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

VOLUMES IV AND IX – PART 2

FREQUENCY SHARING AND COORDINATION BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND RADIO-RELAY SYSTEMS

Geneva, 1986

CCIR

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

2. The objectives of the CCIR are in particular:

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

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

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

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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.
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VOLUME VIII-2	Maritime mobile service.
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VOLUME XIII	Vocabulary (CMV).
VOLUME XIV-1	Information concerning the XVIth Plenary Assembly: Minutes of the Plenary Sessions. Administrative texts. Structure of the CCIR. Lists of CCIR texts.
VOLUME XIV-2	Alphabetical index of technical terms appearing in Volumes I to XIII.

All references within the texts to CCIR Recommendations, Reports, Resolutions, Opinions, Decisions, Questions and Study Programmes refer to the 1986 edition, unless otherwise noted; i.e., only the basic number is shown.

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VOLUMES IV AND IX, PART 2

FREQUENCY SHARING AND COORDINATION BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND RADIO-RELAY SYSTEMS

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SECTION 4/9A: SHARING CONDITIONS

Recommendations and Reports

RECOMMENDATION 355-3

FREQUENCY SHARING BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND TERRESTRIAL RADIO SERVICES IN THE SAME FREQUENCY BANDS

(Questions 32/4 and 17/9)

(1963–1966–1974–1982)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and terrestrial radio services share certain bands above 1 GHz;

(b) that control of mutual interference between stations of the two services is necessary;

(c) that the continued development of both services is desirable;

(d) that it is necessary to restrict the noise contribution, in a telephone channel of either service, caused by interference from stations of the other, to permissibly small amounts;

(e) that among the means for reducing, to permissible levels, interference between systems in the fixed-satellite service and terrestrial radio systems sharing the same frequency bands are:

– on the part of satellite space stations, limitation of the power flux per unit area in unit bandwidth produced at the surface of the Earth;
– on the part of communication-satellite earth stations, limitation of the minimum distance to terrestrial transmitters, appropriate to the technical characteristics concerned and to propagation factors, together with limitation of the maximum power radiated at low angles of elevation;
– on the part of stations in the terrestrial services, limitation of the distance to earth stations, appropriate to the technical characteristics concerned and to propagation factors, together with limitation of the total emitted power and the equivalent isotropically radiated power;

(f) that the application of reasonable constraints on the design of both line-of-sight radio-relay systems and systems in the fixed-satellite service can permit the sharing of frequency bands, but that considerable difficulties may arise in sharing frequency bands with other terrestrial services which involve high power transmitters, highly sensitive receivers, and changing areas of coverage,

UNANIMOUSLY RECOMMENDS

1. that, in sharing between line-of-sight analogue angle-modulated radio-relay systems and systems in the fixed-satellite service, the noise in a telephone channel arising from mutual interference should be limited to a permissibly small amount, compared to the total allowable noise in the appropriate hypothetical reference circuit, as set out at present in Recommendations 356 and 357;

2. that, in sharing between line-of-sight radio-relay systems and digital systems in the fixed-satellite service, the interfering power should be limited to a permissibly small amount, as at present indicated in Recommendation 558 (see Note);

3. that the control of mutual interference between space stations in the fixed-satellite service and line-of-sight radio-relay systems should be through constraints applicable to the use of both, so as to avoid the need for specific coordination procedures between the administrations operating radio-relay stations and those operating space stations; these constraints are set out at present in Recommendations 358 and 406;

4. that questions of sharing between systems in the fixed-satellite service and terrestrial radio systems, other than line-of-sight radio-relay systems, as well as the bases for such sharing, should receive further study;

5. that the control of mutual interference between each earth station of a system in the fixed-satellite service and terrestrial radio stations sharing the same frequency bands should be by the application of specific coordination procedures between the administrations concerned. Recommended procedures are set out in Appendix 28 to Radio Regulations.

Note. – See Report 877 concerning interference to digital radio-relay systems by fixed-satellite service systems.

REPORT 209-5 *

FREQUENCY SHARING BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND TERRESTRIAL RADIO SERVICES

(Questions 32/4 and 17/9)

(1963-1966-1970-1974-1982-1986)

1. Introduction

In considering frequency sharing between systems in the fixed-satellite service and terrestrial radio services, there are four conditions which must be satisfied:

– the signals from the satellites must not cause unacceptable interference to the receivers of the terrestrial service, as in A in Fig. 1;
– the signals from satellite earth-stations must not cause unacceptable interference to the receivers of the terrestrial service, as in B in Fig. 1;
– the signals from terrestrial stations must not cause unacceptable interference to the receivers of satellite-system earth stations, as in C in Fig. 1;
– the signals from terrestrial stations must not cause unacceptable interference in the satellite receivers, as in D in Fig. 1.

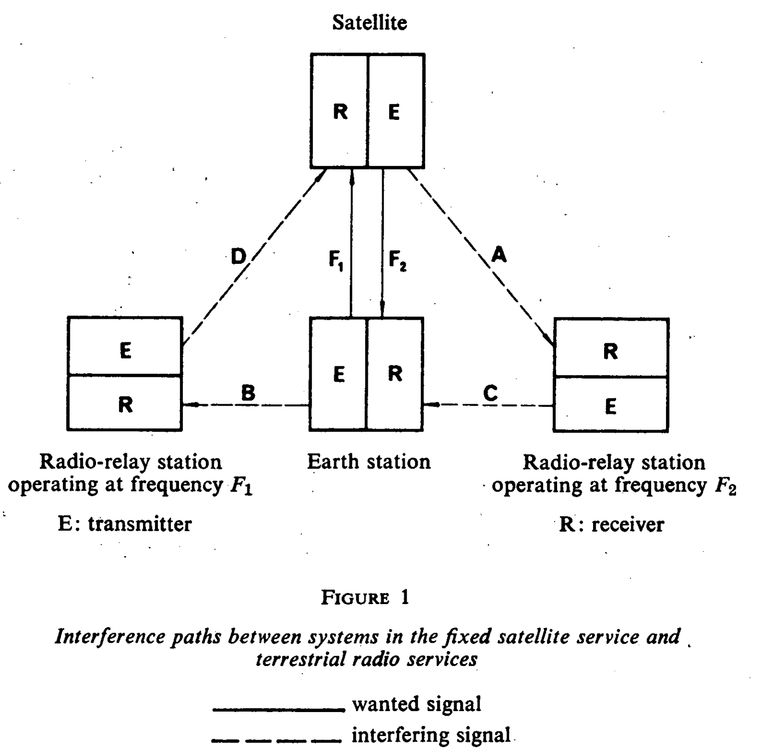

FIGURE 1

Interference paths between systems in the fixed satellite service and terrestrial radio services

Note. — The frequencies shown are in the bands shared between terrestrial radio services and fixed satellite service, allocated to Earth-to-space transmission (F_1) and space-to-Earth transmission (F_2).

---

* This Report should be brought to the attenuation of Study Group 8.

2. Sharing factors

A determination of whether sharing between two systems is possible depends on the following factors:

- the maximum allowable value of interference either in a telephone, in a television, or in a sound channel, at the output of the system subject to this interference;
- the number of specific interference paths between which the total allowable interference must be divided;
- the ratio of the powers, or the ratio of the power spectral-densities, of the wanted signal and the unwanted signal, at the input to the receiver, which would just result in the allowable value of interference at the output of the receiver, taking account of the types of modulation involved;
- the power, or the power spectral-density, of the interfering transmitter;
- the transmission loss along the unwanted signal propagation path, including effective antenna gain, basic transmission loss, and the effect of the polarizations concerned;
- the power, or the power spectral-density, of the wanted transmitter;
- the transmission loss along the wanted signal propagation path, including the effective antenna gains, and basic transmission loss.

The maximum permissible values of interference in the hypothetical reference circuit are given in Recommendation 356 in the case of systems in the fixed-satellite service and in Recommendation 357 in the case of line-of-sight radio-relay systems.

3. Sharing methods

The specific methods for achieving sharing between systems in the fixed-satellite service and terrestrial systems include the following:

- a limitation of the power radiated by the radio-relay transmitters (see Recommendation 406 and Report 393); Annex I gives some details on this matter;
- a limitation of the power spectral density at the surface of the Earth produced by satellites of the fixed-satellite service (see Recommendation 358 and Report 387);
- a specified method of computing the distance within which earth station transmitters or terrestrial transmitters may produce unacceptable interference respectively to terrestrial receivers or earth station receivers sharing the same bands (see Recommendation 359 and Report 382).

Specific limits and computation methods are given in Articles 27 and 28 and Appendix 28 to the Radio Regulations.

Some details on the possibilities of frequency band sharing between the fixed-satellite service and trans-horizon radio-relay systems are given in Annex II.

Some information on frequency sharing between the fixed-satellite service and the terrestrial radiolocation service is also given in Annex III.

4. System trade-offs for sharing between fixed-satellite systems and radio-relay systems

The design performance objectives of radio-relay systems and fixed-satellite services are specified by CCIR Recommendations 393 and 353 respectively for FDM-FM systems and by Recommendation 594 and Recommendation 522 for systems using PCM.

These Recommendations represent a compromise between the preferred standards to be attained for a telephony circuit and the increase in cost with performance of communication systems. For this reason they constitute primary bases for the overall design of terrestrial radio and satellite systems.

The total permitted degradation of any system must be shared among:

- thermal noise,
- interference within the system and
- interference from other systems sharing the same frequency band.

Consistency in the allocation of interference can be achieved if the relevant Recommendations are based on the effect of interference on the total cost of the mutually interfering systems. Detailed consideration of such a technique is given in Murphy [1982] and in CCIR [1978-82]. An example application is summarized in Annex IV.

While this technique may not be readily applicable where more than one administration is concerned, the potential total cost savings may justify consideration of its use.

REFERENCES

MURPHY, J. [September-October, 1982] Determination of minimum cost interference between services sharing the same frequency bands. *Ann. des Télécomm.*, Vol. 37, **9-10**, 413-424.

CCIR Documents

[1978-82]: 4/344(Rev.1), 9/255(Rev.1) (Australia).

ANNEX I

PROTECTION OF SPACE STATIONS IN THE FIXED-SATELLITE SERVICE AGAINST INTERFERENCE FROM TERRESTRIAL RADIO-RELAY SYSTEMS IN SHARED FREQUENCY BANDS ABOVE 1 GHz

When limitation of terrestrial transmitter power is considered, there are two possibilities:

– interference to a satellite in the main beam of a terrestrial radio-relay transmitter;
– interference to a satellite from side-lobe radiation of a large number of terrestrial stations within the satellite coverage area.

The first leads to a limit for the maximum e.i.r.p. of terrestrial stations whose antennas are directed close to the geostationary orbit. The second leads to a limit for the maximum power supplied to the antennas of terrestrial stations.

1. Limitation of e.i.r.p.

For the satellite to be in the main beam the interfering terrestrial station will be located at the horizon visible from the satellite. The permissible e.i.r.p. will depend upon, *inter alia*, the gain of the satellite antenna towards the horizon, which in general will be appreciably less than the main beam gain.

Other parameters of the satellite which enter into the calculation are: the receiver noise temperature, the number of telephone channels and the degree of energy dispersal used.

2. Limitation of power into the antenna

Outside its main beam the gain of a terrestrial-station antenna is largely independent of the in-beam gain. Consequently, when the satellite is not in the main beam the interference may be controlled by limiting the total power fed to the antenna rather than by limiting the e.i.r.p.

The total interference entering the main beam of the satellite antenna therefore depends upon the number of terrestrial stations within the coverage area and the average of their antenna gains in the direction of the satellite. Other parameters of the satellite which are relevant to the calculation are mentioned in the previous section.

ANNEX II

SHARING OF FREQUENCY BANDS BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND TRANS-HORIZON TERRESTRIAL RADIO-RELAY SYSTEMS

1. Introduction

This Annex examines the conditions under which the systems in the fixed-satellite service and trans-horizon systems can share the same frequency band, without causing undue mutual interference.

2. Trans-horizon radio-relay systems

Trans-horizon systems have wide differences in system parameters – for example, transmitter powers from a few hundred watts to 50 kW, antenna diameters from 3 m to 35 m, baseband capacities from 1 telephone channel to 1 television channel, receiver noise figures from 1 dB to 12 dB. It is usually necessary, economically, to choose the system parameters that best suit each specific system and sometimes each specific link. The operating margins that would permit standardization tend to be either not available technically or not feasible economically.

It seems unlikely that trans-horizon radio-relay systems will make any extensive use of parallel radio-frequency channels as in line-of-sight systems.

3. Geometric considerations

The geometric relations of exposure of satellites to the antenna beams of terrestrial radio-relay stations are outlined in Report 393. Although the narrower beamwidths of trans-horizon antennas tend to reduce the exposure probabilities to various satellite orbit systems, the greater transmitter power, receiver sensitivity and antenna gain all increase the probability of significant interference from such beam exposures and even from exposures to major side lobes.

Additionally, trans-horizon links are frequently used between small and greatly separated islands, and in other similar circumstances which limit the choice of possible path directions and which thus preclude this means of avoiding orbit exposures.

4. Interference considerations

4.1 *Interference to and from satellites*

The equivalent isotropically radiated power from the terminal of a trans-horizon system may be of the order of 85 to 90 dBW, i.e., not greatly dissimilar from that of typical earth stations. A satellite in the main lobe of a trans-horizon antenna would therefore receive unwanted and wanted signals of the same order of power, if a frequency were shared in the up-path. If a frequency were shared in the down-path, the unwanted signal in the trans-horizon receiver would be about −110 dBW, which is of the same order as the median value of the wanted signal, and would therefore cause a virtual circuit outage.

4.2 *Interference to and from earth stations*

The problem of coordination distance between earth stations and trans-horizon stations is essentially similar to that of coordination distance between earth stations and line-of-sight stations, except for the larger path basic transmission loss. The loss required to make interference negligible ranges from about 190 dB, when neither terminal looks at the other, to about 300 dB when both stations look at each other (complementary directions in azimuth but beyond line-of-sight).

It should be noted, that much more is known about downward fading in trans-horizon propagation than about the upward fading that is significant in estimating coordination distance. The usual statistics of trans-horizon loss can be seriously distorted above the median value by ducting due to temperature inversions, which have been known to increase the signals received over trans-horizon paths by as much as 60 to 70 dB above the median values for substantial periods of time. Local topographic features below the scattering region can create ducting on particular paths with a much higher prevalence than the average for the region or type of region.

It is advisable to measure the propagation loss in a path likely to suffer interference during a time when temperature inversions along the path are most likely to occur. Basic transmission losses greater than 250 dB are difficult to measure with transportable equipment.

For geostationary satellites, the problem of coordination is eased somewhat by the fact that the antenna of the earth station will always point in one direction, rather than in various directions, as when it is tracking a moving satellite.

5. Conclusions

5.1 It appears likely that the problem of coordination can be solved in most actual situations. It would be eased in a particularly difficult situation, if an unshared frequency band were available, to which the frequencies of the offending link could be transferred.

5.2 Sharing with a system of geostationary satellites would require a restriction over a small part of the surface of the Earth on the range of permissible azimuth directions for trans-horizon links. This restriction will probably not be considered so limiting as to prevent sharing.

5.3 Systems of random satellites in inclined orbits appear at present to require such large restrictions on permissible azimuth directions for trans-horizon links over so much of the world that sharing does not appear to be feasible.

ANNEX III

FREQUENCY SHARING BETWEEN THE FIXED-SATELLITE SERVICE AND THE TERRESTRIAL RADIOLOCATION SERVICE

The fixed-satellite service and the terrestrial radiolocation service have some allocations in the same bands, especially above 50 GHz, as set forth in the Table of Allocations.

There are three major factors which affect sharing: frequency management, geography and interference reduction techniques. These factors, as well as a further discussion of radar spectrum utilization and of theoretical and experimental results for spectrum sharing between FDM-FM and radar systems using pulse blanking, are given in Reports 827 and 828 *, respectively.

ANNEX IV

AN EXAMPLE APPLICATION OF OPTIMIZATION TECHNIQUES TO INTERFERENCE BETWEEN TERRESTRIAL RADIO-RELAY SYSTEMS AND SATELLITE SERVICES

1. Methodology

The first step of the optimization technique is the construction of a model of the mutually interfering systems. Costs are then associated with the parameters of the model which are under the designer's control. This is done by fitting appropriate equations to the cost data available. These costs are then added to determine the total cost of all systems concerned.

Standards of overall performance are available for each system; these include degradation of performance due to all sources. They can be used to bound or render dependent some of the design parameters. (Dependent parameters are fixed in value when all the other parameters have been assigned values.) Further parameters can be made dependent by using the radio propagation equations for signal transmission within each system and for interference propagation between systems. The total cost is then a function of the remaining independent variables.

By varying the independent variables in an optimization program the global minimum cost can be found. The resulting set of parameters is optimum in that they correspond to the minimum overall cost. From them the interference level can be calculated – this is the preferred level of interference to be adopted as a design objective since it is associated with the optimum joint system configuration. The choice of another interference level requires a change in the independent variables and therefore a quantifiable increase in total system cost.

2. Results of an example study

A model of typical interfering systems is illustrated in Fig. 2. Interference from the terrestrial system to or from the space segment is normally avoided by proper orientation of the radio-relay system with respect to the geostationary orbit. A victim SCPC/PSK earth station is assumed which suffers interference from a modem section (as defined in Recommendation 392) of the radio-relay system. In this model the modem section consists of 7 paths of length 40 km and the earth station is located in the middle of the modem section.

Long-term interference (20% of the time) is assumed to occur only between the nearest pair of transmitters or receivers of the modem section and the earth station receiver or transmitter. Short-term interference is assumed to occur only between the earth station and the extreme repeater of the modem section in each direction, R_1 and R_7. The dominant propagation mode is ducting.

In both cases of interference from radio-relay system to earth station and vice versa, it is necessary to optimize the whole modem section in the light of interference to or from one repeater. Since the cost of a radio link is a concave function of the baseband noise in the case of an analogue radio-relay system, it is cheaper to counteract the effect of interference to either the earth station or the radio-relay system by upgrading each repeater by a small amount rather than by adjusting the interfering or interfered with link [Murphy, 1982].

* The last sentence of the "Conclusions" section of Report 828 should be ignored because this sharing situation does not exist in the Table of Allocations of the Radio Regulations.

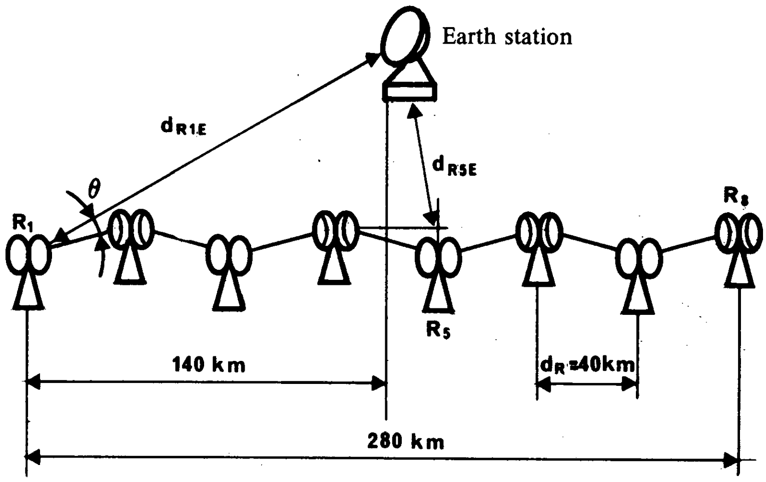

FIGURE 2 – *Model of mutually interfering satellite earth station and terrestrial radio system*

In order to determine the total cost, a set of appropriate cost equations is required. A set of such equations is given in Murphy [1982]; based on these the variation of total cost of the systems modelled in Fig. 2, with the two most important independent parameters, is shown in Fig. 3.

Figure 4 shows that the interference ratio at optimum is approximately proportional to the product of G_{R5E} (antenna gain of the interfering repeater in the direction of the earth station) and G_{ER5} (antenna gain of the earth station in the direction of R_5) but the optimum cost, C_o, is virtually independent up to values of about 40 dB. In practice this means that unless the gain product exceeds this value, the value of J is that which occurs incidentally in the optimization of the two systems in the presence of short-term interference. This value is therefore the *design value* of interference.

At higher values of the gain product where the cost becomes interference-dependent the optimum value of interference is approximately constant. Figure 5 shows explicitly the sharp knee in the cost-optimum interference curve at about −7 dB. This value, at which the cost increases significantly is the *maximum permissible value* of interference.

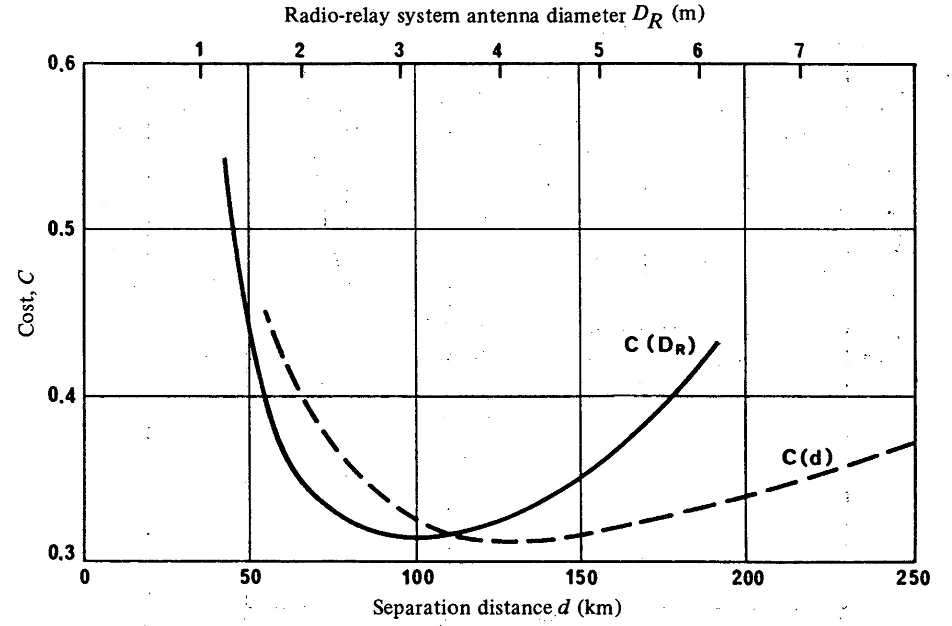

FIGURE 3 – *Variation of total cost of the systems with separation distance d and radio-relay system antenna diameter D_R. The other independent variables are held at their optimum values*

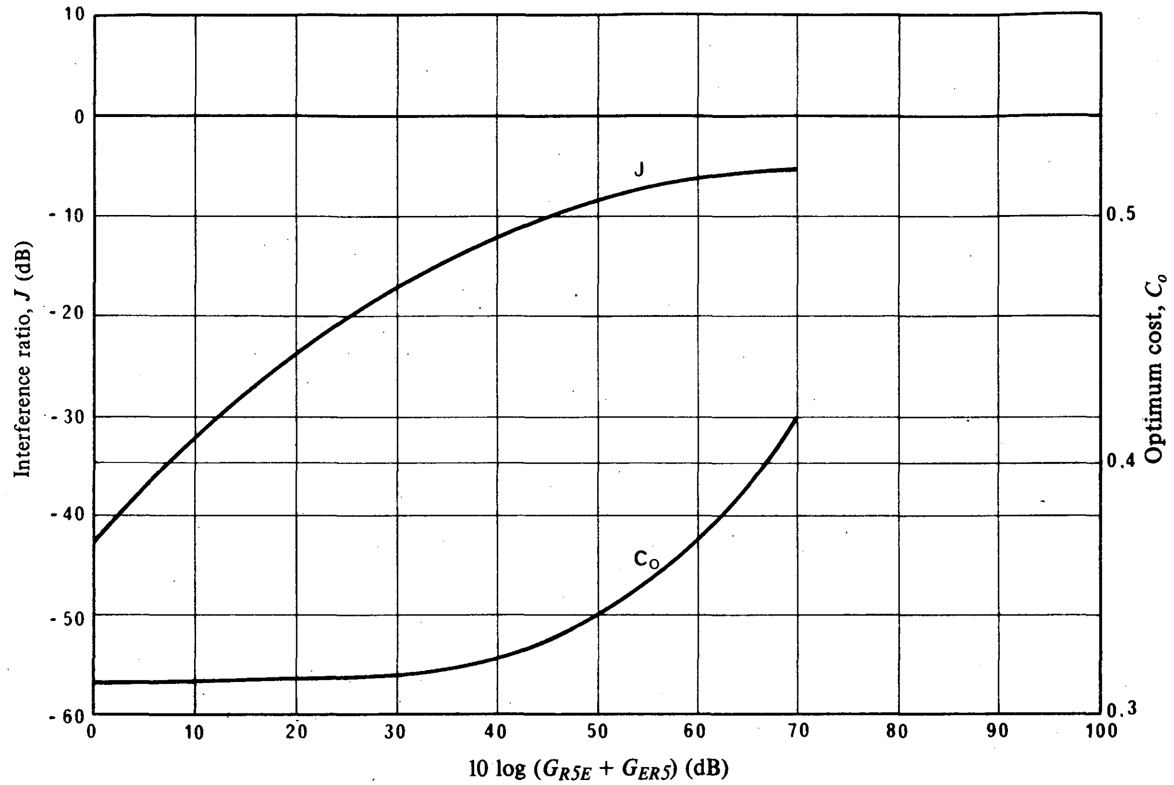

FIGURE 4 – *Variation of cost of the systems and optimum interference with the product of antenna gains of the earth station and the repeater causing long-term interference*

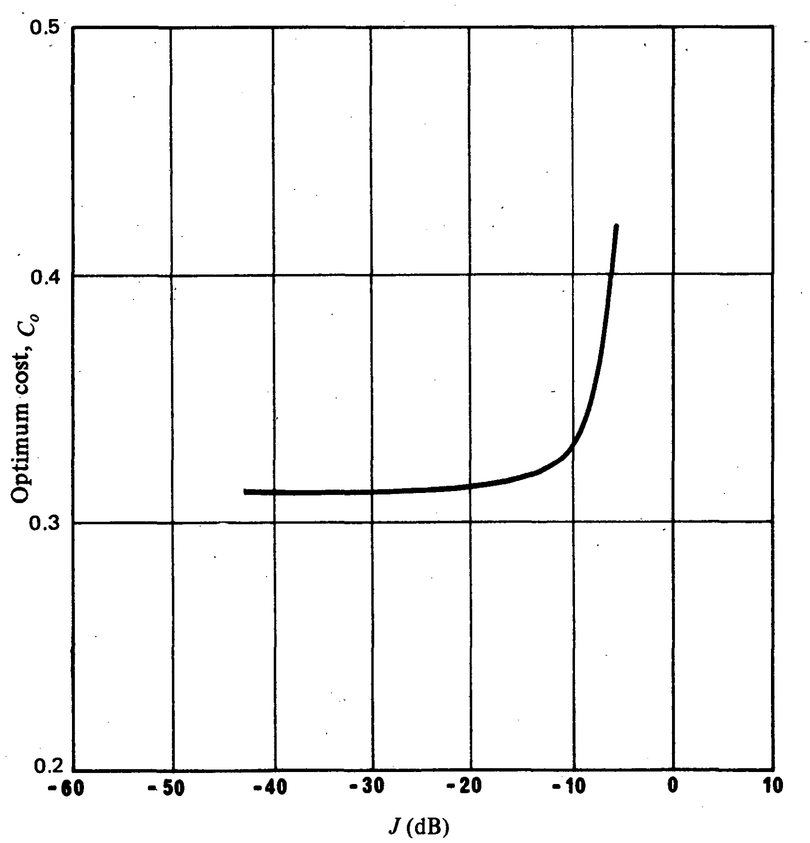

FIGURE 5 – *Relation between optimum cost and level of interference determined by the antenna gains involved in the transmission of long-term interference*

REFERENCES

MURPHY, J. [September-October, 1982] Determination of minimum cost interference between services sharing the same frequency bands. *Ann. des Télécomm.*, Vol. 37, **9-10**, 413-424.

REPORT 876

FREQUENCY SHARING BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND THE FIXED SERVICE IN FREQUENCY BANDS ABOVE 40 GHz

(Questions 32/4 and 17/9)

(1982)

1. Introduction

This Report presents the results of an investigation on the conditions for sharing the frequency bands above 40 GHz between the fixed-satellite service and the fixed service. The interference paths considered in this Report are the four paths shown in Fig. 1 of Report 209. In these cases, interference from a terrestrial station to a satellite receiver is considered negligible because the e.i.r.p. of terrestrial stations will be very low, except in the case where a satellite antenna main beam is directed to a terrestrial antenna main beam, which would be a very rare occurrence. Consequently, the other three interference paths are analyzed. For both terrestrial and satellite systems, only digital modulation is considered for these bands.

2. Basic concept for calculating interference

2.1 *Systems model*

It seems to be difficult to fix system parameters because of the absence of Recommendations or Reports for terrestrial radio-relay systems and satellite services in frequency bands above 40 GHz. In the following sharing analysis, the possible maximum e.i.r.p. value is adopted for an interfering transmitter, and possible sensitive parameters are adopted for a receiver, bearing in mind the foreseeable expansion and development of both satellite and terrestrial systems.

An example of system parameters is given in Annex I, § 1. These assumed parameters may represent a system configuration that is more susceptible to interference than is likely to be encountered in a real situation.

2.2 *Assumed propagation characteristics*

Signals above 40 GHz are attenuated by oxygen and water vapour even under clear sky conditions, and more particularly with rain. According to Report 719, 1/7.5 of the usual value is suggested for the water vapour attenuation, which is in proportion to the water vapour concentration ρ. Thus ρ should be taken as 1 g/m^3. However, this seems too severe, so ρ = 3 g/m^3 is used instead. The 40, 100 and 230 GHz frequency bands are selected, because the interference will be strong due to low atmospheric absorption.

2.3 *Maximum permissible interference*

In calculating the maximum permissible power flux-density for interference from a satellite or terrestrial service, the maximum permissible interference level is assumed to be 10 dB lower than the total noise level of the necessary C/N. Since terrestrial radio-relay systems and satellite services in these bands are likely to use digital modulation, a 1 MHz reference bandwidth is adopted.

3. Power flux-density limits from the satellite station

This section considers interference from a satellite transmitter to a terrestrial receiver. Since the effective propagation path length through a rain-storm is longer than 4 km (Report 564-1 (Kyoto, 1978), Figs. 1 and 2, elevation angle 40° to 50°) in most countries and the span length of terrestrial radio-relay systems is likely to be shorter than 4 km, interference from a satellite will be more attenuated than the wanted terrestrial radio signal during rainfall. Therefore, no rainfall condition is examined.

Initially, in-beam interference is considered. Satellites are assumed to be allocated every 3° in the geostationary orbit, in which case about 50 satellites would appear above the horizon. Since the beamwidths of the receiving antennas are less than 3°, it is assumed that at most one satellite is in the beam of the receiving antenna and the others are outside the beam. The aggregate of interferences from those satellites is neglected because the antenna directivity at more than 3° off-beam angle is greater than 25 dB and the aggregate power flux-density from about 50 satellites is assumed to be 14 dB higher than that from each satellite (reduction by averaging is −3 dB). When most of the beamwidth of the terrestrial receiving antenna is likely to be within ± 1°, and the path inclination is less than 4°, the tolerable maximum power flux-density under free space conditions at elevation angles θ less than 5° should be −101, −96 and −86 dB(W/(m^2 · MHz)) at 40, 100 and 230 GHz, respectively, (see § 2.1 of Annex I to this Report).

Next, off-beam interference is considered. The aggregate of the interference from about 50 satellites is 14 dB higher than from one satellite, as mentioned before. Terrestrial antenna directivity is assumed to be greater than 45 dB, while satellite antenna directivity is assumed to be 0 dB. On these assumptions, the permissible maximum power flux-density on the surface of the Earth from any one satellite, under free space conditions at elevation angle θ greater than 25°, would be −73, −70 and −74 dB(W/(m^2 · MHz)) at 40, 100 and 230 GHz, respectively.

From the discussions above, it is possible to calculate the power flux-density produced at the surface of the Earth by emissions from any one space station under free space propagation conditions. However, it is difficult to fix the power flux-density limit at the present time since the water vapour attenuation factor requires further study. The proposed provisional values are given in Table IV, where the water vapour concentration $\rho = 3$ g/m^3. If ρ is assumed to be 1 g/m^3, the in-beam tolerable maximum power flux-density for the 230 GHz band changes to −100 dB(W/(m^2 · MHz)) and off-beam tolerable maximum power flux-density changes by less than 2 dB.

4. Separation distance between earth station and terrestrial radio station

In this section, the minimum separation distance between the earth station and the terrestrial radio-relay station, necessary to prevent permissible interference values from being exceeded, is considered under both no rain and rain conditions.

At frequencies above 40 GHz, the elevation angle of an earth-station antenna is assumed greater than 30° to avoid significant atmospheric absorption and rain attenuation. Therefore, the antenna gain in the horizontal direction becomes the residual gain, which is taken as −10 dBi, but in a few cases, the elevation angle may be smaller and 10° is adopted as another example. Equation (1) of Report 614 is used for antenna side-lobe gain.

Under no rain or rain conditions, the permissible interference levels are set to error ratios of 10^{-11} or 10^{-3}, respectively. The specific rain attenuation value used in the calculation is derived by dividing the fade margin by the terrestrial span length or by the effective satellite propagation path length. This means that the rainfall rate in the area of concern is assumed constant and that the interference signal attenuation due to rainfall at that rain rate is taken into account. Precipitation scatter is not considered because the scattered signal will be attenuated by precipitation and the propagation paths are unlikely to cross each other. However, this will require further study. The possible system parameters used here are given in Annex I.

From these considerations, even in the case of 40 GHz, which needs the maximum separation distance, the minimum separation distance is about 52 km within ± 1° of the terrestrial antenna main-beam axis and about 1 km for off-axis angles greater than ± 40° for an earth station antenna elevation angle greater than 30°, whilst for an elevation angle of 10°, the minimum separation distances are 127 km and 1.7 km, respectively. The calculation method and precise results are shown in Annex I.

5. Conclusions

The feasibility of sharing frequency bands above 40 GHz between systems in the fixed-satellite service and the fixed service has been investigated. The condition which permits sharing the frequency bands involves restrictions of the maximum power flux-density from any space station at the earth surface under the condition of free space propagation. Provisional values of these restrictions are given in Table IV. Values may be applicable to possible future satellite systems.

The necessary separation distance between a terrestrial radio-relay station and an earth station seems very small.

From the considerations above, frequency sharing between systems in the fixed-satellite service and the fixed service in the frequency bands above 40 GHz seems feasible taking into account the actual situation, though further study is needed to fix the propagation paramaters, i.e. precipitation scatter and water vapour attenuation factors, especially in the case where a satellite antenna main beam is in the direction of a terrestrial antenna main beam.

ANNEX I

1. Assumed system parameters

1.1 *Parameters for systems exposed to interference*

System parameters for the terrestrial radio-relay system are listed in Table I. System parameters for the satellite earth station are listed in Table II. For the satellite system, atmospheric absorption of the desired signal is calculated under the assumptions that ρ (the water vapour concentration in g/m^3) $= 3\ g/m^3$, the elevation angle $\theta = 45°$ and $10°$, and the effective distances of the path through the atmosphere are 4 km and 2 km for oxygen and water vapour, respectively.

1.2 *Parameters for sytems causing interference*

System parameters for the terrestrial radio transmitter are assumed as listed in Table III. The transmitter output power is considered to decrease in proportion to frequency by 6 dB/octave and spectrum bandwidth is assumed rather narrower than that listed in Table I because the power flux-density becomes higher.

Next, the transmitter power for a satellite earth station is assumed to be 10 dB(W/MHz), regardless of frequency, and the antenna gain in the horizontal direction is taken as constant at -10 dBi for an elevation angle of 45°. For an elevation angle of 10°, the antenna gain in the horizontal direction is a function of azimuthal off-beam angle. In the following calculations, it is assumed that the terrestrial station is in the vertical plane that includes the main axis of the earth station antenna (azimuthal off-beam angle = 0°). This is the worst case.

2. Calculating interference

2.1 *Interference from space station to terrestrial radio station*

2.1.1 *In-beam interference* (no rain condition: elevation angle $\theta = 4°$)

Maximum power flux-density under free space conditions is determined by equation (1):

$$pfd_{maxin} = P_i + L_f + L_{at}(\theta) - 10 \log A_e - 10 \log B \tag{1}$$

where

pfd_{maxin} : maximum in-beam power flux-density (dB(W/(m^2 · MHz)))

P_i : permissible interference power (dBW)

L_f : receiving feeder loss (dB)

$L_{at}(\theta)$: atmospheric absorption (dB) (elevation angle $\theta = 4°$, water vapour concentration $\rho = 3\ g/m^3$)

A_e : receiving antenna effective area (m^2)

B : receiving bandwidth (MHz).

Results are -101.3, -95.5 and -86.1 dB(W/(m^2 · MHz)) for 40, 100 and 230 GHz, respectively. These values should be valid outside the main beam of a space station antenna.

TABLE I — *Possible sensitive parameters for a fixed radio-relay system exposed to interference*

Modulation	4-PSK		
Bandwidth (MHz)	200		
Noise figure (dB)	5		
Feeder loss (dB) (each station)	2.5		
Necessary C/N (10^{-11}) (dB)	21		
Frequency (GHz)	40	100	230
Output power (dBW)	– 10	– 18	– 25
Antenna diameter (m) (η = 0.6)	0.6	0.6	0.3
e.i.r.p. (dBW)	33.5	33.5	27.5
Span length (km)	4	3	3
Permissible interference power under no rain (dBW)	– 91.0	– 88.5	– 100.3
Necessary C/N (10^{-3}) (dB)	14	14	14
Permissible interference power under rain (dBW)	– 126	– 126	– 126
Fade margin (dB)	42.0	44.5	32.7

TABLE II — *Possible sensitive parameters for a satellite earth station exposed to interference*

Modulation		4-PSK		
Bandwidth (MHz)		100		
Noise temperature (K)		30		
Antenna diameter (m)		3		
Feeder loss (dB)		2.5		
Necessary C/N (10^{-11}) (dB)		21		
Space station e.i.r.p. (dBW)		70		
Distance (km)		38 000		
Frequency (GHz)		40	100	230
Atmospheric absorption (ρ = 3) (dB)	θ = 45°	0.3	0.6	2.1
	θ = 10°	1.0	2.4	8.7
Permissible interference power under no rain (dBW)	θ = 45°	– 120.1	– 120.4	– 121.9
	θ = 10°	– 120.8	– 122.2	– 128.5
Necessary C/N (10^{-3}) (dB)		14	14	14
Permissible interference power under rain (dBW)		– 144	– 144	– 144
Fading margin (dB)	θ = 45°	31.2	30.8	29.3
	θ = 10°	30.4	29.0	22.8

TABLE III — *Possible worst-case parameters for a fixed radio-relay system causing interference*

Frequency (GHz)	40	100	230
Output power (dBW)	4	– 4	– 11
Transmitting antenna diameter (m)	1	1	1
Antenna gain (dB) ($\eta = 0.6$)	50	58	65
E.i.r.p. (dBW)	54	54	54
Bandwidth (MHz)	100	100	100

2.1.2 *Off-beam interference* (no rain condition: elevation angle $\theta = 25°$).

Maximum power flux-density under free space conditions is determined by equation (2):

$$pfd_{maxoff} = P_i + L_f + L_{at}(\theta) - 10 \log A_e - 10 \log B - 17 + 3 + 45 \tag{2}$$

where

$L_{at}(\theta)$: atmospheric absorption (dB) (elevation angle $\theta = 45°$, $\rho = 3$ g/m^3)

17 dB : 50 satellites

-3 dB : assumed reduction factor by averaging

45 dB : terrestrial antenna directivity at more than 20° off-beam.

Results are -72.5, -69.7 and -73.9 dB(W/(m^2 · MHz)) for 40, 100 and 230 GHz, respectively. These values should be valid on the main axis of a space station antenna.

From these results, the proposed limit of power flux-density produced at the surface of the Earth by emissions from any one space station under free space conditions is given in Table IV. Between 5° and 25° of θ, the permissible power flux-density is determined to be linear to the angle of arrival and is applicable at the lower frequencies.

The permissible e.i.r.p.'s for satellite space stations, corresponding to these values, are 80, 82 and 82 dB(W/MHz) for 40, 100 and 230 GHz, respectively. These values seem high enough, even if possible future advances in satellite communication technology are considered.

TABLE IV — *Proposed provisional power flux-density limit at the surface of the Earth*

Frequency range (GHz)	Power flux-density limit (dB(W/(m^2·MHz)))		
	$\theta \leq 5°$	$5° < \theta \leq 25°$	$25° < \theta \leq 90°$
40-100	– 102	– 102 + (θ–5)	– 82
100-275	– 100	– 100 + (θ–5)	– 80

Note. – Limitation on power flux-density is not necessary in the absorption frequency bands around 60, 120 and 180 GHz.

2.2 *Separation distance between an earth station and a terrestrial radio station*

Necessary separation distance d is given by solving equation (3) below. Parameters are given in Tables I, II and III, and § 1.2 in Annex I.

$$P_{ti} + G_{ai} - 10 \log 4\pi (1000\ d)^2 = P_i + L_f + K \cdot d - 10 \log A_e - 10 \log B + A_r \qquad (3)$$

where

- P_{ti}: interference signal transmitter output power (dB(W/MHz))
- G_{ai}: transmitting antenna gain for interference signal in the direction of receiver concerned (dB)
- d: necessary separation distance (km)
- P_i: permissible interference power given under no rain or rain conditions (dBW)
- L_f: receiving feeder loss (dB)
- K: atmosphere absorption factor ($\rho = 3$ g/m^3) under no rain condition or specific rain attenuator under rain condition (dB/km)
- A_e: receiving antenna effective area (m^2)
- B: receiving bandwidth (MHz)
- A_r: receiving antenna directivity in the direction φ of interference signal transmitter (dB).

The necessary separation area under both no rain and rain conditions overlap at each frequency for the terrestrial receiving station in Fig. 1 and for the terrestrial transmitting station in Fig. 2.

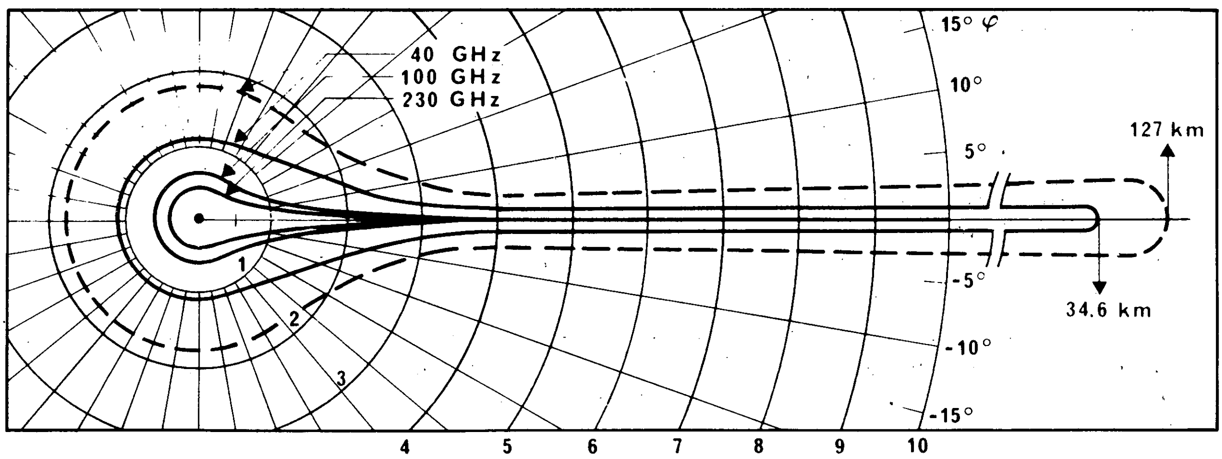

FIGURE 1 – *Necessary separation for terrestrial receiving station*

________ : Earth station antenna elevation angle of 45°

— — — — : 10° at 40 GHz

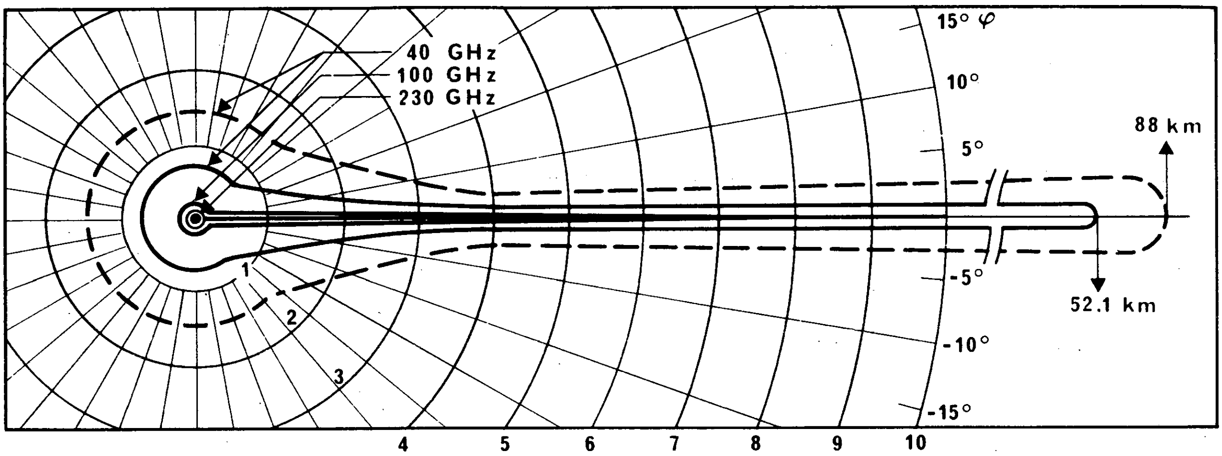

FIGURE 2 – *Necessary separation for terrestrial transmitting station*

________ : Earth station antenna elevation angle of 45°

_ _ _ _ : 10° at 40 GHz

RECOMMENDATION 356-4

MAXIMUM ALLOWABLE VALUES OF INTERFERENCE FROM LINE-OF-SIGHT RADIO-RELAY SYSTEMS IN A TELEPHONE CHANNEL OF A SYSTEM IN THE FIXED-SATELLITE SERVICE EMPLOYING FREQUENCY MODULATION, WHEN THE SAME FREQUENCY BANDS ARE SHARED BY BOTH SYSTEMS

(Questions 32/4 and 17/9)

(1963-1966-1970-1974-1978)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and line-of-sight radio-relay systems share frequency bands in the range above 1 GHz;

(b) that mutual interference would increase the noise in both types of system beyond that which would exist in the absence of frequency sharing;

(c) that it is desirable that the noise due to interference in the telephone channels of systems in the fixed-satellite service because of the transmitters of radio-relay systems should, during most of the time, be a small fraction of the total noise in those systems, as set out in Recommendation 353;

(d) that it is necessary to specify the maximum allowable interference power in a telephone channel, to determine the maximum transmitter power and equivalent isotropically radiated power of line-of-sight radio-relay stations, and to determine whether specific locations for satellite-earth stations and terrestrial radio-relay stations would be satisfactory;

(e) that a distribution of one-minute mean power, as exemplified in Fig. 1 would allot to interference an appropriate fraction of the total noise power permitted in the hypothetical reference circuit;

(f) that systems in the fixed-satellite service may receive interference both through the satellite receiver and through the earth-station receiver, but will receive the higher levels of interference associated with small percentages of time primarily through the earth-station receivers,

UNANIMOUSLY RECOMMENDS

1. that systems in the fixed-satellite service and radio-relay systems sharing the same frequency bands, be designed in such a manner that the interference noise power, at a point of zero relative level in any telephone channel of a hypothetical reference circuit of a system in the fixed-satellite service, caused by the aggregate of the transmitters of radio-relay stations, conforming to Recommendation 406, should not exceed:

1.1 1000 pW0p psophometrically-weighted one-minute mean power for more than 20% of any month;

1.2 50 000 pW0p psophometrically-weighted one-minute mean power for more than 0.03% of any month.

2. that the following Note should be regarded as part of the Recommendation.

Note. – The way in which the above values are to be taken into account in the general noise objective for systems in the fixed-satellite service is defined in Note 6 of Recommendation 353.

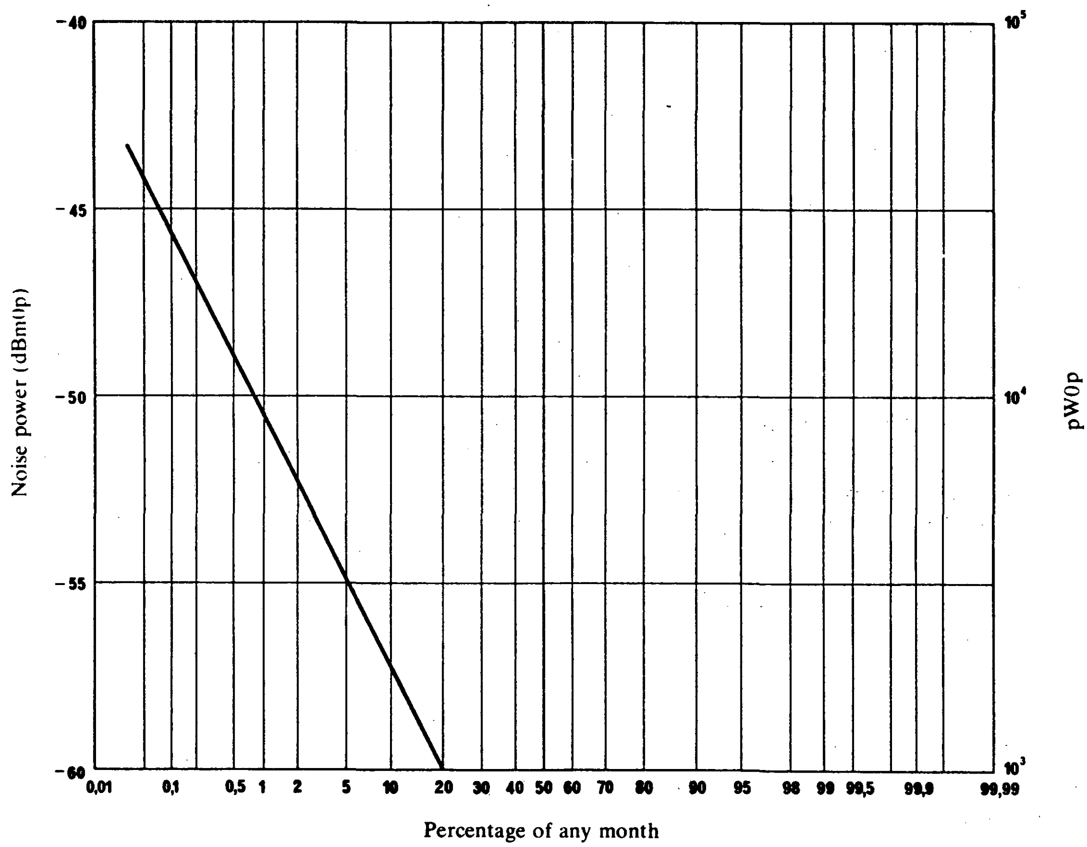

FIGURE 1 – *Example of possible interpolation*

RECOMMENDATION 357-3

MAXIMUM ALLOWABLE VALUES OF INTERFERENCE IN A TELEPHONE CHANNEL OF AN ANALOGUE ANGLE-MODULATED RADIO-RELAY SYSTEM SHARING THE SAME FREQUENCY BANDS AS SYSTEMS IN THE FIXED-SATELLITE SERVICE

(Questions 32/4 and 17/9)

(1963-1966-1974-1978)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and line-of-sight radio-relay systems share certain frequency bands above 1 GHz;

(b) that mutual interference would increase the noise in both types of system beyond that which would exist in the absence of frequency sharing;

(c) that it is desirable that the noise, due to interference in the telephone channels of existing radio-relay systems, emanating from transmitters of satellites and earth stations, should be a fraction of the total noise in those systems, such that it would not be necessary to change the design objectives for radio-relay systems, as set out in Recommendation 393;

(d) that it is necessary to specify the maximum allowable interference power in a telephone channel, to determine the maximum power flux from communication satellites which can be allowed at the surface of the Earth and to determine whether specific locations for satellite-earth stations and terrestrial radio-relay stations would be satisfactory;

(e) that a distribution of one-minute mean power, as exemplified in Fig. 1, would allot to interference a reasonable fraction of the total noise power permitted in the hypothetical reference circuit,

UNANIMOUSLY RECOMMENDS

1. that systems in the fixed-satellite service and line-of-sight analogue angle-modulated radio-relay systems which share the same frequency bands, should be designed in such a manner, that in any telephone channel of a 2500 km channel hypothetical reference circuit for frequency-division multiplex, analogue angle-modulated radio-relay systems, the interference noise power at a point of zero relative level, caused by the aggregate of the emission of earth stations and space stations of the systems in the fixed-satellite service, including associated telemetering, telecommand and tracking transmitters, should not exceed:

1.1 1000 pW0p psophometrically-weighted one-minute mean power for more than 20% of any month;

1.2 50 000 pW0p psophometrically-weighted one-minute mean power for more than 0.01% of any month.

2. that the following Note should be regarded as part of the Recommendation.

Note. – The way in which the above values are to be taken into account in the general noise objective for radio-relay systems is defined in Recommendation 393.

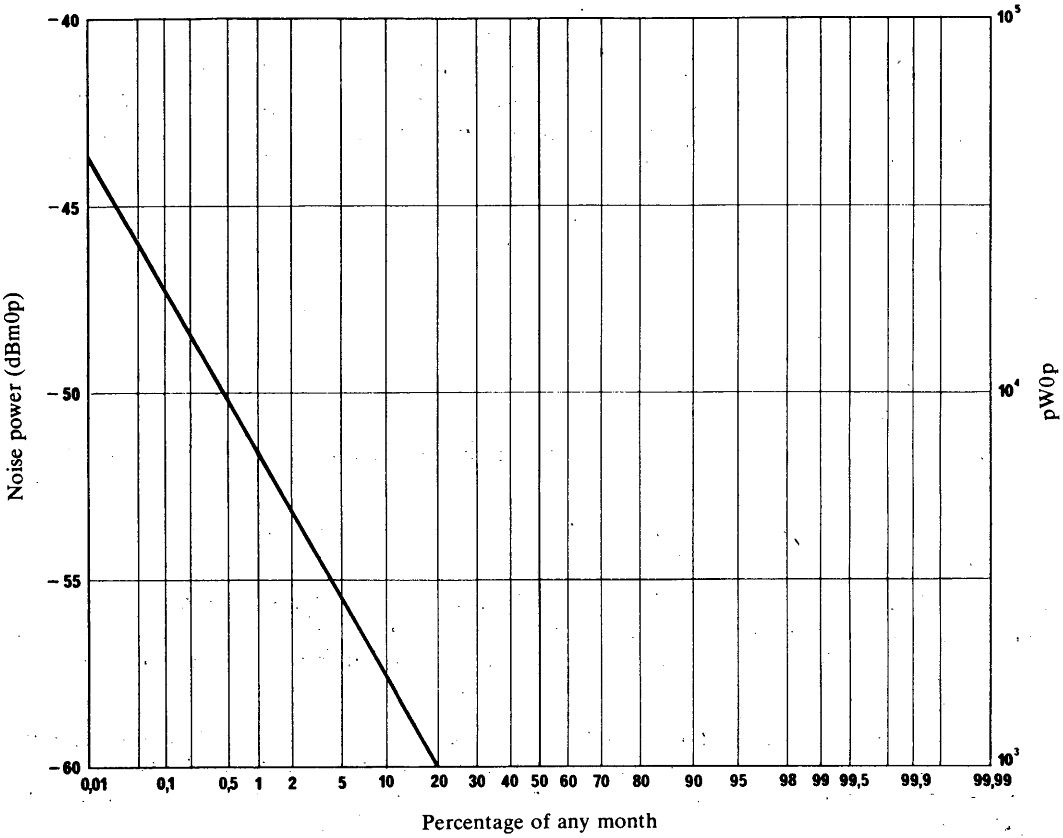

FIGURE 1 – *Example of possible interpolation*

RECOMMENDATION 558-2

MAXIMUM ALLOWABLE VALUES OF INTERFERENCE FROM TERRESTRIAL RADIO LINKS TO SYSTEMS IN THE FIXED-SATELLITE SERVICE EMPLOYING 8-BIT PCM ENCODED TELEPHONY AND SHARING THE SAME FREQUENCY BANDS

(Questions 32/4 and 17/9)

(1978–1982–1986)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and line-of-sight radio-relay systems share frequency bands in the range above 1 GHz;

(b) that interference from radio-relay systems would degrade the bit error ratio performance of a satellite system relative to its performance in the absence of frequency sharing;

(c) that it is desirable that the bit error ratio in systems in the fixed-satellite service due to interference from transmitters of radio-relay systems should, during most of the time, be a controlled fraction of the total bit error ratio in those systems, as set out in Recommendation 522;

(d) that it is necessary to determine the maximum allowable interfering RF power in a satellite system to establish the maximum transmitter power and equivalent isotropically radiated power of line-of-sight radio-relay stations, and to determine whether specific locations for satellite-earth stations and terrestrial radio-relay stations would be satisfactory;

(e) that interference from radio-relay systems may vary with time due to the effect of varying propagation conditions;

(f) that systems in the fixed-satellite service may receive interference both through the satellite receiver and through the earth-station receiver but will receive the higher levels of interference associated with small percentages of time primarily through the earth-station receivers;

(g) that where propagation variations are small it is preferable to define the permissible interference limit as a fraction of the pre-demodulator noise power, as this allows multiple interference entries to be superimposed on each other on the basis of RF power addition,

UNANIMOUSLY RECOMMENDS

1. that systems in the fixed-satellite service and radio-relay systems sharing the same frequency bands be designed in such a manner that the interference to an 8-bit PCM telephony system in the fixed-satellite service caused by the aggregate of the transmitters of radio-relay stations operating in accordance with Recommendation 406, should conform to the following provisional* limit at the output of the hypothetical reference digital path as defined in Recommendation 521;

1.1 the interfering power**, averaged over any ten minutes, should not exceed, for more than 20% of any month, 10% of the total noise power at the input to the demodulator that would give rise to an error ratio of 1 in 10^6;

1.2 the interfering RF power should not cause an increase of more than 0.03% of any month during which the bit error ratio exceeds 1×10^{-4} averaged over 1 min;

1.3 the interfering RF power should not cause an increase of more than 0.005% of any month during which the bit error ratio exceeds 1×10^{-3} averaged over 1 s.

Note 1. – To calculate the limit referred to in § 1.1, it must be assumed that the total noise power at the input to the demodulator is of a thermal nature.

Note 2. – The interference criterion of RECOMMENDS 1.1 is related to the maximum permissible levels of interference in a geostationary-satellite network in the fixed-satellite service using 8-bit PCM encoded telephony, caused by other networks of the fixed-satellite service, as defined in Recommendation 523. Note 7 of Recommendation 523 indicates that the limits of interference power for more than 20% of any month should normally be evaluated with the assumption that the total noise power level present is that which produces the specified bit error ratio under unfaded conditions of the received signal. This is discussed further in Report 793, § 2.

REPORT 793-1

DERIVATION OF INTERFERENCE CRITERIA FOR DIGITAL SYSTEMS IN THE FIXED-SATELLITE SERVICE SHARING BANDS WITH TERRESTRIAL SYSTEMS

(Questions 32/4 and 17/9)

(1978–1986)

1. General

Recommendation 522 provides performance criteria for digital transmissions in systems of the fixed-satellite service. RECOMMENDS 2, Note 4, stipulates that these performance criteria are to apply in the presence of interference due to external sources.

Since the fixed-satellite service shares most of the frequency bands allocated to it with other services, the total permissible interference comprises not only interference from other satellite networks but also from terrestrial systems, and must be divided accordingly to accommodate each of the two interference classes.

This Report considers the derivation of criteria for interference only from terrestrial systems.

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* These criteria may need to be amended in the light of further studies.

** It is assumed in this Recommendation that the long-term interference from the terrestrial radio links is of a continuous nature. The situation relating to cases where interference is not of a continuous nature has not been considered.

2. Long-term interference criteria

The long-term performance criteria for digital transmissions of Recommendation 522 are couched in terms of the required bit error ratio. Hence it would seem to be reasonable to relate the interference criteria also to bit error ratio.

This would be analogous to the case of analogue FDM/FM telephony where both performance and interference criteria are expressed in terms of the voice channel noise power, the latter being a small fraction of the former. However, unlike the situation with analogue FDM/FM telephony, bit error ratios in the digital case do not add in a linear fashion and, to express interference criteria in terms of bit error ratio, reference would have to be made to the overall performance criterion as well as to the magnitude of bit error ratio increase due to the presence of interference.

However, alternative methods of relating interference criteria to overall performance are possible; for example the relationship may be defined in terms of pre-demodulation parameters either by a wanted-to-unwanted carrier ratio (C/I) or by an external-to-internal noise power ratio (I/N). This approach has two advantages: pre-demodulation parameters are readily available (and, in fact, would have to be used also as an interim calculation step in the assessment of bit error ratio increase) and, secondly, the interference components (I) beyond the first two largest components tend to add nearly linearly on a power basis in the pre-demodulation domain. This would facilitate sub-division among interference entries.

In practice, there exists a rather complex relationship between the pre-demodulation parameters (C/I) and (I/N), the bit error ratio increase factor (k)*, and the operating conditions and characteristics of a given digital system. Figure 1 illustrates the relationship between (C/I) and k for a pre-demodulation interference to total noise ratio of -10 dB and for various operating conditions, measured in laboratory simulation of a differentially encoded quaternary PSK (DEQPSK) system.

Figure 1 shows the advantages of increasingly linear operation and of the use of error correction codes. More importantly, though, it shows that an interference criterion which is based on either a bound on the bit error ratio increase factor (k) or on the wanted-to-unwanted carrier ratio (C/I) may reduce the benefits in co-ordination between terrestrial and fixed-satellite systems which may be obtained from applying improved equipment characteristics or operating modes. However, this is not the case for a criterion derived from the internal-to-external noise power ratio (I/N) and a limit based on sub-division of the pre-demodulator noise power is therefore preferable.

In the analogue case (Recommendation 356) the maximum permissible interference from terrestrial stations is taken to be 1/10 of the total noise allowance and it is considered that this ratio would be provisionally appropriate for the digital case also.

It is therefore suggested that the long-term interference criterion for the protection of digital transmissions in systems of the fixed-satellite service, due to interference from terrestrial systems, should be defined** as follows:

– the interfering power***, averaged over any ten minutes, should not exceed, for more than 20% of any month, 10% of the total noise power at the input to the demodulator which would give rise to an error ratio of 1 in 10^6.

The interference criterion of RECOMMENDS 1.1 of Recommendation 523 is related to the maximum permissible levels of interference in a geostationary-satellite network in the fixed-satellite service using 8-bit PCM encoded telephony, caused by other networks of the fixed-satellite service. Note 7 of Recommendation 523 indicates that the limits of interference power for more than 20% of any month should normally be evaluated with the assumption that the total noise power level present is that which produces the specified bit error ratio under unfaded conditions of the received signal. This is discussed further in [CCIR, 1982-86].

3. Short-term interference criteria

For small percentages of the time interference at an earth station from an interfering terrestrial transmitter may be substantially increased relative to that normally (that is during 80% of the time) experienced, due to "interference-favourable" propagation conditions. Hence, for such small percentages of the time a received digital transmission may either be degraded due to its own unfavourable propagation conditions, or due to increased interference under "interference-favourable" propagation conditions, or due to both conditions simultaneously.

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* k is the ratio between net bit error ratio and bit error ratio in the absence of interference.

** These criteria may need to be amended in the light of further study.

*** It is assumed here that the interference is of a continuous nature; the situation relating to cases where interference is not of a continuous nature, for example radar transmissions, has not been considered.

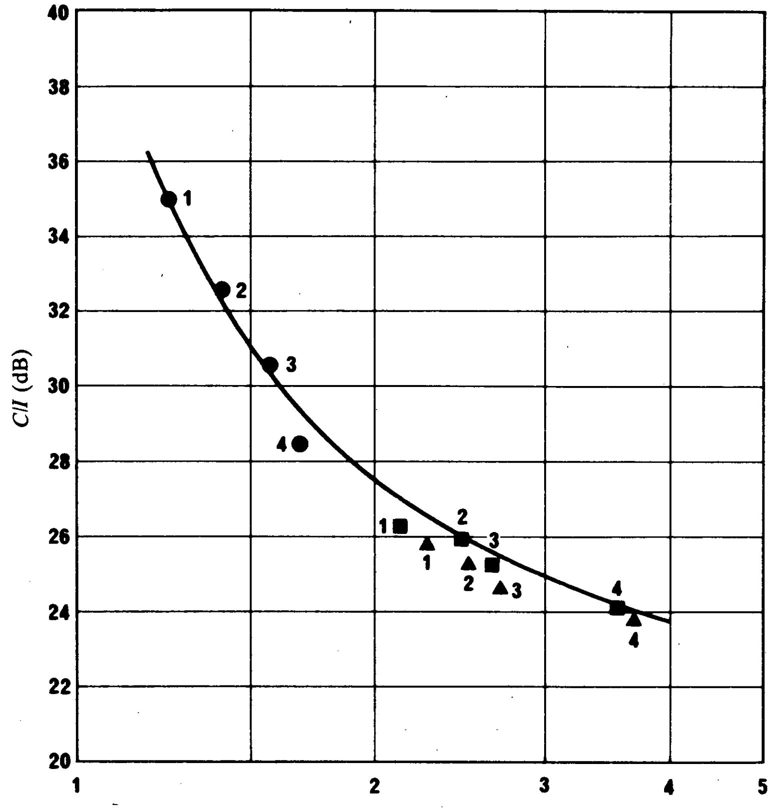

FIGURE 1 – *C/I versus k for various DEQPSK transmission modes. Predemodulation interference component 10%; net BER = 10^{-6}. (Measured in a laboratory simulation)*

●: No FEC (Forward Error Correction)

■: Rate 7/8 FEC

▲: Rate 4/5 FEC

1: Earth station back-off 3 dB; satellite back-off 0 dB (3 dB/0 dB)

2: 6 dB/0 dB

3: 10 dB/4 dB

4: 14 dB/14 dB

Solid line represents averaging of experimental results.

Under most circumstances a single interfering signal is likely to predominate. However, the occurrences of such high level interferers are unlikely to be time correlated. Therefore, in this case, it would be preferable to define the interference allocation as a fraction of the total time the circuit is allowed to operate under degraded conditions. This interference allocation would apply to the two short-term objectives in Recommendation 522 and the following limits *, based on 1/10 of the percentage time allocation, are envisaged:

- the interfering RF power should not cause the bit error ratio, averaged over any one minute, to exceed 1 in 10^4 for more than 0.03% of any month.
- the interfering RF power should not cause the bit error ratio, averaged over any one second period, to exceed 1 in 10^3 for more than 0.005% of any year.

REFERENCES

CCIR Documents

[1982-86]: 4/12-9/11 (United States of America).

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* These criteria may need to be amended in the light of further study.

RECOMMENDATION 615

MAXIMUM ALLOWABLE VALUES OF INTERFERENCE FROM THE FIXED-SATELLITE SERVICE INTO TERRESTRIAL RADIO-RELAY SYSTEMS WHICH MAY FORM PART OF AN ISDN AND SHARE THE SAME FREQUENCY BAND BELOW 15 GHz

(Questions 32/4 and 17/9)

(1986)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and the fixed service share many frequency bands below 15 GHz;

(b) that many radio-relay systems employing digital modulation for telephony are operational or are planned for operation in these shared bands;

(c) that it is necessary to specify the maximum allowable interference into the terrestrial service to determine whether specific locations for satellite earth stations and terrestrial radio-relay stations would be satisfactory;

(d) that the maximum allowable values of power flux-density at the surface of the Earth produced by space stations in the fixed-satellite service using the same bands above 1 GHz as the terrestrial service, are in accordance with Recommendation 358;

(e) that the allowable performance objectives and availability objectives are given respectively in Recommendation 594 and Recommendation 557 for digital radio-relay systems;

(f) that the allowable degradations in performance and availability of a terrestrial digital radio-relay system due to interference from satellite systems of the fixed-satellite service should be expressed as a permissible fraction of the total allowable degradation in performance and availability,

UNANIMOUSLY RECOMMENDS

1. that systems in the fixed-satellite service and terrestrial digital radio-relay systems should be designed in such a manner that, in the 2500 km HRDP defined in Recommendation 556, the permissible degradation in performance and availability resulting from the aggregate of the emissions of earth stations and space stations of the fixed-satellite service, including associated telemetering, telecommand and tracking transmitters operating in accordance with Recommendation 358 should not exceed the following provisional limits:

1.1 the interfering emissions should not degrade the performance by causing an increase of more than 0.04% of the period of time in any month during which the bit error ratio exceeds 1×10^{-6} (integration time, 1 min);

1.2 the interfering emissions should not degrade the performance by causing an increase of more than 0.0054% of the period of time in any month during which the bit error ratio exceeds 1×10^{-3} (integration time 1 s);

1.3 the interference emissions should not degrade the availability by causing an increase in the period of unavailability, as defined in Recommendation 557, of more than 0.03% of any year;

1.4 the interference emissions should not degrade the performance by causing an increase in the number of errored seconds measured at the 64 kbit/s interface by more than 0.032% in any month (see Note 2).

Note 1. – The limits on permissible interference apply to the cumulative sum of the effects of emissions from space stations, direct long-term emissions from earth stations and interference due to the anomalous propagation of emissions from earth stations.

Note 2. – The relationship between BER at the system bit rate and errored seconds of a 64 kbit/s channel is under study as a possible approach for ensuring compliance with RECOMMENDS 1.4 (see Report 930).

REPORT 877-1

INTERFERENCE CRITERIA FOR DIGITAL RADIO-RELAY SYSTEMS SHARING FREQUENCY BANDS WITH THE FIXED-SATELLITE SERVICE

(Questions 32/4 and 17/9)

(1982-1986)

1. Introduction

The feasibility of the sharing of radio frequency bands between fixed satellites and terrestrial radio-relay systems is well established in the case of analogue systems. It is also expected that sharing will be feasible when one or both systems are digital. That is, each system will be able to operate satisfactorily despite the radio interference which arises from the sharing of a common frequency band.

Sharing between analogue satellite and terrestrial radio-relay systems has been made possible by the establishment of meaningful and practical sharing criteria based upon knowledge of the interference mechanisms and their characterization. The interference mechanism on digital systems is quite different from that of analogue systems and therefore it is to be expected that the sharing criteria will be correspondingly different. This Report discusses the basis for establishing the sharing criteria for terrestrial digital radio-relay systems (see Note 1) with fixed-satellite systems. Extensive comparison is made with analogue systems in order to highlight the need for a different approach.

2. The character of interference mechanisms for analogue and digital radio systems

2.1 *Analogue radio systems*

In general, for the purpose of establishing meaningful and practical sharing criteria, analogue sytems are characterized in their linear region by:

- a linear relationship between baseband noise and the receiver carrier-to-noise ratio (C/N) associated with the receiver thermal noise;
- a linear relationship between baseband noise and the received carrier-to-interference ratio (C/I) associated with radio interference;
- the noise at baseband due to the receiver thermal noise being independent of radio interference. Similarly baseband noise due to radio interference is independent of the receiver thermal noise;
- the two components of baseband noise being power additive.

These characteristics have been used to establish the sharing criteria between analogue fixed-satellite and terrestrial radio-relay systems. They are not absolutely correct or applicable under all conditions but they have proven to be very useful and meaningful concepts in solving design problems.

2.2 *Digital radio systems*

Digital systems behave in a totally different manner. They are characterized by:

- the presence of digital errors, due to the receiver thermal noise, which give rise to "noise" in the baseband signal. These are characterized by the concept of bit error ratio (BER). The BER, and hence the baseband noise, is a non-linear function of C/N. Figure 1 is an example of a typical relationship. The effect of this relationship is that there is a well-defined C/N below which the signal is unusable due to high baseband noise and/or misframing in the digital multiplex or channel bands, i.e., the signal is for practical purposes interrupted. Above this critical C/N the baseband noise rapidly becomes negligible and is dominated by the basic PCM quantizing noise. Typically, an increase of 1 dB in C/N will reduce the BER by a factor of 10 corresponding to a 10 dB reduction in the baseband noise arising from the errors. It must be ensured that the design of a digital radio-relay system must have a C/N above the critical value for an acceptably high percentage of the time;
- the fact that interference, in most practical circumstances, does not of itself cause errors but enhances the ability of the thermal noise to cause errors, as indicated by closing of the eye pattern of the digital decision circuit. A convenient way of characterizing the effects of interference is the concept of C/N degradation. This

is defined as the increase required in C/N to restore the BER in the presence of interference. Over most of the practically significant range of C/N the degradation due to a given interference (C/I) is independent of C/N. Thus the effect of interference in most practical circumstances is to move the BER curve of Fig. 1 towards the right by an amount equal to the degradation of C/N. This is shown by the dotted curve in Fig. 1.

It should be noted that the combined effects of thermal noise and interference in digital systems is quite different from that of analogue systems. For digital systems the baseband noise (errors) caused by the thermal noise is dependent upon interference level and, similarly, the baseband noise associated with interference is very dependent upon the thermal noise level. There can be no independent association of the components of baseband noise with the receiver thermal noise or with the interference.

It should also be noted that the specification of C/I alone is insufficient to determine the C/N degradation. The actual degradation is a function of the amplitude distribution of the interference as well as its C/I. In theory, a complete statistical description of the amplitude of the interference is needed in order to determine the degradation. Such information is rarely available for practical systems. One attempt to improve on this situation by reducing the amount of data needed is described in [Rosenbaum and Glave, 1974] in which it is shown that for peak-limited interference a reasonably tight upper-bound can be established for the BER provided that the C/I and the peak/r.m.s. value of the interference is known. Unfortunately, to date, very little is even known of the likely values of peak/r.m.s. to be encountered in practical situations or indeed that the interference will always be peak limited.

When the interference power is small compared to thermal noise, the effect on BER can often be quite accurately estimated by treating the interference power as additional thermal noise of equal power. This approach has also been used when the interference power is equal to or larger than the thermal noise power. However, it can lead to the prediction of very pessimistic results. High levels of interference power will only have similar effects to thermal noise if it has a comparable amplitude distribution. That is, the distribution must be peaky enough to cause actual errors as indicated by momentary closure of the eye pattern. In general, it is not expected that interference from satellite systems will be of that nature, although little is known for certain at this time. The most likely cause of peaky interference is when an interfering signal becomes distorted due to filtering or propagation effects. More knowledge is needed on the nature of interference likely to be encountered in practical situations. This should be derived by theoretical considerations supported by measurements on actual systems.

In the absence of any information on the amplitude statistics of the interfering signal, the power addition of interference and thermal noise gives a useful upper-bound to BER (see Note 2). In many practical problems there are a multiplicity of interference sources. The power addition of these sources and the thermal noise provides a useful method of allocating permissible levels of interference in complex systems.

3. Application of noise and interference characteristics of digital systems to general sharing criteria

3.1 *Analogue systems*

The general interference criteria for radio-relay systems are derived by permitting minor degradations of the important performance requirements. In the case of analogue systems these requirements are:

(a) a maximum value of "long-term" baseband noise assumed to exist during free-space or near free-space propagation conditions;

(b) a "short-term" requirement to allow for fading of the carrier, in which an upper limit is placed on the percentage of time the baseband noise is allowed to exceed a high value, much in excess of the "long-term" noise allowance in (a) above.

The general interference sharing criteria relate directly to these major performance requirements as follows:

– maximum value of "long-term" baseband interference noise which is typically 10% of the "long-term" noise allowance as recommended by the CCIR for the hypothetical reference circuit (HRC). This noise is primarily due to direct interference from satellite transmitters received under free-space conditions;

– a "short-term" requirement in which an upper limit is placed upon the percentage of time the baseband noise due to interference is allowed to exceed a high value, much in excess of the long-term noise allowance. This percentage of the time is typically 10% of the time allowed for high noise due to fading of the carrier as recommended by the CCIR for the HRC (Recommendations 393 and 395). The short-term allowance is primarily related to anomalous propagation of interfering signals from the transmitters of satellite earth-stations;

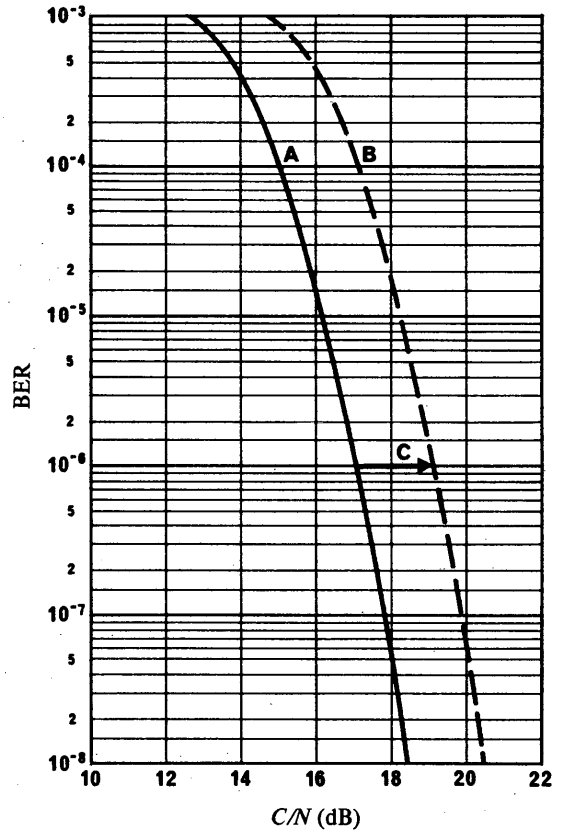

FIGURE 1 – *Typical BER vs C/N characteristic of digital radio-relay systems*

A: no interference
B: with interference
C: degradation

From these general sharing criteria detailed requirements on permissible C/I and the percentage of time they are permitted have been determined. It should be noted that when these criteria are applied to the design of a real system there need be no compromises of any other margins the designer may choose to build into the system. Margins may be designed into the system because circumstances call for a conservative design or because a better performance is required than that recommended by the CCIR.

3.2 *Digital systems*

Considering the digital systems, it follows that the general sharing criteria should be derived by permitting the interference to cause specified degradations of the important performance requirement(s). As was mentioned in § 2 the design of a digital radio-relay system is dominated by the need to maintain the C/N above the critical C/N for a high percentage of the time. This is achieved in the most part by building the system with a large fade margin, typically 35 dB, so that the signal can fade by that amount before reaching the critical C/N below which service is interrupted. During free-space or near free-space conditions, which will exist for most of the time, the BER is negligibly small and, in terms of the system design, it is not a major systems parameter (Note 3). When the C/N is below the critical value, the system is generally considered to be unusable. Typically in a digital system used for telephony, the system is considered to be interrupted if the BER exceeds a value in the order of 10^{-4}.

The sharing criteria for digital radio systems should be defined in terms of allowable degradation in performance and availability due to the presence of interference from the satellite system. The allowance should be expressed as a permissible fraction of the total degradation in performance and availability due to adverse propagation conditions. From this general criterion detailed requirements on C/I for a given percentage of the time can be determined. As with analogue systems, the application of this criterion will not preclude the design of systems having additional margins to achieve a better performance.

It should be especially noted that it is not acceptable to specify sharing criteria in terms of interference giving rise to a given BER. The actual level of interference needed to cause a given BER is very sensitive to the actual thermal noise present and the precise nature of the interference at a given time. Hence, this approach could lead to system designs where the performance could easily deteriorate from being acceptable to being totally unacceptable, say in terms of outage period, due to minor changes in the operating conditions of the system. Also, and of equal importance, this approach could lead to the removal of legitimate margins which the designer built into the system. In fact, in terms of acceptable interference from satellite systems, the conservatively designed system could easily become penalized relative to the less conservatively designed system.

4. Some considerations of the real system problems

4.1 *Basic considerations*

There are two mechanisms by which the interference from satellite systems can increase the outage period of terrestrial digital radio-relay systems:

- low-level "long-term" (e.g. for 80% of any month) interference from the satellite or earth station transmitter which will cause a constant degradation of the C/N (as discussed in § 2) and will reduce the fade margin and thus increase the outage period;
- high-level "short-term" interference due to anomalous propagation of the signal from the transmitter of the satellite earth station. This interference will cause a severe degradation to C/N or perhaps of itself cause errors if it is sufficiently peaky in nature as was discussed in § 2.

It is considered that these two mechanisms will be independent and do not occur simultaneously for signficant periods. The outage periods from each can therefore be added in a simple manner.

4.2 *C/I considerations*

For carrying out the requirements on C/I and in the absence of any detailed information on the nature of the interference, it will have to be assumed that the interference power behaves as thermal noise power of equal value. This will likely be quite an accurate approach for the "long-term" interference which will in practice be equal to or less than the thermal noise power. However, the "short-term" situation presents considerable difficulty. The behaviour of digital systems under conditions of very high levels of interference, high BER and low thermal noise, is not well understood or characterized. Accurate calculation of acceptable C/I ratios is therefore very difficult even for specific circumstances let alone attempts to generalize for the purpose of writing recommendations or guidelines. It would appear that the only practical procedure at this time is to assume that the interference can be treated as thermal noise on the assumption that this approach gives a useful, if not absolute, upper-bound to the BER.

It should not be construed however that because as a matter of expediency we treat the effects of interference power like the effect of thermal noise power, that the predicted results will accurately reflect what actually happens with real systems. The published theoretical relationships between BER, thermal noise and interference are in general consistent with practice provided the interference can be characterized and is less than about 10 dB below the carrier level. Therefore, any conclusions on the behaviour of BER drawn from a simple approach, such as equating interference to thermal noise, should always be checked for consistency with the theory. At high BER caused by high levels of interference the theory may not be very useful and, therefore, one will have to resort to cross-checking predictions with measurements. Study is going to be required on the problem of translating the general sharing criterion suggested in this Report into permissible C/I and the percentage of time they are permitted to occur.

4.3 *Distribution of outage events*

In general, interference can occur into a number of repeaters in a system. In the case of analogue systems due to their intrinsic linear behaviour the noise allowance can at least in theory be distributed over a number of repeaters in any manner. Administrative difficulties may however, impose restrictions on this procedure. In the case of digital systems the total outage period could also in theory be distributed over a number of repeaters in any manner. Arrangements in which all the outage period was allowed at one repeater with a corresponding relatively high level of interference will have to be assessed carefully. Again administrative difficulties may impose restrictions on the distribution of the permissible outage period.

4.3.1 *Computation of J for protected systems*

Assuming that the total outage period due to long term interference is in a single hop exposed to interference from earth stations, then the permissible outage on that hop due to thermal noise and interference is 6.56 times that on the remaining hops of the hypothetical reference digital path (HRDP). This can be shown by assuming that the total permissible interference in a 50 hop HRDP should account for 10% of the total permissible outage, as per Recommendation 615:

$$p_u = 0.9\ p_u \frac{49}{50} + 0.9\ p_u \frac{X}{50} \qquad \%$$

where:

p_u : total permissible outage in the HRDP in percentage of the time.

This yields $X = 6.56$.

If the exposed hop consists of a 1:1 protection arrangement, and assuming that the fading on the regular channel and the protection channel are uncorrelated, the probability of outage is the product of the probability of outage of each of the RF channels in the system. This holds true for the exposed hops as well as the interference-free hops. In the exposed hop, for the particular channel of interest, the value of X would be $\sqrt{6.56} = 2.56$.

If J is the ratio in decibels of the interference-to-thermal noise where the interference is assumed to be noise-like, then the increase in outage due to the presence of the interference as a ratio equals, assuming Rayleigh fading statistics:

$$X = (1 + 10^{J/10})$$

Since $X = 2.56$, $J = 1.93$.

The 1:1 could be either space or frequency diversity; in either case it may be assumed that the interference affects both the regular and the protection channels equally.

Note that if diversity was not used, $X = 6.56$ and hence $J = 7.5$.

4.3.2 *Number of interference entries*

For the purposes of developing coordination contours (see Report 382) it is necessary to estimate the number of non-simultaneous short-term interference entries due to anomalous propagation within the reference bandwidth. For short durations, such entries may be considered uncorrelated. The total duration of such entries must be less than the permissible duration for which the threshold conditions may be exceeded as per Recommendation 615. The number of such entries is a function of the population of earth stations present, the number of space stations with which they may operate, and their relative bandwidth with respect to the reference bandwidth. In this regard, in keeping with the approach used in the development of coordination contours, as a useful approximation, only those interfering emissions which arrive within the main beam of the receiver are counted. As such, despite the relatively large numbers of earth and space stations that have been installed in recent years, the number of "entries" remains tractable. Further study is needed in order to develop a suitable value. Tentatively a value of 3 is suggested.

4.4 *Bidirectional sharing*

In those frequency bands in which the fixed-satellite service uses bidirectional transmission, the impact of interference on the total outage and unavailability of radio-relay systems sharing the same frequency bands consists of three independent mechanisms. The three mechanisms are the reduction of fade margin due to space station "long term" interference, the reduction of fade margin due to earth station "long term" interference, and the high level "short term" interference contribution due to anomalous propagation from transmitting earth stations (see § 3.1). The impact of these three mechanisms on radio-relay systems is discussed in Report 1005.

5. Summary

The following important points are brought out in this Report:

- the allowable performance and availability due to adverse propagation conditions is the dominant design requirement in a digital radio system;
- there can be no independent association of the components of baseband noise due to receiver thermal noise and interference in a digital system;

- interference criteria for sharing are derived by permitting specified degradations in performance and availability due to adverse propagation conditions;
- the sharing criteria must be such that there is no degradation of any additional margins that the designer will need to build into a system, to meet the overall performance objectives;
- the allowable degradations in performance and availability of a terrestrial digital radio-relay system due to interference from satellite systems of the fixed-satellite service should be expressed as a permissible fraction of the total degradation in performance and availability due to adverse propagation conditions.

Note 1. – Digital systems denotes systems carrying telephony with the voice signal being encoded in 8 bit PCM format multiplexed by time division multiplex. The multiplexed digital signal is generally re-encoded, often to a high number of levels, to modulate the radio carrier. It is assumed that the digital signal is fully regenerated at each radio repeater. The basic approach discussed in this Report is also applicable to digital systems carrying other services.

Note 2. – Thermal or Gaussian noise does not have the worst statistics from the BER point of view. Rosenbaum and Glave [1974] shows that even with peak limited interference, constrained so that of itself it does not cause errors, the BER can be worse than with thermal noise of equal power. Presumably this is even more likely if the interference is not peak limited in the sense described in [Rosenbaum and Glave, 1974]. Therefore, in theory, the thermal noise equivalent approach is not a true absolute upper-bound to BER. However there are reasons to doubt (from experience with real systems) whether the absolute upper-bound is applicable to practical situations since in general the interference from satellite systems is unlikely to be very peaky in nature. This is expected to be true even after the interference has undergone various distortions due to filtering and propagation effects. It is on this basis that the thermal noise power equivalence can be considered as a useful upper-bound.

Note 3. – Experience with real systems indicates that digital radio-relay equipment has a residual BER of some very low value (better than say 10^{-16}) which is independent of C/N. It is associated with jitter on the recovered reference carrier used for coherent detection. Further it appears that the residual BER can be worsened by interference. With the worst long-term levels of interference expected to be experienced in a digital system, as occurs when cross-polarization discrimination is used to separate co-channel carriers, the residual BER has been observed to increase by three orders of magnitude. However, the residual BER is still very low (say better than 10^{-13}) and therefore is quite acceptable. This phenomenon is not totally understood. Although at this time, the BER during free-space conditions (which is likely to be residual BER) is not considered to be a major systems parameter, it is advisable in considering the effect of interference from satellite systems to keep track of the understanding of this phenomenon. It is not known at this time if the observed effects are of a fundamental nature or due to the characteristics of particular types of equipment.

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ROSENBAUM, A. S. and GLAVE, F. E. [January, 1974] An error probability upper-bound for coherent phase shift keying with peak-limited interference. *IEEE Trans. Comm. Tech.*, Vol. COM-22, 1, 6-16.

RECOMMENDATION 358-3

MAXIMUM PERMISSIBLE VALUES OF POWER FLUX-DENSITY AT THE SURFACE OF THE EARTH PRODUCED BY SATELLITES IN THE FIXED-SATELLITE SERVICE USING THE SAME FREQUENCY BANDS ABOVE 1 GHz AS LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(Question 17/9 and Study Programme 32C/4)

(1963–1966–1974–1982)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and line-of-sight radio-relay systems share frequency bands;

(b) that, because of such sharing, it is necessary to ensure that emissions from satellites do not cause harmful interference to line-of-sight radio-relay systems;

(c) that radio-relay systems can be satisfactorily protected from the emissions from satellites by placing suitable limits on the power flux-density, set up at the surface of the Earth, in a reference bandwidth;

(d) that, nevertheless, any limitations of the power flux-density set up at the surface of the Earth should not be such as to place undue restrictions on the design of systems in the fixed-satellite service;

(e) that for systems in the fixed-satellite service, methods of carrier-energy dispersal can be employed to reduce the radio-frequency spectral power density of satellite emissions;

(f) that calculations in recent studies demonstrate that power flux-density limits can generally be increased with increasing frequency and still provide adequate protection to line-of-sight radio-relay systems,

UNANIMOUSLY RECOMMENDS

1. that, in frequency bands in the range 2.5 to 23 GHz shared between systems in the fixed-satellite service and line-of-sight radio-relay systems, the maximum power flux-density produced at the surface of the Earth by emissions from a satellite, including those from a reflecting satellite, for all conditions and methods of modulation, should not exceed:

1.1 in the band 2.5 to 2.690 GHz, in any 4 kHz band:

-152	$\mathrm{dB(W/m^2)}$ for	$\theta \leqslant 5°$
$-152 + 0.75\,(\theta - 5)$	$\mathrm{dB(W/m^2)}$ for	$5° < \theta \leqslant 25°$
-137	$\mathrm{dB(W/m^2)}$ for	$25° < \theta \leqslant 90°$

1.2 in the band 3.4 to 7.750 GHz, in any 4 kHz band:

-152	$\mathrm{dB(W/m^2)}$ for	$\theta \leqslant 5°$
$-152 + 0.5\,(\theta - 5)$	$\mathrm{dB(W/m^2)}$ for	$5° < \theta \leqslant 25°$
-142	$\mathrm{dB(W/m^2)}$ for	$25° < \theta \leqslant 90°$

1.3 in the band 8.025 to 11.7 GHz, in any 4 kHz band:

-150	$\mathrm{dB(W/m^2)}$ for	$\theta \leqslant 5°$
$-150 + 0.5\,(\theta - 5)$	$\mathrm{dB(W/m^2)}$ for	$5° < \theta \leqslant 25°$
-140	$\mathrm{dB(W/m^2)}$ for	$25° < \theta \leqslant 90°$

1.4 in the band 12.2 to 12.75 GHz, in any 4 kHz band:

-148	$\mathrm{dB(W/m^2)}$ for	$\theta \leqslant 5°$
$-148 + 0.5\,(\theta - 5)$	$\mathrm{dB(W/m^2)}$ for	$5° < \theta \leqslant 25°$
-138	$\mathrm{dB(W/m^2)}$ for	$25° < \theta \leqslant 90°$

1.5 in the band 17.7 to 19.7 GHz, in any 1 MHz band:

-115	$\mathrm{dB(W/m^2)}$ for	$\theta \leqslant 5°$
$-115 + 0.5\,(\theta - 5)$	$\mathrm{dB(W/m^2)}$ for	$5° < \theta \leqslant 25°$
-105	$\mathrm{dB(W/m^2)}$ for	$25° < \theta \leqslant 90°$

where θ is the angle of arrival of the radio-frequency wave (degrees above the horizontal);

2. that the aforementioned limits relate to the power flux-density and angles of arrival which would be obtained under free-space propagation conditions.

Note 1. – Definitive limits applicable in shared frequency bands are laid down in Nos. 2561 to 2580.1 of Article 28 of the Radio Regulations. The CCIR is continuing its study of these problems, which may lead to changes in the recommended limits.

Note 2. – Under Nos. 2581 to 2585 of the Radio Regulations, the power flux-density limits in the band 17.7 to 19.7 GHz shall apply provisionally to the band 31.0 to 40.5 GHz until such time as the CCIR has recommended definitive values, endorsed by a competent Administrative Conference (No. 2582.1 of the Radio Regulations).

REPORT 386-3

DETERMINATION OF THE POWER IN ANY 4 kHz BAND RADIATED TOWARD THE HORIZON BY EARTH STATIONS OF THE FIXED-SATELLITE SERVICE SHARING FREQUENCY BANDS BELOW 15 GHz WITH THE TERRESTRIAL SERVICES

(Questions 32/4 and 17/9)

(1966-1970-1974-1982)

1. Requirements of systems in the fixed-satellite service

In considering a limit on the permissible horizontally radiated power of earth stations, it is important to bear in mind the needs of systems in the fixed-satellite service that can reasonably be foreseen. This must include systems for multi-channel telephony, television and sound. The use of telephony channels to convey signals such as voice-frequency telegraphy, data and tones for test and signalling purposes must be taken into account, where this affects the maximum power to be transmitted in any 4 kHz band. This bandwidth is appropriate for the protection of analogue angle-modulated radio-relay systems against interfering signals. Any limit of power so established must be suitable for the various methods of modulation, numbers of telephone channels and earth-station antenna sizes that might be used. It is also necessary to consider the characteristics of the satellites which may be used, including the apportionment of noise and the satellite antenna gain. Operational requirements for margin and carrier energy dispersal also bear significantly on the final result.

2. Equivalent isotropically radiated power (e.i.r.p.) of earth-station main beam

Consideration is given to the power requirements for two types of multi-channel telephony system which are illustrative of those likely to require the highest value of transmitted power in any 4 kHz band. The requirements for frequency-modulated television transmission are not thought likely to exceed the values for equal-baseband telephony transmissions, assuming that suitable energy dispersal techniques are being employed.

General equations are presented for the determination of acceptable levels of radiated powers of earth stations. The actual powers may be calculated by substituting the values appropriate to the satellite system under consideration.

2.1 *Frequency-modulation systems*

The required total signal power, P_r, at the input to a satellite receiver is given by:

$$P_r = S/N + 10 \log (kTb) - P - 20 \log (f_r/f_m) \quad \text{dBW} \tag{1}$$

where

S/N: signal-to-noise power ratio corresponding to an assumed up-path noise contribution in a band of width b (usually a telephone channel) (dB),

k: Boltzmann's constant, 1.38×10^{-23} J/K,

T: noise temperature of satellite receiving system (K),

b: bandwidth of a channel considered (Hz). For a telephone channel $b = 3100$ Hz,

P: pre-emphasis improvement (dB),

f_r: r.m.s. channel test tone (0 dBm0) deviation (MHz),

f_m: top baseband frequency (MHz).

To realize the required carrier power at the satellite input an earth station may have to radiate an e.i.r.p., D_s, in a 4 kHz band of up to:

$$D_s = P_r - (28 + 10 \log dF) + M_u - 20 \log (\lambda/4\pi R) - G_r + 3 \quad \text{dBW} \tag{2}$$

where

the 3 dB accounts for light loading conditions when spectrum dispersal techniques are applied according to Report 384, § 4,

M_u: up-path transmission margin (dB),

λ: wavelength of carrier frequency (m),

R: range to satellite (m),

G_r: receive gain of satellite antenna (dB).

The second term in the expression for D_s establishes the highest occurring ratio between the power in a 4 kHz band and the total carrier power (see Report 384, Annex I, § 1), under the assumption that the spectral distribution of the radio-frequency signal is Gaussian with a multi-channel r.m.s. deviation of:

$$dF = f_r\, L \qquad \text{MHz} \tag{3}$$

where

$L = 0.178 \sqrt{n}$,

n = number of telephone channels considered.

Dispersal techniques are currently under study which are intended to limit spectral densities from reaching significantly higher values under light loading conditions.

2.2 *Single-sideband, amplitude-modulation systems (SSB/AM)*

For an SSB/AM system, the power per channel to be received at the satellite input is given by:

$$P_r = S/N + 10 \log (kTb) \qquad \text{dBW} \tag{4}$$

which, with the usual channel spacing of 4 kHz, yields the required earth station e.i.r.p. in a 4 kHz band from:

$$D_s = P_r - 20 \log \left(\frac{\lambda}{4\pi R}\right) - G_r + M_u \qquad \text{dBW} \tag{5}$$

for a 0 dBm0 exciting signal. It should be noted that there is considerable variation of speech signal power among the telephone circuits, but it is considered appropriate to take a value of 0 dBm0 as the maximum power in a telephone channel, averaged over an integrating time of a few seconds.

3. Power radiated toward the horizon, in any 4 kHz band

Since earth stations will usually take advantage of site shielding, knowledge of radiated power in the horizontal plane, as previously defined, is of limited practical interest. Instead, to describe more clearly the radiation characteristics of an earth station, the effective radiated power toward the physical horizon, in any 4 kHz band, should be determined and stated.

It is necessary to determine the smallest occurring angle φ between the main beam of an antenna and the physical horizon, since a decrease of this angle is accompanied by a prohibitive increase in the noise temperature of the receiving system and, at many locations, in depth of fade, a minimum value of $\varphi = 1°$ is stipulated.

Given the minimum angle of elevation, ε, of the *main* beam of the earth station, then φ is to be computed from $\varphi = \varepsilon - \theta_E$, where θ_E is the angle of elevation of the horizon at the same azimuth for which ε occurs. All angles are in degrees.

With φ given, the e.i.r.p. toward the horizon, in any 4 kHz band, may be computed:

$$\begin{aligned} E_H &= D_s - G_s + 32 - 25 \log \varphi \qquad \text{dBW, for } (1° \leqslant \varphi \leqslant 48°) \\ &= D_s - G_s - 10 \qquad \text{dBW, for } (48° < \varphi \leqslant 180°) \end{aligned} \tag{6}$$

where G_s is the maximum antenna gain of the earth station.

The expression for E_H is derived from an equation describing large-aperture earth-station antenna patterns given in Report 391, and the same reservations as to the validity of the equation apply as stated therein. In particular, for some values of φ the real antenna gain component may exceed the corresponding value of the equation by several decibels.

The angle of elevation of the horizon, θ_E, should be determined from at least the centre altitude of the antenna.

Figure 1 shows the e.i.r.p. towards the horizon as a function of the angle of discrimination with the input power-density to the antenna in any 4 kHz band, $D_s - G_s$, as a parameter.

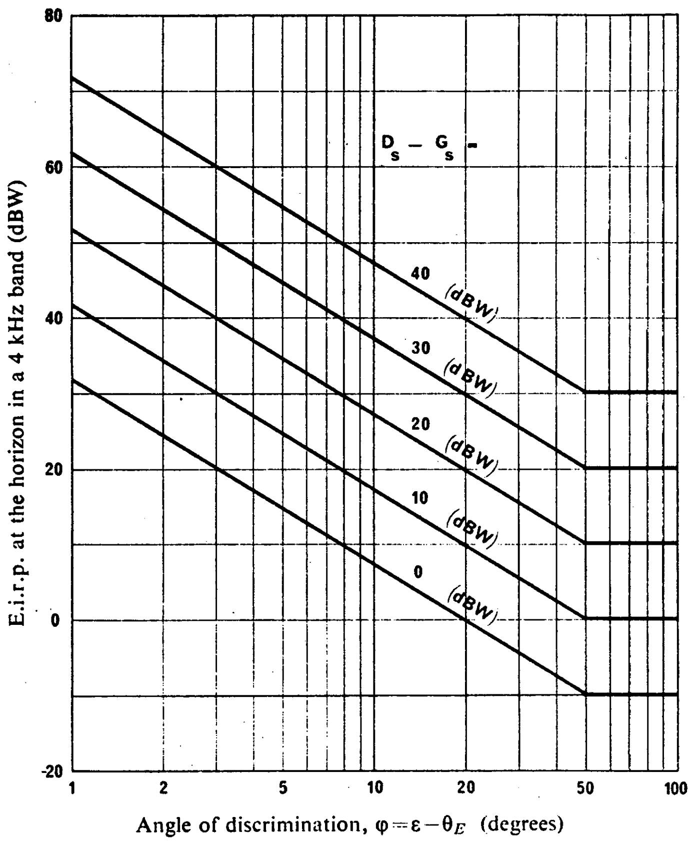

FIGURE 1 – *E.i.r.p. towards the horizon as a function of the angle of discrimination,* φ

$D_s - G_s$ (dBW) parameter

Values of $D_s - G_s$ not coinciding with any of the curves shown may be interpolated linearly in the decibel domain. Annex I provides two representative examples for the derivation of values of $D_s - G_s$.

In the horizontal plane a value of e.i.r.p. of about 35 dBW in any 4 kHz band for an antenna operating at a main beam elevation angle of 3° is generally sufficient for the operation of current systems in the fixed-satellite service. Some margin is required, however, to allow for future systems such as those using smaller diameter antennas, higher channel capacities and different methods of modulation. The limits which were established at the World Administrative Radio Conference, Geneva, 1979, appear to meet these requirements.

Specific limits for the e.i.r.p. of earth stations are laid down in Nos. 2540 to 2548.1 of Article 28 of the Radio Regulations.

4. Consideration of modulating signals other than telephone channels, or of types of modulation other than frequency modulation or single sideband

Where an earth station is being built to be used exclusively with systems in the fixed-satellite service using modulating signals other than telephone channels, in particular television, or using methods of modulation other than frequency-modulation or single-sideband, calculation of values for D_s may be restricted to such modulating signals or methods of modulation.

ANNEX I

The following examples serve to illustrate the use of the equations with assumptions of representative parameter values for a 1200 channel system in the fixed-satellite service:

Parameter	FDM/FM	SSB/AM
S/N up (dB) (1)	56(1)	56(1)
T (K)	1500	1500
P (dB)	2·5	
f_r (MHz)	1·1	
f_m (MHz)	5·0	
P_r (dBW)	−95	−106
dF (MHz)	6·8	
M_u (dB)	3·0	3·0
λ (m)	5×10^{-2}	5×10^{-2}
R (m)	$4{\cdot}16 \times 10^{7}$	$4{\cdot}16 \times 10^{7}$
G_r (dB)	13·0	13·0
D_s (dB(W/4 kHz))	62·1	84·4
G_s (dB)	64·0	64·0
$D_s - G_s$ (dB(W/4 kHz))	−2	20

(1) Corresponding to an up-path noise contribution of 1400 pW.

REPORT 387-5

PROTECTION OF TERRESTRIAL LINE-OF-SIGHT RADIO-RELAY SYSTEMS AGAINST INTERFERENCE DUE TO EMISSIONS FROM SPACE STATIONS IN THE FIXED-SATELLITE SERVICE IN SHARED FREQUENCY BANDS BETWEEN 1 AND 23 GHz

(Question 17/9 and Study Programme 32C/4)

(1966-1970-1974-1978-1982-1986)

1. Introduction

Emissions from space stations will give rise to interference in terrestrial radio-relay systems in shared frequency bands. Unwanted energy capable of producing interference will enter to varying degrees through the main beam or the side lobes of the antennas of the terrestrial stations which comprise a radio-relay system.

While it would be possible to compute the interference effects from the emissions of a given space station on a single radio-relay system, the calculation of cumulative interference effects from many space stations upon each of the large number of radio-relay systems in existence and yet to be implemented, is an impractical task. Therefore, and in view of the comparative uniformity of the characteristics of line-of-sight radio-relay systems, it has been found possible to provide protection for terrestrial radio-relay systems by placing general restrictions on the emissions from space stations.

The restrictions are expressed in terms of values of maximum permissible power flux-density in a reference bandwidth, produced at the surface of the Earth by the emissions of any one space station under assumed free-space conditions.

In determining values of maximum permissible power flux-density, the following criteria are taken as objectives:

- the values should be low enough to avoid exceeding the recommended limits of maximum permissible interference to existing and future terrestrial radio-relay systems using the same frequencies;
- the values must be high enough to allow satisfactory operation of space communications systems.

2. Method of determining the maximum permissible power flux-density

2.1 *Interference criteria*

For the determination of values of maximum permissible power flux-density, the limits of maximum permissible interference in a telephone channel laid down in Recommendation 357 for line-of-sight radio-relay systems using analogue angle-modulated multichannel telephony have been used. For such systems, operating generally below about 15 GHz, it has been shown that a reference bandwidth of 4 kHz is appropriate when considering the effect of unwanted signals at the input of the receivers of the terrestrial stations of the CCIR hypothetical reference circuit.

The maximum allowable values of interference of Recommendation 357 are adequate to protect such radio-relay systems carrying television signals.

In the absence of any recommendation for line-of-sight radio-relay systems carrying digital signals at frequencies above 15 GHz over a single transmission path with negligible Rayleigh fading, it may provisionally be assumed that the carrier-to-total interference ratio for all but 20% of the time should exceed a value of 30 dB at the input of any one terrestrial radio-relay receiver, and that for a small percentage of the time during which the desired signal may be attenuated, mainly by rainfall, the total interference power present at the input of any one terrestrial radio-relay receiver shall not exceed 10% of the thermal noise power at that point.* Since digitally-modulated signals have been shown to be affected by the total interference power within the occupied bandwidth, and since practical bandwidths are likely to be large, a reference bandwidth of 1 MHz has been adopted.

2.2 *Systems models*

To assess the interference effects of the emissions from space stations on terrestrial line-of-sight radio-relay systems, bearing in mind the foreseeable expansion and development of both space and terrestrial systems, appropriate models for both types of systems need to be postulated.

2.2.1 *Model parameters for a terrestrial line-of-sight radio-relay system*

The technical characteristics of model line-of-sight radio-relay systems are described by the parameters listed in Annexes I and II.

In systems carrying angle-modulated analogue multi-channel telephony, both the thermal noise and the interference power (pre- as well as post-detection) may be assumed to be additive over all single transmission paths comprising the system. This assumption cannot be made for systems carrying digital signals.

2.2.2 *Orbit model parameters for space systems*

Of concern are only the characteristics of transmitting space stations. In view of the invariance of the geometry between a given terrestrial radio-relay system and a space station in the geostationary-satellite orbit, the most stringent interference condition is expected to result when, as must be assumed, one or more geostationary space stations are positioned within the main beams of terrestrial receiving stations comprising a radio-relay system.

It has therefore been concluded that the space system model should best be represented by transmitting space stations populating the entire geostationary-satellite orbit visible to a terrestrial system and positioned at uniform intervals (geometric angular spacing of 3 and 6 degrees of arc, representing two cases of different severity).

The effect of interference of emissions from space stations in non-geostationary satellite orbit are considered in § 4.

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* The provisional value of 30 dB is based on digital four-phase PSK systems which are mainly used at present. For eight- or sixteen-phase systems which might be used in the future, this value may have to be reconsidered.

2.3 *Angle dependence of power flux-density limits*

Radio-relay antennas are normally pointed in a nearly horizontal direction. Hence, normally, their greater sensitivity is to interfering power flux arriving in directions tangential (or nearly so) to the Earth's surface. As the angle of arrival of the interference increases, the radiation patterns of the radio-relay antenna provides increasing discrimination. Consequently, the power flux-density may be allowed to increase with the angle of arrival. In determining the extent of the allowable increase, due account has been taken of the characteristics of certain types of radio-relay antennas, e.g., periscope antennas which exhibit poor side-lobe discrimination at angles of up to 90° from the main beam axis.

The various studies made [May and Pagones, 1971] show that a relation between permissible power flux-density and angle of arrival of the general form shown in Fig. 1, is acceptable as far as protection of radio-relay systems is concerned. The higher power flux-density permitted at large angles of arrival is also generally of benefit to systems in the fixed-satellite service using narrow beam antennas. However, since a satellite must comply with the power flux-density limits at all angles of arrival, it is not always practicable to design satellite antennas which can fully exploit the relaxation of the power flux-density limits at higher angles of elevation.

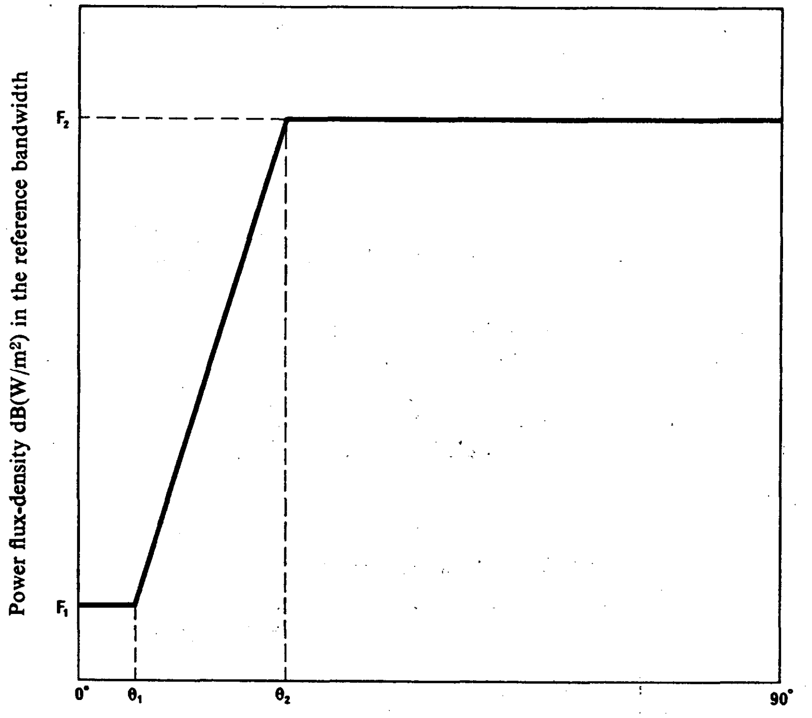

FIGURE 1 – *Power flux-density limit vs. angle of arrival*

2.4 *Interference analysis*

While the characteristics of terrestrial line-of-sight radio-relay systems are well known or can be fairly well anticipated, the specific shape and the absolute levels of the generically derived power flux-density diagram of Fig. 1 had to be further investigated. Specific limits can be defined in terms of the following parameters:

– the range of increase (i.e., the actual values of maximum permissible power flux-density for low and for high elevation angles, the levels F_1 and F_2, respectively, of Fig. 1);

– the rate of increase (i.e., the slope of the line in dB/degree between the elevation angles θ_1 and θ_2 of Fig. 1);

– the values of the angles of arrival θ_1 and θ_2.

The method followed in the statistical analyses is outlined in Annex I.

2.5 *Frequency dependence of power flux-density limits*

As frequency increases from 4 to about 23 GHz, a number of factors have to be taken into account for the derivation of power flux-density limits:

- The receiving system noise temperatures in terrestrial model systems are expected to increase with frequency. Due to beamwidth restrictions in practice, the associated antenna gains are not likely to increase much beyond maximum values in present use at the lower frequencies. Fading, particularly at frequencies above 10 GHz, will increasingly be due to absorption by rain for small percentages of the time. When fading is due to rain, a certain correlation between the weakening of the wanted and the interfering signal can be expected, especially for on-beam exposures. These factors tend to increase the tolerable power flux-density. On the other hand, radio-relay systems may use lower feeder losses which would tend to reduce the permissible limit on power flux-density. The net effect of these considerations results in power flux-density limits which are only slightly higher in the frequency range 10 to 15 GHz, than those for frequencies below 10 GHz.
- At frequencies above about 15 GHz, terrestrial systems are likely to use digital modulation. Although for such systems the interference-additive characteristic of systems carrying analogue angle-modulated signals is no longer applicable, the generally lower sensitivity to interference of digital systems allows a substantial relaxation in the values of maximum permissible power flux-density. At such frequencies, furthermore, the fading will be mainly due to rain attenuation, and correlation between wanted and interfering signals will be appreciable. In addition, atmospheric absorption over the interference path from a space station becomes substantial, in particular for low angles of arrival which include main beam exposures. Annex II shows the derivation of values for power flux-density at about 20 GHz.

3. Limits of power flux-density

Based on the discussions in the preceding sections, it is considered that the likelihood of unacceptable interference from space stations into terrestrial line-of-sight radio-relay systems is small with the limits given below:

- In frequency bands between 1 and about 23 GHz, the frequency bands shared between the fixed-satellite service and the fixed service are indicated in Article 8 of the Radio Regulations. For frequency bands shared between systems in the fixed-satellite service and terrestrial line-of-sight radio-relay systems, the maximum power flux-density produced at the surface of the Earth by emissions from any one space station for all conditions and all methods of modulation should not exceed the values given in Table I.

TABLE I — *Limits of power flux-density* (1)

Frequency range (GHz)	Limit of power flux-density dB (W/m^2)			
	$\theta \leq 5°$ (2)	$5° < \theta \leq 25°$	$25° < \theta \leq 90°$	Reference bandwidth
1.7-2.5 (3)	−154	$-154 + 0.5\ (\theta - 5)$	−144	in any 4 kHz band
2.50-2.69	−152	$-152 + 0.75\ (\theta - 5)$	−137	
3-8	−152	$-152 + 0.5\ (\theta - 5)$	−142	
8-11.7	−150	$-150 + 0.5\ (\theta - 5)$	−140	
11.7-15.4	−148	$-148 + 0.5\ (\theta - 5)$	−138	
15.4-23	−115	$-115 + 0.5\ (\theta - 5)$	−105	in any 1 MHz band

(1) Under Nos. 2581 to 2585 of the Radio Regulations, the power flux-density limits in the band 17.7 to 19.7 GHz shall apply provisionally to the band 31.0 to 40.5 GHz until such time as the CCIR has recommended definitive values, endorsed by a competent Administrative Conference (No. 2582.1 of the Radio Regulations).

(2) θ: the angle of arrival of the wave (degrees above the horizontal).

(3) No frequency bands are at present allocated in the Radio Regulations to the fixed satellite service between 1.7 and 2.5 GHz.

4. Interference from space stations in non-geostationary orbits

For systems utilizing transmitting space stations in randomly disposed orbits, and so long as orbital space is not very densely populated with such space stations, interference contributions to terrestrial radio-relay systems through their antenna main beams is transitory and from a statistical point of view probably acceptably small [Chamberlain and Medhurst, 1964].

Studies of possible interference from space stations in 12-hour elliptical inclined orbits at 4 GHz have indicated that the limit of Recommendation 358 would be adequate.

Results of a study of one possible model by one administration has indicated that the potential interference from space stations in low-circular orbits to FDM radio-relay systems in the shared 2 GHz band produces noise levels below the criteria established in Recommendation 357 [Farrar, 1984 and 1985]. Further studies of interference to other types of system are required.

For other inclined orbits, the conclusions regarding randomly-disposed orbits would most likely apply, with similar safeguards, so long as the earth tracks are not repetitive in the short term. Space stations in non-geostationary equatorial orbits, because of their relative systematic movement might well, *in toto*, produce excessive interference to terrestrial radio-relay systems through the occurence of many contributions through the main beams. It should be noted that in the selection of sites for radio-relay stations no account is taken of satellites using such orbits and any requirements to do so would impose an unacceptable constraint.

5. Effect of the power flux-density limits on the operation of space systems

A brief assessment of the usefulness of space station emissions which comply with the lower limits of § 3 is given below.

The following characteristics typical of relatively simple receiving earth stations are assumed:

TABLE II

Frequency band (GHz)	Antenna diameter (m)	Antenna gain (dB)	Reception system noise temperature (K)
4	7.5	47	500
12	6.0	55	700
20	4.5	57	1000

Assuming free-space conditions and maximum allowable power flux-density for low elevation angles, the receiver power density can be compared with the thermal noise power density, at the input to the earth station receiver. Assuming further wide deviation angle modulation or digital modulation (Gaussian and raised cosine spectrum shapes, respectively), about 4 dB need be subtracted from the carrier/noise density ratio, leaving the available undegraded carrier/noise ratio.

TABLE III

Frequency band (GHz)	Carrier spectral density	Noise spectral density	Carrier/noise ratio (dB)
4	– 137.5 dB (W/4 kHz)	– 165.5 dB (W/4 kHz)	24
12	– 137.0 dB (W/4 kHz)	– 164.0 dB (W/4 kHz)	23
20	– 104.5 dB (W/MHz)	– 138.5 dB (W/MHz)	30

At frequencies below about 15 GHz in which wide deviation angle-modulated signals are used, the resulting margin appears to be quite adequate. At frequencies above 15 GHz in systems using digital modulation, these carrier/noise ratios are only marginally useful for the assumed system parameters.

In some cases higher values of carrier/noise ratio may be desirable. In such cases the higher power flux-density limits associated with the greater elevation angles of arrival are of considerable value in connection with narrow-beam space station antennas; see Annex III.

6. Effect of the power flux-density limits on the design of digital radio-relay systems

Interference from space stations below 10 GHz results in small increase in the degradation of performance due to thermal noise alone. Since the allowable *pfd* limits have been established based upon analogue systems, and since the permissible degradation has been established in accordance with Recommendation 615, it can be anticipated that there may be some constraints on the design of digital radio-relay links. Annex IV examines how the use of orbital avoidance can be effected.

7. Further considerations

The preceding deliberations are based, in part, on the interference allowance of Recommendation 357, on the assumption that this interference allowance would be wholly taken up by transmitting space stations, and on the assumption that the actual number of terrestrial-stations' antennas pointed at the geostationary-satellite orbit is small and in reasonable agreement with statistical models.

If it were decided to use up- and down-path frequency assignments in space systems in an optionally interchangeable fashion, part of the interference allowance of Recommendation 357 would have to be allocated to interference from earth stations which would lead to a corresponding reduction in the permissible power flux-density from space stations.

In addition, the studies referred in § 2.3 were made assuming antenna radiation diagrams of the form in Report 614. These patterns are appropriate for circular apertures that display complete symmetry. However, some types of terrestrial radio-relay antennas do not exhibit circularly symmetrical radiation patterns and the patterns can be assumed to be similar to the reference patterns of Report 614 only in the horizontal plane. Since the interference from space stations is received in all planes, additional studies are necessary. These studies were recently made [Butzien, 1981] with a complete three-dimensional characterization of the pyramidal horn-reflector. The conclusions were similar to previous studies [May and Pagones, 1971]. Specifically, the limits given in § 3 adequately protect radio-relay systems, but the allowable interference may be exceeded in a small percentage of sensitive systems.

It should be noted that if the main beams of terrestrial antennas avoid pointing within 1° of the geostationary-satellite orbit, the potential of interference from space stations may be greatly reduced.

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ANNEX I

DETERMINATION OF POWER FLUX-DENSITY LIMITS IN THE FREQUENCY BAND BETWEEN 1 AND 10 GHz

1. Introduction

To investigate the effect of different power flux-density limits on the feasibility of frequency sharing between transmitting space stations in the geostationary-satellite orbit and terrestrial line-of-sight radio-relay systems, a statistical approach has been adopted by various administrations.

2. Evaluation method

Calculations made assume randomly located radio-relay systems of the length of the CCIR hypothetical reference circuit. The mean system latitude and, in some cases, the mean system end-to-end azimuth, has been varied and certain distributions of elevation angle and azimuth of terrestrial-station antenna main beams around the mean system azimuth have been assumed.

With various assumed power flux-density limits, the aggregate interference from satellites spaced every 3°, and every 6°, all producing the full assumed power flux-densities for all angles of arrival on model terrestrial systems, has been computed.

Absolute values of power flux-density have been selected in such a way that:

– a reasonable increase with the higher angles of arrival could be tolerated;
– non-geostationary and geostationary space stations could be accounted for under the same power flux-density limits;
– the maximum permissible interference power of Recommendation 357 would be exceeded only in a relatively small fraction (≈ 10%) of the "high sensitivity" terrestrial systems, and somewhat lesser percentage for "average sensitivity" systems.

3. Model systems

The technical characteristics representative of radio-relay systems on which the analyses have been performed are shown in Table IV below:

TABLE IV — *Assumed parameters for model radio-relay systems*

Frequency	2.5 GHz	4 GHz	4 GHz
Type of system	High sensitivity	Average sensitivity	High sensitivity
Hop length (km)	60	50	50
Antenna gain (dB)	38	40	42
Feeder loss (dB)	3	3	3
Rec. syst. noise temp. (K)	750	1750	750
Channel thermal noise power per hop (pW0p)	25	25	10 and 25

Radiation diagrams of the general form shown below have been assumed for the terrestrial station antennas:

$$\begin{aligned} G(\varphi) &= G_1 - 25 \log \varphi \quad && \text{dB, for } \varphi_0 \leqslant \varphi \leqslant \varphi_1 \\ &= G_2 && \text{dB, for } \varphi_1 < \varphi \leqslant 180° \end{aligned} \tag{1}$$

where φ = angle, in degrees, from the main beam axis.

4. Results of the calculations

The calculations indicate that the power flux-density limits given in § 3 of this Report would protect the average sensitivity model radio-relay systems adequately but would, in some cases, exceed the allowable values of Recommendation 357 in the highly sensitive model systems.

5. Effects of the variability with time of the wanted and unwanted signal levels

The variability with time to which both the wanted and unwanted signals may be subject has been taken into account to some degree. For example, calculations assuming Rayleigh fading to occur during ⅓ of the month indicate that the power flux-density limits given in Table I of this Report, for the 3 to 8 GHz frequency range would introduce 50 000 pW0p of noise in a telephone channel of a model 4 GHz radio relay system from about 0.003% to about 0.02% of the time, depending on system latitude. The model radio-relay system was assumed to have 1 : 1 switched diversity protection every 5 hops, and the model satellite system was assumed to have satellites spaced at 3°, each producing the allowable power flux-density at all angles of arrival.

More detailed study of these effects is desirable.

ANNEX II

LIMITATION OF POWER FLUX-DENSITY AT THE SURFACE OF THE EARTH FROM COMMUNICATION SATELLITES OPERATING AT ABOUT 20 GHz

This Annex describes, as an example, a representative interference model from which the power flux-density limits for low and high angles of elevation are derived. It is assumed that the same dependence on angle of arrival is applicable at the lower frequencies.

1. Characteristics of the model

As a basis for the calculations a model 4 Φ-PSK digital link is assumed, the parameters of which are listed below:

- 50 mW (−13 dBW) transmitter power,
- 4 dB transmission feeder loss,
- antennas of 1 metre diameter (about 43.5 dB gain and 0.4 m^2 effective area),
- 138 dB free space loss (10 km),
- 400 MHz bandwidth,
- 5 dB receiver noise factor.

In this model the standard received power is −68 dBW, and the thermal noise level is −112.8 dBW.

In addition, the following assumptions are made:

- 3 degree satellite spacing, in which case about 50 satellites would appear on or above the horizon,
- 3 dB atmospheric absorption for the in-beam interference exceeded for more than 80% of any month,
- −3 dB average antenna side-lobe gain for off-beam entries,
- the average power flux-density from 50 satellites is 3 dB lower than the permissible value.

2. Power flux-density limits

First, the in-beam interference is considered, which determines the tolerable power flux-density at low angles of elevation. In the case where the wanted radio-relay signal is attenuated under severe rainfall conditions, the interfering signal from satellites is also attenuated; and because the propagation path of the latter through the atmosphere is longer, the attenuation is generally greater than that of the wanted signal. Therefore, under normal propagation conditions, and on the assumption that the desired-to-undesired signal ratio should be at least 30 dB, the maximum permissible interference is:

$$-68 - 30 = -98 \text{ dBW in 400 MHz.}$$

Taking into account the effective area of the antenna, the feeder loss at the receiver and converting the bandwidth to 1 MHz, the maximum power flux-density for in-beam entries under free-space conditions is −115 dB(W/m^2) in any 1 MHz band.

Next, off-beam interference is considered. The permissible power flux-density at high angles of elevation is determined by the aggregate of this interference. In this case, the objective for rainfall conditions is more severe than that for normal conditions, and calculations for these conditions are sufficient. On the assumption that the permissible power flux-density would be 10 dB lower than the thermal noise level, the maximum allowable value of power flux-density is -110.3 dB(W/m^2) in any 1 MHz band.

As stated before, this limit is the objective in the case where the desired signal is attenuated more than 30 dB on account of rainfall, with an additional 6 dB attenuation assumed for the interfering signals. Accordingly, the permissible power flux-density would be -104.3 dB(W/m^2) in any 1 MHz band.

ANNEX III

USE OF "SPOT BEAM" ANTENNAS ON GEOSTATIONARY SATELLITES

In order to benefit from any increased power flux-density permitted at high elevation angles, the satellite has to be equipped with an earth-oriented antenna with a narrow beam. In the case of narrow beams pointing away from the sub-satellite point (and thus close to the horizon) special precautions need to be taken in order that the satellite emissions should satisfy the power flux-density limit at all elevations.

Basically, these precautions consist of illuminating the surface of the Earth with a smaller power flux-density than the corresponding permissible limit at the beam centre to ensure that the emissions arriving at all angles of elevation satisfy the power flux-density limits.

Figure 2 shows the relationship between the tilt angle α at the satellite (defined as the angle between the geocentric radius vector and a ray to a point on the surface of the Earth) and the corresponding angle of arrival above the horizon of the satellite emissions. Figure 3 shows representative main beam patterns for satellite antennas. Three different beamwidths are shown:

TABLE V

3 dB beamwidth (degrees)	Antenna diameter at 4 GHz (m)
2	2.6
1	5.2
0.5	10.4

The main beam patterns shown are of the general form

$$10 \log (G/G_0) = -12 (\varphi/\varphi_0)^2 \qquad \text{dB} \qquad (2)$$

where φ is the angle from the main beam axis, and φ_0 is the half-power beamwidth.

The solid curve in Fig. 4 shows the maximum power flux-density at the beam centre which satisfies the power flux-density limits shown at all elevation angles. A satellite antenna with a 0.5° half-power beamwidth can closely follow the rapid change in this power flux-density limit at low angles of arrival as the horizon is approached. Broader satellite beams pointing close to the horizon are limited by the power flux-density curve at the horizon.

Figure 4 also shows the loci of satellite antenna beam centres for various beamwidths. Note that for a beam of given width, the flux-density at beam centre must be limited as shown by these curves so that no portion of the antenna beam exceeds the limit shown by the solid line.

These curves illustrate that satellite system designers may not be able to take full advantage of all the higher flux curves in every satellite at every angle of arrival.

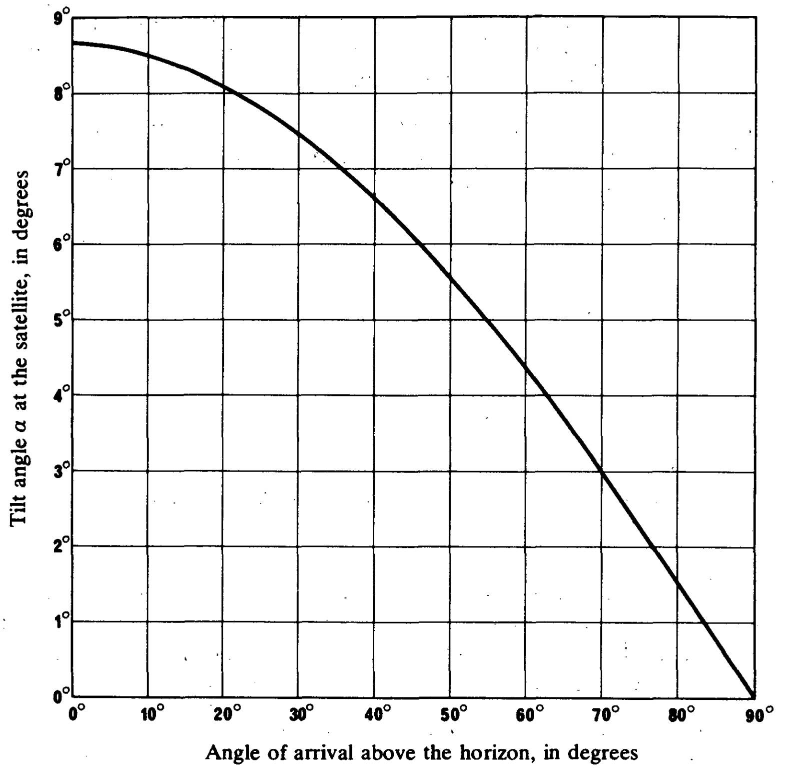
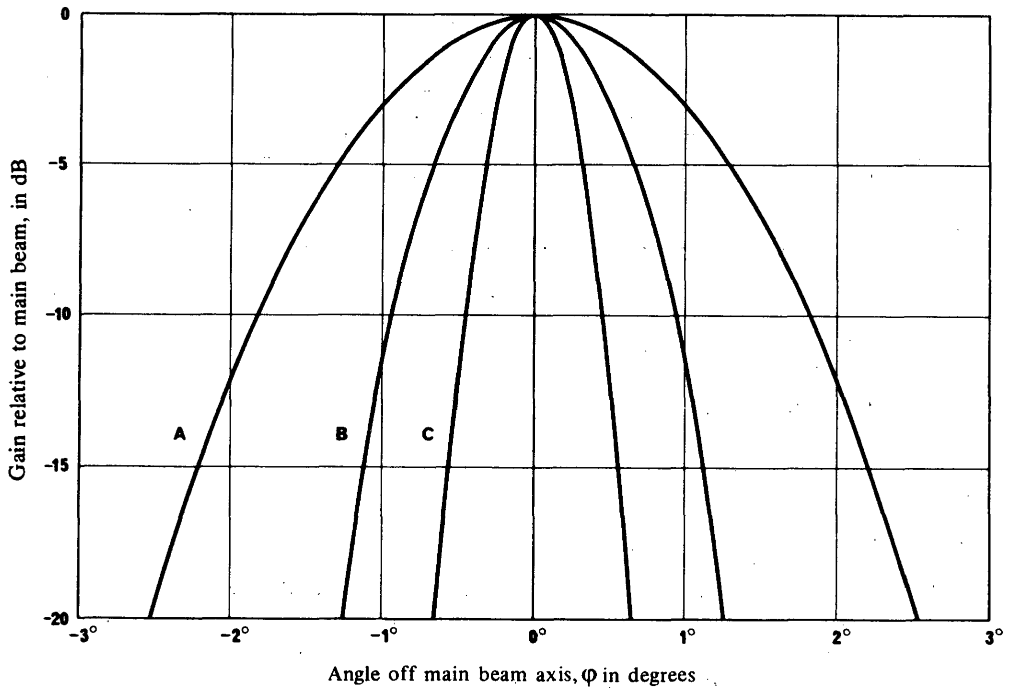


FIGURE 2 – *Tilt angle α at the satellite versus angle of arrival above the horizon*



A: $\varphi_0 = 2°$, $D = 2.6$ m B: $\varphi_0 = 1°$, $D = 5.2$ m C: $\varphi_0 = 0.5°$, $D = 10.4$ m

FIGURE 3 – *Representative main beam patterns for satellite antennae*

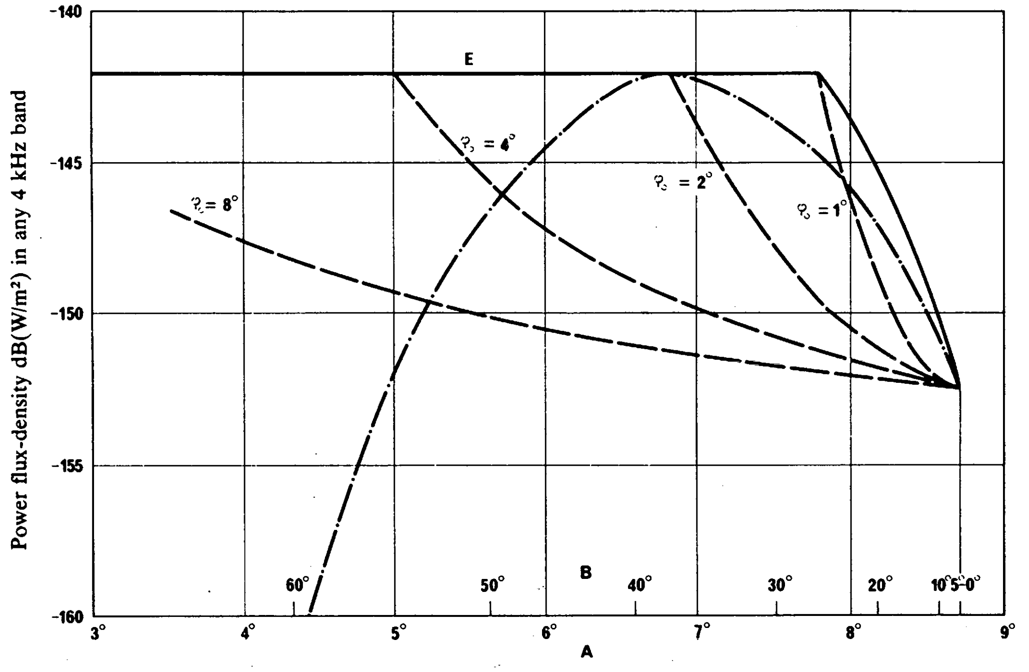


FIGURE 4 – *Maximum power density at the centre of the beam without exceeding curve E*

——— Loci of satellite antenna beam centres for various beamwidths for which the limit imposed by curve E is reached

—·—·— Example of a 2° beam to fit within curve E

——— E: Limit of power flux-density in 3 to 8 GHz band
A: Scale of tilt angle at the satellite (degrees)
B: Scale of angle of arrival above the horizon (degrees)

ANNEX IV

USE OF ORBITAL AVOIDANCE IN THE DESIGN OF DIGITAL RADIO-RELAY SYSTEMS DUE TO LIMITS IN RECOMMENDATION 358

1. Introduction

Recommendation 615 in effect allows 10% of the performance degradation in a digital radio-relay hypothetical reference digital path (HRDP) to be due to interference from fixed-satellite systems (FSS). At the same time, Article 27 of the Radio Regulations and Recommendation 358 specify the allowable power flux-densities due to FSS space stations in various bands.

This Annex examines the impact on the need for orbital avoidance by radio-relay receivers operating in bands shared with the FSS below 15 GHz. It provides an approach that may be used to determine the orbital avoidance constraints in the design of digital radio-relay systems.

2. Digital radio-relay analysis model

For the purposes of this analysis, the following typical parameters, based upon digital radio-relay systems in Canada, are assumed:

- frequency band: 4 GHz
- bandwidth: 20 MHz
- antenna: 4 m dish
  gain: 42 dBi
  pattern: $35 - 25 \log X$ dBi for $1.8 \leqslant X < 25$
  0 dBi for $X \geqslant 25$
  (where X = off-axis angle)
- latitude: 50° N

In order to determine the total degradation in performance caused by a constant interference flux from space stations, it is necessary to calculate the interference power received at each receive station. This is determined from the above parameters and the angle by which the receive antenna avoids pointing at the orbit.

It is considered that very little loss of generality will result if stations are classified as follows:

- Category A: those radio-relay stations whose orbital avoidance is small, i.e. 2 to 10°;
- Category B: those radio-relay stations whose orbital avoidance is large, i.e. in excess of 10°.

The Category A stations may be conservatively simulated by a station which points in a direction of 2° from the orbit, and Category B stations by a station which points 10° from the orbit. For greater accuracy, more categories at smaller angular ranges are possible. However, to illustrate the principle, the above will suffice.

Let Q be the fraction of stations in an HRDP of Category A and $(1 - Q)$ of Category B. It is then possible, as discussed in the following paragraphs, to determine the total degradation in an HRDP and relate it to the recommended value (Recommendation 615) and thus obtain the value for Q.

3. Received interference power

Using the geometric formulation given in May and Pagones [1971], when it is assumed that the orbital spacing between satellites is 3° and the *pfd* limits of Article 27 are met, the received aggregate interference power at a Category A station is found to be:

$$Pr_A/4 \text{ kHz} = -158.1 \text{ dB(W/4 kHz)}$$

Assuming that the interfering signal from the satellite is a television carrier with 2 MHz energy dispersal, then the total interfering power within the 20 MHz passband of the receiver is:

$$\mathrm{Pr}_A = -131.1 \text{ dB(W/20 MHz)}$$

Category B stations have an antenna discrimination of at least $25 \log 10/2 = 17.5$ dB, whence the maximum total power received is:

$$Pr_B = -175.6 \text{ dB(W/4 kHz) or } -148.6 \text{ dB(W/20 MHz)}$$

4. Degradation in performance due to interference

The space station interference is assumed to be a steady interference, not subject to multipath enhancement. It will, therefore, result in a reduction in the fade margin of the radio-relay link affected, and consequently on its performance degradation. The thermal noise power in a typical receiver (T = 750 K; see Report 382) is:

$$N_0 = -126.8 \text{ dB(W/20 MHz)}$$

Assuming that the interference is noise-like (see Report 877), for a given interference to thermal noise ratio, I/N_0, the performance is degraded by a factor, x_p given by:

$$x_p = 1 + 10^{(I/N_0)/10} \tag{3}$$

For a Category A station I/N_0 is -4.26 dB and for Category B, -21.8 dB. From equation (3) for Category A stations, $x_p = 1.38$, and for Category B stations $x_p = 1.007$.

Assuming that there are n stations in the system, and assuming that 10% of total degradation is due to interference from satellites, the degradation due to thermal noise alone in each station is given by:

$$P_{0_T} = \frac{0.9\ P_0}{n}$$

where:

P_0 : total permissible degradation in percentage of time (see Recommendation 594).

Then, with nQ Category A receivers and $(1 - Q)n$ Category B receivers, the total degradation P_0, is:

$$P_0 = P_{0_T} \times 1.38 \times nQ + P_{0_T} \times 1.007 \times (1 - Q)n$$

$$= 0.9\ P_0\ (0.38\ Q + 1.007)$$

Whence, $Q = 27\%$.

5. Discussion of results

The above conservative analysis shows that approximately 27% of the terrestrial receivers in an HRDP may point within 2-10° of the geostationary orbit, if the remaining stations point further than 10° away. Countries whose predominant routings are east-west should take this into consideration.

It is to be noted that in the above analysis the assumed energy dispersal bandwidth necessary is 2 MHz. It is possible that future systems may require higher e.i.r.p. and thus wider energy dispersal, e.g. 4 MHz. The resulting 3 dB increase on interference would change the above 27% figure to 13%.

6. Conclusion

This Annex has shown how the 10% allowance for FSS interference in Recommendation 615 can be accommodated in the design of digital radio-relay systems. It shows that with this allowance, up to 27% of the stations in a given system may point within 2-10° of geostationary orbit. Indeed with the conservative assumptions made in the above classifications this percentage can be increased further in most practical systems. Even with assumed higher satellite e.i.r.p.s in the future, the restrictions are still reasonable.

REFERENCES

MAY, A. S. and PAGONES, M. J. [January, 1971] Model for computation of interference to radio-relay systems from geostationary satellites. *BSTJ*, Vol. 50, 1, 81-102.

REPORT 1005

FREQUENCY SHARING BETWEEN SYSTEMS OF THE FIXED SERVICE AND SYSTEMS OF THE FIXED-SATELLITE SERVICE COMPRISING FORWARD BAND WORKING (FBW) NETWORKS AND REVERSE BAND WORKING (RBW)NETWORKS

(Study Programme 17F/9)

(1986)

1. Introduction

Report 557 describes the sharing difficulties experienced between systems of the fixed service and systems of the fixed-satellite service if unrestricted reverse band working (RBW) is attempted in bidirectionally allocated bands where fixed-satellite systems already operate forward band working (FBW) extensively for international networks. This Report examines the possibility of ameliorating the sharing difficulties discussed in Report 557 thus permitting national and sub-regional satellite networks to be established, based upon RBW. One approach is to constrain RBW to applications using spot beams to serve RBW earth stations with elevation angles not less than, say, 40° at the edge of the coverage area.

2. General RBW

The practicalities of introducing bidirectional working in bands shared with terrestrial radio-relay links by adding RBW satellite networks to FBW satellite networks so that satellite-to-Earth and Earth-to-satellite transmissions take place at the same frequencies are questioned in Report 557.

Section 6 of Report 557 concludes that *pfd* and e.i.r.p. limits of both the satellite and terrestrial fixed services would need to be tightened if the quality of each service is not to be degraded by the addition of RBW.

However, central to such thinking is an assumption of global beams, or spot beams pointing near to the rim of the Earth in order to provide service to earth stations with elevation angles as low as 5°. Thus a satellite antenna gain towards the rim of the Earth exceeding perhaps 18 dB relative to isotropic is implied.

The introduction of constraints on RBW to ease sharing conditions is discussed in the following section, with particular reference to RBW using spot beams to high elevation angle (> 40°) earth stations.

3. RBW using spot beams to high elevation angle (> 40°) earth stations

3.1 *General*

The accelerating requirement for increasing numbers of domestic or sub-regional satellite systems reinforces the need to review whether RBW could be introduced in a manner which would minimize constraints upon both FBW satellite networks, and terrestrial radio-relay networks.

Geometric considerations suggest that if RBW networks were to use, say, 2° spot beams primarily to serve earth stations with high elevation angles exceeding about 40° then many countries could be served without satellite side-lobe gains towards the rim of the Earth exceeding 8 dB relative to isotropic. The side-lobe envelope law, which is based upon Report 810, has been shown in Report 558 to be achievable with offset-fed satellite antennas. Compliance with Report 558 would appear to be necessary from considerations of capacity within the fixed-satellite service itself, so that the amelioration of sharing difficulties would be an additional advantage.

Figures 1 to 4 show the range of coverages that can be achieved with 2° beams, and indicate that the latitudinal extent of the terrestrial footprints depends upon longitudinal separation between satellite and earth-station location. Latitudes several degrees north of 40° N can be reached where little or no longitudinal separation applies whilst latitudes of 30° N can be covered with longitudinal separations of 30°.

Larger beamwidths than 2° can be used but the edge of the coverage footprints needs to be correspondingly further from the rim of the Earth.

3.2 *Potential interference into space stations from stations of the fixed service*

The geometry of sharing between the fixed service and the fixed-satellite service is such that only transmitting stations of the fixed service at the rim of the Earth (as viewed from space stations) have the potential to produce significant levels of interference power into receiving space stations. The particular geometry of RBW using spot beams to high elevation earth stations is such that the high off-axis discrimination of the antenna of the receiving space station (30 dB, see Report 558) would provide sufficient protection from interference from transmitting stations of the fixed service at the rim of the Earth without the need to impose pointing or additional e.i.r.p. restrictions.

3.3 *Potential interference into stations of the fixed service when RBW is introduced into bands used for FBW up links*

The adoption of RBW in bands currently allocated to up links for FBW would introduce an additional source of interference into stations of the fixed service from the transmitting space stations. The *pfd* limits which can be tolerated by the receiving stations of the fixed service have been assessed by assuming that the interference from the space stations produces a noise power level in the receiver 10 dB below that of thermal noise. This assessment indicates that *pfd* limits below those of Recommendation 358 would have to be adopted and typically a *pfd* limit 6 dB at boresight below that of Recommendation 358 would have to be adopted in the 6 GHz band for systems using spot beams to high elevation angle earth stations.

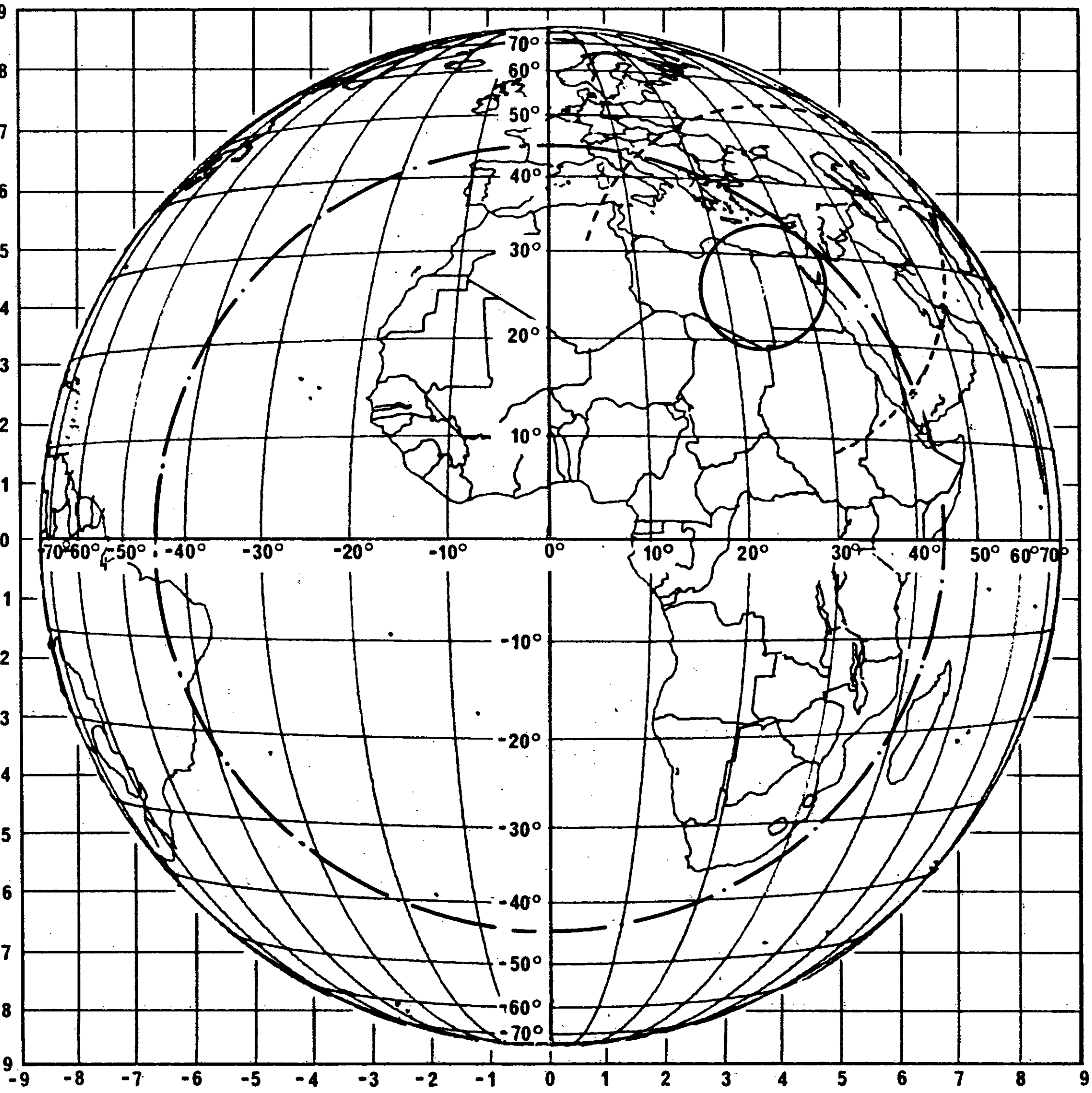


FIGURE 1 – *Permissible range for RBW with 2° beams avoiding additional sharing constraints with terrestrial services*

(View from the geostationary orbit at 0° longitude)

——— Coverage area of typical 2° beam

– – – – −30 dB contour for 2° beam

–——·– Limit of range: minimum earth-station elevation angle of 40°

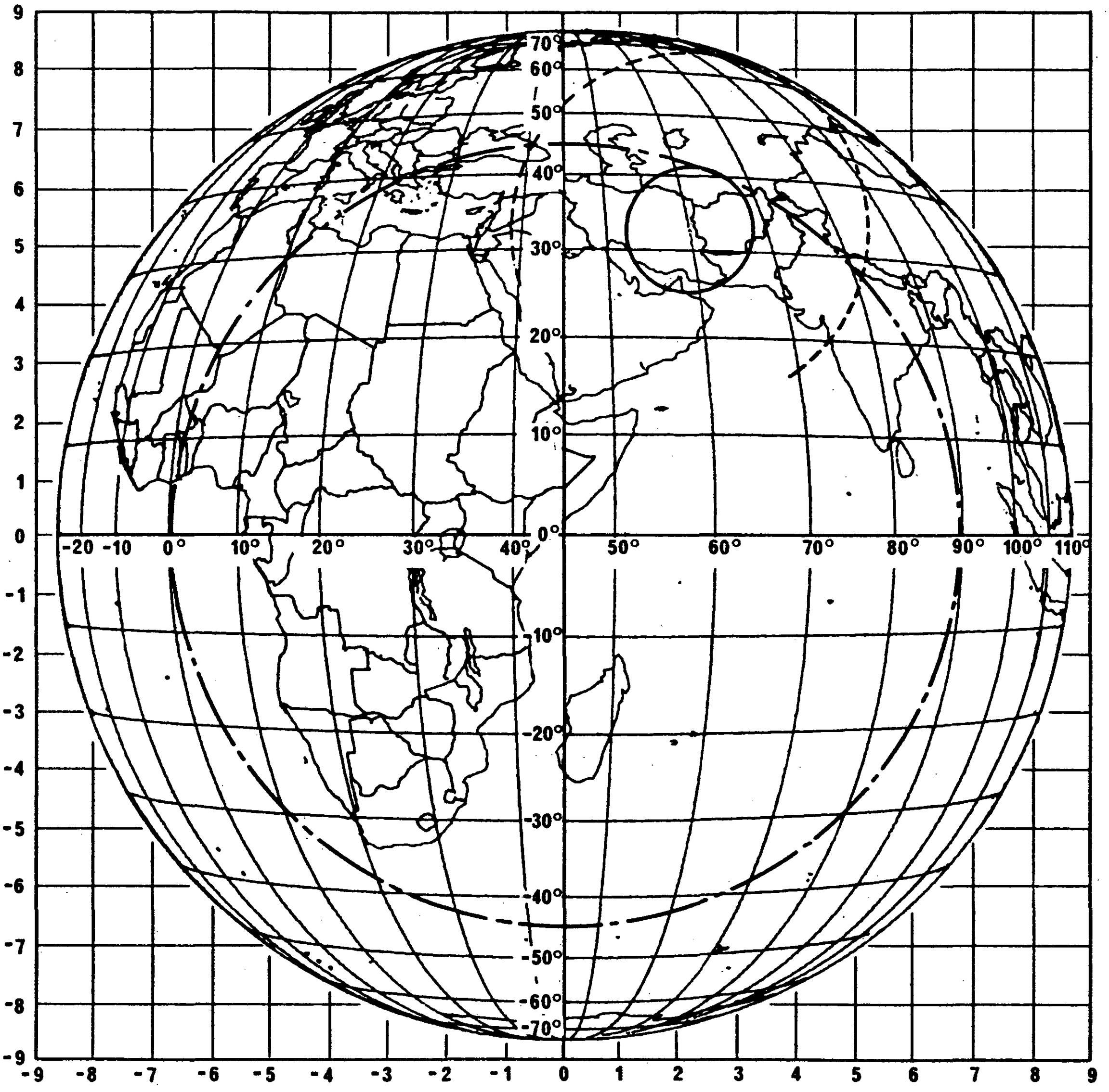


FIGURE 2 – *Permissible range for RBW with 2° beams avoiding additional sharing constraints with terrestrial services*

(View from the geostationary orbit at 45° longitude)

——— Coverage area of typical 2° beam

– – – – –30 dB contour for 2° beam

· — · — Limit of range: minimum earth-station elevation angle of 40°

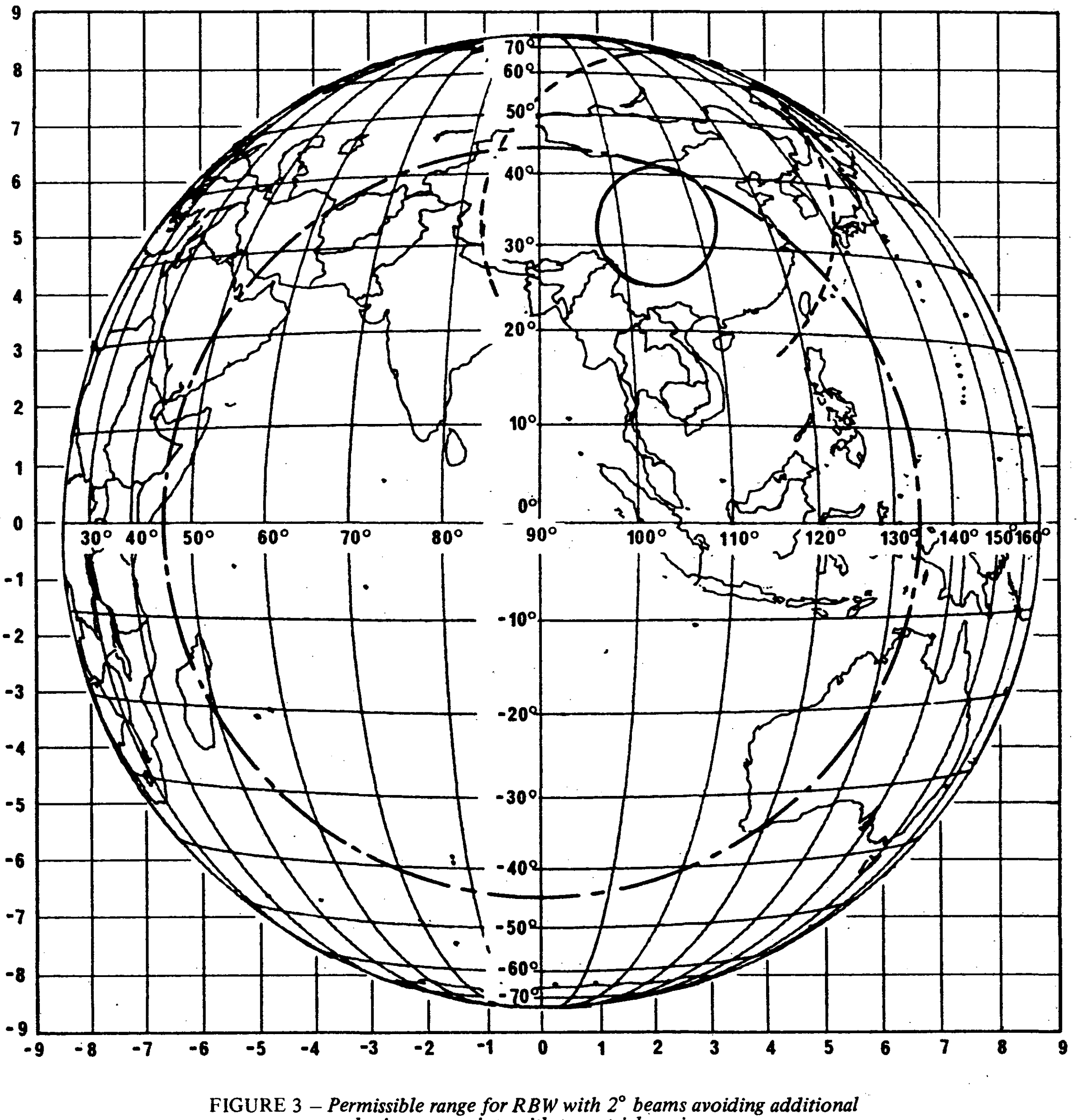


FIGURE 3 – *Permissible range for RBW with 2° beams avoiding additional sharing constraints with terrestrial services*

(View from the geostationary orbit at 90° longitude)

——— Coverage area of typical 2° beam

– – – – –30 dB contour for 2° beam

–·—·– Limit of range: minimum earth-station elevation angle of 40°

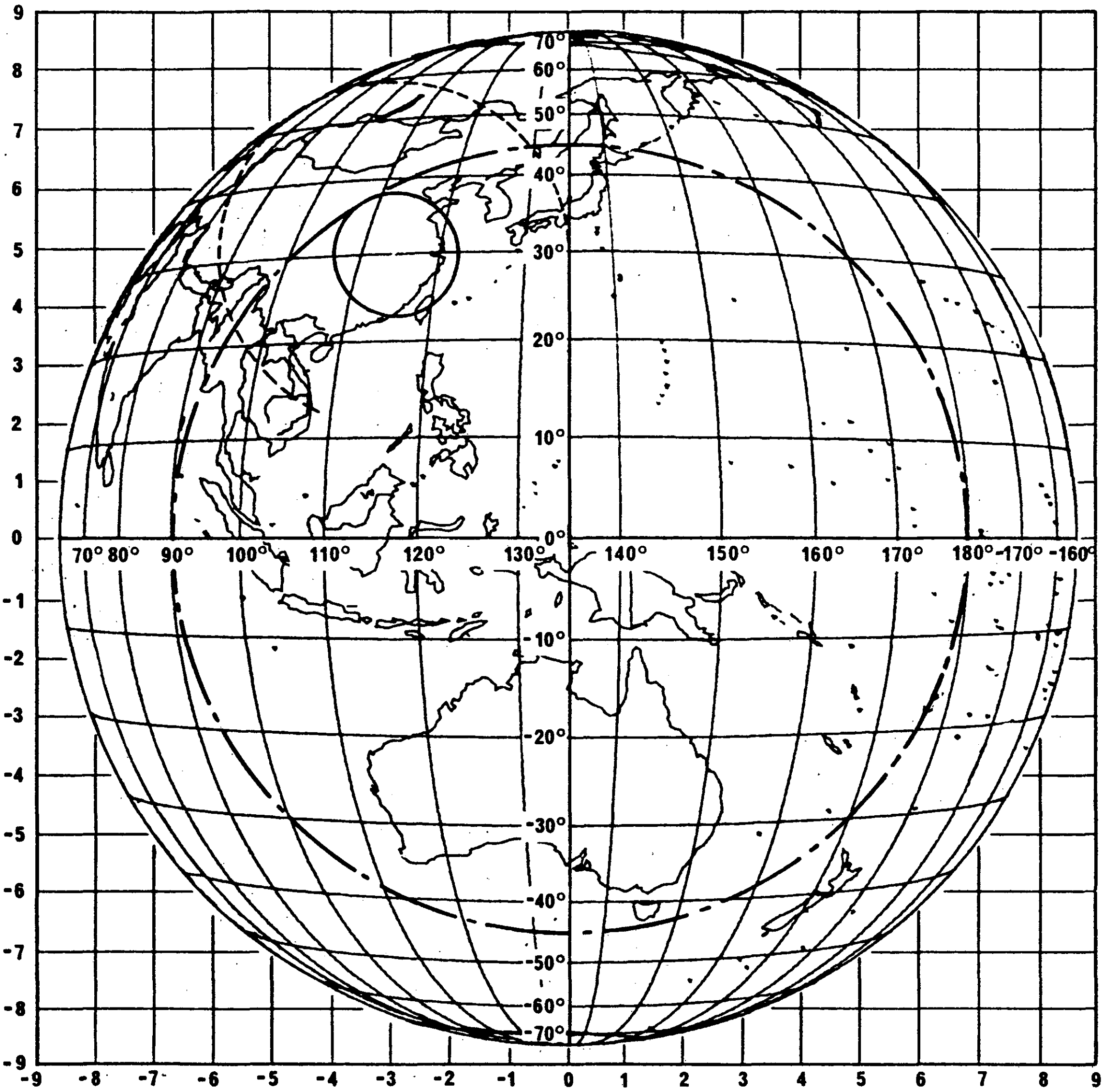


FIGURE 4 – *Permissible range for RBW with 2° beams avoiding additional sharing constraints with terrestrial services*

(View from the geostationary orbit at 135° longitude)

——— Coverage area of typical 2° beam

- - - - –30 dB contour for 2° beam

—·— Limit of range: minimum earth-station elevation angle of 40°

3.4 *Potential interference into stations of the fixed service when RBW is introduced into bands used for forward band working down links*

The adoption of RBW into the bands currently allocated to down links for FBW would introduce a source of interference into stations of the fixed service from the transmitting earth stations in addition to that from the transmitting space stations.

The total outage and unavailability of systems in the fixed service would then be influenced by three independent mechanisms. These are the reduction of fade margin due to space station "long-term" interference, the reduction of fade margin due to earth station "long-term" interference, and the high level "short-term" interference contribution due to anomalous propagation from transmitting earth stations. A recent study estimated the total outage of a radio-relay system in the United States of America using 64-QAM digital modulation technology in an assumed bidirectionally allocated frequency band, by evaluating the contribution of each of these mechanisms. The results of the study indicate a worst-case increase of three orders of magnitude over the 10% values of RECOMMENDS 2 and 3 of Recommendation 615 [Pagones and Prabhu, 1986].

Achievement of a realizable balance between these three mechanisms may vary between different parts of the world, depending on individual circumstances. For example, in those parts of the world where extensive use is made of geostationary satellites, sharing would not be feasible since it would require both the reduction of satellite e.i.r.p. limits and adoption of large separation distances between transmitting earth stations and receiving stations of the fixed service.

In other parts of the world which make less extensive use of geostationary satellites, lower separation distances may be achievable.

4. RBW earth-station coordination with terrestrial radio-relay stations

The usual propagation modes need to be considered when coordinating RBW earth stations and terrestrial radio-relay links, viz., clear-air coupling via mode (1), and precipitation coupling via mode (2).

However, it must be borne in mind that earth-station coordination distances are determined by the short-term (0.01% time) interference experienced during anomalous propagation rather than the long-term 20% time. This results in large coordination distances.

For mode (1), the interference along the great-circle plane containing the boresight will be reduced by at least 22 dB by the increase in RBW earth-station elevation angle, from 5° to more than 40°. At other azimuths the reduction will be less, but it will be from a lower initial value of antenna gain.

For mode (2) the computation is more complex but qualitatively a reduction in coupling can be inferred from the reduced common volume within the atmosphere which results from raising the RBW earth-station elevation angle from 5° to more than 40°.

5. RBW to lower elevation earth stations

Should network operators wish to introduce RBW with lower elevation (< 40°) earth stations (for example in higher latitudes) then the geometry becomes progressively less favourable and studies on a case-by-case basis would need to be carried out. This might well prove practicable but as Figs. 1 to 4 indicate, the provision of RBW to a higher latitude should not require the introduction of additional restrictions on lower latitude countries provided the spot beam approach is employed.

6. Conclusion

The foregoing sets out the ways in which realizable RBW can be introduced in a manner which significantly reduces the scale of the sharing difficulties with terrestrial radio-relay links. It would appear that the highly favourable geometry conferred by high elevation angle earth stations, as typified by spot beam (typically 2°) networks serving countries at latitudes of less than 40°, offers the possibility of the combination of FBW networks, RBW for some domestic and sub-regional networks and terrestrial radio-relay networks, to a far greater extent than would be possible in the higher latitude countries, particularly in those parts of the world which make less extensive use of the geostationary orbit. Further studies are required of systems using large beamwidths.

REFERENCES

PAGONES, M. J. and PRABHU, V. K. [1986] Effect of interference from geostationary satellites on the terrestrial radio network – A case study with bidirectional transmission. *AT&T Tech. J.*

RECOMMENDATION 406-5

MAXIMUM EQUIVALENT ISOTROPICALLY RADIATED POWER OF LINE-OF-SIGHT RADIO-RELAY SYSTEM TRANSMITTERS OPERATING IN THE FREQUENCY BANDS SHARED WITH THE FIXED-SATELLITE SERVICE

(Questions 32/4 and 17/9, Study Programme 17E/9)

(1966–1970–1974–1978–1982)

The CCIR,

CONSIDERING

(a) that systems in the fixed-satellite service and line-of-sight radio-relay systems share certain frequency bands in the range of 1 GHz to about 30 GHz;

(b) that, to avoid significant interference to reception in space station receivers, without excessive transmitter powers at the earth stations of systems in the fixed-satellite service or excessively large antennas, it is necessary to define maximum allowable values for the equivalent isotropically radiated power of line-of-sight radio-relay systems;

(c) that the maximum allowable values of radiated power should be such as not to place undue restriction on the design of line-of-sight radio-relay systems;

(d) that it is desirable that radio-relay systems should employ highly directional antennas;

(e) that it is necessary to avoid relatively constant excessive levels of interference from radio-relay emissions directed at satellites in the fixed-satellite service, and particularly those in the geostationary-satellite orbit;

(f) that the radio-relay system planner often has a choice in routing new systems without severe economic or other penalties being incurred,

UNANIMOUSLY RECOMMENDS

1. that in those frequency bands* between 1 and 10 GHz, shared between systems in the fixed-satellite service and line-of-sight radio-relay systems involving reception at the space station:

1.1 the power delivered to the antenna input of any such radio-relay system transmitter shall not exceed +13 dBW;

1.2 the maximum value of the equivalent isotropically radiated power of any such radio-relay system transmitter shall not, in any case, exceed +55 dBW;

1.3 as far as practicable, sites for new transmitting stations, employing maximum values of equivalent isotropically radiated power exceeding +35 dBW should be selected so that the direction of maximum radiation of any antenna will be at least 2° away from the geostationary-satellite orbit;

1.3.1 if, in a particular case, this should prove impracticable, the maximum values of equivalent isotropically radiated power for each transmitter shall not exceed:

1.3.1.1 +47 dBW for any antenna beam directed within 0.5° of the geostationary-satellite orbit;

1.3.1.2 +47 to +55 dBW, on a linear decibel scale (8 dB per angular degree), for any antenna beam directed between 0.5° and 1.5° of the geostationary-satellite orbit;

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* The frequency bands concerned are given in the Radio Regulations.

1.4 in new radio-relay systems built on existing routes* the maximum values of equivalent isotropically radiated power for each transmitter should not, as far as possible, exceed:

1.4.1 +47 dBW for any antenna beam directed within 0.5° of any location in the geostationary-satellite orbit which has been internationally notified, or, if practicable, the geostationary orbit (see Note 4);

1.4.2 +47 to +55 dBW, on a linear decibel scale (8 dB per angular degree), for any antenna beam directed between 0.5° and 1.5° of any location in the geostationary-satellite orbit which has been internationally notified, or, if practicable, the geostationary orbit (see Note 4);

2. that in those frequency bands** between 10 and 15 GHz, shared between systems in the fixed-satellite service and line-of-sight radio-relay systems involving reception at the space station:

2.1 the power delivered to the antenna input of any such radio-relay system transmitter shall not exceed +10 dBW;

2.2 the maximum value of the equivalent isotropically radiated power of any such radio-relay system transmitter shall not, in any case, exceed +55 dBW;

2.3 as far as practicable, sites for transmitting stations, employing maximum values of equivalent isotropically radiated power exceeding +45 dBW should be selected so that the direction of maximum radiation of any antenna will be at least 1.5° away from the geostationary-satellite orbit;

3. that in those frequency bands** above 15 GHz, shared between systems in the fixed-satellite service and line-of-sight radio-relay systems involving reception at the space station:

3.1 the power delivered to the antenna input of any such radio-relay system transmitter shall not exceed +10 dBW;

3.2 the maximum value of the equivalent isotropically radiated power of any such radio-relay system transmitter shall, in all cases, not exceed +55 dBW;

3.3 there shall be no restriction as to the direction of maximum radiation (see Note 6).

Note 1. – When calculating the angle between the direction of the terrestrial-station antenna main beam and the direction towards the geostationary orbit, the effect of atmospheric refraction should be taken into account (see Report 393).

Note 2. – Receiving stations in terrestrial systems operating in frequency bands between 1 and 15 GHz shared with space systems (space-to-Earth) may benefit from avoiding directing their antenna main beams towards the geostationary orbit, if their sensitivity is sufficiently high.

Note 3. – Definitive limits applicable in shared frequency bands are laid down in Article 27 of the Radio Regulations (Nos. 2502 to 2511.2). The CCIR is continuing to study the question, and these studies may lead in the future to a Recommendation, that the limits should be revised. At the present time, no changes are proposed to the limits as laid down in the Radio Regulations.

Note 4. – The operation of a radio-relay system established on an existing route and exceeding the limits given in § 1.4.1 and 1.4.2 may, in view of the characteristics of the terrestrial and space systems involved, result in objectionable levels of interference to a geostationary satellite whose position has been notified after the radio-relay system has been brought into service; in such a case the action to be taken with regard to both systems to reduce such interference to a level which can be agreed by the administrations concerned should be determined by consultation between those administrations.

Note 5. – The above limits for the bands above 10 GHz should normally afford adequate protection to digital satellite systems using 8-bit PCM encoded telephony (see Report 790).

Note 6. – No. 2504.1 of the Radio Regulations stipulates that the provisions of No. 2504, which correspond to § 3.3 above, shall apply until such time as the CCIR has made a Recommendation as to the need for restrictions in the frequency bands specified in No. 2511 (bands above 15 GHz); all systems introduced after 1 January 1982 should as far as practicable meet any such restriction.

* For the purpose of this Recommendation, an existing route is regarded as one already planned before the conclusion of the XIth CCIR Plenary Assembly, Oslo 1966, and brought into service before 1 January 1973.

** The frequency bands concerned are given in the Radio Regulations.

REPORT 790-1

E.i.r.p. AND POWER LIMITS FOR TERRESTRIAL RADIO-RELAY TRANSMITTERS SHARING WITH DIGITAL SATELLITE SYSTEMS IN BANDS BETWEEN 11 TO 14 GHz AND AROUND 30 GHz

(Questions 32/4 and 17/9, Study Programme 17E/9)

(1978-1982)

1. Introduction

Existing limits on power delivered to the antenna input and e.i.r.p. of terrestrial radio-relay stations in the shared up-path bands between 11 to 14 GHz and around 30 GHz were derived mainly on the basis of studies involving FM transmission. This Report considers their validity for digital satellite systems using 4 Phase-PSK modulation. The satellite system models adopted in the study, and the densities of radio-relay stations, are consistent with those assumed in the earlier FM studies.

2. Assessment of the permissible interference level at the satellite receiver

In Recommendation 522 the long-term performance objective for a digital satellite hypothetical reference circuit (HRC) carrying PCM telephony is that the bit error ratio at the output of the HRC should not exceed 1 in 10^6, 10 minute mean value, for more than 20% of any month.

Since the temporal variation in up-path terrestrial interference reaching a satellite is likely to be small, the use of a permissible interference criterion based on this long-term performance objective is appropriate. Accordingly 10% of the noise power giving rise to an error ratio of 1 in 10^6 is adopted as the limit in the assessment of the tolerable interference levels at the satellite.

It is also reasonable to assume that the effect of the interference is relatively independent of the spectral distribution of the interfering signal – the significant factor being the interfering signal power entering the receiver bandwidth of interest.

Consider now a satellite system using 4 Phase – PSK/TDMA operating at bit speeds in the region of 120 Mbit/s (72 MHz-bandwidth). For such a system the required carrier-to-noise (C/N) to achieve a link bit error ratio of 1 in 10^6 under normal operating conditions is assessed to be about 17 dB and is independent of the radio-frequency used. Therefore, using the 10% of noise criterion, the tolerable carrier-to-total terrestrial interference ratio would be 27 dB. Making the reasonable assumption that the interference allowance is divided equally between the up and down paths the up-path carrier-to-terrestrial interference ratio (C/I_u) becomes 30 dB.

Clearly the level of interference resulting at the satellite depends on the carrier level, which in turn is a function of the up-path noise allocation. For an up-path noise allowance of 10% of the total noise the up-path carrier-to-noise (C/N_u) is 27 dB. The corresponding C/N_u values for 20% and 40% of the total noise allocated to the up-path are 24 and 21 dB respectively. Also, for a satellite system noise temperature of 1000 K, which is considered to be a reasonable minimum for systems operating in the foreseeable future at the frequencies discussed here, the input noise (N_u) is equal to kTB which in a bandwidth of 72 MHz is -120 dBW. Thus the carrier levels for 10, 20 and 40% up-path noise allowances are -93, -96 and -99 dBW respectively. Therefore, using the C/I_u figure of 30 dB, the permissible up-path interference levels (I_u) for the three up-path noise conditions, 10, 20 and 40% of total noise, are -123, -126 and -129 dBW respectively.

Now, the terrestrial interference entering the satellite receiver can be of two types, "direct" and "indirect". A "direct-entry" is taken here to mean an interference from a radio-relay station pointing within 0.5° of the geostationary orbit, whilst "indirect-entry" interference is due to radio-relay stations pointing away from the stationary orbit. Assuming the up-path interference allowance to be shared equally between "direct" and "indirect" interference, the permissible levels for each type become -126, -129 and -132 dBW respectively for systems having 10, 20 and 40% up-path noise allocations.

3. Maximum allowable transmission levels for radio-relay stations

The maximum radio-relay station power levels compatible with the foregoing interference criteria are derived in Tables I to III for two types of satellite receive antennas – full visible earth coverage and narrow beam. In deriving these the following further assumptions were made:

3.1 *Assumptions common to 11 and 30 GHz*

- Direct interference is due to radio-relay stations in the horizon of the satellite visibility, i.e. at the beam-edge of full visible earth coverage antennas. In the case of narrow-beam antennas, direct interference arises from radio-relay stations outside the main beam.
- Indirect interference arises from radio-relay stations within the coverage area of the satellite beam.
- A full visible-earth coverage antenna has an average gain of 18.5 dB and a beam-edge gain of 17 dB.
- The number of radio-relay stations within the coverage area of a narrow beam antenna is proportional to the square of the beamwidth.
- A beamwidth of 1° and a gain of 43 dB for the narrow-beam antenna. *Note.* – Since the gain of the antenna is inversely proportional to the square of the beamwidth and the number of radio-relay stations within the beam is also assumed to be proportional to the square of the beamwidth, the acceptable transmission level per station within the beam is relatively independent of the beamwidth assumed.
- An average off-beam gain in the direction of the satellite horizon of no more than 17 dB for the narrow-beam satellite antennas.
- An average off-beam gain, in the direction of the satellite, of -6 dB for terrestrial radio-relay antennas.
- A polarization discrimination of 3 dB for terrestrial stations within the coverage area (indirect interference).
- No polarization discrimination for terrestrial stations contributing to direct interference.
- A maximum terrestrial station e.i.r.p. of E dBW per radio-frequency channel. This is the relevant parameter in the consideration of direct interference into the satellite system.
- An average power of $(P - 3)$ dBW per radio-frequency channel at the input to the terrestrial-station antenna, where P dBW is the maximum acceptable input level. This is the relevant parameter in the consideration of indirect interference, as outside the main beam the terrestrial station antenna gain is largely independent of the main beam-gain.
- The radio-relay channel bandwidth at 30 GHz may be up to 220 MHz.
- At 11 GHz both wideband and narrowband systems may be used. The narrowband short haul systems operate typically at about 35 dBW and are not subject to the pointing restrictions. The long haul narrowband systems are likely to operate with higher power levels and may be subject to No. 2503 of the Radio Regulations.

3.2 *Assumptions particular to 11 GHz operation*

- 17 500 terrestrial stations using the same carrier frequency as the satellite service and within the full-visible coverage area of the satellite but with their antennas pointing away from the satellite by at least 1.5°. This is based on an average density of radio-relay stations of approximately 1 per 2500 km^2 of inhabited area covered; for the purpose of this calculation one-fifth of the full-visible coverage area is taken to be inhabited.
- 120 terrestrial stations using the same carrier frequency as the satellite service and within the 1° coverage of the narrow-beam satellite antenna but with their antennas pointing away from the satellite by at least 1.5°. This is based on an average density of radio-relay stations of 1 per 2500 km^2.
- Not more than one terrestrial station using the same carrier frequency as the satellite service and situated on the satellite horizon has its beam pointing within 0.5° of the direction of the satellite (see Annex I).
- Free-space basic transmission loss has an average value of 205 dB and a maximum value of 206 dB.
- An atmospheric attenuation, at an angle of elevation near zero, of 5 dB not exceeded for more than 20% of the time (clear weather).
- An average "clear weather" atmospheric attenuation of 2.5 dB in the consideration of indirect interference to a fully visible earth coverage satellite receiver, (elevation angles varying from 1.5° to 90°).

3.3 *Assumptions particular to 30 GHz operation*

- 5000 terrestrial stations using the same carrier frequency as the satellite service and within the 1° beam of the satellite antenna, but with their antennas pointing away from the satellite by at least 1.5°. This is based on an average density of radio-relay stations of approximately 1 per 64 km^2.
- Full visible-earth coverage reception is not utilized by satellites at these frequencies.
- The number of terrestrial stations using the same carrier frequency as the satellite service, and situated in the satellite horizon, but having their beams pointing within 0.5° of the direction of the satellite is 19 (see Annex I).
- An atmospheric attenuation at an angle of elevation near zero, of 12 dB, not exceeded for more than 20% of the time.
- Free-space transmission loss has an average value of 214 dB and a maximum value of 215 dB.

4. Direct interference due to a radio-relay station in the main-beam of narrow spot-beam antenna

The analysis in § 3 does not include the special case where there is a direct interference entry from a terrestrial radio-relay station in the main-beam of a narrow spot-beam satellite receiving antenna directed towards the satellite horizon. The maximum tolerable radio-relay station e.i.r.p. levels under these circumstances, are given in Fig. 1 for a range of spot-beam antenna beamwidths. In deriving Fig. 1, the following assumptions were made, in addition to those listed in Table IV:

- at 30 GHz only one radio-relay station gives rise to direct interference of this type;
- for a narrow-beam satellite antenna the gain in the direction of a radio-relay station in the main-beam, and contributing to direct interference, is 2 dB less than the beam-centre gain; e.g. for a 1° beam this would be 42.5 dB;
- the entire up-link interference budget is represented by the direct interference since the indirect exposures are negligible.

5. Conclusions

The maximum tolerable power delivered to the antenna input and e.i.r.p. levels for radio-relay stations operating in shared bands around 11 to 14 and 30 GHz, have been considered in the context of interference to digital satellite systems. The results of calculations for a range of up-path noise proportions in the satellite system are given in Tables I to III, excluding the case where the radio-relay stations in the satellite spot-beam contribute to direct interference. Taking the more stringent of the levels for each of the two frequency bands, the power P delivered to the antenna input and e.i.r.p. limits for terrestrial stations are seen to be:

P = 18 dBW and e.i.r.p. = 59 dBW when frequencies around 11 to 14 GHz are shared, and

P = 19 dBW and e.i.r.p. = 70 dBW when frequencies around 30 GHz are shared.

Since the recommended power delivered to the antenna input and e.i.r.p. limits in Recommendation 406 for radio-relay stations sharing these frequencies with satellite systems are 10 and 55 dBW respectively, it can be concluded that, digital satellite systems operating around 11 to 14 GHz and 30 GHz are satisfactorily protected.

The analysis in § 4 deals with the case where there is a direct entry from a terrestrial radio-relay station into a narrow spot-beam satellite receiving antenna directed towards the horizon.

The results of this show that at 11 GHz a direct entry at 55 dBW e.i.r.p. into a spot-beam may give rise to excessive interference. However, the Radio Regulations recommend that radio-relay stations operating at the frequency bands between 10 and 15 GHz shall not, where practicable, point within ± 1.5° of the geostationary orbit when the radio-relay e.i.r.p. exceeds 45 dBW. For an e.i.r.p. of 45 dBW, a main-beam direct entry interference into a spot-beam receiving antenna in the 11 GHz band would be acceptable for spot-beams down to about 1° beamwidth. For e.i.r.p. values between 35 and 45 dBW, it can be shown that the main-beam direct entry interference would be acceptable for spot-beams between 1° and 4°. At 30 GHz, the interference is acceptable for spot-beams down to about 0.5° beamwidth.

Clearly, further study is required to determine the desired influence on sharing criteria of the relatively rare occurrence of a narrow spot-beam satellite receiving antenna being directed towards the horizon.

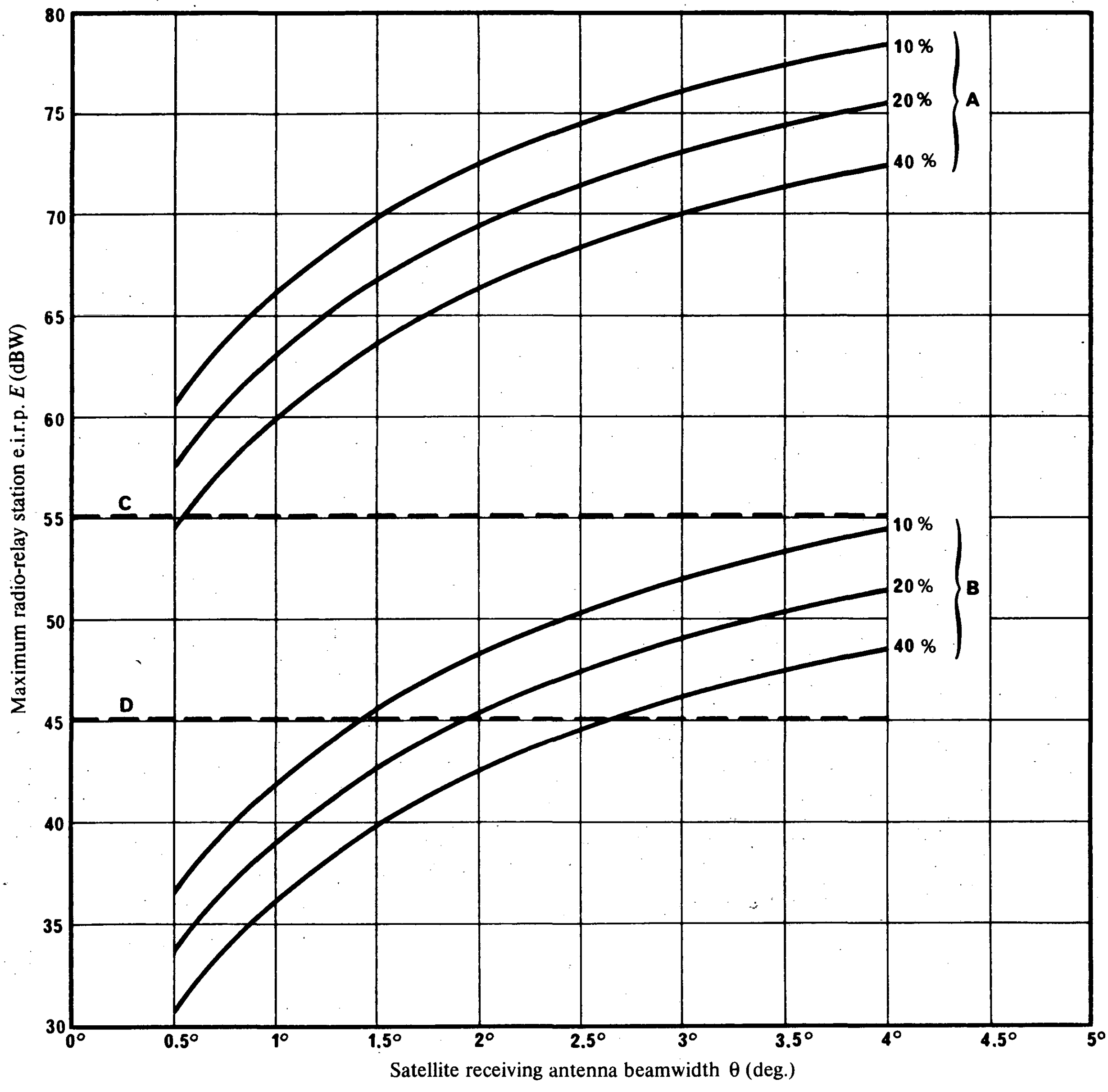


FIGURE 1 – *Maximum terrestrial radio-relay station e.i.r.p. (E), without exceeding interference criteria, for a satellite receiving antenna having a beamwidth* θ, *the beam being directed towards the horizon*

A: Up-path noise allocation at 30 GHz

B: Up-path noise allocation at 11 GHz

C: E.i.r.p. limit in No. 2504 of the Radio Regulations for bands above 15 GHz (no pointing restrictions)

D: E.i.r.p. limit in No. 2503 of the Radio Regulations for stations pointing within ± 1.5° of the geostationary orbit, in bands 10 to 15 GHz

The direct beam interference involving narrow spot-beam satellite antennas involves the joint probability of several rare events. Specifically, this interference occurs only when the spot-beam is at a low elevation angle (< 15°) and when within that coverage area at least one terrestrial transmitter is pointing directly at that satellite. Most cases in middle latitudes involve satellite spot-beams with much larger elevation angles such that the direct beam exposure is not possible. For those cases, appreciable antenna discrimination is available at the satellite receiving antenna. Nevertheless, even this rare direct interference case appears to generate acceptable interference.

TABLE I – *11 GHz Operation*
(Full visible earth coverage)

	Source of Interference	
	17 500 terrestrial stations in satellite beam	One terrestrial station with antenna beam pointing at satellite
Average input power to antenna of each radio-relay station (dBW) per radio-frequency channel	*P*−3	—
Maximum e.i.r.p. of terrestrial transmitter (dBW) per radio-frequency channel	—	*E*
Average off-beam gain of terrestrial antenna in direction of satellite (dB)	−6	—
10 log (Number of terrestrial transmitters)	42.5	0
10 log (Number of radio-frequency channels in 72 MHz-bandwidth of the 120 Mbit/s satellite transmission)	3	3
Basic free-space transmission loss (dB)	205	206
Atmospheric attenuation not exceeded for more than 20% of time (dB)	2.5	5
Polarization discrimination (dB)	3	0
Satellite antenna gain (dB)	18.5	17
Maximum power delivered to the antenna input (*P*) from radio-relay station without exceeding interference level (dBW) per radio-frequency channel	10% up-path noise: +29.5 20% up-path noise: +26.5 40% up-path noise: +23.5	—
Maximum radio-relay station e.i.r.p. (*E*) without exceeding interference level (dBW per radio-frequency channel)	—	10% up-path noise: +65.0 20% up-path noise: +62.0 40% up-path noise: +59.0

TABLE II – *11 GHz Operation*
(Narrow beam coverage)

	Source of Interference	
	120 terrestrial stations in satellite beam	One terrestrial station with antenna beam pointing at satellite
Average input power to antenna of each radio-relay station (dBW) per radio-frequency channel	$P-3$	—
Maximum e.i.r.p. of terrestrial transmitter (dBW) per radio-frequency channel	—	E
Average off-beam gain of terrestrial antenna in direction of satellite (dB)	−6	—
10 log (Number of terrestrial transmitters)	21.0	0
10 log (Number of radio-frequency channels in 72 MHz-bandwidth of the 120 Mbit/s satellite transmission)	3	3
Basic free-space transmission loss (dB)	205	206
Atmospheric attenuation not exceeded for more than 20% of time (dB)	0	5
Polarization discrimination (dB)	3	0
Satellite antenna gain (dB)	43	17
Maximum power delivered to the antenna input (P) from radio-relay station without exceeding interference level (dBW) per radio-frequency channel	10% up-path noise: +24.0 20% up-path noise: +21.0 40% up-path noise: +18.0	—
Maximum radio-relay station e.i.r.p. (E) without exceeding interference level (dBW per radio-frequency channel)	—	10% up-path noise: +65.0 20% up-path noise: +62.0 40% up-path noise: +59.0

TABLE III – *30 GHz Operation*
(Narrow beam coverage)

	Source of Interference	
	5000 terrestrial stations in satellite beam	19 terrestrial stations with antenna beam pointing at satellite
Average input power to antenna of each radio-relay station (dBW) per radio-frequency channel	$P-3$	—
Maximum e.i.r.p. of terrestrial transmitter (dBW) per radio-frequency channel	—	E
Average off-beam gain of terrestrial antenna in direction of satellite (dB)	−6	—
10 log (Number of terrestrial transmitters)	37	13
10 log (Number of radio-frequency channels in 72 MHz-bandwidth of the 120 Mbit/s satellite transmission)	−5	−5
Basic free-space transmission loss (dB)	214	215
Atmospheric attenuation not exceeded for more than 20% of time (dB)	0	12
Polarization discrimination dB	3	0
Satellite antenna gain (dB)	43	17
Maximum power delivered to the antenna input (P) from radio-relay station without exceeding interference level (dBW) per radio-frequency channel	10% up-path noise: +17.0 20% up-path noise: +14.0 40% up-path noise: +11.0	—
Maximum radio-relay station e.i.r.p. (E) without exceeding interference level (dBW per radio-frequency channel)	—	10% up-path noise: +68.0 20% up-path noise: +65.0 40% up-path noise: +62.0

TABLE IV — *11 and 30 GHz operation (narrow beam coverage)*

Direct interference—one of the terrestrial stations contributing to direct interference is in the main beam of the satellite antenna

	Source of interference	
	One terrestrial station in the satellite main beam having its antenna beam pointing at the satellite	
	11 GHz	30 GHz
Maximum e.i.r.p. of the terrestrial transmitter (dBW per radio-frequency channel)	E	E
10 log (Number of terrestrial transmitters in main-beam)	0	0
10 log (Number of radio-frequency channels in 72 MHz-bandwidth of the 120 Mbit/s satellite transmission)	3	−5
Basic free space loss (dB)	206	215
Atmospheric attenuation not exceeded for more than 20% of time (dB)	5	12
Satellite antenna gain in the direction of the terrestrial station in the main beam (dB)	42.5 − 20 log θ; where θ° is the satellite antenna beamwidth	
Polarization discrimination (dB)	0	0
Maximum terrestrial radio-relay station e.i.r.p. (E) without exceeding interference limit (dBW per radio frequency channel)	See Fig. 1	See Fig. 1

ANNEX I

ESTIMATE OF MAXIMUM NUMBER OF RADIO-RELAY STATIONS OPERATING AT 11 AND 30 GHz LIKELY TO POINT WITHIN 0.5° OF A GEOSTATIONARY SATELLITE

Area of annulus of Earth from which an elevation within 0.5° of a given satellite is possible:

$$S = \pi \cdot d \cdot l \tag{1}$$

where,

d = maximum diameter of geostationary satellite coverage area at the Earth (12 600 km);

l = distance subtended at the surface of the Earth by an angle of 0.5° at the centre of the Earth = 55.5 km;

then $S = \pi \times 12\,600 \times 55.5$ km^2.

Area of inhabited land in annulus (assume 20%) S_h is:

$$S_h = 4.4 \times 10^5 \text{ km}^2;$$

Number of 11 GHz radio-relay stations in this area at 1 per 2500 km^2 = 175.

Then assuming a random distribution of azimuths the number of these radio-relay stations pointing within 0.5° in azimuth of stationary satellite position is:

$$\frac{1}{360} \times 175 \approx 0.5; \quad \text{assume 1.}$$

Also, assuming a radio-relay station density of 1 per 64 km^2, the number of 30 GHz stations pointing within 0.5° of the geostationary orbit is:

$$\frac{4.4 \times 10^5}{64} \times \frac{1}{360} \approx 19$$

REPORT 1006*

FIXED SERVICE e.i.r.p. LIMITS FOR THE PROTECTION OF THE BROADCASTING-SATELLITE FEEDER LINKS AROUND 18 GHz

(Questions 32/4 and 17/9, Study Programme 17E/9)

(1986)

1. Introduction

The limits for the e.i.r.p. of fixed service (FS) transmitters are given in Recommendation 406. However, these limits were derived for the protection of the fixed-satellite service (FSS). As a result, when the protection of the broadcasting satellite service (BSS) is involved, there is a special need to limit to a greater extent the degradation of feeder links in order to allocate most of the performance margin to the down link.

The technical parameters for systems in the FSS above 15 GHz are sufficiently different from the BSS to require a separate study to investigate the protection of the BSS feeder links. The FSS is likely to use digital modulation while the BSS will use FM with narrower bandwidths. Furthermore, the BSS requires interference protection of its analogue television signals while the FSS must be protected from interference to digital transmissions.

2. Allowable interference at the satellite receiver

The report of the Conference Preparatory Meeting (CPM) 1982, on technical bases for the RARC SAT-R2, suggested technical parameters for the BSS. These included a faded carrier-to-noise ratio $(C/N)_t$ of 14 dB. This value includes a 6.5 dB fade not to be exceeded throughout 99% of the worst month. Hence a clear weather $(C/N)_t$ of 20.5 dB is an overall performance objective that should include the effects of interference. The FS interference will be assumed to be noise-additive since digital telephony also has a noise-like spectrum. Furthermore, the CPM report suggests that the feeder link should not add more than 0.5 dB to the overall degradation.

We will assume a coincidence of down-link and up-link fades, and we will also assume that the 99% value of the up-link fade is 10 dB. As a result, the clear weather up-link carrier-to-noise ratio $(C/N)_u$ is:

$$(C/N)_u = 14.5 + 9.1 + 10.0 = 33.6 \text{ dB}$$

and the down-link carrier-to-noise ratio $(C/N)_d$ is:

$$(C/N)_d = 14.5 + 6.5 = 21.0 \text{ dB}$$

* This Report should be brought to the attention of Study Groups 10 and 11.

Generally, sharing is based on the principle that both services sharing the band equally could receive a permissible amount of interference.

The interference allocation that seems reasonable in this case would allow the FS to contribute up to 1 dB of degradation to the up link.This would result in an additional degradation to the total $(C/N)_t$ of only 0.12 dB. The contribution of 1 dB on the up link is similar to previous cases of sharing between the FS and other space services, particularly above 15 GHz. The 0.12 dB overall contribution is unexpectedly low and is about an order of magnitude less than usual. This negligible contribution goes beyond the principle of not compromising the overall design of the BSS and suggests that under other circumstances additional interference to the up link may be acceptable.

Accordingly, for the consecutive model assumed, the allowable interference on the up link from FS transmitters becomes:

$$(C/I)_u = (C/N)_u + 6 = 39.6 \text{ dB}$$

It is highly unlikely, from the total population of FS transmitters which are visible from the satellite, that more than one would be expected to be directly visible or that the contributions from the rest would be significant. Accordingly then, the minimum $(C/I)_u$ objective becomes 39.6 dB.

3. Calculation of $(C/I)_u$ at the satellite receiver

A typical e.i.r.p. value of 86 dBW has been considered in Region 2 for feeder link transmitters of the BSS. Using this figure and a maximum e.i.r.p. limit of 55 dBW for a single interfering FS transmitter it is possible to calculate the carrier-to-interference ratio at the satellite receiver. The two e.i.r.p. limits result in a 31 dB difference in favour of the BSS and considering that the FS signal path is tangential to the Earth's surface, there is at least an additional 5 dB of path attenuation because of atmospheric absorption, imposed on the interfering FS signal that is received at the satellite. In addition, 3 dB of additional signal discrimination can be expected at the satellite receiver because of the use of circular polarization for the BSS feeder links and linear polarization for the FS. Finally, a free-space loss difference of 1 dB between the FS interfering path and the BSS feeder link path is expected. Consequently, the minimum $(C/I)_u$ is:

$$(C/I)_u = 31 + 5 + 3 + 1 = 40 \text{ dB}$$

As a result, it appears that adequate protection is provided entirely under the provisions of Recommendation 406.

4. Additional sources of interference discrimination

The interference impact from FS transmitters is likely to be much lower than the calculated value of the previous section for the following reasons. First, any bandwidth difference in favour of the FS will further suppress the FS interference in the BSS up link. For example, if the FS occupies a 220 MHz radio channel then additional interference suppression of about 10 dB is provided. Also, additional interference suppression at the space station may be available because of antenna discrimination, particularly when the BSS up-link coverage antenna has a large elevation angle. Finally, diversity operation or higher e.i.r.p.s for the BSS feeder link in order to combat rain attenuation for severe rain regions will also result in higher signal-to-interference ratios.

5. Conclusion

The coexistence of BSS feeder links with fixed services using digital modulation is feasible with the present e.i.r.p. limit of 55 dBW in Article 27 of the Radio Regulations. Under worst-case conditions an FS digital radio-relay transmission around 18 GHz, interfering with a feeder-link receiver, will cause a maximum degradation of 0.12 dB to the nominal received broadcasting satellite C/N ratio in the 1983 Region 2 Plan. This assumes a feeder-link e.i.r.p. of 86 dBW but does not take into account other factors that may further reduce the effect of terrestrial interference, such as feeder-link antenna discrimination and power spectral density reductions due to differences in channel bandwidths. Since the effect of terrestrial interference is considered negligible and also that additional factors may further reduce the interference, it is concluded that it is unnecessary to have restrictions as to the direction of maximum radiation for terrestrial radio-relay links using digital modulation. The additional factors should also permit some reduction in the feeder-link e.i.r.p. that might be associated with a Region 1 and 3 feeder-link plan without exceeding the negligible interference calculated above, whilst still avoiding the need for restrictions as to the direction of maximum radiation for terrestrial radio-relay links.

REPORT 393-3

INTERSECTIONS OF RADIO-RELAY ANTENNA BEAMS WITH ORBITS USED BY SPACE STATIONS IN THE FIXED-SATELLITE SERVICE

(Questions 32/4 and 17/9)

(1966–1970–1974–1978)

1. Introduction

The exposure of the antenna beams of radio-relay systems to emissions from communication satellites is geometrically predictable when such satellites have circular orbits with recurrent earth tracks (see Report 206, § 2.2), but is only predictable statistically for inclined circular orbits of arbitrary periods. A phased system of these recurrent earth-track satellites can be made to follow a single earth-track and such systems are of increasing interest for communication. Geostationary satellites are a special case, since the equator constitutes the earth-track of all equatorial orbits.

At any Earth location from which the satellites of a single-earth-track system could be seen, successive (non-stationary) satellites would follow a fixed arc through the sky, from horizon to horizon. Moreover, except for inclined orbits, this arc would be independent of longitude and be symmetrical relative to North/South.

Subsequent portions of this Report consider exposure conditions relative to a circular equatorial orbit (including the special case of the orbit of a geostationary satellite) and also the probability of exposure to unphased satellites (non-recurrent earth-track).

Some indication of the extent to which existing antennas of radio-relay systems are directed towards the orbit of a geostationary satellite, has been provided by several administrations. It is shown that although the overall percentage of antenna beams which intersect the geostationary orbit is about 2%, this percentage will be substantially higher if one takes into account the beam extending to $\pm 2°$ from its axis, and the effect of refraction. Examination of the compliance of existing radio-relay stations with Recommendation 406 indicates that the percentage of stations having an antenna-beam direction within $\pm 2°$ of the geostationary-satellite orbit is in the order of 10% in some countries. Furthermore, it cannot be assumed that substantial segments of the orbit in any range of longitude are free from illumination by the antennas of radio-relay systems.

2. Some characteristics of the antenna beams of terrestrial radio-relay systems

Line-of-sight radio-relay systems use antennas with gains of the order of 40 dB and half-power beam-widths of the order of 2°. Trans-horizon systems generally use antennas with higher gain and narrower beams, say 50 dB and 0.5°. In either case, path inclinations are less than 0.5° on the average and rarely in excess of 5°. When all of a negatively inclined beam strikes the Earth, there would be no exposure to an orbit. For horizon-centred beams, the upper half could have exposure.

When passive reflectors are used, spill-over also should be considered.

Since the beams are close to the Earth and traverse a considerable thickness of atmosphere, diffraction and refraction should be taken into account in making precise calculations of exposure.

3. Directions to circular equatorial orbits

It is well known from geometric considerations that the azimuth angle, A (measured clockwise from North) and the angle of elevation, e, of a satellite in a circular equatorial orbit can be expressed by

$$A = \arctan\,(\pm \tan \lambda / \sin \varphi) \tag{1}$$

$$e = \arcsin\,\left[(K \cos \varphi \cos \lambda - 1) / \sqrt{K^2 + 1 - 2K \cos \varphi \cos \lambda}\right] \tag{2}$$

where,

K : orbit radius/earth radius,

φ : earth latitude of the terrestrial station,

λ : difference in longitude between the terrestrial station and the satellite.

Eliminating λ between these two equations leads to

$$A = \text{arc cos}\left\{\left[\frac{\tan e + K^{-1}\sqrt{\tan^2 e + (1 - K^{-2})}}{1 - K^{-2}}\right] \tan \varphi\right\} \tag{3}$$

If necessary, azimuths and elevations to any single-earth-track inclined orbit system, of given height, inclination and equatorial crossings could be determined by an extension of this analysis. For such systems, however, the orbit directions would depend both on latitude and longitude of the terrestrial station.

An antenna directed at the orbit of a non-geostationary satellite (or other single earth-track orbit) will be certain to have intermittent exposure. For a circular equatorial orbit (other than the orbit of the geostationary satellite) with m satellites, antennas having an interference beamwidth of θ radians will have interference for a fraction of the time given approximately by:

$$P = m\,\theta/(2\pi) \tag{4}$$

For the special case of the orbit of a geostationary satellite, P will be either zero or unity.

4. Unphased satellite systems

In this case it is possible to derive only an average probability of exposure to a satellite. Thus, for a system of n orbits of equal height and equal inclination angle, i, it can be shown that the average probability of exposure is given by:

$$P = [mn\,\theta/(8\,\pi \cos \Psi)]\,\{\text{arc cos}\,[(\sin(\Psi - \theta/2))/\sin i] - \text{arc cos}\,[(\sin(\Psi + \theta/2))/\sin i]\} \tag{5}$$

when $\Psi \leqslant (i - \theta/2)$

and where,

m : number of satellites in each orbit,

Ψ : latitude of intersection between the antenna beam and the orbital sphere.

As indicated in the reference [Areshev and Kalashnikov, 1974], in most of the cases encountered in practice, when $i > \theta$, calculations can be made by means of the formula:

$$P = \frac{mn\,\theta^2}{8\pi\sqrt{\sin^2 i - \sin^2 \psi}} \tag{6}$$

The relative error of the calculations made by means of (6) does not exceed 0.25% of those made with formula (5).

For the particular case of the polar orbit, $i = \pi/2$, and the above expression reduces to

$$P = mn\,\theta^2/\,(8\pi \cos \Psi) \tag{7}$$

5. Geometric relations between the directions of radio-relay antennas and the geostationary-satellite orbit

The geostationary-satellite orbit is particularly important, not only from the point of view of the exposure of radio-relay systems to beams from satellites, but also because of the limitations imposed by Recommendation 406 on the directions of radio-relay antennas to protect reception by geostationary satellites.

Equation (3) can be expressed as:

$$A = \text{arc cos}\,\frac{\tan \varphi}{\tan\,[\text{arc cos}\,(K^{-1} \cos e) - e]} \tag{8}$$

where,

A : azimuth (or its complement at 360°) measured from the south in the northern hemisphere and from the north in the southern hemisphere,

K : orbit radius/Earth radius, assumed to be 6.63,

e : geometric angle of elevation of a point on the geostationary-satellite orbit,

φ : latitude of the terrestrial station.

For a given station latitude and for a given angle of elevation the values of the angle A, for the two orbit points, are measured from both sides of the meridian.

Equation (8) has been used to produce the scale in Figs. 1a and 1b whereby the direction of the geostationary-satellite orbits can be determined for latitudes between 0° and 70° approximately. Table I gives the azimuths for the orbit points at an angle of elevation of 0°.

5.1 *The effects of atmospheric refraction*

The usual effect of atmospheric refraction is to bend the radiowave ray towards the Earth; the beam of a radio-relay antenna having an angle of elevation ε, may reach a satellite with an angle of elevation e where:

$$e = \varepsilon - \tau \tag{9}$$

and e and ε are algebraic values, and τ is the absolute value of the correction due to refraction.

The extent of bending depends on the climate of the region where the station is situated (refractive index, gradient of the index, etc.), on the altitude of the station and the initial angle of elevation ε; the variation of τ as a function of ε is particularly rapid at a low negative value of ε.

The value of τ may exceed several tenths of a degree, and this is particularly important for stations at medium or high latitudes, where a slight change in the angle of elevation results in a considerable change of the azimuth to each of the two corresponding points on the geostationary-satellite orbit. Moreover, this correction varies in time with atmospheric conditions. At a given point of latitude and for a given angle of elevation, the azimuth to the orbit will in time scan a certain angular zone.

To apply Recommendation 406, whereas a mean value of refraction will provide substantial protection, to provide full protection it is desirable to consider the maximum and minimum values of bending due to refraction, so as to determine the azimuths of the extremities of this angular zone. This can be done on a statistical basis. Figures 1a and 1b may be used to determine the extreme azimuths of the angular zone, on the basis of extreme angles of elevation e_1 and e_2.

It is not always easy to determine the bending τ as a function of the climate, the altitude of the station and the angle of elevation ε, since the assumption of a reference atmosphere of exponential type is not always applicable (see Report 720) and the probability of the formation of atmospheric ducts is by no means negligible, especially in certain hot maritime areas. Some information on this problem is given in Report 720.

Where a hypothetical atmosphere of exponential type is admissible and where the ground index, N_s, and the gradient ΔN of the index between 0 and 1000 m are related, the curves showing correction τ as a function of the angle of elevation ε can be calculated. Figures 4 to 7 of Report 563 give useful information on the values of ΔN corresponding to various geographical areas; the characteristics of different types of climate are given in the Report 238. Determining the maximum and minimum corrections τ_1 and τ_2 is then equivalent to the assessment of the maximum and minimum of N (or ΔN) corresponding to the particular case under consideration.

The influence of the altitude of the station is very difficult to assess. For positive angles of elevation, the radio beam quickly leaves the atmosphere, the bending τ is relatively slight and the influence of altitude is probably reduced. On the other hand, for negative angles of elevation, a beam crossing the horizon passes twice through the densest layers of the atmosphere; the bending τ is thus greater and its variation with altitude at constant angle of elevation is likely to be much greater. However, there are no accurate data in this connection.

Provisionally, and to provide protection under all conditions, one should adopt the following rules:

5.1.1 in those geographical areas where propagation data are available which will enable the amount of bending to be determined on a statistical basis, the maximum bending (for instance the bending not exceeded for 99.5% of the time) and the minimum bending should be derived from these data;

5.1.2 where such data are not available, the following approximation may be used. Limits of refractive index assuming an exponential reference atmosphere can be calculated from the sea-level radio refractivity, N_0, and the gradient, ΔN (as found in world-wide charts). It can be seen from Figs. 1 and 2 of Report 563 that a range for N_0 between 250 and 400 (ΔN at sea level between -30 and -68, respectively) is representative of minimum and maximum values throughout a large part of the world and throughout the year. Establishing these limits permits the calculation of curves for τ_1 and τ_2 as a function of angle of elevation of the antenna and station height. Such curves are given in Fig. 2.

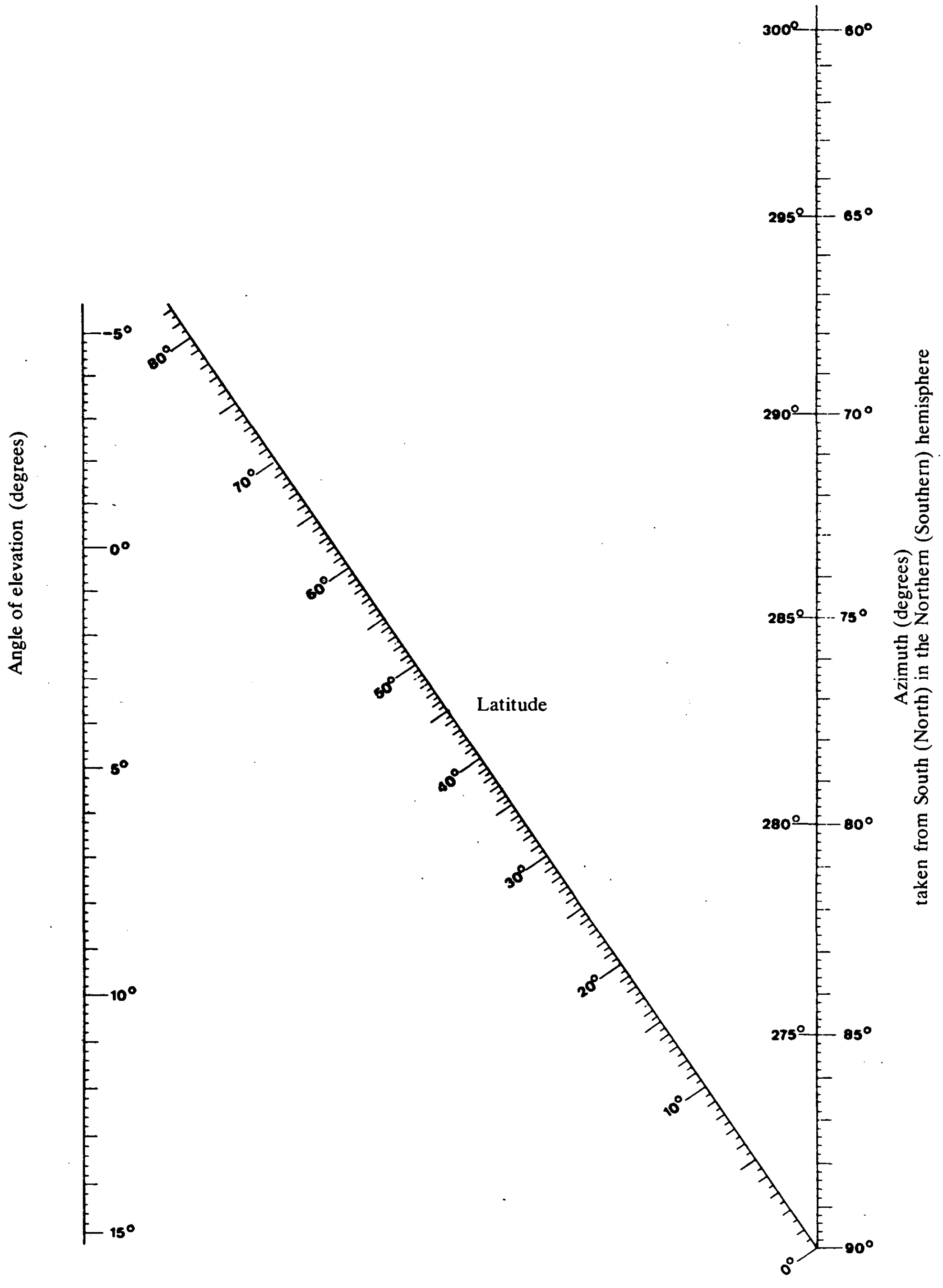


FIGURE 1*a* – *Determination of the direction of the geostationary-satellite orbit — low and middle latitudes*

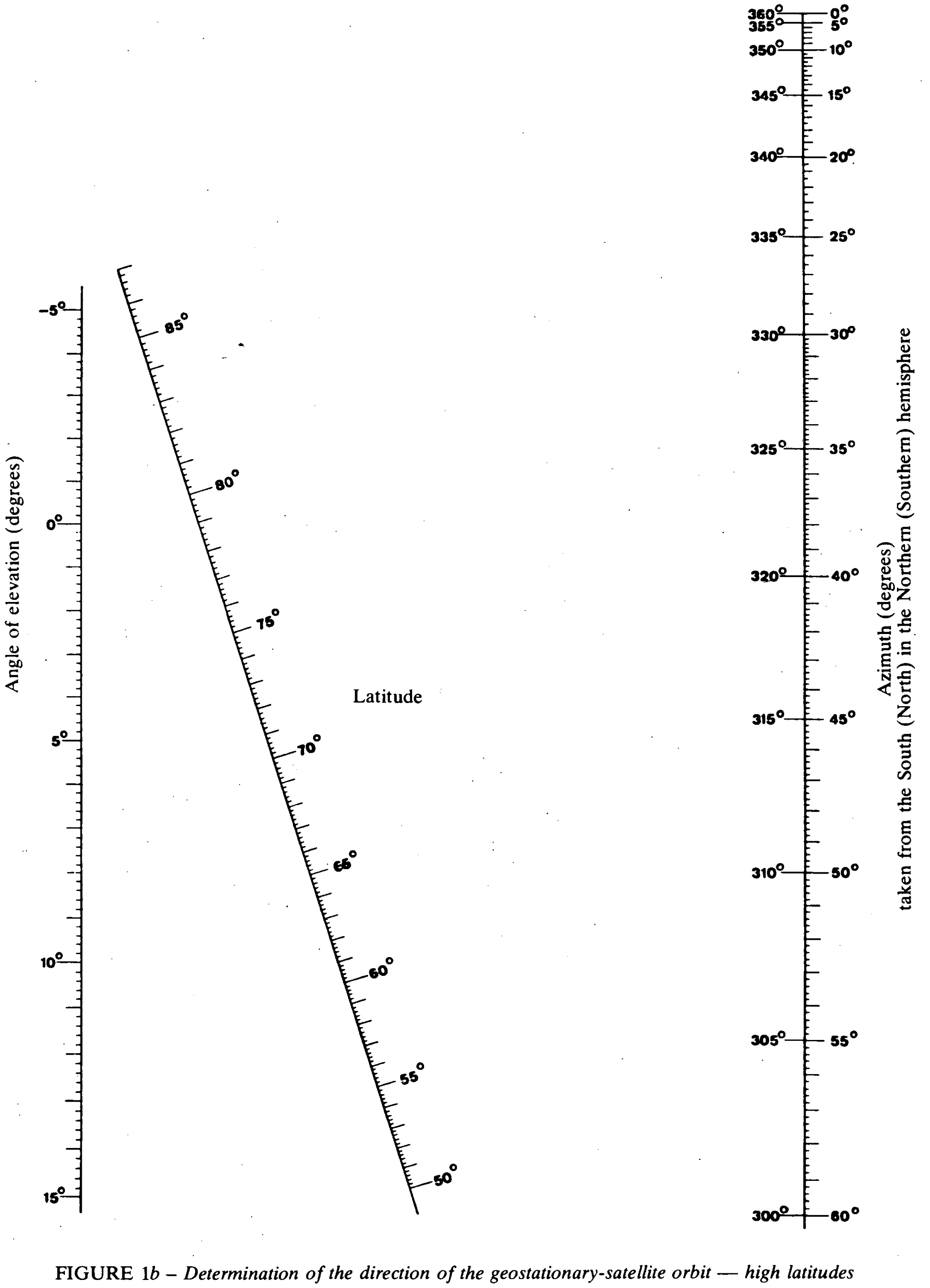
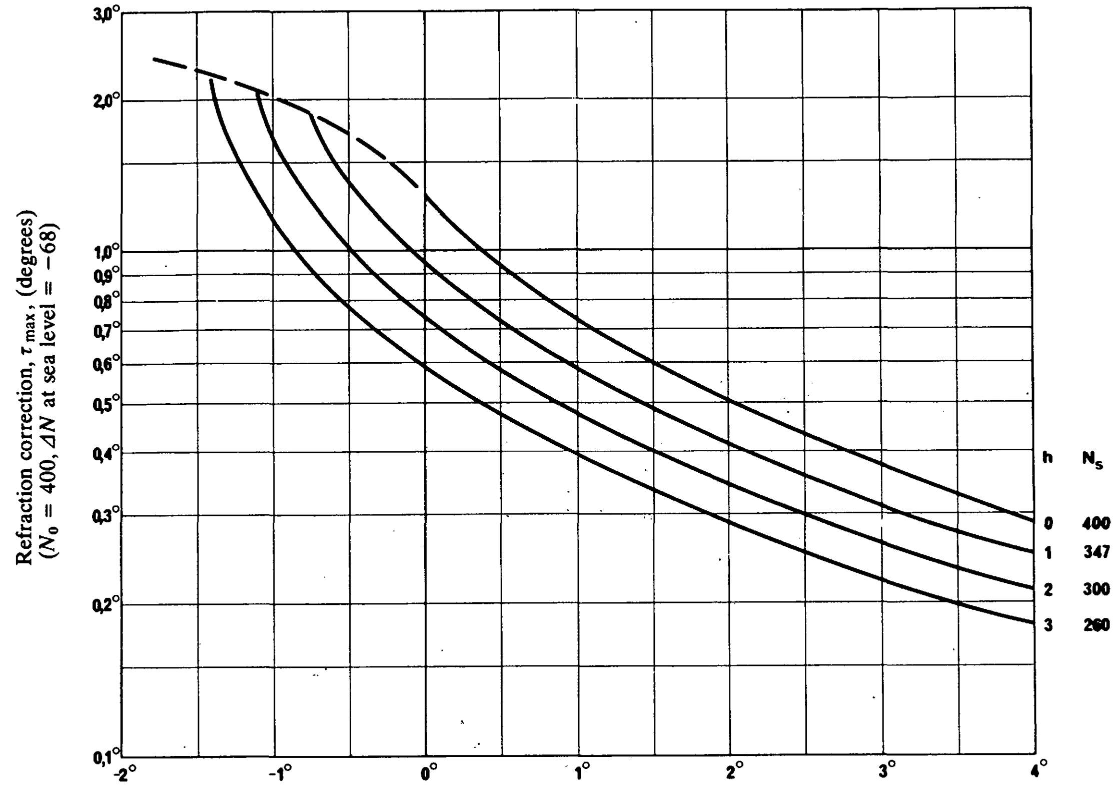


FIGURE 1*b* – *Determination of the direction of the geostationary-satellite orbit — high latitudes*

TABLE I – *Azimuths of the angle of elevation 0° of points on the orbit of a geostationary satellite*

Latitude	Azimuth	Latitude	Azimuth	Latitude	Azimuth
0.00	90.00	24.00	86.11	48.00	80.24
1.00	89.85	25.00	85.92	49.00	79.89
2.00	89.69	26.00	85.73	50.00	79.52
3.00	89.54	27.00	85.54	51.00	79.14
4.00	89.39	28.00	85.35	52.00	78.74
5.00	89.24	29.00	85.15	53.00	78.32
6.00	89.08	30.00	84.95	54.00	77.88
7.00	88.93	31.00	84.74	55.00	77.42
8.00	88.77	32.00	84.53	56.00	76.93
9.00	88.62	33.00	84.31	57.00	76.41
10.00	88.46	34.00	84.09	58.00	75.87
11.00	88.30	35.00	83.87	59.00	75.29
12.00	88.14	36.00	83.64	60.00	74.68
13.00	87.98	37.00	83.40	61.00	74.02
14.00	87.82	38.00	83.15	62.00	73.33
15.00	87.66	39.00	82.90	63.00	72.58
16.00	87.49	40.00	82.65	64.00	71.77
17.00	87.33	41.00	82.38	65.00	70.90
18.00	87.16	42.00	82.10	66.00	69.96
19.00	86.99	43.00	81.82	67.00	68.94
20.00	86.82	44.00	81.53	68.00	67.82
21.00	86.64	45.00	81.22	69.00	66.58
22.00	86.47	46.00	80.91	70.00	65.22
23.00	86.29	47.00	80.58		

Note. — Azimuths (or their complements at 360°) calculated in relation to the meridian of the site, towards the Equator (towards the south for the northern hemisphere, towards the north for the southern hemisphere).



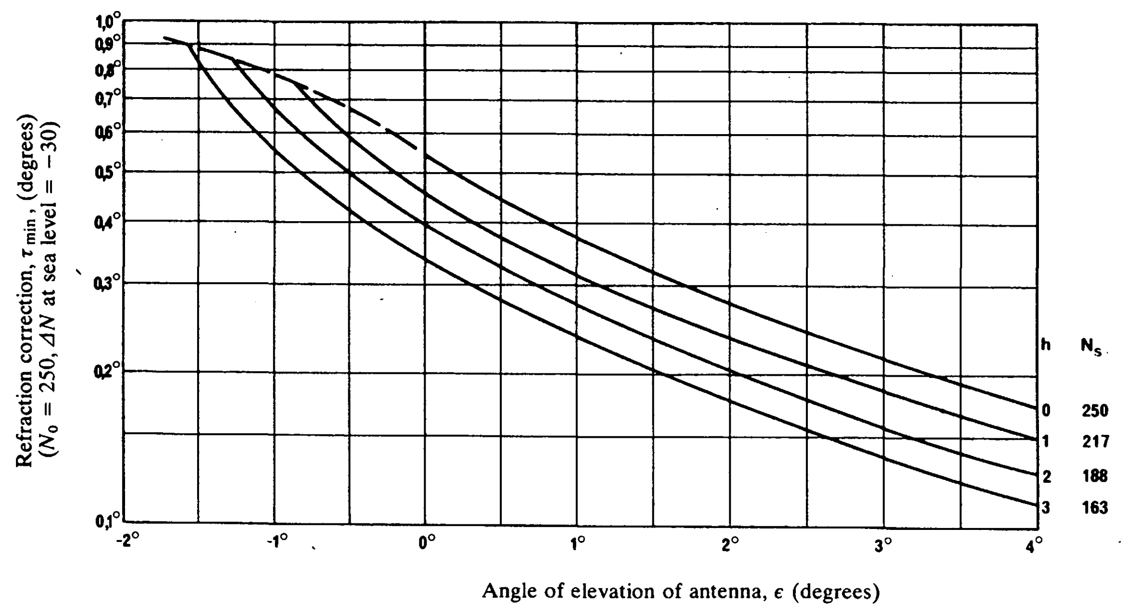


FIGURE 2 – *Refraction correction for angle ε*

h : height of antenna above mean sea level (km)

N_s : refractivity (N units) corresponding to height h for given N_0 limit

Based on *CRPL Exponential Reference Atmosphere,* Bean & Thayer, NBS Monograph 4, U.S. Dept. of Commerce (1959)

5.2 *Angular deviation between an antenna beam and the orbit of a geostationary satellite*

When the angular zone defining the directions for which the antenna points exactly at the orbit (a function of the variation of the effect of refraction in time) has been determined, the antenna direction must be given a certain azimuthal deviation at both extremities of this angular zone, to be sure to obtain a given angular deviation between the direction of the beam of the radio-relay antenna and the orbit of geostationary satellites.

For a proposed radio-relay station with an angle of antenna elevation between +3° and −1°, located in regions where the assumption of an exponential atmosphere with N_0 between 250 and 400 (ΔN at sea level between −30 and −68, respectively) is applicable, Fig. 3 permits one to determine rapidly the azimuths that may be within the critical zone. If the proposed path azimuth does not lie between curves A and B, there is no chance of interference and the proposed azimuth will be satisfactory. The curves of Fig. 3 can be read to about ± 0.5°.

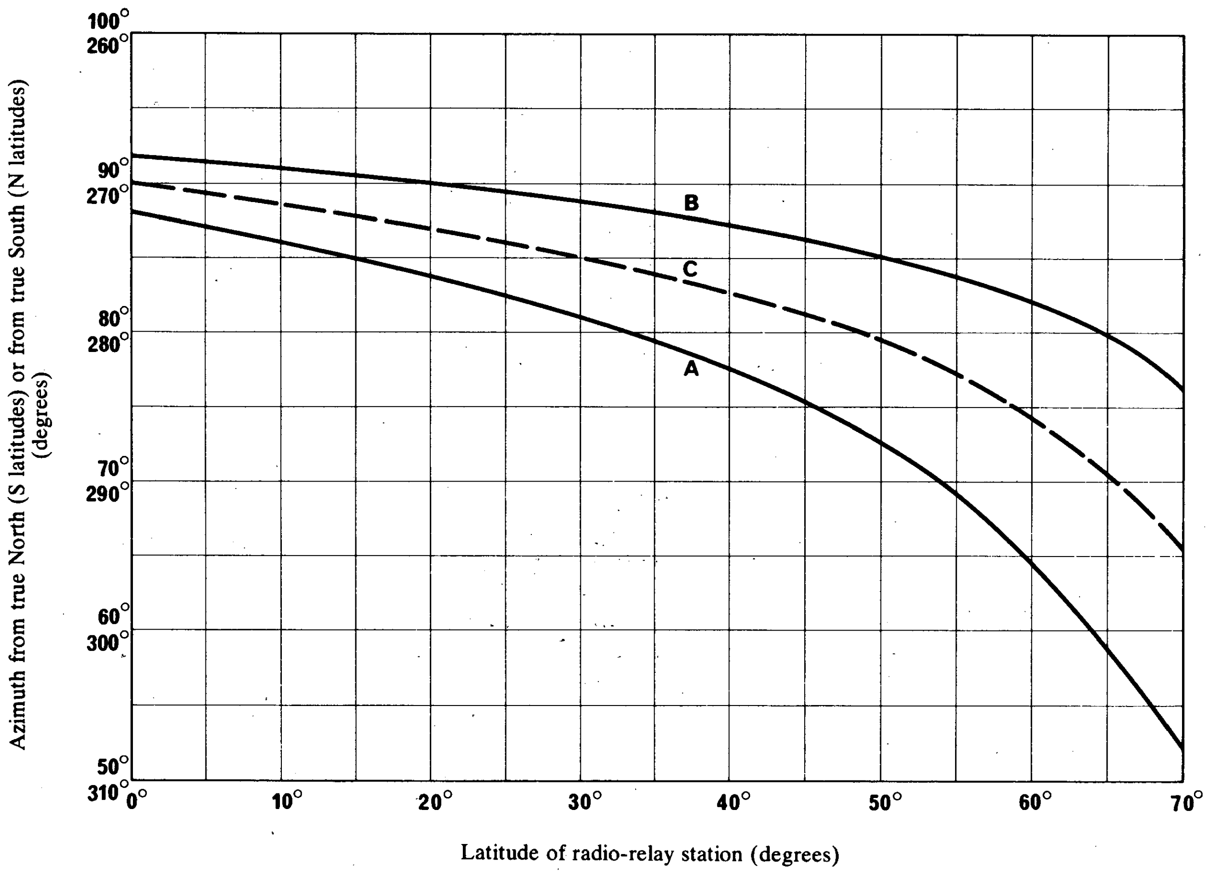


FIGURE 3 – *Screening chart for azimuths to be avoided by radio-relay stations*

Curves A: Separation 2° for an elevation of +3°, assuming τ_{min} (N_0 = 250, ΔN at sea level = −30, h = 0)

B: Separation 2° for an elevation of −1°, assuming τ_{max} (N_0 = 400, ΔN at sea level = −68, h = 1.5 km)

C: Angle of elevation 0°, no refraction (from Table I)

If the proposed path azimuth falls between curve A and curve B of Fig. 3, or if different values of N_0 are to be used, or if the proposed elevation angle is outside the range $+3°$ to $-1°$, then further calculation is necessary. For many cases not covered by Fig. 3, Fig. 4 can be used to determine the azimuthal deviations at both extremities of the central angular zone. Curves are shown for protection of 0.5°, 1.5° and 2°, and other values can be interpolated. Curves A, B and C should be entered towards the meridian and curves D, E or F away from the meridian. The terrestrial horizon has been assumed to be smooth, and at the same elevation angle as the antenna; thus the curves D, E or F are parallel to the horizontal axis 0.5°, 1.5° and 2°, respectively.

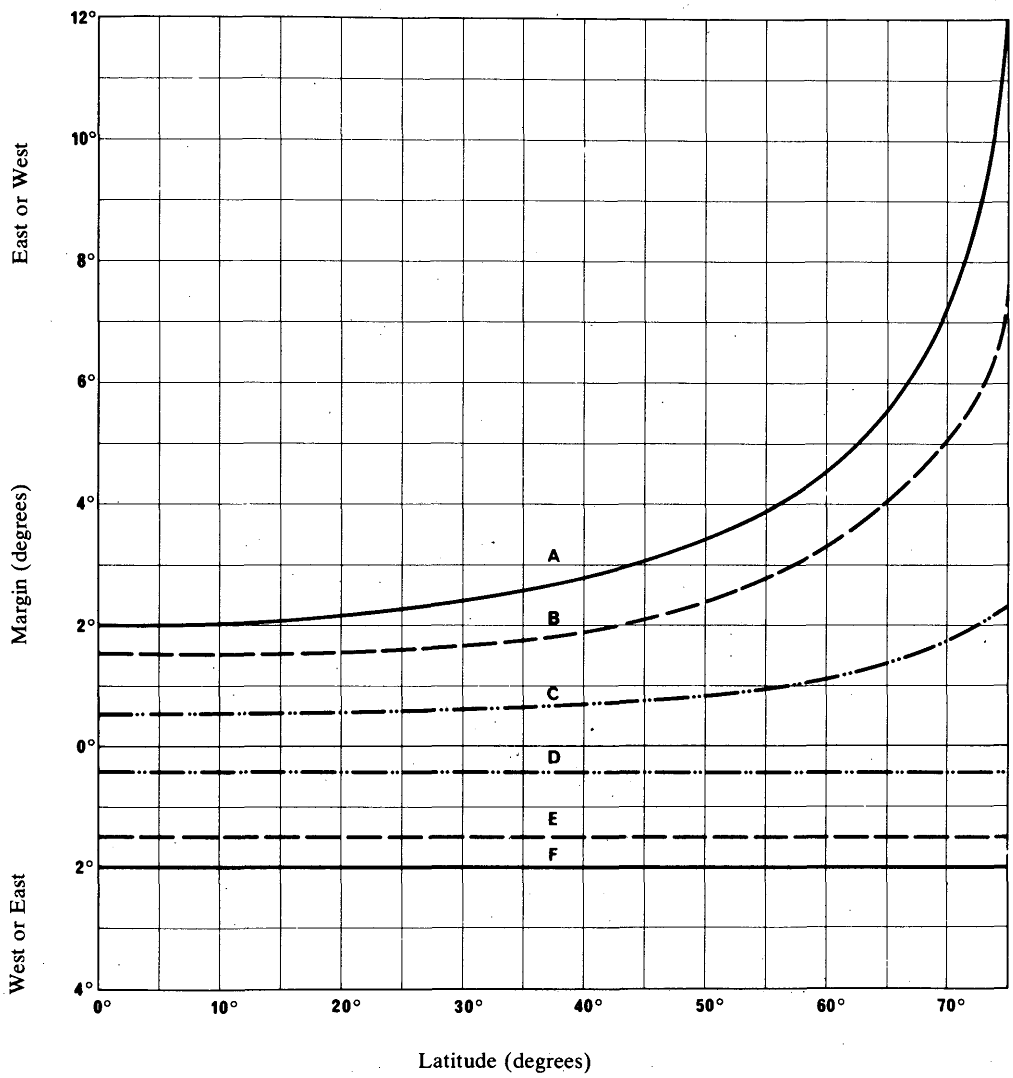


FIGURE 4 – *Azimuth margins (in degrees) between the main direction of the antenna of a radio-relay system and the direction of the orbit of a geostationary satellite, to obtain a protection of 0.5°, 1.5° or 2°*

Curve A: Protection 2°; towards the meridian
B: Protection 1.5°; towards the meridian
C: Protection 0.5°; towards the meridian
D: Protection 0.5°; away from the meridian
E: Protection 1.5°; away from the meridian
F: Protection 2°; away from the meridian

In planning a new radio-relay section, the extent to which it is restricted in the pointing of its antennas by Recommendation 406 can be quickly determined (see Fig. 8). Figure 5 can be used to obtain the angle of elevation, ε, of the transmitting antenna as a function of the difference in altitude between the transmitting and receiving antennas and the length of the section. After correction for refraction in accordance with § 5.1, Fig. 1 can be used to determine the extreme azimuths of the angular zone as a function of the extreme angles of elevation e_1 and e_2. Figure 4 can be used to determine this band which has to be added to one side and the other of the centre azimuth to achieve a desired protection angle of the orbit.

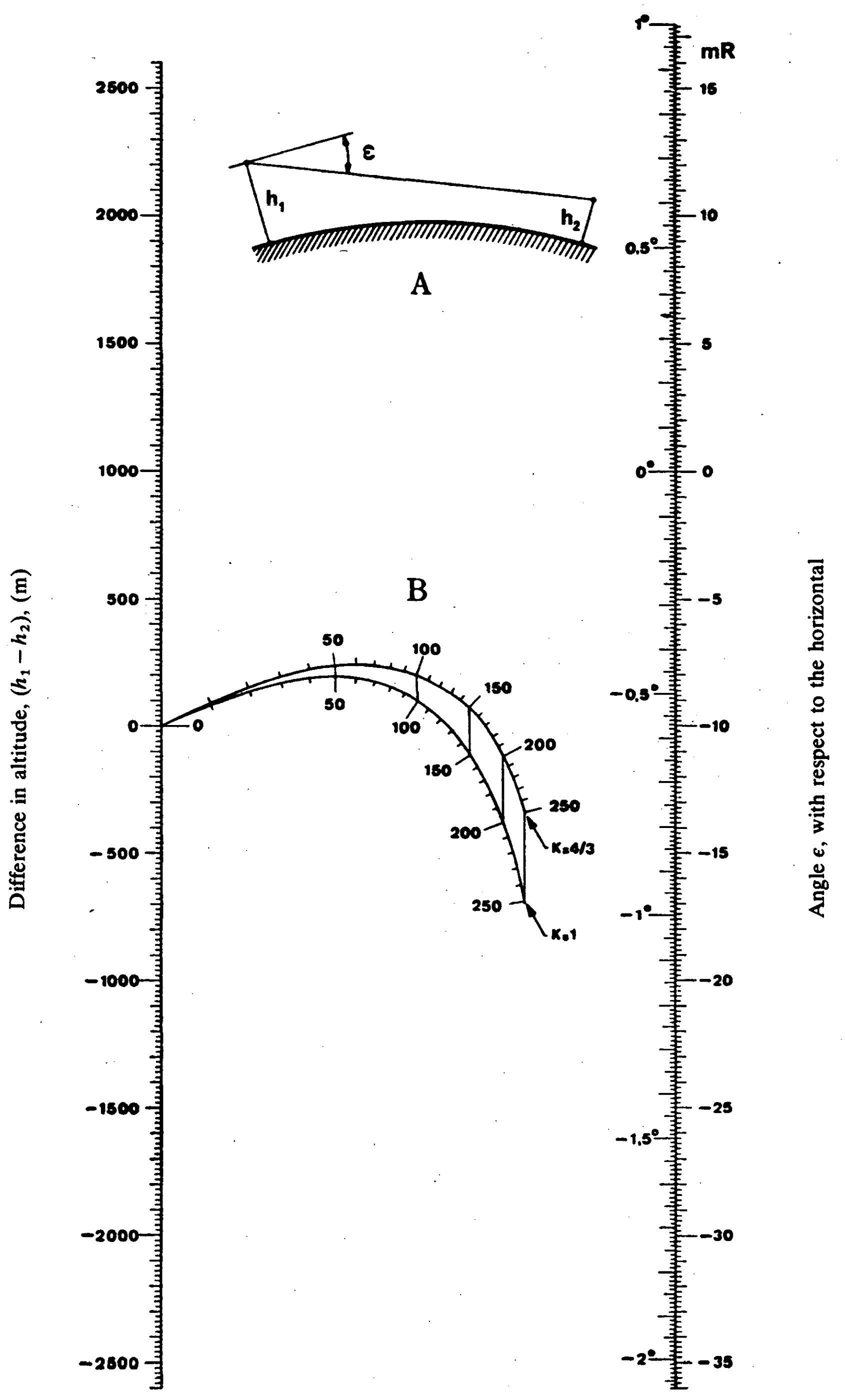


FIGURE 5 – *Pointing of antennae (radio-relay systems)*

A: 1 milliradian = 3.44 minutes of arc = 0.0636 grades B: Distance between stations (km)

This azimuthal band actually depends on the latitude of this station and on the angle of elevation of the antenna. In making an initial approximation for angles of elevations involved, the influence of the magnitude of angle of elevation itself may be ignored, since any error is very small compared with the correction to be used for the effects of refraction. (This amounts to the local approximation of the orbit by a straight line.)

However, in case of doubt, or in special geographical cases, a more comprehensive study of the effect of the horizon is necessary, as described in the next section.

5.3 *Use of a graphical method for more comprehensive determination of azimuths to be avoided*

The graphical method described in reference [Gould, 1967] takes into account the influence of the actual local horizon. The approximations it makes limit its application to stations located below about 70° latitude. Its azimuthal accuracy is approximately 0.1° and is better than that for low angles of elevation.

This method, illustrated in Fig. 6, is based on the consideration of the apparent orbit of a geostationary satellite, taking into account the effect of refraction, the latitude of the terrestrial station, antenna elevation angle and the influence of the local optical (real) horizon.

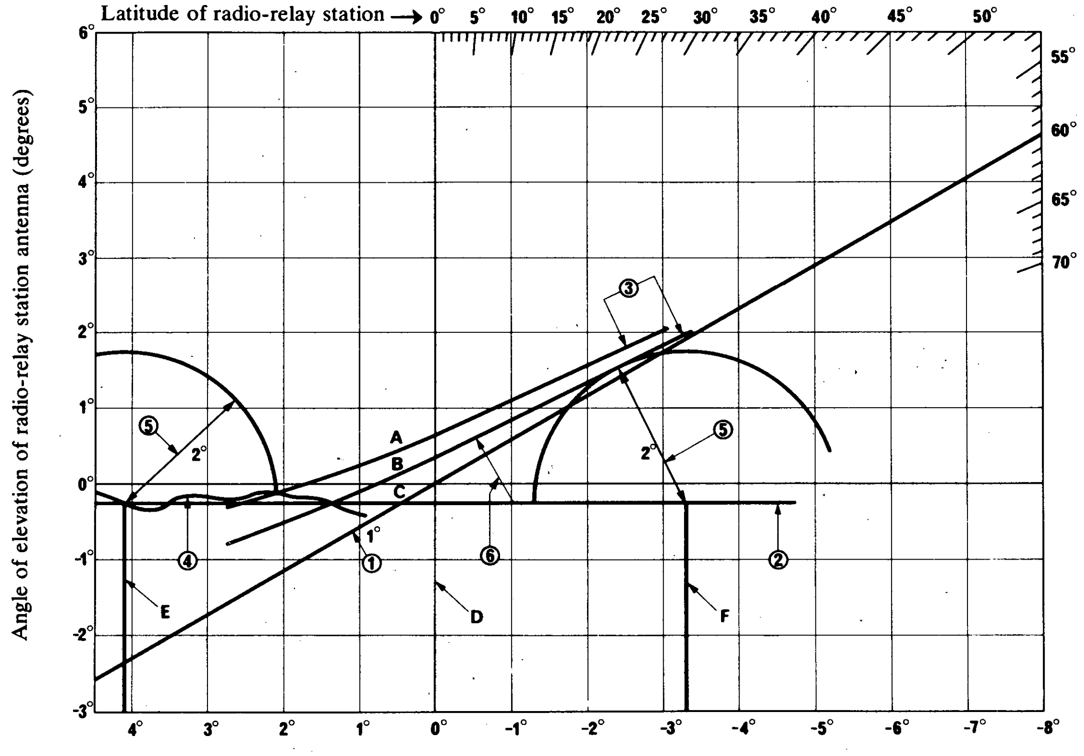


FIGURE 6 — *Sample determination using graphical method*

Radio-relay station altitude: 1 km
Latitude: 60°
Angle of elevation ϵ: $-0.25°$

A: maximum refraction
B: minimum refraction
C: no refraction

D: reference azimuth: 74.68° (from Table I)
E: upper limit 74.68° + 4.1° = 78.78°
F: lower limit 74.68° − 3.3° = 71.38°

Steps in the determination:

1. Plot orbit trace by drawing a line between the centre of the graph and latitude of the radio-relay station.
2. Draw a horizontal line at the proposed angle of elevation of the beam.
3. Elevate this trace to account for refraction. Plot a curve for both the minimum and maximum refraction expected.
4. Sketch the optical horizon in the region of interest.
5. With a compass, or with a straight edge calibrated in degrees, find the two points on the beam elevation line that are two degrees away from the closest of the elevated traces where those traces are above the optical horizon.

To plot the apparent (refracted) orbit, it is necessary to raise the trace of the geometric orbit at each point by a quantity τ, which is a function of the geometric orbit elevation and the station height, as shown in Fig. 7. This Figure has been derived from Fig. 2 using equation (9) hence the restrictions given at the end of § 5.1 also apply to Fig. 7.

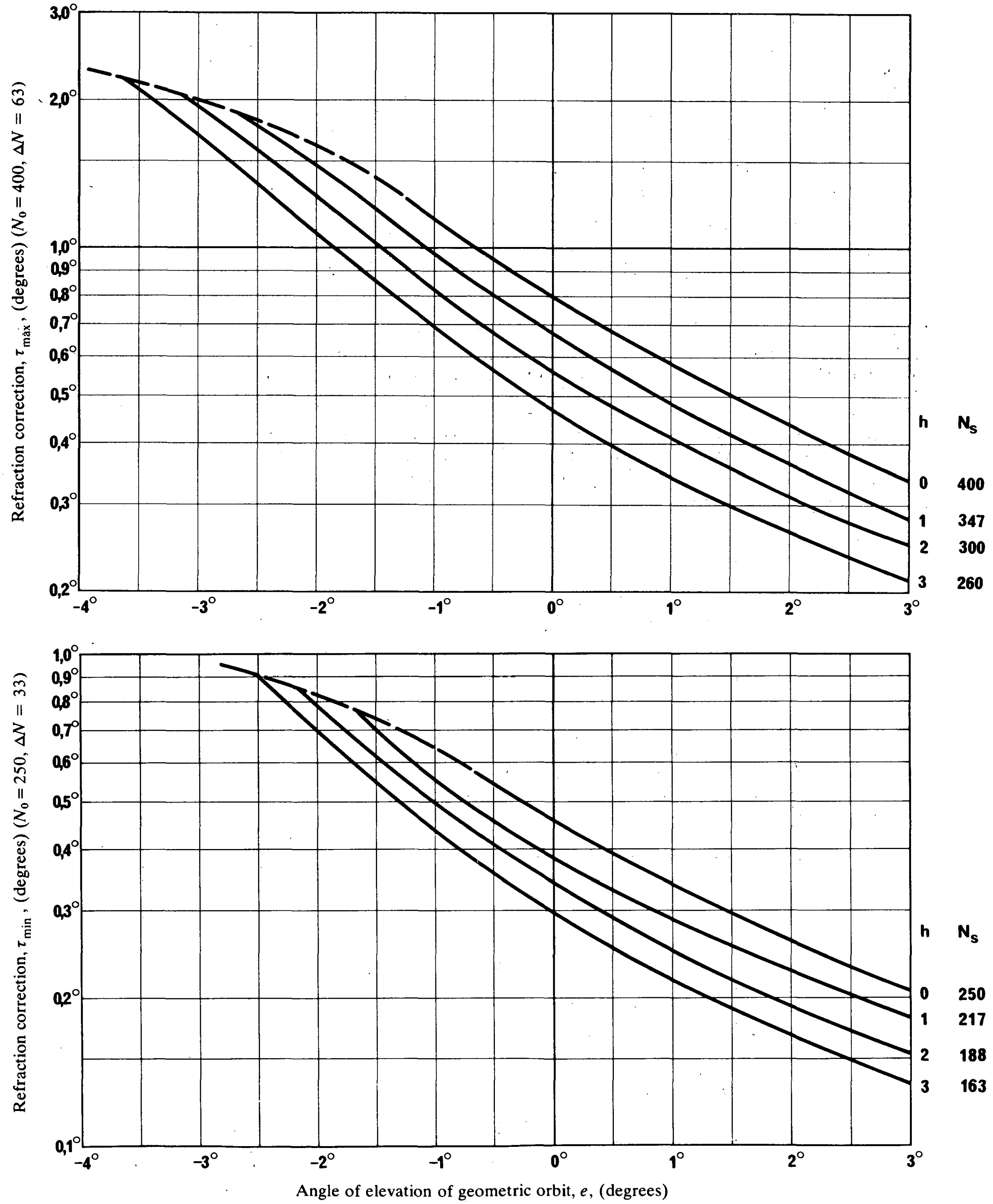


FIGURE 7 – *Refraction correction for angle e*

h : height of antenna above mean sea level (km)

N_s : refractivity (N units) corresponding to height h for given N_0 limit

Based on *CRPL Exponential Reference Atmosphere,* Bean & Thayer, NBS Monograph 4, U.S. Depart. of Commerce, 1959

The method may be summarized as follows:

5.3.1 On Fig. 6 draw a straight line passing through the origin and the point corresponding to the latitude of the station in question. (This implies an approximation of the orbit by a straight line in this small region.) The reference azimuth (0° on Fig. 6) for a zero geometric angle of elevation is given in Table I or in Fig. 1a or 1b.

5.3.2 Draw a horizontal line corresponding to the angle of elevation ε planned for the antenna. This angle can be determined from Fig. 5.

5.3.3 Raise the trace of the geometric orbit at each point by the quantity τ (a function of e) to account for the maximum and minimum refraction expected. This means that there will be two new traces, one corresponding to minimum bending and the other to maximum bending.

5.3.4 Draw the local horizon in the region of the azimuth concerned. For preliminary studies, the method can be simplified by replacing the real local horizon by a mean, approximate horizon.

5.3.5 Using a compass set to a radius of 2°, find on the straight line of the constant angle of antenna elevation, the centre of a circle tangential to the trace corresponding to minimum bending: one of the azimuth limits is thus defined. Subtract this deviation from the centre azimuth determined in Table I, or Fig. 1a or 1b.

Similarly, on the straight line of the constant angle of antenna elevation, find the centre of a second circle such that its closest point of intersection with the maximum bending trace is just above the horizon; the second azimuth limit is thus defined. Add this deviation to the centre azimuth.

5.3.6 This graphical construction can also be used to find the actual angular separation between an existing antenna azimuth and the orbit; this will be the compass radius corresponding to the shortest distance between the point of the antenna direction on the line representing the beam angle of elevation ε, and the nearest orbit trace. Figure 8 may then be used to determine the maximum radiated power permitted by Recommendation 406.

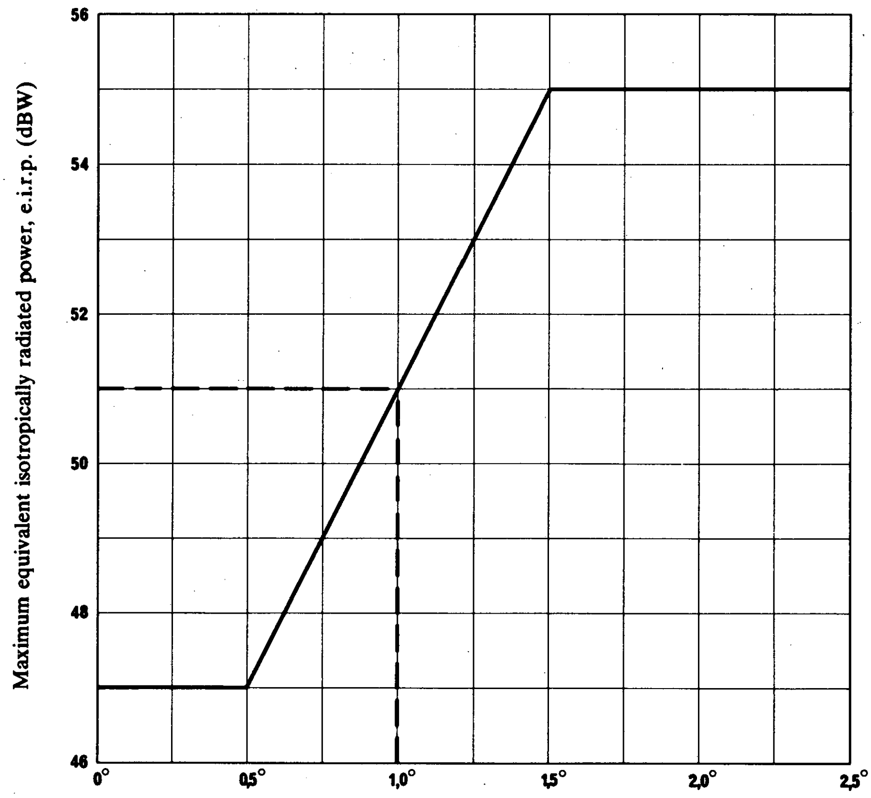


FIGURE 8 – *Maximum e.i.r.p. permitted by Recommendation 406*

— — —: example

5.4 *Analytical methods*

For stations at latitudes between about 70° and 81° (the limit of the zone covered by a geostationary satellite) the various approximations of graphical determinations are no longer valid and analytical methods must then be used. Such methods are useful for the rapid study of a large number of radio-relay stations, as they lend themselves to the use of computers. One such method is given in reference [Lundgren and May, 1969].

If the distribution of the refractive index is given, azimuths to be avoided can also be determined by using an analytical method described in [CCIR, 1966-69]. This computation produces a number of tables showing the azimuths to be avoided as a function of the latitude of a radio-relay station and the elevation angle of its antenna beam. Sample tables are given in [CCIR, 1966-69]. These tables will facilitate the work of finding exposures of the geostationary-satellite orbit with respect to radio-relay beams.

Computer programmes have been developed by several administrations [FCC, 1972; CNET, 1973]. These programmes allow the calculation of the directions to be avoided, and of the angle between the main beam direction of a terrestrial radio-relay antenna and the geostationary-satellite orbit.

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REPORT 791-1

INTER-SATELLITE SERVICE SHARING WITH THE FIXED AND MOBILE SERVICES

(Questions 32/4 and 17/9)

(1978–1982)

1. Introduction

The WARC-79 allocated bands to be shared between the inter-satellite service and the fixed and mobile services as follows: 22.55 to 23.55 GHz, 54.25 to 58.2 GHz, 59 to 64 GHz, 116 to 126 GHz, 126 to 134 GHz, 170 to 182 GHz and 185 to 190 GHz. In some of these bands the attenuation resulting from absorption by water vapour and atmospheric gases is important in facilitating sharing. In other bands, however, such attenuation is less important and other means must be used to assure successful sharing.

This Report investigates the feasibility of frequency sharing between the inter-satellite service and the fixed and mobile services.

2. Atmospheric attenuation

The inter-satellite service is allocated to portions of the spectrum in the vicinity of the atmospheric oxygen and water vapour absorption lines. The absorption of the incident wave with the atmospheric gases is caused by a resonance of molecular electric and magnetic dipoles. Oxygen and water vapour are the only gases that produce significant absorption in the inter-satellite frequency bands.

For the inter-satellite bands of 54.25 to 58.2 GHz, 59 to 64 GHz, and 105 to 130 GHz, the absorption is due primarily to the magnetic interaction of the oxygen dipole with the incident field. The interaction of the water-vapour electric dipole with the incident field produces the absorption at 170 to 182 GHz and 185 to 190 GHz (see Report 719, Figs. 2 and 4).

The dependence of atmospheric attenuation on frequency has been evaluated and documented in Report 719. Theoretical zenith* attenuation values from sea-level through the atmosphere are summarized in Table I. An average atmosphere and a water concentration of 7.5 g/m^3 (representing a moderately humid atmosphere) was used as a basis for these values. The attenuation caused by the water-vapour (H_2O) molecule in the atmosphere can be regarded as only a rough estimate of the actual attenuation because of the wide variation of water content with climate.

TABLE I — *Range of zenith attenuation for the inter-satellite frequencies*

Inter-satellite frequencies (GHz)	Zenith attenuation L_z (dB)	Remarks
22.55–23.55	0 to 1.5	Attenuation depends on relative humidity.
54.25–58.2	11 to 150	Attenuation increases from 54.25 to 58.2 GHz approximately linearly.
59–64	100+	Attenuation varies rapidly about oxygen lines with maximum values of approximately 240 dB.
105–130	1.3 to 100+ to 1.9	Attenuation increases from 1.3 dB at 105 GHz to 100+ dB at 118.8 GHz (O_2 absorption line) and then decreases to 1.9 dB at (130 GHz).
170–182	7.0 to 80 (1)	Attenuation increases from 7.0 to 80 dB for water-vapour concentration of 7.5 g/m^3.
185–190	80 to 13 (1)	Attenuation decreases linearly from 80 to 13 dB for water-vapour concentration of 7.5 g/m^3.

(1) Assumption: Average atmosphere with water-vapour concentration 7.5 g/m^3 at the Earth's surface.

The theoretical one-way attenuation for terrestrial stations located at a range of heights above sea-level is considered in Report 719. Calculations by [Reber, *et al.*, 1970] also show that the shape of the absorption curve in the vicinity of 60 GHz changes from a broad smooth curve at sea-level to one of individual lines (O_2 resonant frequencies) as the starting heights are varied above sea-level. This phenomenon results in valleys of low attenuation between the O_2 resonant frequencies at altitudes above 5 km.

The total attenuation of an incident wave through the atmosphere can be described in terms of the attenuation in the zenith direction (vertical path) and the angle of the wave path above the horizon [OT Report 74-43, 1974]. For elevation angles, θ, greater than about 5°, the attenuation through the atmosphere (L_a) is related to the zenith attenuation (L_z) by the simple cosecant relationship.

$$L_a = L_z \operatorname{cosec} \theta \tag{1}$$

3. Isolation between terrestrial stations and satellites

Since satellites are always separated from terrestrial stations by some portion of the atmosphere, the attenuation due to the atmospheric absorption will be available to isolate these services in addition to free-space loss. For example, the atmospheric absorption loss exceeds 100 dB at 60 GHz for a path from the Earth's surface to the outer atmosphere. The free-space path loss for a path from the geostationary orbit to the closest point on the Earth's surface is approximately 220 dB. The inter-satellite band isolation available at 60 GHz between a fixed station or mobile station on the Earth's surface and a satellite in geostationary orbit is therefore 320 dB or more.

* This refers to a wave travelling vertically upwards from a point on Earth.

The coupled power from a terrestrial station to a satellite is evaluated in terms of the interference power spectral density at a satellite receiver. This spectral density level in dB(W/kHz) at a satellite from a terrestrial station is given by:

$$I = P_t + G_{t(\theta)} + G_{R(\varphi)} - L \tag{2}$$

where,

P_t: the transmitter spectral power density of the terrestrial station in dB(W/kHz);

$G_{t(\theta)}$, $G_{R(\varphi)}$: the respective gains of the terrestrial and satellite antenna for the interfering path in dB (including matching and transmission line loss);

L: the propagation path loss from the terrestrial station to the satellite in dB.

The propagation path loss (L) comprises the free-space propagation loss (L_s), the absorption loss through the atmosphere (L_a), and meteorological losses (L_M).

The level of interference to any satellite link may be estimated by the use of equation (2) and the associated geometry of the signal path of the interference signal. Evaluating equation (2) using only the free-space propagation loss (L_s) and comparing the result to a permissible interference level will determine the amount of isolation required for sharing of the bands.

For those satellites in orbits other than the geostationary orbit, the degree of interference will be a function of the time that the satellite is in view of the terrestrial transmitter. For these satellite links, in randomly dispersed orbits, the interference, if any, will be transitory and the probability of exceeding the interference criteria would be extremely low.

4. Fixed and mobile services sharing with inter-satellite links in a geostationary orbit

4.1 *Introduction*

Article 27 of the Radio Regulations limits the maximum power radiated in the fixed or mobile services when sharing with space radiocommunication services above 1 GHz. Regulation 2505 states: "The maximum equivalent isotropically radiated power of a station in the fixed or mobile service shall not exceed +55 dBW".

Article 27 also limits the power into a fixed or mobile antenna when sharing with space radiocommunication services above 10 GHz. Regulation 2508* states: "The power delivered by a transmitter to the antenna of a station in the fixed or mobile service in frequency bands above 10 GHz shall not exceed +10 dBW".

From Regulation 2505*, and assuming a uniform spectral power density over 4 kHz, the interfering power spectral density from equation (2) is given by:

$$I = 49 \text{ dB(W/kHz)} + G_{R(\varphi)} - L \tag{3}$$

This equation assumes the main beam of the terrestrial transmitter is directed toward the satellite.

For the determination of values of maximum permissible power flux-density of noise-like interference, or the total power of CW-type interference, the limit set forth in Report 548 for unmanned spacecraft receivers operating below 15 GHz will be used. The limit is that an interference level at the receiver input of −161 dB(W/kHz) not exceeded more than 0.1 per cent of the time is acceptable for unmanned space missions. This criterion is based on the following assumptions:

- an operational noise temperature limited by the warm earth of 600 K (−201 dB(W/Hz)); and
- a detection-bandwidth on the satellite greater than 1 kHz (30 dB), due to the need for rapid, automatic acquisition of signals.

The interference-to-noise ratio for 0.1 per cent of the time used in the criterion corresponds to 10 dB. Hence:

$$\text{Interference (0.1\%)} = -201 \text{ dB(W/Hz)} + 30 \text{ dB} + 10 \text{ dB} = -161 \text{ dB(W/kHz)}$$

---

* Although No. 2510 of the Radio Regulations limits the applicability of Nos. 2505 and 2508 to particular frequency allocations below 40 GHz, it will be assumed for the remainder of this analysis that they are generally applicable above 40 GHz as well.

The required receiving antenna gain $G_{R(\varphi)}$ for an inter-satellite link is determined by the path loss between satellites and their ability to stay within a usable 3 dB beamwidth (station keeping). In an earlier study (Report 451) these requirements were analyzed and a maximum antenna diameter of 1.2 m, governed by the satellite launch shroud dimensions, was postulated. For the purposes of this Report, the maximum receiving antenna gain $G_{R(\varphi)}$ will be calculated using this diameter. The resulting gain (54.7 dB at 60 GHz for an antenna efficiency of 55 per cent) should approach the maximum for any practical antenna systems that will be used in the inter-satellite service.

4.2 *Interference from the fixed and mobile services into the inter-satellite service*

Under the e.i.r.p. and power limits cited in § 4.1, the interference level at the inputs to inter-satellite link receivers produced by radiation from terrestrial stations will depend on the gain of the inter-satellite link antennas in the direction of the Earth's limb. If such interference is to be held to acceptably low values, the inter-satellite link antenna gain in this direction must also be limited. This will impose another condition on how close to the Earth's limb the inter-satellite link antennas can point and, hence, on the maximum permissible orbital separation of the satellites involved.

For example, if, at the inter-satellite link receiver input, the maximum permissible single interference entry is required to be 15 dB below the system noise in the Carson's rule bandwidth, then the condition on $G(\theta)$, the inter-satellite link antenna gain towards the limb, is given by:

$$E_T - L + G(\theta) = 10 \log (kT_sB) - 15 \tag{4}$$

where:

E_T: maximum permissible terrestrial e.i.r.p. (55 dBW),

L: free-space loss on interference path (213 dB at 25 GHz),

T_s: system noise temperature (1000 K),

B: the Carson's rule bandwidth of inter-satellite link (780 MHz).

Using the numbers shown in parentheses for illustration, the inter-satellite link will be protected to the desired degree provided that:

$$G(\theta) \leqslant 33.5 \text{ dB}$$

To see what this implies for inter-satellite link path geometry, assume again that the inter-satellite link antenna pattern meets the side-lobe envelope of Report 558. For the inter-satellite link described in Table II (satellite spacing 10°, $G_m = 50$ dB, $\theta_0 = 0.25°$,

where

G_m: maximum antenna gain of inter-satellite link antenna,

θ_0: one half the 3 dB beamwidth of inter-satellite link antenna),

the angle by which the inter-satellite link antenna must avoid the Earth's limb in order to avoid interference from terrestrial transmitters is:

$$\theta_{min} = 0.59°$$

This protection angle is illustrated in Fig. 1.

4.3 *Interference from the inter-satellite service to the fixed and mobile services*

The criterion to protect the fixed and mobile services from the inter-satellite service can be estimated by assuming that the same power flux-densities applicable to the band 17.7 to 19.7 GHz are also applicable to the bands shared between the fixed and mobile services and the inter-satellite service. These are specified in Nos. 2578 and 2580 of the Radio Regulations, as follows:

-115 dB(W/(m^2 · MHz))	for $0° \leqslant \delta < 5°$
$-115 + (\delta - 5)/2$ dB(W/(m^2 · MHz))	for $5° \leqslant \delta < 25°$
-105 dB(W/(m^2 · MHz))	for $25° \leqslant \delta < 90°$

where δ is the angle of arrival.

It can be shown that the power flux-density at the surface of the Earth caused by an inter-satellite link having the characteristics shown in Table II will be actually much lower than those given above.

To show this, note that, under free-space conditions, the interfering pfd produced by an inter-satellite link at the surface of the Earth is:

$$P_{ISL} + G(\theta) - 162 \text{ (dB(W/(m}^2 \cdot \text{MHz)))} \tag{5}$$

where:

P_{ISL} : the maximum inter-satellite link transmitter power density (dB(W/MHz)),

$G(\theta)$: gain of inter-satellite link antenna towards limb of Earth (dB).

Setting this quantity equal to -115 dB(W/(m^2 · MHz)), and assuming that P_{ISL} is at least 10 dB below the total inter-satellite link transmitter power of 10 W as shown in the example of § 1, it follows that $G(\theta)$ should not exceed 47 dB.

To determine how close to the limb of the Earth the inter-satellite link antenna can point, assume that the inter-satellite link antenna pattern meets the side-lobe envelope specified in Report 558 for space station antennas in the fixed-satellite service:

$$G(\theta) = \begin{cases} G_m - 3(\theta/\theta_0)^2 \text{ dB} & \text{for } 1 \leqslant \theta/\theta_0 \leqslant 2.6 \\ G_m - 20 \text{ dB} & \text{for } 2.6 < \theta/\theta_0 \leqslant 6.3 \\ G_m - 25 \log(\theta/\theta_0) \text{ dB} & \text{for } 6.3 < \theta/\theta_0 \leqslant \theta_1/\theta_0 \\ -10 \text{ dB} & \text{for } \theta > \theta_1 \end{cases} \tag{6}$$

where:

θ : angle between inter-satellite link antenna axis and limb of Earth,

G_m : maximum antenna gain (dB) of inter-satellite link antenna,

θ_0 : one-half the 3 dB beamwidth of inter-satellite link antenna,

θ_1 : value of θ when $G(\theta) = -10$ dB.

Setting $G(\theta)$ equal to 47 dB and taking $\theta_0 = 0.25°$ as in the example of § 4.2, it follows that the minimum angle by which the inter-satellite link antennas must avoid the limb of the Earth to prevent interference to terrestrial receivers is only:

$$\theta_{min} = 0.25°$$

This is a negligible restriction on inter-satellite link geometry. The orbital separation between the satellite terminals and the inter-satellite link is:

$$\varphi = 162.8 - 2\,\theta \quad \text{degrees} \tag{7}$$

where, as before, θ is the angle between the inter-satellite link antenna axis and the Earth's limb. Thus the condition on θ imposed by the pfd limit of -115 dB(W/(m^2 · MHz)) is to reduce the maximum permissible orbital separation by only about half a degree below that imposed by the presence of the Earth itself (see Fig. 1).

TABLE II — *Assumed inter-satellite link characteristics*

Transponder output power (W)	10
Antenna half-power beamwidth (degrees)	≈ 0.5 independent of frequency
Antenna gain (dB)	≈ 50 independent of frequency
System noise temperature (K)	1000 (Black sky)
Highest modulation frequency (MHz)	130
Peak frequency deviation of FM carrier (MHz)	260
Carson's rule RF bandwidth (MHz)	780

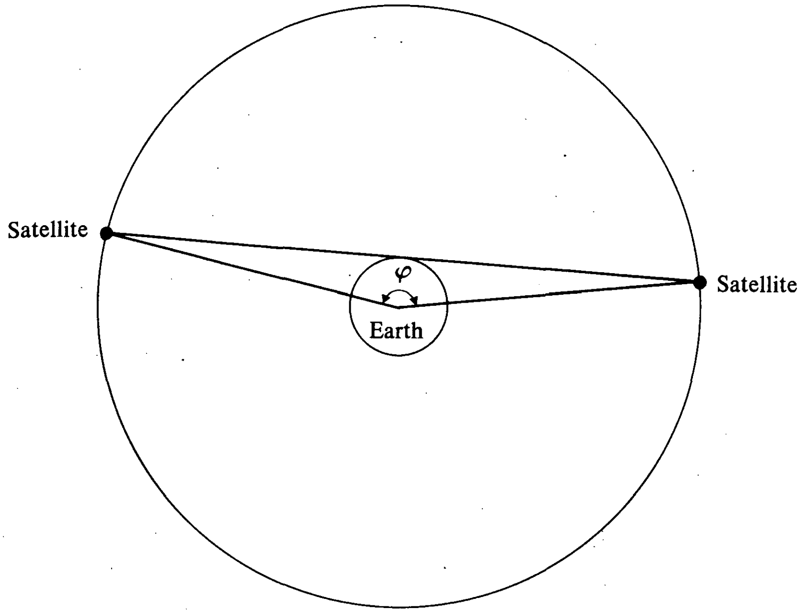

FIGURE 1 – *Maximum possible separation between inter-satellite links to avoid interference*

φ_{max} to avoid inter-satellite beam from hitting the Earth: 162.8°

φ_{max} to avoid interference to fixed and mobile services:

$162.8° - 2\,\theta_F = 162.8° - 2(0.25°) = 162.3°$

φ_{max} to avoid interference to inter-satellite links:

$162.8° - 2\,\theta_I = 162.8° - 2(0.59°) = 161.62°$

The least of these, 161.62° is the controlling separation.

5. Conclusions

The first generation of inter-satellite links will probably use microwave frequencies below about 40 GHz. Previous studies [Welti, 1976 and 1977] of alternative transmission methods suggest a preference for the use of FM remodulation on such links. With this choice, RF bandwidths in the order of 1 GHz in each direction of transmission are indicated for inter-satellite link capacities in the order of 2000 two-way telephone circuits.

With the adoption of simple sharing criteria already in force in nearby bands (cited in § 4.3), coequal sharing appears to be feasible between inter-satellite links having the characteristics described in Table II and the fixed and mobile services in bands near 25 GHz without the need for significant design constraints on systems in any of the services. In the higher bands allocated for the inter-satellite service and the fixed and mobile services, the additional isolation resulting from atmospheric attenuation will provide even greater margins for sharing.

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SECTION 4/9B: COORDINATION AND INTERFERENCE CALCULATIONS

Recommendation and Reports

RECOMMENDATION 359-5

DETERMINATION OF THE CO-ORDINATION AREA OF EARTH STATIONS IN THE FIXED-SATELLITE SERVICE USING THE SAME FREQUENCY BANDS AS THE SYSTEMS IN THE FIXED TERRESTRIAL SERVICE

(Questions 32/4 and 17/9)

(1963-1966-1970-1974-1978-1982)

The CCIR,

CONSIDERING

(a) that, where earth stations and terrestrial stations share the same frequency bands, there is a possibility of interference, both as regards the earth-station transmission interfering with reception at terrestrial stations, and the terrestrial-station transmissions interfering with reception at earth stations;

(b) that, to avoid such interference, it will be desirable for the transmitting and receiving frequencies used by earth stations to be co-ordinated with the frequencies used by terrestrial services, which might be in a position either to receive interference from earth-station transmissions or to cause interference to reception at earth stations;

(c) that this co-ordination will need to be established within an area surrounding the earth station and extending to the limits beyond which the possibility of mutual interference may be considered negligible;

(d) that this area may sometimes involve more than one administration;

(e) that such mutual interference will depend upon several factors, including the transmitter powers, antenna gains in the direction of the unwanted signals, the permissible interference levels at the receivers, mechanisms of radio-wave propagation, radio-climatology, the distance between stations and the terrain profile;

(f) that the possibility of interference will need to be examined in detail in each case, taking all factors into account;

(g) that, as a preliminary to this detailed examination, it is desirable to establish a method of determining, on the basis of broad assumptions, a co-ordination area around an earth station, such that the possibility of mutual interference with terrestrial stations situated outside this area may be regarded as negligible; mutual co-ordination between administrations is required by the Radio Regulations if the co-ordination area of this station overlaps the territory under the jurisdiction of another administration;

(h) that the World Administrative Radio Conference, Geneva, 1979, adopted the method of determining the co-ordination area set out in Appendix 28 of the Radio Regulations and invited the CCIR to continue its studies on the subject (see Recommendation No. 711 of the WARC-79);

(j) that the Conference also adopted Resolution No. 60 inviting the CCIR to maintain the relevant texts as a result of these studies in a format which would permit direct insertion into Appendix 28 of the Radio Regulations in place of existing § 3, 4, 6 or Annex III when it is concluded by the CCIR Plenary Assembly that such an insertion is warranted,

UNANIMOUSLY RECOMMENDS

1. that account be taken of the international co-ordination and planning which will be involved, if earth stations in the fixed-satellite service are to share frequency bands with terrestrial stations in nearby countries without undue mutual interference;

2. that the co-ordination areas of transmitting and receiving earth stations be determined by the method described in Appendix 28 to the Radio Regulations and on the basis of the parameters indicated in that Appendix;

3. that Report 382, which gives the results of complementary studies for the determination of the co-ordination area, could be useful in future but includes for the time being provisional propagation data;

4. that § 3, 4, 6 and Annex II of Report 382 be updated, based on the latest propagation information adopted by Study Group 5, in a format suitable for direct insertion into Appendix 28 of the Radio Regulations;

5. that if such changes are sufficiently significant to warrant revision of Appendix 28, a proposal for such a revision be made to the Plenary Assembly of the CCIR in accordance with Resolution No. 60 of the World Administrative Radio Conference, Geneva, 1979.

REPORT 382-5*

DETERMINATION OF CO-ORDINATION AREA

(Questions 32/4 and 17/9)

(1966-1970-1974-1978-1982-1986)

Preliminary Note

This Report includes certain propagation data given in Reports 724, 563 and 569. Some of this data is of a provisional nature and therefore this Report is not at present being proposed as the basis for any changes in the Radio Regulations. Administrations are requested to compare results obtained using this Report, including the Appendix, with the methods of Appendix 28 to the Radio Regulations, and forward the results of such comparisons to the CCIR.

1. Introduction

This Report describes a procedure for determining the co-ordination area around an earth-station transmitter or receiver in frequency bands between 1 and 40 GHz shared between space and terrestrial radiocommunication services. The procedure described in this Report is related, but not necessarily identical, to that of Appendix 28 to the Radio Regulations. In particular, § 3, 4, 6 and Annex II of this Report may differ from the corresponding elements of Appendix 28, reflecting the most recent propagation-related findings of the CCIR.

The procedure described herein is appropriate for the determination of the co-ordination area in frequency bands in which the fixed-satellite service has a unidirectional (Earth-to-space or space-to-Earth) allocation. The procedure to be followed in frequency bands which are bidirectionally (i.e., Earth-to-space and space-to-Earth) allocated to the fixed-satellite service and shared with a terrestrial service is under study (see Study Programme 17F/9). Elements of the procedure in this Report are also applicable to the determination of the co-ordination area around a transmitting earth station relative to a receiving earth station in bidirectionally allocated FSS frequency bands (see Report 999).

The operation of transmitting and receiving earth and terrestrial stations in shared frequency bands between 1 and 40 GHz may give rise to interference between stations of the two services. The magnitude of such interference is dependent on the transmission loss along the interfering path which, in turn, depends on such factors as length and general geometry of the interfering path (e.g., site shielding), antenna directivities, radio climatic conditions, and the percentage of the time during which the transmission loss should be exceeded.

The purpose of this Report is to provide a method to determine, in all azimuth directions from a transmitting and/or receiving earth station, a distance beyond which the transmission loss is expected to exceed a given permissible level for all but a given permissible percentage of the time. A distance so determined is called a "co-ordination distance" and the end points of co-ordination distances determined for all azimuths define a distance contour around the earth station – the co-ordination contour – which contains the co-ordination area. With the appropriate choice of permissible transmission loss and the associated percentage of the time during which it need not be exceeded, terrestrial stations located outside the co-ordination area should experience or cause only negligible interference.

The co-ordination area is obtained by determining, in all azimuth directions from an earth station, the co-ordination distances, and drawing to scale on an appropriate map the co-ordination contour, which is the boundary of the co-ordination area. This Report describes methods which are suitable for either graphical or computer determination of the co-ordination area.

Although it is based on technical data, the "co-ordination distance" is an administrative concept. Since the co-ordination area is determined before any specific cases of potential interference are examined in detail, it must be based perforce on assumed parameters of the terrestrial systems, while the pertinent parameters of the earth stations are known. So as not to inhibit the technical development of terrestrial systems, the parameters assumed for them must lie somewhat beyond those presently employed.

It should be emphasized that the presence or installation of a terrestrial station within the co-ordination area of an earth station may, but does not generally, affect the successful operation of either the earth station or the terrestrial station, since the procedure for the determination of the co-ordination area is based on very unfavorable assumptions as regards mutual interference.

* This Report should be brought to the attention of Study Group 5.

For the determination of the co-ordination area two cases may have to be considered:

- for the earth station when it is transmitting (and hence capable of interfering with reception at terrestrial stations);
- for the earth station when it is receiving (and hence capable of being interfered with by emissions from terrestrial stations).

Where an earth station is intended to transmit or to receive a variety of classes of emissions, the earth-station parameters to be used in the determination of the co-ordination contour shall be those which lead to the greatest co-ordination distances, for each earth-station antenna beam and in each allocated frequency band which the earth station proposes to share with the terrestrial services.

It is suggested that, together with the co-ordination contour, auxiliary contours should be drawn which are based on less unfavorable assumptions than those chosen for the determination of the co-ordination contour. These auxiliary contours may be used to eliminate, without more precise calculations, certain existing or planned terrestrial stations located within the co-ordination area from further consideration.

2. General considerations

2.1 *Concept of minimum permissible transmission loss*

The determination of co-ordination distance, as the distance from an earth station beyond which harmful interference from or to a terrestrial station may be considered to be negligible, is based on the premise that the attenuation of an unwanted signal is, or can be represented by, a monotonically increasing function of distance.

The amount of attenuation required between an interfering transmitter and an interfered-with receiver is given by the "minimum permissible transmission loss for p% of the time", a value of transmission loss which should be exceeded by the actual or predicted transmission loss for all but p% of the time: *

$$L(p) = P_{t'} - P_r(p) \qquad \text{dB} \tag{1}$$

where:

$P_{t'}$**: the maximum available transmitting power level (dBW) in the reference bandwidth at the input to the antenna of an interfering station;

$P_r(p)$: permissible level of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than p% of the time at the terminals of the receiving antenna of an interfered-with station, the interfering emission originating from a single source.

$P_{t'}$ and $P_r(p)$ are defined for the same radio-frequency bandwidth (the reference bandwidth) and $L(p)$ and $P_r(p)$ for the same percentage of the time, as dictated by the performance criteria of the interfered-with system.

Only small percentages of the time are of interest here, and it is necessary to distinguish between two significantly different mechanisms of propagation for an interfering emission:

- propagation of signals in the troposphere via near-great circle paths; mode (1) see § 3;
- propagation of signals by scattering from hydrometeors; mode (2), see § 4.

2.2 *The concept of minimum permissible basic transmission loss*

In the case of propagation mode (1) the transmission loss is defined in terms of separable parameters, viz.: a basic transmission loss, (i.e. attenuation between isotropic antennas) and the effective antenna gains at both ends of an interference path. The minimum permissible basic transmission loss may then be expressed as:

$$L_b(p) = P_{t'} + G_{t'} + G_r - P_r(p) \qquad \text{dB} \tag{2}$$

where:

$L_b(p)$: the minimum permissible basic transmission loss (dB) for p% of the time; this value must be exceeded by the actual or predicted basic transmission loss for all but p% of the time;

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* When p is a small percentage of the time, in the range 0.001% to 1.0%, it is referred to as "short-term"; if $p \geqslant 20\%$, it is referred to as "long-term".

** Primes refer to the parameters associated with the interfering station.

$G_{t'}$: gain (dB relative to isotropic) of the transmitting antenna of the interfering station. If the interfering station is an earth station, this is the antenna gain towards the physical horizon on the azimuth to the terrestrial station; in the case of a terrestrial station, the maximum expected antenna gain is to be used;

G_r: gain (dB relative to isotropic) of the receiving antenna of the interfered-with station. If the interfered-with station is an earth station, this is the gain towards the physical horizon on the azimuth to the terrestrial station; in the case of a terrestrial station, the maximum expected antenna gain is to be used.

Data on radiation patterns of earth-station antennas are to be found in Recommendation 465 and Reports 391 and 614. Annex I provides numerical and graphical methods to determine the angle between the earth-station antenna main beam and the physical horizon, and the horizon antenna gain, as functions of azimuth.

When considering non-geostationary satellites, $G_{t'}$ or G_r (whichever pertains to the earth-station antenna) is variable with time. In such cases, an equivalent time-invariant earth-station antenna gain is to be used.* This equivalent gain is either 10 dB less than the maximum horizon antenna gain or is that value of horizon antenna gain which is exceeded for no more than 10% of the time (if available), whichever is the greater.

2.3 *Derivation and tabulation of interference parameters*

2.3.1 *The permissible received level of an interfering emission*

The permissible received level of the interfering emission (dBW) in the reference bandwidth, to be exceeded for no more than p% of the time at the receiving antenna terminal of a station subject to interference, from each source of interference, is given by the general formula below:

$$P_r(p) = 10 \log (kT_eB) + J + M(p) - W \qquad \text{dBW} \tag{3}$$

where:

$$M(p) = M(p_0/n) = M_0(p_0) \qquad \text{dB} \tag{4}$$

with:

k: Boltzmann's constant, 1.38×10^{-23} J/K;

T_e: the thermal noise temperature of the receiving system (K), at the terminal of the receiving antenna (see Note 1);

B: the reference bandwidth (Hz), i.e., the bandwidth in the interfered-with system over which the power of the interfering emission can be averaged;

J: the ratio (dB) of the permissible long-term (20% of the time) power of the interfering emission to the thermal noise power of the receiving system at the terminal of the interfered-with receiving antenna (see Note 2);

p_0: the percentage of the time during which the interference from all sources may exceed the permissible value;

n: the number of expected entries of interference, assumed to be uncorrelated for small percentages of the time (see Report 887, § 4.3.2);

p: the percentage of the time during which the interference from one source may exceed the permissible value; since the entries of interference are not likely to occur simultaneously: $p = p_0/n$;

$M_0(p_0)$: the ratio (dB) between the permissible aggregate power level of all interfering emissions (all entries) to be exceeded for p_0% of the time, and that to be exceeded for 20% of the time (see Note 3);

$M(p)$: the ratio (dB) between the permissible power level of one interfering emission (single entry) to be exceeded for p% of the time, and the permissible aggregate power level of all interfering emissions (all entries) to be exceeded for 20% of the time;

W: an equivalence factor (dB) relating interference from interfering emissions to that caused, alternatively, by the introduction of additional thermal noise of equal power in the reference bandwidth. It is positive when the interfering emissions would cause more degradation than thermal noise (see Note 4).

Tables I and II list values for the above parameters.

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* This equivalent antenna gain is not to be used when the earth-station antenna points in the same direction for appreciable periods of time (e.g. when working to space probes or to satellites which are almost geostationary).

TABLE I — *Parameters required for the determination of coordination area for a transmitting earth station*

Type of terrestrial station		Line-of-sight radio-relay station					Trans-horizon radio-relay station
Frequency bands (GHz) (6)		1-10		10-15		15-40	1-10
Type of modulating signal of terrestrial station (1)		A	N	A	N	N	A
Interference parameters and criteria	p_0 (%)	0.01	0.005	0.01	0.005	0.005	0.01
	n	2	3	2	2	2	1
	p (%)	0.005	0.0017	0.005	0.0025	0.0025	0.01
	J (dB) (2)	16	2	16	2	2	9
	M_0 (p_0) (dB) (3)	17	33	17	22	22	17
	W (dB) (4)	0	0	0	0	0	0
Terrestrial station parameters	B (Hz)	4×10^3	10^6	4×10^3	10^6	10^6	4×10^3
	G_r (dB) (5)	45 (7)	45 (7)	50	50	50	52
	ΔG (dB)	3 (7)	3 (7)	8	8	8	10
	T_e (K)	750	750	1500	1500	3200	500
Auxiliary parameters	S (dBW)	176 (8)	150 (8)	178	157	154	192
	P_r (p) (dBW) in B	−131	−105	−128	−107	−104	−140

(1) A: Analogue modulation, N: Digital modulation
For those situations where the type of modulating signal of the terrestrial station could be both analogue and digital, the parameters leading to the largest co-ordination area should be used.

(2) Note 2 in § 2.3.1 defines and discusses the value of the parameter J for both analogue and digital systems. Recommendation 615 contains interference criteria into digital radio-relay systems; the value of J for digital systems requires further study along with the value of p_0 (%) and n.

(3) and (4): See Notes 3 and 4 in § 2.3.1.

(5) Feeder losses are not included in values for G_r.

(6) The allocated frequency bands are given in Appendix 28 to the Radio Regulations.

(7) Value shown is for 6 GHz. For other frequencies, appropriate values are given in Table I bis.

(8) The value shown is for 6 GHz and for other frequencies the values may be deduced from Table I bis. For a definition of the parameter S, see § 2.3.2.

TABLE I bis

Frequencies (GHz)	1.5	2	4	6	7-8
G_r (dB)	35	37	42	45	47
ΔG (dB)	−7	−5	0	3	5

TABLE II — *Parameters required for the determination of coordination area for a receiving earth station*

Space radiocommunications service		Fixed-satellite					Space research		Meteor-ological Satellite (9)	Space Opera-tion Tele-metry (9)	Satellite earth exploration (9)	
							Near-earth	Deep space and manned				
Frequency bands (GHz) (6)		1-10		10-15		15-40	1-10	1-10	1-15	1-10	1-10	10-40
Type of modulating signal (1)	Earth station	A	N	A	N	N	—	—	—	—		
	Terrestrial station	A	A	A	A	N	A	A	A	A		
Interference parameters and criteria	p_0 (%)	0.03	0.003	0.03	0.003	0.003	0.1	0.001			1.0	
	n	3	3	2	1	1	2	1				
	p (%)	0.01	0.001	0.015	0.003	0.003	0.05	0.001				
	J (dB) (2)	−8.5	−8.5	−8.5	−8.5	−8.5	—	—				
	$M_0(p_0)$ (dB) (3)	17	≥ 5	17	≥ 5	≥ 5	—	—				
	W (dB) (4)	4	0	4	0	0	—	—				
Terrestrial station (line-of-sight) parameters	E (dBW) in B	55	55	55	55	35 (7)	25 (8)	25 (8)	55	55	55	
	P (dBW) in B	13	13	10	10	−10 (7)	−17 (8)	−17 (8)	13	13	13	
	ΔG (dB)	0	0	3	3	3	0	0	0	0	0	
Terrestrial station (trans-horizon) parameters	E (dBW) in B	92	92	—	—	—	62 (8)	62 (8)	92	—	—	
	$P_{t'}$ (dBW) in B	40	40	—	—	—	10 (8)	10 (8)	40	—	—	
	ΔG (dB)	10	10	—	—	—	10	10	10	—	—	
Reference bandwidth	B (Hz) (5)	10^6	10^6	10^6	10^6	10^6	1	1			10^6	
Permissible interference power	$P_r(p)$ (dBW) in B	—	—	—	—	—	−220	−220			−154	

(1) A: Analogue modulation; N: Digital modulation.

(2) (3) and (4): See Notes 2, 3 and 4 in § 2.3.1.

(5) In certain systems in the fixed-satellite service it may be desirable to choose a greater reference bandwidth B when the system requirements indicate that this may be done. However, a greater bandwidth will result in smaller coordination distances, and a later decision to reduce the reference bandwidth may require re-coordination of the earth station. It may also be desirable to decrease the value of the reference bandwidth; for example, for narrow-band transmissions the reference bandwidth B might be assumed to be equal to the narrow bandwidth occupied by the wanted transmissions.

(6) The allocated frequency bands are given in Appendix 28 to the Radio Regulations.

(7) These values assume an RF bandwidth of no less that 100 MHz and are 20 dB below total power assumed per emission.

(8) These values are estimated for 1 Hz bandwidth and are 30 dB below the total power assumed for emission.

(9) Parameters associated with these services may vary over a rather wide range. Further study is required before representative values become available.

In certain cases, an administration may have reason to believe that, for its receiving earth station, a departure from the values associated with the earth station, as listed in Table II, may be justified. Attention is drawn to the fact that for specific systems the bandwidths B or, as for instance in the case of demand assignment systems, the percentages of the time p and p_0 may have to be changed from the values given in Table II. For further information see § 2.3.6.

Note 1. – The noise temperature (K) of the receiving system, referred to the output terminals of the receiving antenna, may be determined from:

$$T_e = T_a + (e - 1)\,290 + eT_r \qquad \text{K} \tag{5a}$$

where:

T_a : noise temperature (K) contributed by the receiving antenna;

e : numerical loss in the transmission line (e.g. a waveguide) between the antenna terminal and the receiver front end;

T_r : noise temperature (K) of the receiver front end, including all successive stages at the front end input.

For radio-relay receivers and where the waveguide loss of a receiving earth station is not known, a value of $e = 1.0$ should be used.

Note 2. – The factor J (dB) is defined as the ratio of total long-term (20% of the time) permissible power of the aggregate of all interfering emissions to the long-term thermal radio frequency noise power in the reference bandwidth of a single receiver. In the computation of this factor, the interfering emission is considered to have a flat power spectral density, its actual spectrum shape being taken into account by the factor W (see below). For example, in a 50-hop terrestrial hypothetical reference circuit, the total allowable additive interference power is 1000 pW0p (Recommendation 357) and the mean thermal noise power in a single hop may be assumed to be 25 pW0p. Therefore, since in a frequency-division multiplex/frequency modulation (FDM-FM) system the ratio of a flat interfering noise power to the thermal noise power in the same reference bandwidth is the same before and after demodulation, J is given by the ratio 1000/25 expressed in dB, i.e. $J = 16$ dB. In a fixed-service satellite system, the total allowable terrestrial interference power is also 1000 pW0p (Recommendation 356), but the thermal noise contribution of the down link is not likely to exceed 7000 pW0p, hence $J \geqslant -8.5$ dB.

In digital systems, interference is measured and prescribed in terms of the permissible bit error ratio increase. While the bit error ratio increase is additive in a reference circuit comprising tandem links, the radio-frequency power of interfering emissions giving rise to such bit error ratio increase is not additive, because bit error ratio is not a linear function of the pre-demodulation signal-to-noise or signal-to-interfering emission ratio. Thus, it may be necessary to protect each receiver individually. The matter of interference criteria for the protection of digital transmissions is still under study. However, Recommendation 558 stipulates that the received aggregate level of long-term unwanted emissions should not exceed 10% of the total pre-demodulation noise-plus-interfering power which produces a 10^{-6} bit error ratio in 8-bit PCM encoded telephony signals received by an earth station in the fixed-satellite service. Assuming that the thermal noise power in such a signal would not account for more than 70% of the total noise-plus-interfering power, a value of $J \geqslant -8.5$ dB would also be appropriate.

For digital terrestrial systems, as per Recommendation 594, the outage due to noise and interference is 0.054% of any month for a threshold BER of 1×10^{-3} of which 10% is due to satellite system interference. For systems employing a protection channel, $J = 2$ dB. For systems not employing a protection channel, $J = 7.5$ dB. Further study is required (see Report 877, § 4.3.1).

Note 3. – $M_0(p_0)$ (dB) is the "interference margin", i.e., the ratio (dB) of the short-term (p_0%) to the long-term (20%) allowable power level of the aggregate of all interfering emissions.

For analogue radio-relay and fixed-satellite systems this is equal to the ratio (dB) between 50 000 and 1000 pW0p (17 dB).

In the case of digital systems, system performance can, in most areas of the world, usefully be defined as the percentage of the time p_0 for which the wanted signal is allowed to drop to its operating threshold, defined by a given bit error ratio. During non-faded operation of a system, the desired signal will exceed its threshold level by some margin M_s. The greater this margin, the greater the enhancement of the interfering emission which would degrade the unfaded system to threshold performance.

It can be shown that degradation to threshold of an unfaded system from an enhancement of the level of an interfering emission is given approximately by the expression:

$$M_0(p_0) = M_s - J \qquad \text{dB} \tag{5b}$$

where all parameters are in dB as defined above. However, values of $M_0(p_0)$ greater than about $-10 \log p_0$ dB (where p_0 is in per cent of the time) should generally not be used, especially not with propagation mode (1) on overland paths, since for such higher values of $M_0(p_0)$ co-ordination distances determined only for the small percentages of the time might not afford sufficient protection for nominal (20% of the time) operation of interfered-with systems.

Note 4. – The factor W (dB) is the level of the radio-frequency thermal noise power relative to the received power of an interfering emission which, in the place of the former and contained in the same (reference) bandwidth, would produce the same interference (e.g., an increase in the voice or video channel noise power, or in the bit error ratio). The factor W generally depends on the characteristics of both the wanted and the interfering signals.

For interference between FDM-FM telephony transmissions, W may be calculated from:

$$W = 10 \log [f_m(1 + r\,m)\ D(f_m,0)] \qquad \text{dB} \tag{5c}$$

where:

m: r.m.s. modulation index of the interfered-with signal;

r: multi-channel peak-to-r.m.s. voltage ratio in the interfered-with signal;

Note that the term $f_m(1 + r\,m)$ is equal to one-half of the Carson's rule bandwidth of the interfered-with signal.

The term $D(f_m,0)$ is a convolution term containted in the interference reduction factor B of equation (3) of Report 388.

When the r.m.s. modulation index of the wanted signal is greater than about 0.8, W will not exceed a value of about 4 dB when the reference bandwidth is chosen as the radio-frequency "noise" bandwidth of the wanted signal.

For very low r.m.s. modulation indices of the wanted signal, W may assume a large range of values, increasing with decreasing modulation indices of both the wanted and the unwanted signals. For such cases it has proven useful to choose as the reference bandwidth the nominal voice channel bandwidth of 4 kHz, and then $W \leqslant 0$ dB.

When the wanted signal is digital, W is usually equal to or less than 0 dB, regardless of the characteristics of the interfering signal.

Report 388 contains information by means of which W may be determined more precisely.

2.3.2 *Interference from an earth station: the sensitivity factor*

From equation (2) one can isolate the terms $G_r - P_r(p)$ and define an interference sensitivity factor S (dBW) of the interfered-with terrestrial stations:

$$S = G_r - P_r(p) \qquad \text{dBW}$$

Table I shows values of this factor for various types of terrestrial stations.

The co-ordination contour is associated with a (maximum) sensitivity factor S and may be labelled with its value. In addition, however, it is useful to trace auxiliary contours for which the sensitivity factor S is 5, 10, 15, 20 dB, etc., lower than the factor corresponding to the co-ordination contour. These auxiliary contours may be used to eliminate, without recourse to more precise calculations, certain existing or planned stations located within the co-ordination area from further consideration.

2.3.3 *Interference from a terrestrial station into an earth station: equivalent isotropically radiated power*

From equation (2) one may, likewise, isolate the terms $P_{t'} + G_{t'}$ and define the equivalent isotropically radiated power E' (in dBW) of the interfering terrestrial stations:

$$E' = P_{t'} + G_{t'} \qquad \text{dBW}$$

values for which are listed in Table II.

In addition to the co-ordination contour determined for and labelled with the maximum value for E', it is useful to trace auxiliary contours for which the values E' are 5, 10, 15, 20 dB, etc., lower than the value corresponding to the co-ordination contour. These auxiliary contours facilitate elimination of certain terrestrial stations from further consideration.

2.3.4 *Examples*

– determine the minimum permissible transmission loss and the minimum permissible basic transmission loss in the case of interference from an earth station, operating with a geostationary satellite, into a terrestrial station, operating at 6 GHz, both stations using angle modulation.

Using Table I: $P_r(0.005\%) = -131$ dBW
$S = 176$ dBW

so that, with equation (1):

$$L(p) = L(0.005\%) = P_{t'} + 131 \quad \text{dB}$$

and, with equation (2):

$$\begin{aligned} L_b(p) = L_b(0.005\%) &= P_{t'} + G_{t'} + G_r - P_r(0.005\%) && \text{dB} \\ &= P_{t'} + G_{t'} + S && \text{dB} \\ &= P_{t'} + G_{t'} + 176 && \text{dB} \end{aligned}$$

– determine the minimum permissible transmission loss and the minimum permissible basic transmission loss in the case of interference from a terrestrial station into an earth station operating with a geostationary satellite, at 4 GHz, both stations using angle modulation.

Using Table II: $P_r(0.01\%) = 10 \log T_e - 164$ dB
$E' = 55$ dBW
$G_{t'}$ (assumed) $= 42$ dB, thus $P_{t'} = 13$ dBW

so that, with equation (1):

$$\begin{aligned} L(p) = L(0.01\%) &= 13 - 10 \log T_e + 164 && \text{dB} \\ &= 177 - 10 \log T_e && \text{dB} \end{aligned}$$

and with equation (2):

$$\begin{aligned} L_b(p) = L_b(0.01\%) &= P_{t'} + G_{t'} + G_r - P_r(0.01\%) && \text{dB} \\ &= E' + G_r - 10 \log T_e + 164 && \text{dB} \\ &= G_r - 10 \log T_e + 219 && \text{dB} \end{aligned}$$

under the assumption that the interference power in a voice channel may be 1000 pWp when the thermal noise power is 7000 pWp ($J = -8.5$ dB, see Note 2 above), and the radio-frequency bandwidth is 1 MHz.

2.3.5 *Additional forms of auxiliary contours*

The auxiliary contours described in § 2.3.2 and 2.3.3 may also be labelled in terms of avoidance angles, as discussed in Annex I of Report 448.

2.3.6 *Co-ordination parameters for earth stations receiving very narrow-band transmissions*

2.3.6.1 *General*

In the case of an earth station which receives both broadband and very narrowband transmissions (e.g. single channel per carrier, SCPC, transmissions) it may be desirable to determine two separate co-ordination contours: one for the narrow-band transmissions and one for the broad-band transmissions, indicating the specific frequency bands used for the very narrow-band transmissions. The requirement for co-ordination of narrow-band transmissions may result in larger co-ordination distances. Further study is required to establish appropriate values for the parameters J, p, $M(p)$, W, etc. One administration has proposed a calculation method of such parameters [CCIR, 1978-82a].

2.3.6.2 *Pre-assigned narrow-band transmissions*

For such transmissions, it is appropriate to change the value of the reference bandwidth to the value of the radio-frequency bandwidth occupied by one such narrow-band transmission.

2.3.6.3 *Demand-assigned narrow-band transmissions*

For such transmissions, in addition, it may be appropriate to take into account the reduced probability that a particular frequency channel will be suffering interference at the time when it is actually selected ("demanded") for use at an earth station.

3. Determination of co-ordination distance for propagation mode (1) – great circle propagation mechanisms *

3.1 *Radio-climatic zones*

In the calculation of co-ordination distance for propagation mode (1), the world is divided into four basic radio-climatic zones. These zones are defined as follows:

- Zone A1: coastal land and shore areas, i.e. land adjacent to a Zone B or Zone C area (see below), up to an altitude of 100 m ** relative to mean sea or water level, but limited to a maximum distance of 50 km from the nearest Zone B or Zone C area as the case may be;
- Zone A2: all land, other than coastal land and shore defined as Zone A1 above;
- Zone B: "cold" seas, oceans and other large bodies of water (i.e. covering a circle at least 100 km in diameter) situated at latitudes above 30°, with the exception of the Mediterranean and the Black Sea;
- Zone C: "warm" seas, oceans and other large bodies of water (i.e. covering a circle at least 100 km in diameter) situated at latitudes below 30°, as well as the Mediterranean and the Black Sea.

3.2 *Calculation of co-ordination distance for paths within a single radio-climatic zone*

The co-ordination distance for propagation mode (1) is determined by comparing the minimum permissible basic transmission loss (see § 2.2) between an earth station and a hypothetical terrestrial station with a predicted distance-dependent available basic transmission loss. The distance found by equating the values of minimum permissible and predicted available basic transmission loss is the co-ordination distance.

The following material is presented in two forms. In § 3.2.1 the basic equations are presented by means of which the co-ordination distance may be calculated numerically. In § 3.2.2 a graphical method to determine co-ordination distance is set forth.

3.2.1 *Numerical method*

The predicted available basic transmission loss is given by:

$$L_b(p_x) = 120 + 20 \log f + d(0.01 + \beta_o + \beta_v + \beta_z) + A_h \qquad \text{dB} \tag{6}$$

where:

f: frequency range of interest (GHz),

p_x: percentage of time (%),

β_o: absorption coefficient for oxygen (dB/km),

β_v: absorption coefficient for water vapour (dB/km).

The term β_z is a path attenuation coefficient which depends on the radio-climatic zone, the frequency and percentage of the time:

- for Zone A1: $\beta_{zA1} = [0.109 + 0.100 \log(f - 0.1)]p_x^{0.16}$ dB/km (7a)
- for Zone A2: $\beta_{zA2} = [0.146 + 0.148 \log(f - 0.15)]p_x^{0.12}$ dB/km (7b)
- for Zone B: $\beta_{zB} = [0.05 + 0.096 \log(f + 0.25)]p_x^{0.19}$ dB/km (7c)
- for Zone C: $\beta_{zC} = [0.04 + 0.078 \log(f + 0.25)]p_x^{0.16}$ dB/km (7d)

---

* An alternative method for further study is described in Appendix I.

** In the absence of precise information on the 100 m contour, an approximation (e.g. 300 feet or 91.2 m) may be used. If no suitable contour is available, the 50 km distance limit from the coast line or shore line is applicable.

The absorption coefficient for oxygen depends on frequency:

$$\beta_o = \left[0.00719 + \frac{6.09}{f^2 + 0.227} + \frac{4.81}{(f - 57)^2 + 1.50}\right] f^2/10^3 \qquad \text{dB/km} \tag{8}$$

The absorption coefficient for water vapour is a function of frequency and water vapour density ρ:

$$\beta_v = \left[6.73 + \frac{300}{(f - 22.3)^2 + 7.3}\right] \rho f^2/10^6 \qquad \text{dB/km} \tag{9}$$

where ρ is the water vapour density (g/m^3) and depends on the radio-climatic zone. The following values should be used for ρ:

- for Zone A1: $\rho = 7.5$ g/m^3;
- for Zone A2: $\rho = 5$ g/m^3;
- for Zone B: $\rho = 7.5$ g/m^3;
- for Zone C: $\rho = 10$ g/m^3.

The term A_h in equation (6) is a correction for the earth-station horizon elevation angle θ*. It can be calculated from:

$$A_h = 20 \log [1 + 4.5\, \theta f^{0.5}] + \theta f^{0.33} \text{ dB for } \theta \geqslant 0° \tag{10a}$$

$$= 0 \text{ dB} \qquad \text{for } \theta < 0° \tag{10b}$$

The maximum value for A_h is 30 dB; the use of larger values may not result in sufficient protection.

The minimum permissible basic transmission loss is given in the form of a cumulative distribution with time, defined for $p \leqslant p_x \leqslant 20\%$, as follows:

$$L_m(p_x) = P_{t'} + G_e + 42 + \Delta G - P_r(p) + M(p)\left[1 - \frac{(9 - 5 \log p_x)^{0,5} - 1,58}{(9 - 5 \log p)^{0,5} - 1,58}\right] \qquad \text{dB} \tag{11}$$

where:

G_e: earth-station horizon antenna gain (dBi);

ΔG: difference (in dB) between the maximum antenna gain assumed for the terrestrial station and the value of 42 dB. Tables I and II, respectively, give values for ΔG in various frequency regions.

All other parameters in equation (11) are as previously defined. Note that the percentage of time p_x is the independent variable; the percentage p is that associated with the short-term interference criterion.

To determine the co-ordination distance, the right-hand sides of equations (6) and (11) are set equal, and the distance d is calculated for all time percentages between p and 20%. The largest distance so found is the co-ordination distance d_1 on the azimuth of interest.

* The horizon angle θ is defined here as the angle, viewed from the centre of the earth-station antenna, between the horizontal plane and a ray that grazes the visible physical horizon in the direction concerned.

In most real cases, d_1 will be found for $p_x = p$. To verify this, it is useful to determine d initially only for $p_x = p$ and $p_x = 10p$. When $d(p_x = p) > d(p_x = 10p)$, then $d(p_x = p)$ is d_1, i.e., only the short-term criteria percentage is of concern. In that case it is not necessary to determine d for all percentages p_x. Note that for $p_x = p$ the value of the square brackets in equation (11) is zero.

The above calculations lead to d_1 when the entire hypothetical interference path lies in only a single radio-climatic zone. For the calculation of d_1 along a mixed-zone path, see § 3.3.

3.2.2 *Graphical method*

It may be convenient for users to avail themselves of a graphical method to determine d_1. However, equation (6), which is the basis for the graphical method, contains five variables: $L_b(p_x)$, p_x, f, θ and d, each spanning a range of values. There is a sixth variable: the radio-climatic zone which, however, poses no problem. It is most practical to remove the earth-station horizon angle θ and make it subject to a separate step in the determination of d_1.

To that end, equation (6) is reformulated to yield what is called the basic co-ordination loss $L_1(p_x)$:

$$L_1(p_x) = L_b(p_x) - A_h = 120 + 20 \log f + d(0.01 + \beta_o + \beta_v + \beta_z) \qquad \text{dB} \qquad (12)$$

Figures 2 to 11 have been drawn to show the relationhsip between $L_1(p_x)$, p_x and d_1 for the four radio-climatic zones, each figure dealing with a single frequency. On each figure, four abscissa scales have been provided, representing the four radio-climatic zones.

Figure 1 shows the horizon angle correction A_h as a function of horizon angle θ and frequency.

To determine the co-ordination distance, proceed as follows:

– Plot the basic co-ordination loss, obtained as the difference

$$L_1(p_x) = L_m(p_x) - A_h \qquad \text{dB} \qquad (13)$$

from equations (10) and (11)*, for all percentages of the time between p and 1% on the appropriate figure among Figs. 2 to 11, using the appropriate abscissa scale. This results in a curve which starts above the value p (the percentage of the time associated with the short-term interference criterion) and slants downwards towards the right.

– Find, among the existing curves on the figure, the one which lies entirely below the just-constructed curve segment but touches it at one point. The distance with which this curve is marked is the co-ordination distance d_1. When none of the existing curves touches the newly-constructed curve segment, estimate by interpolation the distance of a curve which would touch the constructed curve segment at one point but would otherwise lie entirely below it. This distance is the co-ordination distance d_1.

Note. – It is generally found that the point at which the two curves touch is the point corresponding to the small percentage of time p. To test whether this is in fact the case, it is not necessary to construct the entire distribution $L_1(p_x)$ but merely two points of it at p and at $10p$. When the distance d for the point at p is greater than the distance found for the point at $10p$, then point at p produces the co-ordination distances d_1, and no other values of p_x need be investigated.

3.3 *Mixed paths*

If the distance being calculated extends through more than one radio-climatic zone (mixed path), the prediction is made as follows:

Designating the successive path sections in different zones by use of the suffixes i, j, k..., it follows that:

$$L_b(p) - A_0 - A_h = \beta_i d_i \qquad \text{dB} \qquad (14)$$

where β_i is the rate of attenuation in the first zone.

* Or from Fig. 1 in the case of A_h.

Now, in the direction considered, if the value d_i is greater than the actual distance D_i in the first zone, it follows that:

$$L_b(p) - A_0 - A_h - \beta_i D_i = \beta_j d_j \qquad \text{dB} \tag{15}$$

and so d_j is found. If the value d_j is greater than the distance D_j of the path in the second zone, it can then be stated that:

$$L_b(p) - A_0 - A_h - \beta_i D_i - \beta_j D_j = \beta_k d_k \qquad \text{dB} \tag{16}$$

from which d_k may be found. This method may be extended as necessary, and in the case given, the total distance d_1 may now be expressed as:

$$d_1 = D_i + D_j + d_k \qquad \text{km} \tag{17}$$

Annex II provides examples for the graphical application of this procedure.

3.4 *Maximum co-ordination distance for propagation mode (1)*

The maximum co-ordination distance for propagation mode (1) shall be 1200 km.

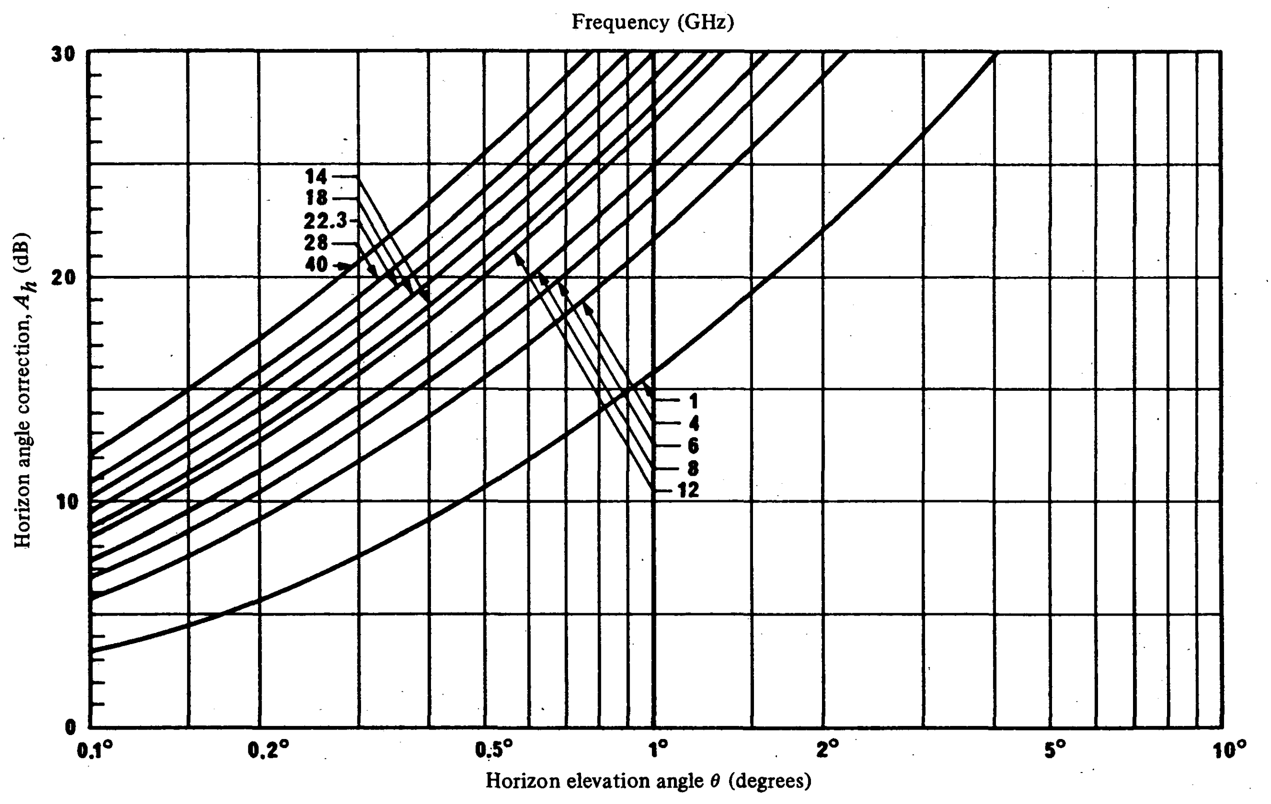


FIGURE 1 – *Horizon angle correction A_h as a function of horizon angle and frequency*

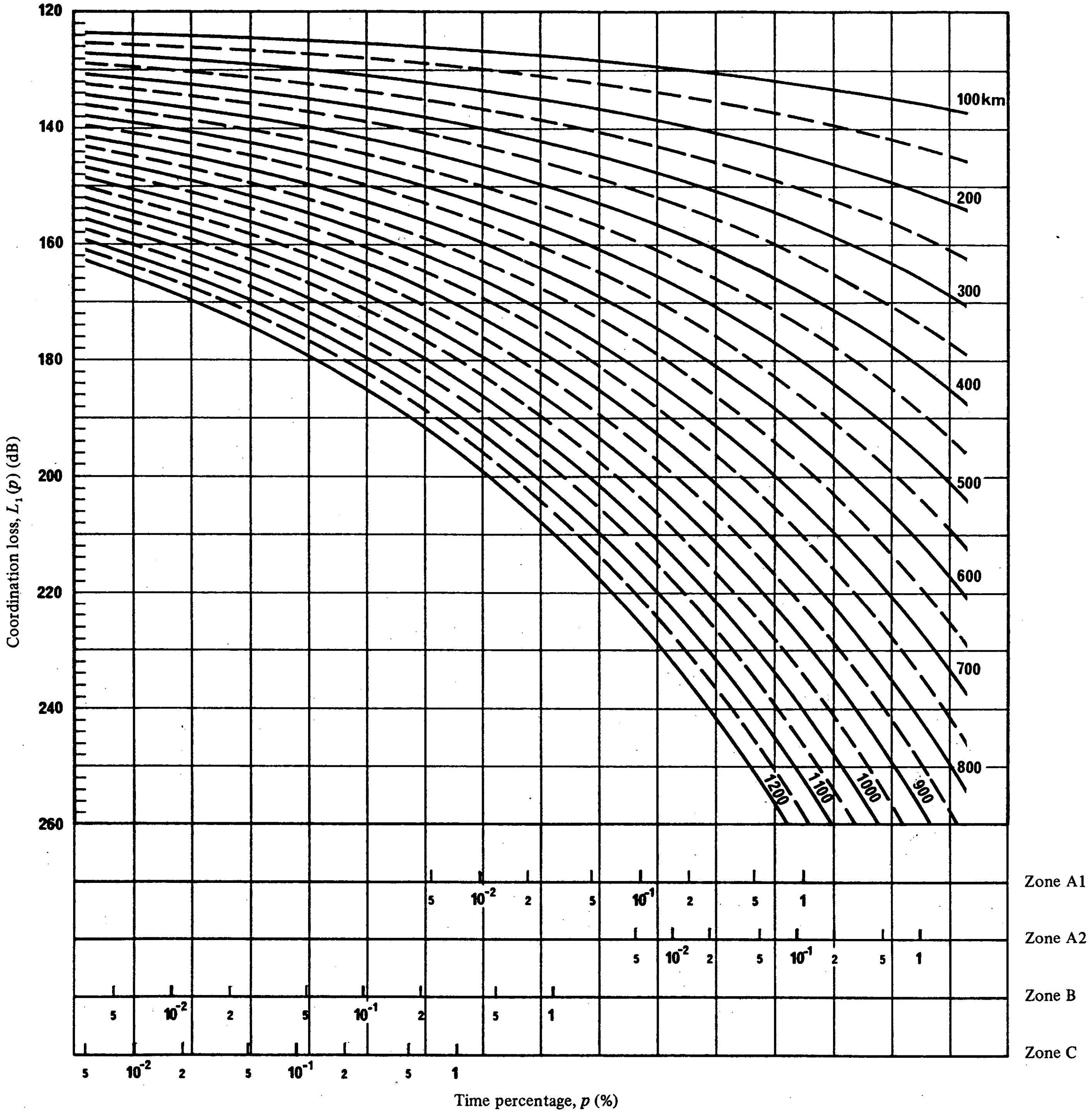


FIGURE 2 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 1 GHz*

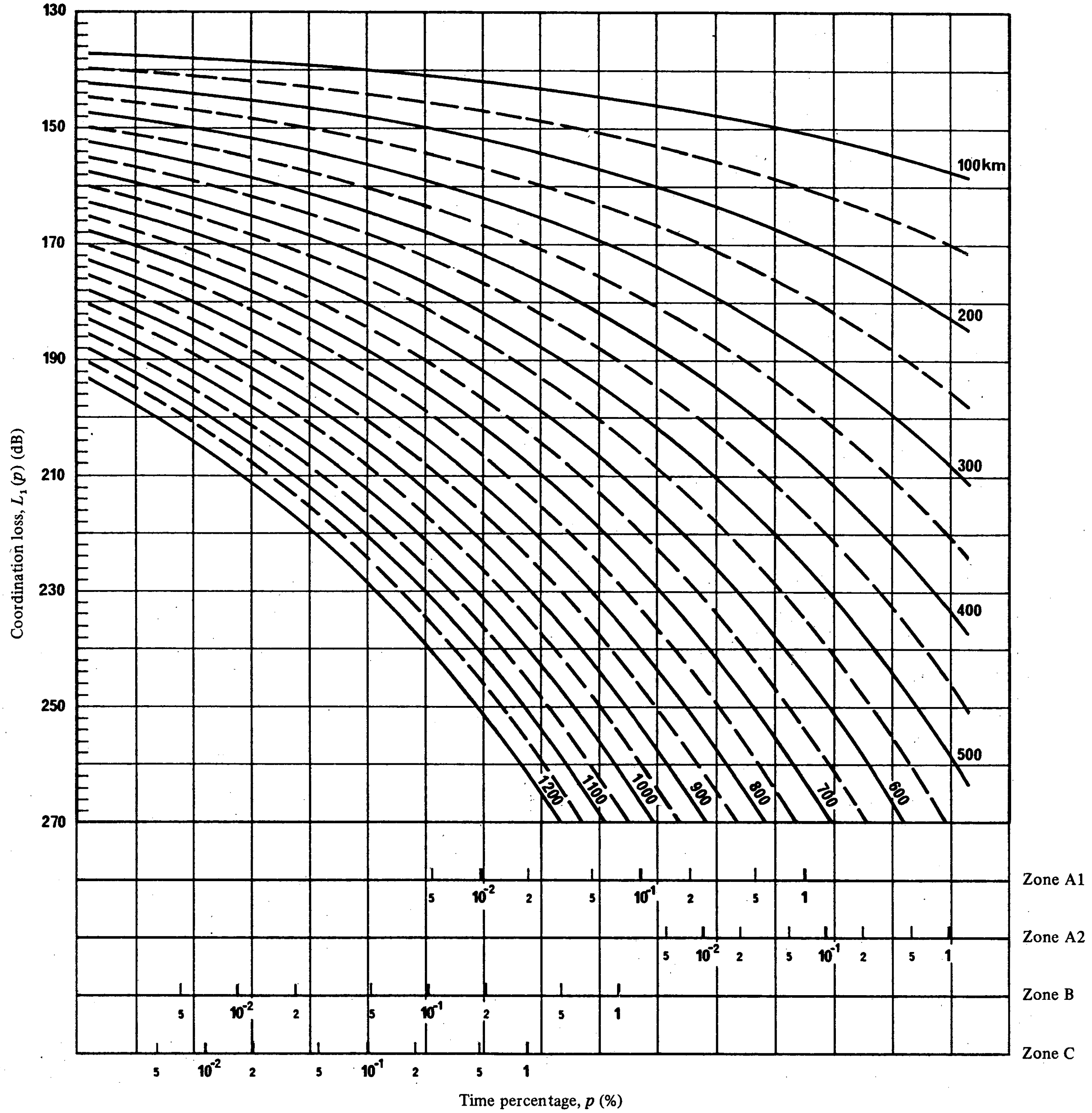


FIGURE 3 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 4 GHz*

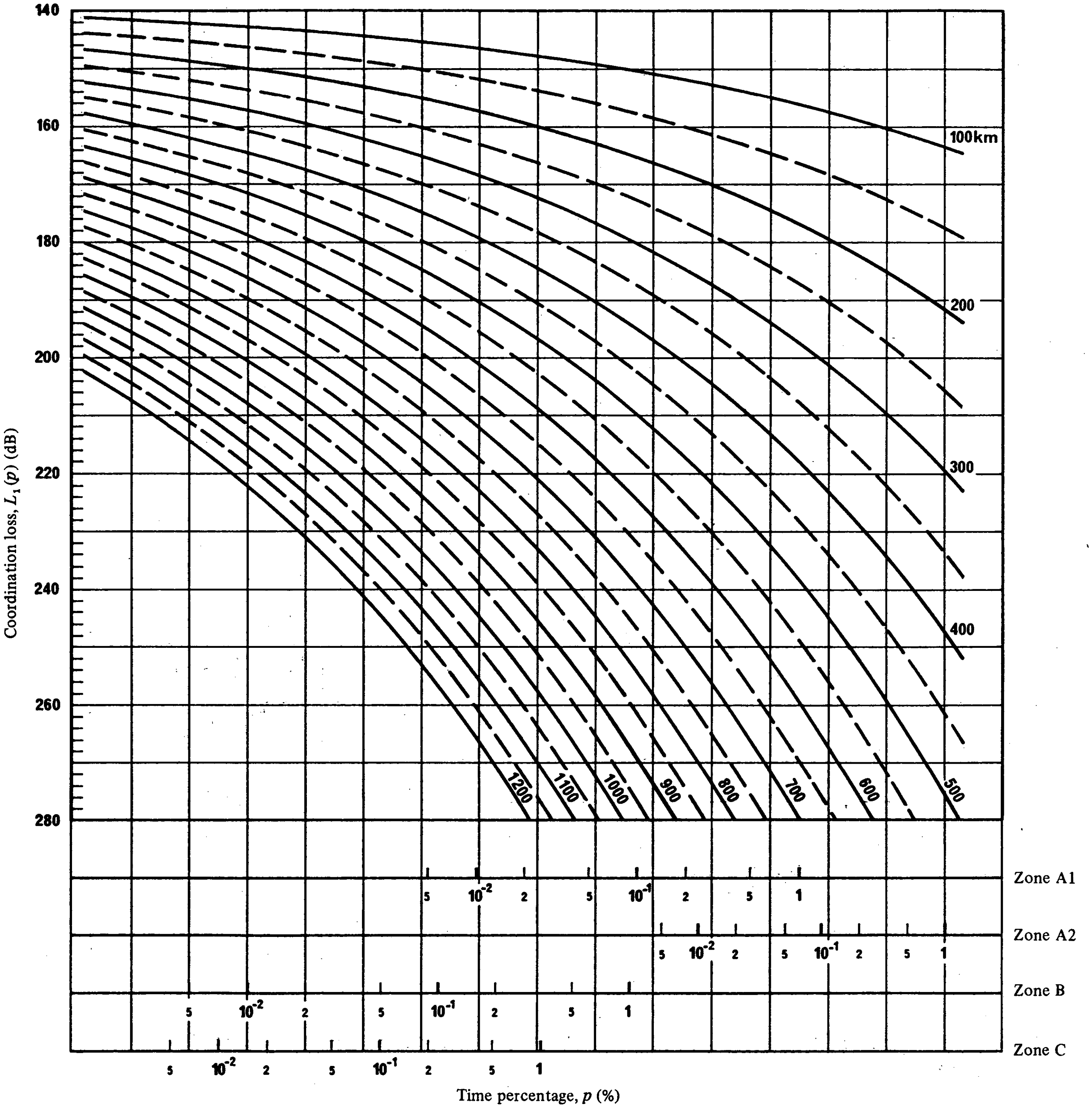


FIGURE 4 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 6 GHz*

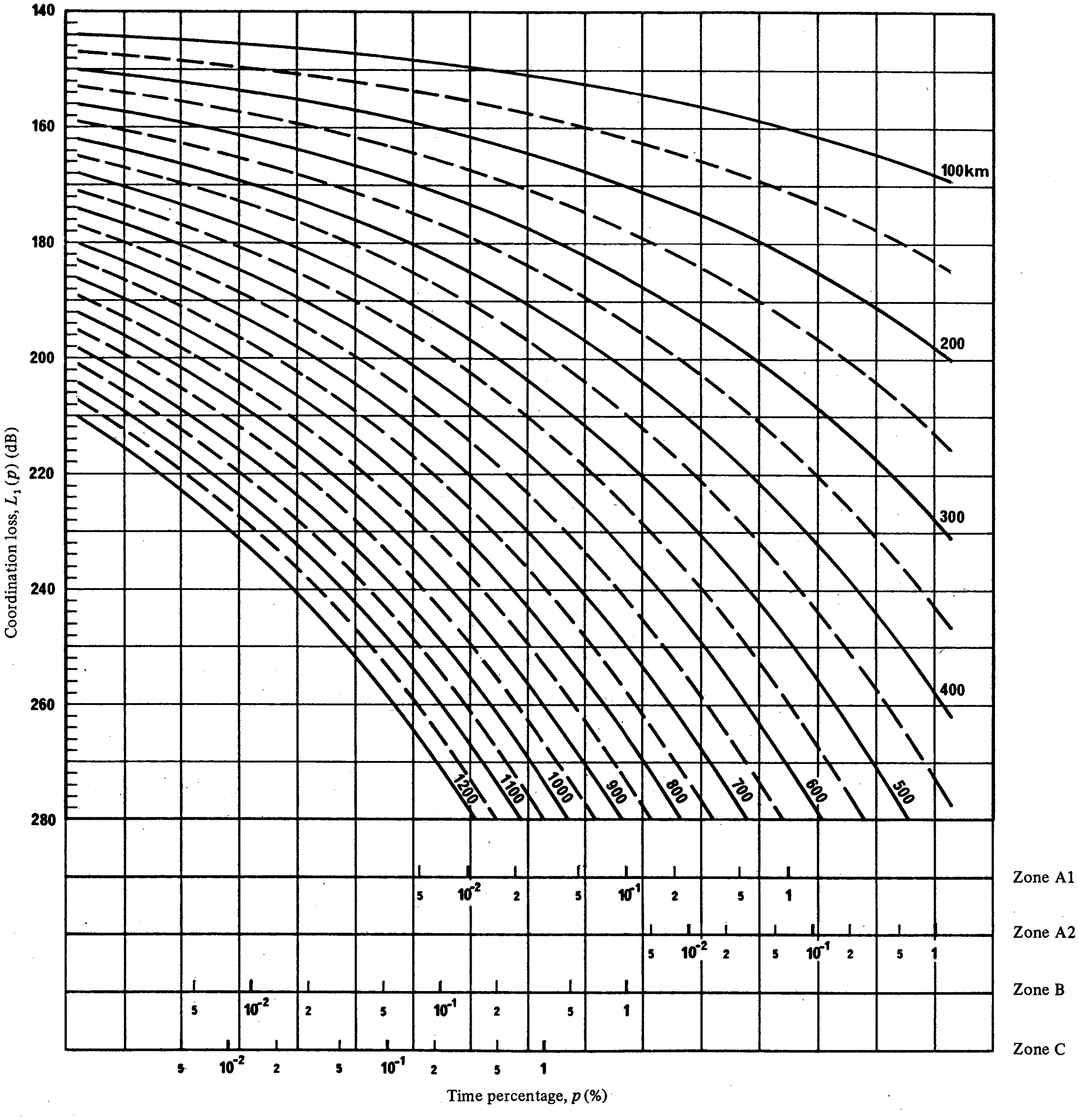


FIGURE 5 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 8 GHz*

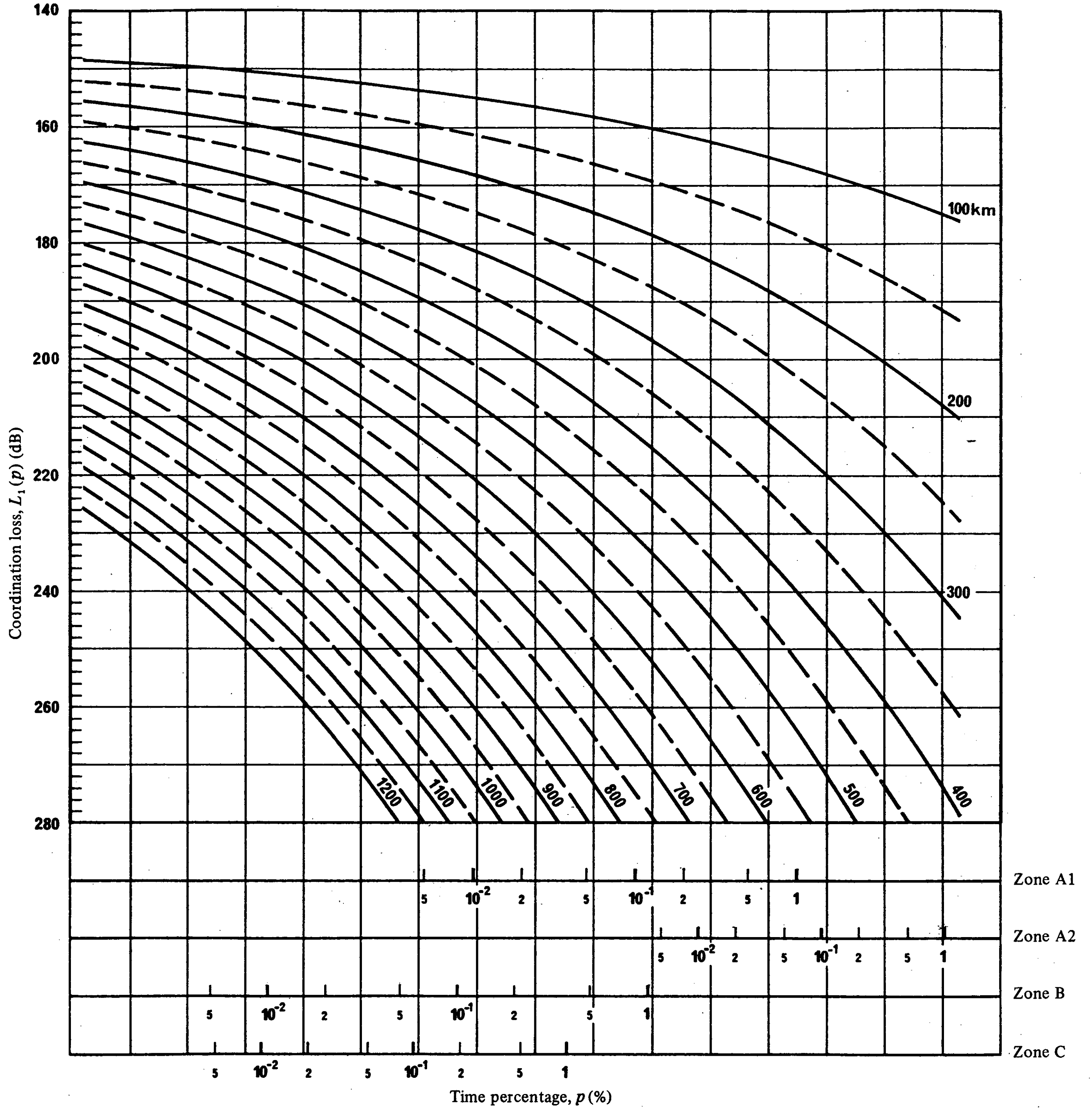


FIGURE 6 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 12 GHz*

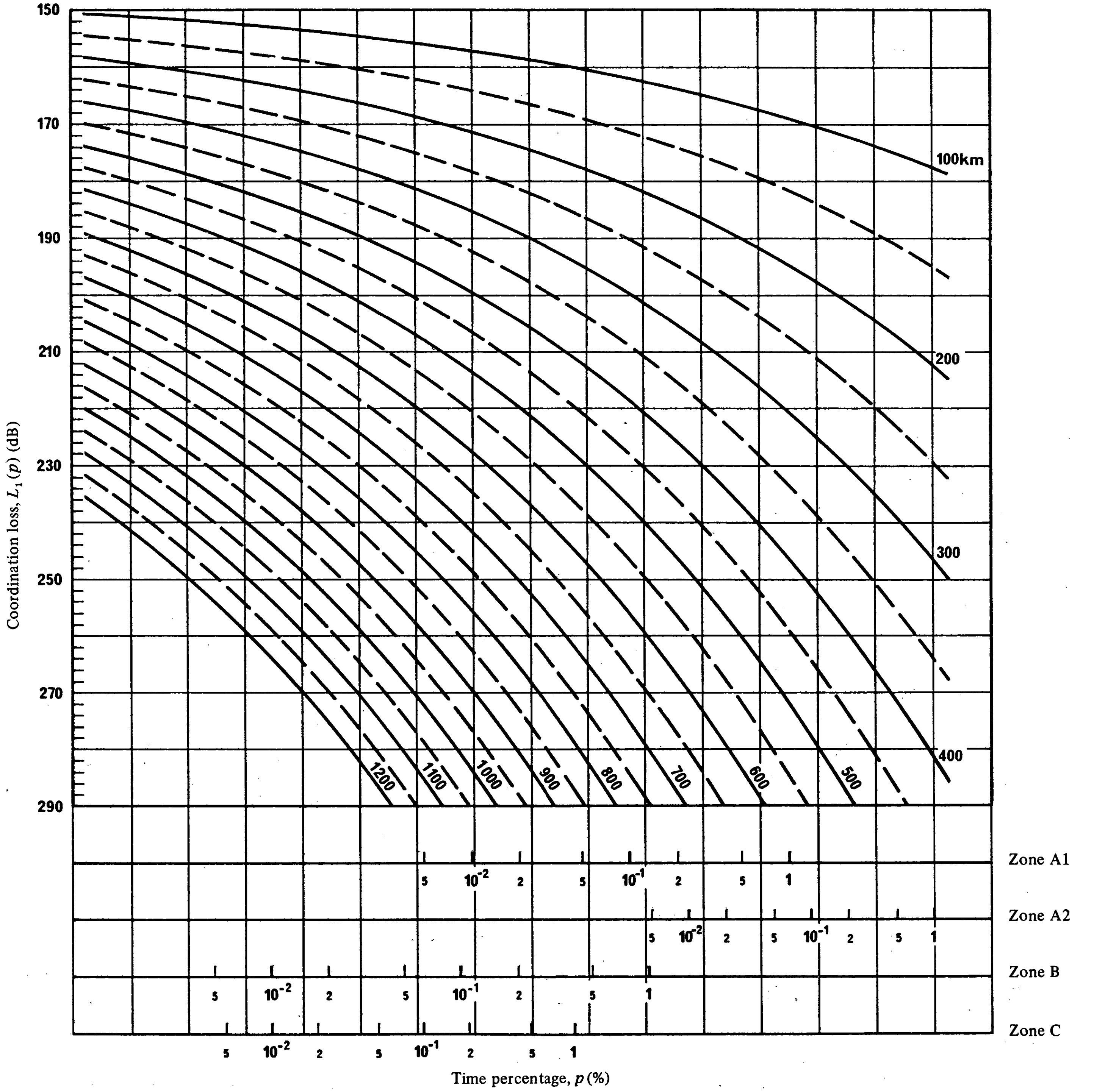


FIGURE 7 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 14 GHz*

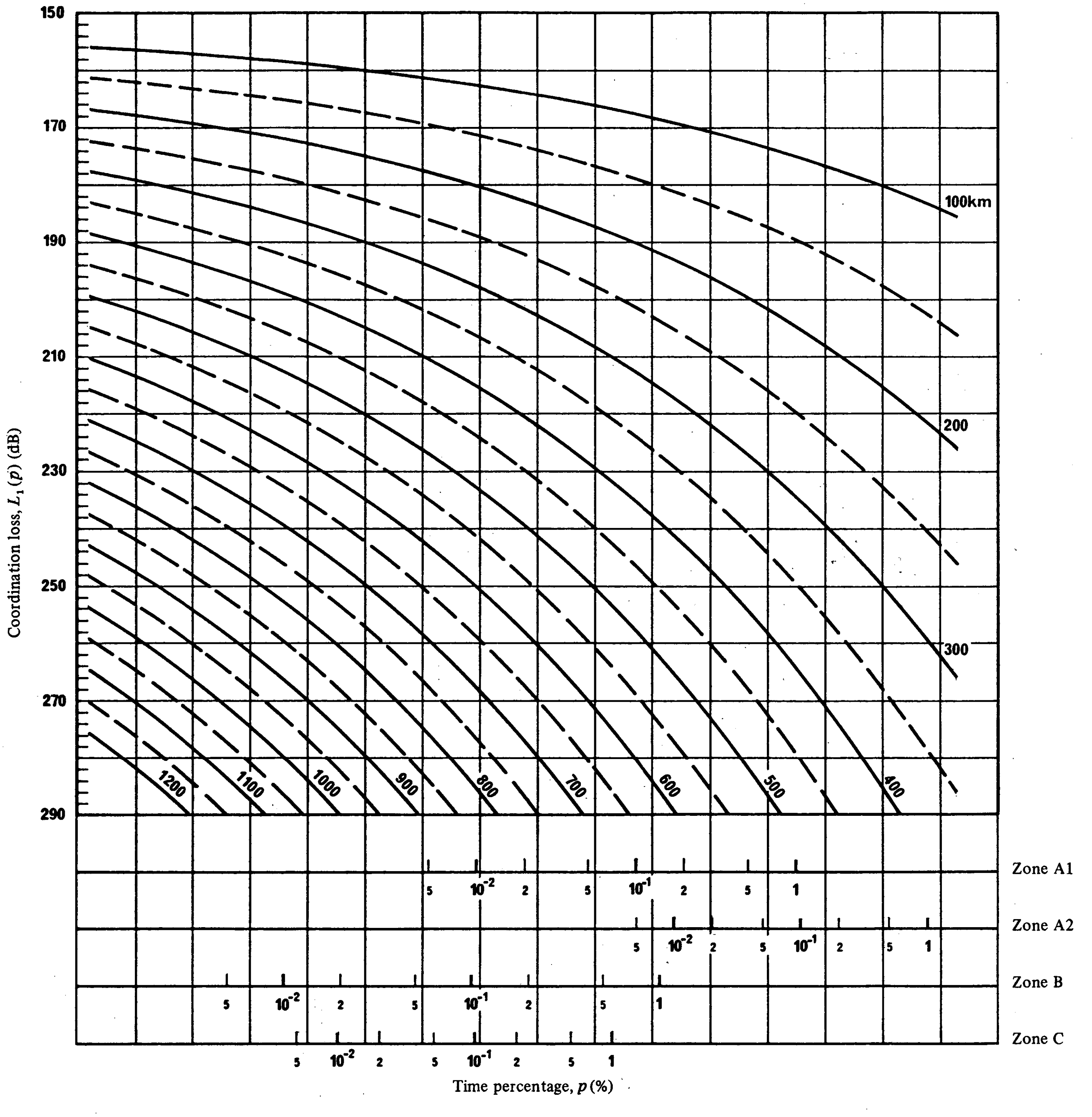


FIGURE 8 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 18 GHz*

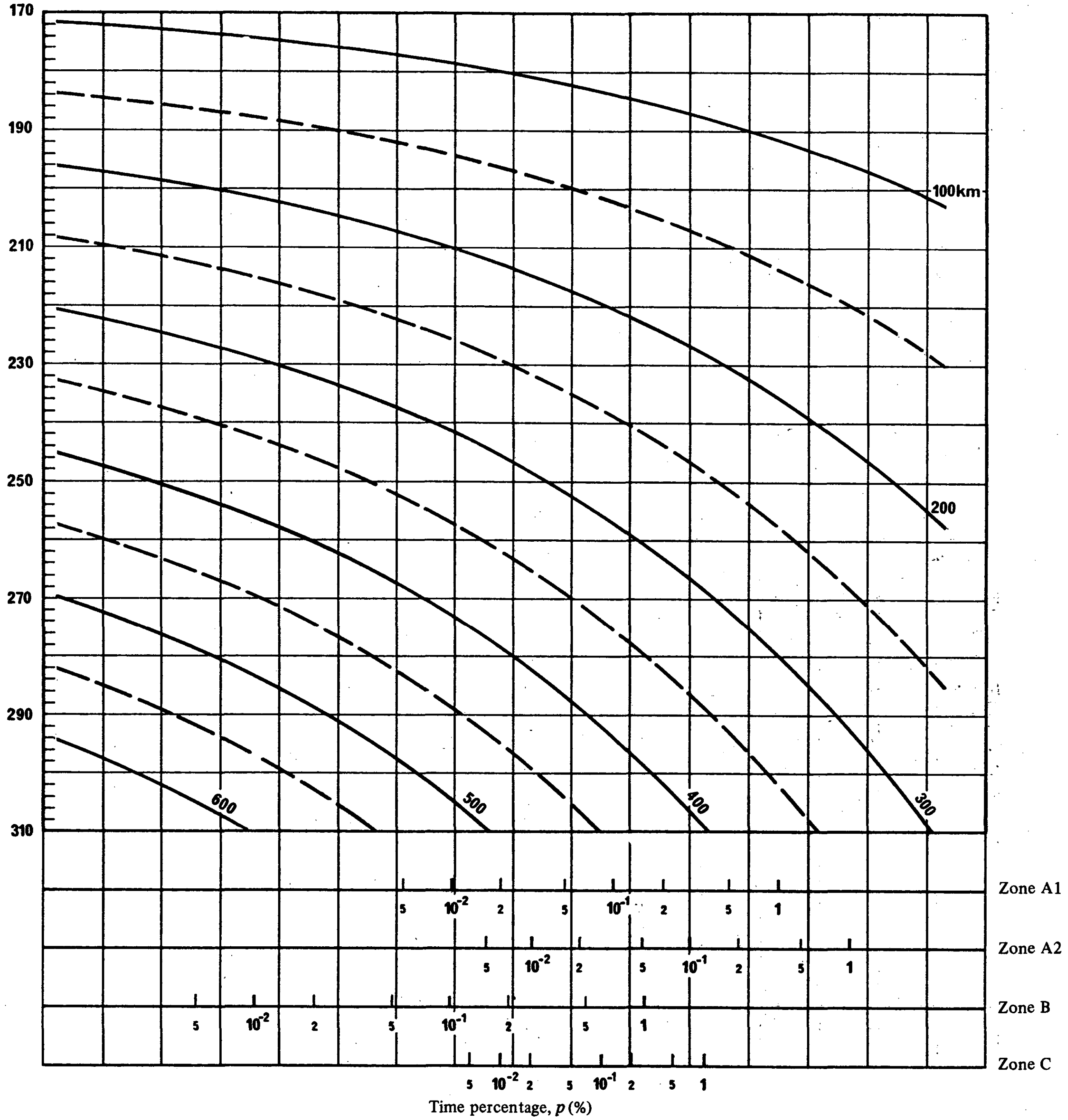


FIGURE 9 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 22.3 GHz*

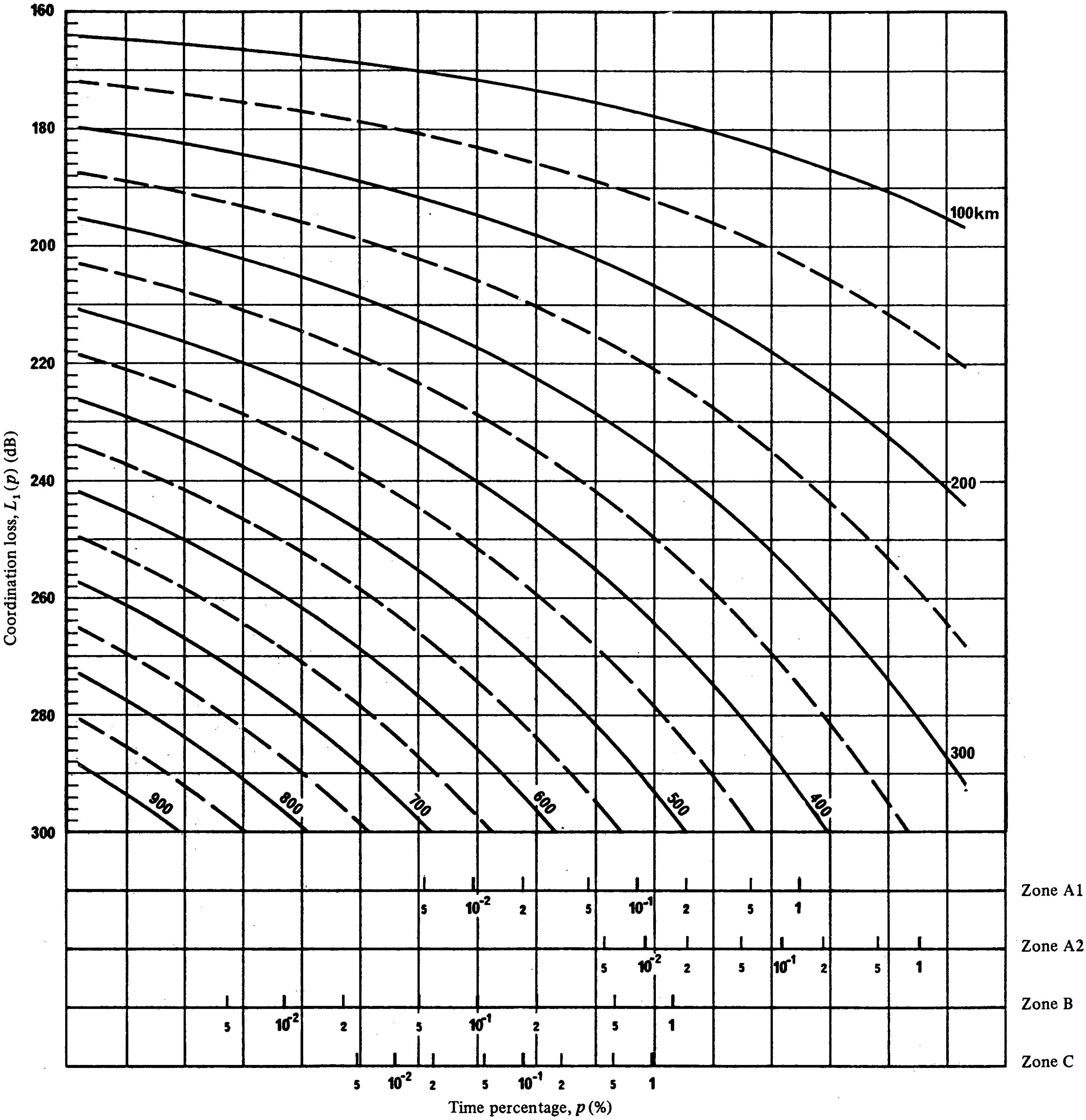


FIGURE 10 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 28 GHz*

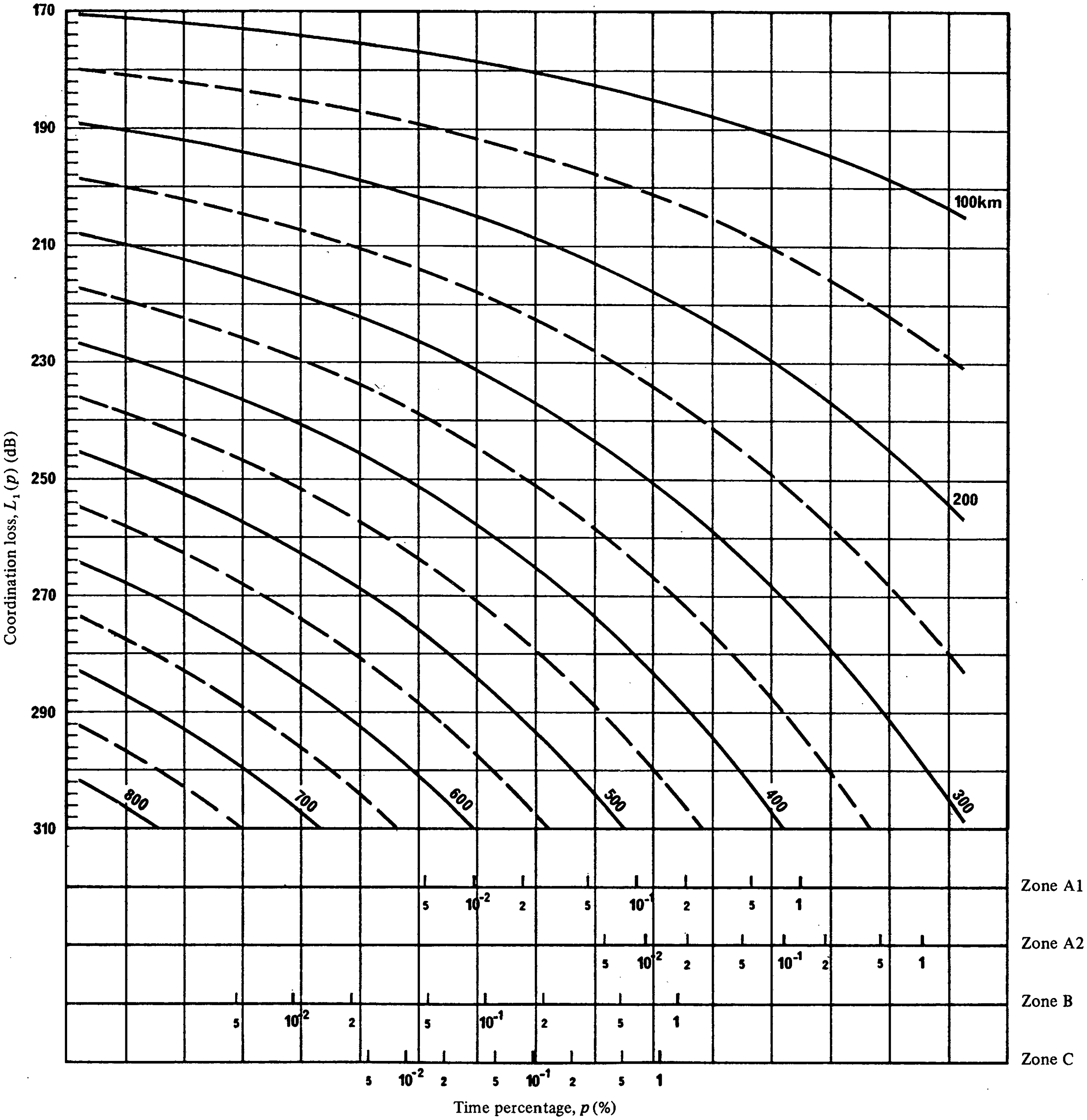


FIGURE 11 – *Coordination loss as a function of time percentage, p, for isopleths of distance; f = 40 GHz*

4. Determination of co-ordination contour for propagation mode (2) scattering from hydrometeors

The determination of co-ordination contour for scattering from hydrometeors (rain scatter) is predicated on a path geometry which is substantially different from that of the great circle propagation mechanisms. As a first approximation, energy is scattered isotropically by rain, so that interference may result for large scattering angles, and for beam intersections away from the great circle path.

4.1 *The normalized transmission loss distribution, $L_2(p_x)$*

To determine the co-ordination contour associated with hydrometeor scatter it is necessary to determine a "normalized transmission loss distribution", which represents the cumulative distribution of the minimum necessary transmission loss, $L_2(p_x)$, for values of p_x between p and 20%. It is calculated from:

$$L_2(p_x) = P_{t'} + \Delta G - P_r(p) + M(p)\left[1 - \frac{(9 - 5 \log p_x)^{0.5} - 1.58}{(9 - 5 \log p)^{0.5} - 1.58}\right] \quad \text{dB} \qquad (18)$$

where:

$p \leqslant p_x) \leqslant 20\%$ (see § 2.3.1).

ΔG: difference (dB) between the maximum gain of terrestrial station antennas in the frequency band under investigation and the value of 42 dB. Values are tabulated in Table I for a transmitting earth station, in Table II for a receiving earth station

and all other parameters are as defined in § 2. For terrestrial stations, values of $P_{t'}$ are tabulated in Table II.

4.2 *Evaluation methods*

4.2.1 *General*

For this propagation mode the previous classification of the terrain into radio-climatic zones is no longer appropriate.

The material is presented in two forms. In § 4.2.2 the basic equations for the relationship between rainfall rate, transmission loss and rain scatter distance are given. The equations allow transmission loss to be expressed versus rainfall rate for any given distance, with the cumulative time distributions of rainfall rate in various "rain climatic zones" given in Annex III.

However, the user will find it easier to take advantage of a graphical method in which the cumulative distributions of rainfall rate for the various rain climatic zones of Annex III have been consolidated with the relationship between rainfall rate, transmission loss, and distance into cumulative distributions of transmission loss with distance as a parameter. This consolidation is reflected in the curve sets of Figs. 12 to 21.

4.2.2 *Numerical determination of transmission loss*

The transmission loss may be calculated as a function of distance r (km)*, frequency f (GHz) and surface rainfall rate R (mm/h) from:

$$\begin{aligned} L = {} & 168 + 20 \log r - 20 \log f - 13.2 \log R - g_T + \\ & + 10 \log A_b - 10 \log C + \Gamma + \beta_o d_o + \beta_v d_v \quad \text{dB} \end{aligned} \qquad (19)$$

where:

R: surface rainfall rate (mm/h), as given in Annex III for various rain climatic zones;

g_T: gain of the terrestrial station antenna (dB), assumed to be 42 dB;

A_b: is given by:

$$\begin{aligned} 10 \log A_b &= 0.005\,(f - 10)^{1.7} R^{0.4} \quad \text{dB} \quad \text{for } 10 \text{ GHz} \leqslant f < 40 \text{ GHz} \\ &= 0 \quad \text{dB} \quad \text{for } f < 10 \text{ GHz} \end{aligned} \qquad (20)$$

* r is the distance between the region of maximum scattering and the location of an eventual terrestrial station.

C is given by:

$$C = \frac{2{,}17}{\gamma_R d_s}\,(1 - 10^{-\gamma_R d_s/5}) \qquad \text{for } f > 4 \text{ GHz}$$
$$= 1 \qquad \text{for } f \leqslant 4 \text{ GHz} \tag{21}$$

γ_R is given by:

$$\gamma_R = kR^{\alpha} \qquad \text{dB} \tag{22}$$

Table III* gives values for k and α for vertical polarization (which yields minimum specific attenuation).

Further:

$$d_s = 3.5\ R^{-0.08} \qquad \text{km} \tag{23}$$

$$\Gamma = 631\ kR^{\alpha-0.5} \times 10^{-[(R+1)^{0.19}]} \qquad \text{dB} \tag{24}$$

$$d_o = 0.7\ r + 32 \text{ km} \qquad \text{for } r < 340 \text{ km}$$
$$= 270 \text{ km} \qquad \text{for } r \geqslant 340 \text{ km} \tag{25}$$

$$d_v = 0.7\ r + 32 \text{ km} \qquad \text{for } r < 240 \text{ km}$$
$$= 200 \text{ km} \qquad \text{for } r \geqslant 240 \text{ km} \tag{26}$$

The gaseous specific attenuation β_o (for oxygen) and β_v (for water vapour) are given in equations (8) and (9) above. The water vapour specific attenuation β_v is to be calculated for an assumed vapour concentration of $\rho = 5$ g/m^3.

Equation (19) allows the transmission loss L to be obtained as a function of the rainfall rate R, with the hydrometeor scatter distance r as a parameter. Using this relationship with the cumulative distribution of rain rate R as given for the rain climates A to P in Annex III, allows cumulative distributions of transmission loss to be derived for each rain climate and for each rain scatter distance.

4.2.3 *Graphical determination of transmission loss*

To facilitate the use of the propagation information in this Report, cumulative distributions of transmission loss have been developed for rain scatter distances between 100 km and 400 km, for five composite rain climates. Each of these five rain climates covers several of the actual rain climates as discussed in Annex III. The resulting cumulative distributions are shown in Figs.12 to 21 for the frequency bands as indicated.

4.2.4 *Determination of the hydrometeor scatter co-ordination contour*

The procedure to determine the hydrometeor scatter contour is as follows:

(a) Determine the transmission loss, using the graphical method (see § 4.2.3) or the numerical method (see § 4.2.2).

When using the graphical method plot, on the relevant figure (i.e., of Figs. 12 to 21) for the frequency of interest, the function $L_2(p_x)$ as obtained from equation (18), using the abscissa percentage scale appropriate for the rain climate in which the earth station is located, as obtained from Annex III.

If the frequency of interest is not covered by those in Figs. 12 to 21, the hydrometeor scatter co-ordination contour should be obtained by linear interpolation between the values of distance obtained for the two adjacent frequencies.

When using the numerical method, curves representing cumulative distributions of transmission loss with distance as a parameter must first be determined for the frequency and the rain climatic zone of interest. They are then used in the same manner as those of Figs. 12 to 21.

* Values of k and α at other frequencies than those in Table III can be obtained by interpolation using a logarithmic scale for frequency and k, and a linear scale for α.

TABLE III – *Values of k and α as a function of the frequency*

Frequency (GHz)	k	α
1	0,000 035 2	0.880
4	0.000 591	1.075
6	0.001 55	1.265
8	0.003 95	1.31
10	0.008 87	1.264
12	0.016 8	1.20
14	0.029	1.15
18	0.055	1.09
20	0.069 1	1.065
22.4	0.090	1.05
25	0.113	1.03
28	0.150	1.01
30	0.167	1.00
35	0.233	0.963
40	0.310	0.929

TABLE IV – *Maximum hydrometeor scatter distances (km)*

Latitude (degrees)	Maximum hydrometeor scatter distances (km)
0 to 30	350
30 to 40	360
40 to 50	340
50 to 60	310
> 60	280

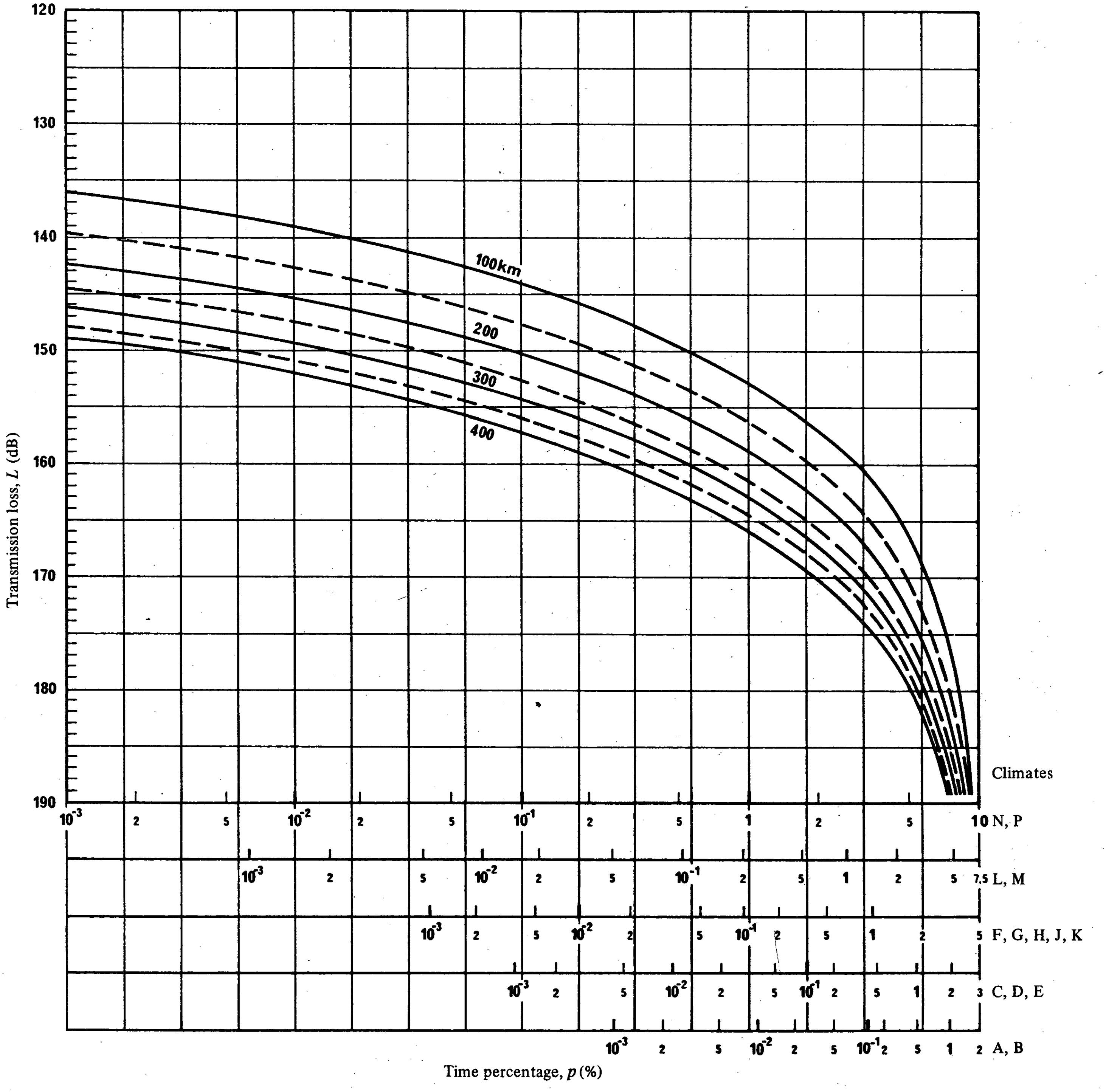


FIGURE 12 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 1 GHz*

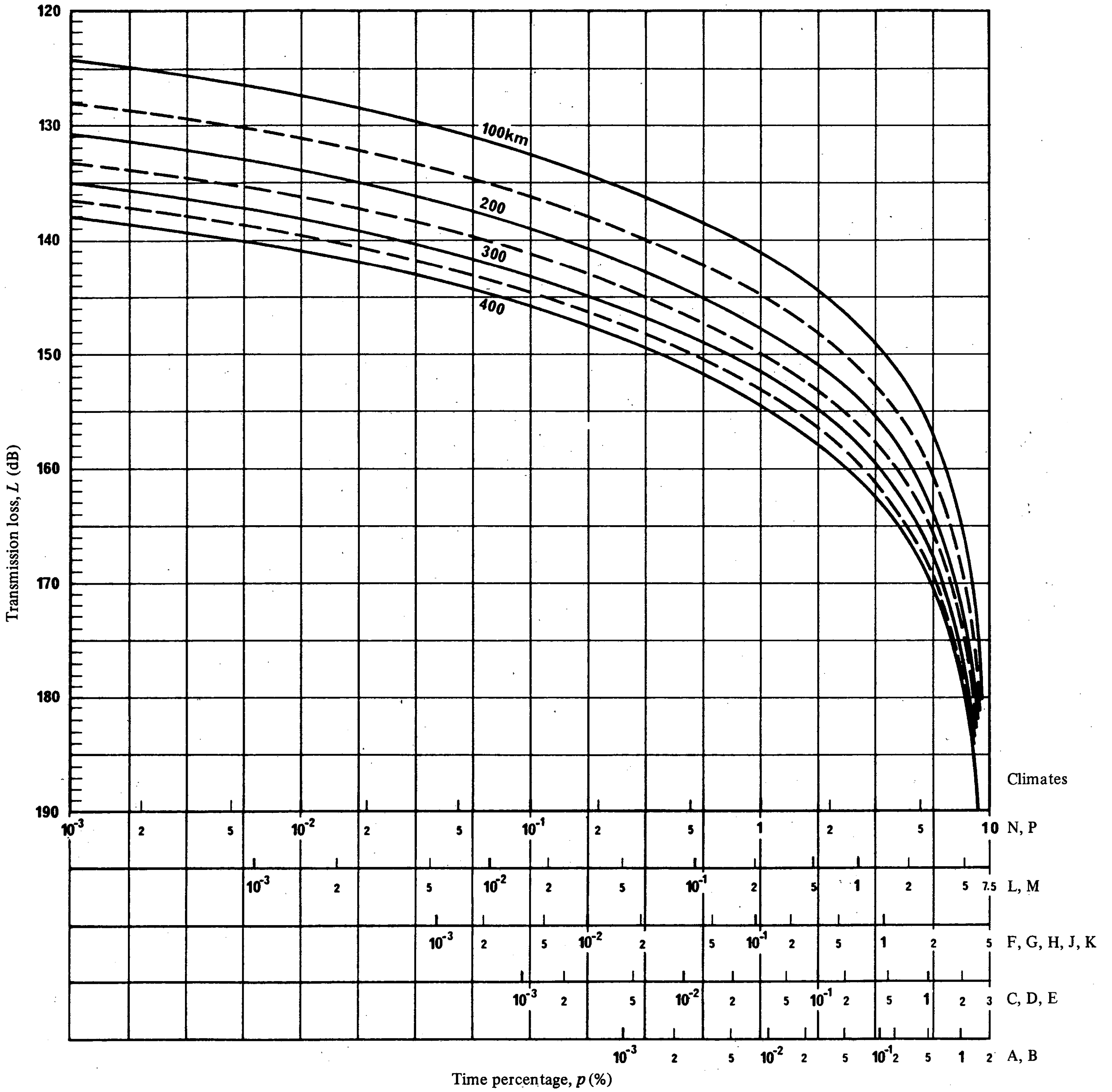


FIGURE 13 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 4 GHz*

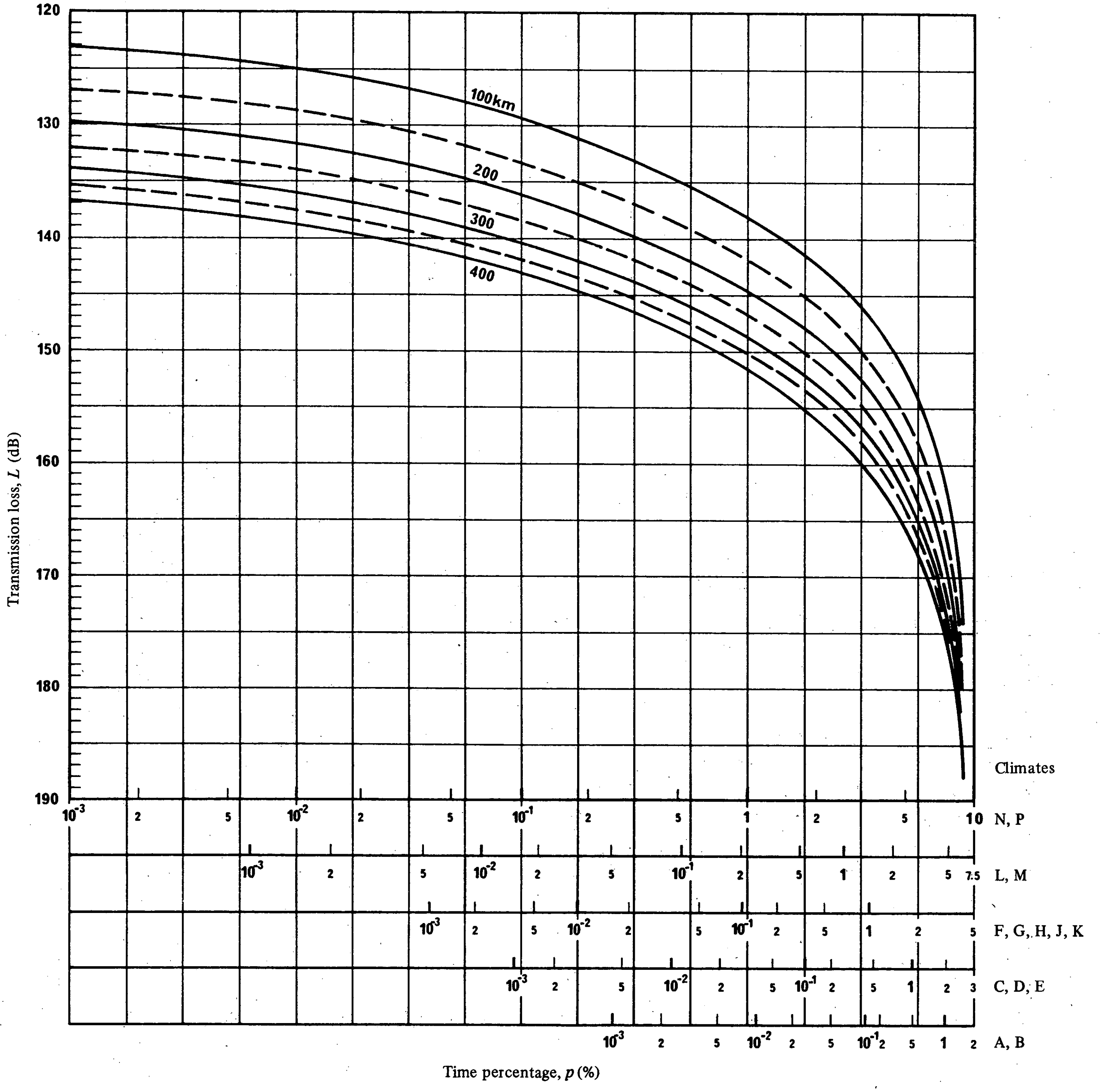


FIGURE 14 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 6 GHz*

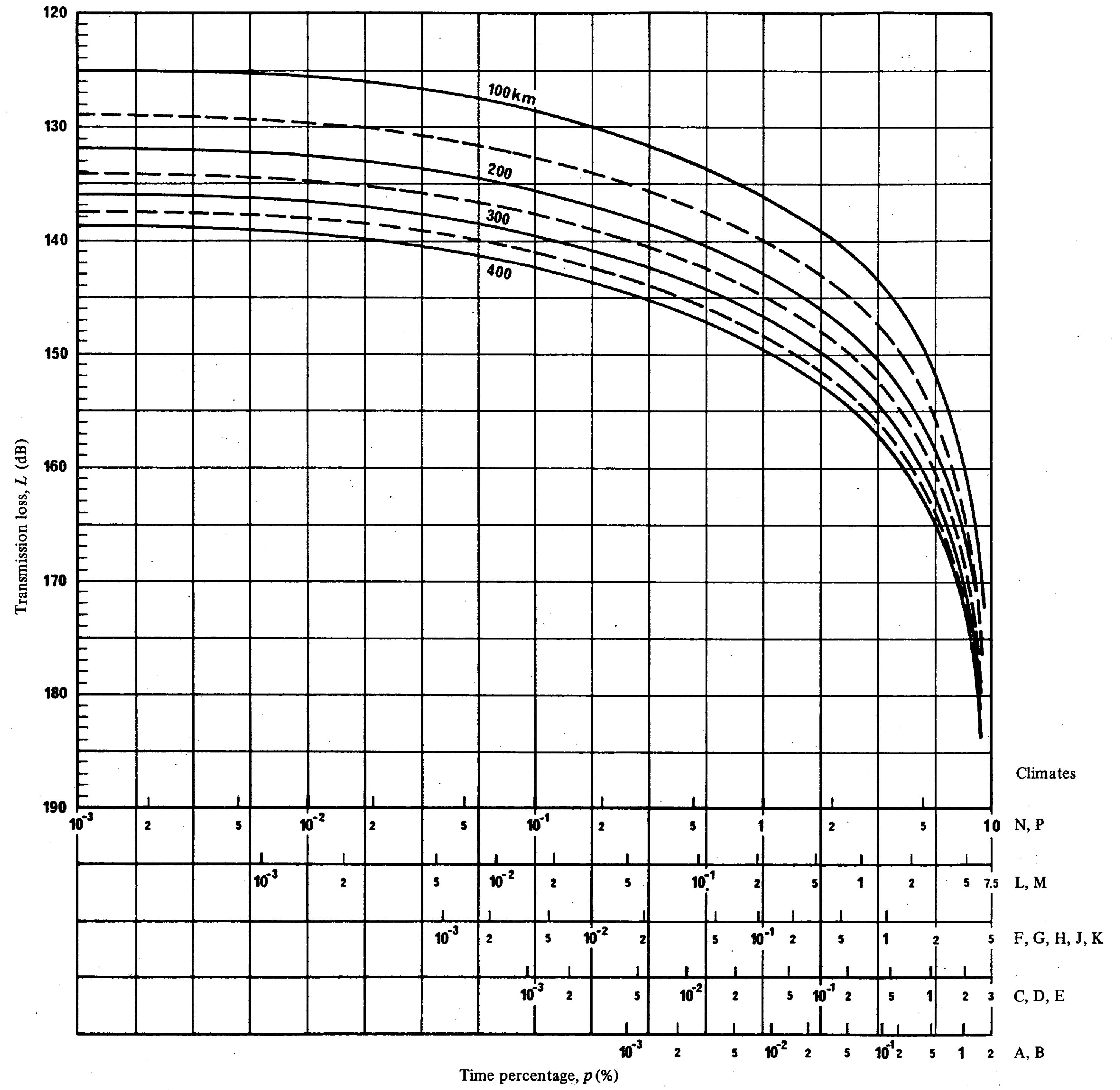


FIGURE 15 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 8 GHz*

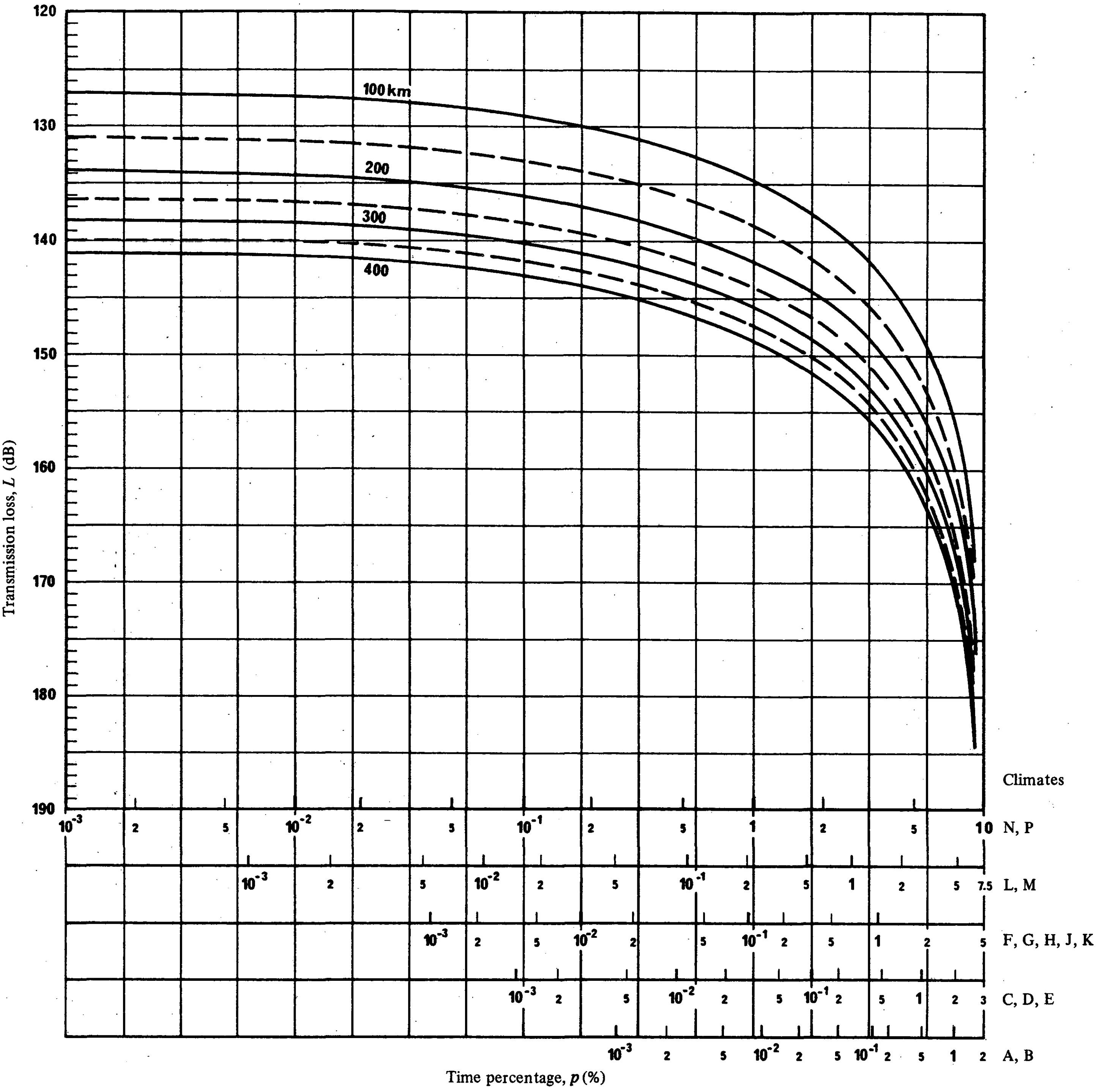


FIGURE 16 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 12 GHz*

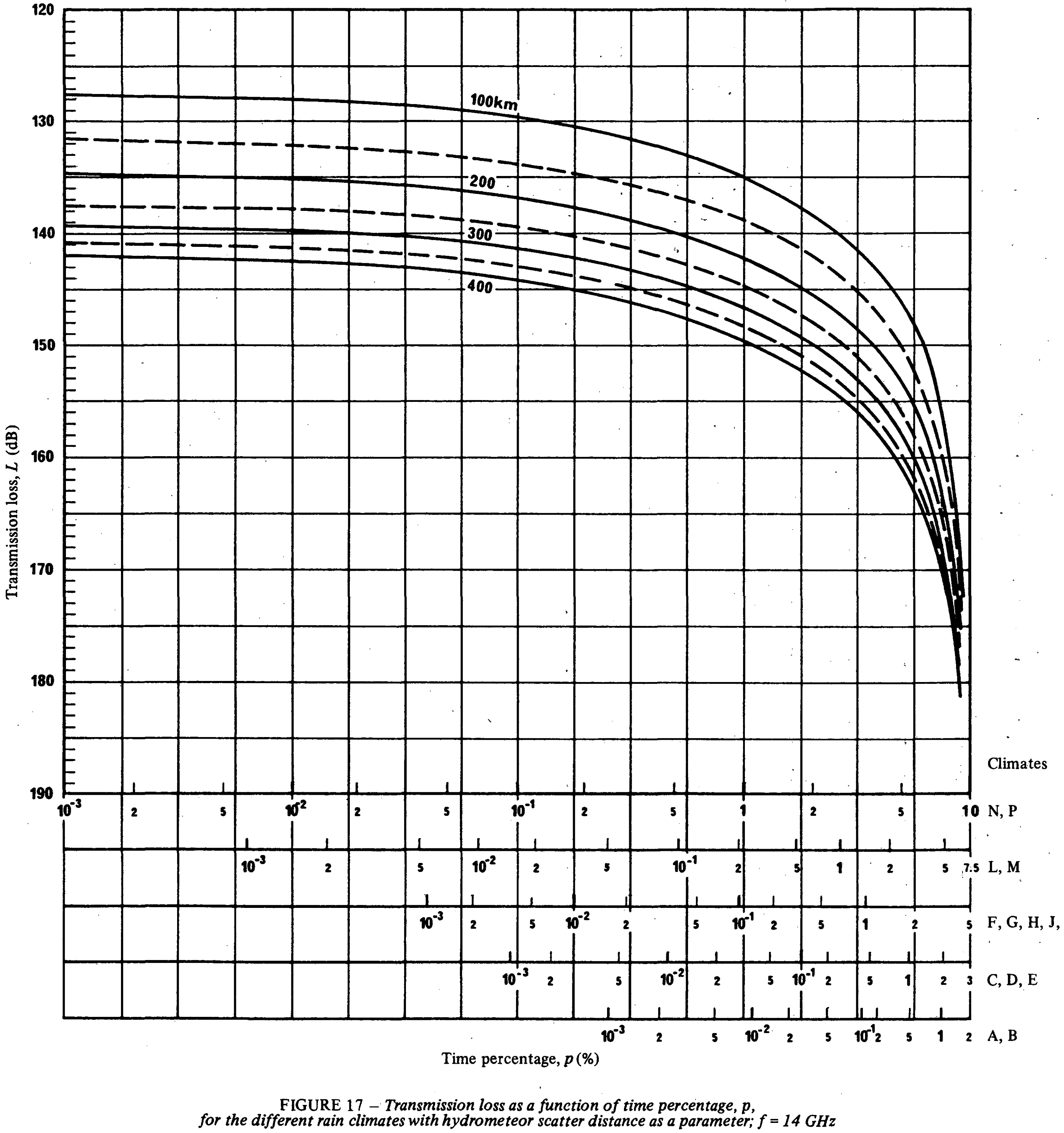


FIGURE 17 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 14 GHz*

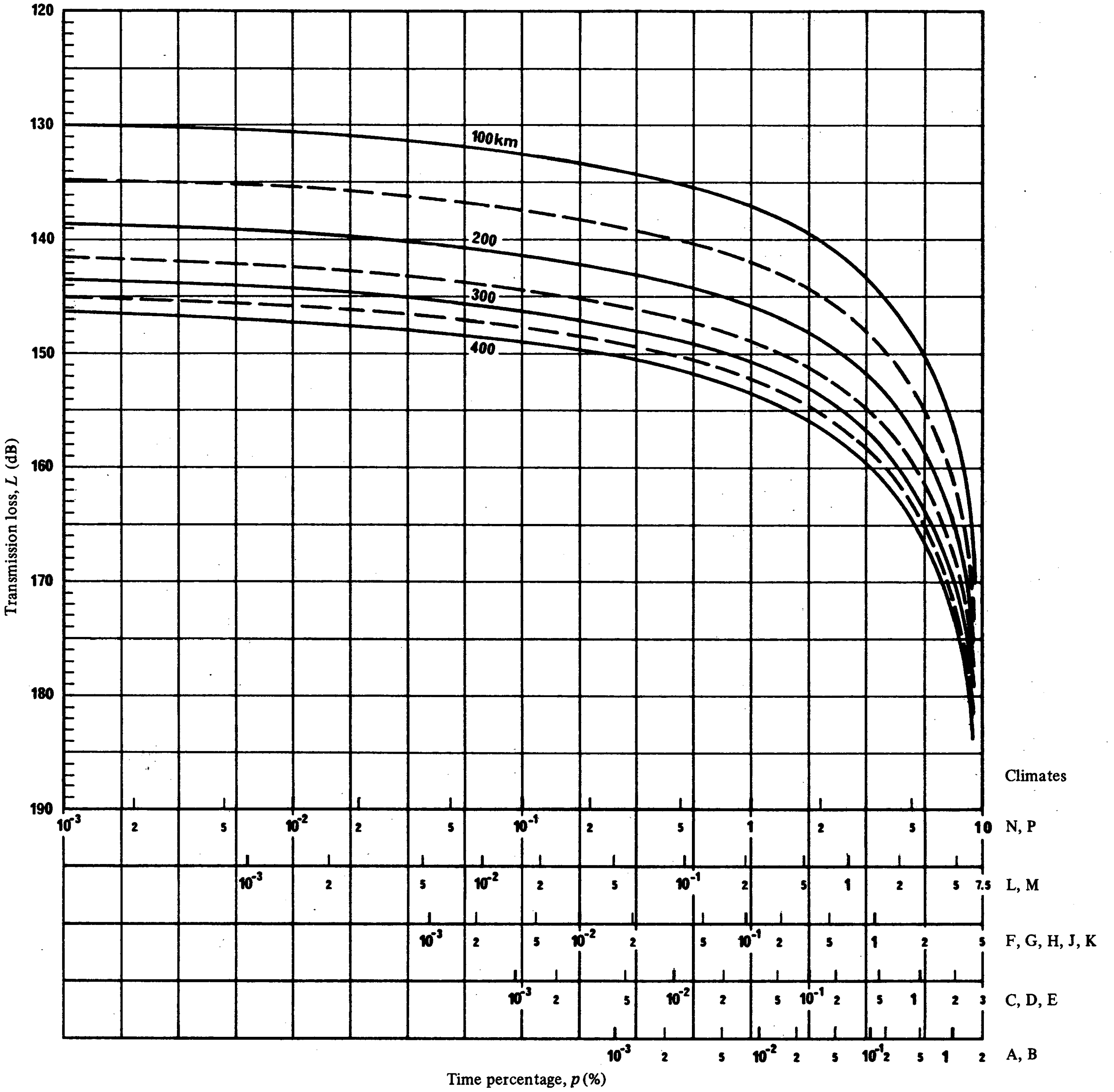


FIGURE 18 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 18 GHz*

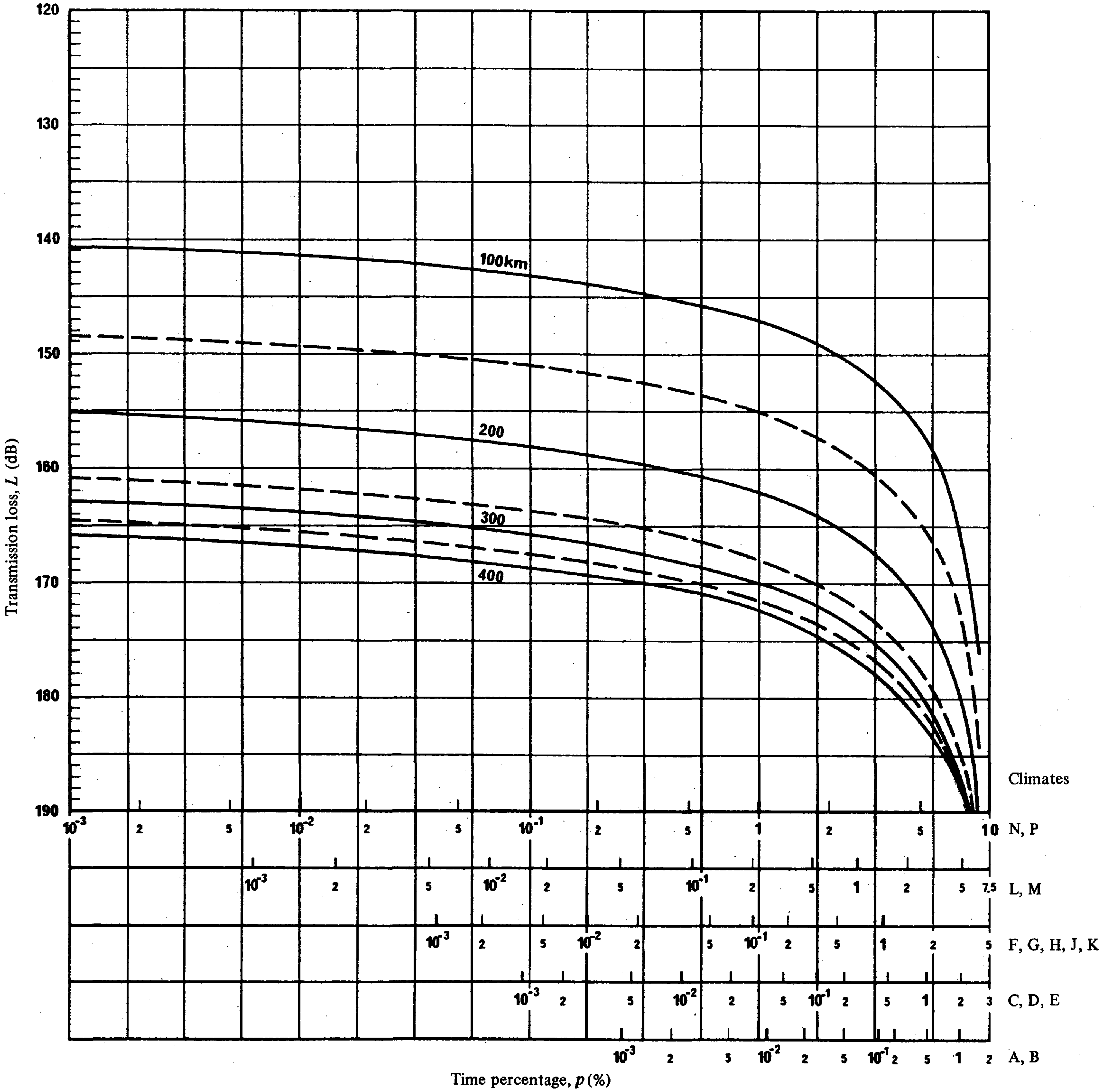


FIGURE 19 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 22.3 GHz*

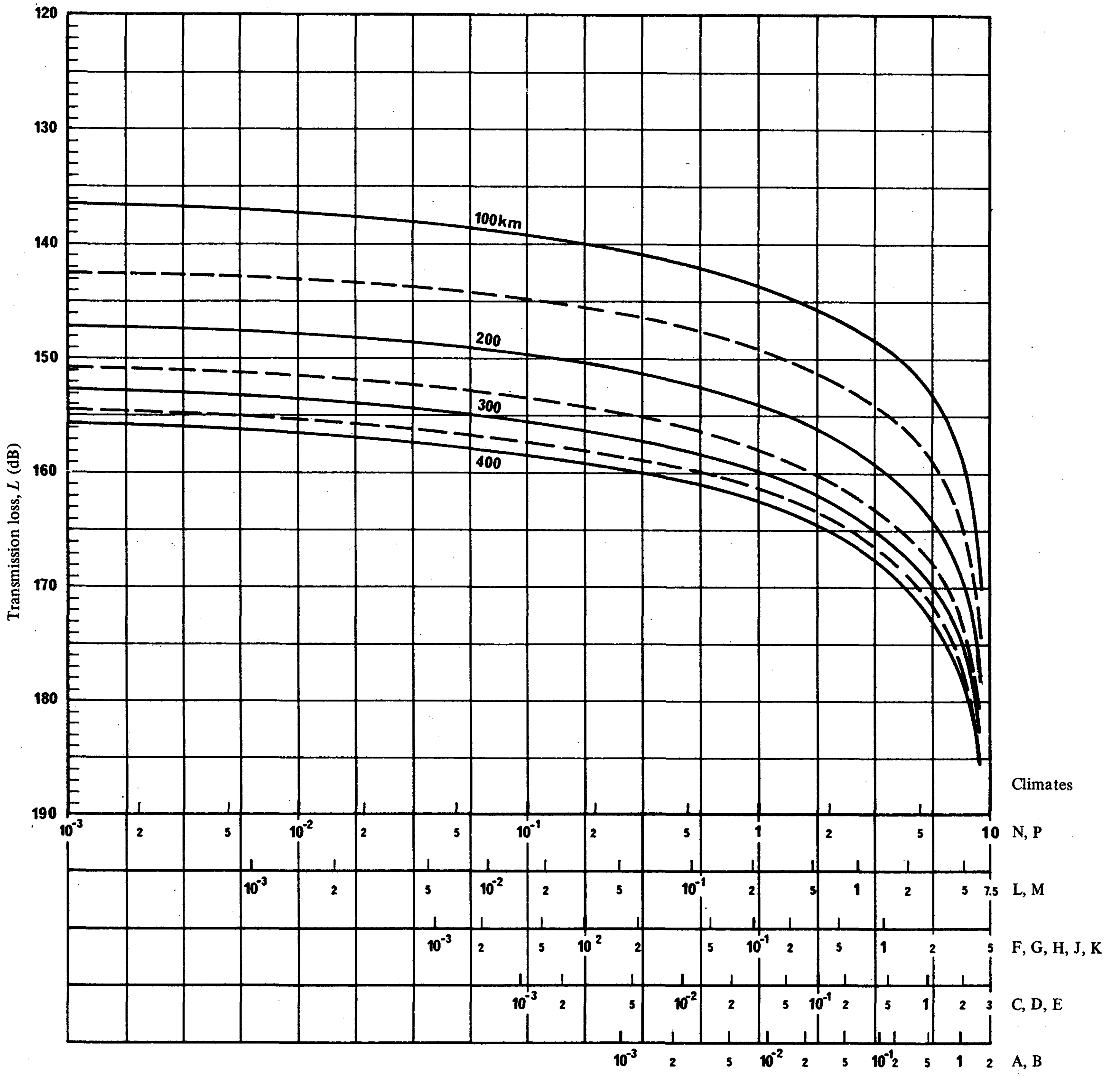


FIGURE 20 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 28 GHz*

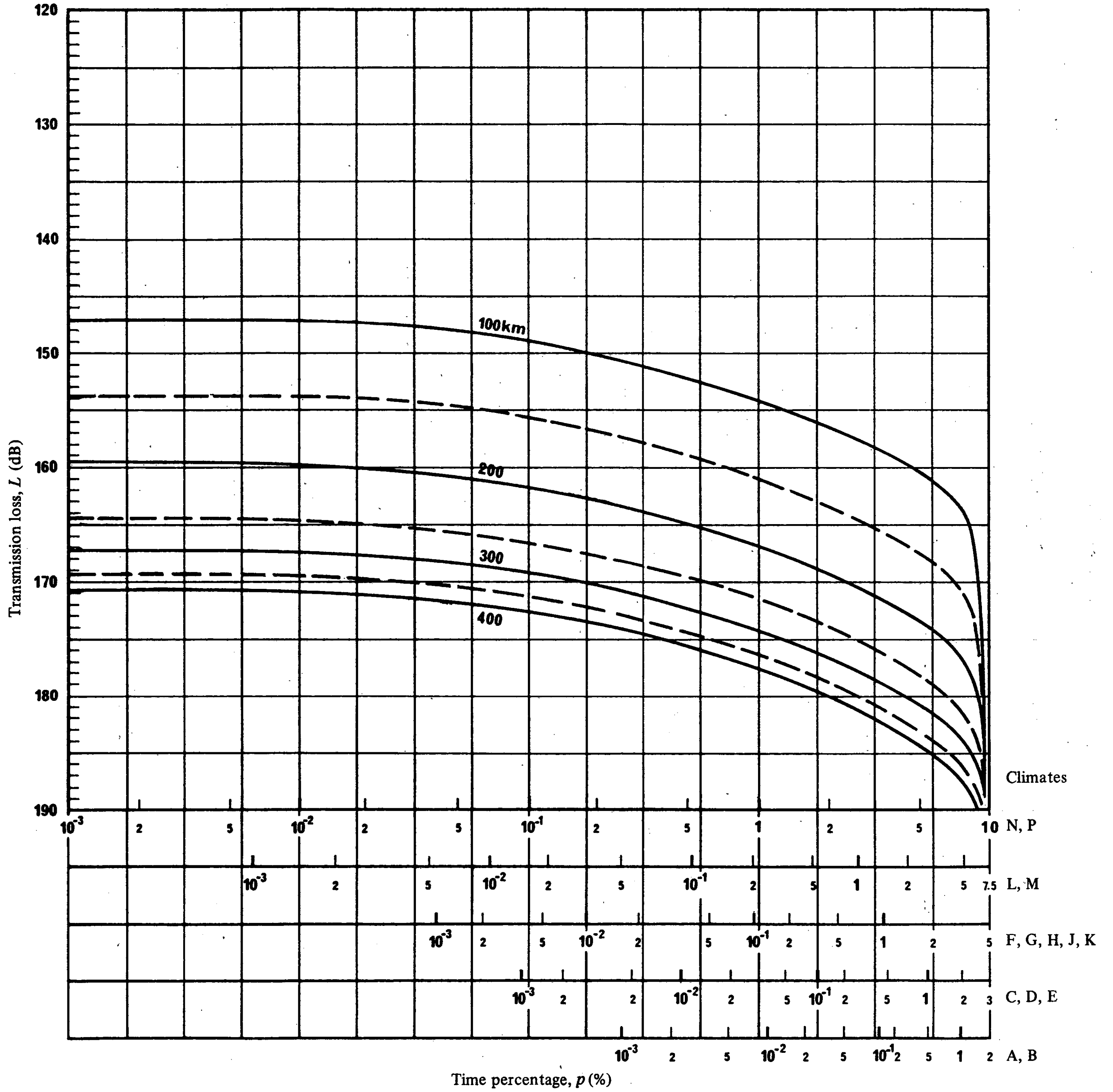


FIGURE 21 – *Transmission loss as a function of time percentage, p, for the different rain climates with hydrometeor scatter distance as a parameter; f = 40 GHz*

(b) Determine, among the various distribution curves, the one lying entirely below the $L_2(p_x)$ curve plotted as in (a) above, and having the smallest distance marking. When this distribtuion curve does not touch the $L_2(p_x)$ curve anywhere, estimate by linear interpolation the distance of a distribution curve that would touch the $L_2(p_x)$ curve at just one point. The distance so identified is denoted r_c. Where none of the available distribution curves lie entirely below the $L_2(p_x)$ curve, assume r_c = 370 km.

(c) Compare the distance r_c with the appropriate distance from Table IV; the smaller of the two compared distances is then the hydrometeor scatter distance d_r.

(d) Determine a point at distance Δd along the earth-station beam azimuth. This can be obtained from Fig. 22 as a function of earth-station antenna main beam elevation angle ε_s and d_r or from the following formula:

$$\Delta d = \frac{(d_r - 40)^2}{17\,000} \cot \varepsilon_s \qquad \text{km} \tag{27}$$

where:

ε_s : earth-station antenna main beam elevation angle (degrees).

(e) Draw a circle of radius d_r around this point. This is the hydrometeor scatter (co-ordination contour for propagation mode (2)). The co-ordination distance for propagation mode (2) on a given azimuth from the earth station is the distance from the earth station to the co-ordination contour on that azimuth, denoted d_2.

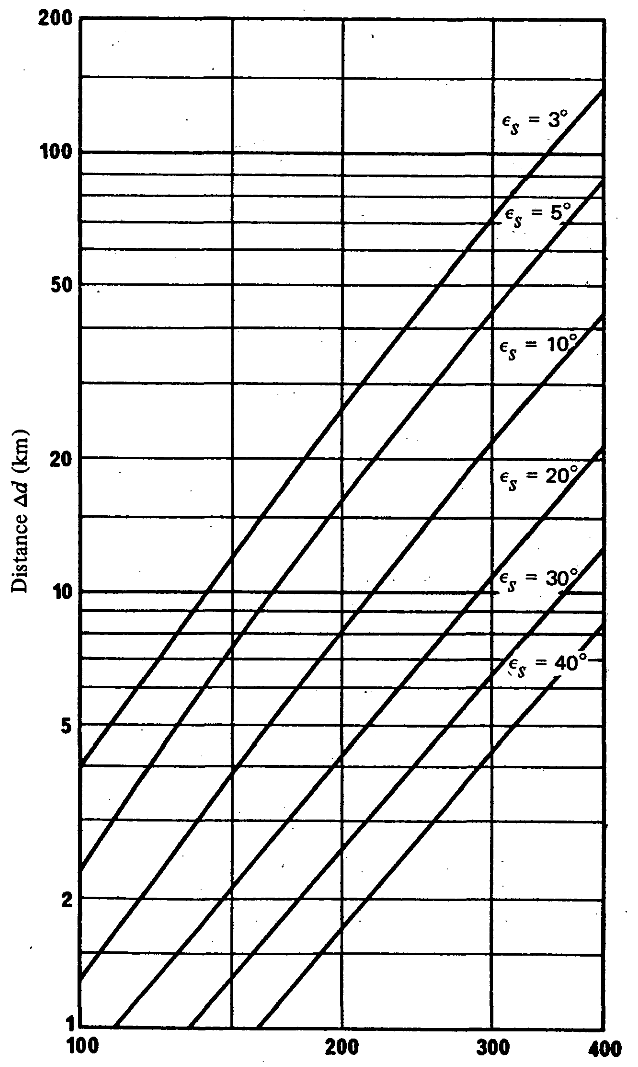


FIGURE 22 – *The distance Δd as a function of the rain-scatter distance d_r and the earth-station antenna main beam elevation angle ϵ_s*

4.3 *Absence of mixed path effects*

As the only significant hydrometeor scatter is that occurring in the general vicinity of the earth station, the question of a mixed path loss does not arise.

5. Minimum value of co-ordination distance

If the method for determining d_1, the co-ordination distance for propagation mode (1), leads to a result less than 100 km, d_1 shall be taken equal to 100 km. Similarly, if the method for determining the rain-scatter distance d_r, leads to a result less than 100 km, d_r shall be taken equal to 100 km.

6. The co-ordination contour

On any azimuth, the greater of the co-ordination distances d_1 or d_2 is the co-ordination distance to be used for the construction of the co-ordination contour.

An example of a co-ordination contour is shown in Fig. 23.

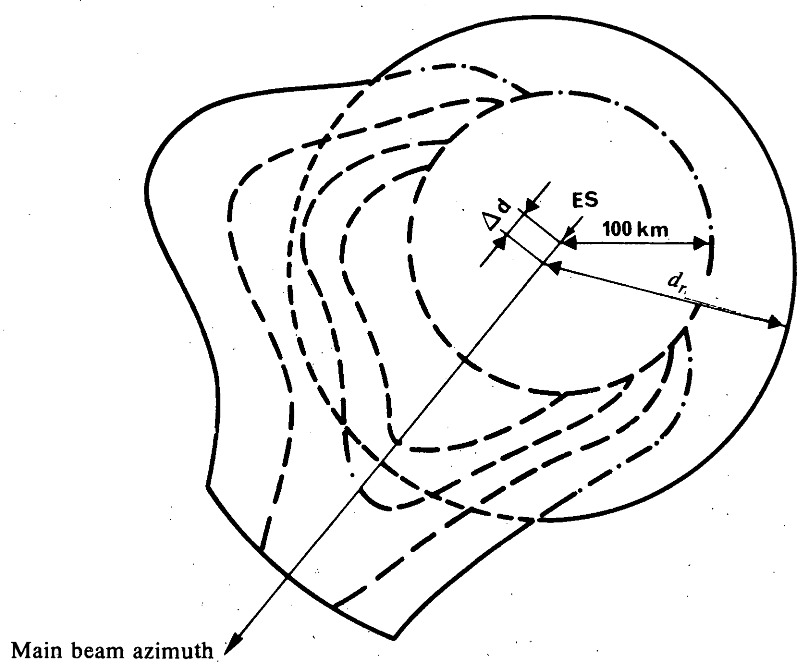


FIGURE 23 – *Example of a coordination contour*

ES : Earth station

———— : Coordination contour

—·—·—·— : Contour for propagation mode (1)

-------- : Contour for propagation mode (2)

— — — — : Auxiliary contours for propagation mode (1)

Note. – If by using the auxiliary contours it is seen that a terrestrial station can be eliminated with respect to propagation mode (1) then:

– if that terrestrial station is outside the contour for propagation mode (2) it may be eliminated from any further consideration;

– if that terrestrial station is within the contour for propagation mode (2) it must still be considered, but for this mode only.

7. Calculation by computer

The process described above for determining co-ordination areas and auxiliary contours may be programmed for computer. By means of such a program, the contours could be drawn automatically on a map.

8. Operational considerations at frequencies above 10 GHz

At frequencies above 10 GHz rain attenuation will weaken the received signals at earth or space stations for small percentages of the time, increasingly so with increasing frequencies.

Where power margins in the up or down links do not suffice to maintain the required continuity of service, it may be necessary to use site diversity or power control, or both.

When power control is used in the up link to combat rain attenuation on the Earth-to-space path, the increased power will tend to produce greater potential interference to terrestrial systems towards which the attenuation may not have increased. It may therefore be necessary to determine co-ordination contours taking into account the maximum powers that may be radiated and the percentages of the time during which given levels of power control may have to be exercised. It is understood that the maximum power which may be emitted by a transmitting earth station should be used to determine the co-ordination area. However, the transmit power will be increased only when rain attenuation exceeds a specified value. Thus, the increased power will not contribute to the interference due to ducting which is a clear sky phenomenon. Therefore, the maximum available transmitting power used to determine the co-ordination area for propagation mode (1) should be different from that for propagation mode (2). In fact, for propagation mode (1), it seems appropriate to use the maximum transmitting power emitted under clear sky conditions as the maximum available transmitting power.

When site diversity is used to combat attenuation, co-ordination contours will have to be determined for both sites. Since precipitation is the mechanism largely responsible for attenuation, each of the two sites will be operated, generally, only up to a given attenuation, i.e., to a given rainfall rate, after which the operation is transferred to the other site. As a consequence, rain-scatter co-ordination distances need to be determined only for those rain rates at which switching to the other site is undertaken. Since the switching rain rates will be substantially lower than the maximum rain rates for the percentage of the time for which continuity of service must be maintained, the rain-scatter co-ordination areas for the two sites may be significantly smaller than that for a single non-diversity site. It is worth noting that this advantage may accrue to both a transmitting and a receiving earth station.

9. Mobile (except aeronautical mobile) earth stations

For the purpose of establishing whether co-ordination for a mobile (except an aeronautical mobile) earth station is required, it is necessary to determine the co-ordination area which would encompass all co-ordination areas determined for each location within the service area within which operation of the mobile earth stations is proposed.

The preceding method may be used for this purpose by determining the appropriate individual co-ordination contours for a sufficiently large number of locations within and on the periphery of the proposed service area and by determining from those a composite co-ordination area which contains all possible individual coordination areas. For further information see [CCIR, 1978-1982b].

10. Revision of propagation data

The material contained in § 3, 4 and 6, and in Annex II of this Report is based, directly or indirectly, on propagation data compiled, interpreted and documented in other CCIR Recommendations and Reports. This material is given in a form similar to Appendix 28 to the Radio Regulations for a subsequent revision in conformity with Resolution No. 60 of the WARC-79. Knowledge regarding propagation is subject to change as new and more reliable data become available, and such change may require or strongly suggest corresponding amendments to the propagation-related material in this Report based on the finding of Study Group 5.

REFERENCES

CCIR Documents

[1978-82]: **a.** 4/7 (9/5) (China (People's Republic of)); **b.** 4/286 (IWP 4/1).

ANNEX I

ANTENNA GAIN IN THE DIRECTION OF THE EARTH-STATION HORIZON FOR GEOSTATIONARY SATELLITES

1. General

The gain component of the earth-station antenna in the direction of the physical horizon around an earth station is a function of the angular separation φ between the antenna main beam axis and the horizon direction under consideration. Therefore, knowledge of the angle φ is required for each azimuth.

The elevation ε_s and azimuth α_s of geostationary satellites as seen from an earth station at a latitude ζ are uniquely related. Figure 24 shows the possible location arcs of geostationary satellites in a rectangular elevation/azimuth plot, each arc corresponding to an earth-station latitude.

The plane representation of the spherical ε_s/α_s co-ordinate system leads to errors in the determination of larger values of φ. However, since antenna patterns at large angles of φ are not yet very sensitive to a variation in the angle φ, the errors do not appear to any significant degree in the horizon antenna gain.

The graphical method described here assumes that the space stations can be located anywhere along an orbital arc. However, for the purpose of co-ordination a given orbital position should be used; hence, in Fig. 25 this position should appear as a point, from which the off-beam angle $\varphi(\alpha)$ should be determined.

Specific relative satellite longitudes may not be known beforehand, but even when they are, the possibility of the addition of a new satellite or the repositioning of an existing one suggests that all or a portion of the applicable arc be considered to hold satellites.

2. Graphical method for the determination of $\varphi(\alpha)$

With the correct arc or segment of arc chosen and suitably marked in Fig. 24, the horizon profile $\varepsilon(\alpha)$ is added to the plot of Fig. 24, as shown in Fig. 25, where an example is given for an earth station located at 45° N latitude for a satellite expected to be located somewhere between relative longitudes of 10° E and 45° W.

For each point on the local horizon $\varepsilon(\alpha)$ the smallest distance to the arc is determined and measured on the elevation scale. The example of Fig. 25 shows the determination of the off-beam angle φ at an azimuth $\alpha(= 210°)$ with a horizontal elevation $\varepsilon(= 4°)$. The measurement of φ yields a value of 26°.

When this is done for all azimuths (in suitable increments, e.g. 5°), a relationship $\varphi(\alpha)$ results.

3. Numerical method for the determination of $\varphi(\alpha)$

For this purpose the following equations may be used:

$$\psi = \arccos(\cos\zeta \cdot \cos\delta) \tag{28}$$

$$\alpha'_s = \arccos(\tan\zeta \cdot \cot\psi) \tag{29}$$

$\alpha_s = \alpha'_s + 180°$ for earth stations located in the northern hemisphere and satellites located west of the earth station. (30a)

$\alpha_s = 180° - \alpha'_s$ for earth stations located in the northern hemisphere and satellites located east of the earth station. (30b)

$\alpha_s = 360° - \alpha'_s$ for earth stations located in the southern hemisphere and satellites located west of the earth station. (30c)

$\alpha_s = \alpha'_s$ for earth stations located in the southern hemisphere and satellites located east of the earth station. (30d)

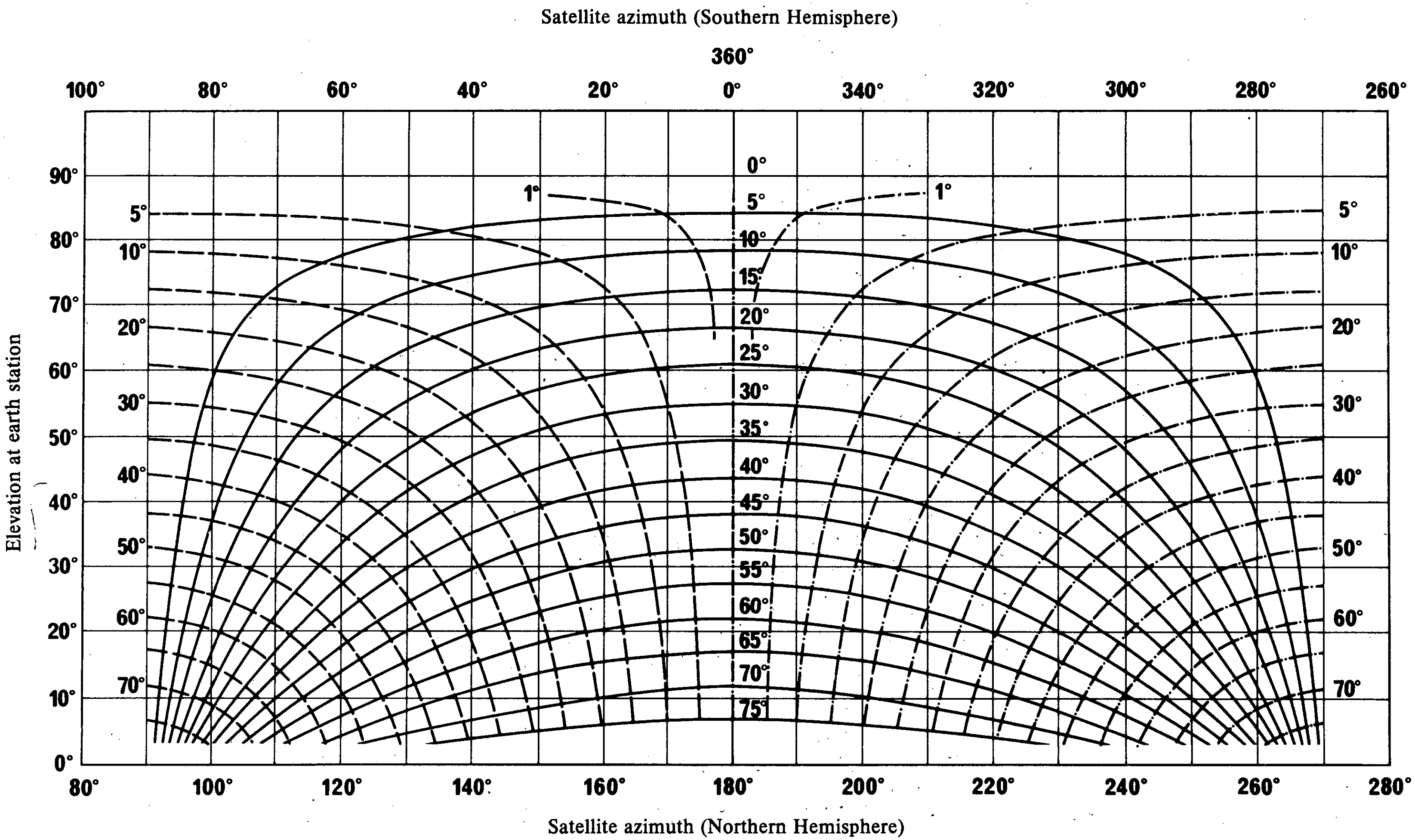


FIGURE 24 – *Position arcs of geostationary satellites*

——————— arc of geostationary-satellite orbit visible from earth station at terrestrial latitude ζ

Difference in longitude between earth station and the sub-satellite point:

— — — — — satellite longitude E of earth-station longitude

—·—·—·— satellite longitude W of earth-station longitude

··—··—··— satellite longitude equal to the earth-station longitude

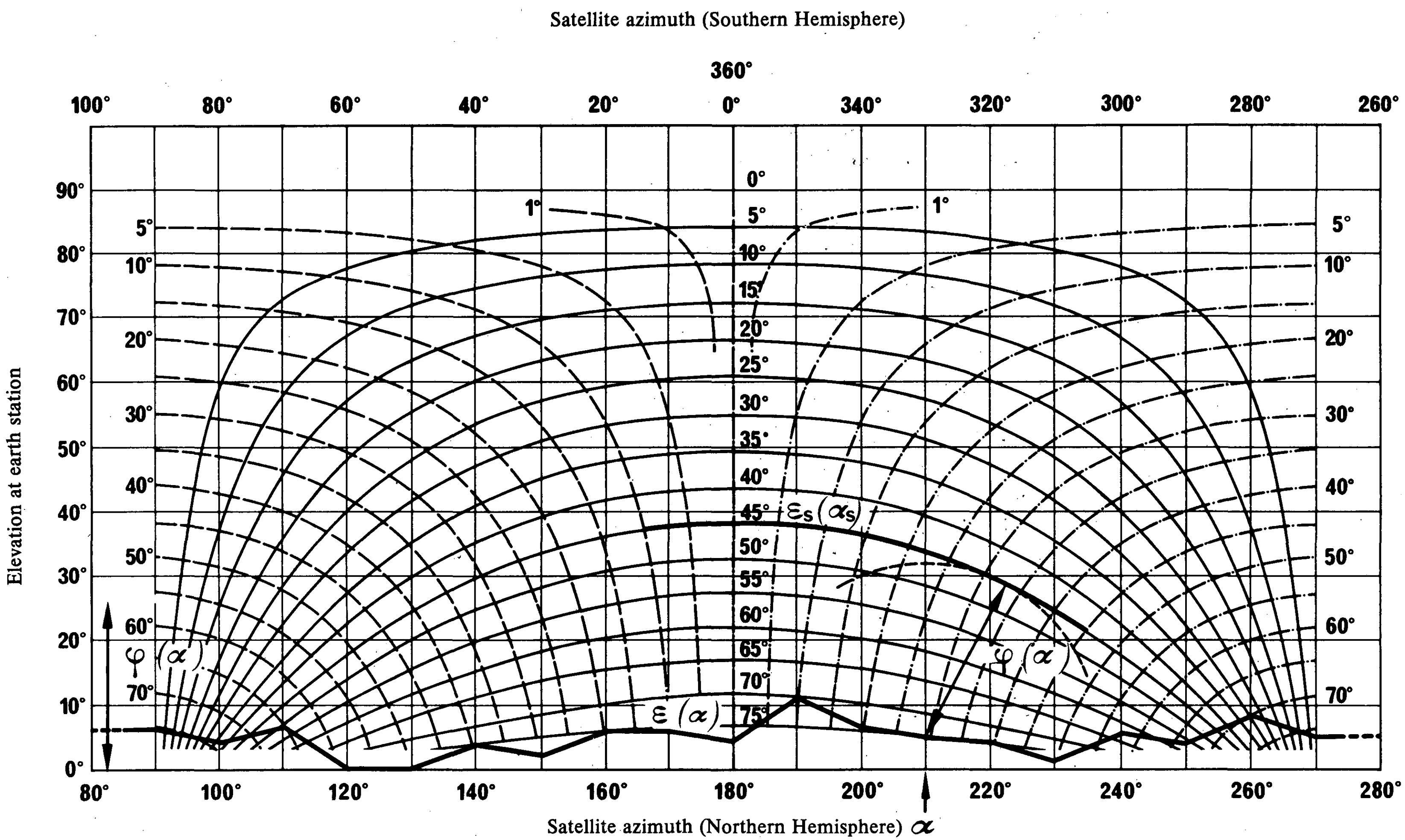


FIGURE 25 – *Example of derivation of* φ

——————— arc of geostationary-satellite orbit visible from earth station at terrestrial latitude ζ

/\/\/\/\/\/\/\ horizon profile ε(α)

Difference in longitude between earth station and the sub-satellite point:

— — — — satellite longitude E of earth-station longitude

—·—·—·— satellite longitude W of earth-station longitude

—··—··— satellite longitude equal to the earth-station longitude

$$\varepsilon_S = \arc\tan\left(\frac{K - \cos\psi}{\sin\psi}\right) - \psi \tag{31}$$

$$\varphi(\alpha) = \arc\cos\left[\cos\varepsilon \cdot \cos\varepsilon_s \cdot \cos(\alpha - \alpha_s) + \sin\varepsilon \cdot \sin\varepsilon_s\right] \tag{32}$$

where:

ζ : latitude of the earth station,

δ : difference in longitude between the satellite and the earth station,

ψ : great circle arc between the earth station and the sub-satellite point,

α_s : satellite azimuth as seen from the earth station,

ε_s : satellite elevation angle as seen from the earth station,

α : azimuth of the pertinent direction,

ε : elevation angle of the horizon in the pertinent azimuth, α,

$\varphi(\alpha)$: angle between the main beam axis and the horizon direction corresponding to the pertinent azimuth, α,

K : orbit radius/earth radius, assumed to be 6.62.

All arcs mentioned above are in degrees.

4. Determination of antenna gain

The relationship $\varphi(\alpha)$ may be used to derive a function for the horizon antenna gain, G(dB) as a function of the azimuth α, by using the actual earth-station antenna pattern, or a formula giving a good approximation. For example, in cases where the ratio between the antenna diameter and the wavelength is not less than 100, the following equation should be used:

$$\left.\begin{array}{lll} G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 & \text{for} & 0 < \varphi < \varphi_m \\ G(\varphi) = G_1 & \text{for} & \varphi_m \leqslant \varphi < \varphi_r \\ G(\varphi) = 32 - 25\log\varphi & \text{for} & \varphi_r \leqslant \varphi < 48^\circ \\ G(\varphi) = -10 & \text{for} & 48^\circ \leqslant \varphi \leqslant 180^\circ \end{array}\right\} \tag{33}$$

where:

D : antenna diameter, λ : wavelength — expressed in the same unit

G_1 : gain of the first side lobe $= 2 + 15\log D/\lambda$

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \quad \text{(degrees)}$$

$$\varphi_r = 15.85\,(D/\lambda)^{-0.6} \quad \text{(degrees)}$$

When it is not possible for antennas with D/λ of less than 100 to use the above reference antenna pattern and when neither measured data nor a relevant CCIR Recommendation accepted by the administrations concerned can be used instead, administrations may use the reference diagram as described below:

$$\left.\begin{array}{lll} G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 & \text{for} & 0 < \varphi < \varphi_m \\ G(\varphi) = G_1 & \text{for} & \varphi_m \leqslant \varphi < 100\frac{\lambda}{D} \\ G(\varphi) = 52 - 10\log\frac{D}{\lambda} - 25\log\varphi & \text{for} & 100\frac{\lambda}{D} \leqslant \varphi < 48^\circ \\ G(\varphi) = 10 - 10\log\frac{D}{\lambda} & \text{for} & 48^\circ \leqslant \varphi \leqslant 180^\circ \end{array}\right\} \tag{34}$$

where:

D : antenna diameter, λ : wavelength — expressed in the same unit

G_1 : gain of the first side lobe $= 2 + 15\log D/\lambda$

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \qquad \text{(degrees)}$$

The above patterns may be modified as appropriate to achieve a better representation of the actual antenna pattern.

In cases where D/λ is not given, it may be estimated from the expression:

$$20 \log \frac{D}{\lambda} \approx G_{max} - 7.7$$

where:

G_{max}: the main lobe antenna gain in dB.

ANNEX II

GRAPHICAL METHOD FOR THE DETERMINATION OF CO-ORDINATION DISTANCE FOR MIXED PATHS

1. Two zones

The procedure to be followed in the case of a mixed path involving two zones is illustrated by the example shown in Fig. 26(a). The earth station is situated in Zone A at a distance of 75 km from Zone B. The graphical presentation described below is particularly useful where more than one boundary between zones may be involved, as in this example.

In the example given below, the co-ordination loss is assumed to be 180 dB, the frequency 20 GHz, and the percentage of time 0.01%. The procedure is as follows:

1.1 determine the distance entirely in Zone A that would give the co-ordination loss. Mark this distance (in this case it is 160 km) from the origin along the abscissa axis of linear graph paper as indicated by the point A (Fig. 26(b));

1.2 determine the distance entirely in Zone B that would give the same co-ordination loss. Mark this distance (in this case it is 530 km) from the origin along the ordinate axis of the chart as indicated by the point B;

1.3 draw a straight line between points A and B representing these distances from the origin;

1.4 starting from the origin, the distance of 75 km from the earth station to Zone B is set off along the abscissa axis of the chart as indicated by the point A_1;

1.5 starting from point A_1 the Zone B path length of 150 km is then set off parallel to the ordinate axis of the chart as indicated by the point B_1;

1.6 the further distance in the next Zone A region is then measured parallel to the abscissa axis from the point B_1 to the point of intersection of the mixed path curve as indicated by X. In Fig. 26(b), this distance is 40 km;

1.7 the co-ordination distance is the sum of the distances $0A_1$, A_1B_1 and B_1X and is equal to

$$75 + 150 + 40 = 265 \text{ km}$$

2. Three zones

In some special cases, the mixed path involves all three radio-climatic Zones A, B and C. A solution to this problem can be found in adding a third dimension to the procedure to be followed for mixed paths involving only two zones. Theoretically, it means that the third co-ordinate has to be determined for a point having co-ordinates corresponding to the known distances in the first two zones and lying in a plane defined by three points on the axes X, Y and Z, corresponding to distances in Zones A, B and C, respectively, that would give the required basic transmission loss.

In practice, the procedure can be reduced to a simple graphical method shown in Fig. 27(a) assuming for example a co-ordination loss (L_1) of 180 dB at a frequency of 20 GHz. It is required to find the co-ordination distance from the earth station in the direction given in Fig. 27(a). Here an earth station is situated in Zone A at a distance of 75 km ($0A_1$) in a given azimuthal direction from Zone B. In the same azimuthal direction Zone B is 150 km (A_1B_1) long and followed by an unknown portion in Zone C (Fig. 27(a)).

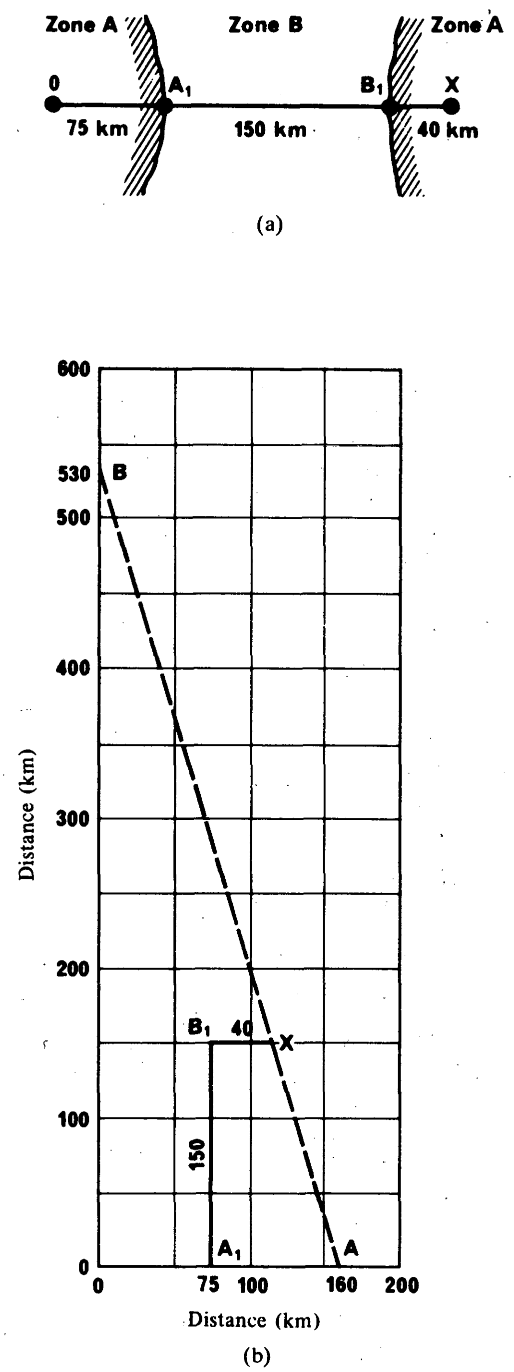


FIGURE 26 – *Example of determination of coordination distance for mixed paths involving Zones A and B*

In this case, the procedure to be applied should be as follows (Fig. 27(b)):

2.1 repeat the same procedure as for mixed paths involving only two zones, given in steps 1.1 to 1.5 above, and continue as follows:

2.2 from the point B_1 draw a line parallel to the line AB to intersect the abscissa axis as indicated by the point D;

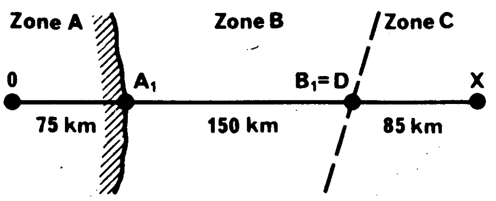
2.3 determine the distance entirely in Zone C that would give the co-ordination loss. Mark this distance (in this case it is 350 km) from the origin along the ordinate axis of the chart as indicated by the point C. Draw a straight line between the points C and A;

2.4 at the point D draw a line parallel to the ordinate axis to intersect the line CA as indicated by X;

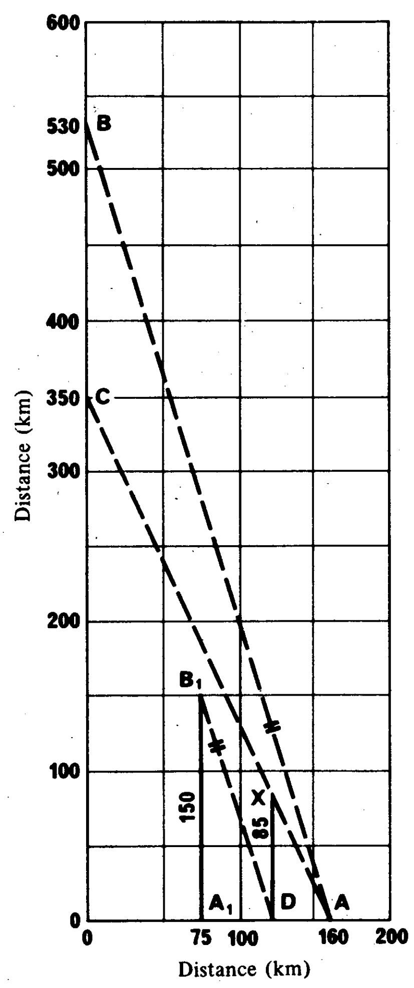
2.5 the distance between the points D and X, which is the unknown distance in Zone C, is found to be 85 km;

2.6 the co-ordination distance is then the sum of the distances $0A_1$, A_1B_1 and DX and in this example is equal to

$$75 + 150 + 85 = 310 \text{ km}$$



(a)



(b)

FIGURE 27 – *Example of determination of coordination for mixed paths including Zones A, B and C*

ANNEX III

CLASSIFICATION OF RAIN CLIMATES

As shown in Fig. 28, the world has been divided into a number of rain climatic zones which show different precipitation characteristics. The curves shown in Fig. 29 represent consolidated rain-rate distributions, each applicable to several of the rain climates of Fig. 28, and corresponding to one of the abscissa scales of Figs. 12 to 21.

For the derivation of the curves of Figs. 12 to 21, the distributions of Fig. 29 have been extended beyond 0.3% to such greater percentages of the time p_c at which the rainfall rate is assumed to approach zero, using the expression:

$$R(p) = R(0.3\%) \left[\frac{\log (p_c/p)}{\log (p_c/0.3)}\right]^2 \qquad \text{mm/h}$$

and using, for $R(0.3\%)$ and p_c, the following values:

Rain climatic zone	$R(0.3\%)$ (mm/h)	P_c (%)
A, B	1.5	2
C, D, E	3.5	3
F, G, H, J, K	7.0	5
L, M	9.0	7.5
N, P	25.0	10

This approach is appropriate for the numerical evaluation of the rain scatter distance.

The rain-rate distributions of Fig. 29 are approximated numerically by the following expressions:

Climates A, B

$$R = 1.1\, p^{-0.465} + 0.25\, [\log (p/0.001) \log^3 (0.3/p)] - [\,|\log (p/0.1)| + 1.1]^{-2} \qquad \text{mm/h}$$

Climates C, D, E

$$R = 2\, p^{-0.466} + 0.5\, [\log (p/0.001) \log^3 (0.3/p)] \qquad \text{mm/h}$$

Climates F, G, H, J, K

$$R = 4.17\, p^{-0.418} + 1.6\, [\log (p/0.001) \log^3 (0.3/p)] \qquad \text{mm/h}$$

Climates L, M

$$R = 4.9\, p^{-0.48} + 6.5\, [\log (p/0.001) \log^2 (0.3/p)] \qquad \text{mm/h}$$

Climates N, P

$$R = 15.6\, \{p^{-0.383} + [\log (p/0.001) \log^{1.5} (0.3p)]\} \qquad \text{mm/h}$$

for the range $0.001 \leqslant p \leqslant 0.3\%$.

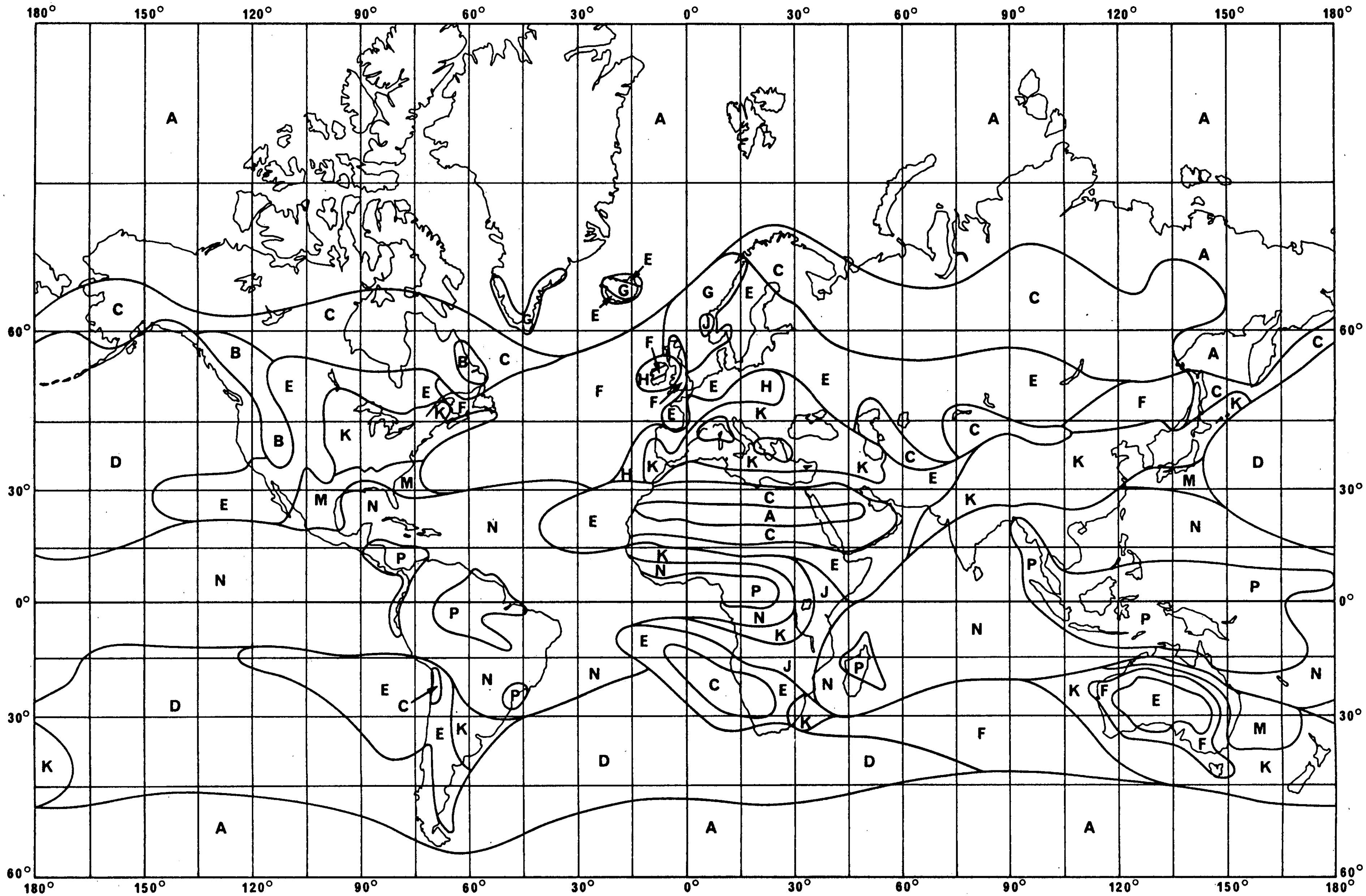


FIGURE 28 – *Rain climatic zones of the world*

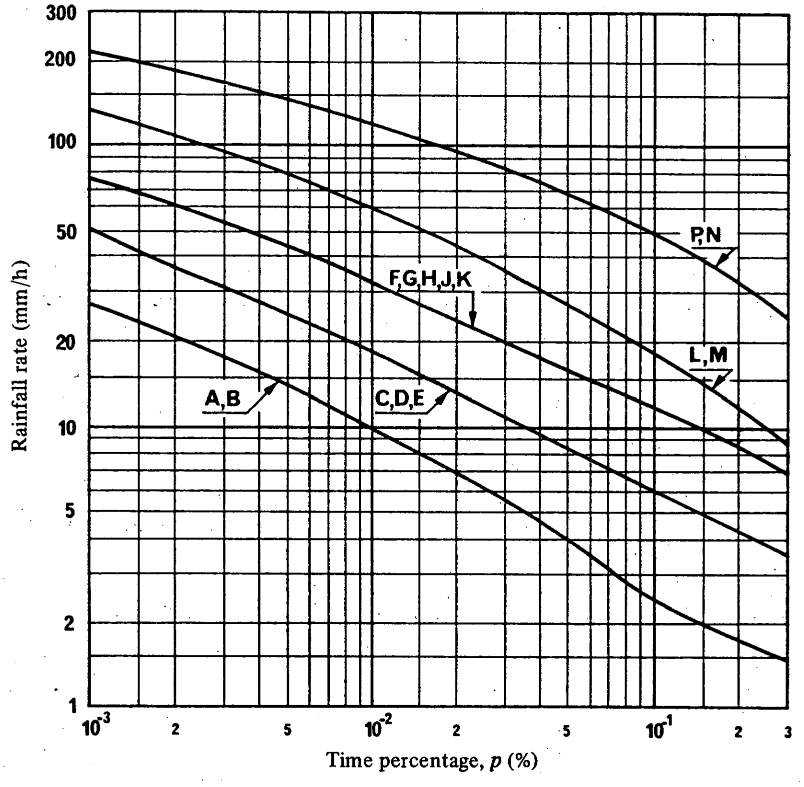


FIGURE 29 – *Consolidated cumulative distributions of rainfall rate for the rain climatic zones of Fig. 28*

APPENDIX I

AN ALTERNATIVE METHOD FOR THE DETERMINATION OF CO-ORDINATION DISTANCE FOR PROPAGATION MODE (1) OF REPORT 382

This Appendix presents an alternative calculation method for the determination of co-ordination distance on terrestrial interference paths and for propagation mode (1).

Administrations are invited to compare this new method with the method of § 3 of the main text of this Report and advise the CCIR of their findings, with a view towards deciding whether to adopt it in connection with the determination of co-ordination distance.

To facilitate this examination, the new method to determine co-ordination distance for propagation mode (1) is set forth in this Appendix in a form suitable for direct substitution of § 3.1 and 3.2 of Report 382.

3.1 *Radio-climatic zones*

In the calculation of co-ordination distance for propagation mode (1), it is convenient to divide the world into three basic radio-climate regions termed Zones A, B and C. These zones are as defined as follows:

- Zone A: all land;
- Zone B: "cold" seas, oceans and other large bodies of water (i.e. covering a circle of at least 100 km in diameter) situated at latitudes above 30°, with the exception of the Mediterranean and the Black Sea;
- Zone C: "warm" seas, oceans and other large bodies of water (i.e. covering a circle at least 100 km in diameter) situated at latitudes below 30°, as well as the Mediterranean and the Black Sea.

3.2 *Calculation of co-ordination distance for paths within a single radio-climatic zone*

The co-ordination distance for propagation mode (1) is determined by comparing the minimum permissible basic transmission loss (see § 2.2) between an earth station and a hypothetical terrestrial station with a predicted distance-dependent available basic transmission loss. The distance found by equating the values of minimum permissible and predicted available basic transmission loss is the co-ordination distance.

The following material is presented in two forms. In § 3.2.1 the basic equations are presented by means of which the co-ordination distance may be calculated numerically. In § 3.2.2 a graphical method to determine co-ordination distance is set forth.

3.2.1 *Numerical method*

The predicted available basic transmission loss is given by:

$$L_b(p_x) = U + 20 \log f + Vf^{1/3} (148\,\theta - 50) + d(Vf^{1/3} + \beta_o + \beta_v) \quad \text{dB} \tag{6}$$

where:

f: frequency of interest (GHz);

p_x: percentage of the time (%);

θ: horizon elevation angle* at the earth station (degrees);

d: path length (km);

β_o: absorption coefficient for oxygen (dB/km);

β_v: absorption coefficient for water vapour (dB/km).

The parameters U and V depend on the radio-climatic zone and on the percentage of the true p_x as follows:

- for Zone A:

$$\begin{aligned} U_A &= 140 + 10 \log p_x + 1.5 (\log p_x)^2 \\ V_A &= 0.11 + 0.01 \log p_x \end{aligned} \tag{7a}$$

---

* The horizon angle θ is defined here as the angle, viewed from the centre of the earth-station antenna, between the horizontal plane and a ray that grazes the visible physical horizon in the direction concerned.

– for Zone B:

$$U_B = 130 + 10 \log p_x + 1.5 (\log p_x)^2$$
$$V_B = 0.075 + 0.01 \log p_x \qquad (7b)$$

– for Zone C:

$$U_C = 130 + 10 \log (p_x/3) + 1.5 [\log (p_x/3)]^2$$
$$V_C = 0.075 + 0.01 \log (p_x/3) \qquad (7c)$$

The absorption coefficient for oxygen depends on frequency:

$$\beta_o = \left[\frac{7.1}{f^2 + 0.33} + \frac{4.5}{(f - 57)^2 + 0.98}\right] f^2/10^3 \qquad \text{dB/km for } f \leqslant 40 \text{ GHz} \qquad (8)$$

The absorption coefficient for water vapour is a function of frequency and water vapour density ρ:

$$\beta_v = \left[6.73 + \frac{300}{(f - 22.3)^2 + 7.3}\right] f^2\rho/10^6 \qquad \text{dB/km for } f \leqslant 40 \text{ GHz} \qquad (9)$$

where ρ is the water vapour density (g/m^3) and depends on the radio-climatic zone. The following values should be used for ρ:

– for Zone A: $\rho = 5$ mg/m^3,

– for Zone B: $\rho = 7.5$ mg/m^3,

– for Zone C: $\rho = 10$ mg/m^3.

The minimum permissible basic transmission loss is given in the form of a cumulative distribution with time, defined for $p \leqslant p_x \leqslant 20\%$, as follows:

$$L_m(p_x) = P_{t'} + G_e + 42 + \Delta G - P_r(p) + M(p) \left[1 - \frac{(9 - 5 \log p_x)^{0.5} - 1.58}{(9 - 5 \log p)^{0.5} - 1.58}\right] \qquad \text{dB} \qquad (10)$$

where:

G_e : earth-station horizon antenna gain (dBi);

ΔG : the difference (in dB) between the maximum antenna gain assumed for the terrestrial station and the value of 42 dB. Tables I and II, respectively, give values for ΔG in the various frequency regions.

All other parameters are as defined previously. Note that the percentage of the time p_x is the independent variable; the percentage p is that associated with the short-term interference criterion.

To determine the co-ordination distance, the right-hand sides of equations (6) and (10) are set equal, and the distance d is calculated for all time percentages p_x between p and 20%. The largest distance so found is the co-ordination distance d_1 on the azimuth of interest.

In most real cases, d_1 will be found for $p_x = p$. To verify this, it is useful to determine d initially only for $p_x = p$ and $p_x = 10p$. When $d(p_x = p) > d(p_x = 10p)$, then $d(p_x = p) = d_1$; i.e., the short-term criterion is the only percentage of the time which is of concern.

The above calculations lead to d_1 when the entire hypothetical interference path lies in only a single radio-climatic zone. For the calculation of d_1 along a mixed-zone path, see § 3.3.

3.2.2 *Graphical method*

It may be convenient for users to avail themselves of a graphical method to determine d_1. However, equation (6), which is the basis for the graphical method, contains five variables: $L_b(p_x)$, p_x, f, θ and d, each spanning a range of values. There is a sixth variable: the radio-climatic zone which, however, poses no problem. It is most practical to remove the earth-station horizon angle θ and make it subject to a separate step in the determination of d_1.

To that end, equation (6) is reformulated to:

$$L_1(p_x) = L_b(p_x) - k\theta = U + 20 \log f + d(Vf^{1/3} + \beta_o + \beta_v) - 50\ Vf^{1/3} \qquad \text{dB} \qquad (11)$$

where:

$$k = 148\ Vf^{1/3} \qquad \text{dB/degrees} \qquad (12)$$

Figures 31 to 40 have been drawn to show the distribution $L_1(p_x)$ versus p_x with distance as a parameter, for the three radio-climatic zones, each represented by a different abscissa scale. Each of the figures is for one frequency.

Figure 30 shows the factor k as a function of frequency, for percentages of the time between 0.001 and 1.0%, and for the three radio-climatic zones.

To determine the co-ordination distance, proceed as follows:

– Plot the basic co-ordination loss, obtained as the difference

$$L_1(p_x) = L_m(p_x) - k\theta \qquad (13)$$

from equations (10) and (12)*, for all percentages of the time between p and 1% on the appropriate figure among Figs. 31 to 40, using the appropriate abscissa scale. This results in a curve which starts above the value p (the percentage of the time associated with the short-term interference criterion) and slants downwards towards the right.

– Find, among the existing curves on the figure, the one which lies entirely below the just-constructed curve segment but touches it at one point. The distance with which this curve is marked is the co-ordination distance d_1. When none of the existing curves touches the newly constrcuted curve segment, estimate by interpolation the distance of a curve that would touch the constructed curve segment at one point but would otherwise lie entirely below it. This distance is the co-ordination distance d_1.

Note. – It is generally found that the point at which the two curves touch is the point corresponding to a small percentage of time p. To test whether this is in fact the case, it is not necessary to construct the entire distribution $L_1(p_x)$ but merely two points of it at p and at $10p$. When the distance for $p_x = p$ is greater than the distance found for $p_x = 10p$, the point at p determines the co-ordination distance d_1, and no other values of p_x need be investigated.

* Or from Fig. 30 in the case of k.

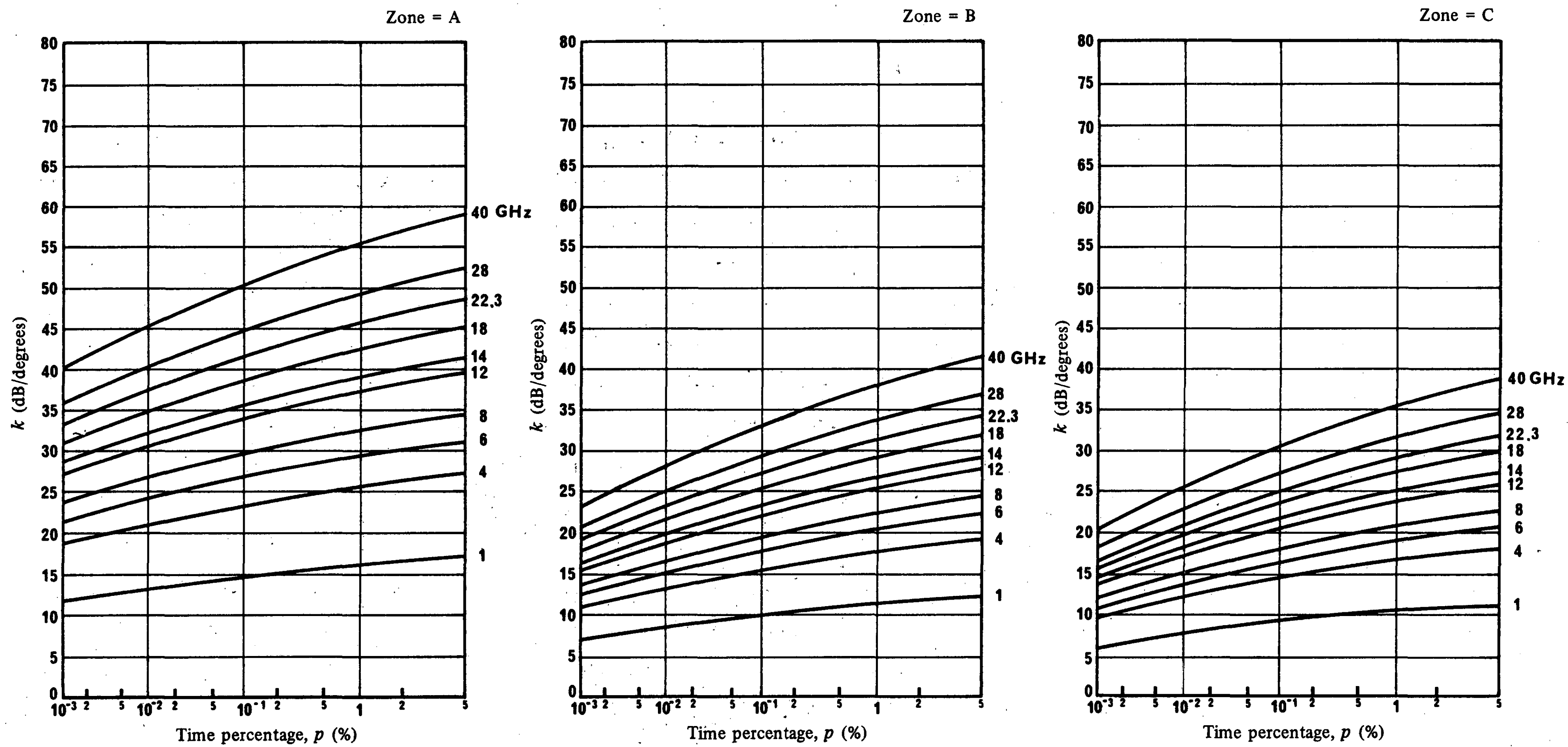


FIGURE 30 – *Factor k in dB/degrees as a function of time percentage, p, for isopleths of frequency in GHz*

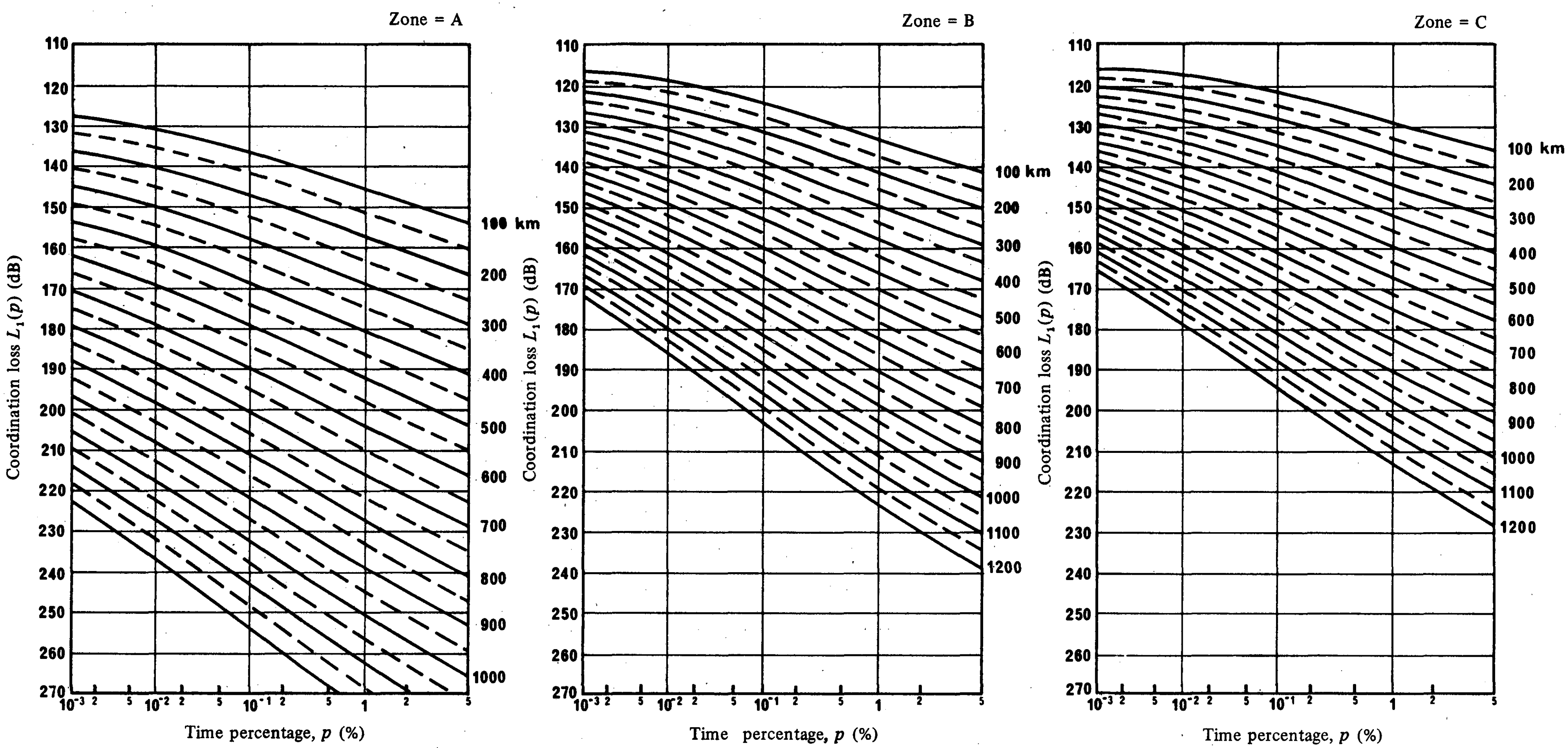


FIGURE 31 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 1.0 GHz

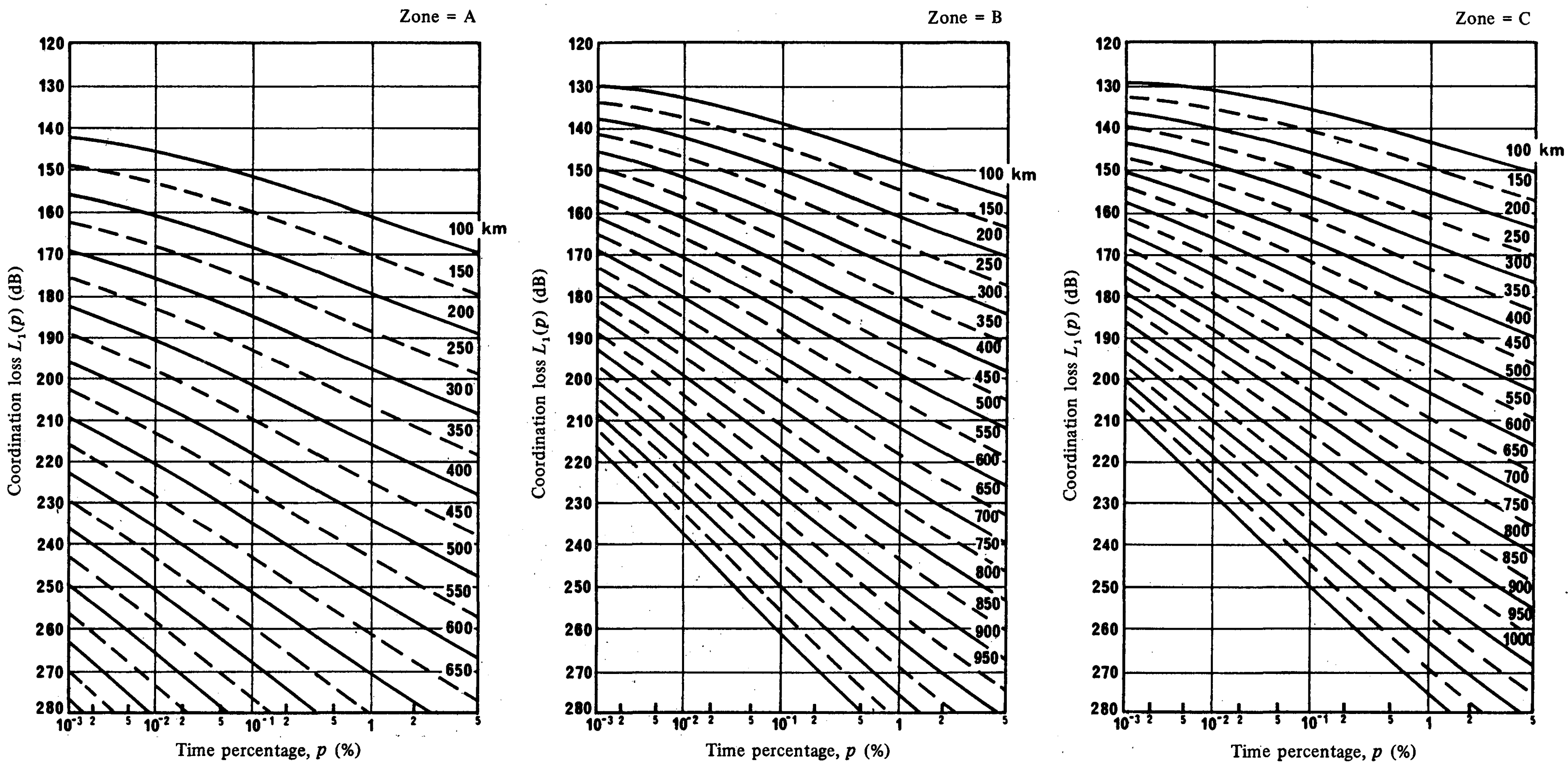


FIGURE 32 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 4.0 GHz

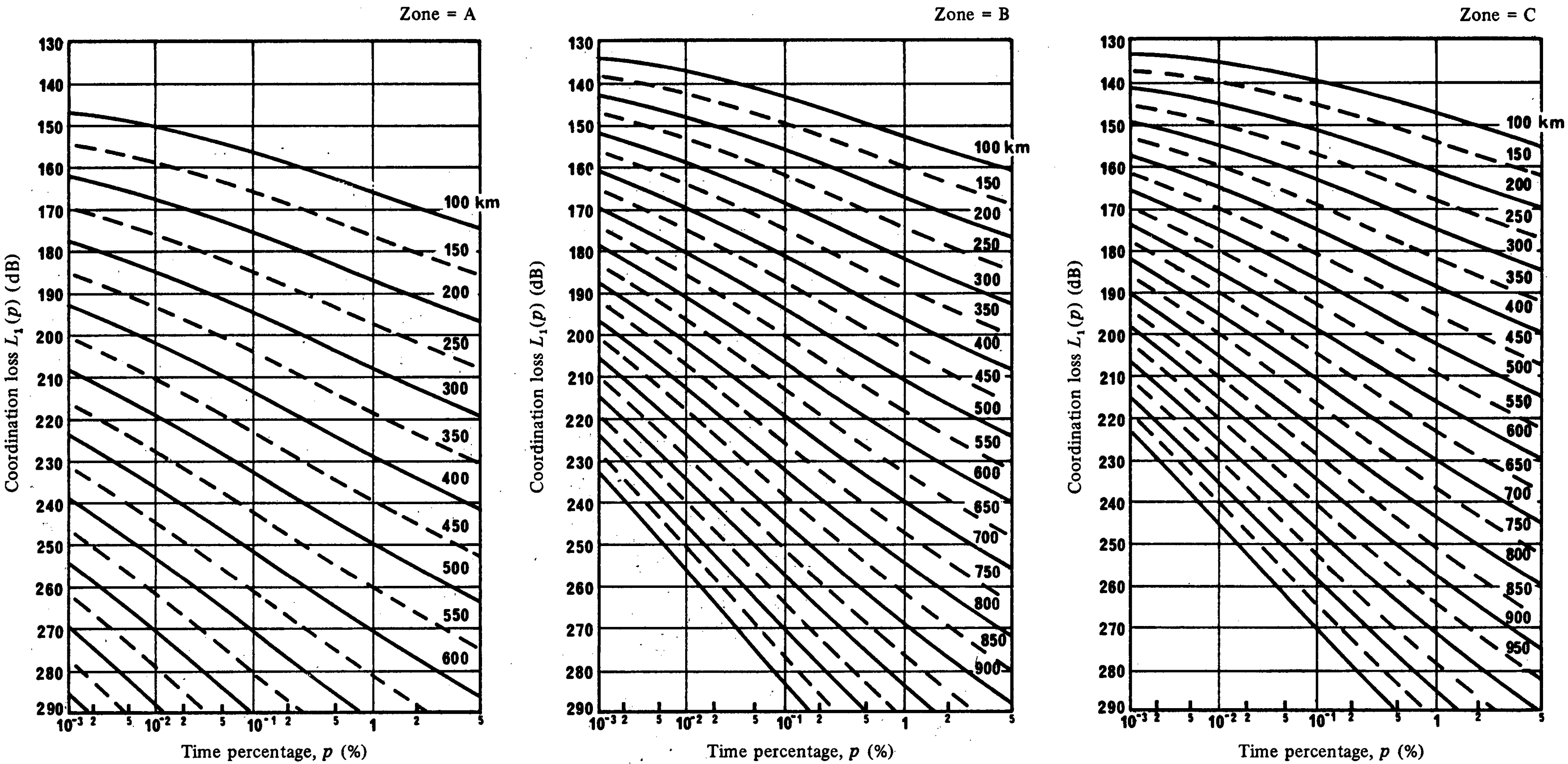


FIGURE 33 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 6.0 GHz

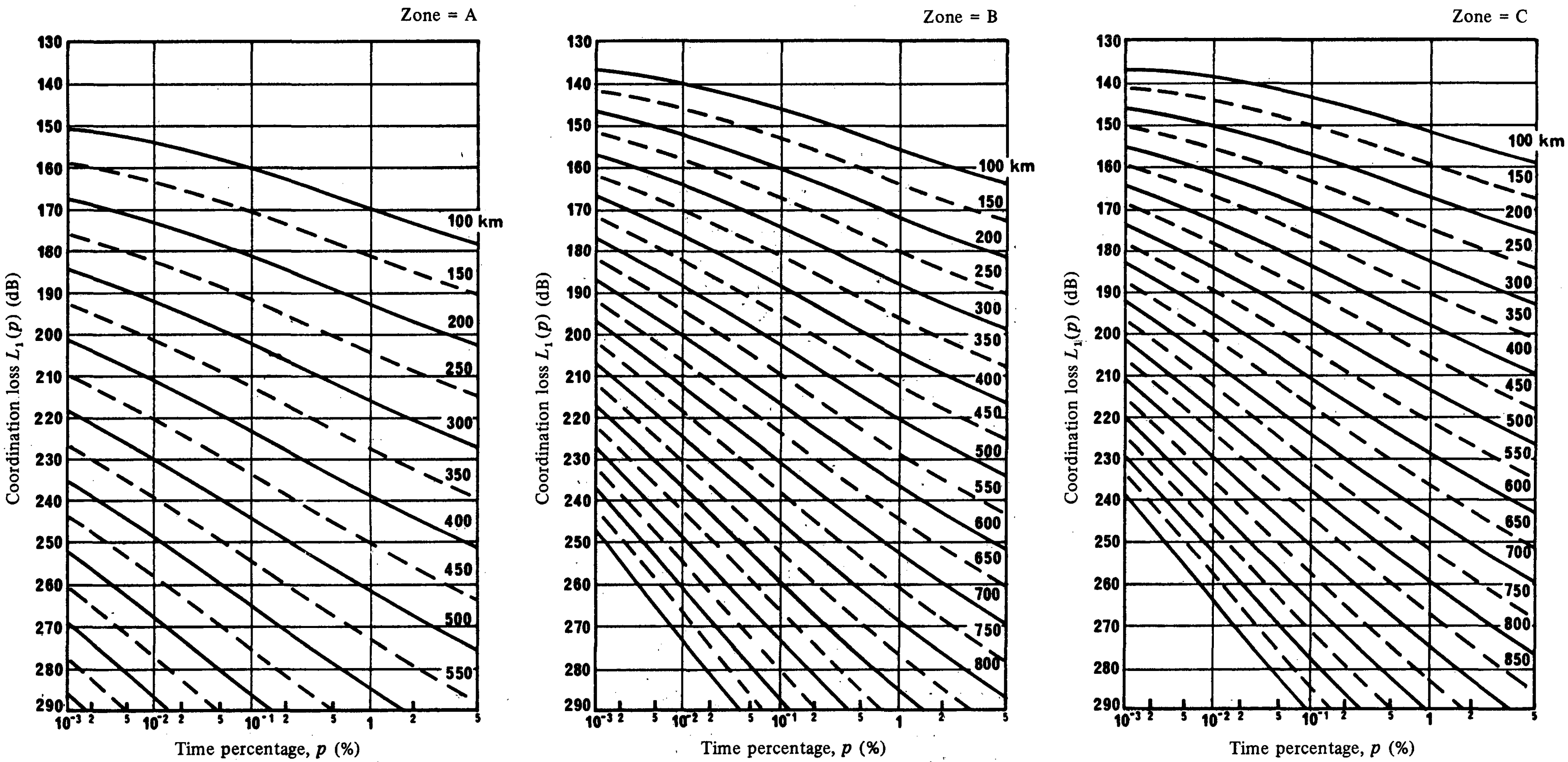


FIGURE 34 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 8.0 GHz

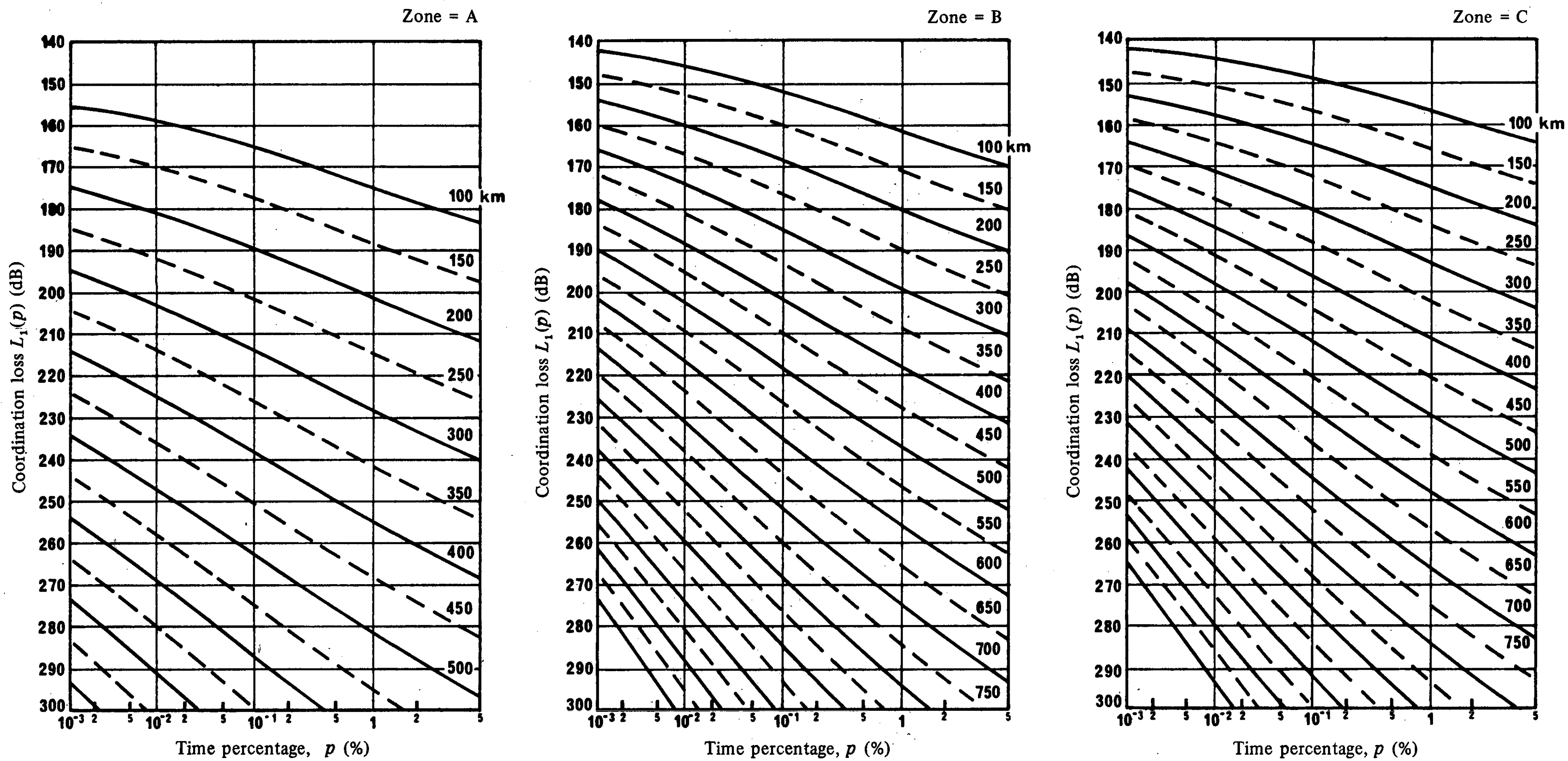


FIGURE 35 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 12.0 GHz

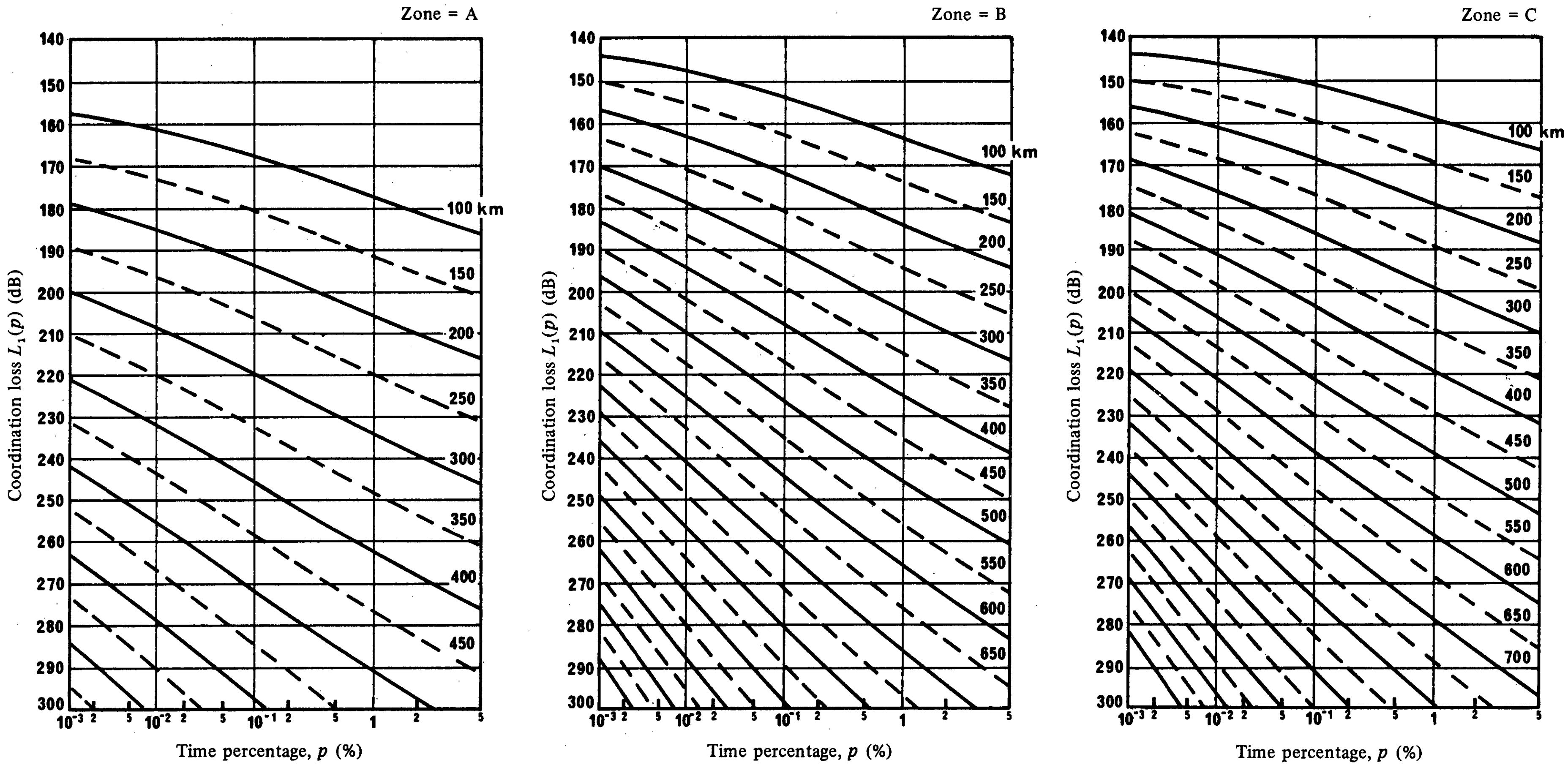


FIGURE 36 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 14.0 GHz

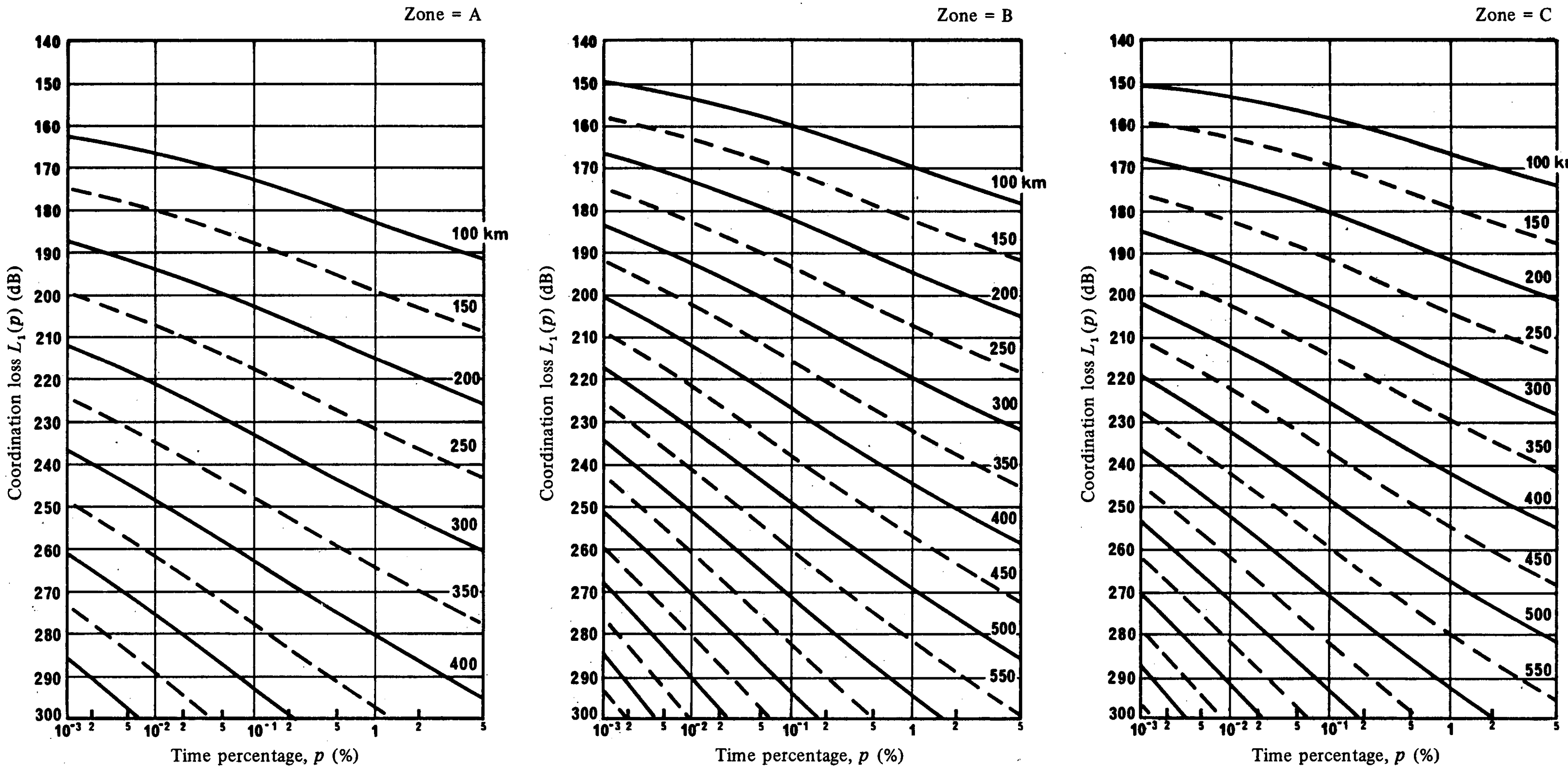


FIGURE 37 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 18.0 GHz

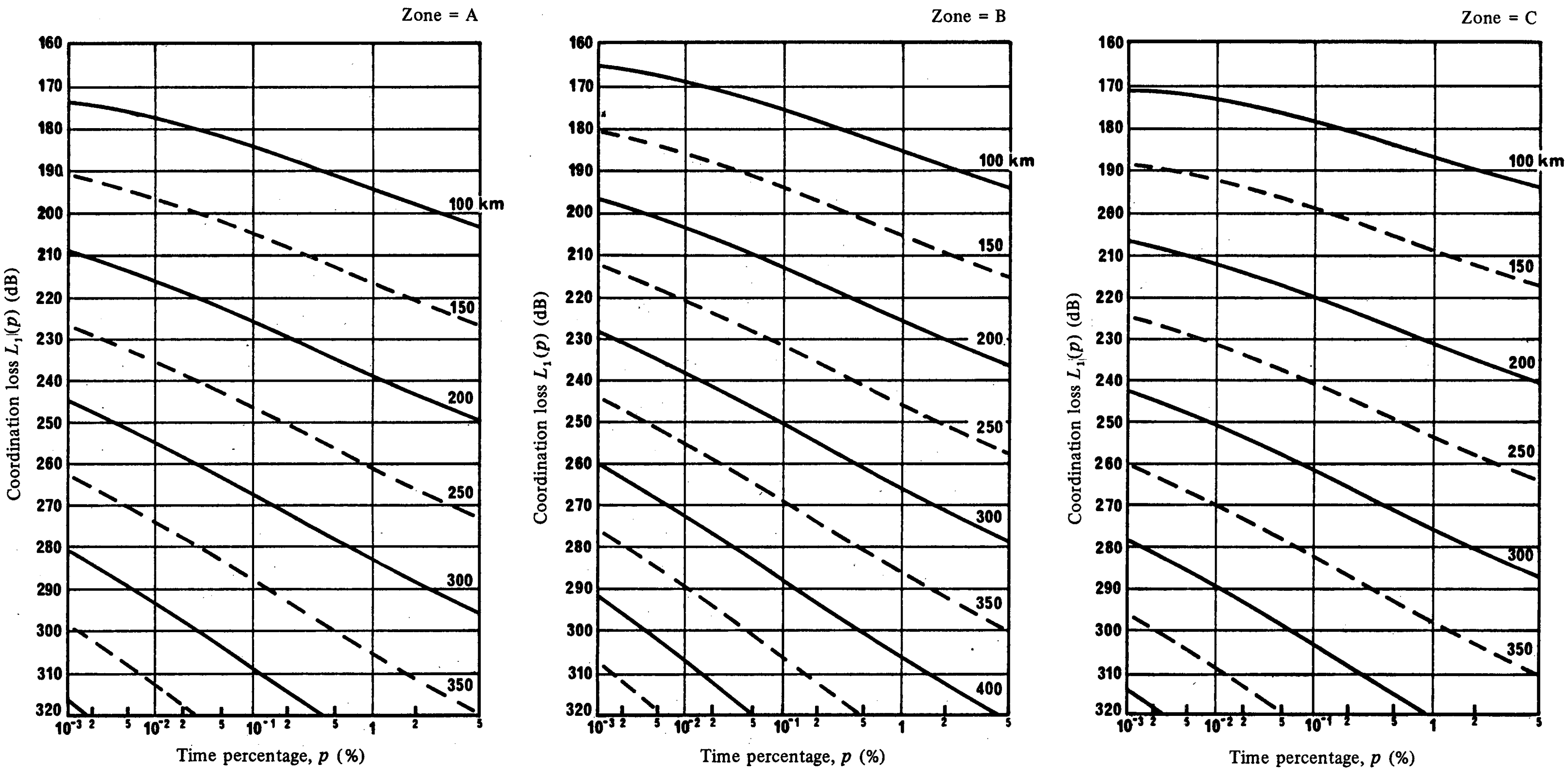


FIGURE 38 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 22.3 GHz

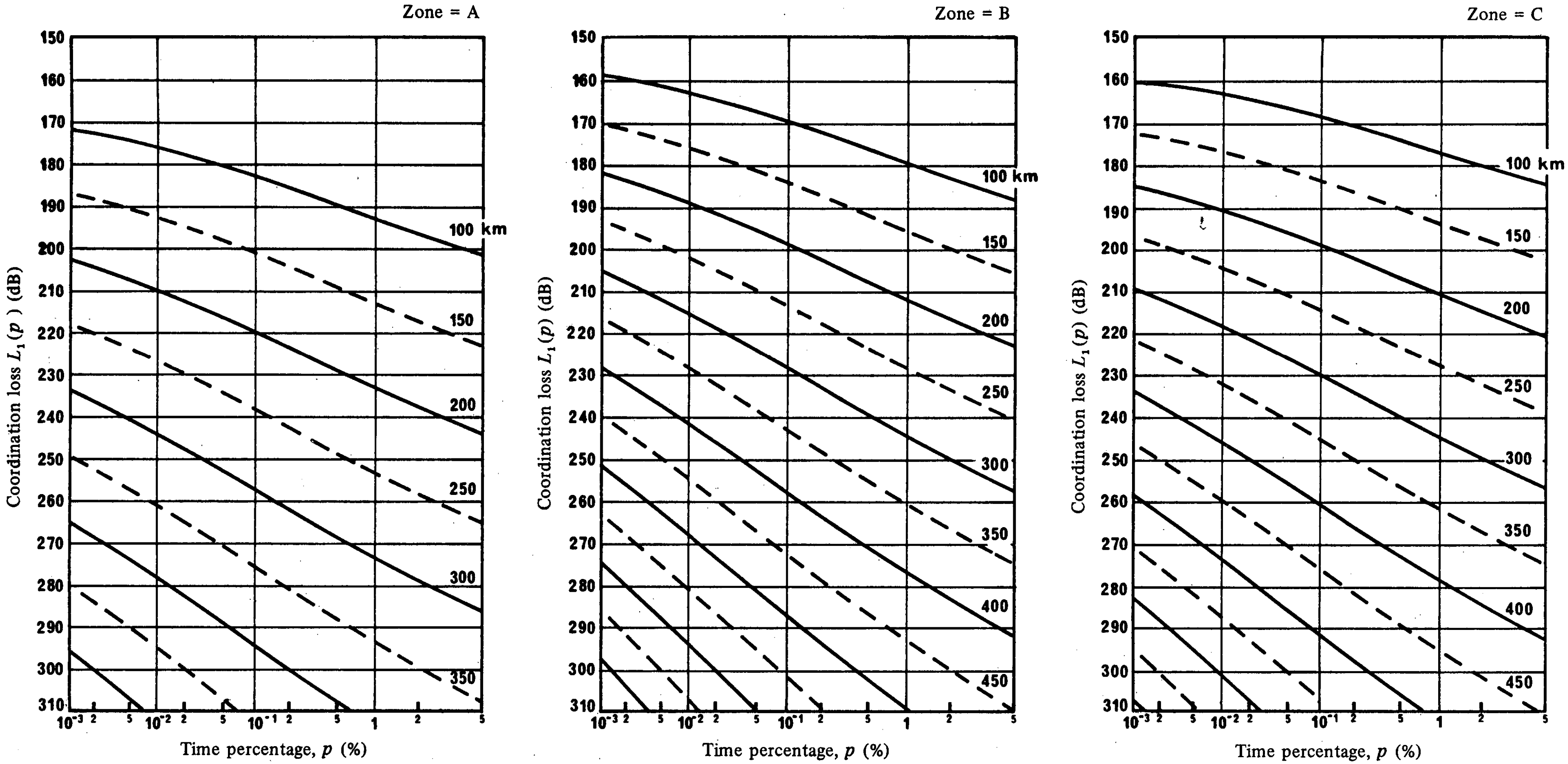


FIGURE 39 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 28.0 GHz

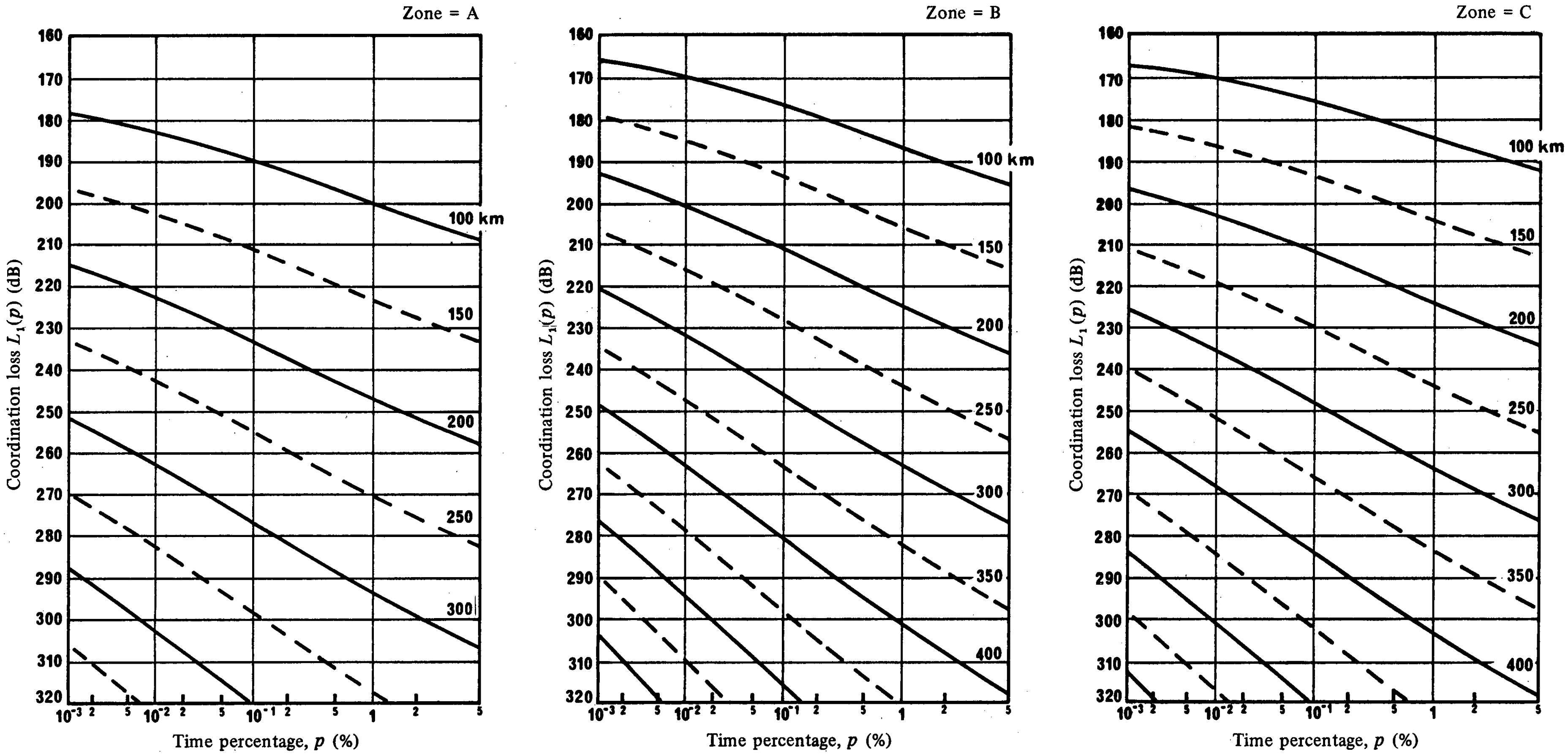


FIGURE 40 – *Coordination loss $L_1(p)$, dB as a function of time percentage, p, for isopleths of distance in km*

Frequency = 40.0 GHz

REPORT 448-4

DETERMINATION OF THE INTERFERENCE POTENTIAL BETWEEN EARTH STATIONS AND TERRESTRIAL STATIONS

(Questions 32/4 and 17/9)

(1970-1974-1978-1982-1986)

1. Introduction

When the co-ordination area of an earth station includes territory of any other administration, mutual consultation between the administrations concerned is required. Each terrestrial station within the co-ordination area must be examined to determine whether it will experience or cause more than a permissible amount of interference. Where the results of a preliminary study indicate possible interference situations or where it appears that the number of interference entries may exceed those assumed in Report 382, the interference probabilities between the earth station and the terrestrial stations must be evaluated on the basis of detailed calculations.

This Report describes a method for assessing whether interference between earth stations and specific terrestrial stations can be expected to exceed a pre-determined permissible level. It is intended only as a guide for administrations since the method for determining the possibilities of interference is subject to agreement between the administrations concerned.

A supplementary approach to the concept of the auxiliary contours presented in Report 382 is also described in Annex I to this Report.

2. Preliminary elimination procedure

The method of calculating co-ordination distance as described in Report 382 assumes certain reference values for the parameters of terrestrial stations. A very large percentage of the actual or planned terrestrial stations remaining within a co-ordination area can be eliminated from further consideration with a knowledge of their actual or planned parameters, by using the auxiliary contours as defined in Appendix 28 of the Radio Regulations (Geneva, 1979).

One set of contours is associated with values of the terrestrial station interference sensitivity factor, S in dBW which is defined as:

$$S = G_r - P_r(p) \tag{1}$$

where,

G_r: the net gain (i.e., the gain of the antenna itself minus the feeder loss in dB relative to isotropic, where the feeder loss is not known, its value should be assumed to be 0 dB) of the receiving antenna of the terrestrial station in the direction of the earth station;

$P_r(p)$: the permissible interference power (in dBW) in the reference bandwidth to be exceeded for no more than p per cent of the time at the receiver input of a station suffering interference (in this case a terrestrial station).

The other set of contours is associated with values of terrestrial station e.i.r.p.:

$$E = P_{t'} + G_{t'} \tag{2}$$

where,

$P_{t'}$: available transmitting power (in dBW) in reference bandwidth B at the input to the antenna of an interfering station (in this case a terrestrial station);

$G_{t'}$: the gain (in dB relative to isotropic) of the transmitting antenna of the terrestrial station in the direction of the earth station.

Each terrestrial station which is located within the co-ordination area may now be examined to determine whether it can be excluded from further considerations:

- for terrestrial stations which may be receiving interference from the earth station, the interference sensitivity factor in the direction of the earth station should be determined. If this value is less than that associated with the nearest contour outside which the station is located, then the station may be excluded. Otherwise, detailed calculations as described in § 3 must be carried out.
- for terrestrial stations which may be causing interference to the earth station, the actual e.i.r.p. in the direction of the earth station should be determined. If this value is less than that associated with the nearest contour outside which the terrestrial station is located, then the station may be excluded. Otherwise, detailed calculations as described in § 3 must be carried out.

The above method has been based on the assumption:

- that the basic transmission loss curves on which Report 382 is based are conservative;
- that the number of interference entries assumed in Report 382 for the calculation of the auxiliary contours is not exceeded.

Terrestrial stations eliminated by the above procedure from further consideration with regard to great circle propagation mechanisms, need nevertheless, be considered further with regard to rain scatter propagation, when they lie within the rain scatter co-ordination area.

Recent work described in Report 1054 points towards terrain scattering as an interference mechanism to be considered under certain circumstances. How this will affect co-ordination should be the subject of further studies.

3. **Determination of interference potential** (great circle propagation mechanisms) (See Report 569)

Terrestrial stations located within the co-ordination area, which cannot be eliminated from further consideration by the method described in § 2 must be subjected to a more detailed analysis.

For each terrestrial station it is necessary to compare the available basic transmission loss for the path and the minimum permissible basic transmission loss value, at which interference is negligible for two time percentages, (1) equal to 20% of the time (p_1), and (2), a low percentage of the time (< 1%) designated p_2.

It may be assumed that interference is negligible when, for both time percentages, the available basic transmission loss for the path exceeds the minimum permissible basic transmission loss.

3.1 *Level of maximum permissible interference*

The level of permissible interference power at the input of the receiver of a terrestrial or an earth station may, in the most general form, be expressed as the unwanted radio frequency power (P_r) from any one of n sources of interference, in a reference bandwidth (B), to be exceeded for not more than specified percentages of the time (p_i). For most practical purposes two such percentages of the time will be adequate; one (p_1), chosen to reflect normal (near median) conditions for which interference contributions from all interference sources may be assumed to occur simultaneously and to add on a power basis, given by:

$$P_r(p_1) = 10 \log (kT_rB) + J - 10 \log n_1 - W \quad \text{dBW} \tag{3}$$

and another (p_2), chosen to reflect significantly enhanced (small percentages of the time) interference conditions, for which interference contributions from all interfering sources may be assumed to occur non-simultaneously and to add on a percentage-of-the-time basis, given by:

$$P_r(p_2/n_2) = 10 \log (kT_rB) + J + M(p_2/n_2) - W \quad \text{dBW} \tag{4}$$

where,

- p_1, p_2: percentages of the time during which the interference from all sources may exceed the permissible level; p_1 represents long term ($p_1 \geqslant 1\%$), and p_2 short-term conditions ($p_2 \leqslant 1\%$);
- n_1: effective number of expected simultaneous equal-level interference contributions, associated with p_1;
- n_2: effective number of expected non-simultaneous equal-level and equal-percentage-of-time, interference contributions, associated with p_2;
- k: Boltzmann's constant, 1.38×10^{-23} J/K;
- T_r: noise temperature of receiving system (under clear sky conditions for earth stations), (K);
- B: reference bandwidth (in Hz) (bandwidth, of concern to the interfered-with system, over which the interference power can be averaged);
- J: ratio (in dB) of the permissible long term (20% of the time) interfering power to the thermal noise power in the receiving system; (see Note 2 of Report 382);
- $M(p_2/n_2)$: ratio (in dB) between the permissible interference powers during (p_2/n_2)% and 20% of the time respectively, for all entries of interference; (see Note 3 of Report 382);
- W: ratio (in dB) of incremental thermal noise power to interference power, at radio frequencies, in the reference bandwidth, for equivalent post-detection signal degradation (see Note 4 of Report 382);

Numerical values for these parameters are listed in Table I.

TABLE I – *Values of parameters relating to equations (1) and (2)*

Frequency range (GHz)		1-10	1-10	1-10	10-15	10-15	10-15	15-40	15-40
Service of interfering system		Fixed satellite	Fixed satellite	Fixed mobile	Fixed mobile	Fixed satellite	Fixed satellite	Fixed mobile	Fixed satellite
Wanted system	Service	Fixed mobile	Fixed mobile	Fixed satellite	Fixed satellite	Fixed mobile	Fixed mobile	Fixed satellite	Fixed mobile
	Station type	Radio-relay	Trans-horizon	Earth station	Earth station	Radio-relay	Radio-relay	Earth station	Radio-relay
	Modulation	A	A	A	A	A	N	N	N
p_1 (%)		20	20	20	20	20	20	20	20
n_1		2	1	3	2	2	2	4	1
p_2 (%)		0.01	0.01	0.03	0.03	0.01	0.003	0.003	0.003
n_2		2	1	3	2	2	1	1	1
B (Hz)		4×10^3	4×10^3	10^6	10^6	4×10^3	10^6	10^6	10^6
J (dB)		16	9	−8	−8	16	0**	0	0**
M (p_2/n_2) (dB)		17	17	17	17	17	30**	5*	30**
W (dB)		0	0	4	4	0	0	0	0
T_r (K)		750	500	—	—	1500	1500	—	3200

* $M(p_2/n_2)$ may assume values between 5 and 40 dB depending on frequency, rain climate and system design.

** These values are appropriate to the general case of uncorrelated fading of wanted and unwanted signals. Where this fading (due to rainfall) can be assumed to be substantially correlated (i.e., when the interference follows the same path as the wanted signal), values for J and M (p_2/n_2) different from those shown may be applicable.

3.2 *Minimum permissible basic transmission loss*

The minimum permissible basic transmission loss for 20% of the time is given by:

$$L_b(20) = P_{t'} + G_{t'} + G_r - P_r(20) \tag{5}$$

The minimum permissible basic transmission loss for p% of the time is given by:

$$L_b(p) = P_{t'} + G_{t'} + G_r - P_r(p) \tag{6}$$

where $p = p_2/n_2$ (from Table I), $P_{t'}$ and $G_{t'}$ are the pertinent parameters of the interfering station on the path of minimum transmission loss, and G_r, $P_r(p)$ and $P_r(20)$ are the pertinent parameters of the station suffering interference on the path of minimum transmission loss.

3.3 *Available basic transmission loss*

The calculation procedures explained in Report 569 or any other procedure acceptable to the administrations concerned may be used.

However, when the terrestrial station concerned is 25 to 100 km from the earth station, a rapid method can be applied which consists of using the curves shown in Figs. 1 and 2, which are deduced from Figs. 10-1-18 and 10-1-19 in the Annex to Chapter 10 of the S.J.M. Report (CCIR Special Joint Meeting, 1971). These curves show the available basic transmission loss values $L_0(0.01)$ and $L_0(20)$ for 0.01% and 20% of the time normalized to 4 GHz, and are applicable irrespective of the nature of the interference path (i.e., for both overland paths and oversea paths). The values for the available basic transmission loss, $L_{b1}(p)$% and $L_{b1}(20\%)$ for p% and 20% of the time, at any frequency, are deduced using the equations:

$$\begin{aligned} L_{b1}(p) &= L_0(0.01) + F(p) + 20 \log (f/4) \\ L_{b1}(20) &= L_0(20) + 20 \log (f/4) \end{aligned} \tag{7}$$

where $F(p)$ is shown in Fig. 1.

If either of the values thus obtained does not exceed the corresponding minimum permissible basic transmission loss, a more accurate method on the lines of those shown at the beginning of this section must be used.

4. **Determination of interference potential** (precipitation scatter)

In cases where interference may be due to rain scatter propagation, the minimum permissible transmission loss:

$$L(p) = P_{t'} - P_r(p) \tag{8}$$

must be calculated and compared with the loss due to rain scatter propagation. If the first value is less than the second, it can be said that the interference due to scattering from precipitation is negligible.

A method of calculating the available transmission loss between an earth station and a terrestrial station where the propagation mechanism is scattering due to precipitation, is given in Report 569.

5. **Consideration of fading**

When estimating the probability of interference between earth and terrestrial stations, account should be taken of the possibility of fading of the wanted signal while the unwanted signal is unchanged.

Further studies are required in order to assess fully the probability of interference, in the general case where both the wanted and unwanted signals vary, taking into account the statistical correlation.

A study conducted in the United Kingdom has shown that there may be some correlation between the incidences of multipath fading of the wanted signal and ducting or super refractive enhancements of the interfering signal. This is discussed further in Report 569.

6. Conclusion

It may be concluded that interference between an earth station and a terrestrial station is negligible when the interference power level for great circle propagation mechanism does not exceed the maximum permissible level of interference for 20% of the time, and also when the interference power level for all propagation mechanisms combined (i.e., great circle and rain scatter propagation mechanisms) does not exceed the maximum permissible level of interference for a small agreed percentage of the time.

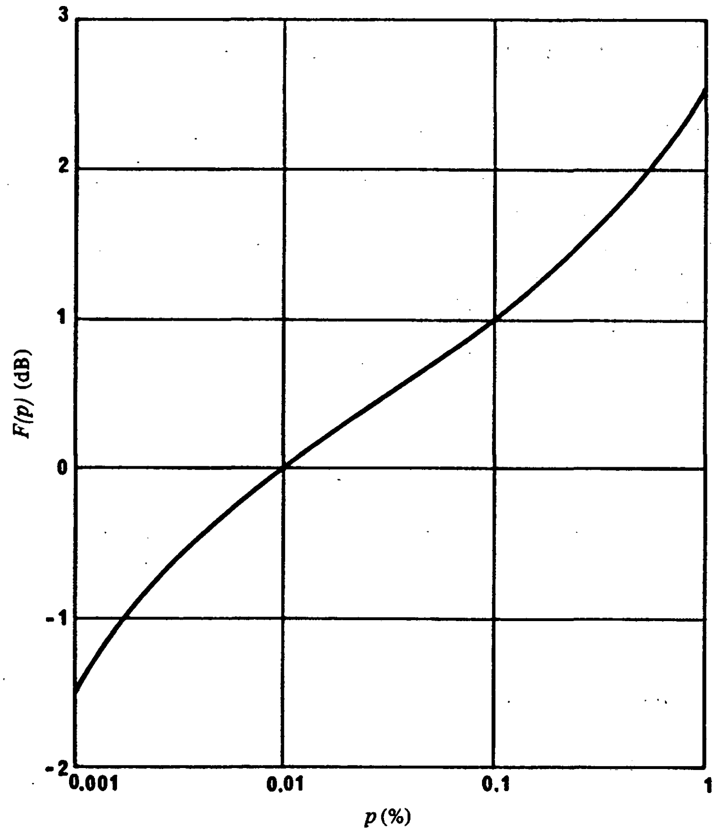


FIGURE 1 – *The time percentage correction factor F(p)*

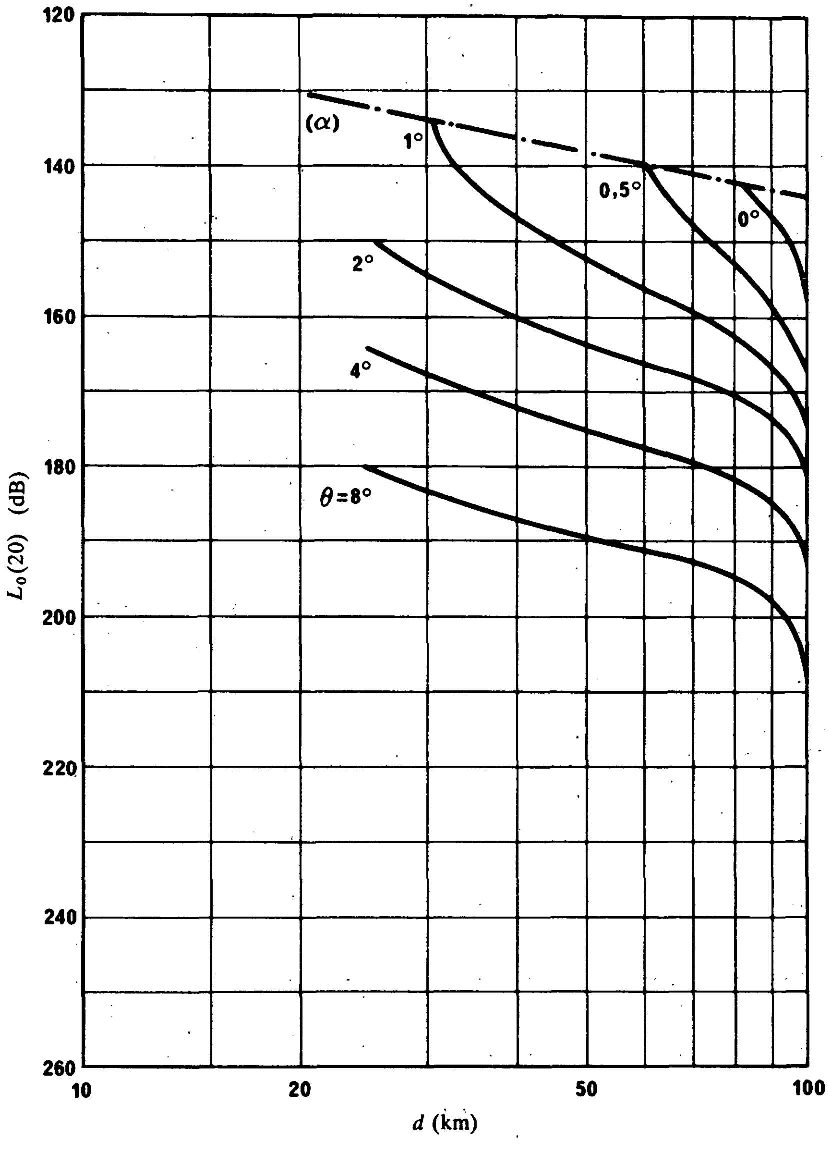


FIGURE 2a – *20% of the time*

(α): free space
d: distance (km) from the earth station to the terrestrial station
$L_0(20)$: basic path transmission loss (dB) normalized to 20% of the time and to 4 GHz
θ: angle of elevation of the physical horizon above the horizontal plane from the earth station in the direction the terrestrial station

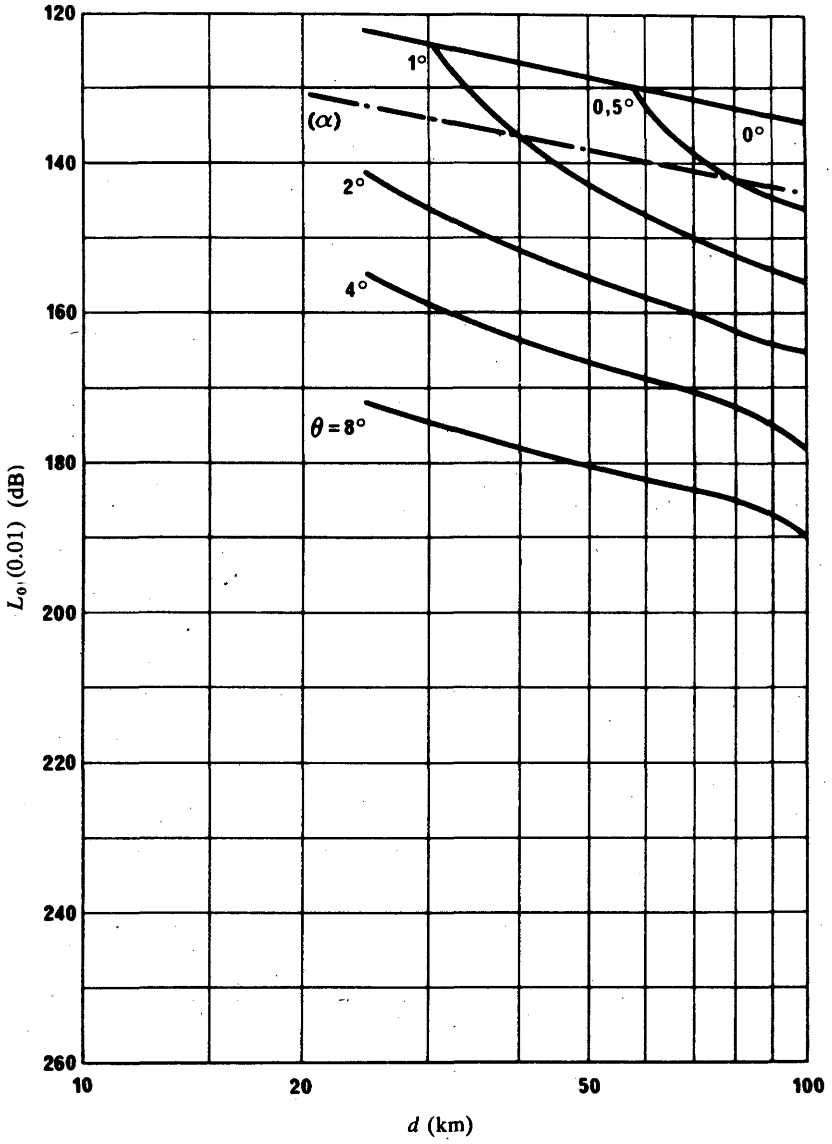


FIGURE 2b – *0.01% of the time*

(α):	free space
d:	distance (km) from the earth station to the terrestrial station
$L_0(0.01)$:	basic path transmission loss (dB) normalized to 0.01% of the time and to 4 GHz
θ:	angle of elevation of the physical horizon above the horizontal plane from the earth station in the direction of the terrestrial station

ANNEX I

AUXILIARY CONTOURS ASSOCIATED WITH AVOIDANCE ANGLE

For a rapid first approximation, particularly when terrestrial stations in an area are drawn on a map of that area, it may be helpful to use avoidance angle contours.

If concerned administrations agree, this method could be used as a supplementary procedure to that referred to in Report 382. However, as this method assumes that all terrestrial stations within the co-ordination area have the same radiation pattern and the same power equal to its maximum permissible value, a number of terrestrial stations which would be eliminated by the general method, given in § 2 of this Report will not be eliminated by the use of the avoidance angle concept.

On the basis of a reference radiation pattern for terrestrial station antennas, such as the one given by equation (3) in Report 614, it is possible to determine a set of auxiliary contours as a function of avoidance angle. The avoidance angle is defined as the azimuthal angle, φ, between the main beam axis of the terrestrial station antenna and the direction towards the earth station. These auxiliary contours for propagation modes (1) and (2) allow the elimination from further consideration of all terrestrial stations having avoidance angles $\geqslant \varphi$ and located outside of the auxiliary contours labelled φ.

The same auxiliary contours for propagation mode (1) drawn for reduced sensitivity S or e.i.r.p. may also be labelled with corresponding avoidance angle. The avoidance angle corresponding to a particular S or e.i.r.p. contour is calculated from the appropriate reference radiation pattern by using the difference between maximum gain and gain in the direction φ degrees off.

Auxiliary contours for propagation mode (2) with avoidance angle as parameter may be determined by an iterative process explained in [CCIR, 1978-82].

Figure 3 illustrates auxiliary contours for propagation modes (1) and (2) for a receiver earth station.

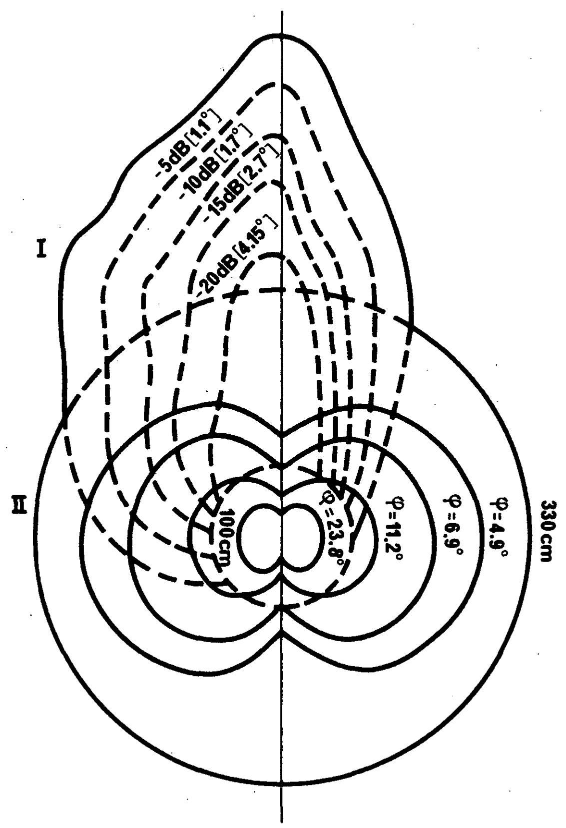


FIGURE 3 – *Example of auxiliary contours associated with avoidance angle φ, for propagation mode (1) (— —) and propagation mode (2) (——)*

REFERENCES

CCIR Documents

[1978-82]: 4/130 (9/101) (Yugoslavia (Socialist Federal Republic of)).

REPORT 388-5

METHODS FOR DETERMINING INTERFERENCE IN TERRESTRIAL RADIO-RELAY SYSTEMS AND SYSTEMS IN THE FIXED-SATELLITE SERVICE

(Questions 32/4 and 23/9, Study Programme 23A/9)

(1966-1970-1974-1978-1982-1986)

1. Introduction

The purpose of this Report is to determine interference in terrestrial radio-relay systems and systems in the fixed-satellite services as a function of the carrier-to-interference ratio, taking into account the modulation used for the transmission.

On the assumption that the interference can be expressed in terms of the spectrum of the interfering signal, general formulations of interference are provided, depending only on the modulation of the wanted signal, the spectrum of the interfering signal being used as a parameter. Simplified formulae or graphs are also shown in most cases.

Spectra of signals are provided to allow determination of interference from the general formulation. This can be done for any combination of wanted and interfering signals corresponding to the following types of modulation and transmission (including angular and amplitude modulations):

- FDM-FM telephony,
- single-channel-per-carrier FM telephony,
- digital PSK transmissions,
- FM television,
- AM telephony.

In the case of analogue telephony transmission (FM or AM telephony), the interference is expressed in terms of noise (in pW). In the case of digital PSK transmission, it is expressed in terms of bit error ratio (BER). In the case of FM television, the expressions given make it possible to estimate the permissible value of carrier-to-interference ratio.

Precautionary notes are included with respect to interference effects which are not predictable by determination based on spectra and with respect to non-linear channel effects.

Finally a large number of references are given to literature which deals with the complex subject of interference in greater depth and upon which the text of this Report was based.

2. Interference formulations

2.1 *Analogue FDM-FM telephony wanted signal*

2.1.1 *General formulation*

The relationship (this linear relationship is only valid for the lower levels of interference into FDM-FM telephony signals) between baseband interference power in a telephone channel and the carrier-to-interference ratio involves the interference reduction factor B (in dB), defined as follows:

$$B = 10 \log \frac{S/N_i}{C/I} \tag{1}$$

where:

S: test signal power in a telephone channel = 1 mW,

N_i: unweighted interference power in a telephone channel (bandwidth: 3.1 kHz),

C: power of the wanted signal carrier (W),

I: power of the interfering signal carrier (W).

The weighted interference power N_p (in pW) is obtained as unweighted power in 1.75 kHz, which gives:

$$10 \log N_p = 87.5 - B - 10 \log (C/I) \tag{2}$$

The interference reduction factor B is expressed as [Medhurst, 1962; Pontano *et al.*, 1973]:

$$B = 10 \log \frac{2 (\delta f)^2 \, p(f/f_m)}{b \, f^2 \, D(f, f_0)} \tag{3}$$

with:

$$D(f, f_0) = \int_{-\infty}^{+\infty} S(F) \, P_1 (f + f_0 - F) \, \mathrm{d}F + \int_{-\infty}^{+\infty} S(F) \, P_1 (f - f_0 - F) \, \mathrm{d}F + S(f + f_0) \, P_{10} +$$

$$+ S(f - f_0) \, P_{10} + S_0 P_1 (f + f_0) + S_0 P_1 (f - f_0) + \frac{S_0 \, P_{10}}{b} \, \delta (f - f_0) \tag{4}$$

$$P_1 (f) = P(f) \, A^2(f) \tag{5}$$

$$P_{10} = P_0 \, A^2(0) \tag{6}$$

$$\begin{aligned} \delta(f - f_0) &= 1 \quad \text{when} \quad f = f_0 \\ \delta(f - f_0) &= 0 \quad \text{when} \quad f \neq f_0 \end{aligned} \tag{6a}$$

where

δf: r.m.s. test tone deviation (without pre-emphasis) of the wanted signal (kHz);

f: centre-frequency of channel concerned, within the wanted signal baseband (kHz);

f_m: upper frequency of the wanted signal baseband (kHz);

$p(f/f_m)$: pre-emphasis factor for centre-frequency of channel concerned, within the wanted carrier baseband;

b: bandwidth of telephone channel (3.1 kHz);

f_0: separation between carriers of the wanted and interfering signals (kHz);

$S(f)$: continuous part of the normalized power spectral density of the wanted signal (Hz^{-1});

S_0: normalized vestigial carrier power of the wanted signal;

$P(f)$: continuous part of the normalized power spectral density of the interfering signal (Hz^{-1});

P_0: normalized vestigial carrier power of the interfering signal;

$A(f)$: amplitude-frequency response of the wanted signal receiving filter, the origin of the frequencies being the centre frequency of the interfering signal carrier.

The power spectral densities are normalized to unity and are assumed to be one-sided (only positive frequencies).

The expression of N_p in terms of the ratio C/I is derived from expressions (2) and (3). In order to determine N_p, it is necessary to determine:

- the wanted signal spectrum (analogue telephony),
- the interfering signal spectrum.

The expressions of these spectra are given in § 3 below.

2.1.2 *Interference between FDM-FM signals*

2.1.2.1 *General formulation*

See § 2.1.1, using expressions of spectra given in § 3.1 below. If within limits determined by the power spectral density of one of the interacting radio signals, equal to −25 and −30 dB, the power spectral density of the other signal is reduced below the maximum by not more than 3-5 dB, the convolution integral can be calculated with great accuracy from the approximate formulae given in [Borodich, 1983].

2.1.2.2 *Interference from a low-modulation-index FDM/FM signal to a high-modulation-index FDM-FM signal*

This case represents a terrestrial radio-relay system interfering into a system of the fixed-satellite service. The baseband channel which receives the most interference is not easily identified. However, the worst interference condition results when the wanted-to-unwanted carrier frequency separation is equal to, or less, than the top baseband frequency of the wanted signal.

The factor B can be determined from the following formula:

$$B = 10 \log \frac{1}{bf^2} \left\{ \frac{2(\delta f)^2 \, p(f/f_m)}{S(f_0 - f) + S(f_0 + f)} \right\} \tag{7}$$

If the modulation index of the wanted signal is greater than 3, the signal spectrum shape is near Gaussian, and formula (7) takes the following form [Medhurst and Roberts, 1964; Johns, 1966a and b]:

$$B = 10 \log \frac{1}{bf^2} \left\{ \frac{2\sqrt{2\pi} \, (\delta f)^2 \, p(f/f_m) \, f_s}{\exp\left[\frac{-(f_0 - f)^2}{2f_s^2}\right] + \exp\left[\frac{-(f_0 + f)^2}{2f_s^2}\right]} \right\} \tag{7a}$$

The definitions of the parameters in formulae (7) and (7a) have been given in § 2.1.1 with the exception of the following:

f_s: r.m.s. multi-channel deviation of the wanted signal (kHz)

$= \delta f \cdot 10^y \cdot (LF)^{1/2}$

LF: load factor, which is less than unity when not in the busy hour;

y	$= (-15 + 10 \log N_c)/20$	for	$N_c \geqslant 240$
	$= (-1 + 4 \log N_c)/20$	for	$60 \leqslant N_c < 240$
	$= (2.6 + 2 \log N_c)/20$	for	$12 \leqslant N_c < 60$

N_c: number of voice channels in the baseband.

Measurements indicate good agreement with calculated values of the factor B [CCIR, 1966-69].

2.1.2.3 *Interference from a high-modulation-index FDM-FM signal to a high-modulation index FDM-FM signal*

This case typically represents both interfering signals of systems in the fixed-satellite service. However, there are possible applications of high-index modulation in terrestrial radio-relay systems especially above 10 GHz where high-index FDM-FM modulation provides signal-to-noise advantages and resistance to interference.

The same comments as in § 2.1.2.2 apply concerning the baseband channel with the most interference and the worst frequency separation. Moreover, the factor B is identical to that given in formula (7) of § 2.1.2.2 with substitution of F_s for f_s.

F_s is defined as follows:

$$F_s = \sqrt{f_{s_1}^2 + f_{s_2}^2}$$

where f_{s1} and f_{s2} are the r.m.s. multichannel frequency deviations of the wanted and interfering signals (kHz).

2.1.2.4 *Interference between FDM-FM signals with intermediate modulation indices*

To calculate the interference between specific signals with low modulation indices at a given carrier frequency separation, the first step is to calculate the convolution of the spectra of these signals using formula (4) and then to apply formulae (3) and (2) to determine the interference in the telephone channels.

Section 3 contains graphs of normalized FDM-FM signal spectra for typical radio-relay and communication-satellite systems. These graphs may be used to calculate the convolution.

Figure 1 contains a number of curves of normalized spectra as a function of the modulation index for given normalized frequency values. These curves may readily be used to plot the spectrum graph for any modulation index from 0.1 to 3. When $m > 3$, the signal spectrum shape is near Gaussian. If the modulation indices of the wanted and interfering signals are greater than 3, formula (7) should be applied to calculate interference, taking into account § 2.1.2.3.

In certain special cases, where the interfering signal may be characterized by its r.m.s. modulation index, and the upper baseband frequency is equal to the wanted signal (i.e. $f_{m1} = f_{m2}$) there is the possibility of calculating the interference function, $D(f, f_0)$, very simply from the normalized curves of Fig. 1.

The equivalent modulation index is determined by:

$$m = [m_1^2 + m_2^2]^{1/2}$$

and for this value of m on the curves in Fig. 1 we find the values $f_m S(f_1)$ and $f_m S(f_2)$, where:

$$f_1 = \frac{(f_0 + b)}{f_{m1}} \quad \text{and} \quad f_2 = \frac{(f_0 - b)}{f_{m1}},$$

and further

$$D(f, f_0) = \frac{1}{f_{m1}} [f_m S(f_1) + f_m S(f_2)]$$

The same method may be used for the approximate determination of $D(f, f_0)$ according to the value of the "equivalent" modulation index:

$$m = \left[m_1^2 + m_2^2 \left(\frac{f_{m2}}{f_{m1}}\right)^2\right]^{\frac{1}{2}}$$

when

$$f_{m2} < f_{m1} \quad \text{and} \quad m_2^2 \left(\frac{f_{m2}}{f_{m1}}\right)^2 \ll m_1^2$$

The symbols used are defined as follows:

f_0: carrier frequency separation;

f_{m1}, f_{m2}: mid frequency of the top baseband channel of the desired and interfering signals respectively;

m_1, m_2: r.m.s. modulation indices of desired and interfering signal respectively.

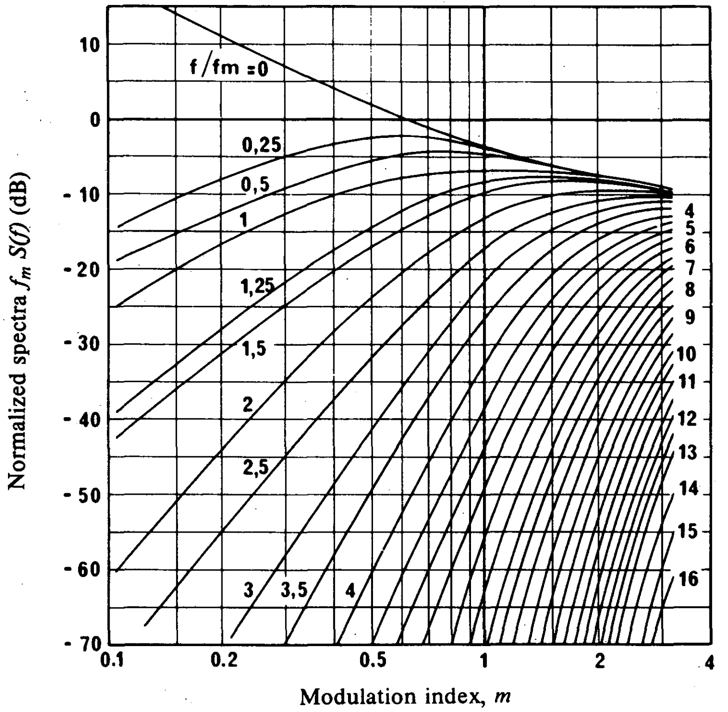


FIGURE 1 – *Normalized spectral density of FDM-FM signals*

2.1.2.5 *Interference from a high-modulation-index FDM-FM signal to a low-modulation-index FDM-FM signal*

This case is typically that of a system in the fixed-satellite service causing interference in a terrestrial radio-relay system. Low-index angle modulation can be regarded as quasi-linear with respect to some types of interfering signal; the calculation of interference in these cases is performed by a simple procedure analogous to that employed for linear DSBAM.

The following approximate formula can be used:

$$\left\{\frac{\text{Interference power in telephone channel}}{\text{Thermal noise power in telephone channel}}\right\} = \left\{\frac{\text{Interfering signal power in two appropriate 4 kHz bands at the receiver input}}{\text{Thermal noise power in same two 4 kHz bands at the receiver input}}\right\}$$

2.1.3 *Interference from angle-modulated digital signals into FDM-FM signals*

Digital systems using PSK or FSK modulation are classes of angle-modulated systems. Consequently, the interference from these systems into analogue, angle-modulated systems is computed by the convolution integral. However, the spectral densities of digital, angle-modulated signals cannot be easily generalized; a specific spectrum is, however, provided in § 3.3. More generalized computation would involve the calculation of the digital spectral density (see § 3.3) the calculation of the analogue spectral density [Ferris, 1968], the convolution of the two densities [Prabhu and Enloe, 1969], and the computation of the factor B.

When a high-modulation-index FDM-FM carrier receives interference from angle-modulated digital signals that occupy a bandwidth small compared with that of the wanted signal, factor B is given roughly by the formula (7).

[CCIR, 1970-74a] gives calculated values of factor B for interference to FDM-FM signals from digital PM signals.

If a wanted FDM-FM signal suffers interference from an unwanted PCM-PSK or DPSK-PM signal that occupies a bandwidth which is large compared with that of the wanted signal, factor B is given by the following simplified formula:

$$B = 10 \log \frac{1}{bf^2} \left\{\frac{2(\delta f)^2 \, P(f/f_m)}{P(f_0 - f) + P(f_0 + f)}\right\} \tag{7b}$$

The normalized spectral power density of the interfering signal $P(f)$ used in this formula is determined by formula (18) given in § 3.3 below.

2.1.4 *Interference from AM signals into FDM-FM signals*

The quasi-linear properties of low-modulation-index angle-modulated signals with respect to interfering signals whose spectral densities do not exhibit excessive variations within the receiver passband, permit the use for such cases of the following approximate formula:

$$\left\{\frac{\text{Interference power in telephone channel}}{\text{Thermal noise power in telephone channel}}\right\} = \left\{\frac{\text{Interfering signal power in two appropriate 4 kHz bands at the receiver input}}{\text{Thermal noise power in same two 4 kHz bands at the receiver input}}\right\}$$

Two 4 kHz bands are used in the formula since there may be asymmetry of the interfering spectrum with respect to the wanted carrier. When a high-modulation-index angle-modulated system receives interference from amplitude-modulated digital signals that occupy a bandwidth small compared with that of the wanted signal, factor B is given roughly by the formula of § 2.1.2.2.

Calculated values of factor B for interference to FDM-FM signals from digital AM signals are available [CCIR, 1970-74a].

2.1.5 *Interference from a narrowband system into an FDM-FM system*

The theoretical expression of § 2.1.1 [Pontano *et al.*, 1973] can be applied to the case of an interfering signal of arbitrary modulation, but with bandwith small compared with that of the interfered-with signal. Interference from SCPC to FDM-FM signals is an example of such a situation. Results are given in [CCIR, 1978-82a and Prasanna *et al.*, 1977] for several SCPC systems having a wide range of characteristics.

2.1.6 *Interference from FM-TV signals into FDM-FM, signals*

When (1) the FM-TV signal modulated only by the dispersal waveform is the interfering signal, (2) the FDM-FM wanted signal with a low number of telephone channels has a spectrum with a width commensurate with that of the interfering signal spectrum, and (3) the carrier frequencies coincide, then formula (4) takes the form:

$$D(f, 0) = P\left[\int_{f-\Delta f/2}^{f+\Delta f/2} S(F)\,dF - \int_{f+\Delta f/2}^{f-\Delta f/2} S(F)\,dF\right] = 2P\int_{-\Delta f/2+f}^{\Delta f/2+f} S(F)\,dF,$$

where:

Δf: frequency deviation of dispersal waveform (peak-to-peak),

$P = 1/\Delta f$ spectral power density of interfering signal (see Fig. 8, $i = 1$).

In the conditions described above, and with reference to formula (3), we may consider that:

$$\int_{-\Delta f/2+f}^{\Delta f/2+f} S(F)\,dF \approx 1 \qquad \text{when} \quad f < f_{m1}$$

so that:

$$B = 10 \log \frac{(\delta f)^2\, \Delta f\, p\,(f/f_m)}{f^2\, b}.$$

2.2 *Single-channel-per-carrier FM telephony wanted signal*

Further studies are required on this item.

2.3 *Digital PSK wanted signal*

Several techniques have been used to calculate the error performance of systems using phase-shift keyed modulation with coherent detection (CPSK) and with differential detection (DPSK) when corrupted by various types of interference and Gaussian noise. One method often used is to represent the interference by additive Gaussian noise of equal power. Where interference is entirely contained within the passband of the wanted system, it can be represented by a sum of randomly-phased sinusoids. Here, exact analytical results can be obtained for the error probability of CPSK and DPSK when subjected to multiple co-channel interferences and Gaussian noise [Rosenbaum, 1969 and 1970].

In many practical situations where an exact statistical distribution of the various interferences is not available, a useful technique is to compute an upper bound on the probability of error [Rosenbaum and Glave, 1974]. This method requires knowledge only of the carrier-to-noise ratio at the demodulator input (C/N), the peak-to-r.m.s. ratio of the interference and the ratio of the powers of the wanted signal and interference (C/I). It should be noted that the results apply to a theoretical system and take no account of practical system restraints; they may be substantially modified by the presence of jitter and other degradations encountered in practical systems.

Other studies which are in progress will provide results for various cases of practical interest, including the effect of frequency separation between the wanted and unwanted carriers [Davies, 1972].

2.3.1 *General information*

The effect of the interference is considered in terms of the increase in error ratio over the rate obtained without interference. If the permissible bit error ratios with and without interference are designated as $(\text{BER})_a$ and $(\text{BER})_0$ respectively.

– *CPSK signals*

The bit error ratio without interference $(\mathrm{BER})_0$ is given in terms of the ratio of the energy per bit to the noise density (E/N_0) by the following formula:

$$(\mathrm{BER})_0 = \frac{1}{2} \operatorname{erfc} \left(\sqrt{\frac{E}{N_0}} \right) \tag{8}$$

where,

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{+\infty} e^{-t^2} \, dt \tag{9}$$

The value of E/N_0 for a specific (BER_0) may be deduced from equations (8) and (9). The BER_a value of the bit error ratio obtained with interference is deduced from the E/N_0 value by the expression [Rosenbaum, 1969]:

$$(\mathrm{BER})_a = \frac{1}{2\pi} \int_0^{\pi} \operatorname{erfc} \left[\sqrt{\frac{E}{N_0}} \left(1 + \frac{\cos \varphi}{\sqrt{\beta \frac{C}{\alpha I}}} \right) \right] d\varphi \tag{10}$$

where β has a value of 1 if the modulation of the wanted signal is two-condition and a value of 1/2 if the modulation of the wanted signal is four-condition. The factor α is the power fraction of the interfering signal by the wanted signal receiving filter. If $A(f)$ is the amplitude-frequency response of this filter, α is obtained from the expression:

$$\alpha = \int_{-\infty}^{+\infty} A(f) \left[P(f) + P_0 \, \delta \right] df \tag{11}$$

where $P(f)$ and P_0 have the same meanings as in 2.1.1 (normalized spectral power densities of interfering signal); these can be found in § 3.

Formula (10) assumes that interference is angle-modulated. In the case of an amplitude-modulated interfering signal (suppressed carrier), formula (8) should be used, where N_0 is the sum of interference and thermal noise power densities.

– *DPSK signals*

Further studies are required.

2.3.2 *Interference to digital signals transmitted by CPSK*

Curves are presented in Figs. 2 to 5 of combinations of C/N and C/I ratios that give rise to upper-bound bit-error probabilities of 10^{-3}, 10^{-5}, 10^{-7} and 10^{-9}, respectively. These curves apply to cases of single or multiple interferences. The parametric curves are presented as a function of the interference peak factor,

$$PF = 20 \log \frac{R}{\tau_r}$$

where:

R: peak value of the interference envelope,

τ_r: root mean square value of the interference envelope.

An unfiltered angle-modulated signal has a value of:

$$PF = 0$$

under this definition.

The upper bound on P_e (symbol error probability) for M-ary CPSK can be obtained from the binary CPSK bound as follows:

$$P_e\,(M\text{-ary}) \text{ at } [C/N]_1 = 2\, P_e\,(\text{binary}) \text{ at } ([C/N]_1 + 10 \log [\sin^2 (\pi/M)])$$

where:

$$C/I(M\text{-ary}) = C/I(\text{binary}) - 10 \log [\sin^2 (\pi/M)].$$

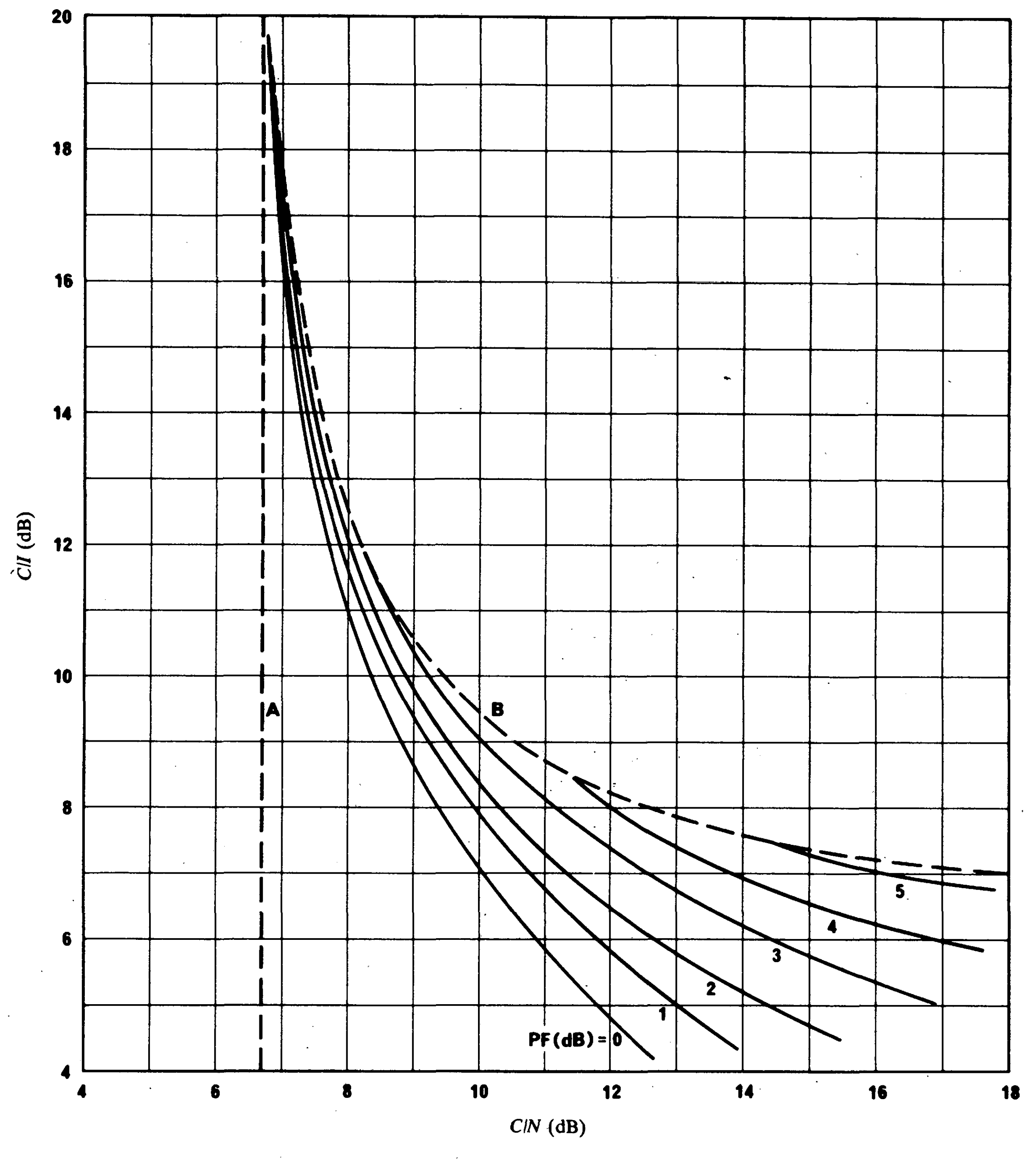


FIGURE 2 – *C/I v. C/N for 10^{-3} BER*

A: *C/N* in absence of interference
B: Interference with characteristics of thermal noise
PF: The interference peak factor

Note. – The curves are theoretical and take no account of practical system restraints.

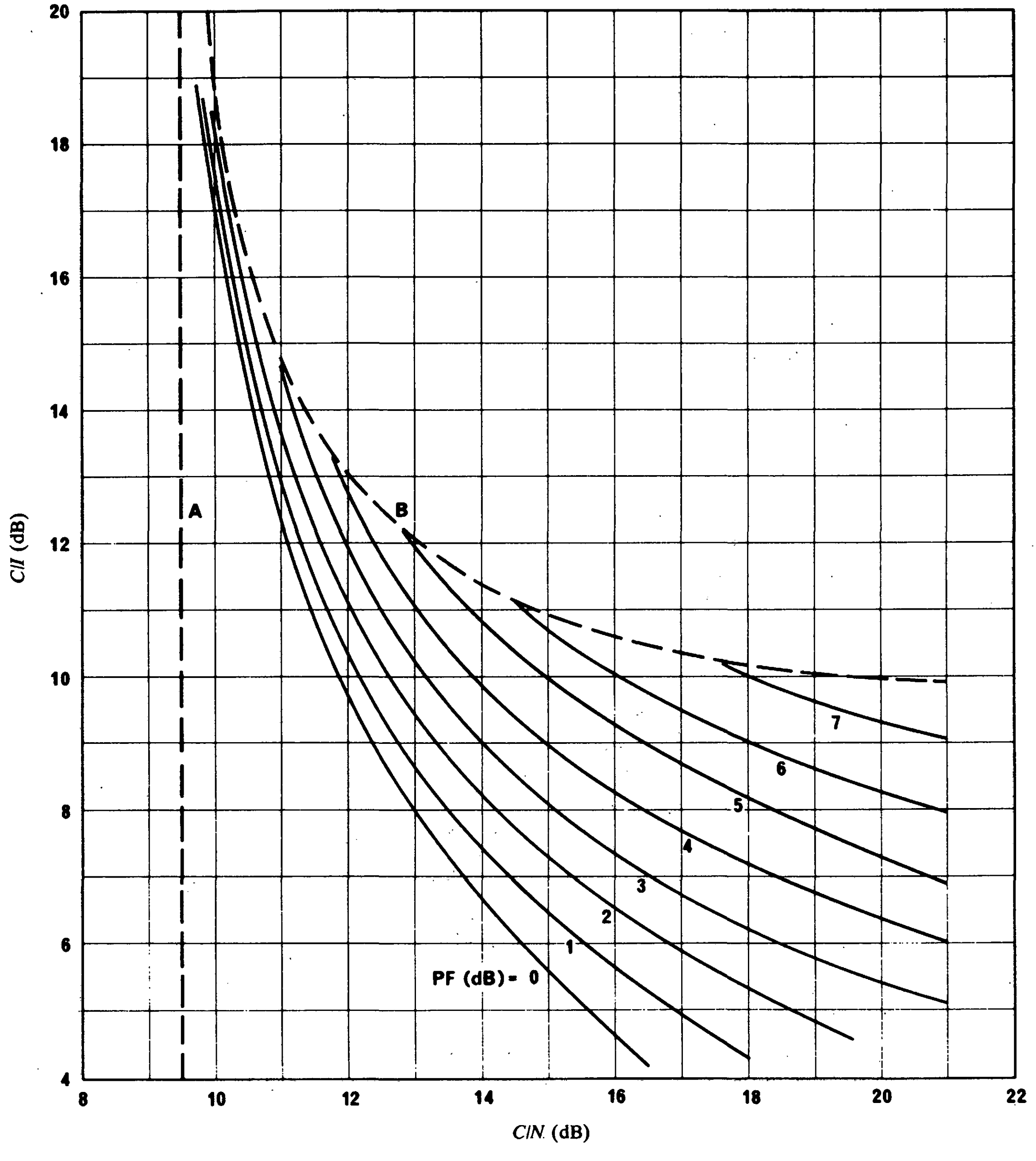


FIGURE 3 – *C/I v. C/N for* 10^{-5} *BER*

A: *C/N* in absence of interference
B: Interference with characteristics of thermal noise
PF: The interference peak factor

Note. – The curves are theoretical and take no account of practical system restraints.

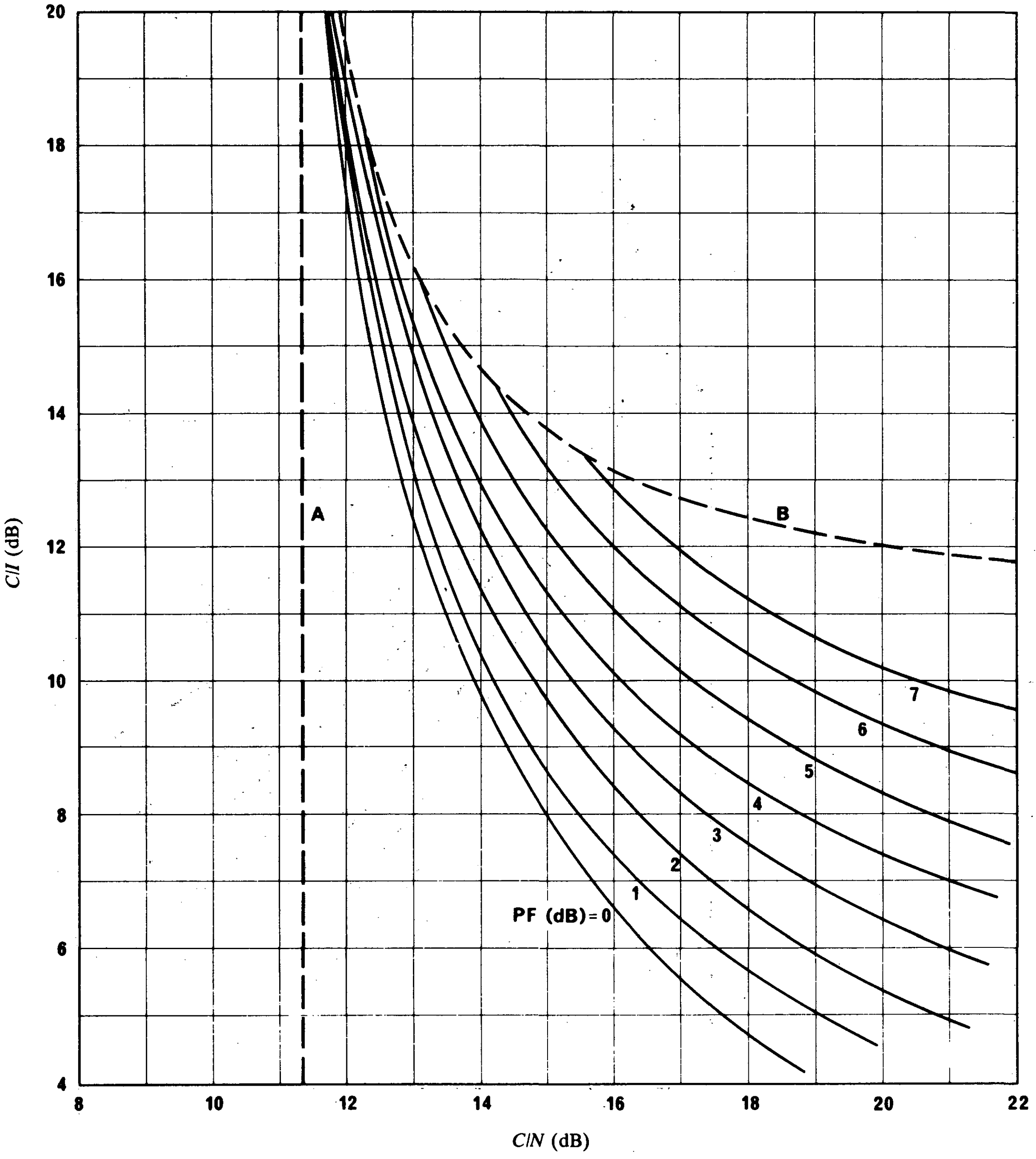


FIGURE 4 – *C/I v. C/N for 10^{-7} BER*

A: *C/N* in absence of interference

B: Interference with characteristics of thermal noise

PF: The interference peak factor

Note. – The curves are theoretical and take no account of practical system restraints.

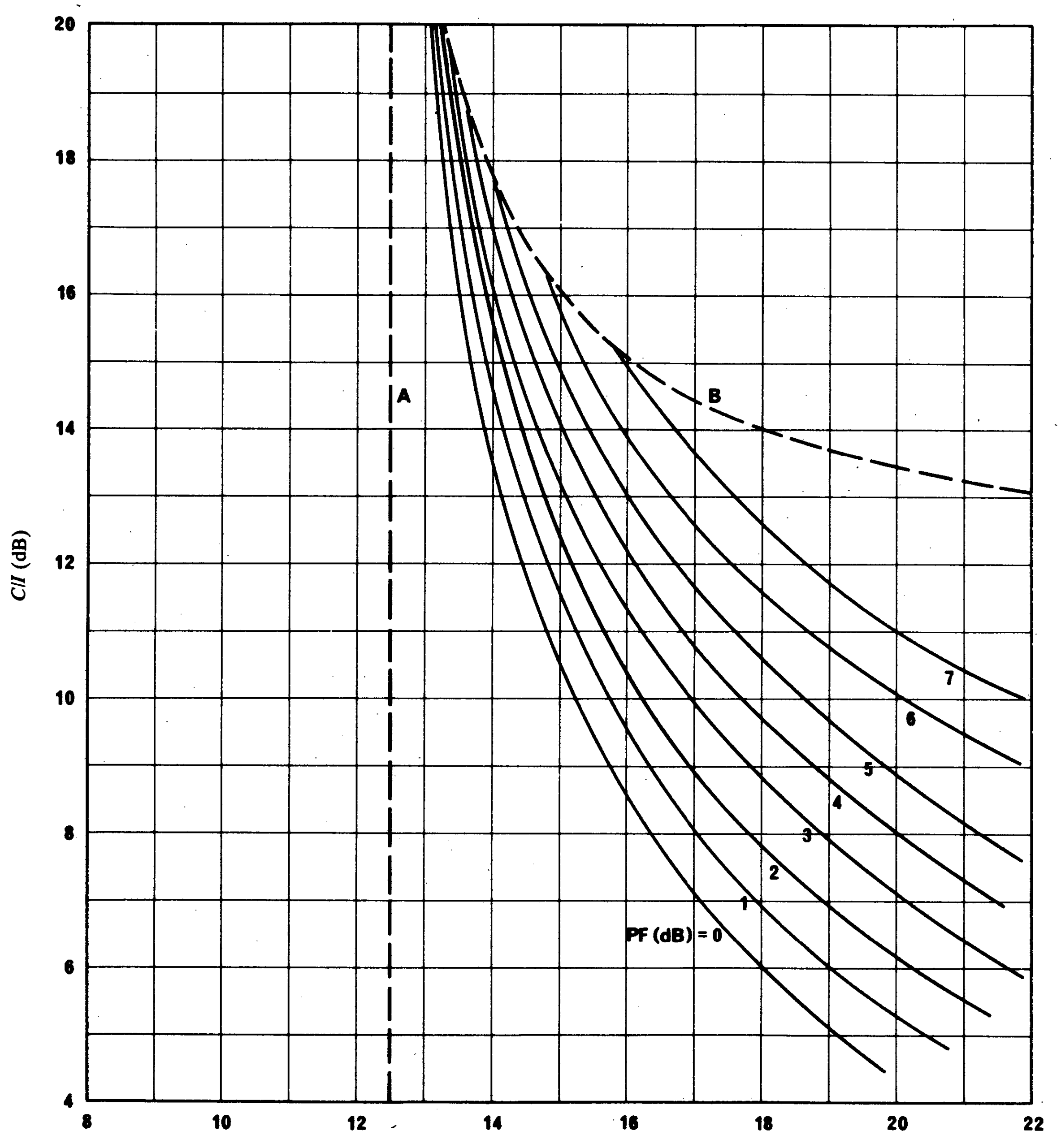
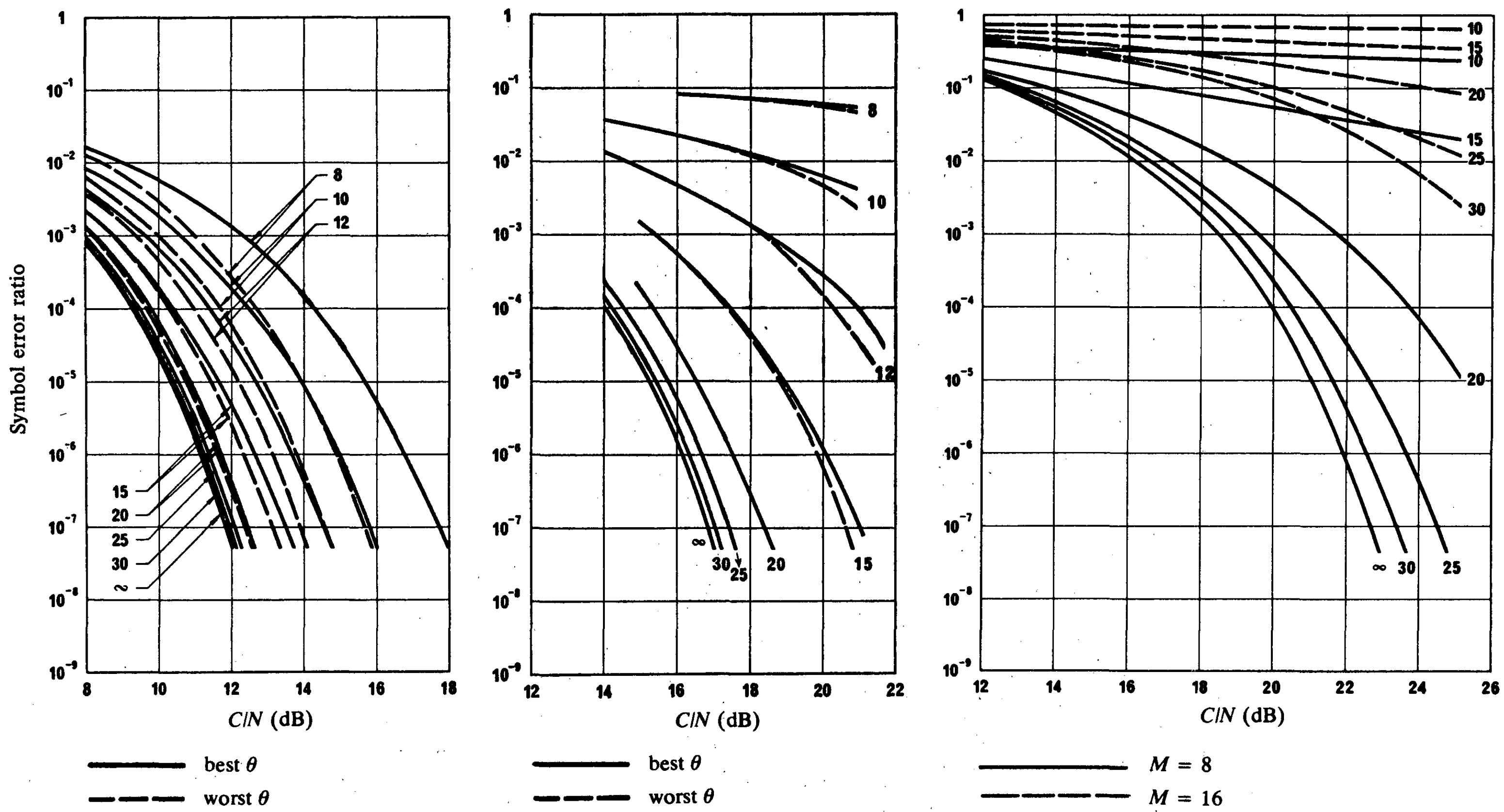


FIGURE 5 – *C/I v. C/N for* 10^{-9} *BER*

A: *C/N* in absence of interference
B: Interference with characteristics of thermal noise
PF: The interference peak factor

Note. – The curves are theoretical and take no account of practical system restraints.



(a) Binary (M= 2)

(b) Quarternary (M = 4)

(c) Eight-phase (M = 8) and sixteen-phase (M = 16)

(The carrier-to-interference ratio C/I (dB) is shown on each curve)

FIGURE 6 – *Interference to a DPSK signal from an angle-modulated signal*

Results identical with those given in [Rosenbaum, 1969] for a single angle-modulated signal (FM, PM, CPSK, or DPSK) interfering with binary CPSK can be obtained directly from the $PF = 0$ curves of Figs. 2 to 5. The corresponding results for interference to ternary and quarternary CPSK can be obtained indirectly from the same curves through the use of the foregoing formulae.

The following general conclusions can be drawn by inspection of the Figures:

- when the interfering signal power is equal to, or larger than, the thermal noise power, the effect of angle-modulation interference is considerably less than that of an equal amount of white Gaussian noise power;
- when the interfering signal power is small compared to the thermal noise power, the effect on error rate can be estimated safely by assuming that the interfering signal is equivalent to Gaussian noise of equal power;
- at a given carrier-to-interference ratio, the vulnerability to interference increases substantially as the number of transmitted phases, M, increases.

2.3.3 *Interference to DSPK signals from angle-modulated signals*

Curves of symbol error ratio against C/N ratio, with C/I ratio as a parameter, for differentially-coherent signals with 2, 4, 8 and 16 transmitted phases, are shown in Fig. 6. The error probability for differential detection is seen to be dependent on an additional parameter, θ, which is the relative phase slip of the interference from one sample to the next. However, the θ dependency diminishes as the number of transmitted phases increases. As a result, θ is assumed as a uniformly distributed random variable for systems with higher than four transmitted phases. Hence, average error probabilities have been derived for $M = 8, 16$; and probability bounds have been derived for the binary and quaternary cases.

The curves for DPSK imply the same conclusions as to the CPSK curves regarding the relative interference effects of white noise and angle-modulated signals, and the dependence of these effects on M. In addition, it can be seen that, in general, differential detection suffers more degradation than coherent detection, except that binary DPSK performs about as well as binary CPSK. Interference degradation is used as a basis for comparison because any disparities in the noise only performance are reconciled.

2.4 *Frequency-modulated television wanted signal*

A protection ratio (R) which can be introduced, represents the carrier-to-interference ratio corresponding to a given impairment. As a result of tests carried out in France, with the interfering signal being an unmodulated carrier, the values of R given in Fig. 7 are expressed as a function of the frequency separation (f_0) between the wanted and interfering signal carriers. The curve in Fig. 7, composed of two straight line segments and two half-lines, is an empirical curve plotted from test data ($\Delta F =$ frequency deviation in the low frequencies of the wanted signal, in MHz).

The subjective interference level chosen was that corresponding to the perceptibility threshold without thermal noise, for an observer placed in a dimly lit room at a distance from the screen equal to six times the height of the picture.

The permissible value $(C/I)_a$ of this ratio is obtained from the expression.

$$\left(\frac{C}{I}\right)_a = \int_{-\infty}^{+\infty} R\,(f-f_0)\; A\,(f)\; [P(f) + P_0\,\delta]\; \mathrm{d}f \tag{12}$$

where $P(f)$, P_0 and $A(f)$ have the same meaning as in 2.1.1.

Calculation of $(C/I)_a$ can be performed once the interfering spectrum is specified (see § 3).

2.5 *Amplitude modulated telephony wanted signal*

2.5.1 *General information*

Further studies are required on this item.

2.5.2 *Interference between amplitude-modulated signals*

The K_4 factor is defined as the amount (in dB) by which the signal-to-interference power ratio exceeds the ratio of the signal spectral density in the appropriate 4 kHz band at the receiver input to the interference density at the same bandwidth.

In consequence of the property of linear modulation of translating interfering signals directly to baseband, the value of the factor K_4 is simply 0 dB for SSBSC, and 3 dB for DSBSC.

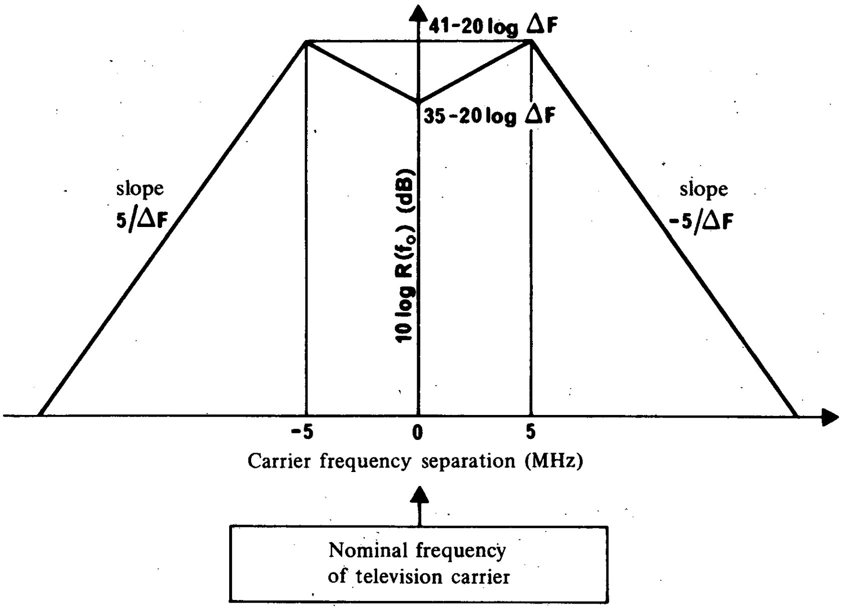


FIGURE 7 – *Protection ratio R (expressed in dB)*

Wanted signal: frequency-modulated TV carrier
Interfering signal: pure carrier

ΔF: frequency deviation in the low frequencies of the wanted signal (frequency-modulated TV), in MHz.

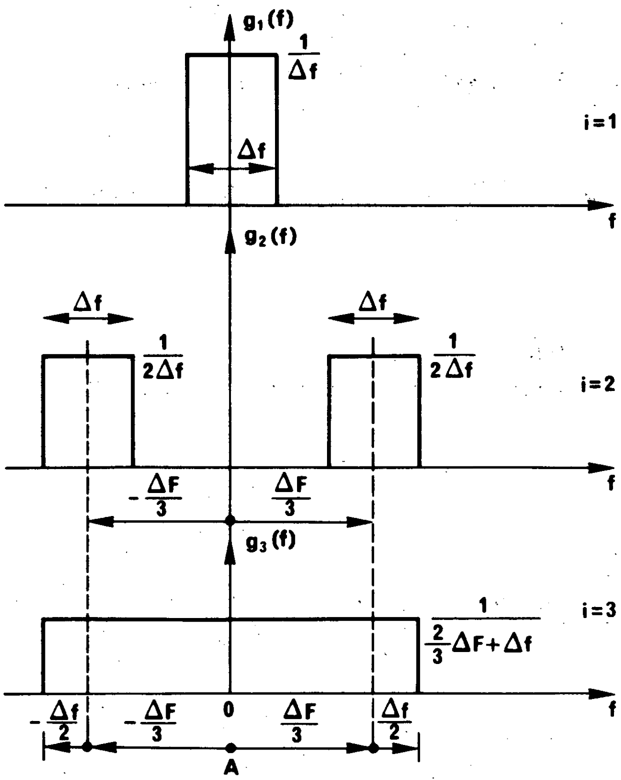


FIGURE 8 – *Frequency-modulated television signal*

Models used to represent the central part of the spectrum

A: Nominal frequency.

2.5.3 *Interference to amplitude-modulated signals from angle-modulated signals*

The values of factor K_4 are again 0 dB for SSBSC, and 3 dB for DSBSC.

The baseband spectrum of the interference will be identical with that of the RF interfering spectrum in the SSBSC case, and with the sum of the RF interfering spectra falling on the upper and lower sidebands in the DSBSC case. As a result, angle-modulated interference with strong carriers will generate tone-interference at baseband. The channel arrangement of AM systems will generally need to take account of this mode of interference.

3. Signal spectra

3.1 *Analogue telephony (FDM-FM) signal*

The signal's normalized power spectral density centred on the carrier frequency is expressed [Borodich, 1976] as:

$$P(f) = e^{-a}\left[\delta(f) + \sum_{n=1}^{\infty} \frac{m^{2n}}{n!} S(f)^{n}_{*} S(f)\right] \tag{13*}$$

where:

$\delta(f)$: Dirac delta function,

$S(f)^{n}_{*}S(f)$: convolution of the function $S(f)$ n times itself.

$S(f)$: normalized spectral density of the signal phase:

$$S(f) = \frac{f_m \, p(f/f_m)}{2f^2(1-\varepsilon)} \tag{14}$$

where ε is the lower to upper frequency ratio in the wanted signal baseband.

The CCIR pre-emphasis characteristics is well approximated by the expression:

$$p(f/f_m) = 0.4 + 1.35\left(\frac{f}{f_m}\right)^2 + 0.75\left(\frac{f}{f_m}\right)^4, \quad \text{when} \quad \varepsilon \leqslant \frac{f}{f_m} \leqslant 1 \tag{15}$$

Here

$$a = R_s(0) - R_s(\infty) \simeq \frac{m^2}{\varepsilon}(0.4 + 1.6\,\varepsilon + 0.25\,\varepsilon^2 + 0.25\,\varepsilon^3) \approx \frac{m^2}{\varepsilon}(0.4 + 1.6\,\varepsilon) \tag{16}$$

where:

$R_s(\tau)$ is the autocorrelation function of $S(f)$.

The normalized power of the vestigial signal carrier is expressed as e^{-a}.

When $m > 1$:

$$P(f) = \frac{1}{f_s\sqrt{2\pi}} e^{-\frac{f^2}{2f_s^2}} \left\{1 + \sum_{n=2}^{\infty} (-1)^n \frac{C_{2n}}{m^{2n}\,2^n} H_{2n}\left(\frac{f}{f_s\sqrt{2}}\right)\right\} \approx$$

$$\approx \frac{1}{f_s\sqrt{2\pi}} e^{-\frac{f^2}{2f_s^2}} \left\{1 + \frac{6.375\cdot 10^{-2}}{m^2} H_4^*\left(\frac{f}{f_s\sqrt{2}}\right) + \frac{7.416\cdot 10^{3}}{m^4} H_6^*\left(\frac{f}{f_s\sqrt{2}}\right) + \right.$$

$$\left. + \left(\frac{2.37\cdot 10^{-2}}{m^4} + \frac{7.16\cdot 10^{-4}}{m^6}\right) H_8^*\left(\frac{f}{f_s\sqrt{2}}\right) + \left(\frac{9.929\cdot 10^{-3}}{m^6} + \frac{5.854\cdot 10^{-5}}{m^8}\right) H_{10}\left(\frac{f}{f_s\sqrt{2}}\right)\right\} \tag{17}$$

* Although the series of formula (13) coverages for all values of system parameters, it does not always provide the most appropriate algorithm for numerical computation, particularly in cases where the normalized r.m.s. multichannel phase and/or frequency deviation (a and m respectively) are large.

where:

f_s: r.m.s. multichannel signal frequency deviation.

$H^*_{2n}(x) = (-1)^n \frac{n!}{(2n)!} H_{2n}(x)$: normalized Hermite polynomial.

Figures 9a to 9e contain spectral graphs plotted according to formula (13) and (17) for modulation indices m adopted in typical radio-relay and communication-satellite systems.

The curves are approximate in the region f/f_m near 0 and 1. The exact values depend upon the particular value of ε. The exact curves for several values of ε are given [CCIR, 1982–86a] in Figs. 9f to 9j for f/f_m near zero. (The inset curves in Figs. 9d to 9e are also accurate enough for f/f_m near zero if ε is equal to or greater than 0.02.)

For modulation indices greater than 1.1, the following empirical formula has been found to fit adequately the curves of $P(f)$ and is a good approximation of equation (17):

$$f_m \cdot P(f) = \frac{1}{m\sqrt{2\pi}} e^{-\frac{x^2}{2m^2(1 + 0.01337\, x^2 \cdot m^{-3.367})}} \tag{17a}$$

where:

$x = f/f_m$

This empirical formula is an adaptation of the Gaussian formula for large modulation indices. For the latter, see [Pontano *et al.*, 1973].

The problems associated with the practical evaluation of F.M. spectra are discussed in [Middleton, 1951; Stewart, 1954; Medhurst *et al.*, 1958; Medhurst, 1960; Ferris, 1968; Borodich, 1976; CCIR, 1978-82b].

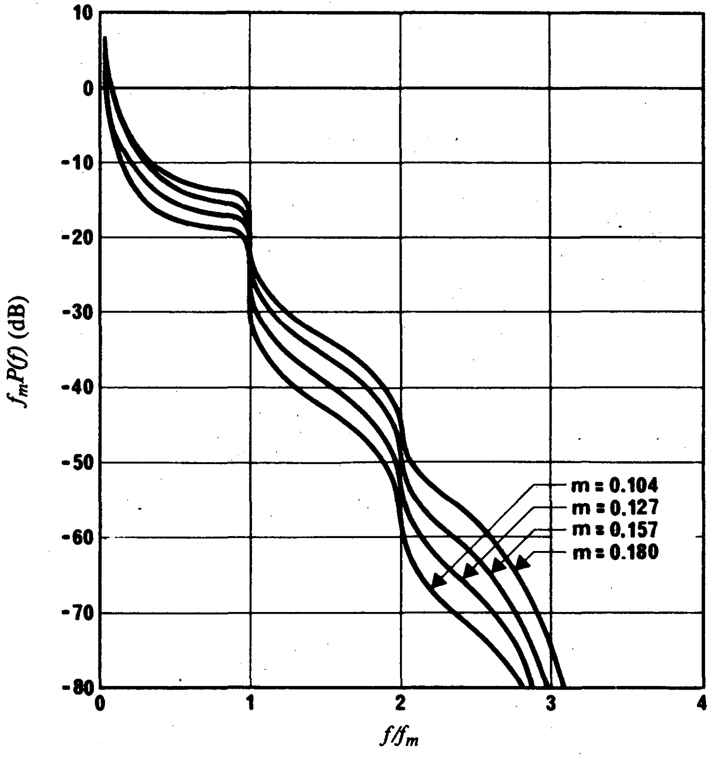


FIGURE 9a – *Normalized power spectral densities for various modulation indices*

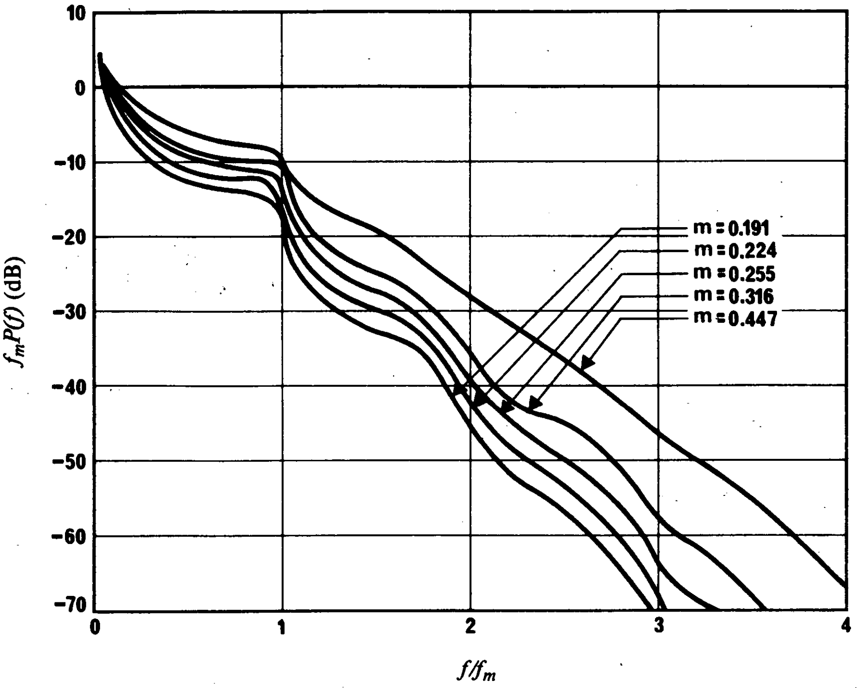


FIGURE 9b – *Normalized power spectral densities for various modulation indices*

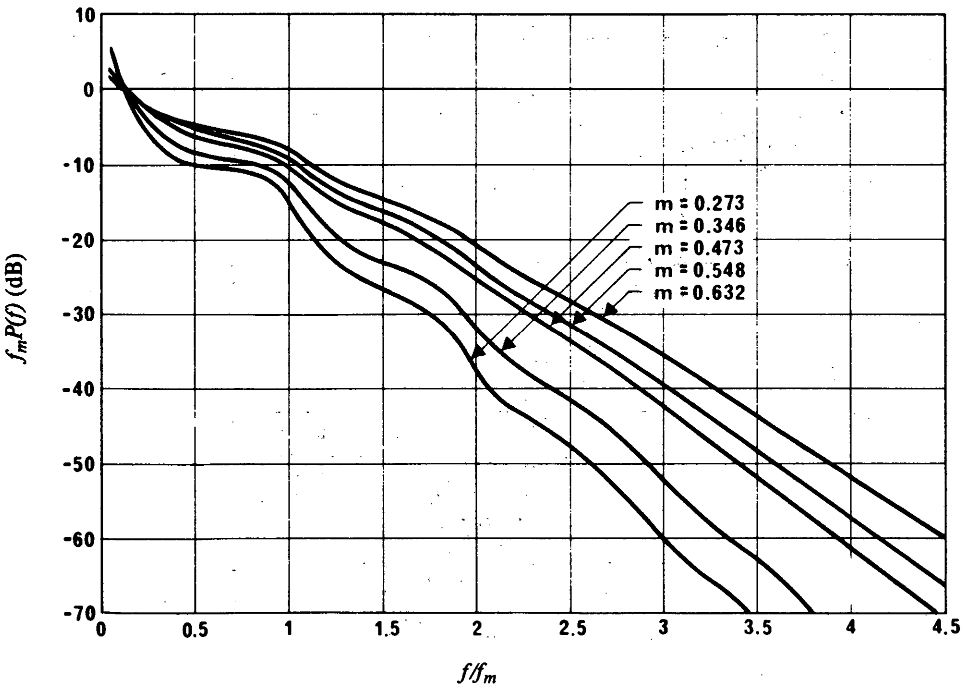


FIGURE 9c – *Normalized power spectral densities for various modulation indices*

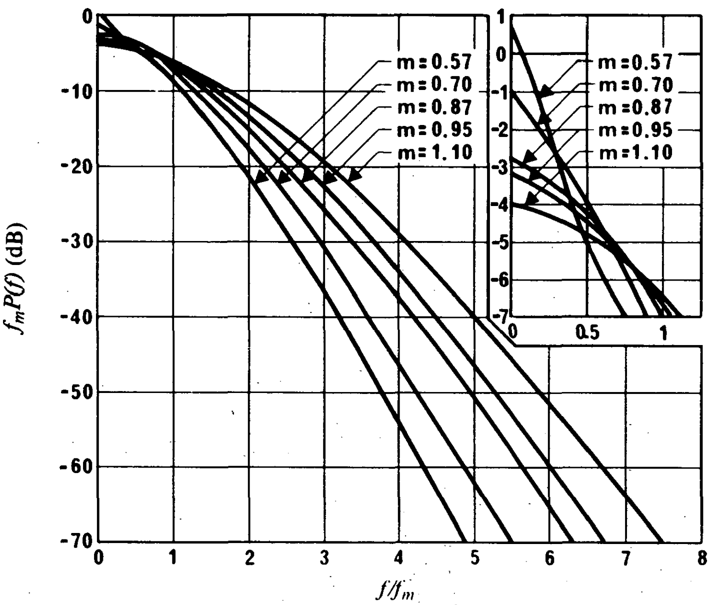


FIGURE 9d – *Normalized power spectral densities for various modulation indices*

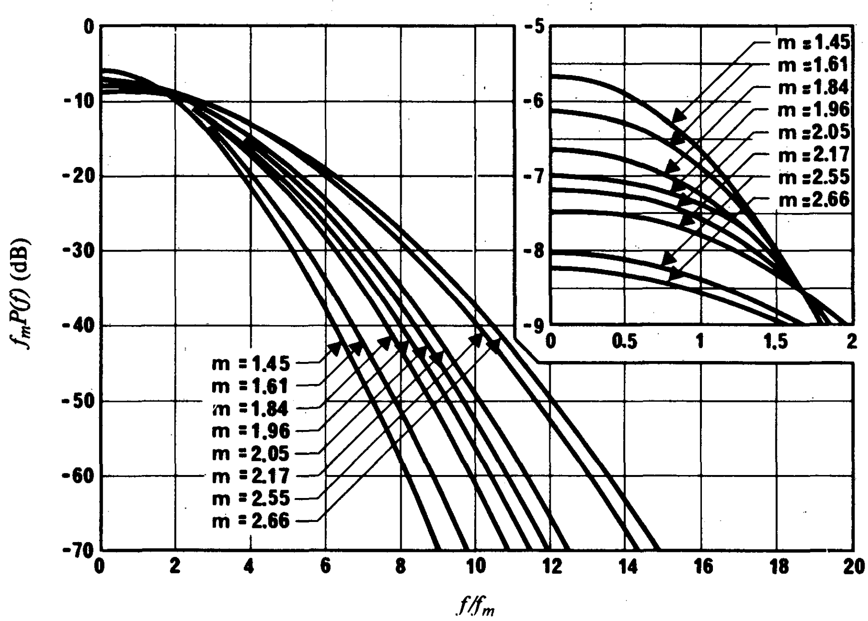


FIGURE 9e – *Normalized power spectral densities for various modulation indices*

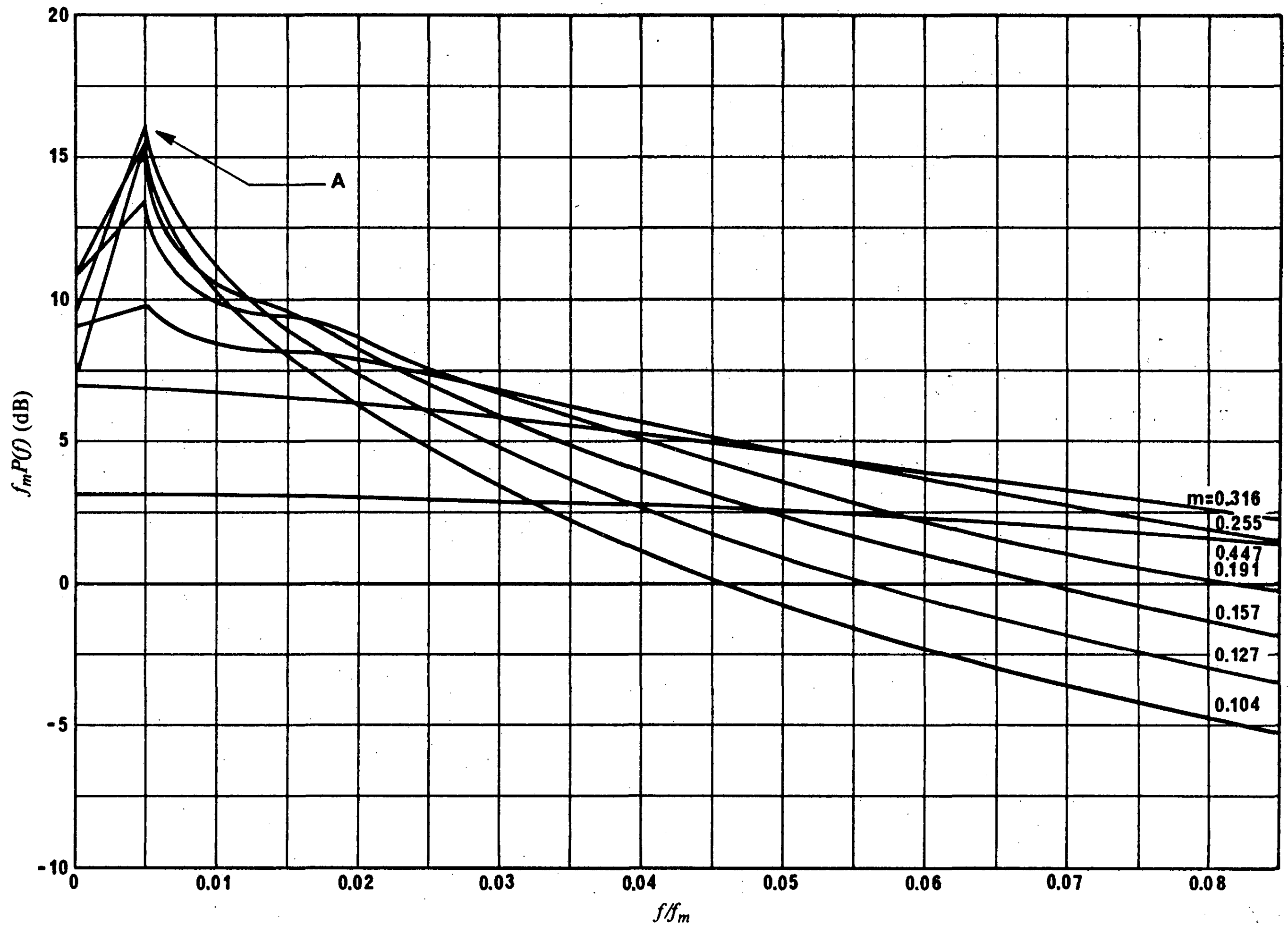


FIGURE 9f – *Normalized power spectral densities for various modulation indices and for ϵ = 0.005*

A: Peak values in dB are 15.9, 15.9, 15.2, 13.6, 9.8, 7.1, 3.2 for m = 0.104 to 0.447 respectively

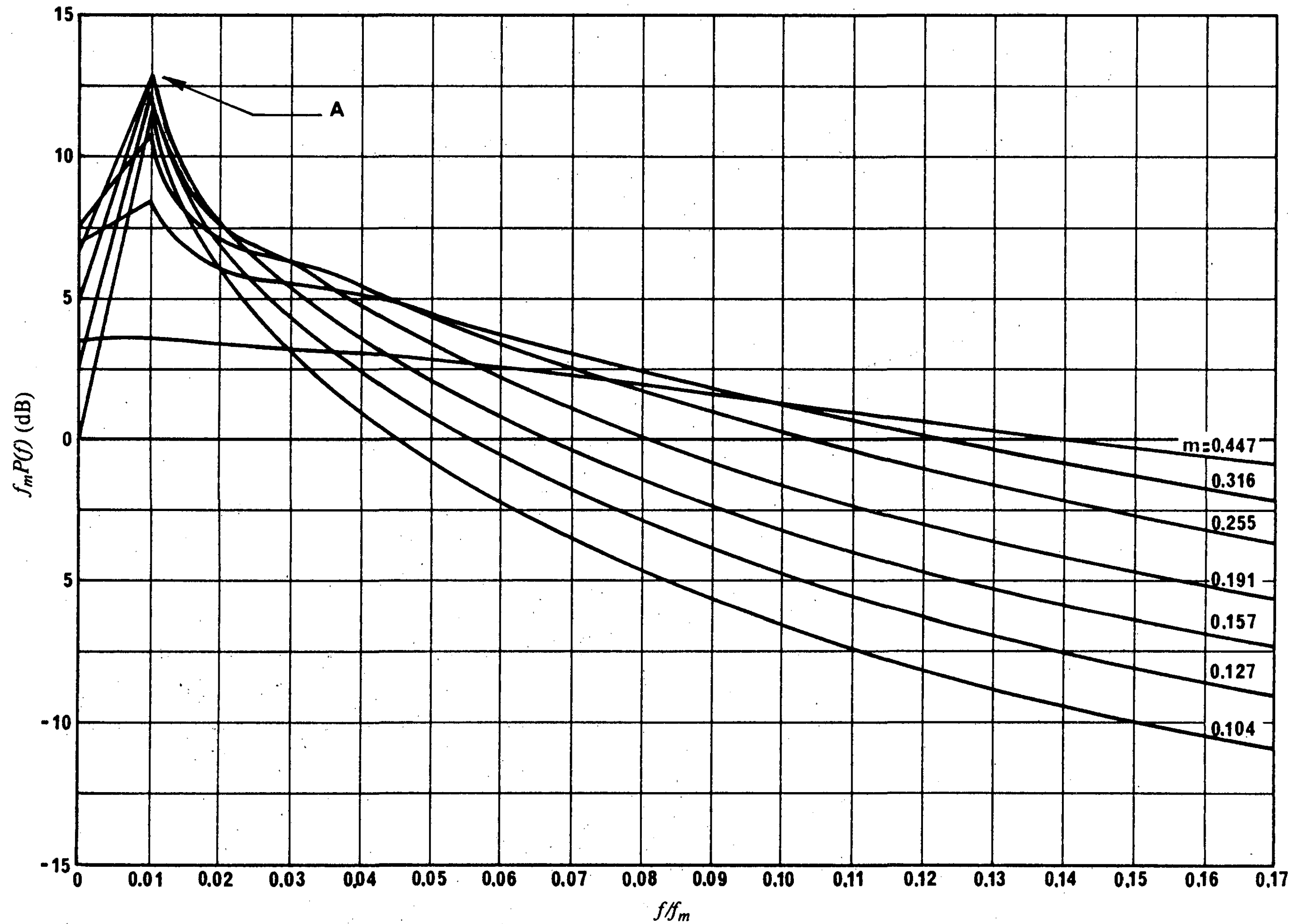


FIGURE 9g – *Normalized power spectral densities for various modulation indices and for ϵ = 0.01*

A: Peak values in dB are 11.6, 12.4, 12.9, 12.8, 10.9, 8.3, 3.5 for m = *0.104 to 0.447 respectively*

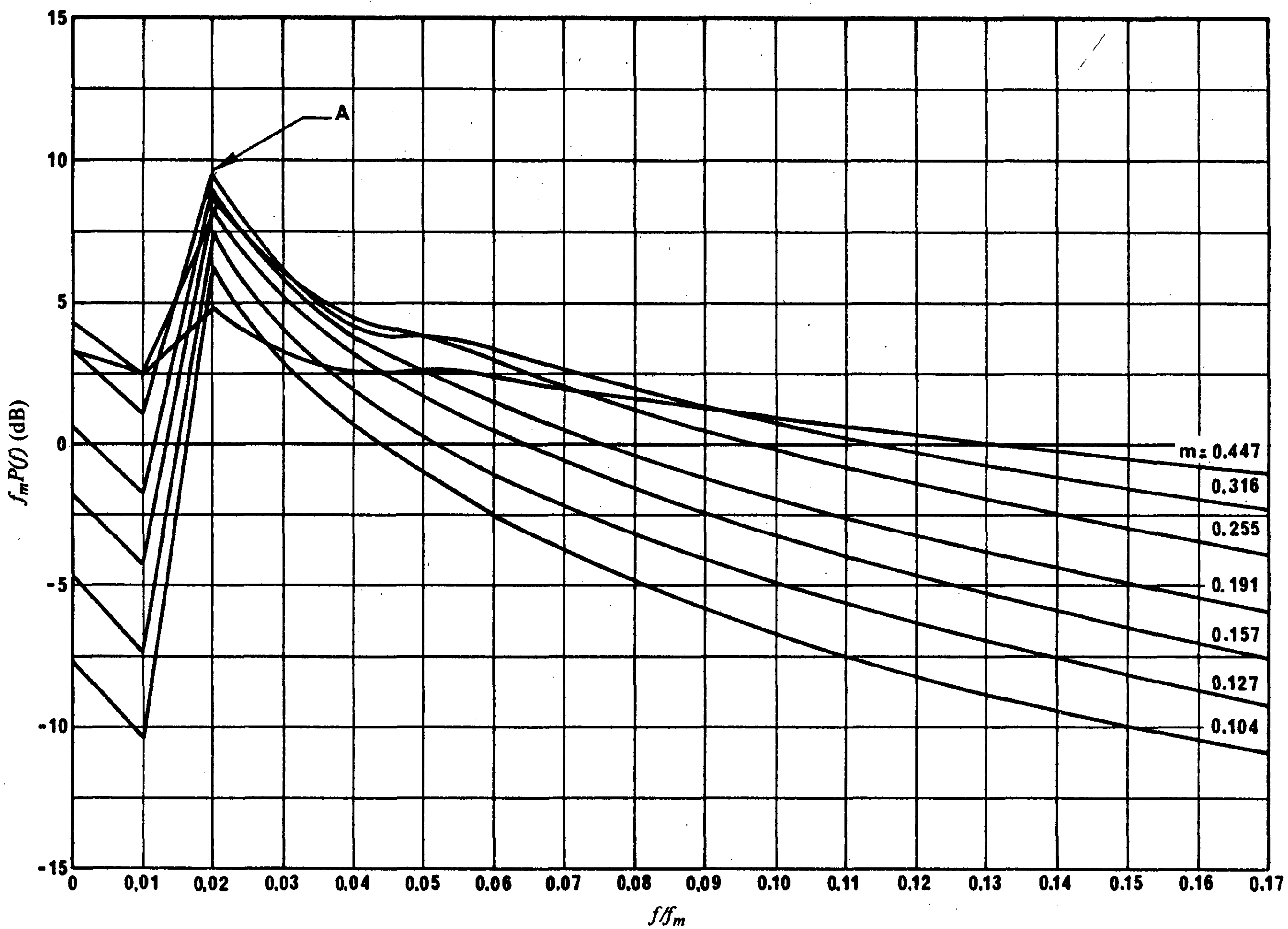


FIGURE 9h – *Normalized power spectral densities for various modulation indices and for* $\epsilon = 0.02$

A: Peak values in dB are 6.5, 7.7, 8.8, 9.5, 9.6, 8.7, 4.8 for m = 0.104 to 0.447 respectively

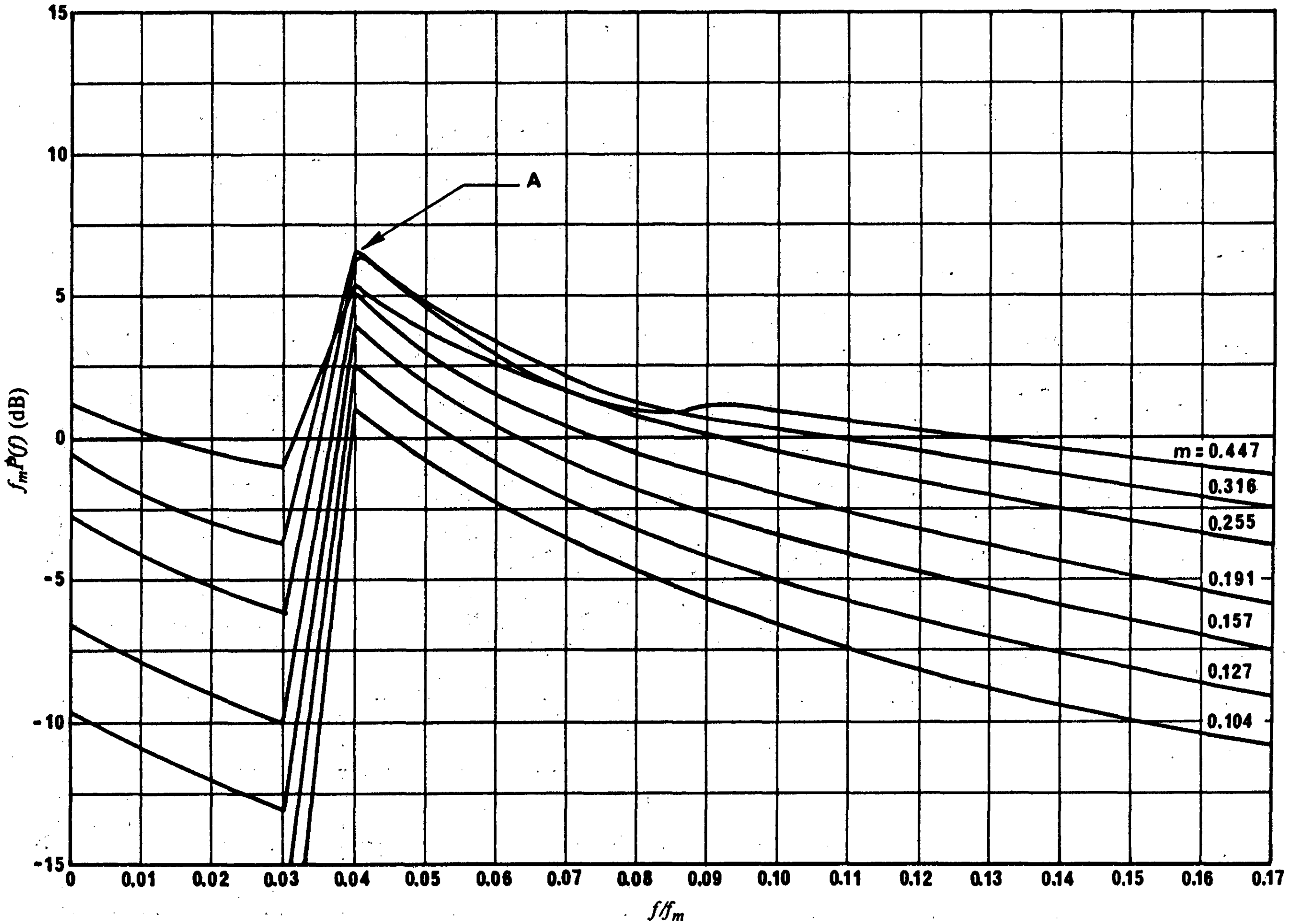


FIGURE 9i – *Normalized power spectral densities for various modulation indices and for* $\epsilon = 0.04$

A: Peak values in dB are 1.0, 2.5, 3.9, 5.1, 6.3, 6.5, 5.2 for m = 0.104 to 0.447 respectively

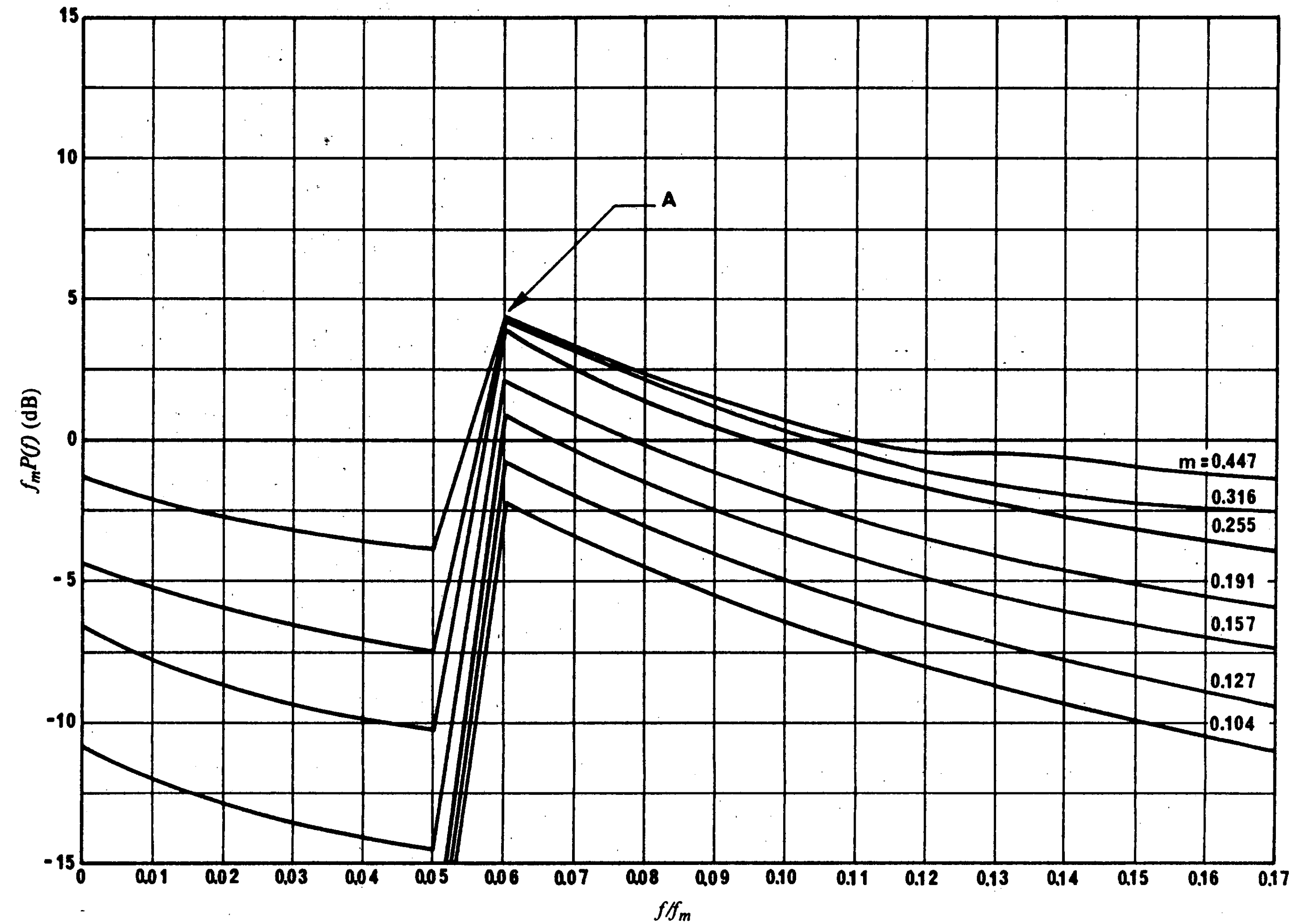


FIGURE 9j – *Normalized power spectral densities for various modulation indices and for ϵ = 0.06*

A: Peak values in dB are −2.3, −0.7, 0.9, 2.2, 3.7, 4.4, 4.3 for m = 0.104 to 0.447 respectively

3.2 *Single channel per carrier FM telephony*

Further studies are required.

3.3 *Digital PSK signal*

The signal's normalized power spectral density centred on the carrier frequency is expressed:

$$P(f) = \frac{1}{\beta D} \left[\frac{\sin\left(\frac{\pi f}{\beta D}\right)}{\frac{\pi f}{\beta D}} \right]^2 \tag{18}$$

where D is the bit rate (in kbit/s), f is the frequency (in kHz) and β has the values as given in 2.3.1.

Formula (18) has been derived for rectangular pulse shapes with random data. More generalized formulation can be found [Postl, 1963; Anderson and Salz, 1965; Jefferis, 1973; Dupraz, 1967].

3.4 *Frequency-modulated television signal (FM-TV)*

After examining the spectrum, we take as the upper bound of the normalized signal spectral power density centred on the carrier frequency the expression:

$$P(f) = \text{Sup} \left\{ \frac{1}{\sqrt{2\pi}\ \Delta F} \exp\left[-\frac{1}{2} \left(\frac{f}{\Delta F} \right)^2 \right],\ g_i(f) \right\} \tag{19}$$

where i may assume three different values (Sup (x, y) designates the greater of the two functions x and y.) The interference obtained for each one of these values is examined in turn, and the highest level of interference is adopted.

Measurements carried out in France [CCIR, 1982-86b], have shown that the $P(f)$ of an FM-TV signal with dispersion is more accurately defined by the following formula:

$$P(f) = \text{Sup} \left\{ \frac{1}{\sqrt{\pi}\Delta F} \exp\left[- \left(\frac{f}{\Delta F} \right)^2 \right],\ g_i(f) \right\} \tag{19a}$$

When determining the allowable level of interference for 20% of the time from an FM-TV signal with dispersion, this value can be assumed to be 10 dB lower than that calculated by formula (19a).

The first part of the expression between square brackets represents the "continuous background" of the spectrum, which is Gaussian; ΔF having the meaning given in 2.4 and f being the frequency (in MHz). The second part, $g_i(f)$, represents the "central" part of the spectrum essentially linked with the lines corresponding to "black" and "white". If Δf is the frequency deviation of the energy dispersal, $g_i(f)$ has the values given in Fig. 8 for $i = 1$, 2 and 3. These values correspond respectively to the case of a uniform picture (black or white), strongly contrasted (typically, "half-line bar" test pattern), slightly contrasted (typically, "staircase" test pattern). The effect of the synchronization line and the colour sub-carrier was disregarded in these models, since the lines concerned are less important in terms of power than the lines taken into account in these models.

However, the model corresponding to $i = 1$ can only be used as it stands for A.C. coupled modulators in which case the spectrum remains centred on the nominal frequency for a black (or white) picture. However, if a D.C. coupled modulator is used, the nominal frequency corresponds in all cases to medium grey; the function $g_i(f)$ must then be centred on a frequency separated by $\pm\ \Delta F/3$ from the nominal frequency.

3.5 *Amplitude modulated telephony signal*

If f_{min} and f_{max} are the lower and upper frequencies of the baseband signal, the normalized spectral power density is equal to:

$$P(f) = \begin{cases} \dfrac{1}{f_{max} - f_{min}} & \text{(SSB – SC case)} \\ \dfrac{1}{2(f_{max} - f_{min})} & \text{(DSB – SC case)} \end{cases}$$

inside the bandwidth of the signal; equal to zero outside.

4. Non-spectral interference effects – linear channel

Besides the spectral interference effects, consideration must be given to effects which are not predictable from power spectral densities. Various interference degradations require examination of time related characteristics. Examples of such degradations are:

– impulse noise in FDM-FM communications systems can result from adjacent channel FM interference [Wachs, 1970]. In this case an FDM-FM carrier located in an adjacent frequency band will occasionally deviate into the desired carrier's passband. If the interference to desired carrier power ratio and the time versus deviation statistics are improper impulsive or click noise will result;

– interference to television can result from a burst transmission carrier such as TDMA. In this case the envelope of the interfering carrier may have frequency components to which the video signal is sensitive. Frequencies near the television line or frame rate may be expected to provide subjectively disturbing degradations;

– interference effects may result from a large carrier, modulated only by the energy dispersal waveform, sweeping past a small narrow passband carrier such as single-channel-per-carrier (SCPC). This situation produces transient effects related to the interference duty factor and sweep rate.

This list of examples is not complete but is meant to illustrate several time dependent interference mechanisms.

Another non-spectral effect in relation to interference performance is dependent on the demodulation technique. Depending on the nature of the interference, one demodulation technique may be preferable. As an example, adjacent channel induced impulsive noise in a wideband FM system may be reduced by the use of a properly designed phase locked loop or frequency modulated feedback demodulator. [Berman *et al.*, 1972]. In the case of digital reception, different carrier and clock timing recovery techniques will have differing sensitivities to specific types of interferences.

5. Non-linear channel effects

5.1 *General*

Most satellite transmission channels in use today have non-linear transmission properties resulting from the transponder and earth station equipment employed. A non-linear relation exists in the transponder between the input and output amplitude (AM/AM) in addition to which the phase transfer function is related to input amplitude (AM/PM conversion). These characteristics have implications for the interference susceptibility of a given communications system. With both the desired signal and interference present at the input of the non-linear device, a multiplicative (non-additive) degradation is generated. Depending on the modulation technique employed, this degradation will manifest itself on baseband performance.

5.2 *Analogue FDM-FM telephony wanted signal*

In dealing with interference to FM analogue signals, two areas should be considered. [Berman *et al.*, 1972]. The presence of the desired carrier and an interfering carrier(s) at the non-linear device input will result in the generation of intermodulation spectral components. These components may then appear as additional interfering carriers. The second area of consideration is when the input combination of desired and interfering signals results in amplitude modulation; this modulation is converted to phase modulation by the AM-PM conversion process. The phase modulation is imparted on the desired carrier and when finally demodulated at the receiver, results in baseband degradation.

Incomplete suppression of the amplitude modulation of the wanted signal by the limiter of the receiver can generate baseband interference, or adjacent channel interference on the slope of the wanted channel's filter can be amplitude modulated; this AM converted to PM thus appears at baseband. The non-linearity of power amplifiers and demodulators are the usual sources of this type of interference [Borodich, 1976].

The non-linear interference can have a severe subjective effect because it can appear as direct cross-talk. Moreover, it can degrade the threshold of the receiver, and this effect is particularly applicable to satellite signals where the level of the wanted signal is usually near the threshold level, and adjacent channel interference may generate a burst of threshold noise.

The non-linear interference mechanisms require investigation when the more conventional linear mechanisms discussed in this Report appear to produce negligible interference. The calculation of this interference requires information on the specific receivers, filters, and AM-to-PM conversion constants [Kantor *et al.*, 1971].

In the investigation and analysis of FDMA-FM systems for the transmission of multi-channel telephony, calculations of interference noise in individual channels should take account of the following sources of interference:

- non-linearity of a realizable limiter,
- non-linearity of a realizable frequency detector,
- threshold effect of an FM receiver (taking account of the modulation index of the interference),
- AM-to-PM conversion in the RF channel.

Analytical expressions for the necessary calculations and details on the method are given by different authors [Dorofeev, 1972; Kantor and Mustafidi, 1973; Mustafidi and Yulin, 1974 and 1975].

5.3 *Digital PSK wanted signal*

The treatment of interference to digital PSK carriers is more complex than the analogue case. Bandpass filtering of the PSK carrier to minimize bandwidth requirements results in significant envelope amplitude modulation at frequencies related to the symbol rate. This, when converted to phase modulation by the AM/PM conversion mechanism, reduces the interference immunity of the system. Separate consideration must be given to the performance of the carrier and clock reference recovery functions of the system. Specification of the modulator and demodulator characteristics with respect to filtering, carrier and clock reference recovery techniques and sampling methods, may be expected to have significant impact on the interference immunity of the system. At the present time there are no analytic expressions available for the computation of the interference effect to PSK carriers transmitted over a non-linear channel. Laboratory measurements on various specific systems have been presented and can be used for guidance. [Wachs and Weinreich, 1975; Weinreich and Wachs, 1976].

6. Measurements of interference into digital systems

The details of a study verified by tests carried out in Japan are contained in [CCIR, 1963-66]. The results show that a considerable reduction in interference is possible from angle-modulation systems into pulse-code modulation systems using phase-shift keying as compared to the mutual interference between two angle-modulation systems.

Similarly, limited tests conducted in France [CCIR, 1970-74b] showed agreement between theory and measured data.

Experiments conducted on the effect of PSK interference and noise on PSK signal demodulators [CCIR, 1982–86c] make it possible to determine the validity of a Gaussian approximation in estimating the effect of PSK interference. Figure 10 shows the error ratio of a coherent 4-PSK demodulator as a function of the energy/bit-to-noise density ratio for two fixed C/I ratios, 10 and 13 dB, and different ratios between interference R_i and signal R_s channel transmission rates (R_i/R_s = 0; 0.5; 1; 2; 5). The carrier-to-interference ratio was established at the demodulator receiving filter output with a band 1.1 times that of the Nyquist band. Figure 11 shows the error ratio as a function of the R_i/R_s ratio for a fixed C/N ratio = 13 dB and three values of C/I ($C/I = C/N$, $C/I = C/N + 2$ dB, $C/I = C/N - 2$ dB). Figure 12 shows the relationship for the use in the wanted signal channel of a convolution code codec at $\gamma = 1/2$ for the code speed with Viterbi decoding.

Examination of the results obtained shows that the representation of co-channel PSK interference as Gaussian noise is correct for $R_i > (4 - 5)\ R_s$, and this applies both to the ordinary channel and to systems using coding, although in the latter case the character of the variation in error ratio is not monotonic. In the region of values of levels of interference commensurate with the thermal noise level, wideband PSK interference produces an increase in error ratio roughly of an order of magnitude in comparison with unmodulated interference of the same level, which is equivalent to a difference in their levels of up to 3-4 dB at a constant error ratio. It should also be noted that 2-PSK interference produces a more perceptible effect on error ratio than 4-PSK interference.

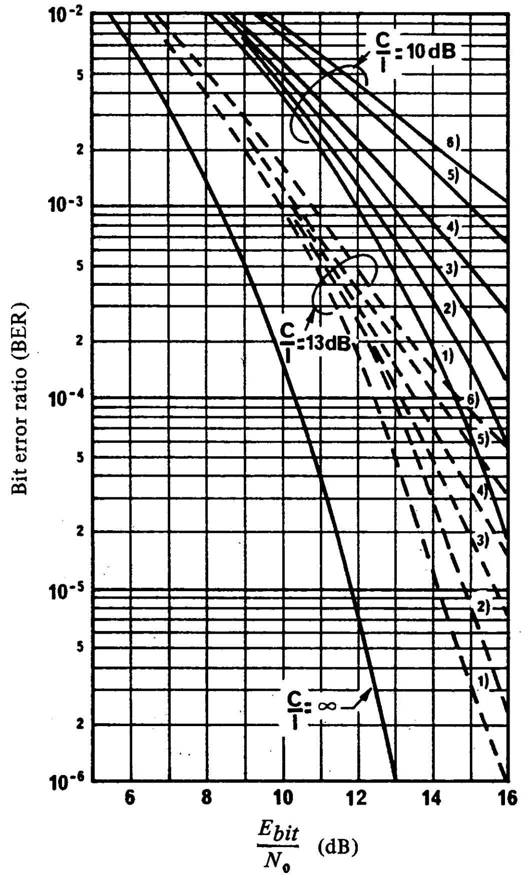


FIGURE 10 – *Error ratio as a function of energy/bit-to-noise density (E_{bit}/N_0) and carrier-to-interference C/I ratios*

1) $\frac{R_i}{R_s} = 0$

2) $\frac{R_i}{R_s} = 1/2$

3) $\frac{R_i}{R_s} = 1$

4) $\frac{R_i}{R_s} = 2$

5) $\frac{R_i}{R_s} = 5$

6) interference in the form of noise

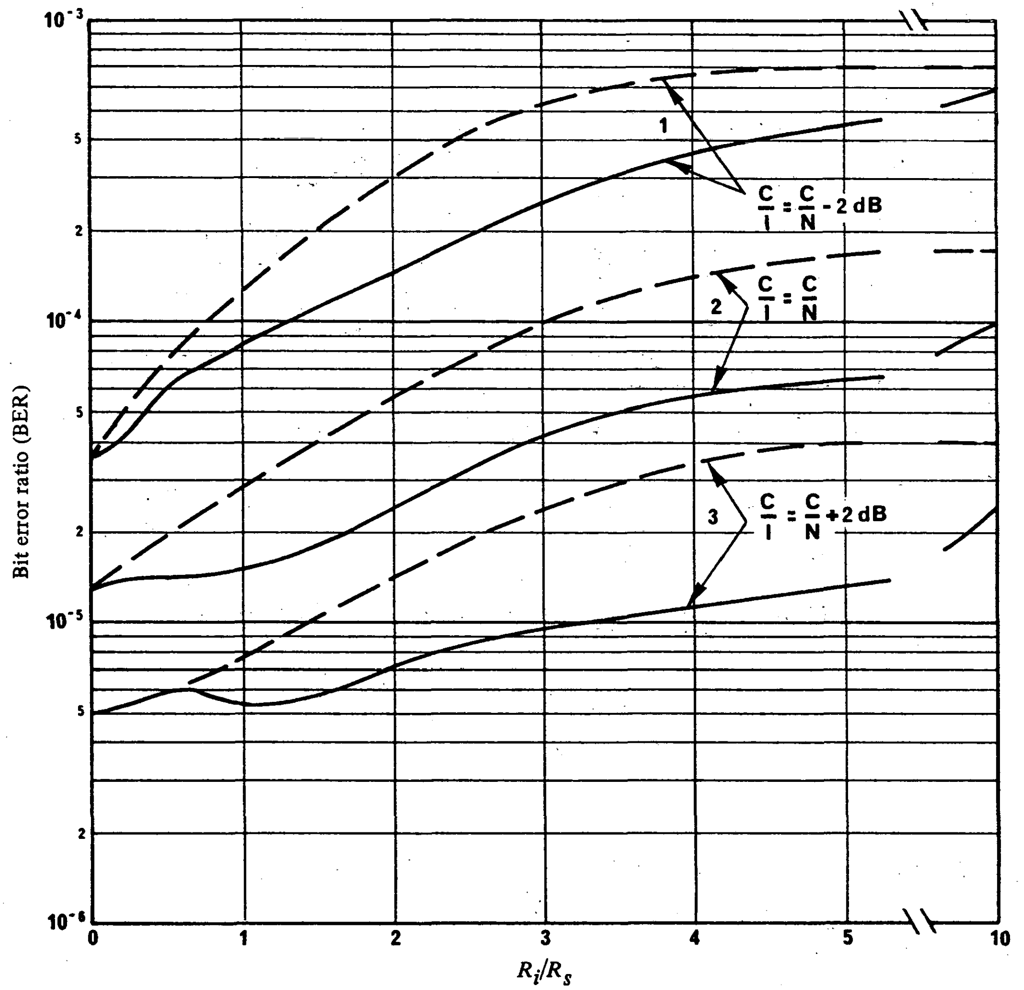


FIGURE 11 – *Coherent 4-PSK demodulator error ratio as a function of R_i/R_s transmission speed ratio*

- - - - 2-PSK interference

——— 4-PSK interference

$\frac{C}{N}$ = 13 dB

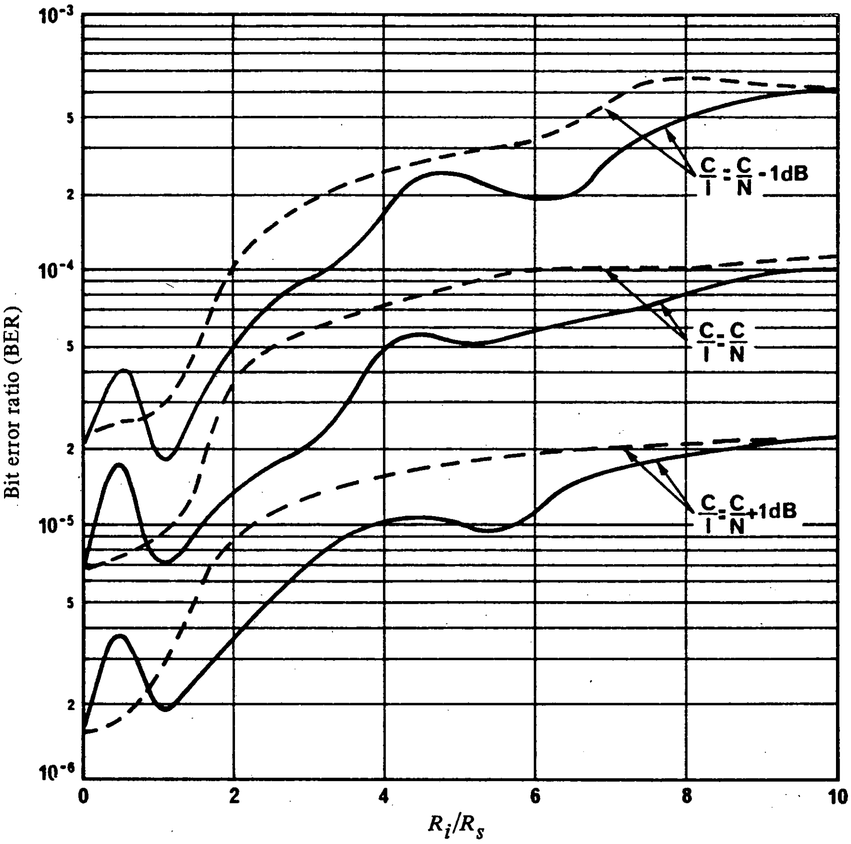


FIGURE 12 – *Error ratio at convolution code decoder output as a function of R_i/R_s transmission speed ratio*

– – – – 2-PSK interference

———— 4-PSK interference

$\frac{C}{N}$ = 9 dB

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REPORT 709-1

CONSIDERATION OF THE COUPLING BETWEEN AN EARTH-STATION ANTENNA AND A TERRESTRIAL LINK ANTENNA

(Question 32/4 and Study Programme 1C/4)

(1978-1982)

1. Introduction

To conserve frequency spectrum and possibly to accommodate interconnection between diversity earth stations, it may be desirable to use the same frequency bands for the space and terrestrial links. To accomplish this goal without frequency restriction, it is necessary that:

- the terrestrial antenna be located in the rear sector of the earth station antenna;
- the terrestrial antenna has a high front-to-back ratio.

A measurement programme has been undertaken which provides good correlation with a derived formula predicting the on-axis coupling factor. A separate programme, demonstrating the feasibility of co-locating a terrestrial antenna sharing the same frequency band under traffic conditions has also been conducted under the following conditions:

- the terrestrial system transmits at a minimum power in the earth station receive band;
- the terrestrial system receiver at the earth station operates in the earth station transmit band;
- low coupling exists between the earth station and terrestrial antennas; and
- power relationships are critical and may require adjustment of the transmission parameters in the radio-relay link.

2. Coupling factor

A relatively simple formula, for estimating the coupling factor between a large earth station antenna and an isotropic antenna located on the rearward projection of its focal axis, has been developed by using geometrical theory of diffraction (GTD). Measurements have been made and it appears the coupling factor can be predicted reasonably well. Figure 1 shows the geometry of the coupling factor given by the formula:

$$C = \frac{P_r}{P_t} = \frac{\lambda}{64\pi^2} G_0 \frac{1}{l^2} \frac{\cos^2 \varphi}{\sin^2 (\psi/2)} \qquad (\theta = 0) \tag{1}$$

where the angles are shown in Fig. 1 and G_0 is the feed/subreflector gain in the direction at the edge of the main reflector. G_0 is fairly constant over most of the main reflector (especially for shaped Cassegrain systems) and has a value given approximately by $4\pi/\Omega^2$, where Ω is the included angle of the reflector. However, due to subreflector diffraction and feed pattern effects G_0 falls off very rapidly just beyond the rim, and it is this reduced value that must be used in equation (1). G_0 may be taken typically as about 12 dB below the value $10 \log 4\pi/\Omega^2$ in the nominal direction of the first unblocked zone at 6 GHz for large earth-station antennas.

The formula for estimating the coupling factor between a large earth-station antenna and an isotropic antenna located in the rear sector of its reflector can also be derived by using GTD [CCIR, 1978-82]. The results of calculations using this method are presented in Fig. 2a which provides the coupling loss for a range of angles θ and distances l.

Figure 2b shows the measured coupling factors between a large antenna and an isotropic antenna.

To demonstrate more practically the concept of using the same frequency bands for the space and terrestrial links, an additional measurement programme was conducted. Figure 3 shows the coupling between a standard gain horn and a 30 m antenna as a function of polarization angle and the distance from the earth-station antenna. In addition, a 12 km radio-relay link was implemented for operation to demonstrate co-channel interconnect operation. The earth antenna was circularly polarized and the terrestrial radio-relay antenna linearly polarized. The collocated 3 m horn reflector antenna transmitting at 4 GHz was located so that its aperture was visible to part of the earth-station antenna rim. The resulting geometry produced relatively strong coupling; in practice most alternative configurations could have resulted in less coupling.

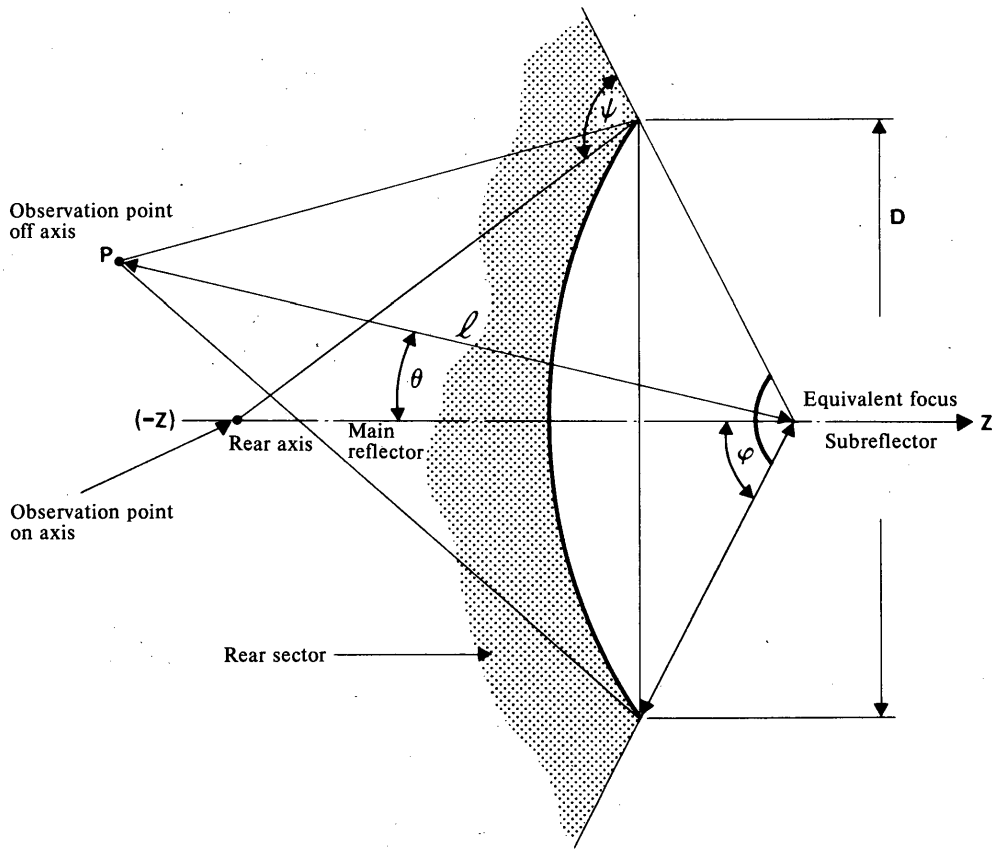

FIGURE 1 – *Geometry for calculation of coupling factor between a large Cassegrain antenna and isotropic antenna located in its geometrical shadow*

D : aperture diameter

φ : half value of the aperture angle

ψ : diffraction angle at reflector edge

ℓ : distance from the focus to the observation point

θ : angle measured from the axis to the observation point P

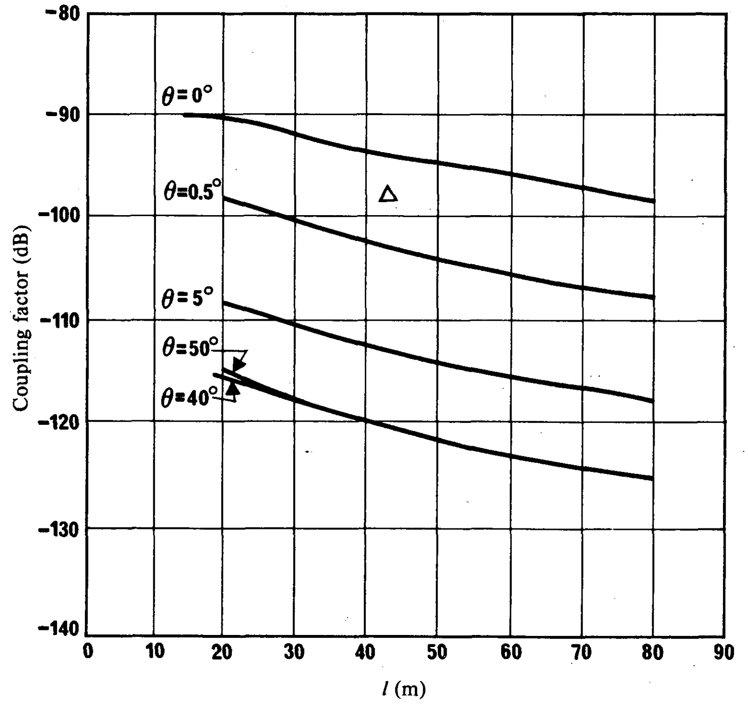

FIGURE 2a – *Calculated coupling factor between 32.0 m antenna and isotropic antenna located in its rear sector (6.0 GHz)*

Δ: point at l = 41.5 m
and θ = 0° from measured data of Fig. 2b

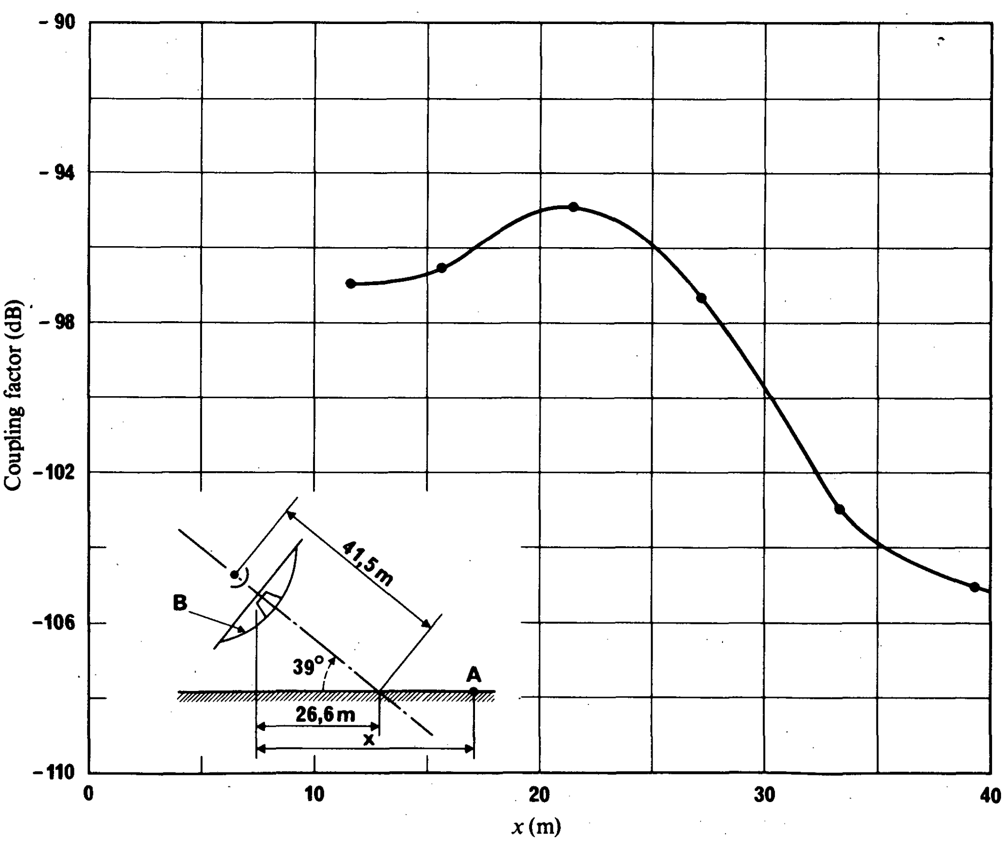

FIGURE 2b — *Measured coupling factor between 30 metre antenna and isotropic antenna located behind antenna*

A: Isotropic antenna
B: 30 metre dish, f = 6.4 GHz

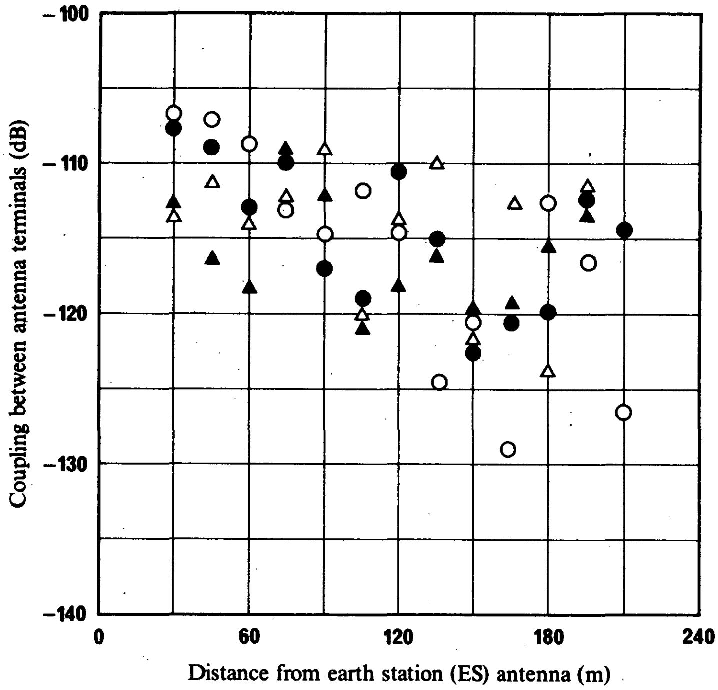

FIGURE 3 — *Coupling between the terminal of the earth-station antenna and the standard gain horn as a function of distance*

- ● 180° off ES main beam Az., vert. pol.
- ○ 180° off ES main beam Az., horiz. pol.
- ▲ 120° off ES main beam Az., vert. pol.
- △ 120° off ES main beam Az., horiz. pol.

3. Feasibility of collocation of an earth-station antenna and a terrestrial antenna

Early during the link demonstration it was established that by far the greatest interference resulted from radiation of the collocated 4 GHz horn reflector antenna into satellite signals received at 4 GHz at the earth-station antenna.

After both the radio relay and the satellite links were calibrated, noise power ratio (NPR) measurements were made in the top baseband channel for a wide variety of space and terrestrial link carrier sizes. The satellite link was adjusted for 7500 pWp in the absence of terrestrial link interference. The terrestrial link was designed to conform with Intelsat-IV transmission parameters and its transmit power was varied in 5 dB steps until a 10 000 pWp noise level was experienced on the space link. The multi-channel modulation index on the terrestrial radio relay link was then reduced by 4 and 10 dB to examine the performance sensitivity to baseband loading. Table I shows the results of these measurements which show good agreement with calculated values.

The coupling factor varied with climatic conditions and antenna polarization. If frequency co-ordination between the space and terrestrial links permitted frequency interleaving, an improvement of 15 dB could be realized, allowing a 4 GHz transmitter power of 5 dBW.

The effects of interference on the terrestrial link were also investigated by setting up a worst-case global configuration. In this configuration 972 channels were transmitted over the space link, while 1800 channels were transmitted over the terrestrial link. Interference into the terrestrial link was not a serious problem, even at considerably reduced power on the 6 GHz terrestrial link. For transmission at 6 GHz from the remote site at a reduced power of only −12 dBW (corresponding to −38 dBm received power), the measured carrier-to-interference ratio was about 30 dB. The corresponding baseband interference was only about 1000 pWp, which agrees closely with the calculated value.

TABLE I — *Summary of space link performance*

Number of channels on space link (1)	Multichannel modulation index on space link	Terrestrial transmit power (dBW)	Number of channels on terrestrial link	Multichannel modulation index on terrestrial link	Coupling factor (dB)	Measured *C/I* (dB)	Calculated (*S/N*) on space link (dB)	Measured (*S/N*) on space link (dB)
432	1.50	- 5.0	1800	0.49	142	33.2	51.6	50.2
432	1.50	- 5.0	1800	0.39	142	33.2	51.6	50.2
432	1.50	- 5.0	1800	0.25	142	33.2	51.3	50.2
432	1.50	-10.0	960	1.10	135	30.8	51.6	50.8
432	1.50	-10.0	960	0.70	135	30.8	51.5	50.8
432	1.50	-10.0	960	0.34	135	30.8	51.5	50.8
432	1.50	-10.0	432	1.50	131	27.0	51.2	50.7
432	1.50	-10.0	432	0.95	131	27.0	51.1	50.7
432	1.50	-10.0	432	0.47	131	27.0	51.1	50.7
252	1.54	- 5.0	1800	0.49	132	19.3	51.6	51.1
252	1.54	- 5.0	1800	0.39	132	19.3	50.8	50.6
252	1.54	- 5.0	1800	0.25	132	19.3	50.6	50.1
252	1.54	- 5.0	432	1.50	132	19.2	51.6	52.1
252	1.54	- 5.0	432	0.95	132	19.2	50.8	51.6
252	1.54	- 5.0	432	0.47	132	19.2	50.2	51.6
252	1.54	- 5.0	252	1.54	132	19.2	50.7	50.7
252	1.54	- 5.0	252	0.97	132	19.2	49.9	50.2
252	1.54	- 5.0	252	0.48	132	19.2	49.6	49.7
24	2.55	-10.0	1800	0.49	127	10.9	50.4	50.9
24	2.55	-10.0	1800	0.39	127	10.9	50.4	49.9
24	2.55	-10.0	1800	0.25	127	10.9	49.0	46.9
24	2.55	-10.0	432	1.50	129	12.2	49.4	49.9
24	2.55	-10.0	432	0.95	129	12.2	49.3	48.9
24	2.55	-10.0	432	0.47	129	12.2	46.2	47.6
24	2.55	-10.0	252	1.54	130	14.0	49.8	49.9
24	2.55	-10.0	252	0.98	130	14.0	49.6	49.4
24	2.55	-10.0	252	0.48	130	14.0	47.4	47.9

(1) INTELSAT IV standard baseband parameters were used.

For the worst carrier combination, the effect of interference on the terrestrial link was negligible for all 6 GHz power levels (transmitted toward the earth station) from +13 dBW to −12 dBW. For transmission at a reduced power of only −12 dBW from the remote site, the measured carrier-to-interference ratio was about 30 dB; the corresponding baseband interference was about 1000 pWp. A wide variety of live and test video signals were transmitted and no impairment was subjectively observed for either link.

4. Experimental confirmation

The test results confirm that collocation of earth station and terrestrial systems using the same frequency band is feasible under controlled conditions.

In the worst case (highest coupling between the two antenna systems), a 10 000 pWp objective on the satellite link could be met if the terrestrial radio relay transmitter power were limited to about −10 dBW and for short links such power is more than adequate.

Additional antenna coupling measurements have been made in the 20 GHz band. The results are described in Annex I. It has been confirmed that the antenna coupling levels estimated from the far-field radiation patterns match satisfactorily with experimental results. The method given in § 3 of Annex I is applicable not only in the rear region of the reflector, but also when the antennas are facing each other [Takano *et al.*, 1979].

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ANNEX I

EXPERIMENTAL STUDIES OF AN EARTH-STATION ANTENNA COUPLING ABOVE 10 GHz

1. Introduction

The earth-station antenna coupling to a terrestrial radio-relay in the 20/30 GHz band needs to be examined, because both systems share the same frequency bands [Takano *et al.*, 1979]. This Annex describes the experimental results and tests conducted to find the antenna directional dependence on the antenna coupling characteristics. The estimation method using far-field radiation patterns rather than the Fresnel zone method used in the body of this Report is also shown to be effective in calculating the near-field antenna coupling at distances as small as 20 m.

2. Measured results

An 11.5 m axisymmetrical Cassegrain antenna [Takano *et al.*, 1979] and an 11.5 m offset Cassegrain antenna [Takano *et al.*, 1980] were used as earth-station antennas. A 2.7 m Cassegrain antenna [Egami *et al.*, 1980] was used as a terrestrial radio-relay antenna.

Antenna locations for coupling measurement are shown in Figs. 4 and 5. As shown in Fig. 4, the 2.7 m antenna is located in the rear sector of the earth-station antenna. The distance between the centres of the antennas is about 20 m. In the case shown in Fig. 5, the 2.7 m antenna is located facing the front of the earth-station antenna with a distance of about 30 m. The antenna coupling characteristics were measured by rotating the 2.7 m antenna and using 19.5 GHz.

The experimental results are shown in Figs. 6 and 7. The abscissae indicate the angles between the 2.7 m antenna beam axis and the direction toward the earth-station antenna.

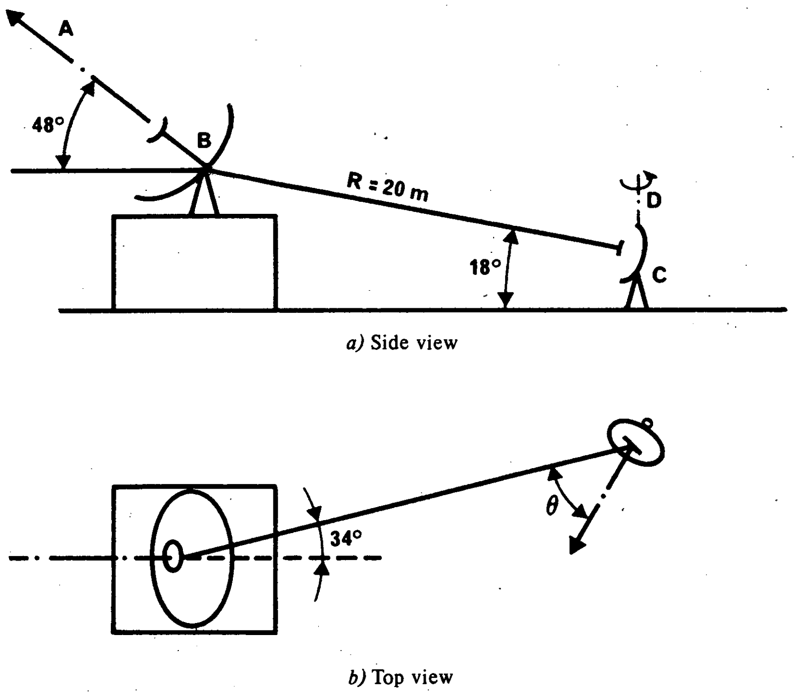

FIGURE 4 – *Antenna location for coupling measurement (R = 20 m)*

A : direction of satellite
B : 11.5 m Cassegrain earth-station antenna
C : 2.7 m terrestrial antenna
D : rotating axis
R : distance between the two antennas

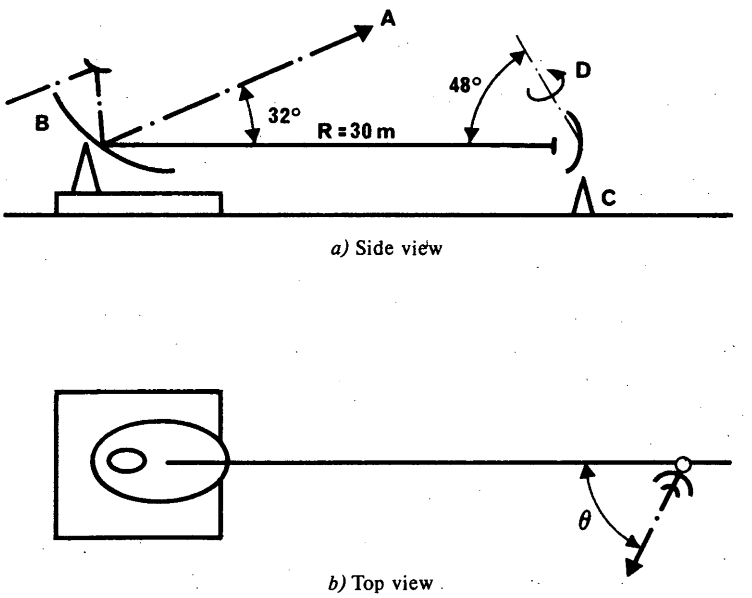

FIGURE 5 – *Antenna location for coupling measurement (R = 30 m)*

A : direction of satellite
B : 11.5 m offset Cassegrain earth-station antenna
C : 2.7 m terrestrial antenna
D : rotating axis
R : distance between the two antennas

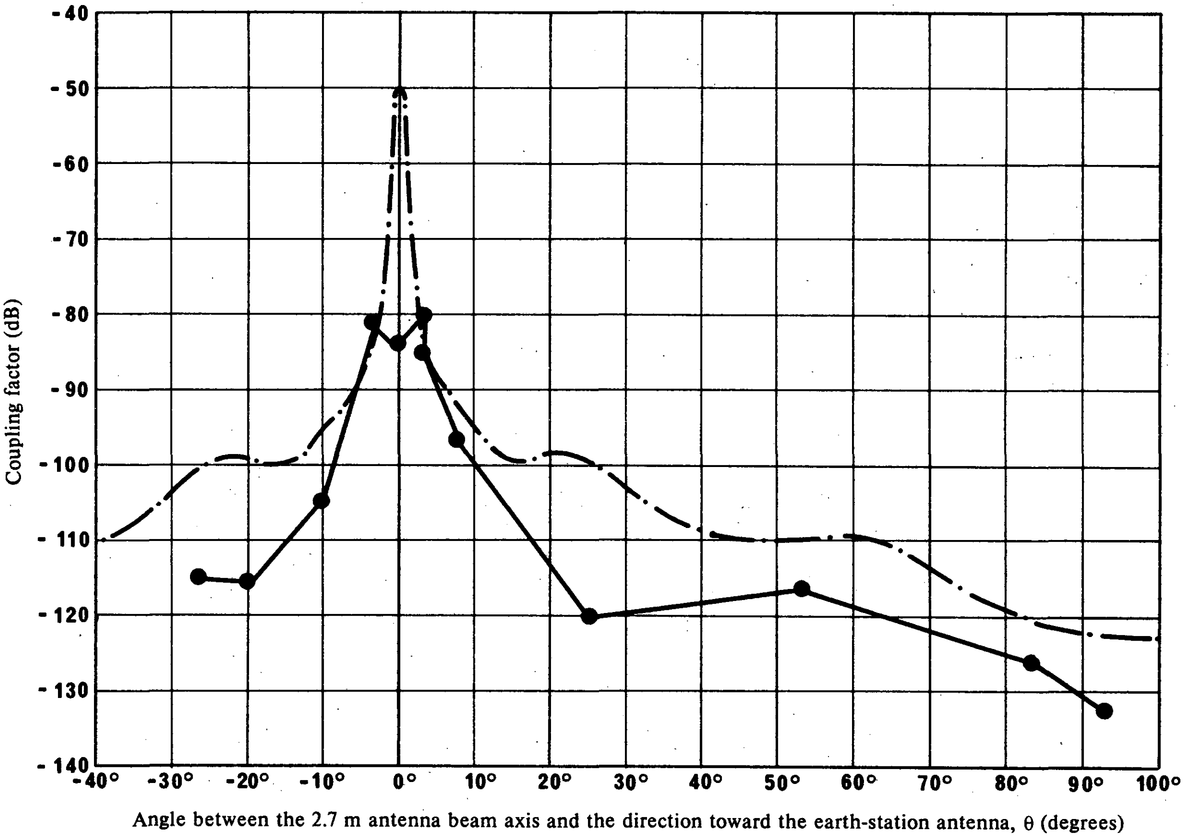

FIGURE 6 – *Measured results for antenna location as shown in Fig. 4*

Measured
Estimated

(f = 19.5 GHz, R = 20 m)

3. Estimation of the antenna coupling

The estimated levels shown in Figs. 6 and 7 are calculated from the far-field radiation patterns and the path losses. The coupling factor C is given as follows:

$$C = \frac{G_t \cdot G_r}{L} \tag{2}$$

where:

G_t: transmit antenna gain in the direction toward the receive antenna,

G_r: receive antenna gain in the direction toward the transmit antenna,

L: path loss $= (4\pi R/\lambda)^2$, R is the distance between the two antennas, and λ is the wavelength.

The test results show that the maximum coupling factors can be approximately estimated by equation (2). Even if the measured coupling level slightly exceeds the predicted level, the difference is less than 5 dB. The coupling factor can also be estimated when the terrestrial antenna and the earth-station antenna are facing each other, as shown in Fig. 5. The validity of this method is suggested in Annex I of Report 390.

The estimation method given in equation (2) seems more effective and practical than that given in equation (1), which gives the coupling factor only for the rearward axis of the earth-station antenna. The reasons are as follows:

– it can be applied when the antennas are facing each other as well as when the earth-station antenna is not facing the terrestrial antenna;

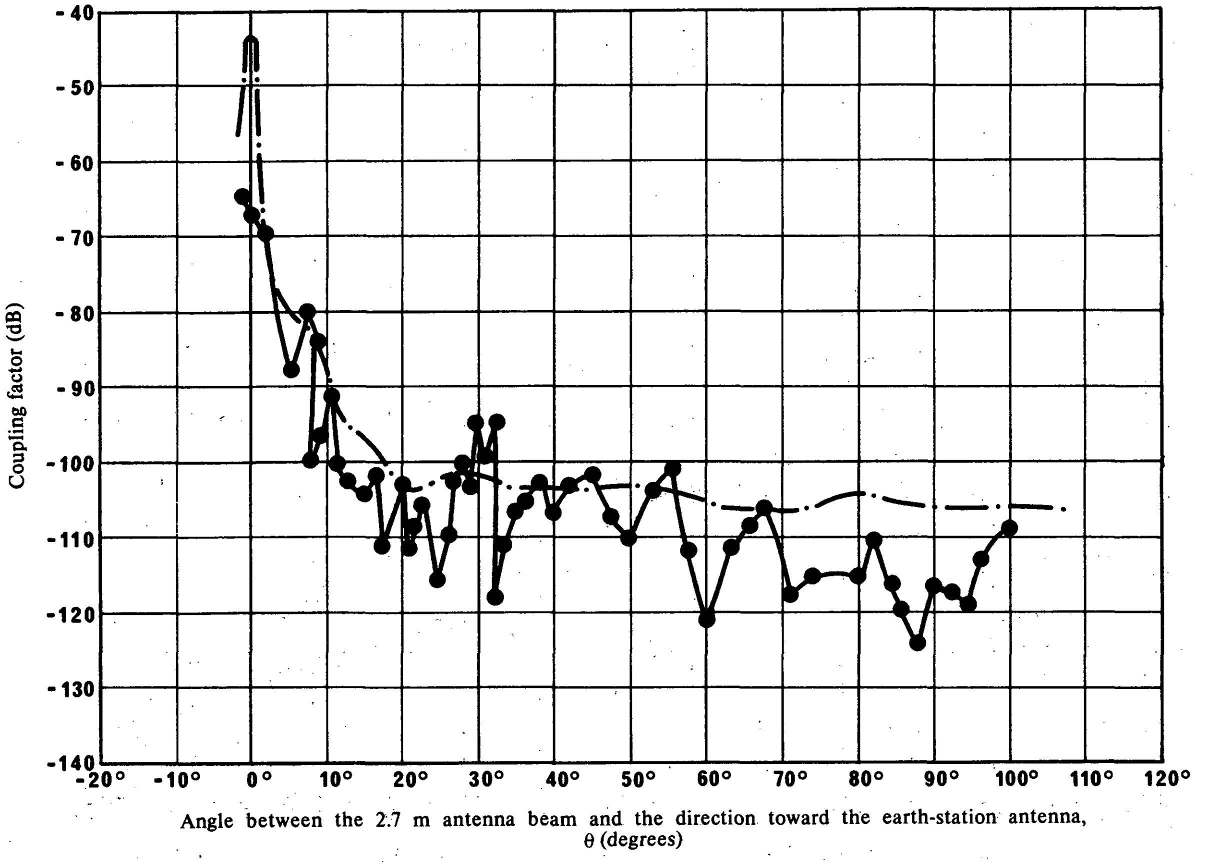

FIGURE 7 – *Measured results for antenna location as shown in Fig. 5*

Measured

Estimated

(f = 19.5 GHz, R = 30 m)

– it can be applied to an asymmetrical reflector antenna such as an offset reflector antenna;

– the degradation factor of the radiation pattern should include not only the reflector edge diffraction but also the effect of surface accuracy and reflector panel-gap scattering [Takano *et al.*, 1980]. Therefore, the estimation method using the radiation patterns gives a more reasonable coupling factor.

4. Conclusion

The experimental results in the 20 GHz band confirm the fact that the antenna coupling factor can be approximately estimated by using the far-field radiation patterns. This estimation method is effective, and is applicable for all earth-station antenna orientations.

In the case where the coupling distance is less than 20 m, further studies should be made.

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REPORT 792-2

CALCULATION OF THE MAXIMUM POWER DENSITY AVERAGED OVER 4 kHz OF AN ANGLE-MODULATED CARRIER

(Questions 32/4 and 23/9, Study Programme 23A/9)

(1978-1982-1986)

1. Introduction

In accordance with Article 11 of the Radio Regulations, an administration which intends to establish a satellite system shall send to the International Frequency Registration Board the information listed in Appendix 4 to the Radio Regulations. Furthermore, an administration requesting co-ordination with any other administration, of a frequency assignment to a space station on a geostationary satellite or to an earth station that is to communicate with a space station on a geostationary satellite, shall send to any other such administration, the information listed in Appendix 3 to the Radio Regulations.

As one item of the information listed in Appendix 3 and Appendix 4, such an administration shall calculate the maximum power density per Hz at the input of the antenna averaged over the worst 4 kHz band for transmitted carriers below 15 GHz. However, generalized methods to calculate the maximum power density of a carrier are not necessarily indicated so far.

This Report shows the methods of calculation of the maximum power spectral density of angle-modulated carriers to be used for notification and co-ordination of frequency assignments to radio astronomy and space radiocommunication stations, except stations in the broadcasting-satellite service, in accordance with Article 11 of the Radio Regulations.

In order to ensure that the worst case interfering situation is used for co-ordination and notification purposes, the power spectral density should be calculated under light traffic load conditions. For an extreme case of a carrier without modulating signal or for an emission in which the necessary bandwidth is less than 4 kHz, the power over 4 kHz is considered to be numerically equal to the total power of the emission.

2. Calculation of the maximum power density (averaged over 4 kHz) of an angle-modulated carrier

2.1 *General*

Given below is the method of calculating the power level in the worst 4 kHz (W/4 kHz). The power density per Hz required by the Radio Regulations is obtained by dividing this value by 4000.

2.2 *Maximum power density per 4 kHz of an FM carrier* [Iwasaki and Fujii, 1976]

2.2.1 *FM carrier modulated by a multi-channel telephony signal*

The maximum power spectral density at full baseband loading is determined either by the residual carrier or by the peaks of the continuous spectrum, depending upon the nature of the modulation. The power of the residual carrier is given by:

$$P_t \exp(-\psi_0) \qquad \text{(W)} \tag{1}$$

The maximum power spectral density in the continuous part of the spectrum can be obtained by the methods described in References [Middleton, 1951; Medhurst, 1960 and 1961; Ferris, 1968], or approximately from the graphs of Fig. 2 of this Report, which were derived by those methods, or from Figs. 9f to 9j of Report 388 noting that the maximum power spectral density is dependent on the value of β of ψ_0 of the system [CCIR, 1982-86]. The graphs of Fig. 2 are presented in normalized form, with normalized spectrum.

$$V(f) = \frac{W_c(f) \cdot f_h}{P_t} \tag{2}$$

and with multichannel modulation index:

$$m = \frac{f_\Delta}{f_h} \tag{3}$$

and r.m.s. phase deviation:

$$\psi_0 = \int_{f_l}^{f_h} \frac{1}{4\pi^2 f^2} W_B(f) \mathrm{d}f \tag{4}$$

The spectral densities given by the graphs can be scaled to any bandwidth, such as 4 kHz, in which the density does not vary appreciably.

In these relations the symbols have the following meanings:

P_t: the total power of carrier (W),

f_Δ: multi-channel r.m.s. deviation (Hz).

$$f_\Delta \begin{cases} f_d \times 10^{\frac{-15+10 \log N_c}{20}} & (N_c \geqslant 240) \\ f_d \times 10^{\frac{-1+4 \log N_c}{20}} & (240 > N_c \geqslant 60) \\ f_d \times 10^{\frac{2,6+2 \log N_c}{20}} & (60 > N_c \geqslant 12) \end{cases}$$

f_d: r.m.s. test tone deviation (Hz),

N_c: number of channels

$W_c(f)$: spectral power per unit bandwidth (W/Hz),

f_h: top frequency of the baseband (Hz),

f_l: bottom frequency of the baseband (Hz),

$W_B(f)$: power density spectrum of the baseband frequency modulation (W/Hz).

The evaluation of ψ_0 for systems with pre-emphasis in accordance with Rec. 275, and of the maximum value of $V(f)$ for such systems having $\psi_0 \leqslant 0.5$ is set out in Annex I of this Report.

For carriers for which $1 < N \leqslant 12$, the maximum power density per 4 kHz is approximated by the expression:

$$P_t \cos^2 \frac{m_b}{1.5} \qquad \text{(W/4 kHz for } m_b < 1) \tag{5}$$

where:

P_t: total power of the carrier, in watts;

m_b: the peak modulation index (radians) due to an 0 dBm test tone in the highest frequency baseband channel.

2.2.2 *FM carrier modulated by a multi-channel telephony signal and an energy dispersal signal of a triangular waveform with fixed amplitude*

Some methods of applying energy dispersal using a low frequency triangular wave to FM-FDM transmissions are given in Report 384.

Triangular wave dispersal systems are normally designed to ensure that the maximum power spectral density per 4 kHz centred on the carrier frequency is maintained within 3 dB of the fully loaded value.

The power spectral density centred on the carrier frequency is given by:

$$\frac{P_t}{\Delta F} \times 4000 \qquad \text{(W/4 kHz)} \tag{6}$$

where:

P_t: the total power of the carrier (W);

ΔF: peak-to-peak frequency deviation due to the energy dispersal signal (Hz).

Non-linearities in the triangular dispersal waveform will normally be present, generally of such a form as to lead to an increase in spectral density away from the carrier, relative to the ideal case.

However the residual deviation of the carrier due to pilot tones, VF telegraph bearers etc., should in most cases considerably diminish the effect of these non-linearities.

Until more evidence is available regarding the performance achievable by the methods described in Report 384, the maximum power spectral density with triangular wave dispersal should be calculated using expression (6).

2.2.3 *FM carrier modulated by a television video signal*

– For the case where an energy dispersal signal of a triangular waveform is superimposed on the video signal, the maximum power density per 4 kHz in the worst case is given by:

$$\frac{P_t}{\Delta F} \times 4000 \qquad \text{(W/4 kHz)} \tag{7}$$

where:

P_t: total power of the carrier (W)

ΔF: peak-to-peak frequency deviation due to the energy dispersal signal (Hz)

Note. – Equation (7) assumes the use of perfectly linear triangular dispersal waveform. Negligible error results from this assumption for current FM TV transmissions.

– For the case where there is no modulation, and an energy dispersal signal is not used, the maximum power density per 4 MHz in the worst case is given by:

$$P_t \qquad \text{(W/4 kHz)}$$

2.3 *Maximum power density per 4 kHz of a phase modulated (PM) carrier modulated by a multi-channel telephony signal* [Yokoyama *et al.*, 1976]

When a PM carrier is modulated by a multi-channel telephony signal, the maximum power density is found at the centre frequency of the carrier. This is true if the top baseband frequency is much larger than the bottom baseband frequency. An expression for the maximum power density assuming this condition is given as follows:

– for $\beta\sigma_a \geqslant 2$:

$$\frac{P_t}{(\beta\sigma_a)\,f_h}\sqrt{\frac{3}{2\pi}} \times 4000 \qquad \text{(W/4 kHz)} \tag{8}$$

– for $\beta\sigma_a < 2$, the maximum power density per 4 kHz is the sum of following two terms:

– continuous spectrum: $P_t \times S(0) \times 4000$ (W/4 kHz) (9)

$S(0)$ can be found from Fig. 1 which gives values for the ratio of the total carrier power to power density in a bandwidth of f_h (Hz).

– residual carrier: $P_t \exp\{-(\beta\sigma_a)^2\}$ (W) (10)

where:

P_t: total power of the carrier (W),

$\beta\sigma_a$: multi-channel phase deviation (rad),

β: r.m.s. test tone phase deviation (rad),

σ_a: loading factor of the multi-channel telephony signal.

$$\sigma_a = \begin{cases} 10^{\frac{-15 + 10 \log N}{20}} & (\text{for } N \geqslant 240) \\ 10^{\frac{-1 + 4 \log N}{20}} & (\text{for } N < 240) \end{cases}$$

N: channel number,

f_h: top baseband frequency (Hz).

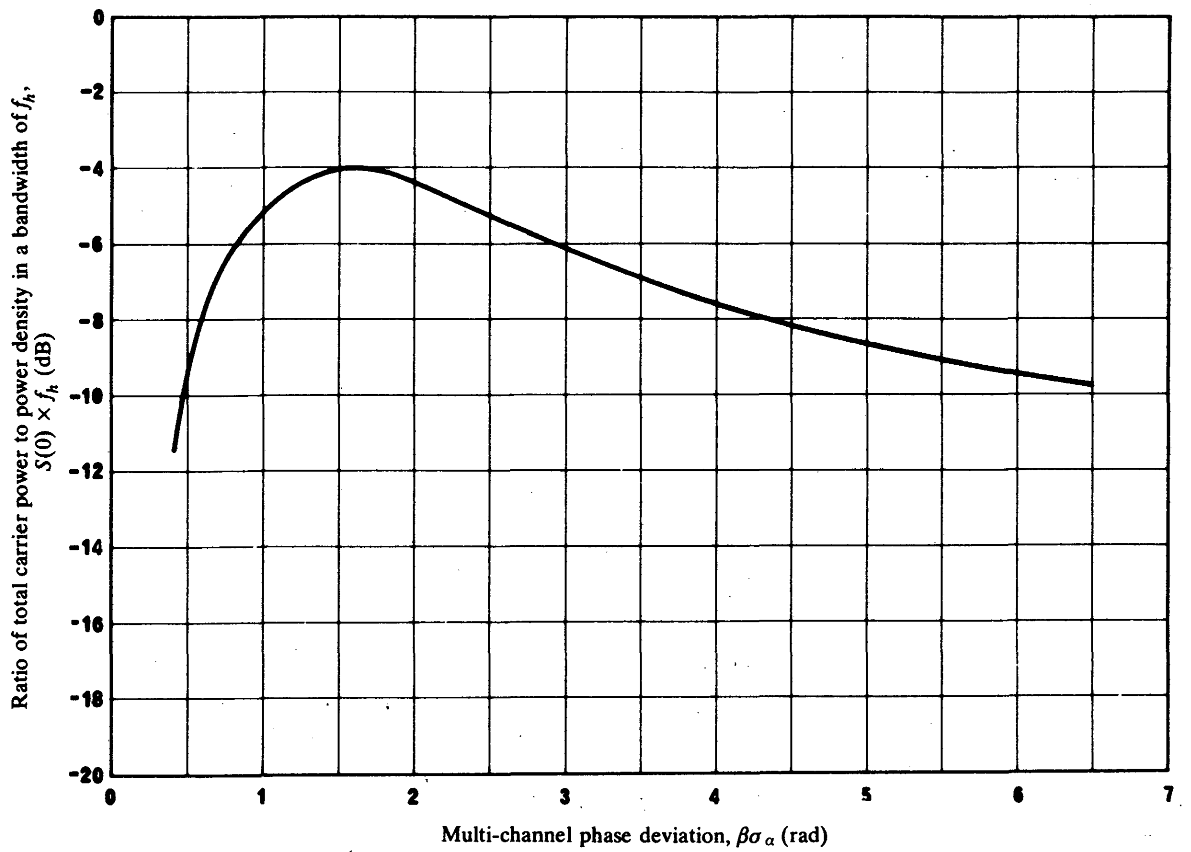

FIGURE 1 – *Power density at the centre frequency of continuous power spectrum of PM carrier in a bandwidth of* f_h

2.4 *Maximum power density per 4 kHz of a PSK carrier*

The maximum power density per 4 kHz of a PSK carrier modulated by a digital energy dispersal signal of a *PN* (pseudo noise) sequence is given by:

$$P_t \times (4000/B) \qquad \text{(W/4 kHz)} \tag{11}$$

when the repetition cycle of the *PN* sequence is longer than 250 μs; and by:

$$P_t \cdot \frac{L+1}{L^2} \left\{ \left[\frac{4000}{1/Lt} \right] + 1 \right\} \qquad \text{(W/4 kHz)} \tag{12}$$

when the repetition cycle of the *PN* sequence is equal to or less than 250 μs;

where:

P_t : total power of the carrier (W),

B : symbol rate (symbol/s),

L : length of the *PN* sequence (symbol),

t : symbol duration (s).

$$\left[\frac{4000}{1/Lt} \right] : \text{ integer part of } \frac{4000}{1/Lt}$$

The expressions given above apply to the case of *PN* sequence modulation of a PSK carrier and would be applicable to cases where the PSK message signal is continuously overlaid by a *PN* scrambling sequence. Large errors could result from the application of these expressions to systems, such as TDMA, in which the preamble portion of the signal, added parity bits, and the like, are not scrambled. Furthermore, in multi-phase systems the spectral uniformity expected from *PN* energy dispersal may be destroyed by the common operation of differential encoding.

It should be noted that the above treatment does not give any guidance as to the assumptions which should be made to cover the case of PSK systems without energy dispersal, under conditions in which bit patterns could repeat in such a manner as to concentrate the power in a relatively small number of spectral lines. Report 384 touches on the problem but further work is required.

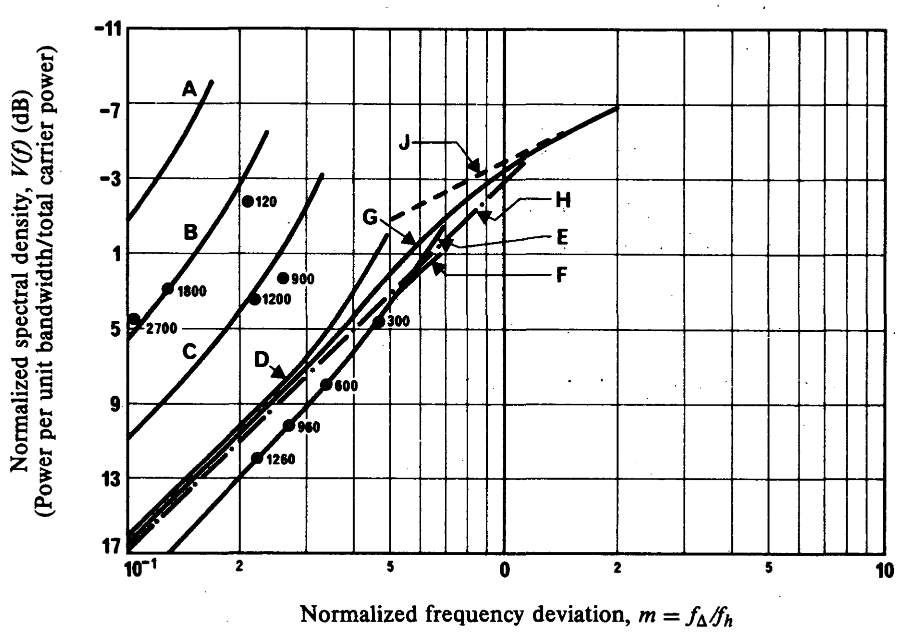

FIGURE 2 – *Maximum spectral density of signal (distributed component) frequency modulated by Gaussian noise*
(pre-emphasis of Recommendation 275)

Curves A: ψ_0 = 0.1
B: ψ_0 = 0.2
C: ψ_0 = 0.4
D: ψ_0 = 1.0
E: ψ_0 = 2.0
F: ψ_0 = 4.0
G: ψ_0 = ∞
H: small-deviation approximation (Report 792)
J: large-deviation approximation
●: values for standard radio-relay systems (as labelled) are for the following baseband limits:

120 channels 60-552 kHz
960 channels 60-4028 kHz
1260 channels 60-5636 kHz

For the remaining radio-relay systems shown in Fig. 2, the maximum power spectral densities are valid for any of the baseband limits specified in Recommendation 380 since their β values are relatively constant and match those used in Fig. 2.

For basebands that have different values of β, Figs. 9f to 9j of Report 388 should be used instead of Fig. 2.

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ANNEX I

CALCULATION OF POWER SPECTRAL DENSITY FOR LOW VALUES OF MEAN-SQUARE PHASE DEVIATION

1. Evaluation of ψ_0 for systems with CCIR pre-emphasis

The CCIR pre-emphasis function is defined as:

$$F(x) = 0.40003 \left\{ \frac{1 + 2.080\, x^2 + 0.4096\, x^4}{1 - 0.8547\, x^2 + 0.4096\, x^4} \right\} \qquad \text{where} \quad x = \frac{f}{f_h}$$

$$\psi_0 = \frac{m^2}{(1-\beta)} \int_\beta^1 \frac{F(x)}{x^2}\, dx \qquad \text{where} \quad m = \frac{f_\Delta}{f_h} \qquad \text{and} \quad \beta = \frac{f_l}{f_h}$$

The integral can be evaluated exactly to give:

$$\psi_0 = \frac{0.40003\, m^2}{(1-\beta)} \left\{ \frac{1}{\beta} + 2.8318 - 2.4640\, R\,(0.8\beta) \right\}$$

where:

$$R(y) = 0.91316 \tan^{-1} \left\{ \frac{0.81519\, y}{1 - y^2} \right\} - 0.20380 \log_e \left\{ \frac{y^2 - 1.82633\, y + 1}{y^2 + 1.82633\, y + 1} \right\}$$

A very good approximation for ψ_0 is given in equation (16) of Report 388 and is as follows:

$$\psi_0 \approx \frac{m^2}{\beta}\,(0.4 + 1.6\beta + 0.25\beta^2 + 0.25\beta^3).$$

2. Evaluation of V_{max} for systems with CCIR pre-emphasis having $\psi_0 \leqslant 0.5$

For $\psi_0 \leqslant 0.5$ the f.m. spectrum in the "first order sideband" region may be approximated by the first term in the Middleton expansion of the second term of equation (13) of Report 388 giving:

$$V(f) = \frac{e^{-\psi_0}}{2} \frac{m^2}{(1-\beta)} \frac{F(x)}{x^2}$$

where:

x : f/f_h;

β : f_l/f_h; and

$F(x)$: pre-emphasis of Rec. 275.

Consequently at $x = \beta$

$$V_{max} = \frac{e^{-\psi_0}}{2} \cdot \frac{m^2}{(1-\beta)} \cdot \frac{F(\beta)}{\beta^2}$$

This result, together with the expression for ψ_0 as a function of m and β may be used to derive curves relating V_{max} to m and ψ_0, such as those given in Fig. 2.

REPORT 449-1

MEASURED INTERFERENCE INTO FREQUENCY-MODULATION TELEVISION SYSTEMS USING FREQUENCIES SHARED WITHIN SYSTEMS IN THE FIXED-SATELLITE SERVICE OR BETWEEN THESE SYSTEMS AND TERRESTRIAL SYSTEMS

(Questions 32/4 and 23/9, Study Programme 23A/9)

(1970–1974)

1. Introduction

In determining the conditions under which systems in the fixed-satellite service can share the same frequency bands with each other as well as with terrestrial systems, it is necessary to relate the ratio of the interfered-with to interfering signal powers to the picture degradation. In contrast to telephony, where computations are reliable, it has not been possible to compute the interference between two frequency-modulated television signals, so it is necessary to rely on measurements.

Measurements have been carried out in several countries and the results are summarized in § 2 and 3 respectively for subjective and objective measurements.

It should be noted that any particular values of interference ratio mentioned in this Report are not recommended as suitable interference objectives. The allowable interference should be included in the overall television noise objective.

2. Subjective measurements

2.1 *Tests performed in the United States of America*

Carefully controlled subjective laboratory tests have been made of interference between carriers, modulated in frequency by pre-emphasized 525-line NTSC colour television signals, with peak-to-peak frequency deviations of 8 MHz to represent terrestrial radio-relay usage, and 24 MHz to represent communication-satellite usage. Pre-emphasis and de-emphasis networks conformed to Recommendation 405, curve B. The interfered-with carrier used a modulating video signal, generated from a test colour slide while the interfering carrier used a modulating video signal obtained from reception of a commercially broadcast television programme. The interfering carrier was also modulated with a 30 Hz triangular carrier-dispersal wave form the amplitude of which was set to produce 2 MHz peak-to-peak frequency deviation. The actual value was not intended as a recommendation for working systems but merely a level which would permit evaluation of its subjective effect on systems with range of deviations. Measurements were made with the two carriers on the same frequency with the two carriers spaced by 10 MHz, and with the two carriers spaced by 20 MHz. Moreover, measurements were made for a 960-channel FDM-FM system and an 1800-channel FDM-FM system interfering into the TV-FM system with the aforementioned carrier spacings. The signal-to-thermal noise ratio of the interfered-with signal was determined by the originating television camera (46.4 dB unweighted and 53.8 dB weighted). The transmission system signal-to-noise ratio was in excess of 73 dB. Consequently, the transmission system did not degrade the originating signal. The results could be different in the presence of additional triangular thermal noise.

Precision television and radio equipment were used, and the interference was scored by ten observers experienced in judging impairments to television pictures. Each observer judged each test condition three times. The test conditions were selected randomly; therefore thirty evaluations were obtained for each test condition and the result was smooth data distributions and a basis for large statistical confidence in results. The viewing conditions for the television pictures were chosen to avoid masking the impairment. The monitor, on which the viewing was done, was located in a darkened room and the brightness and contrast of the picture were adjusted to a level that appeared pleasing to the eyes of the experimenters. Thus, the conditions were similar to viewing conditions in television broadcasting studios and control rooms.

The pictures were judged on a seven-point scale of impairment, ranging from Grade 1, not perceptible, to Grade 7, extremely objectionable. Normal distribution fits were derived for the response of each impairment grade.

Although during the tests the peak-to-peak frequency deviation ratio of the interfered-with system was fixed and the interfering carrier was always intentionally spread, the baseband signal of an actual system may consist of essentially the synchronizing and dispersal signal. This condition was tested and the subjective responses were unchanged as long as:

- all of the interfering radio-channel power is within the wanted signal's bandwidth (peak-to-peak deviation plus twice the highest modulating frequency) whether modulated or not;
- or the interfering radio-channel power is almost entirely outside this bandwidth whether modulated or not.

However, when the modulated interfering carrier has power within the interfered-with spectrum and when unmodulated it is totally outside, the modulated signal produces more interference.

It was established that 525-line monochrome television impairments are close to those for 525-line NTSC colour television.

The tests were made with a single interfering signal.

The interference results corresponding to a Grade 2 or better are reported in Tables I, II and III as a mean (μ) and standard deviation (σ) of a normal distribution fit.

In addition to the 10 observer tests there were additional one-observer tests to determine certain interference impairments not easily evaluated by 10 observers.

TABLE I — *Interference ratio (dB) for a normal distribution fit for Grade 2 or better between an interfered-with video signal generated from a test slide and an interfering video signal comprised of typical colour programme material*

Peak-to-peak frequency deviation (MHz)		Frequency separation (MHz)	μ (dB)	σ (dB)
Interfered-with signal	Interfering signal			
24	24	0	19·9	3·1
24	8	0	19·6	1·5
8	8	0	28·7	2·3
8	24	0	29·2	2·5
24	8	10	14·7	3·0
8	24	10	25·5	3·7
24	24	20	11·9	1·6
24	8	20	7·2	1·6
8	8	20	9·8	2·3
8	24	20	16·5	1·7
24	8	3·24	20·6	3·0

TABLE II — *Interference ratio (dB) for a normal distribution fit for Grade 2 or better between an interfered-with video signal generated from a test slide and an interfering 960-channel FDM-FM signal*

Interfered-with signal Peak-to-peak frequency deviation (MHz)	*Interfering signal* Ratio of r.m.s. frequency deviation to highest baseband frequency		Frequency separation (MHz)	μ (dB)	σ (dB)
	single channel	multi-channel			
24	0·044	0·25	10	11·1	1·5
24	0·044	0·25	0	14·9	2·5
8	0·132	0·75	10	21·4	3·2

TABLE III — *Interference ratio (dB) for a normal distribution fit for Grade 2 or better between an interfered-with video signal generated from a test slide and an interfering 1800 channel FDM-FM signal*

Interfered-with signal Peak-to-peak frequency deviation (MHz)	*Interfering signal* Ratio of r.m.s. frequency deviation to highest baseband frequency		Frequency separation (MHz)	μ (dB)	σ (dB)
	single channel	multi-channel			
24	0·051	0·38	0	14·2	1·9
24	0·051	0·38	20	9·7	1·5

2.1.1 An investigation for a worst frequency spacing was carried out. This investigation was conducted for a continuous frequency separation between co-channel and the top baseband frequency of 4.2 MHz. It was determined that a frequency separation of 3.24 MHz was somewhat more interfering. This spacing was subsequently evaluated by the 10 observers and the results are presented in Table I. The quantative difference in group-observer response proved too small to be reliably defined by subjective tests.

2.1.2 Interference between systems spaced by 40 MHz proved too small to generate any impairment. In fact, the interfering signal had to be greater than the interfered-with signal for interference to be observable. However, the interference mechanism that generates most of the interference depends on the particular receiving filter; consequently, the result of this experiment cannot be generalized.

2.1.3 An investigation was also carried out with the addition of audio frequencies on the interfering and interfered-with systems. The audio frequencies were imposed on the front porch of the horizontal synchronization interval of the television signal in the form of pulse-code modulation signal. No impairment was expected from this 5 kHz channel, and indeed none was measured.

2.2 *Tests performed in the United Kingdom*

A series of tests were carried out to assess the protection ratios required between television systems using frequency modulation. The subjective assessments were made using a monochrome monitor although the signals used were in fact colour signals.

The conditions under which the tests were carried out were not ideal, and the results at this stage have been submitted merely as a rough guide for interference problems. Nevertheless, it is noted that the results obtained accord, in considerable measure, with the results obtained in the more extensive measurements undertaken in the United States of America.

A six-point impairment scale was in these subjective tests ranging from Grade 1, imperceptible, to Grade 6, unusable.

In the main series of tests, with co-channel carriers, at fixed deviation and without energy dispersal, a total of 48 viewers was used. Of these 16 were technical and 32 non-technical, none being skilled in the art of picture appraisal. The picture material on which the assessments were made consisted of selected live transmissions of film and test card.

For the supplementary tests, in which the effects of deviation, energy dispersal, carrier spacing and picture content were investigated, the assessment was made by a single technical viewer relatively experienced in the art of picture appraisal.

In all cases wanted and interfering signals were co-channel. The wanted signal was taken from a broadcast receiver and fed to a 70 MHz FM modulator via a standard pre-emphasis network. The interfering signal was taken from a 625-line grey scale generator and similarly pre-emphasized and modulated. The nominal peak-to-peak deviation for both signals was 8 MHz without pre-emphasis.

The two signals were mixed at intermediate frequencies with an attenuator in the path of the interfering signal to adjust the relative levels. The output of the demodulator was de-emphasized and fed to the viewing monitor.

Tests were first carried out with 8 MHz deviation for both wanted and unwanted signals. It was found that the protection ratios judged by 50% of the viewers to correspond to a particular grade or better varied approximately linearly from 33 dB to 6 dB as a function of the impairment Grades 1 to 6. Particular values were:

50% Grade 1: -33 dB

50% Grade 2 or better: -26 dB.

The deviation of the wanted signal was then varied between 4 and 21 MHz, with the deviation of the interfering signal maintained constant at 8 MHz. It was found that the required protection ratios decreased approximately in proportion to the increase in deviation of the wanted signal (i.e. one dB per dB) as one would expect. However, at the higher deviations (i.e. greater than 12 MHz) there was some departure from this relationship; for example, at 21 MHz the protection ratio was some 2 to 3 dB less than would be expected from linear extrapolation of the low deviation results.

It appears that the use of the appropriate protection ratio for a particular low deviation case, such as 8 MHz, modified in a linear manner (one dB per dB) to take account of the actual deviation, would be an approximate way of dealing with different deviations.

When the assessment of impairment was approximately Grade 1.5, the picture content of the interfering signal had little or no effect on the protection ratio required.

When the impairment was approximately Grade 1.5, the application of energy dispersal wave forms to the unwanted signal had little or no effect on the protection ratio required.

The interference was also found to be unaffected by small changes in the frequency of the interfering carrier. As carrier frequency differences were increased beyond about 1 MHz there was a progressive subjective improvement, especially at high interference levels, but these are not reported quantitatively.

2.3 *Tests performed in France*

A series of tests were carried out as part of a programme to ascertain the acceptable protection ratios between the wanted and interfering signal powers when a carrier, frequency-modulated by a telephone multiplex signal, interferes with a frequency-modulated television signal. The results were expressed in terms of the wanted/interfering signal power ratio (C_u/C_B) commensurate with a specified impairment as a function of the frequency difference between the nominal values of the wanted and interfering carriers.

The wanted signal consisted of a 75% colour bar test pattern transmitted in the 625-line SECAM system. The carrier modulation standards were successively chosen in accordance with those recommended for line-of-sight television radio-relay systems (Recommendation 405 and Recommendation 276) and those used in certain systems in the fixed-satellite service. In the latter case energy dispersal was used (25 Hz symmetrical triangular wave form).

The interfering signal consisted of a carrier, modulated, in accordance with the standards employed in the same satellite systems, by a signal simulating a telephone multiplex signal with maximum capacity of 24, 60, 132 or 1872 channels. The modulating signal was either (a) suitably filtered and pre-emphasized white noise simulating the maximum load of the multiplex in question, or (b) a triangular energy dispersal signal simulating no-load conditions and so adjusted that the spectral density of the dispersal carrier had a maximum value which was 2 dB higher than that obtained with white noise modulation.

Since no satisfactory objective criterion was found by which to characterize the interference to the baseband television signal, it was decided to perform the tests using the subjective method only. The subjective interference level was chosen so as to correspond to the perceptibility threshold in the absence of thermal noise when the observer is in a dimly lit room at a distance from the screen equal to six times the height of the picture. An example of the results is shown in Fig. 1 which shows the interference experienced by a satellite television signal when interfered with by a 132 channel FDM-FM signal.

The nominal frequency of the channel transmitting the television signal was defined as that corresponding to an average grey level (median brightness voltage of the values corresponding to black and white). The frequency-modulation system was such that it was possible to assign a frequency adjustable to the level corresponding to the bottom of the sync pulses.

After repeated measurements in the same conditions it was possible to assess the results obtained to an accuracy of 2 dB.

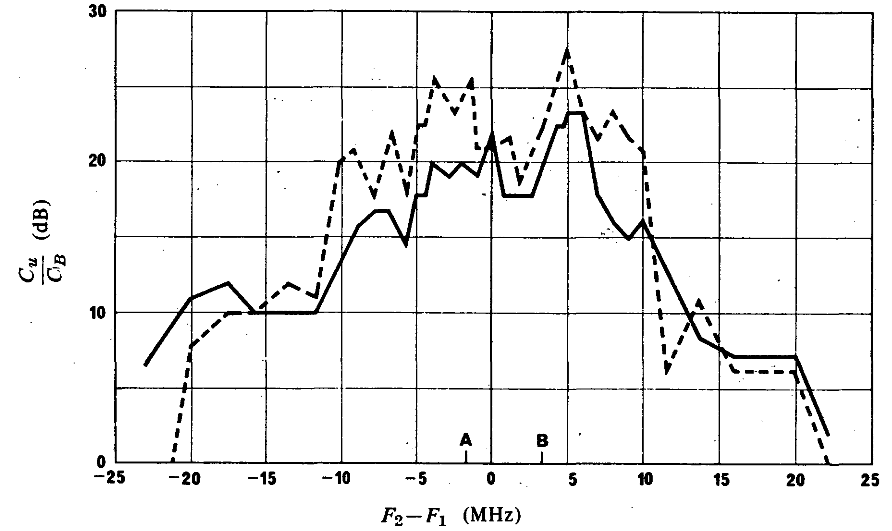

FIGURE 1

Wanted signal: Television (satellite)

Interfering signal: Telephony 132 channels (case 2)

——— : full load

- - - - - : no load

F_1: wanted carrier frequency

F_2: interfering carrier frequency

A : White

B : Bottom of synchronisation

3. Objective measurements

Tests performed in Canada

The results of objective measurements of co-channel 525-line television interference noise, in the presence of thermal noise, are presented. To simulate practical operating conditions, the FM interference was generated using live video-frequency signals as received from a local broadcasting station. The levels of interference and thermal noise were adjusted independently to achieve varied operating conditions. The desired and interfering signals were mixed at intermediate-frequencies. The combined interference and thermal noise was measured at the output of a wideband demodulator.

The subjective results described in § 2 indicate that the interference is not very sensitive to the characteristics of the modulation on the interfering signal but that it is dependent on the deviation of the wanted signal. This suggests using a single formula to calculate the "interference reduction factor" for the case of interference between frequency-modulated television signals.

Fig. 2 gives the results of measurements for a peak-to-peak deviation of both wanted and interfering signals of 24 MHz. Tests were also carried out for a deviation of 8 MHz on the interfering carrier but this had virtually no influence on the level of weighted baseband interference noise. This is in agreement with the subjective tests reported in § 2.

Another fact which came to light was that, in the absence of thermal noise, the weighted interference noise may be approximated by the simple expression:

$$(S/I) = (C/X) + B_v \qquad (1)$$

where:

S/I: peak-to-peak picture signal to weighted r.m.s. interference noise ratio (dB)

C/X: carrier-to-interference ratio (dB)

B_v: video interference reduction factor (dB).

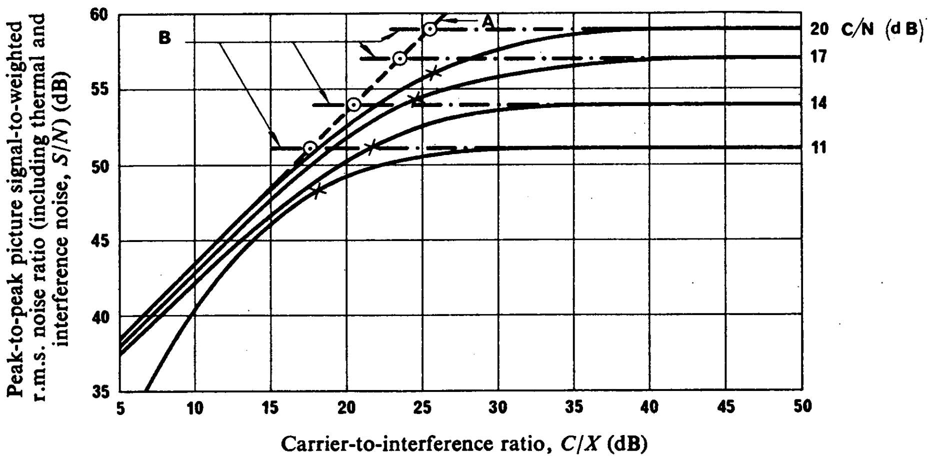

FIGURE 2

Objective measurements of television interference noise in the presence of thermal noise

Peak-to-peak frequency deviation of interfering signal, 24 MHz
Peak-to-peak frequency deviation of wanted signal, 24 MHz
C/N=Carrier-to-noise ratio

Curve A: interference only (extrapolation)

Curve B: thermal noise only (extrapolation)

Note. — At high values of the carrier-to-noise ratio, the signal-to-noise compressions are due to noise in the modulator and demodulator and to other impairments in transmission

× × × : measured points of 3 dB degradation due to interference

⊙ ⊙ ⊙ : 3 dB degradation points derived empirically using power addition of individually weighted baseband components

For the conditions tested, an interference reduction factor, B_v, was found to be 33.5 dB. (The signal-to-interference ratios, S/I, were determined using the peak measured values of the noise over a 5 to 10 second interval where the interfering source was active, i.e., not during test pattern or commercial presentation.)

On the basis of these results and the findings presented in § 2 it is suggested that the following expression be used to determine the interference reduction factor, B_v, for other frequency deviations in the range from 8 to 24 MHz.

$$B_v = 6 + 20 \log \Delta F \qquad \text{dB} \tag{2}$$

where:

ΔF: peak-to-peak frequency deviation of the wanted signal, MHz.

In the presence of thermal noise, the total weighted baseband noise power is equal to the power-sum of the weighted interference noise, as given by equation (1), and the weighted thermal noise contributions. This holds true for carrier-to-interference ratios greater than approximately 15 dB. At lower carrier-to-interference ratios, the signal-to-noise ratio begins to drop more rapidly due to an increase in the susceptiveness of the demodulator to phase reversals by the thermal noise.

4. Tests carried out in the U.S.S.R.

A comprehensive set of results of measurements are described in documents of the study period 1966-69 which are both of an objective and subjective nature. These results in general are in agreement with the results of the measurements reported in § 2.1 and 2.2.

5. Conclusions

Further study of the results reported is required before general conclusions can be drawn. However a few particular conclusions are as follows:

- the protection ratio required to meet any specified performance is approximately inversely proportional to the square of the deviation of the wanted signal;
- provided the wanted signal is modulated the deviation of the interfering signal does not greatly affect the results. This suggests that the results are also applicable for interference from an FM telephony signal;
- generally it can be considered that there is no value of carrier-frequency separation which gives interference much worse than the co-channel case. However certain tests have shown that when the carriers are separated by frequencies near the colour sub-carrier, interference levels higher than the co-channel case can be experienced, as shown in § 2.3;
- the objective results for co-channel interference may be used when each interference entry results in less than perceptible interference. In this case the weighted interference noise calculated by means of the interference reduction factor B_v may be added to the thermal noise in the system;
- the subjective results are applicable in cases where there are higher levels of interference than indicated immediately above, since the objective results do not allow for the fact that, at high levels of interference, the subjective effect may be more objectionable than that of thermal noise.

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QUESTIONS AND STUDY PROGRAMMES

QUESTION 17-1/9

CRITERIA FOR FREQUENCY SHARING BETWEEN RADIO-RELAY SYSTEMS AND SPACE RADIOCOMMUNICATION SYSTEMS

(1969-1978)

The CCIR,

CONSIDERING

(a) that radio-relay systems are now widely employed throughout the world and make extensive use of the radio-frequency spectrum;

(b) that the use of radio-relay systems is expected to continue to expand and that new systems are expected to operate with improved performance and make more efficient use of the radio-frequency spectrum;

(c) that the use of space radiocommunication systems in shared frequency bands is expected to continue to expand;

(d) that the continued development of terrestrial and space services is desirable;

(e) that control of mutual interference between stations of the various services is necessary,

UNANIMOUSLY DECIDES that the following question should be studied:

1. what levels of interference are acceptable and under what conditions do they apply to radio-relay systems in order to facilitate sharing with systems in the space radiocommunication service;

2. what limitations are acceptable to radio-relay systems to facilitate the operation of earth-station and space-station receivers in a shared environment?

Note. – See Report 789.

STUDY PROGRAMME 17E/9

SHARING CRITERIA AND MAXIMUM e.i.r.p. FOR LINE-OF-SIGHT RADIO-RELAY TRANSMITTERS OPERATING IN FREQUENCY BANDS SHARED WITH THE FIXED-SATELLITE SERVICE

(1985)

The CCIR,

CONSIDERING

(a) that emissions from line-of-sight radio-relay transmitters may produce interference in receiving space stations of the fixed-satellite service, in shared frequency bands;

(b) that it is impractical to coordinate between the many terrestrial stations and the many space stations and that, therefore, sharing criteria should be such as to preclude the need for detailed coordination;

(c) that, in devising such sharing criteria, account needs to be taken of the operational and technical requirements of radio-relay systems and the options open to them to comply with such sharing criteria, as well as of the technical and operational characteristics of space stations,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the sharing criteria by which receiving space stations in the fixed-satellite service can be adequately protected against interference from radio-relay transmitters without requiring detailed coordination;

2. the constraints, if any, on the e.i.r.p. of radio-relay transmitters, which may have to be adopted to allow the sharing criteria devised under § 1 above to be met.

STUDY PROGRAMME 17F/9

CRITERIA FOR FREQUENCY SHARING BETWEEN THE FIXED SERVICE AND THE FIXED-SATELLITE SERVICE IN BIDIRECTIONALLY ALLOCATED FREQUENCY BANDS

(1985)

The CCIR,

CONSIDERING

(a) that the existing sharing criteria are based on fixed-satellite systems in unidirectionally allocated frequency bands;

(b) that bidirectional operation on the fixed-satellite service introduces additional interference sources;

(c) that the coordination of earth stations in bidirectionally allocated frequency bands may require new coordination parameters which take into consideration interference sources from the down-link as well as the up-link direction;

(d) that the introduction of transmitting earth stations in a frequency band that currently is allocated for transmitting space stations may impose restrictions on both the fixed and fixed-satellite services;

(e) that both long-term and short-term interference mechanisms must be considered in establishing frequency sharing criteria,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. development of short-term and long-term sharing criteria that take into consideration down-link and up-link interference;

2. development of new coordination parameters for the coordination of transmitting and receiving earth stations and consideration of the inclusion of these parameters in Report 382, noting that earth-station coordination distances are determined by short-term anomalous propagation conditions;

3. development of new pfd limits for the protection of terrestrial receivers and consideration of the inclusion of these limits in Report 387;

4. determination of the limitations that are acceptable to radio-relay systems that will allow for development and growth of the fixed service in frequency bands with new allocations for bidirectional satellite transmissions.

QUESTION 39/9*

TECHNICAL CRITERIA TO BE USED IN THE BOARD'S EXAMINATIONS OF THE PROBABILITY OF HARMFUL INTERFERENCE REQUIRED BY PROVISIONS Nos. 1354, 1506 AND 1509 OF THE RADIO REGULATIONS

(1989)

(The text of this Question is identical to the text of Question 39/4, page 212.)

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* An identical text is allocated to Study Group 4 as Question 39/4. Elements of this Question concerning RR Nos. 1354 and 1509 are studied jointly with Study Group 4. The element concerning RR No. 1506 is for study by Study Group 4.

QUESTION 32/4*

FREQUENCY SHARING BETWEEN SYSTEMS IN THE FIXED-SATELLITE SERVICE AND TERRESTRIAL SERVICES

(1986)

The CCIR,

CONSIDERING

(a) that, in the interest of spectrum conservation, many frequency bands have been allocated on a shared basis to the fixed-satellite service and terrestrial services;

(b) that it should be feasible in most cases for these services to share frequency bands effectively;

(c) that the scope for development and future applications of systems in both kinds of service depends to a great extent upon the manner in which they share frequency bands;

(d) that the use of systems in the fixed-satellite service which may include inter-satellite links and feeder links to satellites in other radiocommunication services, will require extensive use of the radio-frequency spectrum allocated;

(e) that the conditions for effective frequency sharing between radio-relay systems and the fixed-satellite service should be investigated;

(f) that attention should be paid to the conditions for frequency sharing between inter-satellite links in the fixed-satellite service and terrestrial services;

(g) that Resolution No. 101 of the WARC-79 requests the CCIR to study and to determine, as a matter of urgency, suitable criteria applicable to sharing between the fixed and mobile services and feeder links to broadcasting satellites;

(h) that the use of interference reduction and cancellation techniques may make frequency sharing between the fixed-satellite service and terrestrial services more effective,

UNANIMOUSLY DECIDES that the following question should be studied:

1. under what conditions and to what extent can systems in the fixed-satellite service share frequency bands with terrestrial services;

2. what are the appropriate criteria which affect the selection of sites for stations in the fixed-satellite service and for stations of terrestrial services, taking into account the characteristics of the various frequency bands in which these services share, or may share, allocations;

3. what are the preferred technical characteristics of transmitting and receiving antennas for earth stations at fixed locations, from the standpoint of frequency sharing with terrestrial radio services;

4. what are the factors that determine the maximum power, or power density which may be radiated towards the horizon by an earth station;

5. what are the factors that determine the minimum antenna beam elevation angle which should be employed by earth stations;

6. to what degree can electromagnetic shielding between earth stations and stations in other terrestrial radio services, be used or provided by artificial means;

7. what are the appropriate criteria to determine the minimum practicable separation between the locations of radio-relay stations and earth stations in the fixed-satellite service, where either kind of station may transmit and receive, and use any type of modulation;

8. what are the factors which affect the maximum permissible power flux-density in a reference bandwidth which may be produced at the surface of the Earth by emissions from satellites in the fixed-satellite service;

* Newly developed from former Study Programme 2A-4/4 (Geneva, 1982).

9. what criteria are appropriate for frequency sharing between inter-satellite links in the fixed-satellite service and terrestrial services;

10. what criteria are appropriate for frequency sharing between terrestrial fixed and mobile services and feeder links to broadcasting satellites;

11. what are the criteria for determining the maximum permissible e.i.r.p. in the direction of the geostationary-satellite orbit of terrestrial radio-relay stations to allow sharing with the fixed-satellite service;

12. what are the preferred methods for interference reduction and cancellation at earth stations in the fixed-satellite service, and what are the technical characteristics of these methods?

Note. – See Recommendations 355, 356, 357, 359, 406, 558 and 615, and Reports 209, 382, 385, 387, 388, 393, 448, 449, 709, 790, 791, 792, 793, 876, 877, 1005 and 1006.

STUDY PROGRAMME 32A/4

PREFERRED TECHNICAL CHARACTERISTICS AND SELECTION OF SITES FOR EARTH STATIONS IN THE FIXED-SATELLITE SERVICE TO FACILITATE SHARING WITH TERRESTRIAL SERVICES

(1986)

The CCIR,

CONSIDERING

(a) that earth stations of the fixed-satellite service and terrestrial stations may be subject to mutual interference where they share a frequency band;

(b) that the required physical separation between the two kinds of station is an important factor in the effectiveness of sharing;

(c) that site shielding is an effective means to reduce the required physical separation between the two kinds of station;

(d) that the relative location and antenna beam pointing geometry of earth and terrestrial stations also affect the spacing between the two kinds of station;

(e) that terrestrial systems generally comprise a number of links in tandem or connected at nodes, and that their stations are generally located on prominent terrain,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. appropriate techniques and technical criteria to be used in the selection of earth-station site characteristics and the nature of locations to minimize the physical spacing between such sites and stations of terrestrial services;

2. appropriate techniques to provide and evaluate man-made site shielding.

Note. – See Report 385.

STUDY PROGRAMME 32B/4

INTERFERENCE REDUCTION AND CANCELLATION TECHNIQUES FOR THE EARTH STATIONS IN THE FIXED-SATELLITE SERVICE

(1986)

The CCIR,

CONSIDERING

(a) that interference from transmitting stations of terrestrial services to receiving earth stations in the fixed-satellite service affects the effectiveness of frequency sharing between the two types of service;

(b) that means to reduce interference could greatly improve the effectiveness of sharing,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. appropriate techniques by which interference received at an earth station could be reduced, eliminated or otherwise rendered less harmful;

2. conditions under which such techniques would be most effective, the magnitude of the expected improvement and the limitations.

Note. – See Report 875.

STUDY PROGRAMME 32C/4

PREFERRED TECHNICAL CHARACTERISTICS OF SPACE STATIONS IN THE FIXED-SATELLITE SERVICE TO FACILITATE SHARING WITH TERRESTRIAL SERVICES

(1986)

The CCIR,

CONSIDERING

(a) that emissions from space stations in the fixed-satellite service may produce interference in receiving stations of terrestrial services in frequency bands shared by the two kinds of service;

(b) that it is impractical to coordinate between the many terrestrial stations and the many space stations and that, therefore, sharing criteria should be such as to preclude the need for detailed coordination;

(c) that, in devising such sharing criteria, account needs to be taken of the operational and technical requirements of networks in the fixed-satellite service as well as of the requirments of terrestrial services and the measures available to them,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. sharing criteria by which terrestrial services could be adequately protected against unacceptable interference due to emissions from space stations of the fixed-satellite service in shared frequency bands in such a way as not to require detailed coordination between space and terrestrial stations;

2. technical constraints on the pfd of space stations which comply with such sharing criteria, taking into account the technical and operational requirements for such space stations when they are part of networks.

Note. – See Recommendation 358 and Report 387.

QUESTION 39/4*

TECHNICAL CRITERIA TO BE USED IN THE BOARD'S EXAMINATIONS OF THE PROBABILITY OF HARMFUL INTERFERENCE REQUIRED BY PROVISIONS Nos. 1354, 1506 AND 1509 OF THE RADIO REGULATIONS

(1989)

The International Frequency Registration Board (IFRB),

CONSIDERING

(a) the provisions of No. 326 of the International Telecommunication Convention, Nairobi, 1982;

(b) that the Radio Regulations, in Articles 12 and 13, request the IFRB to carry out examinations, *inter alia*, of the probability of harmful interference between terrestrial stations and earth stations (Nos. 1354 and 1509) as well as examinations of the probability of harmful interference between stations of geostationary-satellite networks (No. 1506);

(c) that it is necessary for the Board, when developing its Technical Standards, to have the required information through appropriate Recommendations of the CCIR (see Nos. 1001, 1454 and 1582 of the Radio Regulations);

(d) that the Radio Regulations distinguish the harmful interference (No. 163) from the permissible interference (No. 161);

(e) that in Question 45-2/1 the CCIR decided to study the terms "acceptable interference" and "harmful interference" as well as the problems related to the maximum permissible values of interference and the associated time percentages in a general way, applicable to all radiocommunication services;

(f) that the present CCIR Recommendations and Reports contain criteria for different sharing situations between terrestrial and space services, but there exists no CCIR Recommendation or Report establishing the limits of harmful interference which the Board could consider when developing its Technical Standards to be used for the above mentioned examinations of the probability of harmful interference,

REQUESTS THE CCIR to study the following question:

what criteria for levels of harmful interference are to be recommended to the IFRB for use in its examinations of the probability of harmful interference, in particular in examinations foreseen by provisions Nos. 1354, 1506 and 1509 of the Radio Regulations, and under what conditions and for what associated percentage of time do they apply?

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* Elements of this Question concerning RR Nos. 1354 and 1509 are studied jointly with Study Group 9; an identical text is allocated to Study Group 9 as Question 39/9.

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