XVII A.P.
DÜSSELDORF
21.5-1.6 1990
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XVIIth PLENARY ASSEMBLY
DÜSSELDORF, 1990

INTERNATIONAL TELECOMMUNICATION UNION

REPORTS OF THE CCIR, 1990

(ALSO DECISIONS)

ANNEX TO VOLUMES IV AND IX – PART 2

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

CCIR INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

Geneva, 1990

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

(Study Groups 4 and 9)

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ANNEX TO PART 2 OF VOLUMES IV AND IX

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SECTION 4/9A: SHARING CONDITIONS

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.

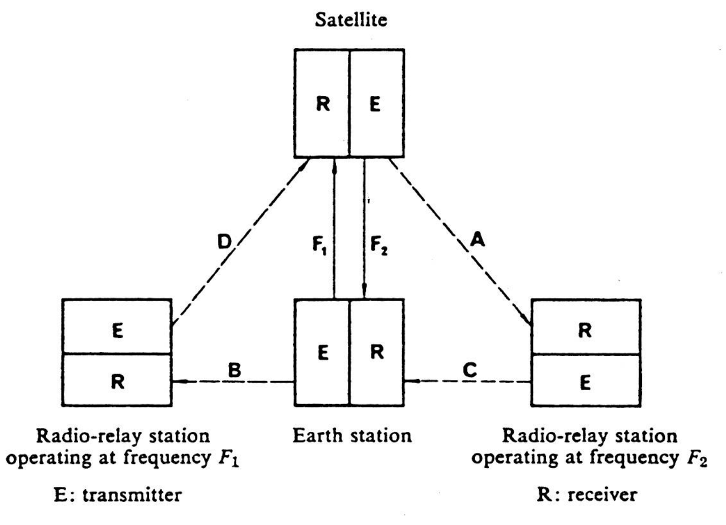

FIGURE 1

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

———— wanted signal
— — — — interfering signal

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 attention 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.

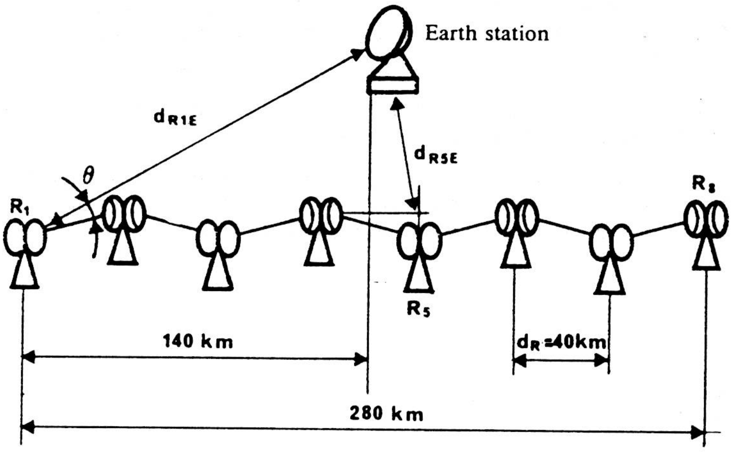

FIGURE 2 – *Model of mutually interfering satellite earth station and terrestrial radio system*

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.

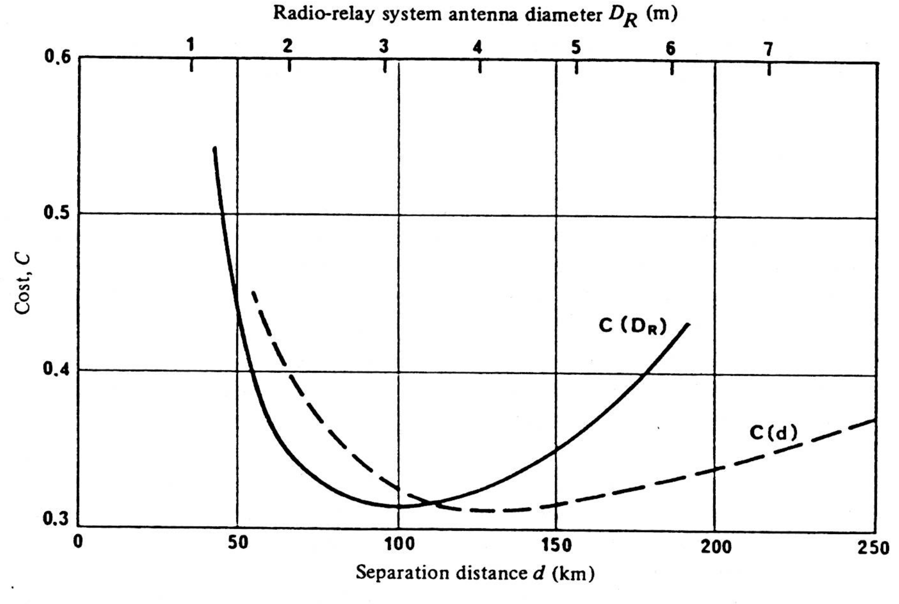

FIGURE 3 – *Variation of total cost of the systems with separation distance d and radio-relay system antenna diameter D_R. The other independent variables are held at their optimum values*

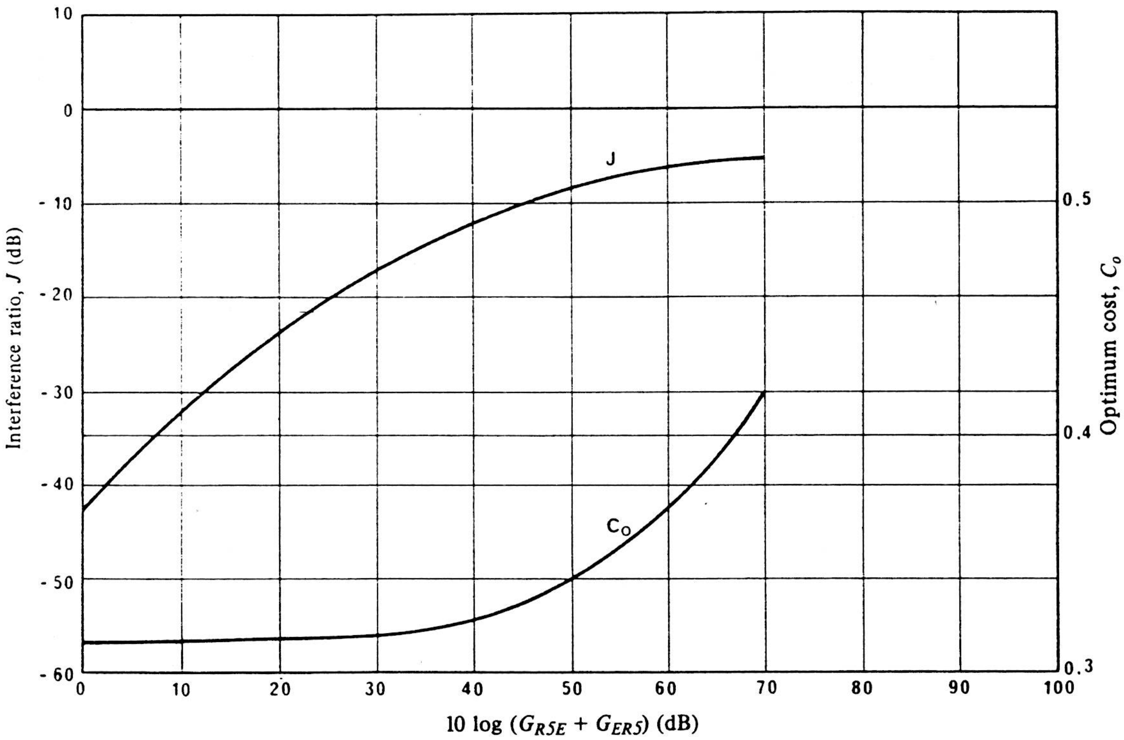

FIGURE 4 – *Variation of cost of the systems and optimum interference with the product of antenna gains of the earth station and the repeater causing long-term interference*

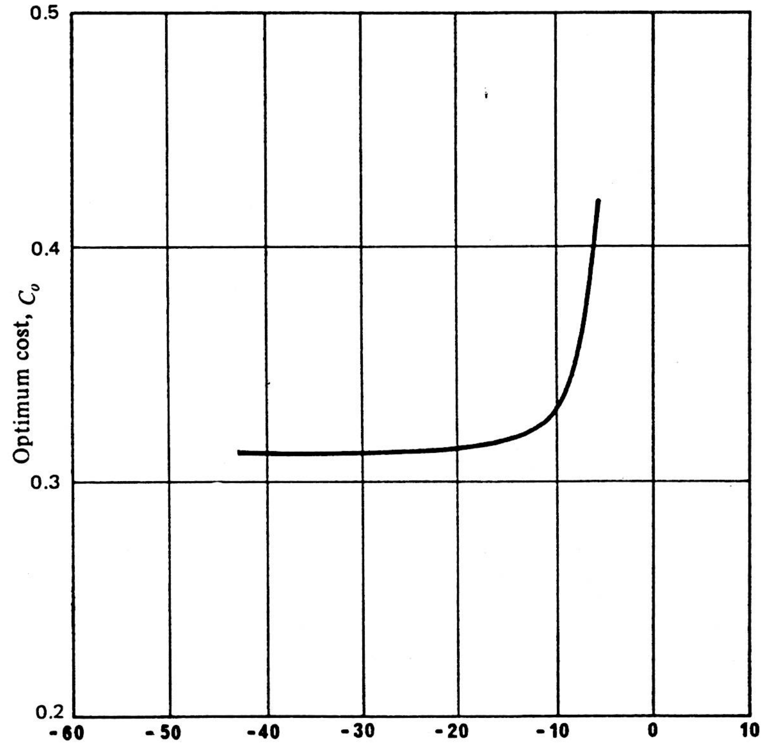

FIGURE 5 – *Relation between optimum cost and level of interference determined by the antenna gains involved in the transmission of long-term interference*

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 θ = 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 θ = 4°)

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

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

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 θ = 4°, water vapour concentration ρ = 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):

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

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.