point, therefore, could be expected to vary with time.

3. Aeronautical and non-aeronautical sources of harmful interference

An important aspect of the study of harmful interference is the determination of whether or not the criteria for harmful interference from non-aeronautical sources has, or should have, any relationship with the technical planning criteria established in the aeronautical services for co-channel and adjacent channel assignments. Frequency assignment planning criteria adopted internationally within the aeronautical services are based on practical considerations which take into account the operational usage of the particular service. In addition, the planning criteria are based, reasonably enough, on the premise that mutual cooperation and internationally agreed aviation standards and procedures are used by everyone involved. It is a point of fact that the 146 Contracting States of ICAO are under certain obligations relative to the adoption of aeronautical standards, recommended practices, and procedures, as set forth in Article 38 of the Convention on International Civil Aviation (Chicago, 1944). Pursuant to these obligations, there is a highly developed international information and

* The Director, CCIR, is requested to bring this Report to the attention of ICAO and IEC, and Study Groups 10 and 11.

registration service which ensures that all aviation facilities and their “frequency protected” service volumes are formally promulgated and available on charts in accordance with Annex 15 to the Convention on International Civil Aviation; and appropriate information from this service becomes part of aircraft flight deck documentation. Thus, in respect of all technical protection criteria adopted in the international civil aviation community against “aeronautical-to-aeronautical” harmful interference, there is comprehensive and significant additional protection provided through the organizational structure of international civil aviation, with ICAO at its focal point.

The additional protection indicated in the above paragraph is largely non-existent for non-aeronautical sources of harmful interference to aviation, some of which are only partially regulated by the ITU. Consequently, there is not necessarily an inherent relationship between aeronautical protection criteria and those criteria which may be appropriate to safety services for application to non-aeronautical sources of harmful interference. Each potential non-aeronautical source of harmful interference requires individual consideration in this respect.

The following external sources of man-made emissions and radiations are known to have caused harmful interference to aeronautical services:

- broadcasting, LF/MF AM and VHF FM;
- cable distribution systems;
- power line distribution systems;
- industrial, medical, and scientific equipment;
- local oscillator emission from domestic electronic equipment.

It should be observed that some of the above are not under the direct purview of the ITU, and therefore, it will be necessary to effect coordination between ITU, ICAO, and other concerned organizations. However, this need not influence CCIR involvement in the investigation of adequate protection criteria.

4. Shared and exclusive allocations

Regardless of the original intentions of radio spectrum planners, there can be no doubt that the pressure on the radio spectrum for additional allocations to the various radiocommunication services can result in aeronautical protection criteria being effectively regarded as non-aeronautical sharing criteria. As a consequence, a safety service must take considerable precautions to ensure that any radio service sharing the same radio band is constrained sufficiently to leave an adequate margin under all likely circumstances so that the aggregate harmful interference never exceeds the required protection criteria.

The constraints of weight, size, and power consumption placed upon airborne equipment have resulted in relatively low powered transmitters and sensitive receivers, which is consistent with general ITU guidance for efficient and effective use of the radio spectrum. Nonetheless, the above set of conditions does cause difficulties for the aeronautical community when interference problems arise. For instance, the wanted signal at the edge of a VHF radiotelephony service volume must be no less than 70 $\mu\text{V/m}$ to meet ICAO standards and recommended practices. For an aircraft flying at, say, 300 m above the ground, such a wanted field strength could be equalled by an unwanted signal source on the ground with an e.i.r.p. of only 16 μW . Many interfering sources can easily produce more than 16 μW . Article 8 of the Radio Regulations, the Table of Frequency allocations, contains examples of sharing arrangements between aeronautical and other radiocommunication services, some of which have resulted in harmful interference problems. In such cases, the need to maintain the necessary aeronautical protection criteria has led to a less efficient use of the radio spectrum for aeronautical purposes than could be achievable with separate exclusive allocations. Thus caution should be exercised before considering any sharing involving the aeronautical radiocommunication services.

Annex II details some of the items to be evaluated when considering the specific problem of sharing with the aeronautical flight test telemetry stations. In this regard Annex II responds to WARC-79 Resolution No. 505.

5. Aeronautical radiocommunication systems

Precise details of aeronautical radiocommunication systems are contained in Annex 10 to the Convention on International Civil Aviation. However brief synopses are given below:

5.1 *HF and VHF digital data interchange and radiotelephony*

Air/ground digital data interchange or radiotelephony constitute a direct link between an aircraft in flight and aeronautical stations on the ground. The number of aircraft flying simultaneously in any given airspace and the multiplicity of air routes flown, result in a complex set of rules and procedures to ensure the safety of air operations. While it is true that interference to air/ground radiotelephony communications is relatively easier to detect, in as much as the pilot can hear it and is normally less likely to be misled, than in the case of interference to digital data interchange or to a radionavigation aid, such interference may nonetheless have serious

consequences, particularly for aircraft contacting approach control of an airport while flying at positions where the ground clearance is of the order of a few hundred feet. Thus, regardless of adherence to precise phraseology and to other standard operational procedures, cases have arisen where even a slight interference to a single phrase has resulted in catastrophic consequences.

The conversion of the above factors into quantitative protection ratio criteria is a difficult task. On the one hand there is general acceptance of the view that some minimum interference to voice communications could normally be accepted, but on the other hand, it needs to be recognized that under difficult operational circumstances, errors that would normally be accepted can assume great significance, and under these circumstances an interference-free service can be vital. Therefore, a general protection ratio for HF and VHF radiotelephony should be developed such that the aggregate interference on any channel should not significantly add to the basic noise level of the safety service receivers used for air-ground communications. Following the same general idea, a protection ratio should be developed for HF and VHF digital data interchange.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.2 *VHF emergency frequencies*

The Radio Regulations and Annex 10 to the Chicago Convention on Civil Aviation contain special provisions for the use and protection of the aeronautical mobile emergency frequencies 121.5 MHz and 243 MHz. Subsequently, the ICAO has agreed on special procedures for monitoring these frequencies while, in addition, the COSPAS-SARSAT system provides for essential alerting capabilities. Also, EPIRBs, compulsory in some countries for carriage on board aircraft, operate on these frequencies. It is important that reception of distress and emergency transmissions will not be impaired. These frequencies are also used by other services for communications with the aeronautical services in the event of an emergency.

5.3 *Instrument landing system (ILS) – (VHF and UHF)*

The ILS consists of a “localizer” (VHF) providing lateral guidance for aircraft to the airport runway, a “glide-path” (UHF) providing the line of descent in the vertical plane, and one, two, or three “marker beacons” providing the aircraft with height and distance checks at known points from the runway threshold. One or more “locators” or other supplementary approach aids such as VOR may be used in conjunction with the ILS to assist in guiding aircraft to the “on-course” radio beams. Each of the above components of the ILS performs a different function and hence it can be seen that these components do not provide any form of redundancy for each other.

In the approach and landing phase of flight, when the aircraft is manoeuvring in close proximity to the ground, it is essential that harmful interference to any of the radio aids in use during this phase of flight be kept at an extremely low level of probability of occurrence. It is particularly relevant to note in this regard that the use of automatic landing systems which utilize ILS guidance signals, is the normal operating procedure for modern large aircraft, regardless of weather conditions. It should be noted that the very high level of protection against harmful interference required to support such operations is only needed within fairly constrained volumes of airspace around the ILS installations, e.g., around aerodromes. This factor may be helpful when considering the practical issues involved in protection against harmful interference.

Because of its critical nature considerable investigation of interference to ILS has occurred and Annex I gives more detailed information and derives protection ratios required under specified circumstances.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.4 *VHF omnidirectional radio range (VOR)*

The VOR system consists of a ground-based beacon radiating an omnidirectional signal providing directional guidance in the horizontal plane in such a manner that the airborne system provides an accurate indication of the compass bearing from the aircraft to the beacon. The system also provides identification signals and allows for voice transmission. The beacon transmits modulated CW signals continuously and can serve simultaneously any number of suitably fitted aircraft. The service volume of some *en route* facilities can extend beyond 300 km.

Most VOR installations provide *en route* service, often in association with DME equipment (see § 5.5). In addition, certain low-power VOR installations are used as holding or approach aids in the vicinity of aerodromes. With respect to the bearing function, interference to VOR can manifest itself as false bearing information to the aircrew and/or automatic flight control system, and this interference would directly impinge on the safety of the flight. The degree of the effect of the interference would depend on its type, strength and duration. In the low-powered VOR cases, even lower levels of interference could be critical to the operation of the aircraft, but fortunately, the service volumes concerned are relatively small.

Compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz is addressed in Report 929.

5.5 *Distance measuring equipment (DME) – (UHF)*

The DME system utilizes coded digital transmissions providing the aircraft with accurate slant-range distance measurements to ground-based beacon positions. The beacon transmits in response to an interrogation from an aircraft, and although the coded interrogation and reply offers a measure of interference protection, the system can become saturated when many aircraft are within range of a beacon. Under these circumstances, interference could be detrimental to safety.

DMEs are most often used in conjunction with VORs to provide international short-range navigational facilities. However, some DMEs are used in association with ILS, and consequently these circumstances may require special provisions to ensure adequate protection against harmful interference.

It is also important to recognize that DME frequency assignments are always “paired” by international agreement with either a VOR or ILS frequency. Consequently, frequency protection considerations need to be satisfied simultaneously on both of the paired frequencies.

5.6 *Radars*

Radar for aeronautical purposes can take many forms with widely varying characteristics and operational usages, e.g., long-range air traffic surveillance, radar altimeters, secondary surveillance radar, very short-range aerodrome surface surveillance, airborne weather detection and navigational assistance.

It is not possible to provide a universal interference assessment to cover these variations, and therefore, each case needs to be considered separately. However, it is worthy of note that regardless of the transmission characteristics employed, it is quite normal for the reception requirements of a radar system to be, necessarily, highly sensitive and thus capable of detecting low levels of unwanted signals.

Sophisticated processing techniques can sometimes be used to alleviate some types of interference, but these techniques are not practicable universally, and under some operational conditions are not acceptable.

Report 914 describes several techniques used on radars to reduce interference, many of which have been successfully adopted by aeronautical radar manufacturers.

5.7 *Non-directional beacons (NDB) – (LF/MF)*

Although at first sight NDBs may appear similar to VORs in concept, there are significant practical differences in their usage. NDBs are more widely implemented than VORs and are frequently used by smaller aircraft, which are, in some cases, not equipped to utilize VORs. NDBs are also frequently used to guide and establish aircraft on flight paths that enable them to acquire more accurate VHF aids (VOR, ILS, etc.) as part of the approach procedure. In addition, the airborne equipment used in association with NDBs is simpler in concept and is less able to cope with interference than more sophisticated airborne equipment. The basic simplicity of the system makes it less able to distinguish between true NDB signals and unwanted emissions near or within the channel passband. In particular, an “overhead beacon” indication on the aircraft flight deck can be falsely provided under certain conditions by interfering signals.

Interference to NDBs is an important issue in the aviation world, because many NDBs are in radio bands which are shared with other users in some parts of the world, and in addition, these bands are sometimes highly congested. Protection criteria against harmful interference must take these facts into consideration.

6. **Aeronautical radiocommunication and radionavigation systems in common use**

In addition to the radiocommunications and radionavigation systems that are specifically detailed in Annex 10 to the Convention on International Civil Aviation (Chicago, 1944) there are a number of such systems that are in regular use by aviation operators which may also be seriously affected by harmful interference.

Some of these systems are briefly described in Annex III to this Report.

7. **Conclusions**

The design of an aeronautical radiocommunication system takes into consideration appropriate levels of integrity and reliability in order to achieve, in a statistical sense, the overall objectives of the total operational system. Criteria to protect aeronautical systems from non-aeronautical sources of interference must be adequate to meet these objectives (see also Recommendation 441).

ANNEX I

SOME INTERFERENCE MECHANISMS RELATED
TO THE INSTRUMENT LANDING SYSTEM**1. Introduction**

Detailed examination of some of the interference mechanisms that could cause harmful interference to the ILS localizer signals has taken place in several aeronautical administrations, and this Annex summarizes some aspects of these examinations. The examinations have encompassed both theoretical studies and laboratory tests, and the degree of correlation has been extremely high.

2. Harmful interference threshold

The criteria establishing the threshold of harmful interference for ILS have been taken from Annex 10 of the Convention on International Civil Aviation (Chicago, 1944).

From the aircraft localizer receiver point of view, interference to a localizer signal will appear as an aberration of the localizer course line (in ICAO terminology, an aberration of the localizer course line is called a "bend"), and will contribute to the total allowable receiver output error. The allowable receiver output error ultimately is a function of the permissible lateral displacement of the aircraft from the localizer course line, and this displacement is dependent on the operational category of the ILS to be fulfilled and the approach speed of the aircraft. Annex 10 contains standards, recommended practices, and guidance material which are necessary for the attainment of the objectives of the instrument landing system, and this material indicates that in order to restrict aircraft deviations to less than 5 m lateral displacement from the localizer course line for Categories II and III, the aberration of the localizer course line must not be greater than 5 μ A. Attention is drawn to the fact that there are other contributors to course aberrations which need to be considered in the attainment of the objectives of the instrument landing system, but these will not be discussed in this Annex. However, these other criteria must be taken into account in order to define satisfactorily protection ratio(s) for ILS. This matter also is addressed in § 4 of Report 929 in light of compatibility between the broadcasting service in the band of about 87-108 MHz and the aeronautical services operating in the band 108-136 MHz.

For the purpose of this Annex, interference mechanisms producing an aberration of the localizer course line of 5 μ A or greater have been defined to be harmful interference; however, in view of the factors mentioned above this value is subject to amendment.

3. Interference mechanisms

Several modes of interference were established by mathematical analysis and confirmed by laboratory tests using several airborne equipments conforming to ICAO standards.

3.1 Interference from an unmodulated carrier signal

Type I – If an unwanted signal is within the ILS localizer receiver RF passband and beats with the localizer carrier signal to produce a difference frequency within about 0.5 Hz of the 90 Hz or 150 Hz ILS sideband signals, the unwanted RF signal field strength must be as low as 46 dB below the localizer carrier level in order not to exceed the 5 μ A limit.

Type II – If an unwanted signal is within the ILS localizer receiver RF passband and beats with the localizer carrier signal to produce a difference frequency within about 10 Hz of the 90 Hz and 150 Hz ILS sideband signals, but not within the Type I tolerance, above, the unwanted RF signal field strength must be as low as 26 dB below the localizer carrier level in order not to exceed the 5 μ A limit.

Type III – If any unwanted signal is within the ILS localizer receiver RF passband with sufficient strength, there will be a progressive "capturing" of the receiver. In this case the unwanted RF signal field strength must be as low as 7 dB below the localizer carrier level in order not to exceed the 5 μ A limit. Very strong signals, in the order of 10 mV or stronger, will cause receiver blocking and cross-modulation.

3.2 Interference from a modulated carrier signal

Type IV – If an unwanted signal contains a carrier with 20% amplitude modulation by a 90 Hz or 150 Hz component, the unwanted RF signal field strength must be as low as 13 dB below the localizer carrier level in order not to exceed the 5 μ A limit. Such an unwanted signal, for example, can arise from the use of 3-phase rectification of a 50 Hz alternating current power supply.

4. Conversion to absolute signal-in-space field strength

Annex 10 to the Convention on International Civil Aviation specifies several signal conditions within the service volume of an ILS, and one of the relevant conditions near the runway threshold is that for facility performance category III localizers, the minimum field strength along the localizer course line shall not be less than 200 $\mu\text{V/m}$. Using this value of minimum field strength, the maximum absolute signal-in-space field strength of an unwanted signal near the runway threshold can be determined as shown in Table I:

TABLE I

Type of interference	Unwanted/wanted ratio (dB)	Field strength of unwanted signal near the runway threshold ($\mu\text{V/m}$)
I	-46	1
II	-26	10
III	-7	90
IV	-13	45

5. Other factors

The preceding paragraphs have developed unwanted/wanted ratios with respect to harmful interference to the ILS localizer, but it is noted that certain operational and statistical factors could affect the practical application of these ratios. For instance, the effects caused by the Doppler shift of frequencies due to the speed of an aircraft, or the probability that an unwanted signal will meet the precise characteristics necessary to cause the particular interference mechanism, have not been taken into consideration, and attention is drawn to the fact that these, as well as other, factors need further study. However, it is relevant to note that the field strengths of unwanted signals shown in § 4, above, in the worst case could imply very severe emission limits on potential interfering sources near aerodrome aircraft approach paths. For example, an emission causing the Type I mechanism would need to be limited to a maximum e.i.r.p. of -95 dBW (3.3 $\mu\text{V/m}$, measured 30 m from the source), in order not to cause harmful interference to an aircraft flying at an altitude of 100 m above the source.

6. Summary and conclusion

The ILS localizer system is susceptible to certain types of interference. Further study is required to determine whether the practical effect of the described mechanisms are in any way alleviated by operational and probabilistic factors.

It is important to note that this Annex examines only those interference mechanisms where the unwanted signal appears within the RF passband of the ILS localizer receiver. There are other known mechanisms, such as intermodulation in ILS localizer receivers, which do not fall within this category. Studies relative to these mechanisms are continuing.

ANNEX II

CONSIDERATIONS FOR SHARING BETWEEN
AERONAUTICAL FLIGHT TEST TELEMETRY STATIONS
AND SPACE AND EARTH STATIONS IN THE
FREQUENCY BANDS 1435 TO 1535 MHz AND 2310 TO 2390 MHz

1. Introduction

Frequencies for aeronautical flight test telemetry are considered in the mobile service.

Flight test telemetry is important to its users because:

- it frequently is necessary for the safety of the pilot and the aircraft;
- it provides the only good record of the nature of a failure that may have caused an accident, thus, it contributes to the safety of future flights;
- it is a daily tool in evaluating the progress of each flight and the performance of the vehicle being tested. The costs of each flight hour may be measured in tens of thousands of dollars. Telemetry significantly reduces the number of hours required to develop the aircraft, or a sub-system of the aircraft.

Because flight test telemetry is vital to its users, telemetry flights should operate without harmful interference. To achieve this end, all telemetry operations are scheduled. The formality of the scheduling varies from area to area of the country, based upon the number of licensees and the number of aircraft each licensee operates. Each geographical area has its own scheduling procedure. For example, in southern California where several telemetry systems share the band on a co-channel and adjacent-channel basis, the scheduling procedure is highly formalized and hour-by-hour schedules are developed to preclude interference. In other areas where a single licensee is isolated either geographically or by frequency separation, the scheduling becomes an informal procedure within the licensee's own organization. However, even under these ideal conditions there are more test vehicles than frequencies and the scheduling must be done.

Technically important aspects about a flight test telemetry station are:

- The bandwidth requirements of each flight and each aircraft installation often vary widely from one another. Emissions from 500KF9 to 3M00F9 are typical. Occasionally emissions of 10M0F9 are authorized.
- Typically, most aircraft or small missiles will have only one telemetry transmitter, however, some aircraft and many spacecraft will be equipped with two or more transmitters that typically have independent transmissions.
- Power output from each transmitter typically ranges between 1 and 65 W into antenna systems that are intended to be omnidirectional, but which in reality contain deep nulls.
- Communication paths frequently require that reliable signals from minimums in the aircraft antenna pattern be received at 150 to 200 km. Frequently, the antenna on aircraft and spacecraft will be well engineered to provide good null-free operation in the most optimum directions for normal flight profiles; however, installations in one-of-a-kind test programs may not be so engineered. In either case, abnormal attitudes encountered in roll, pitch, and yaw manoeuvres may present the nulls in the antenna patterns of the aircraft or spacecraft to the ground antenna. In the event of aircraft or spacecraft failure, this abnormal condition may occur at the most important period of the flight for those engineers and technicians who must analyse the data from the test.

Thus, the signal strength analysis that is considered in this paper will necessarily be the worst-case situation. Interference from any other source during this worst-case situation could cause the data to be totally lost or useless.

Telemetry ground antenna installations vary widely. Simple installations in geographically isolated areas may use some stacked vertical omnidirectional arrays for reception of signals from aircraft flying near the receiver site. Usually they will employ some directive antenna arrays which may be simple horns with about 30° beam-widths, but more often become sophisticated parabolic or helical arrays with automatic tracking. A substantial portion of these sites employ two-axes tracking systems and parabolic reflectors from 2.5 to 10 m in diameter. Larger parabolas become excessively massive for the tracking systems to maintain the test aircraft in the beam under manoeuvring conditions, and beam distortion because of the excessive gravitational forces on the dishes becomes a problem. The use of low-noise receivers is not uncommon. Frequently, the systems are located on mountain tops and track below the local horizon as well as above it, with capabilities of tracking through the

zenith if necessary. Typically, such antennas are calibrated by using quiet space as a reference. The atmospheric noise floor of -204 dB (W/Hz) measured at 290 K, a 4 kHz bandwidth (commonly used as a CCIR reference bandwidth for such purposes), a zero dB signal-to-noise ratio in the receiver IF section, a receiver noise figure of 4 dB referred to the input, and a (9.144 m) (30 foot) diameter antenna (such an antenna has a measured gain of 38 dBi) and an effective aperture correction of 25 dB (corresponding to an approximate frequency of 1.5 GHz) combine to give an atmospheric noise flux level of $-177\text{ dB (W/(m}^2 \cdot 1\text{ kHz))}$. The system can be expected to operate with an FM capture ratio of 16 dB to 19 dB. Therefore, the system will be designed to operate at flux densities of $-161\text{ dB (W/(m}^2 \cdot 4\text{ kHz))}$. Extraneous co-channel signals, such as from a satellite must be at lower levels than $-177\text{ dB (W/(m}^2 \cdot 4\text{ kHz))}$ at the Earth's surface assuming the satellite can be in the field of view of the receiving telemetry ground station.

Telemetry standards commonly specify that spurious emissions from telemetry transmitters must be at levels lower in amplitude than -55 dB (W/3 kHz) . These are conducted or equivalent radiated standards. Converting them to the basis of CCIR practice, this becomes approximately $-54\text{ dB (W/(m}^2 \cdot 4\text{ kHz))}$ if an isotropic radiator is assumed. Although this value exceeds the receiver noise floor for the receiving system, above, by 123 dB, usually the geographic separation of the transmitter from the receiver will be sufficient to guarantee that the receiver will not be adversely effected. The tracking antenna will provide about 33 dB of the required protection, and, since the interfering source can be expected to be on a flight ramp or runway that may be screened by a hill or removed from the runway by more than 5 km, the required protection will be supplied. This spurious emission standard cannot be used as a level of signal that would assure non-interference to the telemetry system.

Table II shows the range of parameters that can reasonably be used by a transmitter for flight test telemetry:

TABLE II

	Range of values to be expected in telemetry systems	
	Low values	High values
Gain, transmitting antenna (airborne) (dBi)	1.7	6
e.i.r.p. (dBW)	-3	18
Gain, receiving antenna (dBi)	2	41
Aircraft transmitter. Beamwidth ⁽¹⁾	360° × 30°	30° × 30°
Ground station. Beamwidth ⁽²⁾	360° × 30°	1.4° × 1.4°

⁽¹⁾ The beamwidth for airborne antenna is referenced to the aircraft vertical axis.
⁽²⁾ The beamwidth of the ground station is referenced to a tracking antenna (high gain) direction of maximum gain. It is usually a receiving antenna, but may be a transmitting antenna.

The current state of the development of aircraft and spacecraft continues to require frequencies for flight testing of both manned and unmanned vehicles. The altitudes of flights for such vehicles vary from a few metres to several hundred kilometres. The range varies from a few hundred metres to earth orbit. The primary distinction between the mobile service used for flight test and the other services where aeronautical or space telemetry equipment is used is the purpose of the transmission. The mobile service is used when the testing of the vehicle is the primary purpose of the flight. Other services are indicated when the primary purpose of the flight is research (atmospheric or space exploration, earth exploration) or operation of the vehicle. The equipment used for telemetering in the different services is often similar or even the same equipment. In cases where continuous data collection is required for an extended period of time, the use is generally not considered to be flight test and therefore, the frequency assignment is made in a band reserved for operational use and frequencies subject to daily or hourly scheduling are not authorized.

2. Interference from a satellite to telemetry ground stations

In Section 1 above, the flux density at the receiver site that will generate harmful interference has been considered. The figure, $-177 \text{ dB (W/(m}^2 \cdot 1 \text{ kHz))}$, will cause the telemetry system to lose range and receiving margin required when the aircraft is at the edge of a test range, which may be at some great distance or some high altitude. The position of the tracking antenna, whether looking at satellite or looking away from it, could introduce a 33 dB or greater signal variation, based upon whether the main lobe or the minor lobes of the antenna encounter a satellite signal.

2.1 Geostationary satellites: Geostationary satellites may be out of view of any particular telemetry receiving site. However, depending upon their longitudinal position, the satellites can appear at local elevation angles up to 39° above the horizon at 48° latitude or up to 55° at 30° latitude. Such angles are clearly possible for telemetry currently in heavy use. It can be shown that even a 30° horn connected to a low noise receiver could suffer interference problems from satellites that have been proposed to operate in these bands. Thus, the $-177 \text{ dB (W/(m}^2 \cdot 4 \text{ kHz))}$ can be assumed to be the level of co-channel receiver-site flux that could be allowed for non-interference of unscheduled satellite transmissions. Since this level is that of quiet space, it is not likely that it would be satisfactory to the satellite system designer.

2.2 Satellites with near-earth orbits: Satellites that are in non-geostationary orbit will progressively traverse the view of every telemetry ground receiving facility. The only way to achieve protection from co-channel operations for the telemetry ground station is by scheduling all transmissions from the aircraft and from the satellite. This requirement would make some data memory systems (for example, tape recorders and computer memories) and some control or command systems for the control of the transmitter on board the satellite necessary. Scheduling would have to be controlled through the same mechanisms/organizations that are used by the mobile service (aeronautical flight test telemetry), with the added complication that the satellite may be seen from several scheduling areas simultaneously. This added requirement could require significant and costly changes to the scheduling organizations and the equipment used for communication between the present areas. Earth exploration satellites authorized in current regulations in the 1525-1535 MHz band, if implemented, would present this kind of scheduling problem in Region 2, although both the mobile service and earth exploration services are secondary to space operations (telemetry) allocations.

2.3 Satellites with near-earth equatorial orbits: Such satellites would present the same problem as geostationary satellites, in that telemetry ground receiving sites would be likely to have their primary antenna lobe intercept the satellite position. This would occur several times a day. Their low altitude compared to the geostationary satellite may hide them from some high latitude receiving sites, but it would also provide less free-space attenuation of their signal. They would, therefore, interfere with telemetry at low latitudes and scheduling and a control system would also be required for co-channel sharing.

3. Interference to satellite receivers due to transmissions from airborne telemetry stations

Generally, the characteristics of satellite-borne receivers and the satellite orbits are not defined well enough to specify in this document the expected degradation in the presence of telemetry signals. Abnormal attitudes of aircraft during stalls, spin tests, or other specific manoeuvres will require consideration at the receiving satellite of the primary beam of the aircraft antenna pattern. Therefore, the e.i.r.p. of the signal from the aircraft could be as great as 24 dBW. The signal could be concentrated at a discrete frequency for short periods of time, but would more usually be spread as an FM signal with modulation index between 1 and 5 and a bandwidth of between 650 kHz and 9 MHz. The altitude of the telemetry transmitter could be from the Earth's surface up to orbital altitudes. The combination of transmitter, antenna, and modulation scheme may be designed for one-time usage and depend heavily on equipment availability. It may not be the optimum design from a communications engineer's viewpoint. It can be seen that unless coordination and scheduling are accepted by all licensees of the band, interference is highly probable.

4. Interference to satellite receivers due to transmission from telemetry ground stations

Telemetry ground station antennas are usually considered to be for receiving purposes only. There is no regulation to this effect, and up link telemetry signals have limited use. The limited bandwidth of the available spectrum, in addition to causing crowding and the demand for more spectrum, is causing innovative systems to be placed upon the aircraft. These systems require data up links to control the data collection process or telemetry up links to combine data on the ground with data collected on-board the airborne vehicle. These systems provide significantly higher field strengths at the satellite than the airborne telemetry systems discussed above. There are not presently enough such systems to give typical power outputs, but the signal strength that is required will be

larger for the aircraft receiving station than the ground receiving station. This is because the airborne receiver will not contain the cryogenic elements required for low-noise receivers, and temperature variation, vibration aboard the aircraft, etc., will rule out many techniques used to produce low-noise receivers.

5. Conclusions

In the 2.3 GHz band, the allocated terrestrial services can share by using the different frequency management techniques already discussed, i.e. scheduling, different frequency assignments, terrain shielding, etc. On the other hand, satellite operations in the same bands with the mobile service will encounter mutual interference with co-channel telemetry users unless all licensees accept a requirement for scheduling. The introduction of continuously transmitting satellites into this scheduling environment would place a severe hardship on telemetry licensees by enlarging the interference areas. The operating organization and communications systems required to establish a single scheduling organization would be costly to all licensees. Practical considerations suggest that such a scheduling procedure would be very difficult to achieve.

Co-channel frequency assignments for the satellite and mobile services are only practical when satellites do not transmit in the space viewed by telemetry receiving sites or when a single scheduling organization can be employed to prevent harmful simultaneous use of a frequency.

Consequential to the frequency allocations of the WARC-79, it is recognized that the maritime mobile-satellite service will require the band 1530-1535 MHz by 1990 and that the space operation service may require the band 1525-1530 MHz after January 1, 1982.

ANNEX III

SOME RADIONAVIGATION SYSTEMS NOT INCLUDED IN ANNEX 10 TO THE ICAO CONVENTION (CHICAGO, 1944)

1. Introduction

A number of commonly used radionavigation systems are employed throughout the world by operators of civil aviation aircraft.

Such systems, when used for navigation of the aircraft, could be subject to harmful interference. Therefore, for the sake of completeness, they are noted in this Annex.

2. Loran-C, Omega and Decca Navigator

Although Loran-C, Omega and Decca Navigator radionavigation systems have been used primarily by mariners, a large number of aircraft operators currently rely on these systems.

Loran-C can provide a position-fixing accuracy of better than 500 m with a repeatability of 18-90 m but its coverage area is geographically limited. A similar performance is provided by Decca Navigator.

Omega can provide reliable world-wide coverage with an accuracy of about 10 km due to its propagation characteristics and phase stability.

Such services require protection from harmful interference. Report 915 discusses the required protection criteria for Loran-C.

3. Satellite radionavigation systems

3.1 A number of satellite radionavigation systems are at the proposal stage or in the course of introduction and will be available to land, marine and aeronautical operators.

3.2 Currently available systems include TRANSIT and GPS (global positioning system) and they provide a position-fixing service. TRANSIT predictable accuracy is 500 m (single frequency) and GPS predictable accuracy will be 100 m or better. As the number of satellites increases in the GPS system the continuity of the service will increase. GPS will also provide ground speed information.

3.3 Signal processing techniques are employed in the satellite receivers to alleviate many types of interference; however, further studies of satellite radionavigation interference protection criteria are required.

REPORT 928

**OPTIMUM CODING AND MODULATION METHOD(S) FOR THE
TRANSMISSION OF DIGITAL DATA BETWEEN TERRESTRIAL
STATIONS AND AIRCRAFT STATIONS OPERATING IN THE
AERONAUTICAL MOBILE (R) SERVICE**

(Question 46/8)

(1982)

1. Introduction

This Report describes the principal features of a bi-directional digital signalling and data communication system which may be employed in the aeronautical mobile (R) service high frequency (HF) bands allocated to that service.

2. Discussion

For many years the unique requirements of aviation have been partially satisfied by the International Civil Aviation Organization (ICAO) selective calling (SELCAL) system. SELCAL, however, provides signalling only in the ground-to-air direction and does not offer the capability for digital data transfer. The recent introduction within several States of more effective and economical management of aircraft movements dictate transition to a modern, standardized bi-directional system. Hence, the international aviation community has conducted experiments to define an improved system to fulfil the requirements of this new operating philosophy. The experiments and experience have indicated more effective use of the available radio frequency spectrum and enhanced integrity of the vital aeronautical safety service can be achieved.

3. Operational requirements

New operational requirements are evolving in many countries to conserve energy and human resources. A system designed to fulfil these needs must satisfy the following basic requirements:

- provide bi-directional signalling for the management of voice communications;
- support more timely and reliable communications and data processing for the automatic exchange of aircraft operating information;
- ensure continued capability to use SELCAL during introduction of the new system.

4. System functions

The specific functions required in a system to meet the foregoing operational requirements include the following:

- signalling for air-to-ground voice communications management;
- signalling for ground-to-air voice communications management;
- identification and location of aircraft initiating air-to-ground signalling;
- identification of the ground station the aircrew wishes to contact;
- identification by the ground station of the SELCAL code or digital address of the aircraft;
- identification of a specific party on the ground with which the crew member desires to converse;
- ground system establishment of a voice communication channel for transmitting safety and regularity of flight communications between the aircrew and desired party on the ground without operator intervention. This capability also may be used for ground-to-air originated voice requests;
- acquire and transmit data from the aircraft on-board system, or sub-system, using digital data transmission without aircrew intervention;
- rapidly transmit information and data related to aircraft safety or other emergency information, without continuous aircrew interaction;
- process digital data transmitted from aircraft for expeditious resolution of action required (if any) by the ground system or personnel;
- notify aircraft, as required, of unusual circumstances which may affect the aircraft safety well in advance of the impending condition(s).

5. System description

Fundamental characteristics of this digital system are as follows:

- voice and calling signals share a common frequency;
- asynchronous data transmission; and,
- two possible methods of modulation and encoding are described in § 7 below.

6. Message elements

6.1 Signalling messages

Signalling messages typically include combinations of the following elements:

- identity of the ground station processing the call;
- identity of the called party;
- SELCAL code of the calling aircraft (air-to-ground only);
- flight number, airframe registration mark or other prescribed identification of the called or calling aircraft;
- geographical position of the calling aircraft (air-to-ground only).

6.2 Digital data messages

Digital data messages typically include the following elements:

- flight number, airframe registration mark or other prescribed identification of the aircraft originating or receiving the message;
- a technical acknowledgement of the last message received by the transmitting terminal indicating whether or not the message was received free of errors;
- coded identification of content and/or desired handling of the text of the message being transmitted;
- message text.

7. Modulation and encoding

Two possible methods of modulating and encoding digital data for transmission in the aeronautical mobile (R) service have reached various stages of development; however, further study of this subject is needed. The two candidate methods of modulating and encoding digital data are as follows:

7.1 One system uses audio frequency shift keying signals to modulate the RF carrier. The tones are interleaved. Theoretical studies conducted by the Radio Technical Commission for Aeronautics, with participation of other international experts, have shown a four-tone system as described below in Table I to be an appropriate method of modulation for HF signalling and data.

TABLE I

Mark		Space	
f_1	935		
	x x x x x x x x x x		
f_2		1375	
		x x x x x x x x x x	
f_3	1815		
	x x x x x x x x x x		
f_4			2255
			x x x x x x x x x x

7.2 Another method of modulating and encoding digital data employs the four-signature coding system.

To meet both the requirements of a separate signature for the “1”, “0” and to differentiate between successive bit positions, four separate signatures can be deployed as in Table II:

TABLE II

		Bit order					
		1	2	3	4	5	6
		1	0	0	0	1	1
Signature 1	Even “1”						×
Signature 2	Odd “1”	×				×	
Signature 3	Even “0”		×		×		
Signature 4	Odd “0”			×			

It can be seen that alternate bits are separately coded and that each bit can be separately identified. If separate detectors for each of the four signatures are used some distinct advantages emerge. The advantages are as follows:

- each “1” and “0” is transmitted and detected as a signal in its own right, thus a “1” corrupted by noise will not be mistaken as an “0” because of its absence, as in the case of a single detector, which must assume an “0” unless a “1” signal is received;
- the break-up of a signal due to noise will not be mistaken as a number of separate bits of information;
- redundancy of signal can be employed, giving a higher probability of communication. Any resulting time variation due to the detection of the signature can be accommodated in the receiving equipment;
- an effective error detection facility is a feature of the coding procedure;
- simple and foolproof receiving equipment can be built, using the properties of the code to permit three-state statistical processing.

7.2.1 Interaction of encoding and hardware

Binary information is usually received and stored in two-state registers e.g., in core storage. A problem arises of how to deal with the residue of the previous message, either both the “1s” and the “0s” must be presented to the bi-stable or the register must be cleared to the “1” or the “0” state. In both cases, the register is biased before receiving the incoming information. Should information fail to be detected or there be a malfunction in the input equipment to the register, an error may be produced. It can be seen that the receiving register is an extension of the detecting apparatus and the argument for having separate detectors for each of the four signatures must be extended into the register itself.

By careful design of a three-state register, many of the problems of bit allocation and error detection disappear. The three-state register that is being referred to should not be confused with a tri-stable having three voltage levels. It is a three-wire system, each wire carrying a two-state signal which is either on or off.

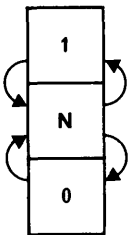


FIGURE 1

N = Nothing

The normal conditions of the bi-stable, i.e. "1" and "0", are still present but there is a third state of "nothing" or no information. The logic conditions are chosen such that the three-state can change from "nothing" to the "1" or "0" state, or it can form the "0" or "1" to the "nothing" state but there is no way in which it can change from a "1" to an "0" or from an "0" to a "1" (see Fig. 1). Input signals from the detectors are connected to those three-state devices.

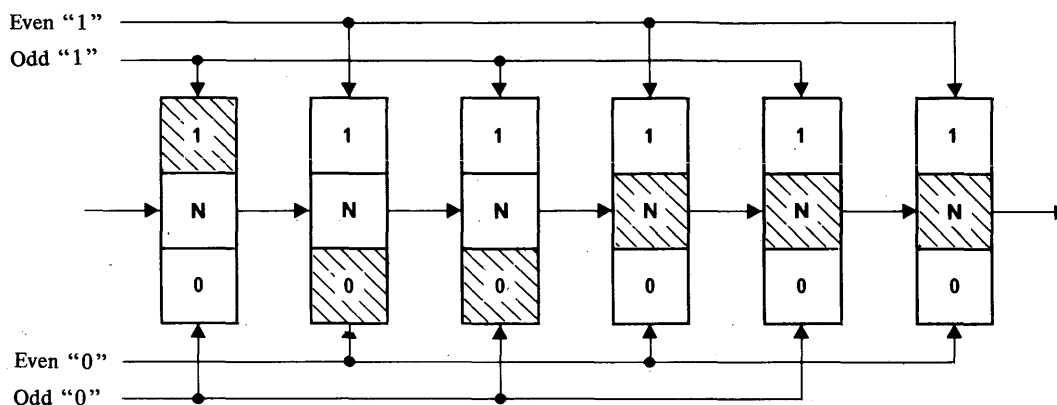


FIGURE 2

N = Nothing

It should be noted that the detector outputs are connected directly to the three-states. Each stage is connected to its predecessor so that any stage in the "nothing" condition forces the succeeding stage also into the "nothing" condition and hence cannot carry information, i.e. a "1" or an "0". Thus to clear the register of any residual information a pulse is applied to the "nothing" input of the first stage, which forces the second stage to the "nothing" condition. This signal will now propagate through the register, turning each stage to the "nothing" condition. To check that the register is cleared it is only necessary to look at the last stage to see that it is in the "nothing" state. Had there been a malfunction of any of the three-states due to component or connection failure, then "nothing" would not have propagated to the last stage and would not be detected, (see Fig. 2).

Having cleared out the previous data, the register is now ready for the reception of new data. On receiving the first bit of the message shown in Table II which is an odd "1", the first stage would be turned from the "nothing" to a "1" condition. This odd "1" signal will also try to change each of the other odd stages to the "1" condition but as the previous even stages are in the "nothing" condition no other three-state can support information. Should there be a number of separate pulses on the odd "1" input line which might be caused by break-up of the signal, or two odd "1s" in succession with the even bit missing due to the detector being unable to make a decision through the noise, only one bit will be registered. Later a decision will be taken on which of these two cases applied.

Following Table II, the second piece of information to be received will be an even "0". This will be registered in the second three-state as an "0". The second three-state can support information as its predecessor is no longer in the "nothing" condition. Note, no other succeeding even three-state is able to support the incoming "0" signal.

The third piece of information to be received will be the odd "0". This will operate on the third three-state only. The signal trying to force the first three-state into the "0" state will not succeed because of the logic condition that the three-state cannot change from a "1" or an "0" or an "0" to a "1".

The even "0", which is the fourth bit of information, will act both on the second and fourth stages. As the second stage is already at "0" the input of another signal is of no concern.

7.2.2 Error detection

Knowing the number of bits that are being transmitted, missing bits of information can be detected by looking at the condition of the last three-state which should have been filled. Should this be in the "nothing" condition, then obviously data must be missing.

Should an odd and even signal be detected at the same time, overflow will occur. Such errors can be detected by seeing that there are n and not $n + 1$ bits (or more) in the message. In addition, if an odd "1" or an odd "0" (or an even "1" and an even "0") are detected simultaneously, the error may be detected by a gate and a bi-stable. In practice this system has been found to give a very high order of integrity.

The remaining problem to be solved is how to detect the end of the message. Since each bit is received non-synchronously, the receiving equipment would be waiting for further information when the message ends. One possible solution would be to use an over-ride timer which is reset as each incoming piece of information is detected. When the timer has run down, the input signals to the register could be gated out and the error detecting criteria applied. Such a method of detecting the end of the message would in fact restrict the use of the system. A better solution to the problem is presented later.

7.2.3 Message characteristics

Messages to be transmitted by such a system fall into the two following categories: messages of dependent data, and messages made up of independent components. A good example of dependent data is an air traffic control position report. This may take the form of an address (aircraft registration), latitude, longitude and height [Parker, 1967; Russell-Smith and Parker, 1969]. It is most important that the whole of this message be received correctly as an error in any part may invalidate its usefulness. For security, error detection should be applied over the entire contents of the message.

Messages consisting of independent components are typical in a teletype system where a long message can occur. When receiving such information, it is undesirable to apply error detection over the entire message as a single error would necessitate retransmission. Each character of the message must be treated individually and reliance placed on the error correction and/or redundancy existing within the printed word and sentence. It is therefore desirable that the encoding system under discussion be capable of handling the short blocks of binary information forming the characters.

7.2.4 Reception of clear text

Clear text is received in two separate registers, each having the same number of stages as the bits in a character, plus an overflow stage for error detection. The four information lines, odd "0", even "0" and odd "1" and even "1" are connected to both registers as in the previous discussion (see Fig. 3). Two control lines, B1 and B2 determine the register which will operate at any time and these are fed from detectors which detect two additional "inter-block" signatures.

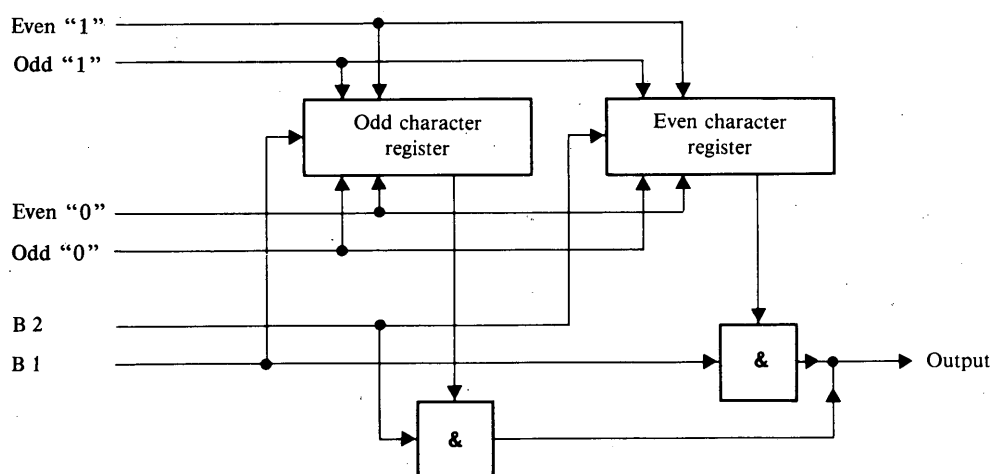


FIGURE 3

One register handles the even characters and the other the odd characters. There are now six input signals instead of four. At the beginning of the message a signal will clear the odd register to its "nothing" condition, after which, the odd and even bit information will be entered into the register. When all the data forming the first block has been completed, a signal on B2 sets the even character register to the "nothing" condition and releases the contents of the first register for error detection. When the second register (even character register) is filled, a signal applied to B1 will clear the odd register ready for further data and release the contents of the second register for error detection.

7.2.5 Inter-block markers

Unfortunately, the process described in § 7.2.4 increases the number of signatures required from four to six at the expense of time, and bandwidth or reliability.

There are four invalid combinations of information signatures which could generate errors. They are:

- an odd "0" immediately followed by an odd "1";
- an odd "1" immediately followed by an odd "0";
- an even "0" immediately followed by an even "1";
- an even "1" immediately followed by an even "0".

To avoid an increase in bandwidth whilst retaining the same reliability as with the four-signature system these combinations of signature can be used in place of the inter-block markers, B1 and B2, in Fig. 4. The hardware is simplified but some increase in message transmission time is incurred.

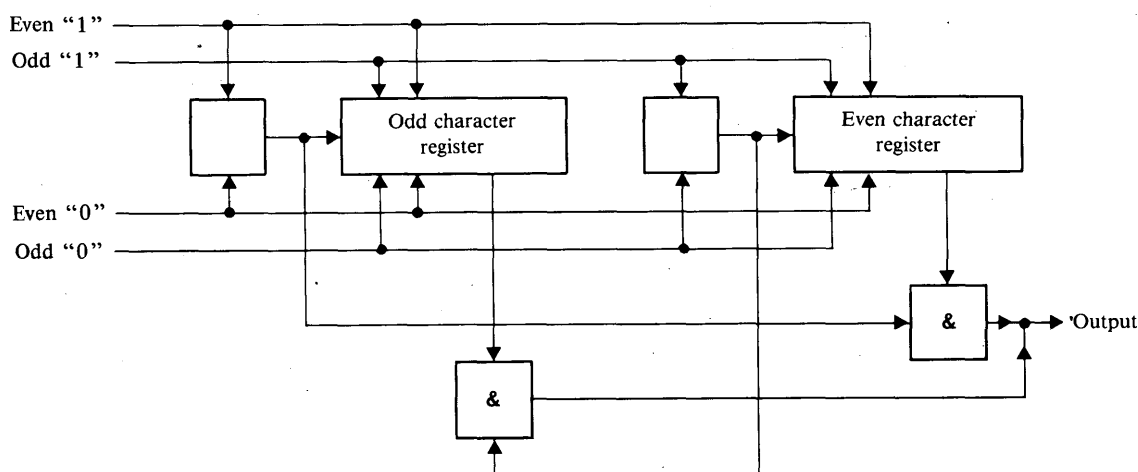


FIGURE 4

The use of four signatures for inter-block markers in this way is completely compatible with the rest of the data-encoding system. If the inter-block markers appeared within a character the error-detecting circuits would reject the character. Should information appear during the inter-block period no inter-block marker would be detected. These inter-block markers can also be used to determine the end of a message making the use of a timer unnecessary.

Using these techniques a building-block approach to digital communications is possible, each data block having an independent integrity check. A message may start with an address and format control, technical acknowledgement etc. This may be followed by a message such as a position report or clear text with error detection over the whole. Alternatively, a combination of address and dependent data blocks or clear-text with individual error-checking may be transmitted and received.

7.2.6 Modulation methods

For this method of coding and when using current airborne HF SSB equipment, it would be advantageous to use frequency-shift keying of a subcarrier which would then amplitude modulate the RF carrier — thus ensuring compatibility with the conventional DSB system. However, there could be advantages in the use of two-frequency “chirp” modulation (i.e. two frequencies “up” and two frequencies “down” for the four signatures) in any future developments.

8. Character encoding

Message characters may be encoded in accordance with the International Standards Organization (ISO) Alphabet No. 5, including the use of odd parity.

9. Message formats

The basic signalling message format may consist of the following elements: Prefix, Mode, Ground Address, Party Address, Airline Identification, and Suffix. The Prefix consists of the ISO Alphabet No. 5 “SOH” (Start of Header) character. The mode character contains the numeric character one, “1”, which identifies the HF signalling format for ground processing. This character is used as a discriminant in voice/data signal path switching within the ground station. The ground address field contains a three-character alpha identifier of the ground station through which communications is desired. The party address field contains the two-character numeric which identifies the station with whom voice communications is desired. The ground address and party address characters are entered by air control panel action. The airline identification is derived automatically from the aircraft installation. The Prefix, Mode and Suffix characters are permanently stored in the avionics equipment. The Suffix character consists of the ISO Alphabet No. 5 control character “ETX” (End of Text). The foregoing basic message format may be summarized in Table III.

TABLE III

Element	Number of characters	Example
Prekey	1	8 bits
Prefix	2	SOH
Mode	1	1
Ground address	3	NYC
Party address	2	12
Airline identification	2	TW
Suffix	1	ETX

The foregoing basic signalling message format may be expanded by means of additional alpha/numeric character sequences. The format expansion will necessitate appropriate changes to the data entry facilities of the aircrew's control unit. The basic format and typical example of format expansion are as follows:

Basic format:

SOH	MODE	NYC Address	12 Ground Party	TW Airline Identifier	ETX

Format expanded to include provision for a ten-digit telephone number:

SOH	MODE	NYC	12	212 456 7890 Telephone Number	TW	ETX

Note. — The telephone number may be entered without the first three characters (area code); however, the field should then be filled with leading zeros.

Format expanded to include Flight Identification:

SOH	MODE	NYC	12	TW	0403 Flight Identification	ETX

Format expanded to include SELCAL Code:

SOH	MODE	NYC	12	TW	0403	EFCD SELCAL Code	ETX

Format expanded to include Flight Sector:

SOH	MODE	NYC	12	TW	0403 (Note)	EFCD	 6 or 12345 Sector	ETX

Note. — This numeric field must be present since it delimits and separates the two alpha fields... Contents may be zeros.

The expanded message format may be configured to individual user requirements by the use of alternating alpha/numeric data element fields. The data message format consists of the following elements: Prefix, Mode, Aircraft Address, Technical Acknowledgement, Label, Uplink Block Identifier (ground-to-air only), Start of Text, and Suffix. The Prefix consists of Prekey and the ISO Alphabet No. 5 "SOH" characters. The Mode Field contains the numeric character "2". The Aircraft Address field contains the registration mark or flight number of the aircraft (up to 7 alpha/numeric characters). The Technical Acknowledgement Field contains the ISO Alphabet No. 5 "ACK" (Acknowledgement) and "NAK" (Negative Acknowledgement) character depending upon whether or not the message being technically acknowledged was received error-free. The Label Field contains two alpha/numeric characters which are used to define the content and/or the desired handling of the information contained in the text field of the message. The Up link Block Identifier Field contains coded information which enables the aircraft sub-system to identify duplicates of messages. The start of Text Field contains the ISO Alphabet No. 5 "STX" character. The Text Field contains up to 220 characters of alpha/numeric data (the text of the message). The Suffix Field contains the ISO Alphabet No. 5 "ETX" (End of Text) character.

Note. — Conditions pertaining to patent matters in § 7.2 of this Report are on file with the CCIR (see Doc. 8/561, 1978-82).

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RECOMMENDATION 591-1 *

**COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND OF ABOUT
87-108 MHz AND THE AERONAUTICAL SERVICES IN THE BAND 108-136 MHz****

(Question 61/8)

(1982-1986)

The CCIR,

CONSIDERING

- (a) that high-powered FM broadcasting service operations in close geographic proximity to aerodrome facilities are at times incompatible with airborne ILS, VOR and VHF communications equipment utilizing those facilities, and that this is a widely recognized problem among many users of aviation facilities in the Northern Hemisphere of ITU Region 2 and parts of Region 1;
- (b) that in accordance with RR No. 44, the aeronautical radionavigation service is "A radionavigation service intended for the benefit and for the safe operation of aircraft";
- (c) that FM broadcasting transmitters employ power levels which are relatively much higher than aeronautical services transmitters;
- (d) that aeronautical radionavigation and communication receivers have varying degrees of signal sensitivity and susceptibility to interference;
- (e) that high power broadcasting transmissions may cause interference to airborne receivers, depending upon relative distance between the transmitter and receiver;
- (f) Recommendation No. 704 of the World Administrative Radio Conference (Geneva, 1979) (WARC-79) which addresses potential interference problems between the FM broadcasting service and the aeronautical radionavigation service;

UNANIMOUSLY RECOMMENDS

1. that administrations be invited to advise the broadcasting and aviation communities of the potential FM broadcasting and aeronautical systems incompatibility problem;
2. that administrations develop or, where applicable, strengthen coordination procedures between the aviation and broadcasting communities to minimize future problems;
3. that Report 929 be used as the best available guidance to date on the above matters.

* The Director, CCIR, is requested to bring this Recommendation to the attention of the International Civil Aviation Organization (ICAO) and Study Groups 1 and 10.

** This band will be expanded to 137 MHz by 1 January, 1990.

REPORT 929-1 *

**COMPATIBILITY BETWEEN THE BROADCASTING SERVICE IN THE BAND
OF ABOUT 87-108 MHz AND THE AERONAUTICAL
SERVICES IN THE BAND 108-136 MHz****

(Question 61/8)

(1982-1986)

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* The Director, CCIR, is requested to bring this Report to the attention of Study Group 10 and to the International Civil Aviation Organization (ICAO).

** This band will be expanded to 137 MHz effective 1 January, 1990.

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1. Background and introduction

1.1 Frequency modulation (FM) broadcasting service interference to airborne instrument landing systems (ILS) localizer, VHF omnidirectional radio range (VOR) and VHF communications equipment (see Note) is a widely recognized problem among users of aviation facilities. In Region 2, the FM broadcasting service operates in the 88-108 MHz band and has caused interference problems in the adjacent VHF aeronautical services band 108-136 MHz. In Region 1 the FM broadcasting band has been expanded up to 108 MHz, and therefore administrations in that Region may experience interference problems.

Note. — For a description of the ILS, VOR and VHF communications systems, attention is drawn to Report 927.

1.2 In air/ground communication receivers, this interference problem ranges from nuisance background FM broadcasting audio to distorted and garbled reception. In airborne ILS localizer and VOR receivers, the interference problem ranges from nuisance background FM broadcasting audio to errors in course deviation and flag operation. The interference to these navigation receivers is thought to be the more serious problem, as an error in course deviation, especially during the critical approach and landing phase, is not as readily evident to the pilot as the disruption of communications.

1.3 The level of interference to aircraft receivers is usually most severe at airports having major FM broadcasting facilities nearby, and the interference varies with the type of aircraft and associated navigation and communication (NAV/VOM) equipment. The problems experienced are the result of factors such as:

- FM broadcasting stations operate with high-power levels of up to 100 kW e.r.p., whereas aeronautical facilities such as air/ground communication transmitters and ILS localizers operate at low-power levels, in the order of 0.02 kW e.r.p.
- Spurious emissions from FM broadcasting stations.

- The susceptibility of existing airborne receivers to this form of interference. ICAO has addressed the problem of high-powered, adjacent-band FM broadcasting interference and has produced new interference immunity standards for airborne receivers in Annex 10 to the Convention on International Civil Aviation applicable as of 1998.
- Lack of a guard-band between the highest assignable frequency for FM broadcasting and the lowest assignable radionavigation frequency.

There is an increasing probability of harmful interference due to the growing need for additional aeronautical frequency assignments and the growing number of FM broadcasting applications for new frequencies, power increases and relocation.

2. Types of interference mechanisms

2.1 *Type A interference*

2.1.1 *Introduction*

2.1.1.1 In the normal operation of broadcast transmitters, type A interference may arise in two ways. First, a single transmitter may generate spurious emissions or several broadcast transmitters may intermodulate to produce terms in the aeronautical frequency bands; this is termed type A1. Second, the side bands of a broadcasting transmitter may include non-negligible components in the aeronautical bands; this mechanism, which is designated type A2, will in practice arise only from transmitters having frequencies near to 108 MHz.

2.1.1.2 From the viewpoint of the aviation receiver, the spectral characteristics of the unwanted signal are of particular significance. To a first approximation, the effects of modulated FM broadcasting signals are likely to be “noise-like” in the receivers, with a consequential reduction in the wanted operational performance of aviation receivers.

2.1.1.3 In addition, adverse effects in the ILS/VOR audio (identification) channel can occur.

2.1.1.4 However, if unmodulated broadcast transmission were to produce stable frequency components close to the ILS modulation signal frequencies (e.g. ± 15 Hz of the modulation frequencies 90 Hz and 150 Hz) then highly significant interference could occur even at very low levels of unwanted signals (see Report 927).

2.1.2 *Type A1 interference*

Variously described as “in-band” or “on-channel”, caused by spurious emissions (including intermodulation products) from the broadcast transmitter station. This is generally a low-level effect and can be regarded as harmful interference, as defined in the Radio Regulations, in cases where the level is sufficient to affect the performance of avionics receivers. No rejection can be provided at the airborne receiver. Suppression at source, the choice of broadcast assignment, and/or distance separation are the only practical solutions.

2.1.3 *Type A2 interference*

Interference to ILS channels near to the 108 MHz band edge due to out-of-band emissions from broadcasting stations operating on carrier frequencies in the upper end of the broadcasting band.

2.2 *Type B interference*

2.2.1 *Introduction*

2.2.1.1 Mechanisms producing this type of interference can occur due to radiations from broadcast transmitters outside the aeronautical band. Their incidence depends on a number of factors which include:

- the very large power differentials between the two services;
- the wide variability of the geometry between the aircraft, the aviation ground transmitters and the FM broadcasting transmitters;
- the susceptibility of the aviation receivers (which varies from receiver to receiver and which also depends on the frequency separation between wanted and unwanted signals);
- the installed aviation system differences (particularly antenna radiation pattern and feeders);
- the FM broadcasting station antenna radiation pattern.

2.2.1.2 The airborne receiver, designed to work in a low-power environment and needing to detect small wanted input signals, cannot easily cope in the presence of an unwanted signal close in frequency and at a very much greater power level (perhaps higher by 80 dB or more).

2.2.1.3 The two main interference mechanisms involved are receiver-generated intermodulation (B1) and receiver desensitization (B2). It is important to note that these are separate mechanisms with separate characteristics.

2.2.2 *Type B1 interference*

Intermodulation generated in an airborne receiver as a result of the receiver being driven into non-linearity by a high-powered broadcasting signal outside the aeronautical band. In this case at least two broadcasting signals need to be present and they must have a frequency relationship which, in non-linear combination, can produce an intermodulation product within the wanted RF channel in use by the airborne receiver. One of the broadcasting signals must be powerful enough to drive the receiver into regions of severe non-linearity but interference may then be produced even though the other signal(s) may be significantly less powerful.

Perhaps the most serious practical aspect of this mechanism from the frequency planning viewpoint is that an acceptable existing situation involving FM broadcasting signals at non-critical levels can be transformed into a practical problem by, for example, the addition of a new broadcasting station or an increase in power at an existing broadcasting station.

2.2.3 *Type B2 interference*

Desensitization or "front-end overload" which occurs when an airborne receiver RF section is overloaded by a single (or multiple) broadcasting transmission outside the aeronautical band. The effect arises because the RF selectivity of airborne receivers is relatively wide-band and it is difficult to provide sharp RF "cut-off" immediately below 108 MHz.

3. **Assessment criteria and techniques**

3.1 *Introduction*

3.1.1 Some of the coordination procedures presented in this part of the Report reflect the technical criteria developed by Interim Working Parties 8/12 and 10/8 and the Regional Administrative Conference for FM Sound Broadcasting in the VHF Band (Region 1 and certain countries concerned in Region 3) (Geneva, 1982 and 1984). However, noting that the CARR-1(2) assessment criteria have not been universally adopted, information is presented on other assessment methodologies being applied in various parts of the world.

3.2 *Regional Administrative Conference for FM Sound Broadcasting in the VHF Band (Region 1 and certain countries concerned in Region 3) – CARR-1(2) (Geneva, 1984)*

3.2.1 *Introduction*

3.2.1.1 The decision of the World Administrative Radio Conference (Geneva, 1979) to generally extend the VHF/FM broadcasting band to 108 MHz, puts broadcasting and aeronautical radionavigation services in adjacent frequency bands. That this might lead to problems of interference, was recognized in the agenda of the Regional Administrative Conference for FM Sound Broadcasting in the VHF Band (Region 1 and certain countries concerned in Region 3), First Session (CARR-1), (Geneva, 1982) to determine the technical constraints to be used in planning the new band for the broadcasting service.

3.2.1.2 To further study the compatibility situation, Joint Interim Working Party 8-10/1 met in May, 1984 and prepared a consolidated report which outlined the possibilities and techniques for improving suppression of intermodulation products at broadcast transmitting stations, dealt with aspects of the necessary protection ratios for the aeronautical radionavigation receivers, and presented future improvements of the immunity of airborne radionavigation equipment to interference from FM broadcasting stations. It also described some procedures that may be used to better assess interference situations in general or in special circumstances.

3.2.1.3 With technical criteria provided by the JIWP 8-10/1 and submission of contributions from administrations to this Conference, compatibility criteria and assessment criteria were agreed. Compatibility between the FM broadcasting frequency plan and the existing frequency plan for the aeronautical radionavigation service was not fully studied. Also, no compatibility tests with the aeronautical mobile (R) service were performed. Incompatibilities identified with the aeronautical services were not taken into account in all cases when selecting FM broadcasting frequencies.

Coordination procedures agreed are based upon the following technical characteristics.

3.2.2 *Coordination contour around the test point of an aeronautical radionavigation station*

3.2.2.1 The coordination contour is defined by the projection on the Earth's surface of circles around each test point of the radionavigation station to be protected, with a radius as defined in § 3.2.2.2 and 3.2.2.3. Broadcasting stations outside the coordination contour were considered as being unlikely to affect the service provided by the aeronautical radionavigation station concerned and were therefore disregarded.

3.2.2.2 For types A1, A2 and B2 interference the radius is 125 km.

3.2.2.3 For type B1 interference the radius is 500 km.

3.2.2.4 Only broadcasting stations which are in line-of-sight of the test point concerned were taken into account.

3.2.3 *Test points*

The calculations were limited to four test points only. These test points were chosen by the administration concerned in accordance with the conditions described in § 3.2.3.1 and 3.2.3.2.

As the number of test points is insufficient, the administrations concerned may introduce additional test points for future coordination between administrations.

3.2.3.1 *Instrument landing system (ILS)*

Points A, B, C and D are defined in Fig. 1. In some cases, the height of test point A differed from that indicated in Fig. 1.

3.2.3.2 *VHF omnidirectional range (VOR)*

The four cardinal points (N, E, S and W) of the circle forming the boundary of the service area at a height of 1000 m above the VOR were chosen as test points by certain administrations. Other administrations preferred four other test points (with different locations or heights, or both), which they considered more significant.

3.2.4 *Polarization*

No account was taken of polarization differences between the broadcasting and the aeronautical radionavigation signals except in special cases (e.g. circular polarization of the broadcasting signal).

The interfering signals were assumed to have the same polarization (vertical or horizontal) as the navigation system. If, instead, the broadcasting station has a different polarization, there is in theory some reduction of received interfering signal levels, but it was agreed in this case, not to make any allowance. In cases, however, where an equal power in the other plane of polarization is added at the transmitter (e.g. circular polarization), an allowance was made by adding 1 dB to the effective radiated power of the polarization component in the same plane as that used by the navigation system.

3.2.5 *Protection criteria for ILS and VOR*

Annex 10 to the Convention on International Civil Aviation contains specifications and characteristics relevant to the protection of both ILS and VOR.

3.2.5.1 *Wanted signal*

The minimum field strength to be protected is:

- ILS: 40 $\mu\text{V/m}$ (32 dB($\mu\text{V/m}$)),
- VOR: 90 $\mu\text{V/m}$ (39 dB($\mu\text{V/m}$)).

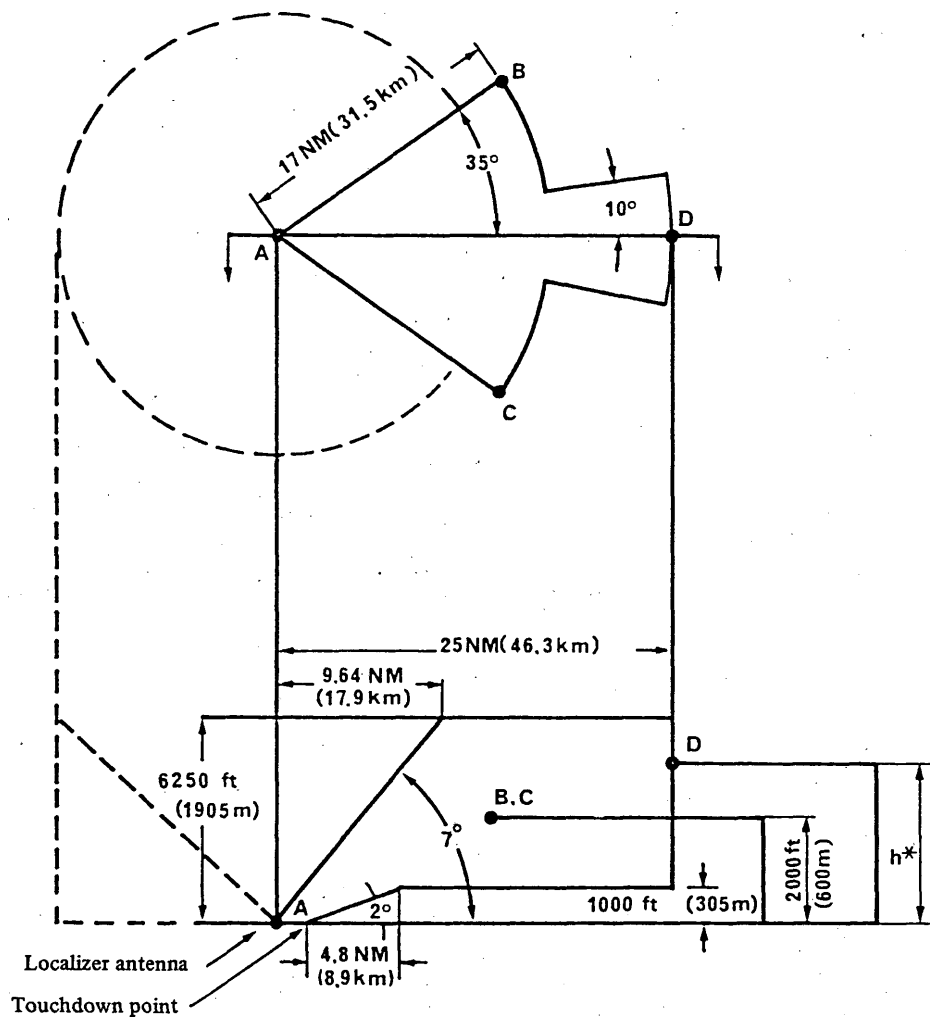


FIGURE 1 – ILS localizer protection volume

- : Limits of the ILS back-beam protection volume
- (A, B, C, D): test points for the ILS localizer
- h*: altitude indicated by the administration
- NM: nautical miles

3.2.5.2 Principles of calculation

The field strength of every broadcasting station in the band 87.5-108 MHz inside the coordination contour and within line-of-sight of a test point of an aeronautical radionavigation station was calculated at this test point as an interfering signal.

For types A1 and A2 interference this field strength was compared with the minimum field strength to be protected of the wanted signal, as indicated in § 3.2.5.1.

For type B1 interference the relevant intermodulation formulae were applied.

For type B2 interference the broadcasting signal level was compared with the maximum permitted level.

Where applicable, the field strength, E , was converted to signal power, N , at the receiver input according to the following formula:

$$E \text{ (dB}(\mu\text{V/m))} = N \text{ (dBm)} + 118 + L_s + L(f)$$

where:

L_s : system fixed loss of 3.5 dB;

$L(f)$: system frequency-dependent loss at frequency, f , of 1 dB per MHz from 108-100 MHz and then 0.5 dB per MHz below 100 MHz.

3.2.5.3 A1 interference

3.2.5.3.1 Protection ratio

A protection ratio of 17 dB was assumed, including a small safety margin in order to take account of multiple interference entries resulting from different broadcast transmitters.

3.2.5.3.2 The field strength of the interfering signal at the test point was calculated on the basis of the following level of the spurious component (in the case of several transmitters contributing to one spurious component – see category 3.2.5.3.3 (a) – the most powerful transmitter is taken as the reference in the calculation):

- 40 dB below the transmitter e.r.p., for transmitter e.r.p. below and equal to 2.5 W;
- 250 μW e.r.p. for transmitter e.r.p. above 2.5 W and below 79 kW;
- 85 dB below the transmitter e.r.p. for transmitter e.r.p. equal to and above 79 kW.

An antenna gain of 10 dB was assumed in defining the levels given above.

The levels of the spurious emission given above are valid in the band 108-137 MHz.

3.2.5.3.3 For the analysis of type A1 interference, the following two categories of spurious emissions exist:

- (a) spurious emissions resulting from an intermodulation process caused at the transmitter site, e.g. by multiple transmitters feeding the same antenna;
- (b) spurious emissions with the exception of those covered by (a).

Where the actual frequency of the spurious emission is known, Table I gives the values of protection ratio to be used for frequency differences up to 200 kHz from radionavigation transmitters. Type A1 interference need not be considered for frequency differences greater than 200 kHz.

TABLE I

Frequency difference between spurious emission and wanted signal (kHz)	Protection ratio (dB)
0	17
50	10
100	– 4
150	–19
200	–38

In the computer analysis during the Conference, the worst case was assumed for category 3.2.5.3.2, i.e. a spurious component coinciding with the aeronautical frequency under consideration.

3.2.5.3.4 During the Conference, no analysis was made for category 3.2.5.3.3 (a) due to lack of data.

3.2.5.4 Type A2 interference

The protection ratio values are given in Table II.

TABLE II

Frequency difference between wanted signal and broadcasting signal (kHz)	Protection ratio (dB)
150	-41
200	-50
250	-59
300	-68

A frequency difference less than 150 kHz cannot occur. For frequency differences greater than 300 kHz, this type of interference need not be considered.

3.2.5.5 Type B1 interference

Third-order intermodulation products of the form:

$f_{intermod} = 2 f_1 - f_2$ (two-signal case) or

$f_{intermod} = f_1 + f_2 - f_3$ (three-signal case)

with $f_1 > f_2 > f_3$,

generated in the airborne ILS or VOR receiver will cause an unacceptable degradation of receiver performance, if $f_{intermod}$ coincides with, or is close to, the frequency of the wanted signal and the inequalities given below are fulfilled subject to the conditions in § 3.2.5.5.4.

Intermodulation of the second order is irrelevant and intermodulation of a higher order than three has not been considered.

N_1 , N_2 and N_3 in the inequalities below have the following meaning:

N_1 : level (dBm) of the broadcasting signal of frequency f_1 (MHz) at the input of the aeronautical radionavigation receiver;

N_2 : level (dBm) of the broadcasting signal of frequency f_2 (MHz) at the input of the aeronautical radionavigation receiver;

N_3 : level (dBm) of the broadcasting signal of frequency f_3 (MHz) at the input of the aeronautical radionavigation receiver.

$\max \{0.4; 108.1 - f\}$ in the inequalities below has the following meaning: either 0.4 or $108.1 - f$, whichever is greater.

3.2.5.5.1 Two-signal case

$$2 \left(N_1 - 20 \log \frac{\max \{0.4; 108.1 - f_1\}}{0.4} \right) + N_2 - 20 \log \frac{\max \{0.4; 108.1 - f_2\}}{0.4} + 120 > 0$$

3.2.5.5.2 Three-signal case

$$\begin{aligned} & N_1 - 20 \log \frac{\max \{0.4; 108.1 - f_1\}}{0.4} + \\ & + N_2 - 20 \log \frac{\max \{0.4; 108.1 - f_2\}}{0.4} + \\ & + N_3 - 20 \log \frac{\max \{0.4; 108.1 - f_3\}}{0.4} + 126 > 0 \end{aligned}$$

3.2.5.5.3 Frequency offset conditions

Before applying the formulae given in § 3.2.5.5.1 or 3.2.5.5.2, a correction is applied to each signal level which is a function of the frequency difference between the wanted signal and the intermodulation product; this correction is given in Table III.

$$N_{1,2,3} \text{ (corrected)} = N_{1,2,3} - \text{correction term}$$

TABLE III

Frequency difference between wanted signal and intermodulation product (kHz)	Correction term (dB)
0	0
± 50	2
± 100	8
± 150	16
± 200	26

For frequency differences beyond ± 200 kHz, type B1 interference need not be considered.

3.2.5.5.4 Trigger and cut-off values

The trigger value is the minimum power level at the input to the airborne ILS or VOR receiver considered necessary for a broadcasting signal to initiate the generation of intermodulation products which are potentially of sufficient power to exceed the receiver interference threshold. The trigger value for each contributing broadcasting signal of frequency, f , at the ILS or VOR receiver input was derived from the following formula:

$$N = -42 + 20 \log \frac{\max \{0.4; 108.1 - f\}}{0.4}$$

The cut-off value is the minimum power level at the input to the airborne ILS or VOR receiver considered necessary for a broadcasting signal to contribute to the non-linear process which results in the formation of an intermodulation product potentially of sufficient power to exceed the receiver interference threshold.

For the compatibility analysis, a cut-off value of 12 dB below the trigger value was chosen.

An intermodulation analysis was therefore carried out only if at least one signal was equal to or above the trigger value provided that the other signal or signals were equal to or above the cut-off value.

3.2.5.6 Type B2 interference

Table IV contains maximum permitted levels of broadcasting signals at the input to the airborne ILS or VOR receiver.

TABLE IV

Frequency of broadcasting signal (MHz)	Level (dBm)
107,9	-20
106	-5
102	5
≤ 100	10

For intermediate values, the maximum permitted level was determined by linear interpolation.

3.2.6 Limits relating to aeronautical radionavigation services

The aeronautical radionavigation services of another administration need not be considered if the distance from the sound broadcasting station to the nearest point on the boundary of that administration is more than 500 km.

3.2.7 Separation distances for compatibility

3.2.7.1 Table V gives the maximum separation distances between a test point of the radionavigation station to be protected and a sound broadcasting station at which the protection criteria for A1, A2, B1 and B2 types of interference are all met. The more critical requirements are those for A1 and B1; the higher of the two separation distances is shown in each case.

TABLE V — Maximum separation distance (km) between a test point of a radionavigation station and a sound broadcasting station required for coordination purposes

Effective radiated power of broadcasting station		Broadcasting station frequency (MHz)					
		≤ 100	102	104	106	107	107.7-107.9
(dBW)	(kW)	Separation distance (km)					
55	300	40	53	99	245	500	500
50	100	22	31	57	141	302	500
45	30	20	20	31	77	166	494
40	10	20	20	20	45	96	285
35	3	20	20	20	24	52	156
30	1	20	20	20	20	30	90
25	0.3	20	20	20	20	20	49
20	0.1	20	20	20	20	20	29
≤ 15	0.03	20	20	20	20	20	20

3.2.7.2 The A1 distances assume the protection ratio for frequency coincidence, and that the level of the broadcasting transmitter spurious emissions conform to the level given in § 3.2.5.3.2. The B1 distances ensure that the signal level is below the cut-off value as given in § 3.2.5.5.4 with free-space propagation, but are subject to an upper limit of 500 km due to the practical considerations of the line-of-sight limit, in conformity with § 3.2.4.

3.2.7.3 Where two or more assignments are used at a common site, the highest e.r.p. must be taken.

3.2.7.4 Linear interpolation shall be used for e.r.p. (dBW) and frequency values not appearing in Table V.

3.2.7.5 Preliminary analyses based on these distances assume, in the case of A1 and B1 types of interference, that there is frequency coincidence between a spurious emission or intermodulation product and the frequency of the radionavigation station. When the frequencies of the radionavigation station and of all broadcasting transmitters that may be involved are known, detailed calculations can be made for all types of interference using the data for protection of the aeronautical radionavigation service given in § 3.2.2 and 3.2.5. However, in the case of A1 type interference it will be necessary to check that the transmitter does not generate significant spurious components apart from third-order intermodulation products.

3.2.7.6 Any case-by-case study may take into account other relevant factors such as details of the propagation path between the broadcasting station and the aeronautical test point, and the radiation pattern of the broadcasting antenna in both the vertical and horizontal planes.

3.2.8 *Unresolved matters*

3.2.8.1 Certain unresolved matters were indicated in § 8, general recommendations and are subject to future studies as outlined in § 9.

3.3 *France*

3.3.1 *Introduction*

3.3.1.1 This methodology has been developed in order to remedy the shortcomings of the CARR-1(2) which recognized in its Final Acts that the number of test points was insufficient, as four test points is inadequate, in many cases, to assess the compatibility of ILS and VOR volumes.

3.3.1.2 The basic principle of this method is still to verify compatibility at a number of fixed measurement points using the CARR-1(2) assessment criteria. The advantage of the method is that processing is wholly independent of the number and location of broadcasting stations. It is not necessary to re-calculate the measurement points every time the broadcasting plan is modified.

3.3.1.3 The number of points is high enough to obviate the need for special arrangements for broadcasting stations within the protection space of the aeronautical aid ILS or VOR. Furthermore, the amount of information obtained provides a very accurate idea of the problems that could arise at any point within this space.

3.3.2 *Method*

3.3.2.1 The measurement point distribution applies the concept of a cut-off value (or “limiting value”; see § 4.3.3) the level below which a station can no longer contribute to a type B1 intermodulation product likely to disturb the airborne receiver.

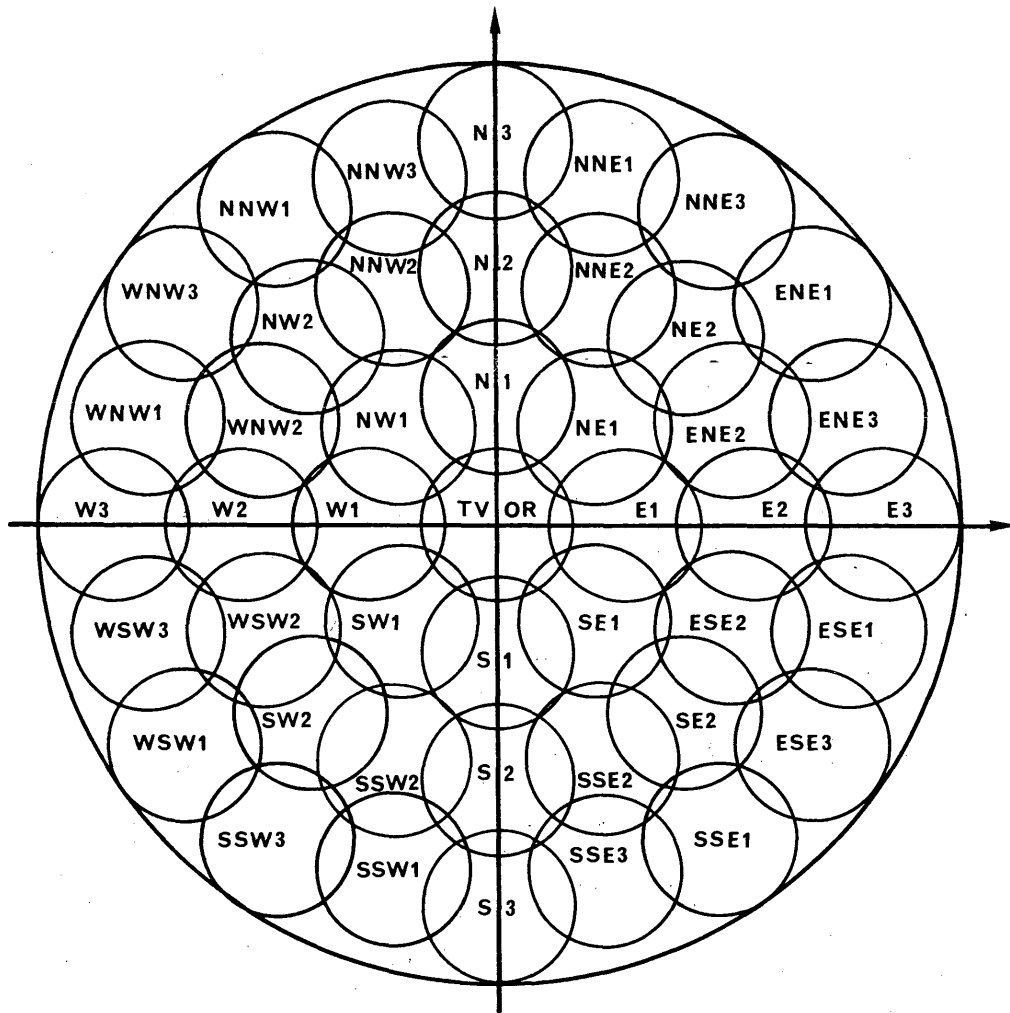
3.3.2.2 With this cut-off value, it is possible to calculate the maximum distance above which a broadcasting station can no longer cause type B1 interference. This distance is used in turn to optimize the distribution of measurement points in order to cover the whole protection space.

3.3.2.3 The results obtained are as follows:

- a) ILS: 14 measurement points are used for ILS analysis. Figure 2 contains a graph showing the proposed distribution. The density of measurement points has been increased for the critical landing area.
- b) For VOR, the ICAO/FCB recommends that it is necessary to distinguish between landing VOR (TVOR), for which the whole area has to be protected, and en route VOR, for which it is sufficient to protect the air routes.
 - TVOR: 45 measurement points spread uniformly throughout the service area, which is circular. The proposed distribution can be seen in Fig. 3 where the operational range is 25 NM.
 - VOR: 50-200 measurement points, depending on the extent and number of routes to be protected in the VOR area in question.
- c) It should be noted that the measurement points can be generated automatically, even for VOR. In the latter case, the air routes are determined by linking the VOR in question to its neighbours and eliminating those routes which are highly improbable.
- d) Figure 4 contains an example of the automatic generation method. It is better to produce more routes than necessary in order to achieve a more thorough protection of the space. If a real route is not delineated by two VORs in line with each other a theoretical VOR can be introduced in the input file in order to produce the route.

3.3.3 *Computer processing*

3.3.3.1 The method described is highly suitable for computer processing. The software developed has the advantage of being both simple and very complete: the choice of a methodology based on the use of fixed measurement points, has the enormous asset of enabling stations to be examined in sequence, which avoids “multi-run” processing and allows a large number of measurement points without any appreciable effect on calculation time. The software developed is at present in use in France and other countries, with data bases of the parameters of broadcasting transmitters and aeronautical stations.



Point	N1	N2	N3	NNE1	NNE2	NNE3	NE1	NE2	ENE1	ENE2	ENE3
ρ (km)	13	26	39	37	26	39	14	27	39	26	37
θ (degrees)	0	0	0	18	24	35	45	45	55	66	73

Point	E1	E2	E3	ESE1	ESE2	ESE3	SE1	SE2	SSE1	SSE2	SSE3
ρ (km)	13	26	39	37	26	39	14	27	39	26	37
θ (degrees)	90	90	90	108	114	125	135	135	145	156	163

Point	S1	S2	S3	SSW1	SSW2	SSW3	SW1	SW2	WSW1	WSW2	WSW3
ρ (km)	13	26	39	37	26	39	14	27	39	26	37
θ (degrees)	180	180	180	198	204	215	225	225	235	246	253

Point	W1	W2	W3	WNW1	WNW2	WNW3	NW1	NW2	NNW1	NNW2	NNW3
ρ (km)	13	26	39	37	26	39	14	27	39	26	37
θ (degrees)	270	270	270	288	294	305	315	315	325	336	343

FIGURE 3 — Distribution of TVOR measurement points

Note. — Test point height in this application is 300 m. This value can be changed as appropriate.

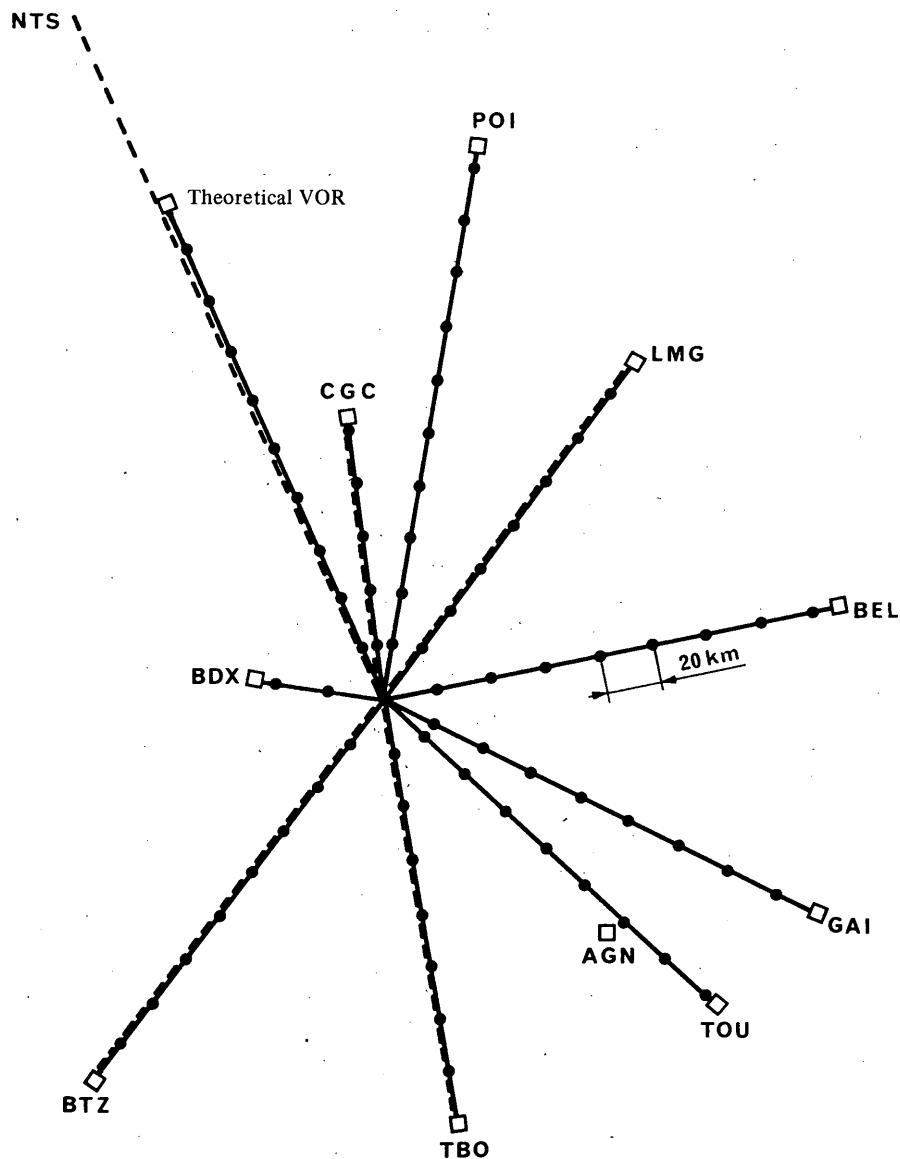


FIGURE 4 – Distribution of VOR measurement points

Example of Sauveterre VOR

- Route generated automatically
- == Actual ICAO route
- Measurement point generated automatically

In addition to the five actual routes (one of which is generated by a theoretical VOR) the programme generates five other possible routes, bringing the total number of measurement points to 73.

Note. — Test point heights in this application are a function of distance but always above the radio horizon.

3.4 United States of America

3.4.1 Type B

In the United States of America, procedures have been developed to evaluate the effect of high-power FM broadcasting stations on airborne VHF communication and navigation systems [Sawtelle and Dong, 1978]. Tests of airborne receivers indicated that at least one strong FM signal (prime signal) was required to force the receiver RF into non-linear operation. Once the receiver was operating in the non-linear mode, the prime signal could mix with other signals 10 to 20 dB lower in level (secondary signals) to produce harmful intermodulation products. Testing of receivers indicated that the minimum prime signal level at the input to the receiver was approximately -10 dBm for airborne communication receivers and -20 dBm for airborne navigation receivers. The minimum secondary signal level for both types of airborne systems was approximately -30 dBm. By assuming a lossless isotropic receiver antenna, no line loss, and free space propagation loss,* contour distances corresponding to received power levels of -10 , -20 , and -30 dBm can be calculated using the following formula:

$$d = \frac{\log^{-1} (e.i.r.p. - P - C - L_R)/20}{f}$$

where:

d : contour radius (nautical miles);

C : 37.8 for d in nautical miles, or 32.4 for d in kilometres;

e.i.r.p.: equivalent isotropic radiated power of the FM broadcasting station (dBm) (e.i.r.p. = e.r.p. + 2.15 dB) including vertical radiation patterns as appropriate;

f : FM centre frequency (MHz);

P : contour power level desired, either -10 , -20 , or -30 dBm;

L_R : avionics antenna out-of-band rejection.

Out-of-band avionic antenna rejection (L_R) can be found as follows:

For a navigation antenna:

$L_R = 3$ dB plus 1 dB/MHz below 108 MHz.

For a communication antenna:

$L_R = 10$ dB for FM signals from 100-108 MHz;

or:

$L_R = 10$ dB plus 2 dB/MHz below 100 MHz for FM signals from 88-100 MHz.

The out-of-band antenna rejection value (L_R) is subject to wide variations which are a function of airborne antennas and installation differences.

Figures 5 and 6 give a pictorial presentation of the interference prediction method using the Venn diagram technique.

3.4.2 Communication example (type B)

In this example, FM station No. 1 is presently operating on 96.5 MHz with 100 kW e.r.p. and is located approximately 30 nautical miles (55.5 km) from the airport. FM station No. 2 is being proposed to operate on 107.9 MHz with 100 kW e.r.p. at a location approximately 3 nautical miles (5.6 km) from the airport. An interfering intermodulation signal is predicted on the airport tower frequency 119.3 MHz ($2 \times 107.9 - 96.5 = 119.3$). The solid circle indicates the -30 and -10 dBm contours for FM stations No. 1 and No. 2, respectively. The cross-hatched area indicates the area where intermodulation interference in avionic receivers is likely within the service volume of the control tower frequency. If the antenna rejection of the airborne communication antenna is considered, the respective interference contours would recede to those shown by the broken circles. In this case intermodulation interference is significant only when the airborne communication antenna provides no rejection of the FM band. Even if FM station No. 1 was not involved, interference could result from the assignment of FM station No. 2 within the service volume of the tower frequency due to receiver front end overload (type B2) or spurious interference (type A1). The method used to predict spurious interference and front-end overload is described in § 3.4.4 and 3.4.5.

* Free space loss closely approximates median transmission loss curves when transmitter and receiver are within line-of-sight (LOS). LOS for an aircraft at about 1500 m (5000 ft) would be a minimum of 87 nautical miles regardless of FM station antenna height.

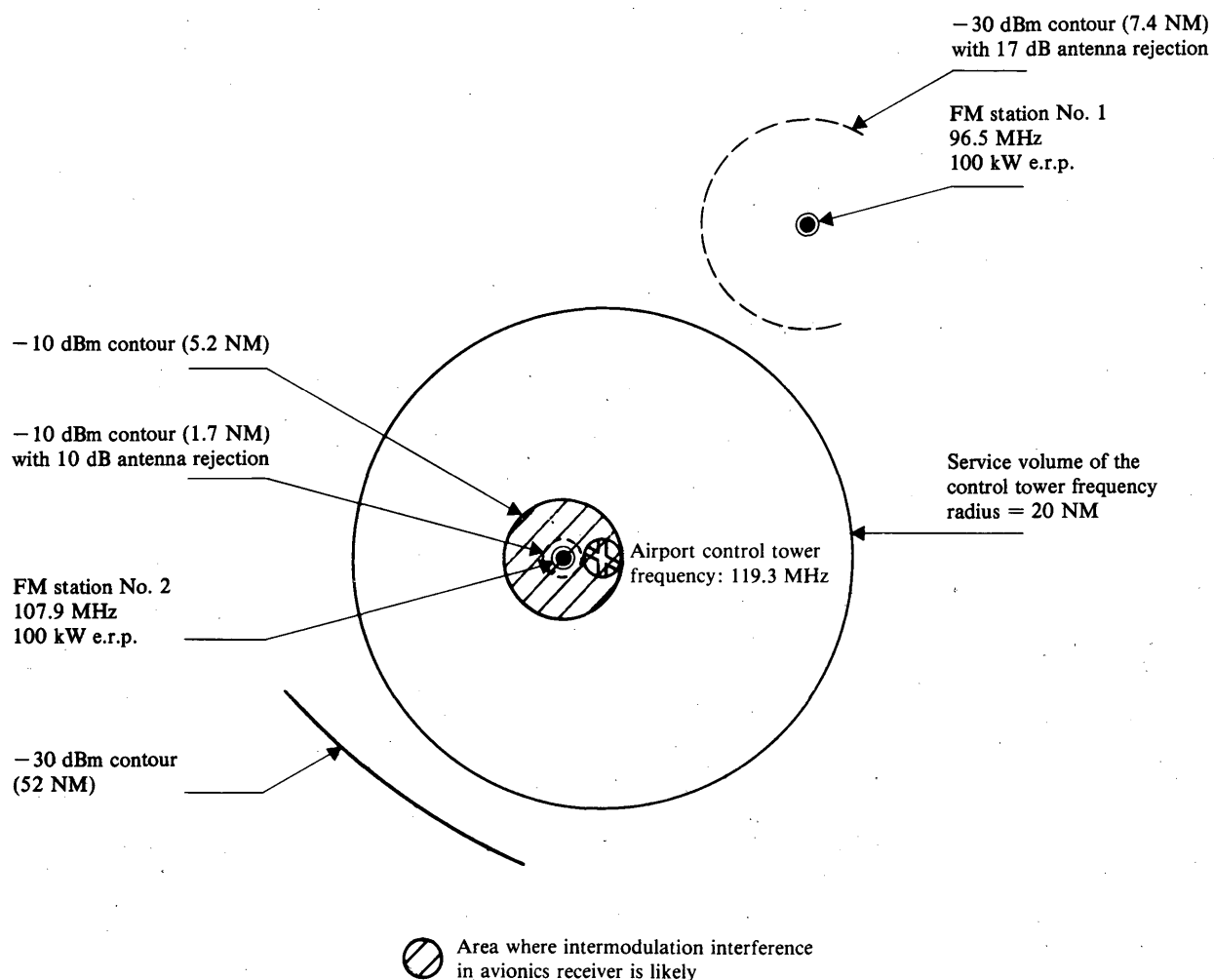


FIGURE 5 - Example of method used to predict interference to communications receivers

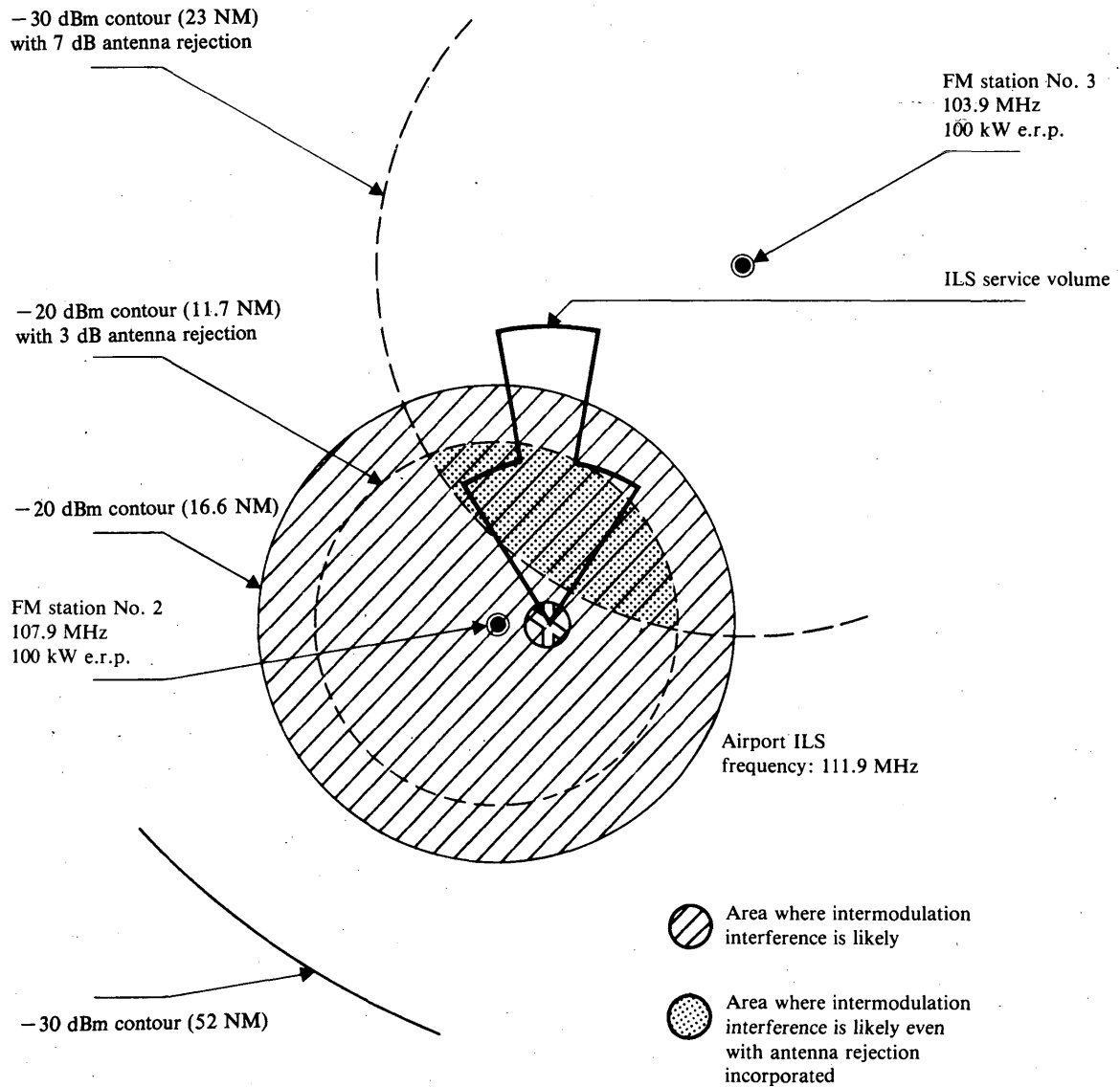


FIGURE 6 – Example of method used to predict interference to navigation receivers

3.4.3 Navigation example (type B)

In this example, the existing FM station operates on 103.9 MHz with 100 kW e.r.p. at a location approximately 25 nautical miles (46 km) from the airport. The affected navigation facility is an ILS localizer operating on 111.9 MHz ($2 \times 107.9 - 103.9 = 111.9$). The service volume of the ILS is indicated by the "keyhole" pattern in Fig. 6. A -20 dBm contour was used as the prime signal level. The intersection of the -30 dBm contour from FM station No. 3 with the -20 dBm contour from FM station No. 3 indicates a wide area of potential intermodulation interference covering most of the localizer service volume (cross-hatched area). Even the application of aircraft antenna rejection would still result in an area of potential intermodulation interference along a critical portion of the ILS approach path (shaded area).

3.4.4 Interference from spurious emissions (type A)

The spurious interference occurs when the receiver responds to components of the FM signal which are introduced into the aeronautical frequency bands, and, thus, within the receiver (IF) response. The major factors involved in calculating interference of this form are the receiver sensitivity, the FM spurious emission limits, and the power (e.i.r.p.) of the FM station. The antenna, filter, and receiver selectivity of the aeronautical systems under these conditions have no effect as the FM spurious emission is an on-frequency interfering signal. Thus, spurious interference to VHF aeronautical systems can occur when: $\text{e.i.r.p.} - L_D - S_R \geq R_S$ and,

where:

e.i.r.p.: equivalent isotropic radiated power of the FM station (dBm) ($\text{e.i.r.p.} = \text{e.r.p.} + 2.15 \text{ dB}$);

L_D : free space transmission loss in dB;

S_R : spurious emission limit in dB below the FM station power;

R_S : receiver sensitivity in dBm.

For FM station No. 2 provided in the Figs. 5 and 6 examples:

e.i.r.p. = 164 kW or 82 dBm (for e.r.p. = 100 kW) including vertical antenna patterns as appropriate;

$L_D = 37.8 + 20 \log (119.3) + 20 \log (3) = 89 \text{ dB}$;

$S_R = 80 \text{ dB}$ (This would represent the worst-case spurious emission level which could be encountered in the United States of America if the spurious emission limitation is 80 dB below the station power on frequencies separated more than 600 kHz from the carrier);

$R_S = -97 \text{ dBm}$ (typical for most airborne receivers).

Therefore: $82 \text{ dBm} - 89 \text{ dB} - 80 \text{ dB} = -87 \text{ dBm}$ which is approximately 10 dB greater than the typical aeronautical receiver sensitivity, therefore, spurious interference is possible under these conditions. If FM station No. 2 in Fig. 5 was moved to a location approximately 9.8 nautical miles (18.2 km) from the airport, or if the power of the FM station was reduced 8 dB, or if the maximum spurious radiation was limited to 88 dB below the fundamental frequency, aircraft receivers and aeronautical ground facilities at the airport would be protected from FM broadcasting spurious interference. Little can be done to protect aircraft flying in the immediate vicinity of a radiating high-power FM broadcasting station antenna as current state-of-the-art aeronautical receivers were not designed to operate in a high-power environment.

3.4.5 Aeronautical receiver overload (mainly type B)

Front end overload or desensitization of an aeronautical receiver occurs when the receiver RF section is driven into non-linear operation by the high-power FM signal. Intermediate frequency selectivity will not provide any protection as the overload occurs in the broadband RF section which will usually respond to most signals in the FM broadcasting frequency band. Tests have shown that an FM signal level of from 0 to -10 dBm at the input of the aeronautical receiver is sufficient to overload the receiver. The example of FM station No. 2 in Figs. 5 and 6 portrays the area of potential interference and illustrates how moving the broadcasting station one mile further away from the aerodrome would protect the airport ILS and control tower frequencies from FM broadcasting interference.

3.4.6 *Conversion to field strength*

In order to provide more meaningful results the airborne receiver input levels used in the above procedure need to be converted into field strength values. In practice such a conversion is known to exhibit considerable variation in values. However, bearing in mind the guidance nature of the coordination procedure presented above, the simple assumption of an isotropic antenna and a loss-less feeder cable has proved adequate in the context.

3.5 *Canada*

3.5.1 *Introduction*

3.5.1.1 Computerized techniques have been developed to permit the plotting of areas of potential FM broadcasting interference to aircraft radionavigation receivers. The interference contours can be based on CARR-1(2) interference assessment criteria or can be tailored to test data gathered on a particular aircraft/receiver combination. These plots are used to provide guidance in the assignment of FM, VOR and localizer frequencies, on a case-by-case basis. For example, these plots may indicate if a more detailed analysis is required (e.g. taking into account the vertical radiation pattern of the FM antenna), or if it is necessary to conduct flight and/or other testing.

3.5.2 *Interference plots*

3.5.2.1 Multi-colour plots can be made directly on aeronautical charts to assist in identifying airways that pass through the areas of potential interference (which is particularly useful for VOR interference assessment). Plots can also be made on service area diagrams, as shown in Fig. 7. This plot shows the area of potential interference for the 2-signal type B1 case: $2(107.9) - 107.1 = 108.7$ MHz. Similarly, Fig. 8 shows areas of potential interference for a 3-signal type B1 case.

3.5.2.2 Plots can be made for type A1, A2 and B2 interference cases, as well as for 2 and 3-signal type B1 interference cases. These plots are made after a detailed computer analysis and print-out has identified those cases of concern.

3.5.3 *Refinement of analysis method*

3.5.3.1 Several computer enhancements are under development. These enhancements, among others, include improved modelling of actual FM broadcast antenna radiation patterns (especially the horizontal patterns) and segmenting the ILS service areas into areas of expected localizer signal levels (rather than using the minimum localizer signal level throughout the service area).

4. *Test results*

4.1 *Introduction*

The work carried out by the CARR-1(2) and the CCIR (Joint Interim Working Party 8-10/1) was based upon a limited number of localizer/VOR receivers currently in use. Sections 4.3 and 4.4 contain the results of new measurements not available to the CARR-1(2).

4.2 *Finland*

4.2.1 *Introduction*

4.2.1.1 Studies and laboratory tests on type B1 interference in ILS-localizer receivers have been performed in Finland. The construction of about 40 receivers was studied and three of those were actually measured. The receivers measured were Collins 51RV 2, Collins 51RV 4B and King KX-175B.

The interference criterion chosen was $\pm 7.5 \mu\text{A}$ change in course guidance current of $90 \mu\text{A}$. Combinations of unwanted signals (f_1 and f_2) were selected to produce an intermodulation product of third order both in the lower end and the upper end of the ILS band. Wanted signal levels were -86 dBm , -76 dBm and -66 dBm .

4.2.1.2 Studies showed that all 40 receivers had front-ends tunable according to the selected ILS frequency.

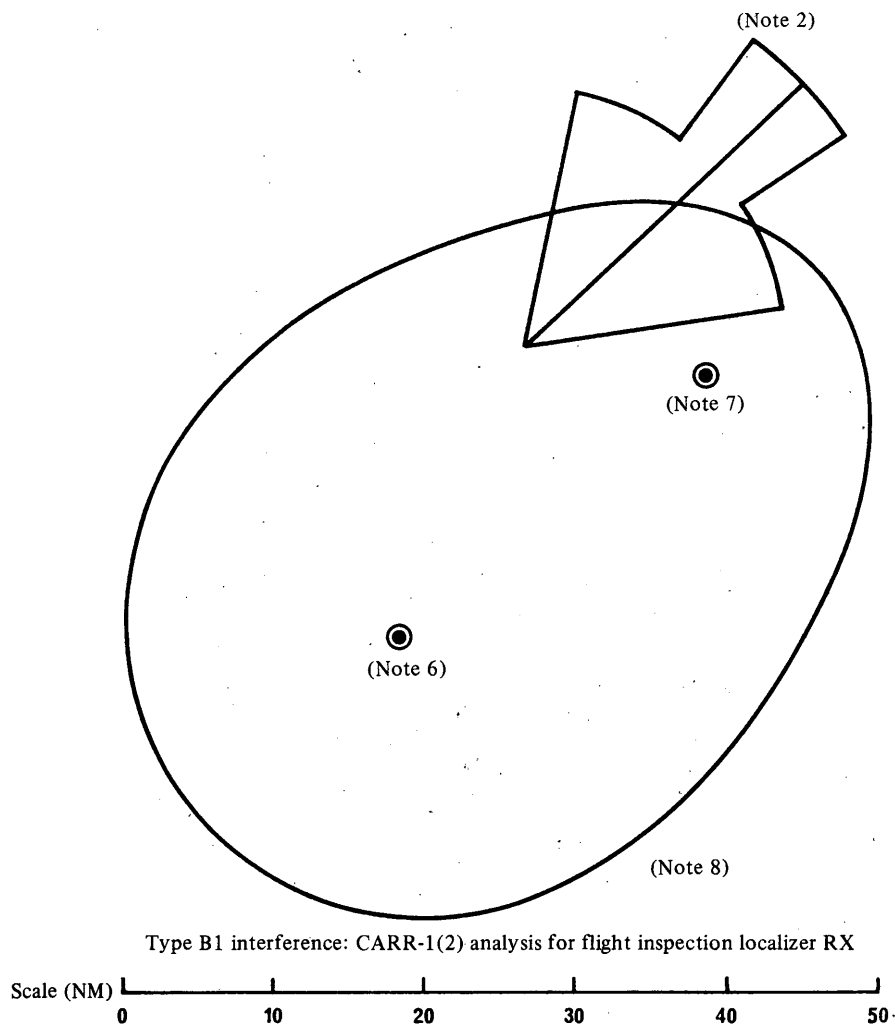


FIGURE 7 – Example of 2-signal type B1 potential interference contour plot

Note 1. – Date of analysis: 13 September, 1985.

Note 2. – Frequency, site and coordinates of ILS under analysis: 108.7 MHz, Toronto, 43° 40' 22", 079° 40' 00", azimuth 47°.

Note 3. – Description of type of analysis (type B1 receiver intermodulation product) and localizer frequency being tested: 108.7 MHz.

Note 4. – Intermodulation product under analysis: $2(107.9) - 107.1 = 108.7$ MHz.

Note 5. – Difference in frequency between localizer frequency and the intermodulation product (IMP) frequency: 0 kHz.

Note 6. – Identification, frequency, site, effective radiated power (e.r.p.) and coordinates of one of the FM stations in the IMP (● indicates the position of the FM station): CING, 107.9 MHz, Burlington, 50 kW, 43° 21' 10", 079° 52' 00".

Note 7. – Identification, frequency, site, e.r.p. and coordinates of the other FM station in the IMP (● indicates the position of the FM station): CILQ, 107.1 MHz, Toronto, 10 kW, 43° 38' 33", 079° 23' 15".

Note 8. – Equation used to plot potential interference contour(s) can be based on CARR-1 (2) criteria or some modification thereof (in this case, the modified equation, i.e. $2N_1 + N_2 + 93 \geq 0$ dBm, is based on data gathered on a flight inspection receiver). This equation and interference contour is plotted around the positions ● of the FM stations; the area of potential interference is inside this contour.

Note 9. – A.R. is the rejection of aircraft antenna system at the two FM broadcast frequencies; it can be based on CARR-1 (2) characteristics or on data gathered on the specific aircraft used for flight testing or any desired characteristic, i.e.:

A.R. = 3.60 dB for 107.9 MHz, and

A.R. = 4.40 dB for 107.1 MHz.

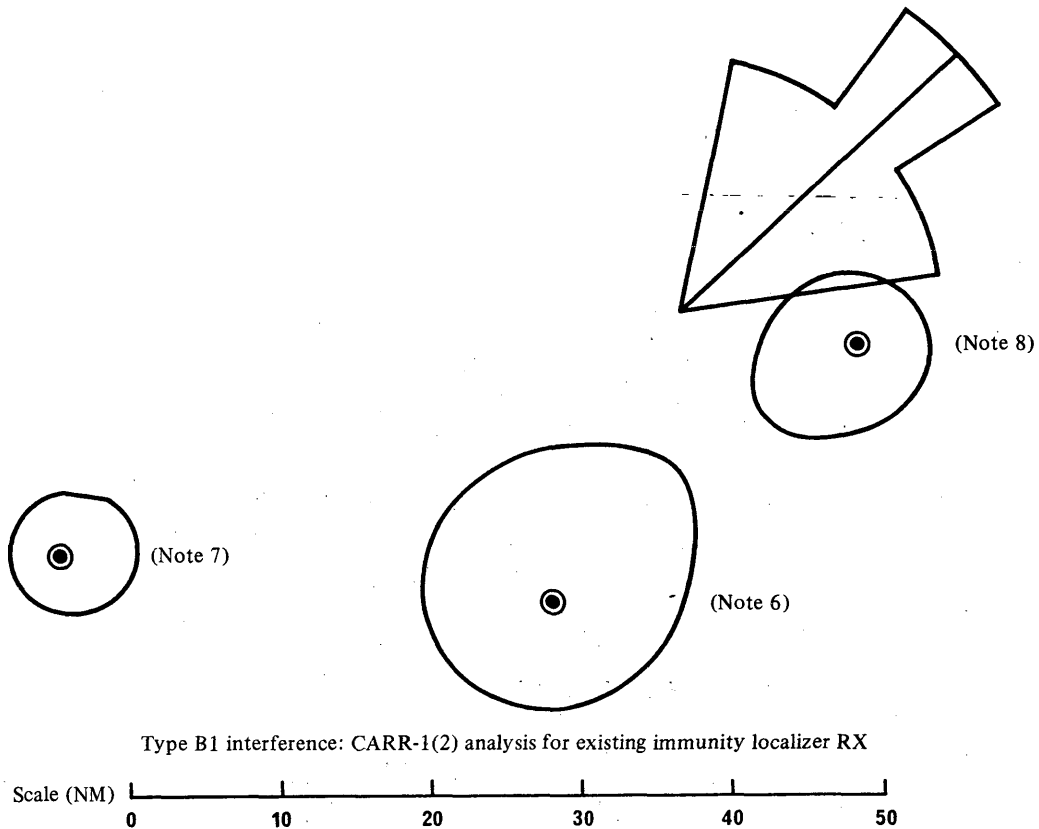


FIGURE 8 – Example of 3-signal type B1 interference contour plot

Note 1. – Date of analysis: 13 September, 1985.

Note 2. – Frequency, site and coordinates of ILS under analysis: 108.7 MHz, Toronto, 43° 40' 22", 079° 40' 00", azimuth 47°.

Note 3. – Description of type of analysis (type B1 receiver intermodulation product) and localizer frequency being tested: 108.7 MHz.

Note 4. – Intermodulation product under analysis: 107.9 + 105.3 – 104.5 = 108.7 MHz.

Note 5. – Difference in frequency between localizer frequency and the intermodulation product (IMP) frequency: 0 kHz.

Note 6. – Identification, frequency, site, effective radiated power (e.r.p.) and coordinates of the first FM station in the IMP (⊙ indicates the position of the FM station): CING, 107.9 MHz, Burlington, 50 kW, 43° 21' 10", 079° 52' 00".

Note 7. – Identification, frequency, site, e.r.p. and coordinates of the second FM station in the IMP (⊙ indicates the position of the FM station): CFCA, 105.3 MHz, Kitchener, 100 kW, 43° 24' 15", 080° 38' 05".

Note 8. – Identification, frequency, site, effective radiated power (e.r.p.) and coordinates of the third FM station in the IMP (⊙ indicates the position of the FM station): CHUM, 104.5 MHz, Toronto, 40 kW, 43° 38' 33", 079° 23' 15".

Note 9. – Interference criterion equation of CARR-1 (2): $N_1 + N_2 + N_3 + 35.99 + 126 \geq 0$ dBm.

Note 10. – A.R. rejection of aircraft antenna system at the three FM broadcast frequencies:

A.R. = 3.60 dB for 107.9 MHz

A.R. = 6.20 dB for 105.3 MHz

A.R. = 7.00 dB for 104.5 MHz.

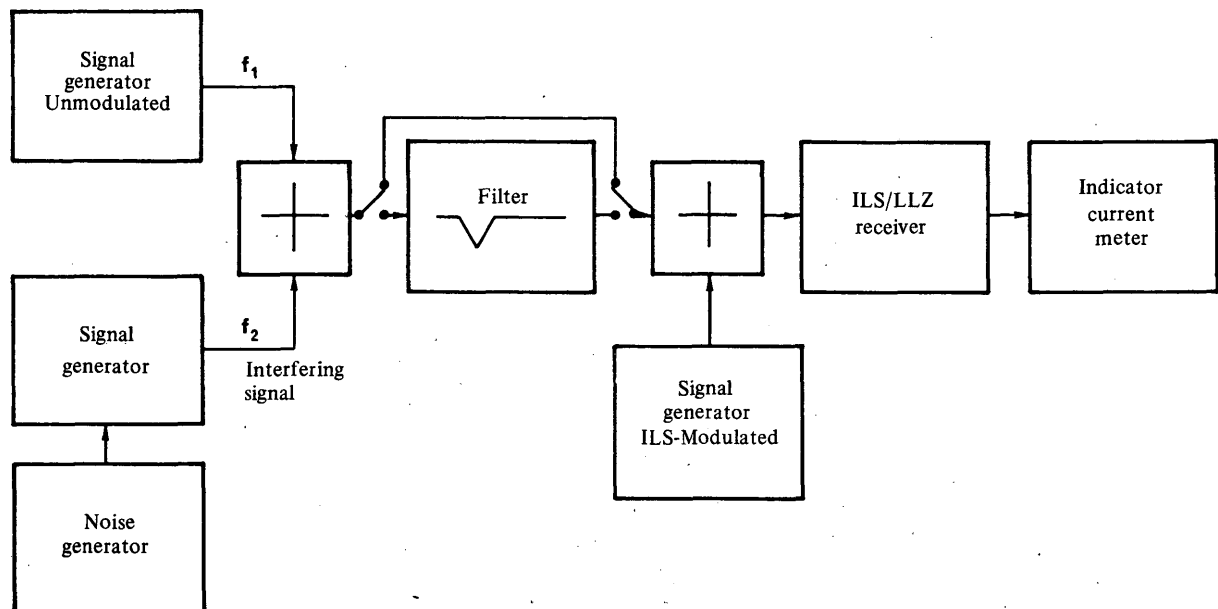


FIGURE 9 – *Intermodulation measurement test set-up (interference type B1)*

Interfering signal at f_2 has noise modulation with weighting according to Recommendation 559 and 32 kHz r.m.s. deviation.

Filter at wanted signal frequency (f_a).

Wanted signal level –86 dBm, –76 dBm or –66 dBm.

Indicator criterion $\pm 7.5 \mu\text{A}$ change from 90 μA .

4.2.2 Test results

4.2.2.1 In the frequency range below 107.7 MHz the measurement results seemed to follow the formula:

$$2N_1 + N_2 + 3\left(A - B \log \frac{\Delta f}{0.4}\right) \geq 0$$

where:

$\Delta f = f_a - f_1$ (MHz)

f_a : ILS channel tuned frequency (MHz),

f_1 and f_2 : broadcasting frequencies ($f_1 \geq f_2$),

N_1 : signal level at f_1 (dBm),

N_2 : signal level at f_2 (dBm).

TABLE VI – Interference threshold, interference type B1

A. Broadcasting frequencies in the range 107.7-108 MHz	
Receiver	Condition for interference
No. 1	$2 N_1 + N_2 + 81 \geq 0$
No. 2	$2 N_1 + N_2 + 96 \geq 0$
No. 3	$2 N_1 + N_2 + 129 \geq 0$
B. Broadcasting frequencies in the range below 107.7 MHz	
Receiver	Condition for interference
No. 1	$2 N_1 + N_2 + 3 \left(27 - 10 \log \frac{\Delta f}{0.4} \right) \geq 0$
No. 2	$2 N_1 + N_2 + 3 \left(32 - 5 \log \frac{\Delta f}{0.4} \right) \geq 0$
No. 3	$2 N_1 + N_2 + 3 \left(43 - 20 \log \frac{\Delta f}{0.4} \right) \geq 0$
	where $\Delta f = f_a - f_1$

where:

- N_1 : level of f_1 (dBm)
- N_2 : level of f_2 (dBm)
- f_1 and f_2 : broadcasting frequencies (MHz)
- f_a : ILS channel tuned frequency (MHz)
- $2f_1 - f_2 = f_a \quad (f_1 > f_2)$

Note 1. – Frequencies selected (MHz):

f_1	107.9	107.1	103.1	107.9
f_2	107.7	106.1	98.1	103.9
f_a	108.1	108.1	108.1	111.9

and the linear models given in this Table were fitted to the results.

- Note 2. – Interfering signal with Recommendation 559 weighting (coloured noise, 32 kHz r.m.s. deviation)
- Wanted ILS signal level –86 dBm
 - Criterion for interference $\pm 7.5 \mu\text{A}$ change in course guidance current 90 μA .

4.2.2.2 Coefficient *A* varied from 27 to 43 and coefficient *B* from 5 to 20. As the coefficients depend considerably on the receiver selected more different receiver designs should be measured.

4.2.2.3 The measurements showed also that with higher levels of the wanted signal (+10 dB, +20 dB) the intermodulation immunity to unwanted signals improves with some of these receivers, almost in relation to the increase in the wanted signal level.

4.2.2.4 For the case with three interfering signals the interference threshold formula should have the following general form:

$$N_1 + N_2 + N_3 + 3A + 6 \text{ dB} - C \log \frac{\Delta f_1 \times \Delta f_2 \times \Delta f_3}{(0.4)^3} \geq 0$$

where:

$\Delta f_i = f_a - f_i$ (MHz) and

C: determined by the slope of the filter before the component where intermodulation arises ($C \neq B$).

For a single tuned circuit $C = 20$.

4.2.2.5 The additional +6 dB term comes from the theoretical difference between type $2N_1 + N_2$ and type $N_1 + N_2 + N_3$ terms.

4.3 France

4.3.1 Introduction

4.3.1.1 The tests were conducted in the summer of 1984 on the following localizer/VOR receivers:

- Becker NR2030
- Collins 51RV 1A
- King KX-175B
- Narco NAV 121

The tests were conducted in a Faraday cage. The desired signal levels were –86 dBm for localizer and –79 dBm for VOR. The undesired signals were generated by actual broadcast transmitters using modulation as per Recommendation 559.

4.3.2 Distinction between types A2 and B2 interference effects

4.3.2.1 The method consists in measuring the protection ratios when the broadcast signal is first modulated by noise coloured in accordance with CCIR standards and then unmodulated. The interference from the CW signal must be of the B2 type since it has no side bands. If the protection ratios are the same, then any side-band energy received in the passband of the receiver is not the determining factor.

Note. – The measurements were made under the following conditions: if Δf is the difference between the radionavigation frequency (ILS/VOR) and the broadcasting frequency, the measurement for $\Delta f = 0$ and $\Delta f = 50$ kHz (reference values) could only be made with a broadcasting frequency of 108.0 MHz in VOR and 108.1 MHz in ILS.

4.3.2.2 If the broadcasting frequency is then kept at 107.9 or 108.0 MHz and the frequency of the radionavigation signal is shifted within its band by Δf , the radionavigation receivers will always have the same desensitization characteristic since the latter depends only on the broadcasting frequency.

Note. – For $\Delta f = 0$, in the case of the unmodulated signal, the value given is an indicative one.

4.3.2.3 The first set of measurements (see Table VII) was made with an output filter of a stereophonic FM transmitter (3 cavities). Its bandwidth was 530 kHz at –3 dB and 800 kHz at –10 dB. The filter served to attenuate the transmitter's residual noise (already low to start with) outside its wanted band, thus making it possible to measure very low protection ratio values (below –80 dB). The filter did not in any way affect the quality of the wanted signal from the broadcasting transmitter. The other measurements were made without the filter; the results are given in Table VIII. It can be seen that for values of Δf of about 200 to 300 kHz, the filter makes very little difference to the results when the signal is modulated.

4.3.3 Applicability of cut-off values to assessment criteria

4.3.3.1 Demonstration of the non-existence of a cut-off level

4.3.3.1.1 The tests made on a sample of radionavigation receivers, presented in Annex I, show that the concept of the cut-off phenomenon does not exist in reality. In fact, the figures here below show what really happens.

TABLE VII – *Broadcasting transmitter equipped with a band-pass filter*

Δf	Receiver A				Receiver B				Receiver C	
	ILS		VOR		ILS		VOR		VOR	
	M	N	M	N	M	N	M	N	M	N
0	11.5	13.0	10.5	26.0	10.0	11.0	10.0	26.0		
50	−14.0	−61.0	−12.5	−49.0	−12.0	−60.0	−17.0	−63.0	−1.0	−49.0
100	−48.0	−74.0	−50.0	−74.0	−41.5	−69.0	−47.0	−72.0	−44.0	−54.0
150	−76.0	−77.0	−75.0	−70.0	−70.0	−71.0	−76.0	−76.0	−53.0	−53.0
200	−79.5	−80.0	−79.0	−74.0	−72.0	−72.0	−78.0	−79.0	−52.5	−52.5
300	−80.5	−83.0	−76.0	−74.5	−74.5	−75.0	−92.0	−90.0		
400	−85.0	−86.0	−87.0	−88.0	−76.0	−76.0	−91.0	−93.0		
500	−79.0	−86.0	−74.0	−75.0	−76.5	−76.5	−92.0	−92.5		
800	−86.0	−86.0	−86.0	−88.0	−77.0	−77.0	−91.0	−91.0		
1000	−86.0	−86.0			−74.0	−77.0				

M: broadcasting signal modulated by coloured noise.

N: broadcasting signal not modulated.

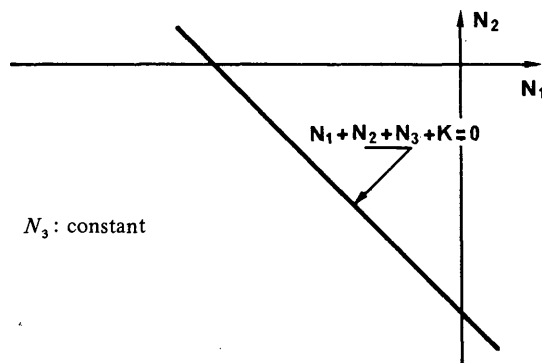
TABLE VIII – *Broadcasting transmitter without band-pass filter*

Δf	Receiver A				Receiver B	
	ILS		VOR		VOR	
	M	N	M	N	M	N
0	8.0	10.0	10.0	10.0	3.0	8.0
50	−11.0	−22.5	−12.0	−24.0	−15.5	−32.0
100	−46.0	−57.0	−47.0	−57.5	−49.0	−68.5
150	−72.5	−73.0	−72.0	−73.0	−70.0	−70.0
200	−76.0	−76.5	−76.0	−75.0	−78.0	−77.0
300	−78.0	−77.5	−77.0	−75.5	−81.5	−82.0
400	−80.5	−80.0	−81.5	−82.0	−86.5	−86.5
500	−79.0	−83.0	−74.5	−75.0	−92.0	−93.0
800	−79.0	−85.0	−82.0	−84.0	−90.0	−92.0
1000	−81.0	−85.5	−79.0	−79.0	−89.0	−90.0

M: broadcasting signal modulated by coloured noise.

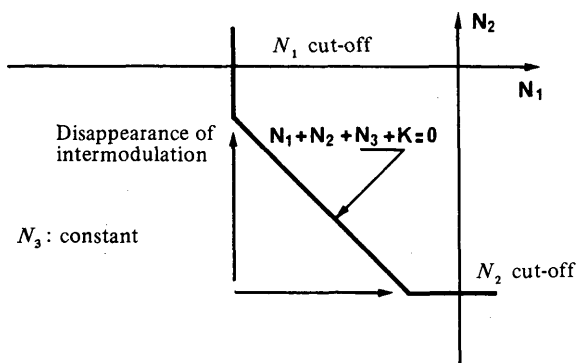
N: broadcasting signal not modulated.

4.3.3.1.2 The intermodulation criterion is a linear law in N_1 , N_2 , N_3 of the form $N_1 + N_2 + N_3 + K = 0$. If we take the position $N_3 = \text{constant}$, the relation between N_1 and N_2 can be plotted as follows:



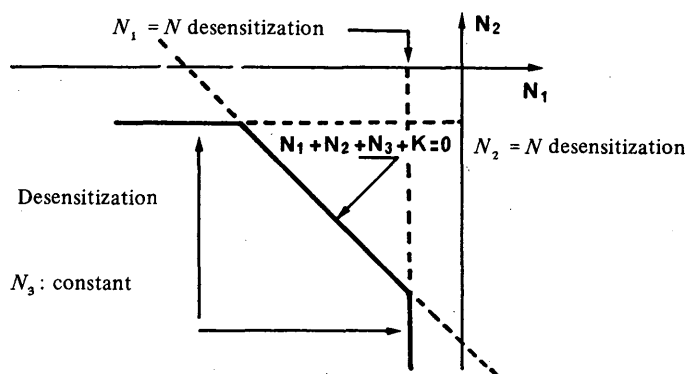
4.3.3.1.3 The existence of a cut-off threshold on N_1 is expressed by the fact that for $N_1 \leq N_1 \text{ cut-off}$, there is no longer any intermodulation. The same is true for $N_2 \leq N_2 \text{ cut-off}$.

4.3.3.1.4 If such a cut-off value really existed, the above theoretical curve would in practice be distorted as follows:



4.3.3.1.5 The tests made on radionavigation receivers have made it possible to draw Figs. 13 to 18 (see Annex I).

4.3.3.1.6 The distortion described above is never found in these curves. We may however note that they have the following shape:



4.3.3.1.7 This is explained by the occurrence of a desensitization phenomenon, which, beyond a certain threshold, conceals the intermodulation phenomenon.

4.3.3.2 Conditions at the limits when type B2 interference outweighs type B1 interference

4.3.3.2.1 Assumptions

A disturbance by three broadcasting stations is expressed by:

- the combination of frequencies:

$$f_1 + f_2 - f_3 = f_{\text{aeronautical}}$$

- the equation for the levels:

$$N(f_1) + N(f_2) + N(f_3) + K(f_1, f_2, f_3, f_{\text{aero}}) = 0$$

We denote $x(f)$ by the expression:

$$20 \log \frac{\max \{108.1 - f; 0.4\}}{0.4}$$

in which $\max \{a; b\}$ represents the greater of two values a and b .

Thus for $f \geq 107.7$ MHz, $x(f) = 0$.

We can also write:

$$K = 126 - x(f_1) - x(f_2) - x(f_3)$$

The desensitization level at frequency f is denoted by $N_d(f)$ (see § 4.2.2 of Joint Interim Working Party Report 8-10/1).

4.3.3.2.2 Theoretical attempt to find the transition point between the two types of interference

We shall attempt to find the minimum level $N_l(f)$ corresponding to the transition from type B1 interference to type B2.

For a signal of frequency f_1 , this value is obtained by a simultaneous desensitization caused by signals f_2 and f_3 , or:

$$N_l(f_1) + N_d(f_2) + N_d(f_3) + 126 - x(f_1) - x(f_2) - x(f_3) = 0 \quad (1)$$

Permutating the signals, we also get:

$$N_l(f_2) + N_d(f_1) + N_d(f_3) + 126 - x(f_1) - x(f_2) - x(f_3) = 0 \quad (2)$$

$$N_l(f_3) + N_d(f_1) + N_d(f_2) + 126 - x(f_1) - x(f_2) - x(f_3) = 0 \quad (3)$$

It is logical to make the assumption that $N_l(f)$ has the form:

$$N_l(f) = x_0 + x(f) \quad (4)$$

where x_0 is a constant to be determined. Measurements have always yielded frequency dependences of the form $x(f)$.

If we introduce equation (4) into equations (1), (2) and (3), we get:

$$x_0 + x(f_1) = -126 + x(f_1) + x(f_2) + x(f_3) - N_d(f_2) - N_d(f_3)$$

$$x_0 + x(f_2) = -126 + x(f_1) + x(f_2) + x(f_3) - N_d(f_3) - N_d(f_1)$$

$$x_0 + x(f_3) = -126 + x(f_1) + x(f_2) + x(f_3) - N_d(f_1) - N_d(f_2)$$

Resolving this equation, we get:

$$x_0 + 126 = 2[x(f_1) - N_d(f_1)] = 2[x(f_2) - N_d(f_2)] = 2[x(f_3) - N_d(f_3)]$$

We can thus write for any frequency, f , involved in an intermodulation product:

$$N_d(f) = -1/2(x_0 + 126) + x(f)$$

$N_d(f)$ is thus defined in two ways:

- firstly, by three sections of curve (see Fig. 2, § 4.2.2 of the Joint Interim Working Party 8-10/1 Report).

It should be noted that such a law is obviously the linear approximation of a law without discontinuity;

- secondly, by the function $x(f)$, which, allowing for a vertical shift, is represented by the constant:

$$1/2(x_0 + 126)$$

Comparing these two laws graphically (see Fig. 10), we find that the three sections of curve constitute a good approximation of the law $x(f)$ for $1/2(x_0 + 126) = 20$. This gives $x_0 = -86$.

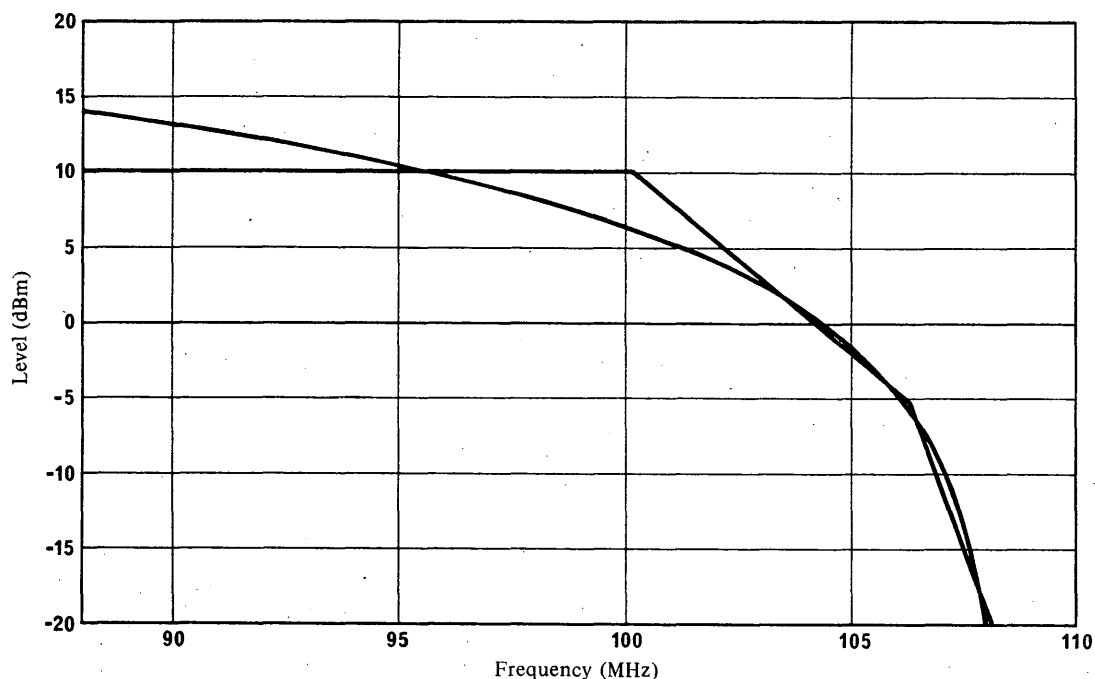


FIGURE 10

4.3.3.3 Conclusion

Although the hypothesis of cut-off thresholds was disproved by the experimental measurements, it was shown that it was pointless in practice to deal with type B1 interference appearing below a certain threshold. The effects of such interference are then completely obscured, because the preponderant disturbance is type B2. On the basis of the above calculations the following formulae should be used, defining the limiting values:

- Current ILS and VOR receivers:

$$N(f) \geq -86 + 20 \log \frac{108.1 - f}{0.4} \quad \text{dBm} \quad \text{for } f \leq 107.7$$

$$N(f) = -86 \quad \text{dBm} \quad \text{for } f \geq 107.7$$

- Future ILS and VOR receivers:

$$N(f) \geq -58 + 20 \log \frac{108.1 - f}{0.4} \quad \text{dBm} \quad \text{for } f \leq 107.7$$

$$N(f) = -58 \quad \text{dBm} \quad \text{for } f \geq 107.7$$

These values are plotted on the curves of Fig. 11.

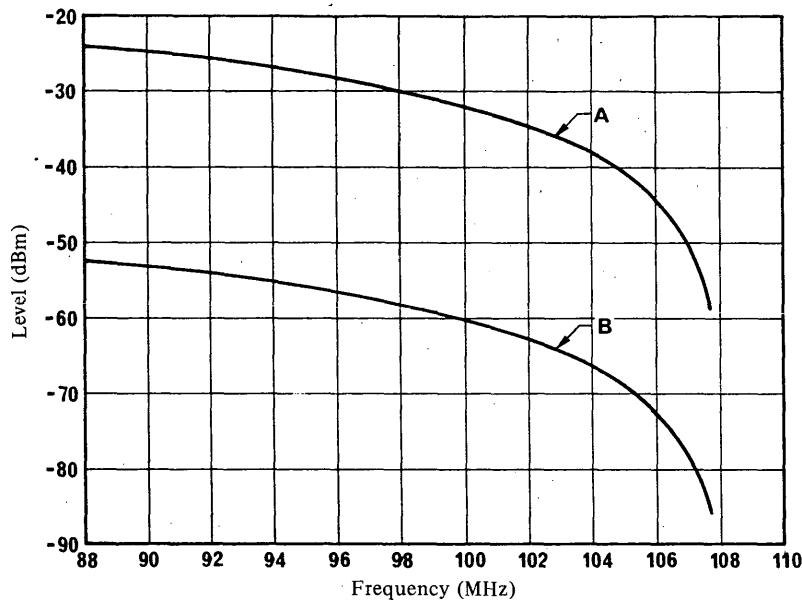


FIGURE 11

Curves A: future receivers
 B: current receivers

4.4 *Canada and the United States of America*

4.4.1 A measurement programme on interference to avionics receivers from signals from FM broadcast services was undertaken by the United States Federal Aviation Administration and Transport Canada. The tests were conducted both at ARINC laboratories in Annapolis, Maryland, United States of America and at Transport Canada laboratories in Ottawa, Canada. Annex II presents results of these tests.

4.4.2 Canadian experience indicates that in-service performance of the total airborne radionavigation installation differs from bench-measured performance from an FM/NAV service compatibility point of view. Therefore, the FM and NAV systems modelling needs further refinement, and correlation to field operation needs to be established in order to develop reliable interference analysis methods. The test data presented in Annex II, § 3 should be viewed in this light. Studies are continuing in an effort to correlate bench test results with operational experience.

5. **Specific aspects of the interference assessment problem**

5.1 *Basis for assessment*

5.1.1 *Common reference point for airborne equipment measurements and future specifications*

5.1.1.1 Voltage is referenced to the receiver input calculated on the basis of the generator output across 50 Ω (see Fig. 12). It is stressed that this does not affect the final results in terms of permissible field strengths at the receiver antenna but is solely a highly desirable means of reducing confusion in the future. Figure 12 also shows an example of the resulting RF generator level setting procedures.

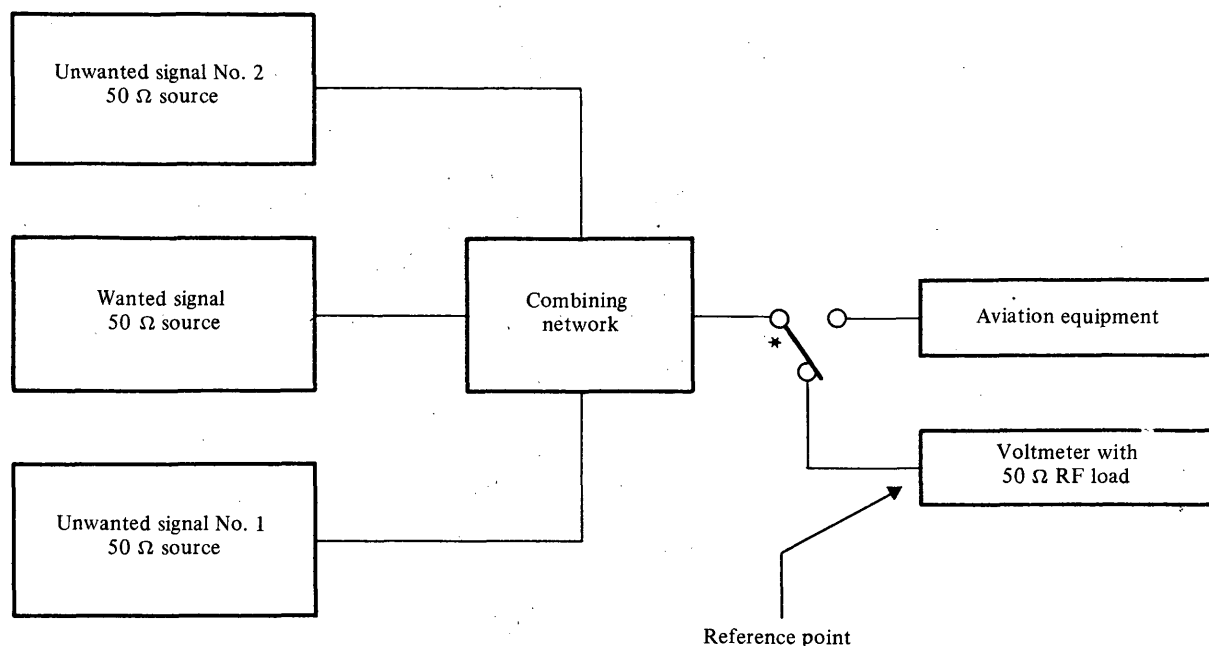


FIGURE 12 – Definition of standard reference point for specification and measurement of airborne receiver immunity

* Substitute voltmeter with 50 Ω load for aviation equipment to set RF levels.

5.1.2 *Wanted signal characteristics*

5.1.2.1 *ILS*

A minimum wanted signal of 40 $\mu\text{V/m}$ is taken, as given in Annex 10 to the ICAO Convention.

5.1.2.2 *VOR*

A minimum wanted signal of 90 $\mu\text{V/m}$ is taken, as per Annex 10 to the ICAO Convention. (Note. – Further information, in particular on the effect of the radio horizon, below which the wanted field strength falls rapidly, is available in Annex 10 to the ICAO Convention.)

5.1.2.3 *COM*

It should be noted that Annex 10 to the ICAO Convention does not specify a *minimum* field strength for communication – rather it states that 75 $\mu\text{V/m}$ shall be exceeded for a “large percentage of occasions”. In practice there are many occasions when VHF communications need to take place below the 75 $\mu\text{V/m}$ level and hence a lower figure is considered appropriate, for quantitative assessment purposes. It was considered that a value of 40 $\mu\text{V/m}$ is appropriate. (Note. – Further information, in particular on the effect of the radio horizon, below which the wanted field strength falls rapidly, is available in Annex 10 to the ICAO Convention.)

5.2.1.4 *Special factors*

The above values are regarded as appropriate for assessing airborne equipment immunity against interference from FM broadcasting. However, in practice, it should be noted that:

- ground equipment may, at some specific locations, provide field strengths of the wanted signal above the quoted levels. Such circumstances may offer additional margins in particular difficult broadcast assignment cases;
- the choice of a representative level for COM services for compatibility assessment is particularly difficult. There are many occasions and circumstances where safety messages are required to be passed using a wanted signal below 10 μV . In addition, the assessment of voice quality is largely subjective and hence difficult to quantify;

- in the ILS and VOR systems, arrangements are made to cause a “flag” to appear in the ILS (or VOR) receiver to warn the air crew or auto-pilot when the wanted signal falls below a certain level (e.g. due to ground equipment malfunction). However, if interference is present it may prevent the “flag” from appearing and thus create a critical situation. These circumstances have been observed in actual practice during flight investigation of FM broadcast interference;
- some interference incidents in the past have been found to be due to re-radiated intermodulation from within the emergency locator transmitters carried on board.

5.1.3 *Standard interference thresholds for bench measurements*

Note. – It is stressed that these thresholds are for the purpose of standardizing bench measurements and whilst they are chosen to be reasonable representations of typical operational situations there will be some circumstances where they do not provide adequate protection to the aviation service in practice.

5.1.3.1 *Measurements*

5.1.3.1.1 *ILS*

The changes to course guidance current due to the interference effects from FM broadcasting signals should not be permitted to add appreciably to the course structure perturbations permissible in Annex 10 to the ICAO Convention due to other causes. With the wanted signal at the required level (§ 5.1.2.1) and the signal adjusted for a difference in depth of modulation (DDM) of 0.093, the change in course guidance current should not exceed 7.5 μ A. In the case of changes to flag operation, there is less assurance in defining common criteria to cover all designs of flag systems. Therefore until further refinement can be made, the following tentative limits may be employed:

- in the case of an unwanted signal forcing a flag to appear for more than 1 s (auto-pilot performance may be affected by a shorter time period);
- in the case of the unwanted signal forcing a flag to disappear when there is no desired signal present, the value which just puts the flag out of sight for more than 1 s. (The absence of an ILS signal does not represent a typical operational situation but could be a dangerous one.)

The above values should be used for both type A and B interference modes.

Note. – The above does not consider centering error. The centering error due to FM broadcasting interference, when statistically combined with other specified environmental conditions, should not be permitted to exceed the levels prescribed by the ICAO.

5.1.3.1.2 *VOR*

The wanted signal at the required level (§ 5.1.2.2) shall be modulated with a standard VOR test signal as described in the Radio Technical Commission for Aeronautics (RTCA) Document DO-153A, Minimum performance standards for VOR. The interference threshold should then be:

- a change of the bearing indication by 0.5° corresponding to 7.5 μ A deflection current; or
- a change in the audio voltage level by 3 dB; or
- the appearance of the flag for more than 1 s.

5.1.3.1.3 *COM*

- With a signal at the required level (see § 5.1.2.3) the interference criterion should be a reduction in the audio signal plus noise-to-noise ratio, $(S + N)/N$, to 6 dB.
- With no wanted signal present, the interference shall not cause more than 5 dB (equivalent RF) increase in AGC voltage or an audio interference plus noise-to-noise ratio, $(I + N)/N$, of greater than 6 dB.

5.1.4 *Unwanted (broadcast) signal characteristics*

5.1.4.1 In many instances the worst case ILS/VOR interference problem is generated by utilizing actual FM programme material as the unwanted signals taking into account Region 1 and Region 2 FM transmission characteristics, including supplementary channels where applicable.

5.1.4.2 It was decided to propose the standard modulation characteristic as per Recommendation 559 for the purposes of comparison of bench measurements and to stress its limitations beyond that context.

Note 1. — Particular attention may need to be made on the bench to reduce unintentional noise modulation effects.

Note 2. — If using a single signal source to simulate third-order transmitter intermodulation products, increased deviations may be required.

5.2 *Airborne equipment*

5.2.1 *Current international standardization principles*

Airborne equipment is subject to a very high degree of national and international standardization. However this has always been directed towards those aspects which ensure:

- an adequate performance under ICAO-specified conditions of wanted signal-in-space;
- interchangeability of equipment between manufacturers;
- safety when carried onboard aircraft (e.g. fire risk, etc.); and
- specified minimum performance over a specified range of temperature, pressure, etc.

As far as electromagnetic compatibility is concerned the international standardization has also had to ensure that adequate adjacent channel rejection characteristics are specified — and in turn this becomes a key factor in the extensive national and international coordination of frequency assignment activity within the aviation community. In addition very stringent conditions are laid down to ensure that airborne equipment does not adversely affect, and is not adversely affected by, other airborne equipment installed in close proximity on the aircraft.

The scope of the standardization of airborne equipment has, however, necessarily had to take cognizance of the vital fact that the airborne system is not capable of standardization on those aspects which are affected by differences between airframe types. The antenna and feeder characteristics are the main areas of difficulty here, because the airframe exerts considerable influence over the antenna and feeder characteristics and very wide variations exist. In consequence, ICAO traditionally tends to specify “signal-in-space” characteristics to ensure minimum acceptable performances and airborne equipment design has sought to ensure that the “black boxes” will be adequate to process the wanted signals under adverse antenna/feeder circumstances.

5.2.2 *Current equipment and expected improvements*

Tests so far carried out on airborne receivers, including those described in § 4 of this Report, have shown wide variations in those characteristics and susceptibilities relevant to the rejection of very high-level unwanted signals. ICAO has addressed the problem of high-powered adjacent band FM broadcast interference and has produced new interference immunity standards for airborne receivers in Annex 10 to the ICAO Convention applicable as of 1998. Short-term improvements may be possible on a case-by-case basis (for example, in the form of add-on RF rejection filters) but these methods are not considered as feasible general solutions.

It is, however, very important to note that there are practical limits to the technical improvements that can be realized in both the short- and long-terms, and therefore airborne equipment improvements cannot reasonably be expected to resolve all compatibility problems with the FM broadcasting service. Accordingly, close coordination between aeronautical and broadcasting authorities will continue to be required in the long term.

6. *Summary of study*

The study of potential interference between the FM broadcasting service and the aeronautical radionavigation services in the band 108-118 MHz, has received considerable attention in a number of administrations as reported above. These studies take on a special importance in regions where the band up to 108 MHz has recently become available to FM broadcasting and where, therefore, broadcast planning is imminent.

It is evident that no simple technical solutions to the incompatibility problem are immediately available. The interference potential from high-powered FM broadcasting stations (singly or otherwise) to ILS, VOR and/or VHF R/T will depend on many factors. Apart from airborne equipment performance itself, the most important factors as shown in § 4 will involve combinations of:

- broadcasting transmitter power (e.r.p.) and antenna characteristics (height, directivity, etc.);
- separation distances;
- frequency separation;
- frequency relationships;
- geographical and topographical aspects.

In this Report, § 2 explains how all the interference mechanisms can be divided into two main categories, type A and type B.

Some examples of each type of interference to VHF-radionavigation and R/T receivers are shown in detail in § 3 and some conclusions arrived at in terms of theoretical geographical areas where interference is likely to appear, taking into account the different combinations and values of the above parameters.

Taking this framework into account, it will be possible for the administrations to consider throughout the process of planning, case by case, all the potential conflicts e.g. along the guidelines presented in this Report.

It will be necessary for the relevant broadcasting and civil aviation authorities to consider, in close cooperation, possible solutions to eliminate any potential interference problems between the two services.

7. Conclusions

7.1 The problem is complex and not capable of complete resolution by adoption of a single set of protection criteria. The complication is introduced mainly by the wide variability of aircraft equipment characteristics which need to be accommodated, particularly antenna/feeder characteristic variations between different airframe types.

7.2 The interference potential from type A and type B mechanisms both need to be addressed in practice. ILS and VOR in the sub-band 108-118 MHz have the greatest potential for serious difficulties (and at the same time are operationally the most critical from a safety viewpoint).

7.3 The volume of critical airspace to be protected in ILS cases is relatively small, but in the VOR and VHF R/T cases it may be very large.

7.4 Airborne equipment improvements to reduce the interference potential have already been specified by the ICAO. These improvements will not solve the problems completely, and will be incorporated by 1998.

7.5 The calculations given in this Report show that the current requirements of the Radio Regulations (in respect of spurious emission limits for FM sound broadcasting transmitters above one kW) would possibly require large distance separations in order to avoid type A interference problems. Suppression levels of better than 85 dB are known to have been achieved in practice in seeking solutions to specific cases of difficulty (see also § 3.2.5.3.2).

7.6 The guideline procedures in this Report strongly indicate that frequency assignment coordination and siting and suppression coordination will be needed to supplement any general criteria in order to reduce the interference potential. Because of the large line-of-sight distances involved this interference potential may exist across, as well as within, national boundaries.

7.7 For at least the type A mechanisms, it is evident that adequate reduction of the levels of unwanted signals at the aviation receiver will involve the broadcasting power, the separation distance and the frequency separation. In this respect any ability to avoid the use of the highest powers at the broadcasting channels closest to 108 MHz will assist considerably in difficult cases in the vicinity of aerodromes.

7.8 Both the aeronautical and broadcasting services need to cooperate closely in order to minimise restrictions on their freedom to deploy their respective facilities.

8. General recommendations

8.1 Close and continuing assignment coordination between aeronautical and broadcasting authorities appears to be the only practical way to reduce the probability of harmful interference to the aeronautical services to generally acceptable levels.

8.2 Further study is required in order to develop standard harmful interference threshold criteria for the measurement of airborne ILS, VOR and VHF R/T system performance in the presence of high-powered FM broadcasting signals.

9. Future tests and investigations

9.1 Compatibility between the aeronautical radionavigation service and the sound broadcasting stations in the bands concerned should be studied and in particular:

9.1.1 protection ratio values for future airborne receivers against spurious emissions from sound broadcasting stations (referred to as A1 type of interference) in cases where the frequency of the spurious emissions does not coincide with the aeronautical frequency;

9.1.2 protection ratio values for present and future aeronautical receivers against out-of-band emissions from sound broadcasting stations (referred to as A2 type of interference) including measurements of FM broadcast spectra;

9.1.3 criteria for prediction of third-order intermodulation (referred to as B1 type of interference) generated in airborne receivers by three unwanted signals, for receivers meeting the ICAO standard for two-signal intermodulation for future receivers;

9.1.4 the effect of sinusoidal modulation of the sound broadcasting transmitters during test and line-up and any precautions or procedures to be adopted at broadcasting stations in order to maintain the agreed protection of the aeronautical radionavigation service;

9.2 compatibility between the aeronautical mobile (R) service and the sound broadcasting service in the bands concerned;

9.3 compatibility criteria that can be used to predict potential interference in an assignment decision context including the determination of the correlation of bench tests with in-service operational performance of aeronautical receivers;

9.4 cumulative effect of multiple FM broadcast signals;

9.5 the applicability of cut-off values in the assessment process;

9.6 FM broadcast antenna pattern characterization;

9.7 statistical analysis of data;

9.8 description of, and experience with, assessment techniques in correlation with flight test and operational experience;

9.9 effect of FM broadcast signals on auto-pilot system performance;

9.10 effect on assessment criteria of special techniques used in FM broadcasting (e.g. subsidiary communication carriers, increases in deviation);

9.11 the effect of FM broadcast signals on digital communications in the 118-137 MHz band.

REFERENCES

SAWTELLE, E. M. and DONG, J. G. [July, 1978] Interference in communications and navigation avionics from commercial FM stations. FAA-RD-78-35, National Technical Information Service (NTIS) US Dept. of Commerce, Washington DC, USA.

ANNEX I

This Annex I contains French test data on 3-signal type B1 interference.

Interpretation of the curves

The laws sought are of the form:

$$N_1 + N_2 + N_3 + K = 0$$

where N_1 , N_2 , N_3 are the respective levels in dBm of the three broadcasting transmitters at frequencies f_1 , f_2 , f_3 .

To make them easier to use, the curves have been plotted for three values of N_3 ; each of these curves in (N_1, N_2) must have a slope of -1 :

$$N_1 + N_2 + (N_3 + K) = 0$$

The modification in the slope is brought about by the desensitization of the receiver.

On each of the curves, levels (N_1, N_2, N_3) are found which are lower than the cut-off level proposed in Annex IX of the report of Joint Interim Working Party 8-10/1 and for which type B1 interference was measured. Some of these points are marked by squares.

The cut-off levels are represented by broken lines. They depend on the frequency and the type of receiver used: ILS or VOR.

Under each of the curves is given the equation of the intermodulation law in its conventional form, when the slope is -1 :

On the curves of Fig. 18, the desensitization of the receiver can be seen:

- when $N_1 = -20$ dBm for $f_1 = 107.9$ MHz, the same disturbance is found with $N_2 = -50, -60$ or -70 dBm;
- similarly, when $N_2 = -8$ dBm for $f_2 = 107.5$ MHz, the same disturbance is found with $N_1 = -40, -50, -60$ or -70 dBm.

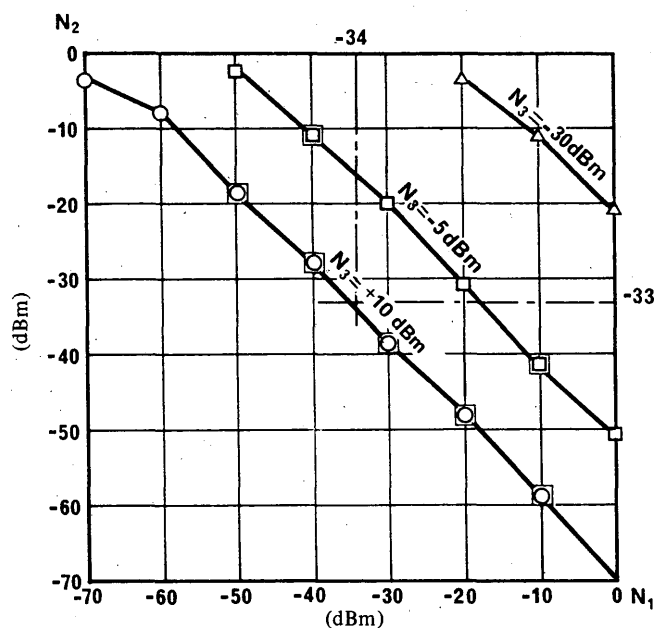


FIGURE 13 - Type B1 interference test

Equation obtained: $N_1 + N_2 + N_3 + 60 = 0$

Receiver type: receiver A
 Signal type: ILS localizer
 Receiver frequency: 108.1 MHz
 Wanted signal: -86 dBm (50Ω)

$f_1 = 104.1$ MHz
 $f_2 = 103.7$ MHz
 $f_3 = 099.7$ MHz

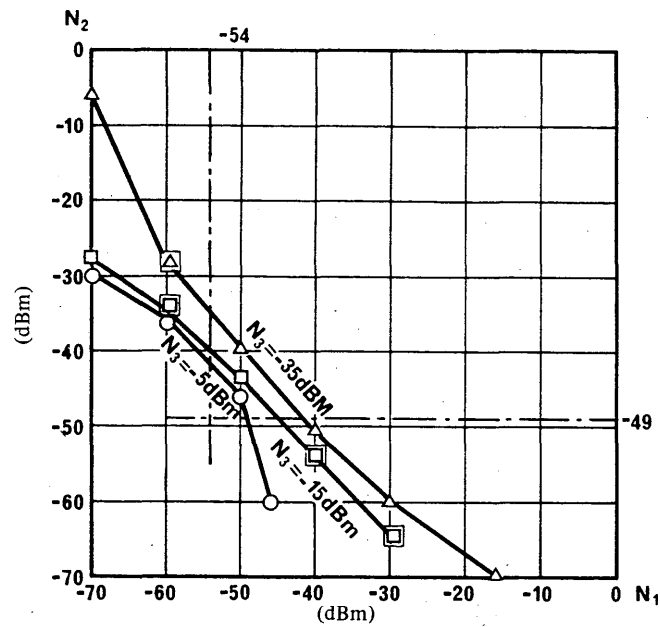


FIGURE 14 – Type B1 interference test

Equation obtained: $N_1 + N_2 + N_3 + 126 = 0$

Receiver type: receiver B

Signal type: ILS localizer

Receiver frequency: 108.1 MHz

Wanted signal: -86 dBm (50 Ω) $f_1 = 107.9 \text{ MHz}$ $f_2 = 107.4 \text{ MHz}$ $f_3 = 107.2 \text{ MHz}$

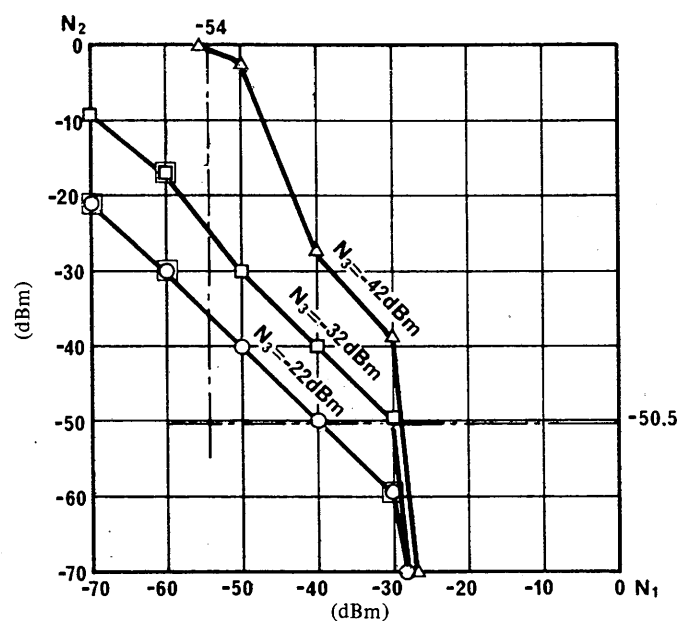


FIGURE 15 – Type B1 interference test

Equation obtained: $N_1 + N_2 + N_3 + 112 = 0$

Receiver type: receiver C
Signal type: ILS localizer
Receiver frequency: 108.5 MHz
Wanted signal: -86 dBm (50 Ω)
 $f_1 = 107.9$ MHz
 $f_2 = 107.5$ MHz
 $f_3 = 106.9$ MHz

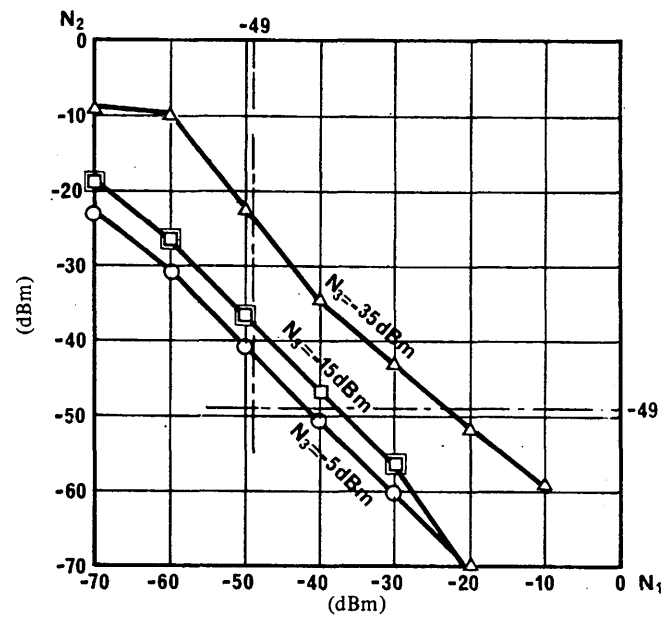


FIGURE 16 – Type B1 interference test

Equation obtained: $N_1 + N_2 + N_3 + 108 = 0$

Receiver type: receiver B
Signal type: VOR
Receiver frequency: 108.2 MHz
Wanted signal: -79 dBm (50 Ω)
 $f_1 = 107.9 \text{ MHz}$
 $f_2 = 107.4 \text{ MHz}$
 $f_3 = 107.1 \text{ MHz}$

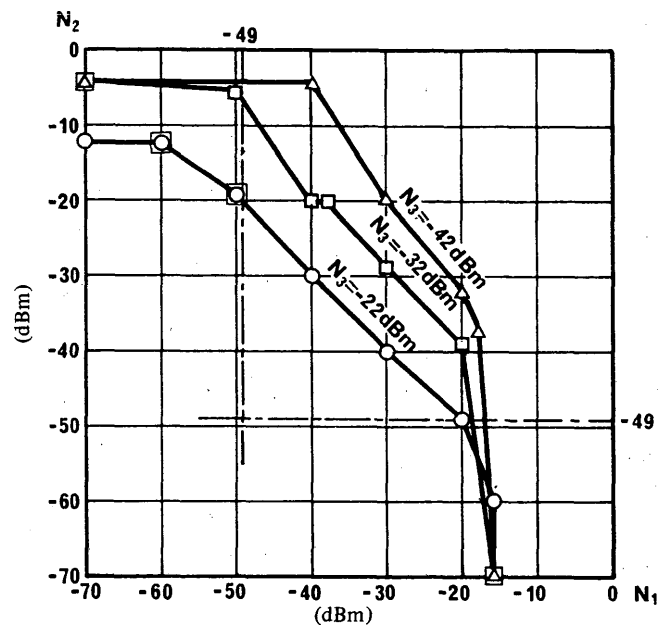


FIGURE 17 – Type B1 interference test

Equation obtained: $N_1 + N_2 + N_3 + 90 = 0$

Receiver type: receiver C

Signal type: VOR

Receiver frequency: 108.5 MHz

Wanted signal: -79 dBm (50 Ω) $f_1 = 107.9$ MHz $f_2 = 107.5$ MHz $f_3 = 107$ MHz

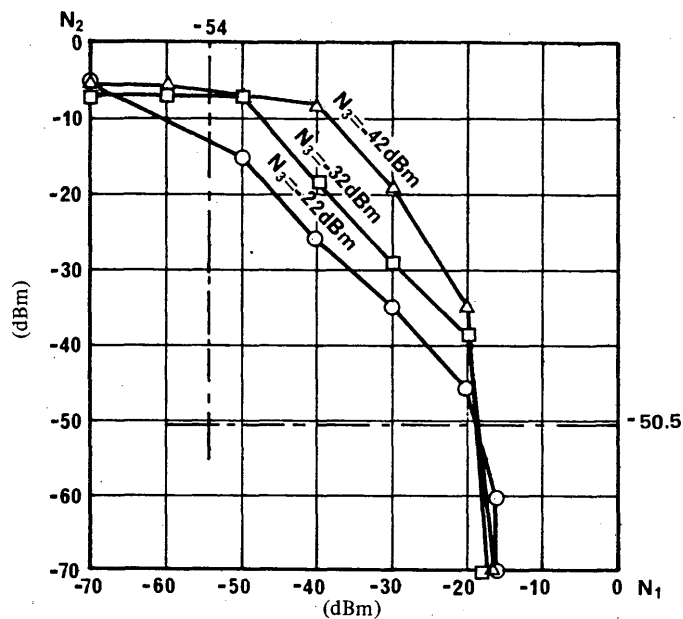


FIGURE 18 – Type B1 interference test

Equation obtained: $N_1 + N_2 + N_3 + 87 = 0$

Receiver type: receiver A

Signal type: ILS localizer

Receiver frequency: 108.5 MHz

Wanted signal: -86 dBm (50 Ω) $f_1 = 107.9$ MHz $f_2 = 107.5$ MHz $f_3 = 106.9$ MHz

ANNEX II

1. Introduction

1.1 This Annex II contains the results of a joint Canadian/United States test programme.

1.2 Description of tests

1.2.1 Type A2 interference

1.2.1.1 Tests were conducted to determine the extent of interference caused by sideband energy from FM broadcast signals on ILS localizer and, to a lesser extent, VOR receiver performance.

1.2.1.2 Earlier results of a limited test effort were submitted to the JIWP 8-10/1. They became the basis for type A1/A2 interference criteria in the JIWP 8-10/1 report, were subsequently accepted by the CARR-1(2) and used as a basis for the A1/A2 protection criteria in Appendix 1 paragraphs III and IV of its Final Acts. The results reported herein extend that data base to fifteen receivers (nine general aviation and six air-carrier types).

1.2.1.3 Each ILS localizer receiver was subjected to four different FM modulations used to simulate FM broadcast signals; CCIR coloured noise, pink noise, pre-recorded voice, and rock music. While a minimum desired signal level was used for most of the tests, several higher desired signal levels were used for some tests to determine if the receivers were operating in their linear range. Cross-pointer and flag data were recorded for both on-centre line and off-centre line simulated aircraft approaches. AGC data was recorded for mechanism analysis.

1.2.2 *Type B2 interference*

1.2.2.1 ILS localizer receiver overload thresholds caused by FM broadcast signals were examined.

1.2.2.2 Pure carrier (CW) signals were employed for the interferer to determine type B2 desensitization thresholds.

1.2.3 *Type B1 interference*

1.2.3.1 Receiver intermodulation interference tests were conducted on thirteen ILS localizer receivers; both airline quality and general aviation type.

1.2.3.2 The tests first examined the sensitivity of the receivers to different types of modulation used to simulate FM broadcast signals. Tests were run with and without a desired signal present.

1.2.3.3 A comprehensive set of equi-signal level data was taken for both 2- and 3-signal, third-order receiver intermodulation products on localizer frequencies 108.1, 109.1 and 110.1 MHz. The results were compared against those calculated from existing and future immunity formulae presented in the Final Acts of CARR-1(2), and JIWP existing immunity formulae presented in the JIWP 8-10/1 report. All three forums, ICAO, JIWP and CARR-1(2), adopted the same future immunity formulae. These formulae are contained in § 4 of the present Annex.

1.2.3.4 Several receivers were tested to examine the effect of various desired localizer signal levels on the interference threshold, and the effect of unequal interfering signal levels.

2. Type A2/B2 tests

2.1 *Introduction*

2.1.1 A total of 20 receivers were tested for type A2/B2 interference effects at ARINC laboratories, Annapolis, Maryland, United States of America, during August-September, 1984 (see Table IX for a list of receivers tested).

TABLE IX

Unit under test (UUTs)
King KX-175B
KNS-80
KN-53
KNS-81
KNR-615
Collins VIR 351 TSO
51RV 1
51RV 1A
51RV 2B
ILS 70
Cessna ARC RT 385A
Narco NAV 121
NAV 825
Bendix RNA 26C
RNA 34A

2.2 Test procedures

2.2.1 Figure 19 is the set-up used for all the tests.

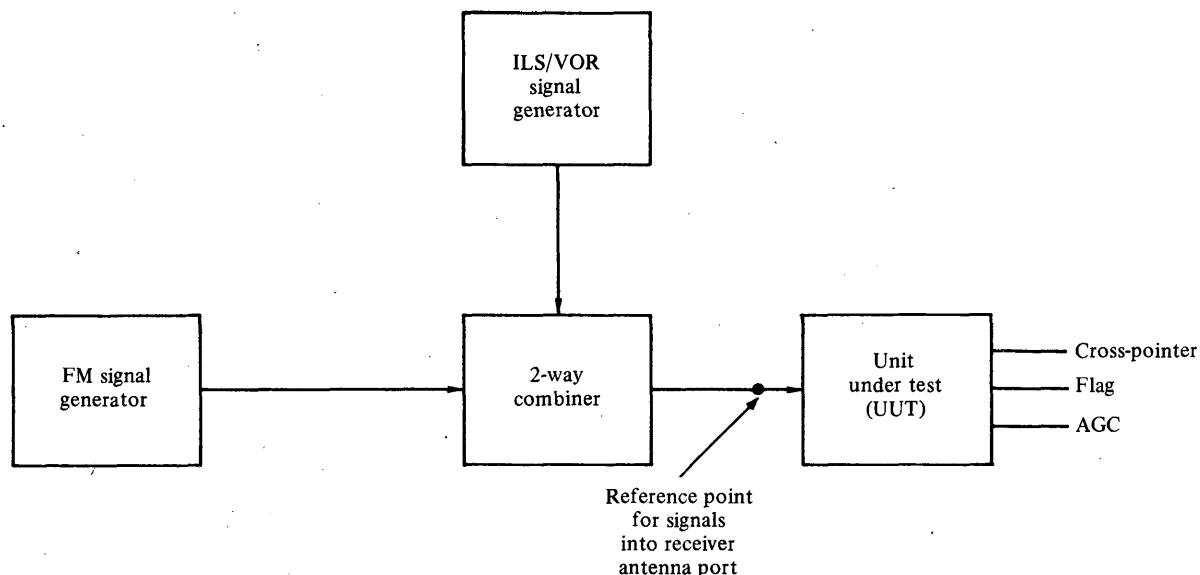


FIGURE 19 – Block diagram of test set-up for type A2/B2 tests

2.2.2 For the A2/B2 tests, the amplitude modulated wanted signal (W) simulated a ground localizer signal with a carrier frequency of 108.1 MHz. Differences in the depth of modulation (DDM) of 0.0 and 0.093 were used. A DDM of 0 corresponds to a centre-line approach. A DDM of 0.093 corresponds to the standard deflection of 90 μ A and is a manufacturer specified receiver calibration point. Linearity of the ILS receiver performance was investigated by varying the wanted signal level from -76 dBm to -106 dBm where possible and measuring the W/U ratio at each level.

2.2.3 Various unwanted signals, U , were fed into the antenna port of the UUT along with a wanted signal, W . For each data point, the unwanted signal was introduced at an undetectable level and increased until the interference threshold for the cross-pointer and flag were exceeded, as monitored by a multimeter, strip chart recorder and visual observation of flag action.

2.2.4 The actual FM broadcasts used were:

- part of a routine which included speech, laughing, applause and periods of silence; and
- music recorded from an on-air FM broadcast station which included both loud and soft passages.

CCIR coloured noise was generated by passing white noise through a filter whose characteristics are described in Recommendation 559, Fig. 2, curve B. Pink noise was generated by a suitable source.

2.2.5 Peak deviation was set to 75 kHz (broadcast standard). The FM modulated signal was adjusted until the peak deviation due to the audio input exceeded the 75 kHz limit no more than 10 times per minute (broadcast standard).

2.2.6 For A2 and B2 tests, a single simulated FM signal was generated. The interference threshold (see § 2.2.7) was approached from below. If the cross-pointer threshold was reached first, the FM signal was further increased until the flag threshold was also reached.

2.2.7 *Interference criteria*

2.2.7.1 *Cross-pointer*

Change in cross-pointer current greater or equal to $\pm 9 \mu\text{A}$ which lasts for a period of time greater or equal to approximately 0.2 s. A fluctuation which lasts less than about 200 ms is not considered significant because it has a negligible effect on cross-pointer activity.

2.2.7.2 *Flag (with wanted signal)*

Appearance of the flag for a period of time greater or equal to approximately 1 to 2 s. The appearance of the flag indicates an unusable wanted signal.

2.2.7.3 *Flag (no wanted signal)*

Disappearance of the flag for a period of time greater or equal to approximately 1 to 2 s. The disappearance of the flag is an indication that a usable wanted signal is present.

2.3 *Test results*

2.3.1 *General test observations*

2.3.1.1 Both air carrier and general aviation type receivers were included in the tests. Test results transcended type; e.g. no general statements could be made as to which group included the worst and best performers. A large range of responses was seen from model to model. Results were found to be surprisingly consistent from unit to unit of the same model.

2.3.2 *A2 VS B2 interference*

2.3.2.1 One of the objectives of the tests was to determine if the interference detected was of the A2 type (sidebands of the unwanted signal received within the passband of the receiver) or B2 (desensitization due to strong off-tuned signal). To determine this, the protection ratio for CW was compared to that for the FM modulated signal (all other parameters remaining equal). The interference from the CW must be of the B2 variety since it has no sidebands. If the protection ratio with modulation was the same as that without, it was assumed that both were of the B2 variety. Put another way, if the protection ratios are the same, then any side-band energy received in the passband of the receiver is not the determining factor. If the protection ratio with modulation is higher (requiring a smaller U to exceed the same threshold) then it was assumed to be of the A2 type.

2.3.2.2 A2/B2 test results are shown in Fig. 20 in the aggregate. Both the existing and future B2 immunity criteria curves from Fig. 27 are reproduced in part on Fig. 20. The current receivers as a whole exceed the existing immunity criteria, i.e. the data points fall below the upper curve. The future immunity curve represents an improvement of 10 dB. More than half of the receivers will require increased immunity to meet the future criteria for all Δf .

2.3.2.3 The test results show that the exact form of FM modulation used for bench testing did not seem to make much difference for A2/B2 protection ratios. In general, A2 and B2 effects data for $\Delta f > 200 \text{ kHz}$ do not differ by more than 2 dB.

However, for a few of the receiver types tested, the CW-only interferer (type B2) did require a higher signal level than an FM modulated interferer for isolated cases out to $\Delta f = 800 \text{ kHz}$. This was unexpected.

2.3.2.4 For some specific receiver/frequency combinations, the protection ratio for CW was actually higher than that for FM modulation. This may be due to the fact that the unwanted signal frequency fell on a spurious response frequency of the unit under test (UUT). The FM signal with its broad spectrum would deposit only a small amount of its energy on that frequency. The CW signal would deposit all or most of its energy at that frequency, requiring a smaller CW signal to have the same effect as the modulated signal.

2.3.2.5 In most of the tests, the cross-pointer and flag interference thresholds were exceeded before significant audio interference was heard in the identification channel.

2.3.2.6 If AGC data, while being inconclusive, seems to indicate that in many cases the UUT was desensitized by the RF AGC and no signals reached the IF amplifier. Both IF and RF AGC data were recorded for one receiver, and the results were consistent with this hypothesis.

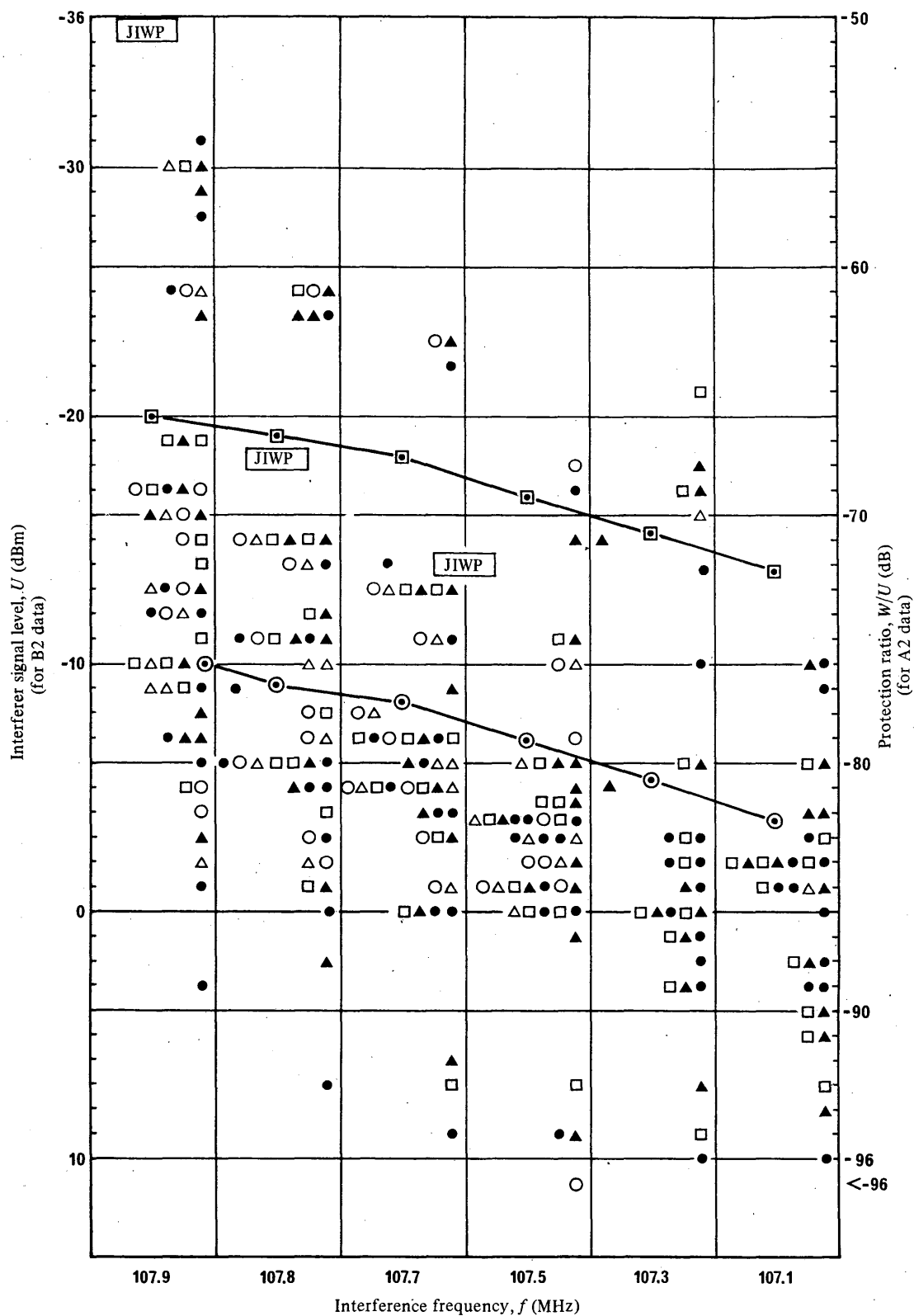


FIGURE 20 – Protection ratios for ILS localizer receiver

Type A2/B2 interference

ILS frequency: 108.1 MHz

- CW
- ▲ CCIR noise
- Pink noise
- △ Voice
- Rock music

$$\Delta I = 9 \mu\text{amp}$$

$$W = -86 \text{ dBm}$$

$$DDM = \pm 0.093$$

JIWP : Type A2 immunity

Type B2 immunity thresholds:

⊙ Future

⊠ Current

2.3.2.7 A1/A2 data was taken at wanted signal levels of -76 , -86 , -96 and -106 dBm where possible to determine if the receivers were operating linearly at -86 dBm. The results indicate that in some cases the receivers were bordering on overload for a desired signal level of -76 dBm. However, others exhibited linear relationships, that is, the same W/U ratio was achieved for the range of W from -76 dBm to -96 dBm.

2.3.2.8 Most of the receivers reached the cross-pointer threshold before reaching the flag threshold. Some receivers desensitized the cross-pointer as soon as the flag showed, others did not. Some receivers tested, exhibited large cross-pointer errors before the flag showed, and in some UUTs the flag never showed for interference levels up to the maximum tested, $+10$ dBm.

2.3.2.9 The effects of interference on cross-pointer were the greatest off centre-line, e.g. with a wanted signal DDM of 0.093. When on centre-line, 0 DDM, the flag was displayed before the cross-pointer threshold was exceeded. Often the cross-pointer threshold was never exceeded for interference levels up to $+10$ dBm.

- An explanation is that the interference affects both the 90 and 150 Hz filters equally, tending to move the cross-pointer to the centre and creating the illusion of being closer to the centre-line than is actually the case (i.e. widening of the approach path). This was observed for the vast majority of tests with a 0.093 DDM;
- when the receiver is receiving a centre-line ILS signal, this effect is masked. The predominant on-centre line interference effect is to desensitize the receiver to the wanted signal causing the flag to be displayed even when a good signal is present.

2.3.2.10 Large cross-pointer errors were found to occur in some of the tested receivers as a result of the reception of a strong FM signal. This type of interference could be construed as a valid course since it occurred with the flag still hidden. In a few receivers this error took the form of a strong "fly left" indication.

3. Type B1 tests

3.1 Introduction

3.1.1 A total of 13 receivers were tested for type B1 interference effects at Transport Canada laboratories in Ottawa, Canada, during May 1984.

3.2 Test procedure

3.2.1 The airline-quality and general aviation-type ILS localizer receivers tested for 2-signal and 3-signal, third-order receiver intermodulation (type B1) interference effects were:

- Bendix RNA 26C
- Bendix RNA 34A
- Cessna RT 385A
- Collins 51RV 1
- Collins 51RV 1A
- Collins ILS 70
- Collins VIR 351
- King KNR-615 (two units)
- King KNS-80
- King KX-175B
- Narco NAV 121
- Narco NAV 825

3.2.2 Tests were first conducted to determine the sensitivity of these receivers to different types of modulation on the broadcasting signals causing intermodulation interference. Modulations used were CCIR coloured noise (as per Recommendation 559), pink noise and taped music programme material. The broadcasting frequencies for the 2-signal and 3-signal intermodulation products were selected to correspond to broadcasting signals in the Ottawa area. Actual on-air broadcast signals received via an antenna system were fed into the localizer receivers to provide a basis for comparison with the other types of modulation.

3.2.3 Using an appropriate modulation based on the preceding modulation sensitivity tests, testing was carried out on all the receivers for 2-signal and 3-signal intermodulation effects on localizer frequencies 108.1, 109.1 and 110.1 MHz.

3.2.4 On a few receivers, additional tests were conducted to investigate the effect of increasing the desired localizer signal level and the effect of unequal interfering signal levels.

3.2.5 The block diagram for the 3-signal tests set-up is shown in Fig. 21. Maximum deviation for modulation on the broadcasting (stereo mode) signals was the North American standard of 75 kHz peak. The maximum equi-signal level generated by the test set-up was -5 dBm. When the on-air broadcasting signals were used, they were fed directly into the receivers from an antenna located outside the test laboratory and attenuated as necessary from a maximum equi-signal level of -15 dBm.

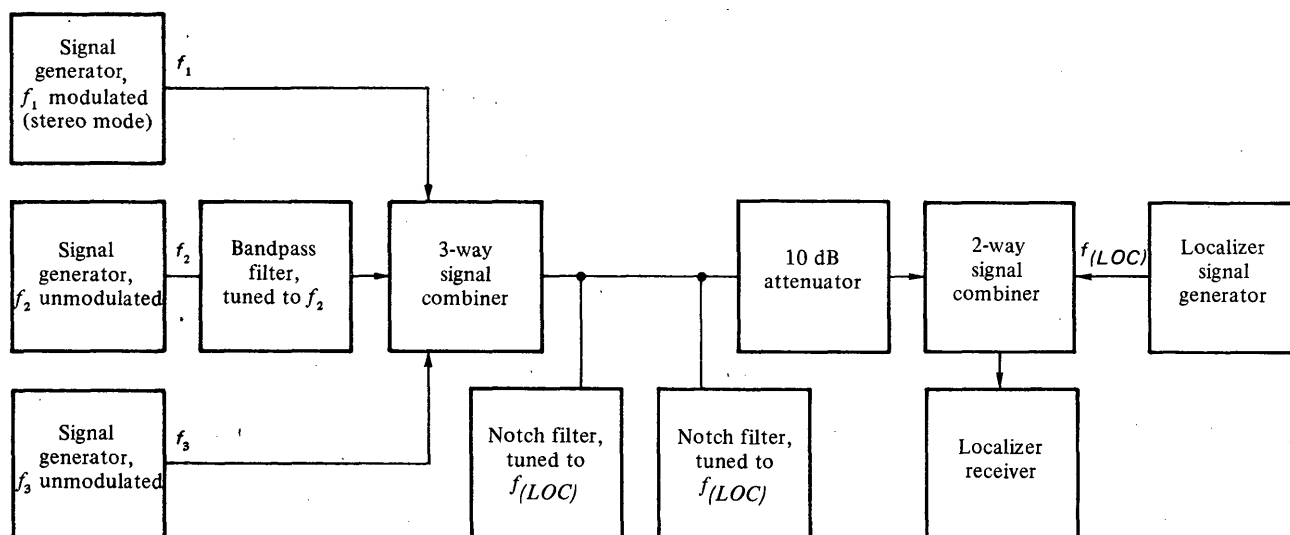


FIGURE 21 – Block diagram of test set-up for 3-signal type B1 tests

f_1, f_2, f_3 : broadcasting frequencies, $f_1 > f_2 > f_3$

$f_{(LOC)}$: localizer frequency

3.2.6 The interference criteria used were the appearance of the flag or a change of $7.5 \mu\text{A}$ in cross-pointer current for a localizer signal with a difference in depth of modulation (DDM) of 0.093 (90 Hz > 150 Hz). Conversion of the minimum localizer field strength of $32 \mu\text{V/m}$ through an isotropic loss-less antenna/feeder system results in a received signal level of -86 dBm; for test purposes, a desired signal level of -89 dBm was used as it accounted for the signal splitter loss in a typical aircraft localizer receiver installation. In tests where there was no desired signal present, the interference criterion was the flag being pulled down for a period of time exceeding 1 s. The equi-signal levels of the interfering signals were tabulated whenever an interference criterion was exceeded.

3.3 Test results

3.3.1 Modulation sensitivity tests

3.3.1.1 The results of the modulation sensitivity are contained in Table X for the 2-signal case $2(106.9) - 105.3 = 108.5$ MHz and in Table XI for the 3-signal case $106.1 + 105.3 - 103.3 = 108.1$ MHz.

TABLE X — *Effect of modulation on equi-signal levels for the 2-signal intermodulation product:
2(106.9) – 105.3 = 108.5 MHz*

Localizer signal status	Modulation		Measured equi-signal levels (dBm)													
	f_1 (MHz) 106.9	f_2 (MHz) 105.3	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L 108.50	RX L 108.55	RX M
On	On-air	On-air	-27	-24	-20	-21	-23	-20	-27	-34	-29	-33	-39	-37	-34	-39
On	CCIR	CW	-26	-24	-20	-21	-23	-19	-27	-33	-28	-34	-38	-36	-34	-38
On	CW	CCIR	-27	-25	-21	-22	-24	-19	-28	-34	-28	-34	-39	-36	-32	-39
On	Pink	CW	-26	-24	-20	-21	-23	-19	-27	-33	-28	-33	-38	-36	-34	-38
On	CW	Pink	-27	-25	-21	—	-24	-19	-28	-34	-29	-34	-39	-36	-32	-39
On	Tape	CW	-28	-25	-21	-23	-23	-19	-28	-35	-29	-35	-40	-38	-34	-40
Off	On-air	On-air	-30	-34	Nil	-26	Nil	Nil	Nil	-30	Nil	-37	Nil	Nil	-39	Nil
Off	CCIR	CW	Nil	-28	Nil	-24	Nil	Nil	Nil	Nil	Nil	-22	Nil	Nil	-39	Nil
Off	CW	CCIR	Nil	-10	Nil	Nil	Nil	Nil	Nil	—	—	Nil	Nil	Nil	-36	Nil
Off	Pink	CW	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Off	CW	Pink	Nil	Nil	Nil	—	Nil	Nil	Nil	—	—	Nil	Nil	—	Nil	—
Off	Tape	CW	-27	-33	Nil	-27	Nil	Nil	Nil	Nil	Nil	-33	Nil	Nil	-38	Nil

RX: Receiver

3.3.1.2 In tests where there was a desired localizer signal present, the different type of modulation resulted in only a 1-2 dB change in equi-signal levels and agreed closely with those obtained when the on-air broadcast signals were used.

3.3.1.3 In the tests where there was no wanted signal present, the on-air signals were able to cause interference in about one-half of the receivers tested in the 2-signal case and about one-third of the receivers in the 3-signal case. It was noted that when the flag indicator dropped from view (falsely indicating the presence of a valid localizer signal), the equi-signal level was a few dB to 10 dB less than that required to cause type B1 interference when a localizer signal was present. The CCIR coloured noise modulation was not able to cause interference in the 3-signal case; however, in the 2-signal case, coloured noise modulation of f_1 (the highest FM broadcast frequency in the intermodulation product) was able to cause interference in some of the receivers, whereas similar modulation of f_2 (the other broadcasting frequency) was unable to cause interference. The pink noise modulation was unable to cause interference in tests where there was no localizer signal present.

3.3.1.4 As an additional test in the 2-signal case, receiver L was tuned to 108.55 MHz while the intermodulation product remained at 108.50 MHz (see Table X). It was found that this receiver was more susceptible to interference when there was a frequency difference of 50 kHz between the intermodulation product and the tuned localizer frequency.

3.3.1.5 Based on these tests, CCIR coloured noise was used to modulate broadcasting frequency f_1 in the receiver intermodulation tests.

TABLE XI – *Effect of modulation on equi-signal levels for the 3-signal intermodulation product:
106.1 + 105.3 – 103.3 = 108.1 MHz*

Localizer signal status	Modulation			Measured equi-signal levels (dBm)												
	f_1 (MHz) 106.1	f_2 (MHz) 105.1	f_3 (MHz) 103.3	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L	RX M
On	On-air	On-air	On-air	-20	-20	Nil	-20	-22	Nil	-23	-32	-23	-30	-34	-29	-36
On	CCIR	CW	CW	-20	-21	-17	-20	-22	-16	-24	-34	-25	-30	-36	-30	-36
On	CW	CCIR	CW	-20	–	-17	-20	-22	-17	-24	-32	-24	-30	-36	-30	-35
On	Pink	CW	CW	-20	-21	Nil	-20	-22	-16	-24	-32	-24	-30	-36	-30	-36
On	CW	Pink	CW	–	–	–	-20	-22	-16	-24	-32	-25	-31	–	-30	-36
On	Tape	CW	CW	-21	-21	-18	-22	-23	-17	-25	-33	-28	-32	-37	-32	-38
Off	On-air	On-air	On-air	-25	-28	Nil	-24	Nil	Nil	Nil	–	Nil	-31	Nil	Nil	Nil
Off	CCIR	CW	CW	–	Nil	Nil	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil
Off	CW	CCIR	CW	Nil	–	–	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil
Off	Pink	CW	CW	Nil	Nil	Nil	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil
Off	CW	Pink	CW	–	–	–	Nil	Nil	Nil	Nil	–	Nil	Nil	–	–	–
Off	Tape	CW	CW	-16	-6	Nil	Nil	Nil	Nil	Nil	–	Nil	Nil	Nil	Nil	Nil

RX: Receiver

3.3.2 Receiver intermodulation tests

3.3.2.1 The results of the 2-signal tests are contained in Table XII and plotted in Figs. 21, 22 and 23 for localizer frequencies 108.1, 109.1 and 110.1 MHz respectively. Similarly, the results of the 3-signal tests are contained in Table XIII and plotted in Figs. 24, 25 and 26. In addition to the equi-signal level test data, theoretical levels were also calculated using the following different formulae (detailed in § 4 of this Annex):

- the existing immunity formulae in the Final Acts of the CARR-1(2), referred to as “CARR existing” in Tables XII and XIII;
- the future immunity formulae in the Final Acts of the CARR-1(2), referred to as “CARR future” in Tables XII and XIII. Note that the 3-signal formula was derived in § 4;
- the formulae of Document 20 submitted to the CARR-1(2) by the Federal Republic of Germany, referred to as “Doc CARR/20” in Tables XII and XIII. The basic difference from the “CARR existing” formulae is that the “Doc CARR/20” formulae contain frequency sensitive terms based on the actual LOC frequency, whereas the “CARR existing” formulae use the LOC band edge frequency of 108.1 MHz;
- the existing immunity formulae of the Joint Interim Working Party 8-10/1 Report, § 4.2.2, referred to as JIWP in Tables XII and XIII.

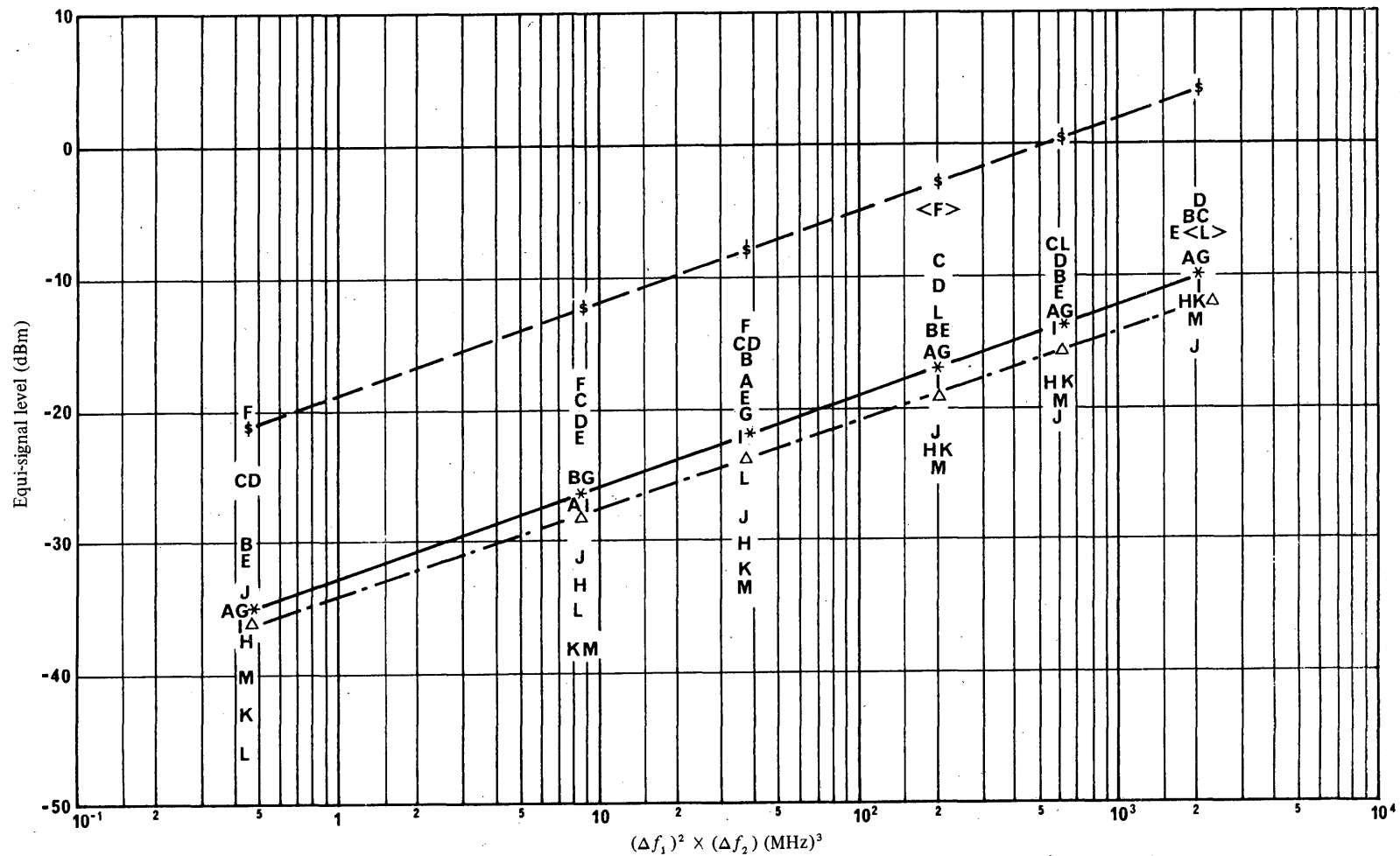


FIGURE 22 - 2-signal intermodulation on 108.1 MHz

- * CARR-1(2) existing immunity
 - - - \$ CARR-1(2) future immunity
 - · - · Δ CARR-1(2) Doc. 20
 - · · · JIWP 8-10/1 existing immunity
- } see Note

A-L: data points for receivers A to L inclusive from Tables XII and XIII

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$$\Delta f_i = f_{(LOC)} - f_i$$

$f_{(LOC)}$: localizer frequency (MHz)

f_i : broadcast frequency (MHz)

$$f_1 > f_2 > f_3$$

i : 1, 2, 3

Note. - JIWP curve and Doc. CARR/20 curve overlap.

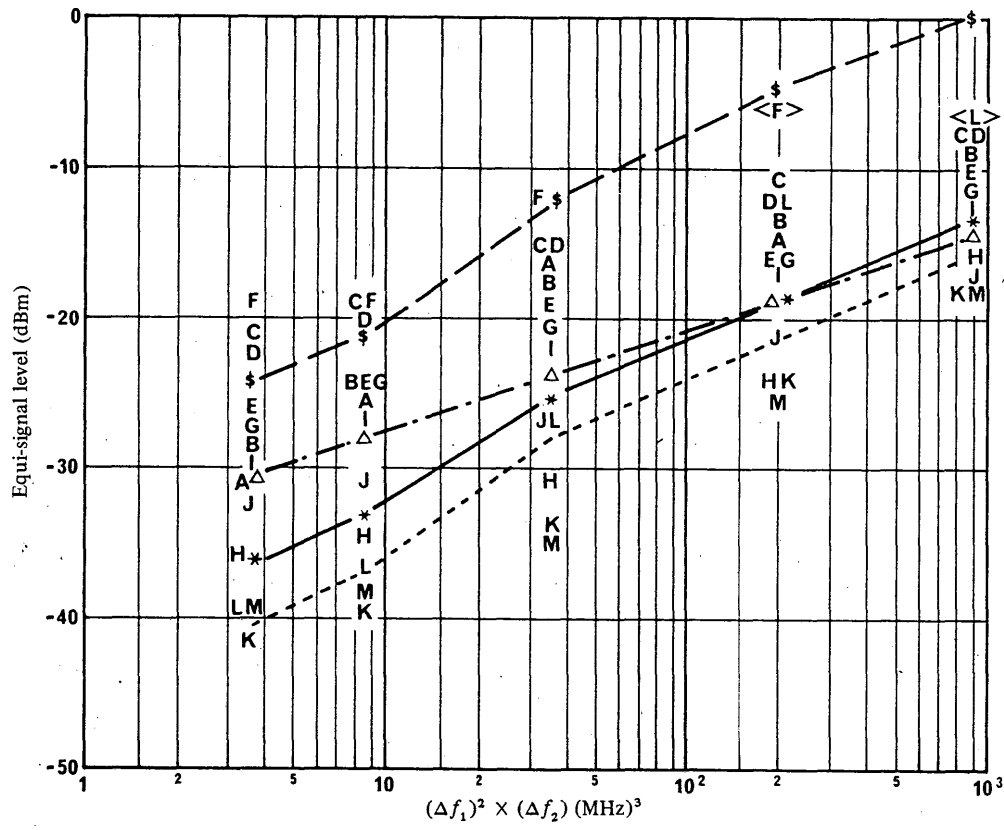


FIGURE 23 – 2-signal intermodulation on 109.1 MHz

- *— CARR-1(2) existing immunity
- \$— CARR-1(2) future immunity
- Δ— CARR-1(2) Doc. 20
- JIWP 8-10/1 existing immunity

A-L: data points for receivers A to L inclusive from Tables XII and XIII

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$$\Delta f_i = f_{(LOC)} - f_i$$

$f_{(LOC)}$: localizer frequency (MHz)

f_i : broadcast frequency (MHz)

$$f_1 > f_2 > f_3$$

i : 1, 2, 3

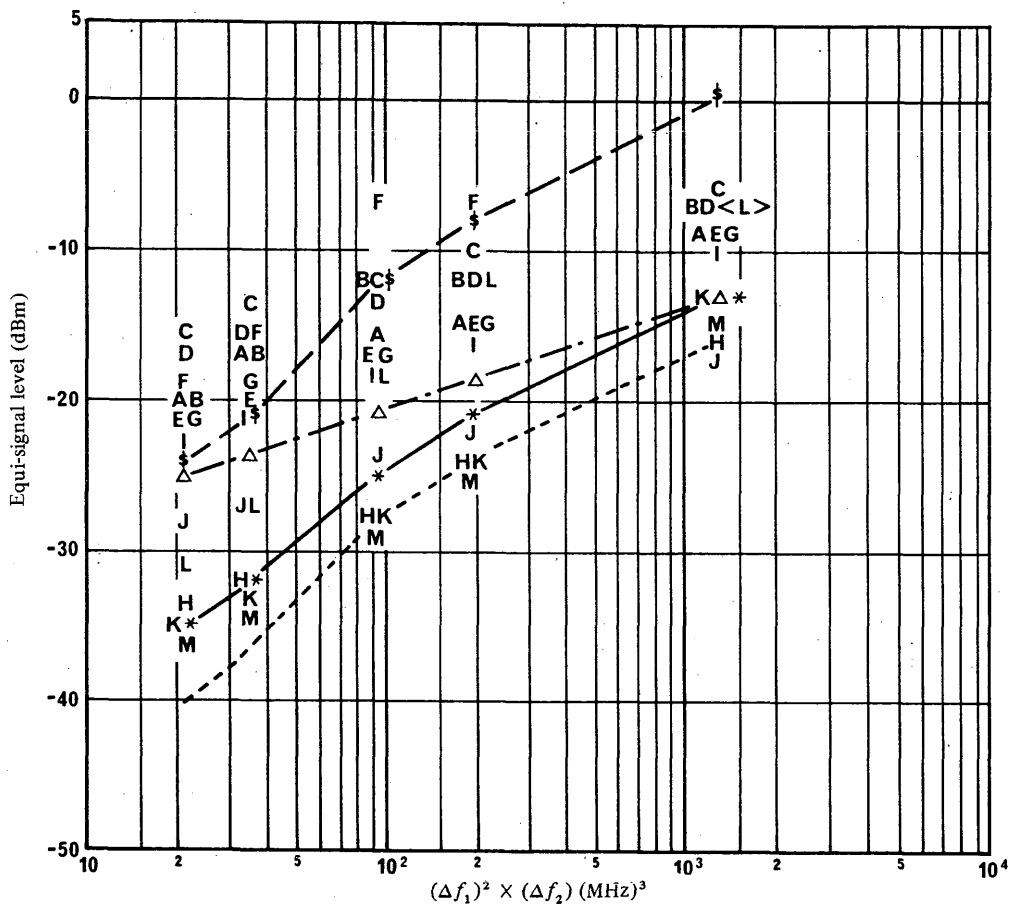


FIGURE 24 – 2-signal intermodulation on 110.1 MHz

- *— CARR-1(2) existing immunity
- \$--- CARR-1(2) future immunity
- Δ--- CARR-1(2) Doc. 20
- JIWP 8-10/1 existing immunity

A-L: data points for receivers A to L inclusive from Tables XII and XIII

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$\Delta f_i = f_{(LOC)} - f_i$

$f_{(LOC)}$: localizer frequency (MHz)

f_i : broadcast frequency (MHz)

$f_1 > f_2 > f_3$

i : 1, 2, 3

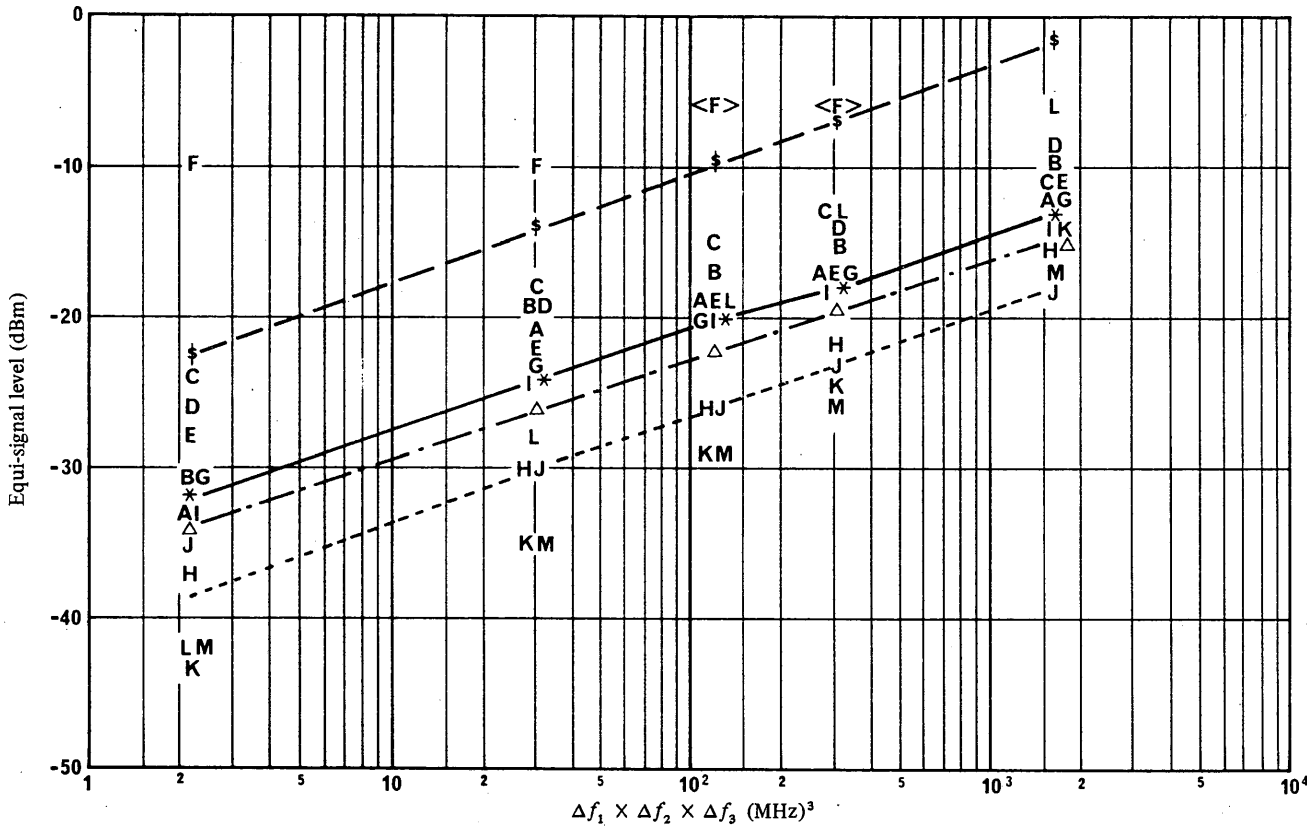


FIGURE 25 – 3-signal intermodulation on 108.1 MHz

- *— CARR-1(2) existing immunity
- \$— CARR-1(2) future immunity
- △— CARR-1(2) Doc. 20
- JIWP 8-10/1 existing immunity

A-L: data points for receivers A to L inclusive from Tables XII and XIII

<>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$$\Delta f_i = f_{(LOC)} - f_i$$

$f_{(LOC)}$: localizer frequency (MHz)

f_i : broadcast frequency (MHz)

$$f_1 > f_2 > f_3$$

i : 1, 2, 3

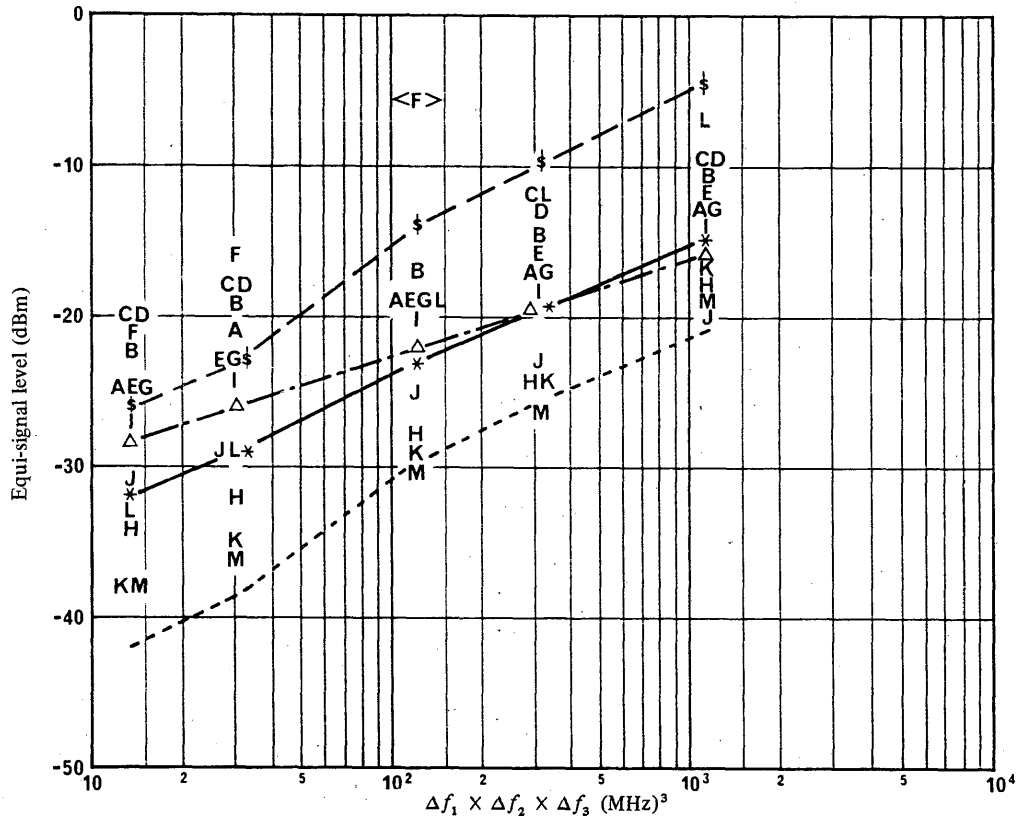


FIGURE 26 – 3-signal intermodulation on 109.1 MHz

- *— CARR-1(2) existing immunity
- \$— CARR-1(2) future immunity
- △ CARR-1(2) Doc. 20
- JIWP 8-10/1 existing immunity

A-L: data points for receivers A to L inclusive from Tables XII and XIII

<F>: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$$\Delta f_i = f_{(LOC)} - f_i$$

$f_{(LOC)}$: localizer frequency (MHz)

f_i : broadcast frequency (MHz)

$$f_1 > f_2 > f_3$$

i : 1, 2, 3

TABLE XII — Measured and calculated equi-signal levels for 2-signal, third-order receiver intermodulation (type B1) interference

Frequencies (MHz)			Measured equi-signal levels (dBm)													Calculated equi-signal (dBm)			
f_1	f_2	$f_{(LOC)}$	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L	RX M	Doc. CARR/ 20	CARR existing	CARR future	JIWP
107.5	106.9	108.1	-35	-30	-25	-25	-31	-20	-35	-37	-36	-34	-43	-46	-40	-36.4	-34.5	-20.5	-36.5
106.5	104.9	108.1	-27	-25	-19	-21	-22	-18	-25	-33	-27	-31	-38	-35	-38	-27.9	-26.0	-12.0	-28.0
105.5	102.9	108.1	-18	-16	-15	-15	-19	-14	-20	-30	-22	-28	-32	-25	-33	-23.7	-21.7	-7.7	-23.7
103.5	98.9	108.1	-16	-14	-9	-11	-14	> -5	-16	-23	-18	-22	-23	-13	-24	-18.7	-16.8	-2.8	-18.9
101.5	94.9	108.1	-13	-10	-8	-9	-11	-	-13	-18	-14	-20	-18	-8	-19	-15.6	-13.6	+0.3	-15.7
98.1	88.1	108.1	-9	-6	-6	-5	-7	-	-9	-12	-11	-15	-12	> -7	-13	-12.0	-10.0	+4.0	-12.0
107.9	106.7	109.1	-30	-28	-21	-22	-26	-19	-27	-36	-29	-32	-41	-39	-39	-30.4	-36.4	-24.0	-40.0
107.5	105.9	109.1	-25	-24	-19	-20	-24	-19	-24	-34	-26	-30	-39	-36	-38	-27.9	-32.7	-20.5	-36.5
106.5	103.9	109.1	-16	-17	-15	-15	-19	-12	-20	-30	-21	-26	-33	-26	-34	-23.7	-25.2	-12.0	-28.0
104.5	99.9	109.1	-14	-13	-10	-12	-15	> -6	-15	-24	-16	-21	-24	-12	-25	-18.7	-18.5	-4.9	-20.9
101.5	93.9	109.1	-	-9	-8	-8	-10	-	-11	-16	-12	-17	-18	> -7	-18	-14.4	-13.4	+0.3	-15.7
107.9	105.7	110.1	-20	-20	-16	-17	-21	-19	-21	-34	-23	-28	-35	-31	-36	-25.1	-34.8	-24.0	-40.0
107.5	104.9	110.1	-17	-17	-14	-16	-20	-16	-19	-32	-21	-27	-33	-27	-34	-23.7	-31.6	-20.5	-36.5
106.5	102.9	110.1	-16	-12	-12	-13	-17	-7	-17	-28	-18	-24	-28	-18	-29	-20.8	-24.5	-12.0	-28.0
105.5	100.9	110.1	-15	-12	-10	-12	-15	-7	-15	-24	-16	-22	-24	-12	-25	-18.7	-20.8	-7.7	-23.7
101.5	92.9	110.1	-9	-7	-6	-7	-9	-	-9	-16	-10	-17	-13	> -7	-15	-13.3	-13.2	+0.3	-15.7

RX: Receiver

TABLE XIII — Measured and calculated equi-signal levels for 3-signal,
third-order receiver intermodulation (type B1) interference

Frequencies (MHz)				Measured equi-signal levels (dBm)													Calculated equi-signal (dBm)			
f_1	f_2	f_3	f_{LO}	RX A	RX B	RX C	RX D	RX E	RX F	RX G	RX H	RX I	RX J	RX K	RX L	RX M	Doc. CARR/ 20	CARR existing	CARR future	JIWP
107.5	106.5	105.9	108.1	-33	-31	-24	-26	-28	-10	-31	-37	-33	-35	-43	-42	-42	-33.8	-31.9	-22.5	-38.5
106.5	104.5	102.9	108.1	-21	-19	-18	-19	-22	-10	-23	-30	-24	-30	-35	-28	-35	-26.1	-24.2	-14.0	-30.0
105.5	102.5	99.9	108.1	-19	-17	-15	-	-19	> -6	-20	-26	-20	-26	-29	-19	-29	-22.1	-20.2	-9.7	-25.7
104.5	100.5	96.9	108.1	-17	-15	-13	-14	-17	> -6	-17	-22	-18	-23	-24	-13	-25	-19.4	-17.5	-6.9	-22.9
101.5	95.3	88.7	108.1	-12	-10	-11	-9	-11	-	-12	-15	-14	-18	-14	-6	-17	-14.5	-12.6	-1.7	-17.7
107.9	106.3	105.1	109.1	-25	-22	-20	-20	-25	-21	-25	-34	-27	-31	-38	-33	-38	-28.5	-31.8	-26.0	-42.0
107.5	105.5	103.9	109.1	-21	-19	-18	-18	-23	-16	-23	-32	-24	-29	-35	-29	-36	-26.1	-28.6	-22.5	-38.5
106.5	103.5	100.9	109.1	-19	-17	-	-	-19	> -6	-19	-28	-20	-25	-29	-19	-30	-22.1	-22.5	-14.0	-30.0
105.5	101.5	97.9	109.1	-17	-15	-12	-13	-16	-	-17	-24	-18	-23	-24	-12	-26	-19.4	-19.1	-9.7	-25.7
103.5	97.5	91.9	109.1	-13	-11	-10	-10	-12	-	-13	-18	-14	-20	-17	-7	-19	-15.7	-14.7	-4.6	-20.8
107.9	105.3	103.1	110.1	-19	-15	-15	-16	-20	-14	-20	-31	-21	-27	-31	-23	-32	-23.5	-29.1	-26.0	-42.0
107.5	104.5	101.9	110.1	-18	-15	-	-	-19	-6	-20	-29	-20	-25	-28	-20	-30	-22.1	-26.5	-22.5	-38.5
106.5	102.5	98.9	110.1	-16	-14	-12	-13	-17	> -6	-16	-25	-17	-23	-24	-12	-26	-19.4	-21.3	-14.0	-30.0
104.5	98.5	92.9	110.1	-13	-10	-10	-10	-12	-	-12	-19	-14	-20	-16	> -7	-22	-15.7	-15.9	-6.9	-22.9
99.5	98.7	88.1	110.1	-10	-7	-9	-8	-9	-	-10	-15	-12	-16	-13	-	-15	-13.1	-12.7	+0.6	-15.4

RX: Receiver

In Figs. 22 to 27 inclusive, the parameters plotted on the horizontal axis are meaningful because the intermodulation mechanism depends on the product of frequency differences (see § 4) and because the data calculated using the Doc CARR/20 formulae will form a straight line on semi-logarithmic graph paper.

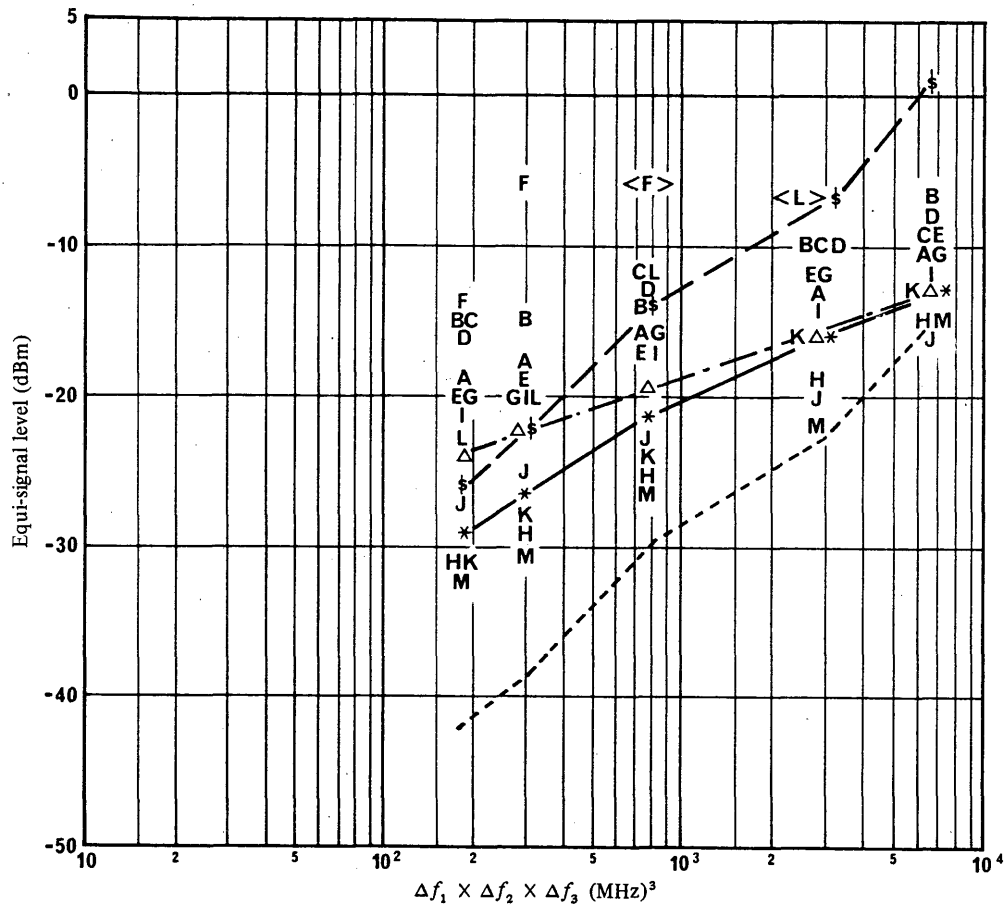


FIGURE 27 – 3-signal intermodulation on 110.1 MHz

- * CARR-1(2) existing immunity
- \$ CARR-1(2) future immunity
- Δ CARR-1(2) Doc. 20
- JIWP 8-10/1 existing immunity

A-L: data points for receivers A to L inclusive from Tables XII and XIII

< >: maximum amplitude limit of test set-up; actual equi-signal level higher than this level

$$\Delta f_i = f_{(LOC)} - f_i$$

$f_{(LOC)}$: localizer frequency (MHz)

f_i : broadcast frequency (MHz)

$$f_1 > f_2 > f_3$$

i : 1, 2, 3

3.3.2.2 Figures 22 to 27 inclusive indicate that, based only on bench tests results, approximately one-third of the receivers tested were not protected by the CARR-1(2) existing immunity formulae.

3.3.2.3 None of the receivers tested met the CARR-1(2) future immunity specification for all 2-signal intermodulation combinations at 108.1, 109.1 and 110.1 MHz; one receiver did, however, exceed the specification at 109.1 and 110.1 MHz. Some receivers exceeded the future immunity specification at 109.1 and 110.1 MHz for small differences between the localizer frequency and highest broadcasting frequency.

3.3.2.4 Only one receiver exceeded the possible future immunity specification for all 3-signal intermodulation combinations at 108.1, 109.1 and 110.1 MHz; some receivers exceeded the specification at 109.1 and 110.1 MHz for small differences between the localizer frequency and highest broadcasting frequency.

3.3.3 Effect of increased localizer signal levels

3.3.3.1 Table XIV shows the effect of varying the level of the localizer signal on the interfering equi-signal levels. For a 30 dB increase in localizer signal (i.e. from -90 dBm to -60 dBm), the corresponding increase in equi-signal levels was non-linear and ranged from a low of 4 dB for receiver A to a high of 23 dB for receiver M.

TABLE XIV – Effect of varying localizer signal level on interfering equi-signal levels

Frequencies (MHz)			Measured equi-signal levels (dBm)																			
			Receiver A				Receiver I				Receiver J				Receiver L				Receiver M			
f_1	f_2	f_{LOC}	LOC signal (dBm)				LOC signal (dBm)				LOC signal (dBm)				LOC signal (dBm)				LOC signal (dBm)			
			-90	-80	-70	-60	-90	-80	-70	-60	-90	-80	-70	-60	-90	-80	-70	-60	-90	-80	-70	-60
107.5	106.9	108.1	-36	-32	-26	-23	-38	-33	-27	-18	-36	-30	-24	-17	-47	-44	-39	-32	-39	-34	-25	-16
106.5	104.9	108.1	-27	-25	-21	-19	-27	-23	-18	-13	-32	-26	-22	-16	-36	-32	-24	-19	-37	-31	-21	-14
105.5	102.9	108.1	-18	-16	-13	-14	-21	-18	-14	-10	-27	-23	-19	-14	-25	-21	-17	-14	-31	-27	-18	-11
103.5	98.9	108.1	-16	-12	-9	-6	-16	-13	-9	-6	-22	-18	-16	-12	-12	-9	-7	-	-22	-20	-12	-7
101.5	94.9	108.1	-13	-9	-6	-	-13	-10	-7	-	-20	-15	-14	-10	-8	> -6	-	-	-17	-15	-8	-
107.9	105.7	110.1	-23	-19	-15	-10													-36	-30	-21	-14
107.5	104.9	110.1	-21	-18	-13	-9													-34	-28	-19	-12
106.5	102.9	110.1	-18	-15	-11	-7													-28	-24	-15	-10
105.5	100.9	110.1	-15	-12	-9	> -7													-24	-21	-12	-8

3.3.4 Effect of unequal interfering signal levels

3.3.4.1 Three receivers were tested to determine if equations of the form $2N_1 - N_2 = K$ (2-signal type B1) hold for unwanted signal levels N_1 and N_2 which differ from each other. Referring to Tables XV and XVI, it is seen that the range of signal levels for which the equation is valid varies from +7 dBm to -80 dBm. The difference between signal levels for a given intermodulation product was as great as 62 dB for the 2-signal case and 87 dB for the 3-signal case. The limiting condition is the generation of type B2 desensitization when one of the signals is too large.

4. Localizer/VOR receiver immunity formulae

4.1 Third-order intermodulation interference (type B1)

Let: f_i = the i^{th} FM frequency: f_1, f_2, f_3 (MHz)

and: N_i = the i^{th} FM received power level (dBm)

then: a_i = $\max \{0.4; 108.1 - f_i/0.4\}$

and: $a(f_i) = 20 \log(a_i)$

Note. – No interference when formulae are satisfied.

4.1.1 Annex 10 to the ICAO Convention – future immunity

Reference: Annex 10 to the ICAO Convention, § 3.1.4 (ILS) and 3.3.8 (VOR).

4.1.1.1 2 signal

$$2N_1 + N_2 - 3a(f_1) + 72 < 0$$

TABLE XV — 2-signal type B1 effects with unequal signal levels
(Illustrating the wide range of signal levels for which the type B1 equation holds)

2-signal $2[f_{(1)}] - f_{(2)} = f_{(ILS)}$ $f_{(ILS)} = 108.7 \text{ MHz}$		
Interfering signal level (dBm)		$2(N_1) + N_2$ (dBm)
$N_1(f_1)$	$N_2(f_2)$	
-50 -20	-7 -68	-107 -108
-10 -40	-71 -9	-91 -89
-30 0	+1 -62	-59 -62
-20 0 10	+5 -38 -60	-35 -38 -40
-10 0 +10	+2 -17 -38	-18 -17 -18

Note. — Five different frequency combinations for $f_{(1)}$ and $f_{(2)}$ were used yielding five different summations.

TABLE XVI — 3-signal type B1 effects with unequal signal levels
(Illustrating the wide range of signal levels for which the type B1 equation holds)

3-signal $f_{(1)} + f_{(2)} - f_{(3)} = f_{(ILS)}$ $f_{(ILS)} = 109.3 \text{ MHz}$			
Interfering signal level (dBm)			$N_1 + N_2 + N_3$ (dBm)
$N_1(f_1)$	$N_2(f_2)$	$N_3(f_3)$	
+1 -40	-40 +1	+1 +1	-38 -38
-70 -80 -60	+2 +7 -1	+2 +7 -1	-66 -66 -62

Note. — Two different sets of frequencies $f_{(1)}$, $f_{(2)}$ and $f_{(3)}$ are represented.

4.1.2 *JIWP 8-10/1 – existing immunity*

Reference: JIWP 8-10/1 report, § 4.2.2.

4.1.2.1 *2 signal*

$$2N_1 + N_2 - 3a(f_1) + 120 < 0$$

4.1.2.2 *3 signal*

$$N_1 + N_2 + N_3 - 3a(f_1) + 126 < 0$$

4.1.3 *JIWP 8-10/1 – future immunity*

Reference: JIWP 8-10/1 report, § 4.4.2.

4.1.3.1 *2 signal*

$$2N_1 + N_2 - 3a(f_1) + 72 < 0$$

4.1.3.2 *3 signal*

$$N_1 + N_2 + N_3 - 3a(f_1) + 78 < 0$$

4.1.4 *CARR-1(2) – existing immunity*

Reference: CARR-1(2) Final Acts, Annex 2, § 7.6.5.

4.1.4.1 *2 signal*

$$2N_1 + N_2 - 2a(f_1) - a(f_2) + 120 < 0$$

4.1.4.2 *3 signal*

$$N_1 + N_2 + N_3 - a(f_1) - a(f_2) - a(f_3) + 126 < 0$$

4.1.5 *CARR-1(2) – future immunity*

Reference: CARR-1(2) Final Acts, Annex 5, § 1.2.1.

4.1.5.1 *2 signal*

$$2N_1 + N_2 - 3a(f_1) + 72 < 0$$

4.1.5.2 *3 signal*

The Final Acts of CARR-1(2) specify a future immunity formula for the 2-signal case only, but states that a comparable relaxation in the criterion for the 3-signal case could possibly be expected. Based on this assumption, expansion of the 2-signal case to the 3-signal case yields:

$$N_1 + N_2 + N_3 - 3a(f_1) + 78 < 0$$

4.1.6 *Annex V – existing immunity*

Reference: JIWP 8-10/1 report, Annex V.

4.1.6.1 *2 signal*

$$2N_1 - 2a(f_1) + N_2 - a(f_2) + 120 < 0$$

4.1.6.2 *3 signal*

$$N_1 - a(f_1) + N_2 - a(f_2) + N_3 - a(f_3) + 126 < 0$$

4.1.7 *CARR-1(2) – type B1 correction term*

Reference: CARR-1(2), Final Acts, Annex 2, § 7.6.5.3

where: N_i (corrected) = N_i – correction termand: $i = 1, 2, 3$

Δf $f_{(ILS)} - f_{(intermod)}$ (kHz)	Correction term (dB)
0	0
± 50	2
± 100	8
± 150	16
± 200	26

4.1.8 CARR-1(2) Doc. 20 formulae – existing immunity

Reference: Doc. CARR-1(2)/20, Federal Republic of Germany.

Let: $\Delta f_i = f_{(LOC)} - f_i$

where $f_{(LOC)}$: actual localizer frequency

then: $a(f_i) = 20 \log (\Delta f_i/0.5)$ for $\Delta f_i \geq 0.4$

$a(f_i) = 0$ for $\Delta f_i < 0.4$

4.1.8.1 2-signal case

$$2N_1 + N_2 - 2a(f_1) - a(f_2) + 120 < 0$$

4.1.8.2 3-signal case

$$N_1 + N_2 + N_3 - a(f_1) - a(f_2) - a(f_3) + 126 < 0$$

4.2 Desensitization (B2 type)

See Fig. 28.

4.3 Co-channel interference (type A1)

Reference: JIWP 8-10/1 § 4.2.2 (current immunity)

§ 4.4.2 (future immunity)

CARR-1(2) Final Acts, Annex 2, § 7.6.3.3 (current and future immunity)

Δf (kHz)	JIWP protection ratio (dB)	CARR-1(2) protection ratio (dB)
0	17	17
± 50	10	10
± 100	5	– 4
± 150	2	– 19
± 200	– 1	– 38

4.4 Side-band interference (type A2)

Reference: JIWP 8-10/1 § 3.5.2.2 (current immunity)

CARR-1(2) Final Acts, Annex 2, § 7.6.4 (current and future immunity)

Δf (kHz)	JIWP protection ratio (dB)	CARR-1(2) protection ratio (dB)
100	–	– 41
200	– 50	– 50
250	–	– 59
300	– 68	– 68
500	– 72	–

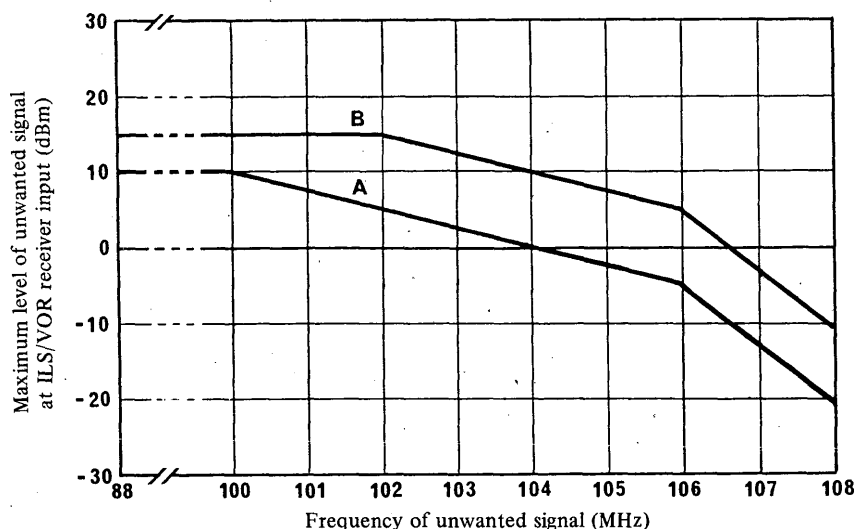


FIGURE 28 – ILS/VOR desensitization immunity criteria (type B2)

A: existing immunity:

- JIWP 8-10/1, § 4.2.2
- CARR 1(2), Final Acts, Annex 2, § 7.6.6

B: future immunity:

- JIWP 8-10/1, § 4.4.2
- CARR 1(2), Final Acts, Annex 5, § 1.2.2
Annex 10 to the ICAO Convention,
Amendment 65, § 3.1.4.2

REPORT 1051

PUBLIC MOBILE TELEPHONE SERVICE WITH AIRCRAFT

(Question 74/8)

(1986)

1. Introduction

1.1 This Report deals with the general principles of a public mobile telephone service to aircraft and, in particular, with operational and technical characteristics which are important for satisfactory operation.

1.2 Public mobile telephone systems considered in this Report are defined as aircraft systems for public correspondence which are connected to the international public switched telephone network (PSTN).

1.3 Various efforts are under consideration by different administrations and organizations to implement systems to provide this service. It should be noted that a VHF/UHF terrestrial system, even if international agreement is reached on technical compatibility, could not provide this service over oceanic or polar areas. All aspects set out below should be considered in future systems, whether they use terrestrial or space techniques.

1.4 Features of the terrestrial system developed in Japan are presented in Annex I.

2. General operational considerations for public mobile telephone service with aircraft

2.1 The system should be fully compatible and capable of interfacing with the international public switched telephone network, and simple in operation.

2.2 An adequate number of channels should be provided to meet the foreseeable demand for the service.

- 2.3 The system should be modular in design, with the capability of meeting single or multiple channel requirements.
- 2.4 The quality of service should be comparable to that of the public switched network (voice and data).
- 2.5 The system should provide, in so far as possible, uninterrupted coverage throughout the designated service areas with the capability of coordinated operation across national borders.
- 2.6 A capability to call to and from aircraft is desirable.
- 2.7 Automatic setting-up and administrative handling of calls to and from the mobile stations should be provided.
- 2.8 The system must have no influence on the safe operation of the aircraft.

3. System technical characteristics for public mobile telephone service with aircraft

3.1 Frequency band

3.1.1 To be determined. (International operation depends upon agreement regarding an adequate amount of spectrum in suitable bands.)

3.2 Modulation

3.2.1 Various types of modulation, for example FM, PM, ACSSB (amplitude companded SSB), and SSB-AM, have been proposed. Each method has advantages and disadvantages in communication quality, spectrum efficiency and economy. Further study is needed to aid in reaching international agreement regarding the types of modulation to be used.

3.3 Signalling

3.3.1 A completely automatic public mobile telephone system for use with aircraft requires an advanced signalling method for call control and channel acquisition.

3.3.2 Examples of such signalling systems are contained in Report 742.

3.4 Voice and data encoding

3.4.1 To be determined.

3.5 Airborne equipment

3.5.1 Size and weight of equipment should be minimal.

3.5.2 If possible, the equipment should make provision for other communication functions.

3.5.3 The airborne equipment must be electromagnetically compatible with other aircraft systems in accordance with appropriate regulatory requirements.

3.5.4 The system should have minimal impact on aircraft engineering, maintenance and operations.

4. Conclusion

4.1 It is recognized that this Report represents only an initial step in defining the operational and technical factors to be considered regarding a public mobile telephone service with aircraft. Further study is needed on many aspects of the proposed system to facilitate arriving at international standards.

ANNEX I

PUBLIC MOBILE TELEPHONE SYSTEM WITH AIRCRAFT IN JAPAN

1. Introduction

In Japan, a public mobile telephone system with aircraft has been developed. This system is economically realized through partial joint operation with the land mobile telephone (cellular) network. Moreover it is configured in the form of an integrated mobile communication system.

2. Operational features

Operational features are as follows:

- fully automatic direct-dial operation in conjunction with the public switched telephone network (PSTN);
- roaming : location registration and remote file access;

- hand-off;
- speech/non-speech service;
- service for not only airlines but also for general aviation use;
- coverage of almost all regular domestic air routes.

3. System functions

The system configuration is shown in Fig. 1.

The system functions are as follows:

- the system is composed of mobile station equipment installed on board aircraft and land station equipment on the ground;
- the land station equipment consists of the following components:
 - transmitters and receivers for transmission of various signals over a radio path;
 - mobile control station equipment for controlling the speech path set-up;
 - exchange equipment for connecting the mobile network and public switched telephone network (PSTN);
- the mobile control station and exchange equipment are used in common with the land mobile telephone system;
- speech path set-up control for both air-to-ground and ground-to-air calls is realized by a single radio channel, and the control messages are fully digitized;
- speech quality that meets the requirements for public telephone service is obtained.

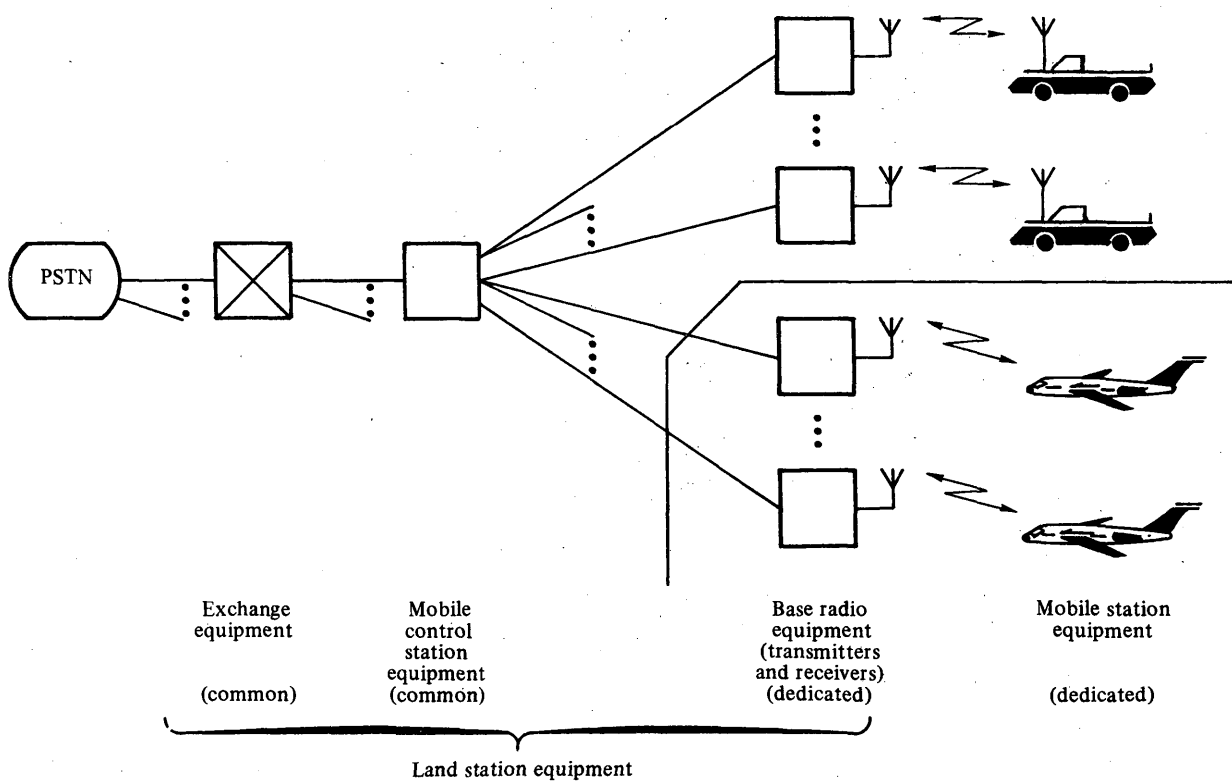


FIGURE 1 – System configuration

4. Technical characteristics

Technical characteristics are based on the land mobile telephone (cellular) system (see Report 742-1 and [CCIR, 1982-86a]).

The major characteristics are shown in Table I.

TABLE 1 — *Technical characteristics*

Frequency (MHz)		800-900
Channel spacing (kHz)		25
Total number of duplex channels		80
Type of modulation		PM
Power output (W)	Base station	40
	Mobile station	10

The modulation type is phase modulation, which is better than SSB-AM in that less receiver input power is required, especially for non-speech digital signal transmission. Also, transmission quality degradation due to Doppler shift is negligible and equipment cost is low.

5. Conclusion

This system is planned to go into service in 1986.

REFERENCES

CCIR Documents
[1982-86]: a. 8/401 (Japan).

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 text of this Question can be found in Volume VIII-1.

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 text of this Question can be found in Volume VIII-1.

STUDY PROGRAMME 7A-3/8

**TECHNICAL CHARACTERISTICS OF LAND MOBILE EQUIPMENT
BETWEEN 25 AND 1000 MHz**

(1966-1974-1981-1984)

The text of this Study Programme can be found in Volume VIII-1.

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 text of this Study Programme can be found in Volume VIII-1.

STUDY PROGRAMME 7C-1/8

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

(1966-1974)

The text of this Study Programme can be found in Volume VIII-1.

STUDY PROGRAMME 7E/8

FREQUENCY PLANNING METHODS FOR THE LAND MOBILE SERVICE

(1980)

The text of this Study Programme can be found in Volume VIII-1.

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 text of this Question can be found in Volume VIII-1.

STUDY PROGRAMME 12A-1/8

RADIO-PAGING SYSTEMS

Standardization of code and format

(1980-1986)

The text of this Study Programme can be found in Volume VIII-1.

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 CCIR,

CONSIDERING

- (a) Recommendations 312 and 405 of the World Administrative Radio Conference (Geneva, 1979), Recommendation 313 (Rev. Mob-83) and Recommendation 604 (Rev. Mob-83) of the World Administrative Radio Conference for Mobile Services (Geneva, 1983);
- (b) that the International Maritime Satellite Organization (INMARSAT) has been established,

* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

UNANIMOUSLY DECIDES that the following question should be studied with respect to aircraft and/or ships:

1. what are the preferred types and technical and operating characteristics of the following systems:
 - 1.1 mobile-satellite system;
 - 1.2 radiodetermination-satellite system;
2. what are the preferred frequency bands for such systems;
3. are combined systems for radiocommunication and radiodetermination purposes feasible and advantageous;
4. is the sharing of frequencies with other systems feasible, and if so, with what other systems and under what conditions;
5. what are the various technical and operating problems concerning communication and/or radiodetermination systems using satellite techniques for aircraft and/or ships, when relevant factors, such as traffic distribution, system complexity, economic efficiency, interfacing with terrestrial telecommunication networks, and new types of services, are taken into account?

Note. — See Reports 912 and 924.

STUDY PROGRAMME 17A-1/8*

TECHNICAL CHARACTERISTICS OF SYSTEMS PROVIDING COMMUNICATION AND/OR RADIODETERMINATION USING SATELLITE TECHNIQUES FOR AIRCRAFT AND/OR SHIPS

(1968-1970-1980)

The CCIR,

CONSIDERING

- (a) that there is a need for more reliable long-distance communication between land stations and:
 - aircraft,
 - ships;
- (b) that systems employing space communication techniques could be employed to ensure a service of sufficient reliability;
- (c) that communication with aircraft and ships will be needed for the transmission of telephony and telegraphy (including data transmission, direct printing, facsimile) or both;
- (d) that in the interest of conservation of the radio-frequency spectrum and to minimize the equipment which aircraft and ships carry, there might be overall merit in establishing a joint and/or adjacent aeronautical mobile/maritime mobile communication band;
- (e) that the use of common satellites for the mobile services — aeronautical and maritime — might be advantageous, especially if the same order of frequency were used;
- (f) that important advantages, including those of frequency economy, might arise from combined systems for communication and radiodetermination,

* The Director, CCIR, is requested to bring this Study Programme to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the International Maritime Satellite Organization (INMARSAT) and through the Secretary-General of the ITU, the United Nations Committee on the Peaceful Uses of Outer Space, and, in particular, to invite the cooperation of ICAO, INMARSAT and IMO in this study. This Study Programme should also be brought to the attention of Study Group 4.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the preferred types of orbit to provide:
 - 1.1 communication via satellite between aeronautical earth stations in the aeronautical mobile-satellite service and aircraft and between coast earth stations in the maritime mobile-satellite service and ships;
 - 1.2 a radiodetermination satellite service for aircraft and for ships;
2. the preferred frequencies and technical characteristics for:
 - 2.1 satellite-aircraft links;
 - 2.2 satellite-ship links;
 - 2.3 satellite-feeder links;
3. the technical feasibility of developing and operating satellite systems for both the aeronautical mobile-satellite service and the maritime mobile-satellite service;
 - 3.1 in the same frequency bands;
 - 3.2 in the same frequency bands as other space and/or terrestrial services;
4. the technical feasibility of developing and operating systems employing space communication techniques jointly for communication and radiodetermination purposes for aircraft and/or for ships.

Note. — See Recommendations 546, 549, Reports 509, 599, 751, 752, 754, 758, 760, 762 to 768, 917, 920 to 923 and 1050.

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 CCIR,

CONSIDERING

- (a) Recommendations No. 201 (Rev. Mob-83), and No. 604 (Rev. Mob-83) of the World Administrative Radio Conference for Mobile Services, (Geneva, 1983);
- (b) that the bands 121.45 to 121.55 MHz and 242.95 to 243.05 MHz have been also allocated to the mobile-satellite service for the reception on-board satellites of emissions from emergency position indicating radio beacons (EPIRB) transmitting at 121.5 and 243 MHz;
- (c) that the technical characteristics of EPIRBs transmitting at 121.5 and 243 MHz are given in Appendix 37A (Mob-83);
- (d) that the use of the band 406.0 to 406.1 MHz which is allocated to the mobile-satellite service is limited to low power satellite emergency position-indicating radio beacons;
- (e) that the bands 1544 to 1545 MHz (space-to-Earth) and 1645.5 to 1646.5 MHz (Earth-to-space) have been allocated to the mobile-satellite service and are limited to distress and safety operations,

* The Director, CCIR, is requested to bring this Study Programme to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT) and invite them to cooperate in the study.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the feasibility of using the frequencies allocated to the mobile-satellite service, especially for ships and survival craft, in particular with regard to distress, search and rescue and safety operations;
2. the operating, technical and economic consequences of employing a single frequency band or multiple frequency bands for shipboard equipment, satellite EPIRBs, and other satellite facilities;
3. determination of the role of maritime mobile-satellite in a coordinated distress system, as well as in safety operations.

Note. — See Reports 761 and 919.

STUDY PROGRAMME 17F-2/8

AVAILABILITY OF CIRCUITS IN THE MARITIME MOBILE-SATELLITE SERVICE

(1978-1980-1981)

The CCIR,

CONSIDERING

- (a) that continuity of traffic on established links in the maritime mobile-satellite service may be interrupted by equipment failure or by natural phenomena (solar interference, attenuation due to multipath or atmospheric effects);
- (b) that the interruptions may be divided into self-restoring interruptions (protection switching, natural phenomena) and interruptions which include repair time;
- (c) that site diversity of earth stations and protection switching, to increase availability when required, convert long interruptions to very brief ones;
- (d) that traffic may be interrupted by sudden variations of signal level at baseband, by the complete disappearance of the wanted signal or by a high level of noise or, in the case of digital transmission systems, by bursts of errors;
- (e) that in planning a satellite link, decisions must be taken on receive signal margins, protection switching, etc. which have a major impact on the link availability and the cost of its provision;
- (f) that availability requirements may be different for different types of transmission (telephony, telegraphy, data transmission);
- (g) that the duration of some interruptions may depend on the configuration of the satellite network: they may also depend on whether earth stations are always attended or unattended at the onset of an interruption and on whether or not the earth station antennas are readily steerable to point from one satellite to another;
- (h) that the shore-to-ship and ship-to-shore hypothetical telephone reference channels are dissimilar;
- (j) that, since the shore-satellite link is fixed and the ship-satellite link is mobile, they may need to be considered independently;
- (k) that ship earth stations will be subject to environmental conditions that vary not only with time but also with the location of the ship within the satellite coverage area;
- (l) that a reliable communication system will have a positive impact on ship, crew and passenger safety;
- (m) that reliable communications are desirable even under adverse conditions;
- (n) that terms and definitions that are required in connection with these studies should, as far as possible, be based on internationally accepted expressions,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. rate of incidence and the duration of self-restoring and other interruptions to be expected in modern satellite systems between points defined by the hypothetical reference circuit;
2. for satellite links with and without site diversity protection, the proportion (in frequency and in duration) of interruptions due to propagation effects;
3. preferred characteristics (e.g. switching time) for equipment protection arrangements;
4. proportion of interruptions due to maintenance, including human error;
5. preferred characteristics of devices that would prevent malfunctioning of other systems connected in tandem at baseband;
6. ship earth station availability, taking account of such factors as redundancy, tracking capability, etc.;
7. compilation of a list of terms and definitions currently used in the documents of various international bodies dealing with terminology which are applicable to these studies, and a list of additional terms and definitions which may be required.

Note. — See Report 918.

STUDY PROGRAMME 17G/8*

FREQUENCY SHARING BETWEEN THE MARITIME MOBILE-SATELLITE SERVICE AND THE SPACE OPERATION SERVICE IN THE 1530-1535 MHz BAND

(1981)

The CCIR,

CONSIDERING

- (a) Recommendation No. 708 of the World Administrative Radio Conference, Geneva, 1979;
- (b) that the frequency band 1530 to 1535 MHz has been allocated on a shared basis to the maritime mobile-satellite service (space-to-Earth) and to the space operation service (space-to-Earth);
- (c) that the allocation to the maritime mobile-satellite service of the band 1530 to 1535 MHz shall be effective from 1 January 1990,

UNANIMOUSLY DECIDES that the following study should be carried out:

the criteria for frequency sharing between the maritime mobile-satellite service (space-to-Earth) and the space operation service (space-to-Earth) in the frequency band 1530 to 1535 MHz.

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.

* The Director, CCIR, is requested to bring this Study Programme to the attention of the International Maritime Organization (IMO), the International Maritime Satellite Organization (INMARSAT) and Study Group 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 text of this Question can be found in Volume VIII-1.

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 CCIR,

CONSIDERING

- (a) that there are frequency bands allocated to the mobile-satellite service which could have earth stations on ships, land and/or aircraft all operating within the same system;
- (b) that the operating and technical characteristics of the mobile-satellite service may differ from those particularly applicable to the aeronautical mobile-satellite service, land mobile-satellite service or maritime-satellite service;
- (c) that the frequency bands are shared with other services in most cases;
- (d) that a number of networks are in existence or are planned for the mobile-satellite service in these frequency bands;
- (e) that the operational characteristics of earth stations in the mobile-satellite service may result in coordination requirements for earth stations and space stations different from those found in the fixed-satellite service,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the preferred technical and operating characteristics for a mobile-satellite system which would have earth stations on ships, land and/or aircraft all operating within the same system;
2. what are the technically preferred multiple access and modulation methods for such a system;
3. what are the preferred performance characteristics of earth stations and space stations for such a system;
4. what are the sharing criteria for networks in the mobile-satellite service;
5. what are the sharing criteria between networks in the mobile-satellite service and other services sharing the same frequency bands?

Note. — See Reports 771, 772 and 773.

STUDY PROGRAMME 32A/8**

**A GLOBAL LOW-ORBIT SATELLITE SYSTEM FOR DETECTION
AND POSITIONING OF LOW-POWER TRANSMITTERS**

(1980)

The CCIR,

CONSIDERING

- (a) that many of the current available terrestrial systems for alerting and radiodetermination services suffer from technical shortcomings which cannot be overcome without unreasonably high costs;
- (b) that the technique for systems based on satellites for these needs is developing rapidly;

* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

** The Director, CCIR, is requested to bring this Study Programme to the attention of the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Maritime Satellite Organization (INMARSAT).

- (c) that different system concepts for search and rescue in maritime and partly also in the aeronautical field employing geostationary satellites and low altitude polar orbiting satellites will be tested and evaluated in the near future;
- (d) that strong requirements exist today, and will probably grow stronger with time, for systems for detection and positioning in remote areas;
- (e) that these requirements could be obtained by utilizing a satellite system employing low-orbit satellites, with active ranging facilities;
- (f) that the total costs for establishing a highly reliable low-orbit satellite system will be high and may require the participation of many countries;
- (g) that the requirement for keeping the terminal costs reasonable is internationally agreed;
- (h) that the availability of frequency spectrum for such applications is limited,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the preferred technical and operating characteristics of a future global low-orbit satellite system for detection and positioning of low-power transmitters;
2. the possibilities of incorporating such a system as part of an existing or planned low-orbit satellite system.

QUESTION 33-1/8

**INTERFERENCE TO RADIONAVIGATION SERVICES FROM OTHER SERVICES
IN THE BANDS BETWEEN 70 kHz AND 130 kHz**

(1976-1978)

The 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 text of this Question can be found in Volume VIII-1.

QUESTION 37-1/8

**SYSTEMS WITH IMPROVED SPECTRUM EFFICIENCY
FOR THE LAND MOBILE SERVICE**

(1978-1982)

The text of this Question can be found in Volume VIII-1.

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 text of this Question can be found in Volume VIII-1.

STUDY PROGRAMME 39A/8

FUTURE PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEMS

(1985)

The text of this Study Programme can be found in Volume VIII-1.

QUESTION 40-2/8

DIGITAL TRANSMISSION IN THE LAND MOBILE SERVICE

(1978-1982-1986)

The text of this Question can be found in Volume VIII-1.

STUDY PROGRAMME 40A/8

DIGITIZED SPEECH TRANSMISSION IN THE LAND MOBILE SERVICE

(1982)

The text of this Study Programme can be found in Volume VIII-1.

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 CCIR,

CONSIDERING

- (a) the importance of using the radio frequency spectrum as efficiently as possible;
- (b) the continuing development of airborne electronic equipment using digital techniques;
- (c) a considerable proportion of aeronautical air-ground-air communications is of a routine or semi-routine nature;
- (d) the future need for exchange of digital data between aircraft and the ground to exploit the potential of automated processing systems now being introduced on the ground for air traffic control, for airline control of operations and for utilizing instrumental outputs on-board the aircraft;
- (e) the need to detect and correct errors in the two-way information exchange between aircraft and ground stations sufficiently to ensure meeting the overall communication integrity and flight safety requirements;
- (f) the effects on the transmission characteristics of screening and multipath reflections in the air-ground radio propagation path and the effects of interference on communications in the aeronautical (R) bands;
- (g) the characteristics of aircraft radio systems, particularly the limited radiated power, the antenna directional properties and the high radio noise levels,

UNANIMOUSLY DECIDES that the following question should be studied:

in the bands allocated for the aeronautical mobile (R) service:

1. what is the optimum coding method for information which is to be transferred in air-ground-air digital data communications;
2. what are the optimum methods of providing the degree of error protection required;
3. what are the optimum methods of modulation for the air-ground and ground-air digitized data transmissions?

Note 1. — The Director, CCIR, is requested to bring this Question to the notice of ICAO and to invite that Organization to make its requirements known to the CCIR.

Note 2. — See Reports 769 and 928.

QUESTION 47-1/8

PREFERRED TECHNICAL AND OPERATIONAL CHARACTERISTICS FOR THE LAND MOBILE-SATELLITE SERVICE

(1978-1982)

The CCIR,

CONSIDERING

- (a) that there may be a need for the land mobile-satellite service;
- (b) that there is an increasing need for land mobile systems to extend the benefits of radiocommunications to the largest possible number of users;
- (c) that the assumed need for a land mobile-satellite service must be analysed and, in particular, the desirable operational requirements;
- (d) that the World Administrative Radio Conference (Geneva, 1979) has adopted Recommendation No. 1 relating to the use of space radiocommunication systems in the event of natural disasters, epidemics, famines and similar emergencies;
- (e) that the scope for development and future application of land mobile-satellite systems may depend to a great extent upon the feasibility of sharing frequency bands used by other services, without mutual interference;
- (f) that it may not in all cases be possible for such systems to share frequency bands with other services, because of mutual interference;
- (g) that the operational requirements will have a decisive influence upon the capacity requirements of future systems and in consequence the requisite frequency bandwidth;
- (h) that the efficiency of orbit-spectrum utilization in land mobile-satellite systems will be determined in part by the technical characteristics employed, such as modulation methods and parameters, frequency re-use techniques or the arrangement of radio frequency carriers;
- (j) that the establishment of land mobile-satellite systems may require international agreement on the technical characteristics to be employed, including baseband, modulation and radio frequency characteristics;
- (k) that satellite communications with land mobile earth stations have been successfully demonstrated,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what requirements are foreseen for systems in the land mobile-satellite service;
2. for these requirements:
 - 2.1 what are the technically preferred range of frequencies and modulation methods for the land mobile-satellite service and the associated penalties for each;
 - 2.2 what are the preferred performance characteristics of earth stations and space stations in systems of this service;
 - 2.3 to what extent frequencies may be shared between this service and other services and what sharing criteria are applicable;
 - 2.4 what system characteristics must be defined to ensure compatibility with other systems and to ensure making most effective use of frequency bands which may be allocated?

Note. — See Reports 770 and 925.

QUESTION 48-1/8

TECHNIQUES AND FREQUENCY USAGE IN THE AMATEUR SERVICE

(1978–1982)

The text of this Question can be found in Volume VIII-1.

QUESTION 49/8

RADIOCOMMUNICATION FOR SHORT-RANGE HEARING AIDS

(1978)

The text of this Question can be found in Volume VIII-1.

QUESTION 50/8

TECHNICAL FEASIBILITY OF FREQUENCY SHARING BY THE AMATEUR SATELLITE SERVICE

(1972–1974)

The text of this Question can be found in Volume VIII-1.

QUESTION 51-1/8

AUTOMATIC DETERMINATION OF LOCATION IN THE LAND MOBILE SERVICE

(1982–1986)

The text of this Question can be found in Volume VIII-1.

QUESTION 52-1/8

**INTEGRATION OF PUBLIC MOBILE RADIOCOMMUNICATION SERVICES
IN THE VHF/UHF FREQUENCY BANDS**

(1982-1986)

The text of this Question can be found in Volume VIII-1.

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 (NB-PSK) 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 text of this Question can be found in Volume VIII-1.

QUESTION 57/8

**SHARING CRITERIA FOR THE INTER-SATELLITE SERVICE
AND THE RADIONAVIGATION SERVICE IN THE BAND 32-33 GHz**

(1982)

The CCIR

CONSIDERING

Recommendation No. 707 of the World Administrative Radio Conference (Geneva, 1979),

UNANIMOUSLY DECIDES that the following question should be studied:

what are the sharing criteria for the inter-satellite service and the radionavigation service in the band 32-33 GHz?

QUESTION 58-1/8

TECHNICAL CHARACTERISTICS OF MARITIME RADIOBEACONS

(1982-1986)

The text of this Question can be found in Volume VIII-2.

QUESTION 60/8*

**BROADCASTING AND AERONAUTICAL RADIONAVIGATION SERVICES
IN THE LF BANDS**

Interference between Regions

(1982)

The CCIR,

CONSIDERING

- (a) that the use, in Region I, of the LF bands by high power broadcasting stations could cause harmful interference to aeronautical radionavigation service non-directional beacons (NDB) operating in the same bands in Regions 2 and 3;
- (b) that non-directional beacons are used world-wide as a prime source of basic navigational data in the aeronautical radionavigation service;
- (c) that the aeronautical radionavigation service is a safety service;
- (d) that No. 2854 of the Radio Regulations states that the assignment of frequencies to aeronautical radio beacons in the bands 160 to 435 kHz shall be based on a protection ratio against interference of at least 15 dB for each beacon throughout its service area;
- (e) that No. 346 of the Radio Regulations states the basic principle of the equality of right to operate and accordingly, the stations of each service on one Region must operate so as not to cause harmful interference to services in other Regions;

* The Director of the CCIR is requested to bring this Question to the attention of ICAO. This Question should also be brought to the attention of Study Groups 5, 6 and 10.

(f) that the Plan contained in Annex I to the Final Acts of the Regional Administrative LF/MF Broadcasting Conference (Regions 1 and 3), Geneva, 1975, includes a number of new broadcasting transmitters and increases in power of transmitters already in use, thereby changing the probability of harmful interference to the safety services;

(g) that Resolution No. 500 of the WARC (Geneva, 1979) provides for a downward shift in the carrier frequencies of broadcasting transmitters in the LF band in Region 1, to take effect progressively from 1 February, 1986,

UNANIMOUSLY DECIDES that the following question should be studied:

what are the criteria for compatible operation which ensure that no harmful interference occurs between the broadcasting service in Region 1 and the aeronautical radionavigation service (non-direction beacons) in Regions 2 and 3, both operating as primary services in the same LF band in their respective Regions, taking into account:

- the agreed protection criteria for each service;
- the LF radio propagation characteristics;
- the characteristics of beacon receivers;
- the nominal usable field strengths;
- possible limitations which might result from mutual interference between transmitters within each service?

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 CCIR,

CONSIDERING

- (a) Recommendation No. 704 of the World Administrative Radio Conference (Geneva, 1979);
- (b) that two distinct and different aeronautical radionavigation systems operate in the band 108-118 MHz; namely:
 - Instrument Landing System (ILS) localizer (108-112 MHz);
 - VHF Omnidirectional Range (VOR) (108-118 MHz);
- (c) that the aeronautical mobile (R) service operates in the band 118-137 MHz;
- (d) that interference to these aeronautical services has been experienced by several mechanisms due to high-powered FM broadcast transmissions operating in the band 88-108 MHz;
- (e) that high-powered FM broadcast transmitters and VHF aeronautical receivers are sometimes operated in close geographic proximity of aerodrome facilities;
- (f) that high-powered FM broadcast signals are a potential source of interference to aeronautical receivers;
- (g) that the performance characteristics of airborne receiver installations may also cause incompatibility between the high-powered FM broadcasting and these VHF aeronautical services;
- (h) that transmissions from aeronautical transmitters may cause interference to the broadcasting service;
- (j) that it would be desirable to study possible methods of achieving compatibility between the aeronautical VHF services and the FM broadcasting service,

* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO). This Question should also be brought to the attention of Study Groups 1 and 10.

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the interference problems arising from the operation of the broadcasting service in the band of about 87-108 MHz and the different VHF aeronautical services in the band 108-137 MHz;
2. what is the susceptibility of existing and future aircraft receivers to the following types of interference arising from the operation of high-powered FM broadcasting stations at various power levels, frequency separations from the aeronautical frequency and relative distances between the broadcasting, aeronautical and aircraft stations:
 - desensitization (front-end overloading) of the receiver;
 - intermodulation generated in the receiver;
 - spurious emissions from FM broadcast stations and radiation produced by non-linear interaction between FM broadcast emissions;
3. what are the variations in the susceptibilities of existing airborne receivers to such interference and, in particular, in what measure is this variation due to differences in avionics equipment installation practices, e.g. antenna feeder cable lengths, antenna position on airframe, type of antenna;
4. what are the protection criteria applicable to the services involved;
5. what technical methods can be used to achieve compatibility between the FM broadcast service and the VHF aeronautical services?

Note. — See Recommendation 591 and Report 929.

QUESTION 62-1/8*

INTERFERENCE TO THE AERONAUTICAL MOBILE AND AERONAUTICAL RADIONAVIGATION SERVICES

(1982-1986)

The CCIR,

CONSIDERING

- (a) that the aeronautical radionavigation service is a safety service;
- (b) the increasing concern being expressed over the degree of control of harmful interference to the aeronautical mobile and aeronautical radionavigation services;
- (c) that the types of radiation which can cause harmful interference to these services can differ widely depending on the particular technical and operational characteristics involved;
- (d) that it may be possible in some cases to identify in detail the characteristics of the interfering radiation;
- (e) that the radiations from many of the potential sources of harmful interference are the subject of standards and measurement methods developed by the International Electrotechnical Commission (IEC);
- (f) that the practical control of harmful interference often needs to be effected by the national legislation of individual Administrations and it is common for the above-mentioned IEC standards and measurement methods to be adopted in this context;
- (g) that there would be considerable practical advantages if there were a better understanding of the relationships between these IEC test and measurement standards and the protection criteria for these services,

* The Director, CCIR, is invited to draw the attention of the International Civil Aviation Organization (ICAO), the International Electrotechnical Commission (IEC) and the CISPR to this Question.

UNANIMOUSLY DECIDES that the following question should be studied:

1. are the IEC/CISPR recommended limits and measurement methods adequate for the protection of these aeronautical services;
2. what methods can be recommended for stating detailed protection criteria taking into account the cumulative effects of interference, including that caused by other radio services and ISM?

Note. — See Reports 926 and 927.

QUESTION 63/8

**USE FOR THE RADIONAVIGATION SERVICE OF THE
FREQUENCY BANDS 2900-3100 MHz, 5470-5650 MHz,
9200-9300 MHz, 9300-9500 MHz AND 9500-9800 MHz**

(1982)

The 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 text of this Question can be found in Volume VIII-1.

QUESTION 68/8

**TECHNICAL CHARACTERISTICS FOR LAND MOBILE RADIO SYSTEMS
WHICH USE EQUIPMENT OF REDUCED COST
WITHOUT LOSS OF SYSTEM PERFORMANCE**

(1986)

The text of this Question can be found in Volume VIII-1.

QUESTION 69/8

**FREQUENCY SHARING BETWEEN THE MOBILE SERVICES AND THE BROADCASTING
SERVICE (TELEVISION) BELOW 1 GHz**

(1986)

The text of this Question can be found in Volume VIII-1.

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 text of this Question can be found in Volume VIII-1.

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 text of this Question can be found in Volume VIII-1.

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 text of this Question can be found in Volume VIII-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 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 certain number of countries;
- (b) that these systems serve primarily surface-operated mobile units;
- (c) that public correspondence is not permitted in bands allocated exclusively to the aeronautical mobile service;
- (d) that the public travelling in private and air transport aircraft are generally without public correspondence communications while airborne (see Radio Regulation No. 3571 Mob-83);
- (e) that user demand has been expressed for an automated airborne voice/data public correspondence system which should be capable of providing adequate capacity in all regions of operation;
- (f) that the operation of a public mobile telephone service with aircraft must not inhibit the operation of the aeronautical safety services;
- (g) that various national systems in use, or proposed, both terrestrial and satellite, are not necessarily compatible;
- (h) that for international operation it is essential to agree upon common parameters of the system for world-wide use;

* The Director, CCIR, is requested to bring this Question to the attention of the International Civil Aviation Organization (ICAO) and the CCITT.

- (j) that integration of satellite and terrestrial systems aboard aircraft may be advantageous;
- (k) Question 52/8 on the integration of public communication services in the VHF/UHF frequency bands,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what operational facilities and technical characteristics, including grade of service, need to be specified to permit international operation of a public mobile telephone service with aircraft;
2. from a technical point of view, what frequency bands are most suitable for a public mobile telephone service with aircraft using terrestrial and/or space techniques;
3. what are the system parameters and technical characteristics of equipment for use in a public mobile telephone service with aircraft using terrestrial and/or space techniques on which international agreement is desirable;
4. what level of integration, if any, with other public mobile telephone systems is practicable and in what time frame;
5. what protection criteria are required for the aeronautical safety services;
6. what degree of automatic operation is possible or desirable for the system?

Note. — See Report 1051.

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 text of this Question can be found in Volume VIII-1.

QUESTION 78/8*

**COORDINATION BETWEEN AN EARTH STATION AND MOBILE STATIONS
IN THE MOBILE SERVICES**

(1987)

The International Frequency Registration Board (IFRB),

CONSIDERING

- (a) the provisions of No. 326 of the International Telecommunication Convention (Nairobi, 1982);
- (b) that the present Appendix 28 to the Radio Regulations does not contain the sharing criteria to be used for coordination between an earth station of the fixed-satellite service, the maritime mobile-satellite service, the aeronautical mobile-satellite service or the land mobile-satellite service on the one hand and a mobile station of the land mobile service, the maritime mobile service or the aeronautical mobile service on the other hand;
- (c) that the Board, in its day-to-day application of the provisions of the Radio Regulations, encounters cases involving stations of the space and terrestrial services mentioned in (b) above and as such urgently needs guidance from the CCIR on a method to be used to determine the coordination area in such cases,

REQUESTS THE CCIR urgently to study the following question:

1. what characteristics should be used for the terrestrial mobile stations (land, maritime and aeronautical) to calculate a coordination area involving these stations;
2. what method should be used to identify administrations, the services of which may be affected when terrestrial mobile stations (ship or aircraft or a vehicle on land) and ship earth stations, aircraft earth stations or land earth stations are operating in the same area?

QUESTION 79/8**

**USE OF STEERABLE SPOT BEAMS BY SPACE STATIONS
IN THE GEOSTATIONARY-SATELLITE ORBIT**

(1987)

The International Frequency Registration Board (IFRB),

CONSIDERING

- (a) the provisions of No. 326 of the International Telecommunication Convention (Nairobi, 1982);
- (b) the inadequacy of suitable technical guidance to consider the interference potential created by the use of steerable spot beams from a space station on a geostationary-satellite orbit;
- (c) the urgent need of the IFRB to have such a guidance to enable it to treat cases of steerable spot beams used by such space stations within the framework of Appendix 29 to the Radio Regulations,

REQUESTS THE CCIR:

urgently to study the method to be used to calculate interference between satellite networks in which the space stations on the geostationary-satellite orbit use steerable spot beams.

* An identical text is allocated to Study Group 4 as Question 35/4.

** An identical text is allocated to Study Group 4 as Question 36/4.

QUESTION 80/8*

**SHARING BETWEEN THE EARTH EXPLORATION-SATELLITE SERVICE
OR THE METEOROLOGICAL-SATELLITE SERVICE ON THE ONE HAND
AND OTHER SPACE SERVICES OR THE METEOROLOGICAL AIDS SERVICE
ON THE OTHER**

(1987)

The International Frequency Registration Board (IFRB),

CONSIDERING

- (a) the provisions of No. 326 of the International Telecommunication Convention (Nairobi, 1982);
- (b) that Question 12-2/2 and Study Programmes 12A-2/2, 12B-1/2, 12C/2 and associated Reports and Recommendations do not provide the necessary information for the application of Appendices 28 and 29 to the Radio Regulations to frequency assignment notices to space or earth stations in the Earth exploration-satellite service and the meteorological-satellite service when the Board has to examine them with respect to the provisions of No. 1060 and No. 1107 of the Radio Regulations, as well as in cases where the Board has to apply other procedures, such as the procedure of Article 14, to these notices;
- (c) that in view of the urgency to treat the concerned frequency assignment notices, the Board adopted provisional Rules of Procedure in these cases (see Note);
- (d) that it is necessary for the Board to develop its Technical Standards to have the required information through appropriate Recommendations of the CCIR (see No. 1582 of the Radio Regulations),

REQUESTS THE CCIR:

to study the parameters which need to be used in application of Appendices 28 and 29 to the Radio Regulations when the Earth exploration-satellite service or the meteorological-satellite service shares the same frequency bands with the meteorological aids service or with other space services.

Note. — The provisional Rules of Procedure have been published in Documents 2/39, 4/129, 8/27, 9/136, IFRB (1986-1990).

* An identical text is allocated to Study Group 2 as Question 26/2, to Study Group 4 as Question 37/4.

QUESTION 81/8*

**COORDINATION AREA OF AN EARTH STATION OF THE
FIXED-SATELLITE SERVICE SHARING THE SAME
FREQUENCY BAND WITH THE RADIONAVIGATION SERVICE**

(1987)

The International Frequency Registration Board (IFRB),

CONSIDERING

- (a) the provisions of No. 326 of the International Telecommunication Convention (Nairobi, 1982);
- (b) that Question 17-1/9, Question 32/4, related Study Programmes 17E/9 and 17F/9 and 32A/4, 32B/4 and 32C/4, as well as the associated Reports and Recommendations of the CCIR, do not provide information permitting the application of the method of Appendix 28 to the Radio Regulations to calculate the coordination area of an earth station in the fixed-satellite service sharing the same frequency band with the radionavigation service;
- (c) that in view of the urgency to treat the concerned frequency assignment notices, the Board adopted provisional Rules of Procedure in these cases (see Note);
- (d) that it is necessary for the Board to develop its Technical Standards to have the required information through appropriate Recommendations of the CCIR (see No. 1582 of the Radio Regulations),

REQUESTS THE CCIR:

to study the situation of sharing referred to above and provide, as soon as possible, the parameters of the radionavigation service to be taken into account in applying the method described in Appendix 28 to the Radio Regulations in such a case.

Note. — The provisional Rules of Procedure have been published in Documents 4/130, 8/28, 9/137, IFRB (1986-1990).

* An identical text is allocated to Study Group 4 as Question 38/4.

QUESTION 82/8

SYSTEM CONCEPTS OF THE MOBILE-SATELLITE SERVICE

(1988)

The CCIR,

CONSIDERING

- (a) Recommendation No. 405 of the World Administrative Radio Conference (Geneva, 1979), and Recommendations Nos. 313 (Rev.Mob-83) and 312 (Rev.Mob-87);
- (b) that there is a need for more reliable long distance communication between existing terrestrial networks and mobile earth stations, such as maritime, aeronautical and land mobile stations;
- (c) that international connectivity among the various mobile-satellite services is important;
- (d) that integration of the various mobile-satellite services is now being studied to construct economical systems, provide users with useful services and to share the limited frequency resources effectively;
- (e) that integration of the mobile-satellite and land mobile services is also being studied to make more effective use of frequency resources and to provide an economic system;
- (f) that integration of mobile station equipment aboard aircraft for communications with satellite and terrestrial systems may be advantageous;
- (g) that a hypothetical reference circuit and path are needed to provide a guide for design and construction of systems for mobile-satellite services,

DECIDES that the following question should be studied:

1. what are the preferred fundamental system concepts in the following services:
 - 1.1 maritime mobile-satellite service;
 - 1.2 aeronautical mobile-satellite service;
 - 1.3 land mobile-satellite service;
2. what are the technical feasibility, advantages and preferred system concepts for providing communications between two or more of the above-mentioned services;
3. what are the technical feasibility, advantages and preferred system concepts for providing communications to enable mobile terminals to communicate using one or more of the above-mentioned services and terrestrial mobile services;
4. what are the technical requirements and preferred system concepts for interconnection of the above-mentioned services with terrestrial telecommunication services;
5. what are the technical and operational items to be recommended by the CCIR relating to each of the mobile-satellite services and integrated systems;
6. what is the preferred configuration of hypothetical reference circuit/path for mobile-satellite systems?

Note. — See Recommendation 546, Reports 768, 770, 771, 921 and 1051.

QUESTION 83/8

EFFICIENT USE OF THE RADIO SPECTRUM AND
SHARING OF FREQUENCY RESOURCES IN THE MOBILE-SATELLITE SERVICE

(1988)

The CCIR,

CONSIDERING

- (a) Resolution No. 208 (Mob-87) and Recommendation No. 104 (Mob-87) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1987);
- (b) that there are shared frequency bands allocated to different mobile-satellite services and other services;

- (c) that the operating and technical characteristics of a system supporting the mobile-satellite service may differ from those applicable specifically to the aeronautical mobile-satellite service, land mobile-satellite service or maritime mobile-satellite service;
- (d) that in the interest of conservation of the radio-frequency spectrum and to minimize the equipment which mobile units carry, there might be overall merit in establishing shared or adjacent frequency bands for the mobile services and the mobile-satellite services;
- (e) that the use of a common satellite for the mobile-satellite services might be advantageous, especially if the same band of frequencies were used;
- (f) that the operating characteristics of mobile stations may require different coordination measures from those used for the fixed-satellite service;
- (g) that integration of mobile station equipment aboard aircraft for communications with satellite and terrestrial systems may be advantageous,

DECIDES that the following question should be studied:

1. what are the preferred frequency bands for such systems including satellite to mobile earth station links, mobile earth station to satellite links and feeder links;
2. what are the preferred frequency bands for feeder links in the fixed-satellite service for the aeronautical mobile-satellite service, the land mobile-satellite service, the maritime mobile-satellite service and the mobile-satellite service operating in the bands 1530-1559 MHz and 1626.5-1660.5 MHz;
3. what is the feasibility of intersystem and intrasystem frequency sharing in the case of mobile-satellite systems, and sharing criteria;
4. what is the feasibility of frequency sharing between mobile-satellite services and other services, and sharing criteria;
5. what are the most suitable frequency bands for a public mobile telephone service with aircraft using terrestrial and space techniques;
6. what is the feasibility of frequency sharing between mobile-satellite systems which use non-geostationary orbits with systems which use the geostationary orbit;
7. what are the spot beam system planning concepts which provide for flexible frequency and power allocation to beams while providing for efficient use of the spectrum allocated to the mobile-satellite services;
8. what are the permissible interference criteria for intersystem frequency coordination;
9. what are the practical strategies for achieving efficient use of the geostationary orbit and frequencies allocated to the mobile-satellite services, recognizing that some networks will be optimized for regional coverage and some will be optimized for global coverage?

Note. — See Reports 765 and 773.

QUESTION 84/8

POTENTIAL TYPES OF ORBIT IN MOBILE-SATELLITE SERVICES

(1988)

The CCIR,

CONSIDERING

- (a) Recommendation No. 405 of the World Administrative Radio Conference (Geneva, 1979), Recommendation No. 313 (Rev.Mob-83) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1983);
- (b) that the geostationary-satellite orbit can provide global coverage within latitudes approximately between the 70° parallels from three satellite locations, and would be suitable for most maritime and aeronautical applications;
- (c) that congestion of the geostationary-satellite orbit is increasing rapidly, and utilization of other types of orbit could assist in relieving this congestion;

- (d) that important international civil air routes traverse polar regions, and communication with aircraft by satellite in such regions is important and desirable;
- (e) that the elevation angles from the geostationary orbit at higher latitudes are very low, accentuating the communication problems from multipath and shadowing effects;
- (f) that non-geostationary-satellite orbits may be applicable in a combined system with the radiodetermination-satellite service,

DECIDES that the following question should be studied:

what are the potential types of orbit to provide mobile-satellite services?

Note. — See Report 772.

QUESTION 85/8

AVAILABILITY OF CIRCUITS IN MOBILE-SATELLITE SERVICES

(1988)

The CCIR,

CONSIDERING

- (a) that service interruptions may be caused by natural and man-made phenomena, e.g. solar interference, ignition noise, attenuation due to multipath or atmospheric effects, which cause the disappearance of the wanted signal due to high levels of noise, or in the case of digital transmission systems, by resultant bursts of errors;
- (b) that the level of equipment provision and techniques adopted, e.g. site diversity, can improve availability;
- (c) that system parameters, e.g. receive signal margins, equipment redundancy, etc., affect link availability;
- (d) that availability requirements may be different for different types and directions of transmission (telephone, telegraphy, data transmission) and for different mobile-satellite services;
- (e) that since one section of the satellite link is fixed and the other section of the satellite link is mobile, they need to be considered independently;
- (f) that mobile earth stations will be subject to environmental conditions that vary not only with time but also with the location of the stations within the satellite coverage area;
- (g) that terms and definitions that are required in connection with these studies should, as far as possible, be based on internationally accepted expressions,

DECIDES that the following question should be studied:

1. what is the definition of availability in a hypothetical reference circuit;
2. what is the achievable system/link availability of a mobile-satellite system taking into account CONSIDERING (f);
3. what is the achievable availability of a land earth station, coast earth station, aeronautical earth station and base earth station;
4. what is the achievable availability of mobile earth stations taking into account CONSIDERING (f);
5. what is the preferred relationship between availability and propagation characteristics;
6. what are the preferred characteristics (e.g. switching time) for the arrangement of equipment protection;
7. what are the preferred characteristics of devices that would prevent malfunctioning of other systems connected in tandem at baseband;
8. what is the preferred compilation of a list of terms and definitions currently used in the documents of various international bodies dealing with terminology which is applicable to these studies, and a list of additional terms and definitions which may be required?

Note. — See Recommendations 547, 549, 552, Reports 764, 917, 918 and 1049.

QUESTION 86/8

PERFORMANCE OBJECTIVES FOR MOBILE-SATELLITE SERVICES

(1988)

The CCIR,

CONSIDERING

- (a) that cost aspects and system reliability will limit achievable signal-to-noise-ratio;
- (b) that the total noise power or bit error ratio in the hypothetical reference circuit as appropriate should not be such as would appreciably affect transmission of information;
- (c) that the extent of fading cannot be determined fully until more experimental data are available;
- (d) that the bit error ratio may vary with time due to the effect of varying propagation conditions, including the effects of multipath fading;
- (e) that the performance objectives may not be achieved for short periods due to the effect of other sources of noise, such as interference;
- (f) that CCIR Recommendation 522 defines bit error ratio requirements for fixed-satellite services for various percentages of any month;
- (g) that CCITT Recommendation G.821 defines ISDN bit error ratio requirements for various time intervals and also defines the permissible percentage of degraded minutes, severely degraded seconds and errored seconds (or equivalent error-free seconds);
- (h) that CCIR Report 997 has applied the bit error ratio performance quality measures used in CCITT Recommendation G.821 to the fixed-satellite services;
- (j) that less stringent performance objectives than those required for fixed-satellite services may be adequate for mobile-satellite services;
- (k) that different performance objectives may be appropriate to each of the various mobile-satellite services;
- (l) that a number of techniques such as time division multiple access (TDMA), single channel per carrier (SCPC), and low rate encoding (LRE) are being used in digital satellite links,

DECIDES that the following question should be studied:

1. what are the allowable noise power/bit error performance objectives and preferable noise power/bit error performance distributions in a hypothetical reference circuit/path (see Question 82/8);
 2. what is the preferred relationship between circuit noise power/bit error performance and propagation characteristics;
 3. what bit error ratios, defined over what time intervals, or defined over percentages of any month as in CCIR Recommendation 522, are appropriate to mobile-satellite services;
 4. what acceptable criteria relating to degraded minutes, severely degraded seconds and errored seconds (or equivalent error-free seconds), are appropriate to mobile-satellite services;
 5. which of the above criteria in 3 and 4 is appropriate or is a combination required?
-

QUESTION 87/8

**TRANSMISSION CHARACTERISTICS FOR A MOBILE-SATELLITE
COMMUNICATION SYSTEM**

(1988)

The CCIR,

CONSIDERING

- (a) Resolution No. 44 (Mob-87) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1987);
- (b) that the INMARSAT organization provides international mobile-satellite communications and other organizations plan to offer international or domestic mobile-satellite services;
- (c) that land and aeronautical mobile-satellite systems have been studied progressively in several countries and organizations;
- (d) that FM analogue modulation is used for telephony in the INMARSAT system at present and other analogue modulation techniques are being considered for the mobile-satellite services;
- (e) that digital communication techniques could provide efficient use of limited bandwidth and powers, and would support a wide variety of data communication services or message communication services;
- (f) that modulation techniques and systems should be robust under fading and shadowing conditions;
- (g) that the efficiency of orbit-spectrum utilization in mobile-satellite systems will be determined in part by the technical characteristics employed, such as modulation methods and parameters, impact of frequency re-use techniques or the arrangement of radio-frequency carriers,

DECIDES that the following question should be studied:

- 1. what are the preferred transmission characteristics for the following systems:
 - 1.1 land mobile-satellite system;
 - 1.2 maritime mobile-satellite system;
 - 1.3 aeronautical mobile-satellite system;
 - 1.4 mobile-satellite systems incorporating two or more of the above systems;
- 2. what are the technically preferred multiple access, modulation and coding methods for such systems;
- 3. what are the preferred performance characteristics of earth stations and space stations for such systems;
- 4. what terminal characteristics could be common to facilitate compatibility between the land, maritime, and aeronautical mobile-satellite services?

Note. — See Recommendations 548, 553, 550, Reports 509, 751, 760, 771 and 923.

QUESTION 88/8

**PROPAGATION AND MOBILE EARTH STATION ANTENNA
CHARACTERISTICS FOR MOBILE-SATELLITE SERVICES**

(1988)

The CCIR,

CONSIDERING

- (a) that antenna performance substantially affects system design in mobile-satellite services;
- (b) that multipath fading due to reflection and shadowing due to foliage in mobile-satellite systems are important factors in designing and constructing systems;

- (c) that there are various techniques which may be adopted for the pointing of antennas;
- (d) that the configuration of airborne antenna systems is severely constrained by its effect on aircraft performance;
- (e) that services using medium and low gain antenna systems are being examined by INMARSAT and other organizations;
- (f) that characteristics of multipath fading are being studied in CCIR Study Group 5 under Question 1/5,

DECIDES that the following question should be studied:

1. what are the preferred types of antenna systems and their characteristics for:
 - 1.1 shipborne use;
 - 1.2 airborne use;
 - 1.3 land use;
2. what fading and shadowing reduction techniques can be applied to mobile antenna systems in a mobile-satellite service?

Note. — See Reports 762, 763, 770, 902, 922, 925, 1047 and 1048.

QUESTION 89/8

COMPATIBILITY FOR INTERWORKING BETWEEN THE MOBILE-SATELLITE SYSTEMS AND TERRESTRIAL NETWORKS INCLUDING ISDN

(1988)

The CCIR,

CONSIDERING

- (a) that interconnection of mobile communication circuits with the terrestrial networks is required;
- (b) that interworking between a mobile-satellite system and the terrestrial networks is being studied by the CCITT;
- (c) that interworking between a mobile-satellite system and the ISDN is also being studied by the CCITT;
- (d) that mobile-satellite systems have inherent restrictions with regard to the channel characteristics resulting from the radio path;
- (e) that consideration of communication characteristics in the mobile-satellite service needs to take account of the CCITT studies and that the CCITT studies would benefit from CCIR consideration of their impact on the mobile-satellite service,

DECIDES that the following question should be studied:

1. what are the technical characteristics of future systems providing digital data and voice communication in the mobile-satellite service, taking into account the studies of the CCITT on interworking between mobile-satellite systems and the terrestrial networks;
 2. what are the preferred characteristics of the interface between ISDN and the systems in the mobile-satellite services?
-

QUESTION 90/8*

**TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS
PROVIDING RADIOCOMMUNICATION USING SATELLITE TECHNIQUES
FOR DISTRESS AND SAFETY OPERATIONS**

(1988)

The CCIR,

CONSIDERING

- (a) Resolution No. 205 (Rev.Mob-87) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1987);
- (b) Recommendation No. 201 (Rev.Mob-83) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1983) and Recommendation No. 604 (Rev.Mob-87);
- (c) that the use of the band 406.0 to 406.1 MHz (Earth-to-space) which is allocated to the mobile-satellite service is limited to low power satellite emergency position-indicating radio beacons;
- (d) that transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through a low polar-orbiting satellite system in the 406 MHz band have been evolved (Recommendation 633);
- (e) that the bands 1544 to 1545 MHz (space-to-Earth) and 1645.5 to 1646.5 MHz (Earth-to-space) have been allocated to the mobile-satellite service and are limited to distress and safety operations;
- (f) that transmission characteristics of a satellite emergency position-indicating radio beacon (satellite EPIRB) system operating through geostationary satellites in the 1.6 GHz band have been evolved (Recommendation 632);
- (g) that the International Maritime Organization (IMO) is placing a major reliance on the use of satellites for the relay of distress signals in the development and design of their Global Maritime Distress and Safety System (GMDSS), which is scheduled to become operational in the early 1990s,

DECIDES that the following question should be studied:

1. what are the preferred technical and operating characteristics of systems providing radiocommunication using low-orbiting or geostationary-satellite techniques, for distress and safety operations;
2. what are the various technical and operating problems and economic factors concerning radiocommunication systems using satellite techniques for ships, aircraft and land mobile units (including satellite EPIRBs and ELTs), in particular with regard to distress, search and rescue and safety operations;
3. what are the conditions for compatibility between satellite EPIRBs in the band 406-406.1 MHz and services using adjacent bands?

Note. — See Recommendations 632, 633, Reports 749, 761, 912, 919, 1042, 1045 and 1046.

QUESTION 91/8

**TECHNICAL AND OPERATING CHARACTERISTICS OF
THE RADIODETERMINATION-SATELLITE SERVICE**

(1988)

The CCIR,

CONSIDERING

- (a) Resolution No. 708 (Mob-87) of the World Administrative Radio Conference for the Mobile Services (Geneva, 1987);
- (b) that there is a need for reduction of the cost of terminal equipment;

* The Director of the CCIR is requested to bring this Question to the attention of ICAO, IMO and INMARSAT.

- (c) that few frequency bands are available for radiodetermination-satellite services;
- (d) that there are various radiodetermination systems;
- (e) that important advantages, including those of frequency economy, might result from integrated systems for communication and radiodetermination,

DECIDES that the following question should be studied:

1. what are the preferred system concepts and technical and operating characteristics of systems in the radiodetermination-satellite service;
2. what are the preferred frequency bands for radiodetermination-satellite services;
3. what is the technical feasibility of frequency sharing between the radiodetermination-satellite service and other services, and sharing criteria (considering the bands 1610-1626.5 MHz, 2483.5-2500 MHz and 2500-2516.5 MHz with the aeronautical radionavigation, fixed, mobile, radiolocation and radioastronomy services);
4. what are the potential interference conditions between the radiodetermination-satellite service and the services in adjacent frequency bands;
5. what is the technical and operational feasibility of an integrated system for communication and radiodetermination;
6. what are the preferred types of orbit for the radiodetermination-satellite service?

Note. — See Reports 766 and 1050.

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 text of this Resolution can be found in Volume VIII-1.

OPINION 42-1

**METHODS OF MEASUREMENT OF TECHNICAL CHARACTERISTICS
OF EQUIPMENT FOR THE LAND MOBILE SERVICE
BETWEEN 25 AND 1000 MHz**

(1970-1974)

The text of this Opinion can be found in Volume VIII-1.

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 text of this Opinion can be found in Volume VIII-1.

OPINION 73

**INTERFERENCE DUE TO MAN-MADE NOISE IN THE
VARIOUS MOBILE SERVICES**

(1982)

The text of this Opinion can be found in Volume VIII-1.

DECISION 32-4*

**TECHNICAL AND OPERATING CHARACTERISTICS OF SYSTEMS IN THE
MARITIME MOBILE-SATELLITE SERVICE**

(Question 17/8)

(1978-1980-1981-1984-1985)

CCIR Study Group 8,

CONSIDERING

- (a) that the maritime mobile-satellite service will need agreement on the technical and operating characteristics of future systems and services which may be used;
- (b) that there will be a large number of users of satellite systems in the Future Global Maritime Distress and Safety System (FGMDSS);
- (c) Recommendation 312 of the World Administrative Radio Conference, Geneva, 1979, and Recommendation 201 (Mob-83);
- (d) that the CCIR has completed the development of Recommendations for satellite EPIRBs operating with geostationary satellites at 1.6 GHz and with polar-orbiting satellites at 406 MHz (see Recommendations 632 and 633);
- (e) that the IMO and INMARSAT are interested in having the CCIR continue its study on specific characteristics of the FGMDSS and that particular attention should be drawn to satellite distress alerting systems and associated trials,

DECIDES

1. that Interim Working Party 8/7 (IWP 8/7) should be maintained;
2. that the Interim Working Party shall continue its work on technical and operational characteristics of satellite subjects necessary in connection with the FGMDSS, including the following areas:
 - 2.1 means to obtain up-date of position information with geostationary satellite EPIRBs with an estimation of required accuracy of position location;
 - 2.2 means to minimize effects of potential interference to satellite EPIRB systems;
 - 2.3 factors related to the integration of geostationary and polar-orbiting satellite systems;
 - 2.4 technical and operating characteristics of satellite systems for promulgation of maritime safety information including shore-to-ship distress alerting;
3. that this IWP shall determine for the maritime mobile-satellite service:
 - 3.1 the characteristics of systems employing medium gain and low gain antennas and the interface between these systems and the terrestrial networks;
 - 3.2 technical characteristics of speech coding techniques for possible implementation in the new systems referred to in § 3.1 above;
 - 3.3 technical and operating characteristics of satellite systems for safety and distress, including use of low G/T ship earth-stations and an interface with ships' navigation equipment (see also Question 55/8);
 - 3.4 practicability of new services, for example public correspondence with aircraft, including their possible technical and operating characteristics (see also Question 74/8);
 - 3.5 technical and operating characteristics of systems providing radiodetermination through maritime mobile satellites used for communications;
4. that the IWP shall, as required, study and prepare contributions on the maritime mobile-satellite service necessary for the 1987 World Administrative Radio Conference for the Mobile Services (WARC MOB-87);
5. that the Interim Working Party should also carry out any additional studies referred to CCIR by the IMO or the INMARSAT Organization and agreed by the Chairman of Study Group 8 in consultation with the Director, CCIR. The additional studies would be circulated to all administrations participating in the work of Study Group 8;

* The Director, CCIR, is requested to bring this Decision to the attention of the CCITT, the International Maritime Organization (IMO), and the International Maritime Satellite Organization (INMARSAT).

6. that the Chairman and the composition of Interim Working Party 8/7 shall be as shown in Annex I;
7. that the Interim Working Party should attempt as far as practicable to carry out its work by correspondence. However, to ensure that basic studies are to be completed within an acceptable time scale, meetings may be called as necessary.

ANNEX I

The following Administrations, International Organizations and Recognized Private Operating Agencies have indicated that they wished to participate in the work of Interim Working Party 8/7:

Administrations:

Germany (Federal Republic of)
 Argentina
 Australia
 Brazil
 Canada
 China (People's Republic of)
 Denmark
 United States of America
 France
 India
 Italy
 Japan
 Norway
 New Zealand
 Netherlands
 Poland (People's Republic of)
 United Kingdom
 Sweden
 U.S.S.R.

International Organizations and Recognized Private Operating Agencies:

IMO
 INMARSAT Organization
 ESA
 CIRM

International Telecommunication Union:

IFRB

Chairman of Interim Working Party 8/7:

Mr. Y. Hirata
 Research and Development Laboratories
 Kokusai Denshin Denwa Co. Ltd. (KDD)
 1-23 Nakameguro 2-Chome
 Meguro-Ku, Tokyo 153
 Japan
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DECISION 69

FUTURE PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEMS

(1985)

The text of this Decision can be found in Volume VIII-1.

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)

CCIR Study Groups 8 and 10,

CONSIDERING

- (a) Question 61/8 and Question 46/10;
- (b) Recommendations GTECH/1 and GTECH/2 of the Regional Administrative Conference for FM Sound Broadcasting in the VHF Band (Region 1 and certain countries concerned in Region 3), Geneva, 1984;
- (c) the provisions of Resolution 24;
- (d) that the need for compatibility between the broadcasting and aeronautical services is recognized as a world-wide matter;
- (e) that the studies could best be carried out jointly between Study Groups 8 and 10,

DECIDE

1. that Joint Interim Working Party 8-10/1 should continue its work;
2. that this Joint Interim Working Party should study:
 - 2.1 compatibility between the aeronautical radionavigation service and the sound broadcasting stations in the bands concerned and in particular:
 - 2.1.1 protection ratio values for future airborne receivers against spurious emissions from sound broadcasting stations (referred to as A1 type of interference) in cases where the frequency of the spurious emissions does not coincide with the aeronautical frequency;
 - 2.1.2 protection ratio values for present and future aeronautical receivers against out-of-band emissions from sound broadcasting stations (referred to as A2 type of interference);
 - 2.1.3 criteria for prediction of third-order intermodulation (referred to as B1 type of interference) generated in airborne receivers by three unwanted signals, for receivers meeting the ICAO standard for two-signal intermodulation for future receivers;
 - 2.1.4 the effect of sinusoidal modulation of the sound broadcasting transmitters during test and line-up and any precautions or procedures to be adopted at broadcasting stations in order to maintain the agreed protection of the aeronautical radionavigation service;
 - 2.2 compatibility between the aeronautical mobile (R) service and the sound broadcasting service in the bands concerned;
 - 2.3 compatibility criteria that can be used to predict potential interference in an assignment decision context including the determination of the correlation of bench tests with in-service operational performance of aeronautical receivers;
3. the Joint Interim Working Party shall report at regular intervals to Study Groups 8 and 10. The Joint Interim Working Party shall at regular intervals inform Study Group 1 of the progress of its work;
4. that as far as practicable the work should be conducted by correspondence, but that it may meet on the proposal of its Chairman, following consultation with the Director, CCIR;
5. that the Chairman and composition of Joint Interim Working Party 8-10/1 shall be as shown in Annex I.

* The Director, CCIR, is requested to bring this Decision to the attention of the International Civil Aviation Organization (ICAO).

ANNEX I

1. At the first meeting of JIWP 8-10/1 the following Administrations and other participants in the work of the CCIR were members of the Joint Interim Working Party:

Administrations:

Germany (Federal Republic of)
 Australia
 Austria
 Belgium
 Canada
 United States of America
 Finland
 France
 Italy
 Norway
 Netherlands
 United Kingdom
 Sweden
 Switzerland
 Yugoslavia (Socialist Federal Republic of)

International Organizations and Recognized Private Operating Agencies:

EBU
 IATA
 ICAO
 Norddeutscher Rundfunk
 Rhode & Schwarz

- 1.1 At the Final Meetings of Study Groups 8 and 10 the following Administrations expressed the wish to participate:

Administrations:

Brazil (Federative Republic of)
 China (People's Republic of)
 Hungarian People's Republic
 Iran (Islamic Republic of)
 Japan
 New Zealand
 Union of Soviet Socialist Republics

2. The Chairman of the Joint Interim Working Party will be:

Mr. Jorma Karjalainen
 General Directorate of
 Posts and Telecommunications
 Radio Department
 P.O. Box 511
 SF-00101 HELSINKI
 Finland
 Tf: + 358 0 696 61
 Tx: 124545 radios sf
 Telefax: + 3580 696 6410

DECISION 73

**CCIR STUDIES TO BE CARRIED OUT IN THE INTER-SESSIONAL PERIOD
 FOR SUBMISSION TO THE SECOND SESSION OF THE WARC ORB(2)**

(1985)

This Decision, adopted by Study Groups 1, 2, 4, 5, 8, 9, 10 and 11 at the Final Meetings in 1985, was reviewed by the Plenary Assembly and replaced by Resolution 90 which appears in Volume XIV-1.

ALPHABETICAL INDEX OF KEY WORDS AND TERMS OF VOLUME VIII-3

A

Accuracy positioning RDSS (Rep.1050)

Adjustment method (Rep.751)

Aeronautical radionavigation service (Rep.929)
service, sharing with RDSS (Rep.1050)
station (Rep.929)

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ABBREVIATIONS

A

ACK	acknowledgement
ACR	average crossing rate
ACSB	amplitude companded single sideband
ADF	automatic direction finding
ADM	adaptive delta modulation
ADPCM	adaptive differential PCM
ADVM	adaptive (variable slope) delta modulation voice modem
AFC	automatic frequency control
AGC	automatic gain control
AI	articulation index
AIRT	asynchronous interference reduction techniques
ANBFM	adaptive narrow-band FM modem
APC	adaptive predictive coding
APC-AB	adaptive predictive coding with adaptive bit allocation
APD	amplitude probability distribution
ARBs	aeronautical radar beacons
ARINC	Aeronautical Radio Inc.
ARPA	automatic radar plotting aid
ATC	adaptive transform coding
ATC	air traffic control

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
BITEs	backward interworking telephony events
BPSK	binary phase shift keying
BWO	backward wave oscillators

C

CBSS	station sending in the collective B-mode
CCITT	International Telegraph and Telephone Consultative Committee
CDM	companded delta modulation
CES	coast earth station
CFAR	constant false alarm rate
CISPR	International Special Committee on Radio Interference
C/I ₀	carrier-to-intermodulation-noise density ratio
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
CPSK	coherent phase shift keying
CT	international transit centre
CTP	coordinated trials program
CV	channel Vocoder

D

DECPSK	differentially encoded phase shift keying
DF	direction finding
DM	delta modulation
DME	distance measuring equipment
DN	Decca navigator
DPSK	differential phase shift keying
DRCS	distress radio call system
DSC	digital selective calling
DSI	digital speech interpolation
DX	first transmission

E

EC	earth coverage
ELBA	emergency location beacon
ELT	emergency locator transmitter
EPIRB	emergency position-indicating radio beacons
e.r.s.	effective receiver sensitivity
ESA	European Space Agency
ETX	end of text

F

F _a	effective antenna noise factor
FDMA	frequency division multiple access
FDM/PM	frequency division multiplexed before phase modulating
FEC	forward error correction mode B
FFSK	fast frequency shift keying
FGMDSS	Future Global Maritime Distress and Safety System
FITEs	forward interworking telephone events
FRENA	frequency and amplitude
FSK	frequency shift keying

G

GMSK	Gaussian filtered MSK
GOES	geostationary operational environmental satellite
GSFC	Goddard Space Flight Center
G/T	gain-to-noise temperature ratio
GTDS	global telecommunications system

H

HDLC high level data link control

I

IALA International Association of Lighthouse Authorities
ICAO International Civil Aviation Organization
IEC International Electrotechnical Commission
IFRB International Frequency Registration Board
IHO International Hydrographical Office
ILS instrument landing systems
IMO International Maritime Organization (since 22 May 1982)
INMARSAT International Maritime Satellite Organization
INTELSAT International Telecommunications Satellite Organization
IOC index of cooperation
IRS information receiving station
ISO International Organization for Standardization
ISS information sending station
IT interrogator transponder
ITOFAR interrogated time offset frequency agile racon

L

LHC lefthand circularly polarized
LNA low noise amplifier
LOS line-of-sight
LPC linear predictive coding
LSB least significant bit
LUT local user terminal

M

MCS maritime transponder on Intelsat-V satellites
MIC marked idle channel
MID maritime identification digits
MOS mean opinion score, coding evaluation
MPEC multi-pulse excited coding
MRIT maritime radar interrogator transponder
MSB most significant bit
MSC maritime switching centre
MSK minimum shift keying
MSS mobile-satellite service
MTBF mean-time-between failure
MTT message transfer time
MTTR mean-time-to-repair

N

NAD noise amplitude distribution
NASA United States National Aeronautics and Space Administration
NAVSTAR GPS NAVSTAR global positioning system
NBDP narrowband direct printing
NBFM narrowband frequency modulation
NBPSK narrowband phase-shift keying
NBVM narrowband voice modulation
NC narrow coverage
NCAR National Center for Atmospheric Research
NCK negative acknowledgement
NDB non-directional beacons
NMEA National Marine Electronic Association
NMT Nordic mobile telephone system
NOAA United States National Oceanographic and Atmospheric Administration
NRL Naval Research Laboratory

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
PPI plan position indicator
PRF pulse repetition frequency
PRFD pulse repetition frequency discrimination
PRN pseudo-random noise code
PSK phase-shift keying
PSK/PM subcarrier PSK
PSTN public switched telephone network

Q

QAM quadrature amplitude modulation
QPSK quaternary phase shift keying

R

Racon radar beacon
RAMS Nimbus-6 random access measurement system
RCC rescue coordination centre
REL P residual excited linear predictive coding
RHC right-hand circularly polarized

ROSES receive-only ship earth station
RSMS radio spectrum measurement system
RT radiotelephony
RX retransmission

S

SACP satellite aeronautical prober
SAMSARS satellite-aided maritime search and rescue system
SAR search and rescue
SBC-ADPCM subband coding with ADPCM
SBC-APC subband coding with APC
SBSS station sending in the selective B-mode
SCPC single channel per carrier
S/D filter smear desmear filter
SDL specification and description language
SELCAL selective calling
SES ship earth station
SHOSAC shore-to-ship distress alerting channel
SINAD signal plus noise plus distortion to noise plus distortion
SIT shipborne interrogator-transponder
S/N signal-to-noise ratio
SOLAS International Convention for the Safety of Life at Sea
SPITEs switching process interworking telephony events
SSB single sideband
SSFC sequential single frequency code

T

TCXO temperature compensated crystal oscillators
TDAL tunnel diode amplifier/limiter
TDMA time division multiple access
TFM tamed frequency modulation
TWEB transcribed weather broadcast
TWERLE wind, energy conversion and reference level experiment
TWT travelling wave tube
TWTA travelling wave tube amplifier

U

USGCSS United States Government Communications Satellite System

V

V_{avg} average voltage
V_d impulsiveness ratio
 (= $20 \log V_{rms}/V_{avg}$)
VDU video display unit
VELP voice excited linear predictive coding
VFT voice-frequency telegraphy
VOLMET aeronautical mobile meteorological service channels
VOR VHF omnidirectional radio range
V_p peak voltage
V_{qp} quasi-peak voltage
V_{rms} root-mean-square voltage

W

WMO World Meteorological Organization

