SECTION 10/11E: SHARING

REPORT 631-4*

FREQUENCY SHARING BETWEEN THE BROADCASTING-SATELLITE SERVICE (SOUND AND TELEVISION) AND TERRESTRIAL SERVICES

(Question 1/10 and 11, Study Programmes 1A, 1C, 1D and 1E/10 and 11)

(1974-1978-1982-1986-1990)

1. Introduction

Under the Radio Regulations, as revised by the World Administrative Radio Conference, Geneva, 1979, the broadcasting-satellite service has allocations, or is permitted to operate, under certain conditions in the following bands, all shared with other services:

- 620 to 790 MHz, which is mainly used by the fixed, mobile, and terrestrial broadcasting services;
- 2500 to 2690 MHz to be shared with the fixed, mobile, broadcasting and fixed-satellite services;
- 11.7 to 12.5 GHz in Region 1 to be shared with the fixed and broadcasting services on a primary basis (and with the mobile service on a secondary basis);
- 11.7 to 12.2 GHz in Region 3 where it is to be shared with the fixed, mobile and broadcasting services;
- 12.2 to 12.70 GHz in Region 2, shared with the fixed, mobile and broadcasting services;
- 12.5 to 12.75 GHz in Region 3 shared with the fixed, mobile and fixed-satellite services;
- 22.5 to 23 GHz in Regions 2 and 3, where it is to be shared with the fixed and mobile services (and, in the upper 0.45 GHz of that band, with the inter-satellite service);
- 40.5 to 42.5 GHz to be shared with the broadcasting service on a permitted basis; and
- 84 to 86 GHz to be shared with the fixed, mobile, and broadcasting services, except that these services cannot cause harmful interference to broadcasting-satellite earth stations operating in accordance with a plan yet to be adopted by a subsequent Administrative Radio Conference.

2. Elements to be considered in frequency sharing

In establishing the bases for frequency sharing between the broadcasting-satellite, terrestrial and inter-satellite services, certain elements should be considered. These include the protection ratio necessary to ensure that the interference from one of the services will be acceptable to the others.

Values for protection ratios involving the broadcasting-satellite and terrestrial service are listed in Report 634. Also, the technical characteristics of the sharing systems, such as e.i.r.p., antenna aperture, sidelobe levels, receiver sensitivity and the kind of modulation used; and geographical considerations (such as the line of direction from the interfered-with to the interfering position and the establishment of "exclusion areas" and the service areas) are factors to be taken into account. Constraints and limitations to these factors may be required to permit frequency sharing. Further sharing in a common area may be achieved by time sharing.

If co-area, co-frequency sharing is not possible, constraints and limitations necessary to permit sharing through the use of geographical frequency-sharing arrangements would be required.

Before taking a step that would restrict or prevent the operation of a service having a primary allocation in a band, and which are involved in one or more of the interference situations discussed in this report, every effort should be made to increase the feasibility of sharing between the services.

* This Report should be brought to the attention of Study Groups 8 and 9.

Among the measures that could increase the feasibility of sharing are the following:

- use of performance objectives and availability criteria commensurate with the needs of the service to be provided;
- selection of characteristics of the model system to be protected that would result in minimum sensitivity to interference, consistent with practical system designs (e.g. adequate transmitter power and antenna gains, reasonable path lengths, "rugged" modulation methods, etc.) (Note that in most cases, decreasing sensitivity to interference also improves system performance.);
- restricting the operation of highly sensitive systems to band segments not also allocated to a service having a relatively high potential to cause interference.

Among the steps that could restrict, or prevent the operation of, a service having a primary allocation are CCIR Recommendations or Radio Regulations establishing interference threshold (trigger) levels, or power flux density limits.

2.1 *Sound broadcasting*

In existing broadcasting-satellite allocations, there is no distinction made between sound and television systems. Satellite broadcasting in the band 620 to 790 MHz is permitted by No. 693 of the Radio Regulations but is limited to FM(TV).

The WARC-79 has recommended that the band 500 to 2000 MHz be analyzed to establish optimum locations for satellite sound broadcasting. Further study is required to determine whether there is any specific region of this band which is particularly desirable. Further study is also required to determine if sharing is feasible and, if so, under what conditions. Report 941 (Study Group 9) concludes that in the case of the protection of terrestrial radio-relay systems against a possible FM satellite sound-broadcasting system operating in the band 1427 to 1530 MHz, some form of energy dispersal would be required on the satellite emission. Digital modulation provides energy dispersal inherently. The application of artificial energy dispersal to FM satellite sound-broadcasting transmissions requires further study. The study in Report 941 assumed powers of the order indicated in Report 955 and that protection required limitation of the flux to the values applicable in the 2500 to 2690 MHz band (see § 4.1). Even with 14 dB energy dispersal (i.e. a power flux-density in a 4 kHz band 14 dB below the total PFD) protection of the fixed service appeared possible only under certain conditions, including a wide geographical separation between the broadcasting-satellite service area and the radio-relay systems concerned.

2.2 *Television broadcasting*

2.2.1 *General equation for the limiting value of power flux-density of the unwanted signal to protect the wanted service*

As previously noted, when a broadcasting-satellite service shares frequencies with a terrestrial service, it may be necessary to impose limitations on the power flux-density produced by the unwanted signal at the receiving stations of the wanted service. A general equation for determining the limit on power flux-density is:

$$F_s = F_{tqp} - R_q + D_d + D_p - M_r - M_i \qquad (1)$$

(*Note.* – This equation may not be valid when the satellite signal arrives near grazing incidence. In this case an additional margin must be included.)

where:

F_s: maximum power flux-density (dB(W/m^2)) to be allowed at the protected station,

F_{tqp}: minimum power flux-density (dB(W/m^2)) to be protected, i.e. the power flux-density which, in the face of thermal noise only, yields the output signal quality q that is to be exceeded for some specified high percentage of the time p,

R_q: protection ratio (ratio of the wanted-to-interference signal power at the receiver input) (dB) for barely detectable interference when the output signal quality has been degraded by the thermal noise to q,

D_d: discrimination (dB) against the interfering signal due to directivity of the receiving antenna,

D_p: discrimination (dB) against the interfering signal due to polarization of the receiving antenna. This factor is often combined with D_d as a single term,

M_r: margin (dB) for possible ground reflection of interfering signal,

M_i: margin (dB) for possible multiple interference entries.

The limit on power flux-density given by equation (1) insures that the output signal quality at the receiving station of the wanted signal will be equal to q even when the power flux-density of the system has faded to the level F_{tqp}. During p% of the time, the power flux-density of the system will be higher than F_{tqp} and the output signal quality will be higher than q.

If it is desired to express F_s in terms of the median value of power flux-density from the wanted system, F_{tqm}, which yields the same output quality statistics, the equation is:

$$F_s = F_{tqm} - M_p - R_q + D_d + D_p - M_r - M_i \qquad (2)$$

where M_p is the difference (dB) between the median value of the wanted signal level and the level exceeded p% of the time.

Equations (1) and (2) can be applied to calculate the limits on the unwanted power flux-density, appropriate to any given wanted service. In the case of the terrestrial broadcasting service, the receiving station to be protected is assumed to be on the boundary of the potential service area of the terrestrial transmitter. This boundary is defined as the geographic contour within which the power flux-density from the terrestrial transmitter equals or exceeds that required to produce an output signal (television picture or sound) of acceptable quality in the absence of interference and man-made noise at 50% of the locations for at least p% of the time, where for example, p has a specified value in the range from 90% to 99%. In the terrestrial broadcasting service it is also traditional to describe the incident signal in terms of field-strength in dB(μV/m) rather than in terms of power flux-density in dB(W/m^2). The former can be obtained from the latter by adding 145.8 dB.

2.2.2 *Power flux-density requirements*

Report 215 discusses examples of the required power flux-densities for the broadcasting-satellite service in some detail, and Table XIVa and b of that Report contains numerical values of such power flux-densities. Report 811 indicates power flux-densities relevant to planning this service in the 12 GHz band.

Corresponding values for terrestrial amplitude-modulation television broadcasting services are indicated in Report 961.

2.2.3 *Field strengths and power flux-densities to be protected*

The field strengths and power flux-densities requiring protection are discussed in the sections concerning each frequency band.

2.2.4 *Protection ratios*

Report 634 deals with this subject in some detail and presents required values of protection ratio for different systems.

2.2.5 *Use of special techniques to meet limitations on power flux-density*

Energy dispersal techniques for frequency modulation could be considered to "spread" the radiated power over a wide radio frequency band to meet power flux-density limitations. Careful consideration, however, should be given to technical and economic impacts of the application of such techniques on the systems.

Some examples of the use of energy dispersal are given in the sections concerned.

2.2.6 *Calculation of power flux-density produced by a geostationary satellite*

Several methods may be used to calculate the power flux-density at a given point on earth as produced by a broadcasting satellite (see, for example, Report 215).

3. Sharing in the 620 to 790 MHz band

Television broadcasting from satellites using frequency modulation only is dealt with in this section.

3.1 *Sharing with the terrestrial broadcasting service*

Frequency-sharing between a broadcasting-satellite system and a terrestrial broadcasting system requires that the receivers of each system be protected against interference from the emissions of the other system. The terrestrial receivers can be protected by imposing limits on the power flux-density produced by the broadcasting satellite at points within the terrestrial service area, as described in § 3.1.1. Conversely, the broadcasting-satellite system receivers can be protected against interference by requiring adequate separation between the terrestrial transmitter and the satellite receiver. An example of the separation required in a particular case is given in § 3.1.2.

3.1.1 *Protection of the terrestrial broadcasting service*

To protect the terrestrial television broadcasting service from interference from a television broadcasting satellite, it is necessary to place a limit on the power flux-density that the satellite is allowed to produce at points within the service areas of the terrestrial television broadcasting stations.

A provisional value for this limit in the band 620 to 790 MHz is given in Recommendation No. 705 of the WARC-79:

$$F_s = \left\{ \begin{array}{l} -129 \\ -129 + 0.4\,(\delta - 20) \\ -113 \end{array} \right\} \text{dB(W/m}^2\text{)} \quad \begin{array}{l} \text{for } 0° < \delta \leq 20° \\ \text{for } 20° < \delta \leq 60° \\ \text{for } 60° < \delta \leq 90° \end{array}$$

where δ (degrees) is the angle of arrival of the satellite signal above the horizontal plane.

In Recommendation No. 705 of the WARC-79, the CCIR was urged to study the frequency-sharing criteria to be applied in this band and to recommend a value to be used in lieu of the provisional limit. Several administrations subsequently conducted such studies and have made their individual suggestions regarding the limit on power flux-density that should be adopted.

In each case, the limit was calculated from an equation equivalent to equation (1) or equation (2). While there was not unanimity in the suggested limits on power flux-density, the differences can be understood in terms of the differences between the values assumed for the parameters in the equations. These assumptions are summarized in Table I; they will be discussed in some detail in order to illuminate the problems involved in reaching agreement on a satisfactory limit on the power flux-density.

3.1.1.1 *Minimum terrestrial power flux-density to be protected*

Recommendation 417 gives the values 67 and 70 dB(μV/m) for the field-strengths in Band V (610 to 960 MHz) corresponding to F_{tqp} and F_{tqm} in equations (1) and (2), respectively. The Recommendation also notes that "in a practical plan, because of interference from other television transmissions, the field-strengths that can be protected will generally be higher". Nevertheless, some administrations studying the question were agreed that advances in receiver technology and practical experience with terrestrial television reception suggested that consideration should be given to protecting lower values of field strength.

The EBU has suggested that in the service areas where a minimum median protected field of 70 dB(μV/m) at 50% of the locations is taken as a basis, there is often a considerable number of home receivers and relay stations providing satisfactory pictures with a lower field. It can be considered that points where the field is about 65 dB(μV/m) provide a satisfactory coverage. In many cases it is the only way of providing a service, because no other frequency is available. It is therefore necessary to protect a field of 65 dB(μV/m) against the total interference. Nevertheless, if this value is increased to 68 dB(μV/m) and if power-law addition is assumed, the field to be protected against interference caused only by satellites should be taken as equal to 65 dB(μV/m). The minimum power flux-density to be protected for the terrestrial system is then −81 dB(W/m^2).

Table I shows examples of calculations of the limiting values of power flux-density from a broadcasting satellite required to protect the terrestrial broadcasting service. The example from the USSR gives the values of power flux-density, taking into account the following:

- frequency band occupied by the interfering signal;
- bandwidth of the amplitude-modulation, vestigial-sideband receiver;
- level of random noise at the output of the amplitude-modulation, vestigial-sideband receiver.

3.1.1.2 *Protection ratio*

The values of protection ratio given in Table I were measured under different conditions. More detailed results are given in Report 634, which also discusses the various measuring conditions and system parameters which affect the assessment of protection ratio. In that Report, it is suggested that, where possible, the protection ratio should be defined for a specified combination of conditions and parameters. Corrections which may be applied for different conditions and parameters are also given in Report 634. The value of protection ratio proposed by the EBU (see Table I) is based on the reference conditions.

3.1.1.3 *Directivity discrimination*

None of the examples takes explicit account of the directivity of the receiving antenna; instead they consider the worst case in which the interfering satellite signal arrives from a direction close to the receiving antenna axis. However, all administrations appear to accept the idealized antenna pattern for Band V given in Recommendation 419, although the USA Administration notes that in practice, more directive antennas are likely to be used at the service area boundaries in question. In any case, using the pattern of Recommendation 419 would lead to an escalation of satellite power flux-density with angle of arrival similar to that given in the provisional limit of Recommendation No. 705 of the WARC-79.

3.1.1.4 *Polarization discrimination*

If circular polarization is used for the broadcasting satellite transmission, a discrimination of up to 3 dB may be expected from the linearly polarized terrestrial receiving antenna. Report 339 (New Delhi, 1970) contained data for the discrimination that will be achieved in the usual case where the satellite transmitting antenna and the terrestrial receiving antenna are not to be aligned with each other.

3.1.1.5 *Margin for ground reflections*

There is no direct experimental evidence regarding this quantity, but the United Kingdom Administration reports that extrapolation to Band V of experimentally verified theoretical predictions of reflection from irregular terrain at 230 MHz suggest that 3 dB is a reasonable value. The Administration of France and the EBU agree with this assumption and cite extreme cases of near unity reflection of terrestrial signals from the sea which could enhance the interfering signal by 6 dB.

TABLE I – *Examples of the calculation of the limiting values of power flux-density from a broadcasting satellite required to protect the terrestrial broadcasting service in the band 620 to 790 MHz*

1. *Data relating to the wanted signal*				
Source documents		(1978-82) 10-11S/11 (EBU)	(1970-74) 11/64 (USA)	(1978-82) 10-11S/53 (USSR)
1.1 Television standard and system		I/PAL, L/SECAM, G/PAL	M/NTSC	K/SECAM
1.2 Assessment scale		Quality 5-point (5: excellent)	Impairment 6-point (1: imperceptible)	Impairment 5-point (5: imperceptible)
1.3 Grade of picture quality		4.5	3	4.5
1.4 Picture signal-to-unweighted noise ratio (dB)		≥41.5	27	Not less than 40
1.5 Minimum field strength to be protected against interference caused by satellite (dB(μV/m))		65	56(1)	70
1.6 Minimum power flux-density, terrestrial, to be protected, F_{tqp} (dB(W/m²))		−81	−90	−76
2. *Data relating to the protection ratio*				
Source documents		(1978-82) 10-11S/11 (EBU)	(1970-74) 11/49 (USA)	(1978-82) 10-11S/53 11/116 (USSR)
2.1 Picture content of wanted signal		Slides	Slides and off-the-air programmes	Slides
2.2 Characteristics of unwanted signal	Picture content	Colour-bars	Colours-bars and off-the-air programmes	Colour-bars
	Frequency deviation peak-to-peak (MHz)	12	18	22
	Pre-emphasis	Yes	No	Yes
	Dispersal	No	No	No
2.3 Protection ratio R_q (dB)		54(2)	35	47(3)
3. Directivity discrimination, D_d (dB) (4)		–	–	–
4. Polarization discrimination, D_p (dB)		2	–	2
5. Reflection margin, M_r (dB)		3	–	3
6. Multiple interference entry margin, M_i (dB)		–	–	–
7. Resultant limit on power flux-density, F_s (dB(W/m²))		−136	−125	−124

(1) The assumed fading margins are those associated with an e.i.r.p. of 2 MW from an antenna at a height of 300 m in the terrestrial broadcasting service. Median field strengths of 60 dB(μV/m) and 65 dB(μV/m) would yield the same picture quality as above, for 90% and 99% of the time, respectively.

(2) For L/SECAM the protection ratio is 50.5 dB.

(3) Protection ratios for various peak-to-peak deviations are shown in Fig. 8 of Report 634.

(4) No directivity discrimination can be assumed, since only angles of elevation less than 20° are considered.

3.1.1.6 *Multiple interference margin,* M_i

In the service area of a terrestrial transmitter, a satellite can cause interference only when the receiving antennas point in a direction not very different from that of the satellite. It is therefore unnecessary to allow for interference from several satellites, if it can be assumed that there will never be more than one satellite emission at the same time on the same channel and in about the same direction.

3.1.1.7 *Summary and conclusions*

From information provided by the EBU, the numerical value has been calculated for the limit which should be imposed on the power flux-density to protect terrestrial broadcasting in the band 620 to 790 MHz, against the emissions from future satellites, using frequency-modulation television. The result is given for systems I/PAL, L/SECAM and G/PAL. For these three systems, the figure is -136 dB(W/m^2), for the reference conditions. This is 7 dB lower than the provisional value recommended by the WARC-79.

The service area boundaries were defined in terms of very nearly the same minimum values of terrestrial field strength to be protected as recommended by the CCIR, and possible fading of the terrestrial signal at the service area boundaries was neglected.

The example presented by the Administration of the USA afforded protection to a much lower terrestrial field strength, taking into account both an assumed better receiving installation, significant terrestrial signal fading, and a lower picture quality. In the USA, a lower protection ratio is used which corresponds to the lower assumed picture quality and is based on a wider frequency deviation for the interfering frequency-modulation satellite signal, as well as picture contents more typical of off-the-air programming. The satellite power flux-density limit in the example presented by the USA Administration was -125 dB(W/m^2), i.e. 4 dB higher than the provisional value recommended by the WARC-79.

Under the conditions presented by the Administration of the USSR in Table I, footnote (2), the limit for the power flux-density was -124 dB(W/m^2), i.e. 5 dB higher than the provisional value recommended by the WARC-79.

Having studied all the values incorporated in equation (1) as well as the results of protection ratio measurements in television for maximum permissible power flux-density at the surface of the Earth from broadcasting satellites operating in the band 620 to 790 MHz, the USSR Administration proposed the following values:

$$F_s = \begin{Bmatrix} -77 - R_{oq} + \gamma \\ -77 - R_{oq} + \gamma + 0.4(\delta - 20) \\ -61 - R_{oq} + \gamma \end{Bmatrix} \text{dB(W/m}^2) \quad \begin{matrix} \text{for } 0° < \delta \leq 20° \\ \text{for } 20° < \delta \leq 60° \\ \text{for } 60° < \delta \leq 90° \end{matrix}$$

where $\gamma = 0.45\ (D_v - D_{ov}) + M_d D_{dv}$, the correction coefficient depending on the energy distribution of FM interference, taking account of its perception by the viewer.

R_{oq} is the protection ratio for the value of the frequency deviation D_{ov} taken as reference (determined from the corresponding curve in Fig. 8 of Report 634);

D_{dv} is the peak-to-peak amplitude of the frequency deviation due to the dispersal signal in MHz; and,

M_d is the coefficient determined from Fig. 9, Report 634.

In evaluating F_s it was assumed that,

$$F_{tqp} = -76 \text{ dB(W/m}^2), \quad D_d = 0, \quad D_p = 2 \text{ dB}, \quad M_r = 3 \text{ and } M_i = 0$$

Until greater agreement is reached concerning the values to be assumed for the relevant parameters, it is premature for the CCIR to recommend a single value for the satellite power flux-density limit necessary to protect terrestrial broadcasting. Indeed the possibility cannot be dismissed that it may be necessary to adopt different power flux-density limits for combinations of wanted and unwanted signals having different signal standards.

3.1.2 *Protection of the broadcasting-satellite service*

Protection of the broadcasting satellite ground receiving stations is normally achieved by maintaining a minimum separation between them and the terrestrial transmitter. The minimum separation depends on the characteristics of both the earth receiving installation and the transmitting station in the terrestrial broadcasting system. An example of the terrestrial power flux-density and separation distance required to protect the satellite service is given in Figs. 1 and 2 for the following characteristics:

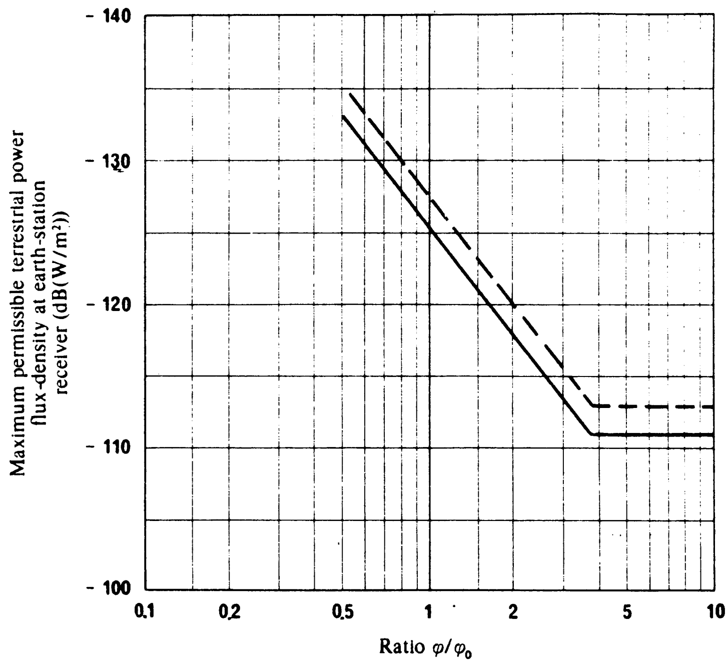


FIGURE 1 — *Example of maximum permissible power flux-density from a terrestrial transmitter to protect an earth-station receiver*

φ : direction of terrestrial transmitter relative to the axis of the main beam of the earth-station antenna

φ_0 : 3 dB beamwidth of earth-station antenna

——— : 525-line system M (Canada, USA)

– – – – : 625-line systems

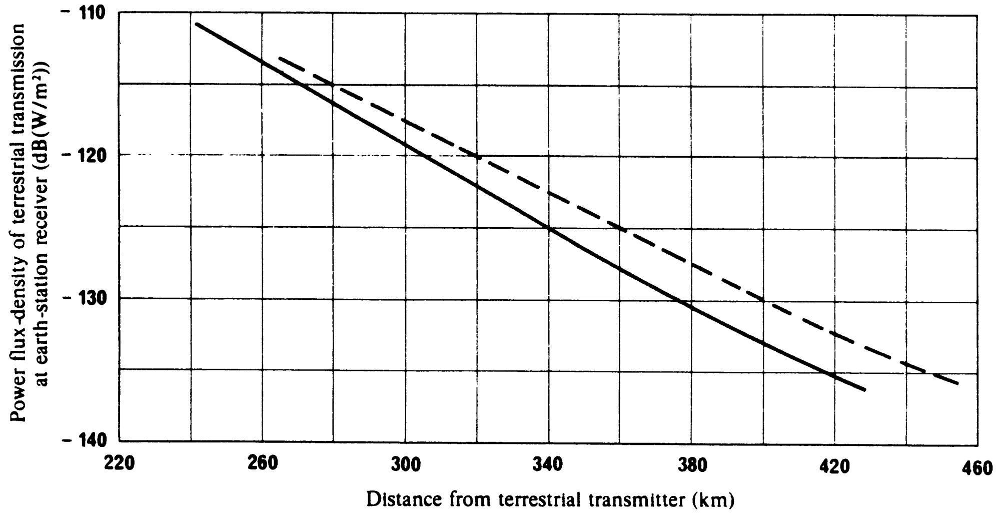


FIGURE 2 — *Example of separation distance to protect earth-station receivers from terrestrial transmitters*

Terrestrial transmitter e.i.r.p.: 1 MW

Antenna height above average terrain: 300 m

Frequency: 700 MHz

——— : 525-line system M (Canada, USA)

– – – – : 625-line systems

3.1.2.1 *Terrestrial broadcasting system*

- transmit station e.i.r.p.: 1 MW;
- transmit antenna height above average terrain: 300 m;
- luminance signal-to-unweighted r.m.s. noise, for just perceptible interference: 36 dB (525 lines), 45 dB (625 lines);
- minimum signal to be protected: 64 dB(μV/m) (525 lines), 65 dB(μV/m) (625 lines);
- receive antenna maximum gain (Recommendation 419): 16 dB;
- required protection ratio from satellite service: 42 dB (525 lines) and 52 dB (625 lines).

3.1.2.2 *Broadcasting-satellite service for community reception*

Frequency modulation with peak-to-peak deviation: 10.6 MHz (525 lines), 13 MHz (625 lines):

- luminance signal-to-unweighted r.m.s. noise (edge of beam area): 36 dB (525 lines), 45 dB (625 lines);
- satellite power flux-density at edge of beam area:
  -118 dB(W/m^2) (525 lines),
  -110 dB(W/m^2) (625 lines);
- receive antenna gain (3.3 m diameter, 9° beamwidth): 25 dB;
- receive antenna discrimination (Report 810): $(10.5 + 25 \log \varphi/\varphi_0)$;
- required protection ratio from terrestrial service: 18 dB (525 lines), 28 dB (625 lines).

Note. – The calculations do not include allowance for polarization discrimination nor for ground reflections or multiple interference. Note also that the example shown in this section uses a protection ratio of 18 dB which would result in a picture impairment level between 3.5 and 4 for less sensitive material. Report 634 now indicates that protection ratios as high as 32 dB may be required for less impairment of more sensitive material. Such protection ratios would result in larger required separation distances and larger required angles of discrimination.

3.2 *Sharing with fixed and mobile services*

Limitations on power flux-densities which would have to be imposed on the broadcasting-satellite television service to protect fixed and mobile services, including trans-horizon radio-relay systems, at present allocated the same frequency bands as the broadcasting service, may cause difficulties in such sharing. Careful consideration is, therefore, necessary before introducing the broadcasting-satellite service. Tropospheric scatter systems which point towards the geostationary orbit are particularly vulnerable. Examples of the required power flux-density limits in the case of sharing with land mobile services are given in Annex I.

4. Sharing in the band 2500 to 2690 MHz

4.1 *Sharing with the fixed service*

(*Note.* – Proposed fixed-satellite systems used for television distribution are also subject to these considerations to the extent that they are technically similar to broadcasting-satellite systems.)

The band 2500 to 2690 MHz is shared by the fixed, mobile, fixed-satellite and broadcasting-satellite services, all of which have primary allocations in the band. Other services have secondary allocations in the upper portion of the band, 2655 to 2690 MHz. Both the broadcasting-satellite and the fixed-satellite services are subject to the same limit on power flux-density (as given in Nos. 2561 to 2564 of the Radio Regulations). Therefore, the considerations and conclusions of this section apply to both these services.

The terrestrial systems in the fixed service which are considered for frequency-sharing with broadcasting or fixed satellites include line-of-sight and trans-horizon radio-relay systems and a certain type of television distribution system. Conditions of sharing between the television broadcasting-satellite service and other terrestrial services are not presented due to the lack of sufficient data.

The type of broadcasting-satellite system chosen for examination is one designed for community reception. An example of the parameters of such a system is given in Table II.

TABLE II – *Example of the characteristics of a satellite television system for community reception (operating in the vicinity of 2600 MHz)*

(System M, USA and Canada)
Circularly-polarized emission
Frequency modulation
Equivalent rectangular bandwidth: 20 MHz
Earth-station receiving antenna gain (2.5 m paraboloid): 34 dB(1)
Earth-station receiving antenna discrimination: $10.5 + 25 \log (\varphi/\varphi_0)$ where: φ : angle off the main beam axis, φ_0: angle between the half-power points, 3.1°
Minimum side lobe gain: 0 dB
Satellite field-strength to be protected at beam edge: 28 dB(μV/m)
Luminance signal-to-unweighted r.m.s. noise: 36 dB
Required protection ratio from ITFS(2): 30 dB(3)

(1) A 2.5 m diameter antenna has been used in this example because it is considered to result in overall minimum system cost for many Region 2 applications, as found in a study performed in the United States [Kelley *et al.*, 1976].

(2) ITFS means "Instructional Television Fixed Service".

(3) Taken from Report 634.

4.1.1 *Sharing with line-of-sight radio-relay systems*

Although this case could not be studied in detail owing to lack of relevant information, it should be noted that the establishment of circuits comprising a large number of relay stations often implies the repetitive use of frequencies according to a plan occupying a continuous section of the allocated band which cannot be departed from without difficulty (see Recommendations 283 and 382).

Co-channel operation between a broadcasting-satellite system and a terrestrial radio-relay system results in a number of limitations because the presence of a transmitter of a terrestrial radio-relay system within, or in the neighbourhood of, the service area of the broadcasting satellite system gives rise to a "hole" in the broadcasting service area. This makes planning of the radio-relay channelling very difficult.

4.1.2 *Sharing with trans-horizon radio-relay systems*

Frequency-sharing between broadcasting-satellite systems and trans-horizon radio-relay systems in the vicinity of 2600 MHz is technically feasible only to the extent that each system can accept certain technical and operational limitations required to protect it against interference from the other. (See also § 8.4.3 of the Report of the Special Joint Meeting, Geneva, 1971.)

4.1.2.1 *Protection of trans-horizon systems*

Protection of trans-horizon systems from harmful interference from the broadcasting-satellite service is currently provided by a combination of power flux-density limits on the satellites (Nos. 2561 to 2564 of the Radio Regulations), by a statement urging that trans-horizon system antennas not be directed toward the geostationary-satellite orbit (No. 764 of the Radio Regulations) and by inference, not within 2° of it (No. 2502 of the Radio Regulations).

Methods for determining the azimuths and elevation angles to be avoided by trans-horizon system antennas are given in Report 393.

4.1.2.2 *Protection of broadcasting-satellite systems*

The receivers of the broadcasting-satellite service would be susceptible to interference from trans-horizon radio-relay transmitters within an elongated zone which extends for a considerable distance in the direction in which the trans-horizon antenna is pointed; the extent of this zone is a function of the antenna directivity and the relative directions of the trans-horizon link and the satellite. Therefore, the establishment of a satellite broadcasting coverage area would prevent the introduction of new trans-horizon systems in that area and also, nearby, if the entire area were to be protected from interference.

4.1.3 *Sharing with a certain type of fixed terrestrial television distribution*

An example of the characteristics of the type of terrestrial television distribution system in question is given in Table III. These characteristics are typical of the Instructional Television Fixed Service (ITFS) system used in parts of Region 2. Specifically, such systems utilize approximately 10 W transmitters with omnidirectional, or directional, antennas and specified receiving points (educational institutions) which employ directional parabolic receiving antennas. A range of more or less standardized receiving antennas is used with apertures of 0.61, 1.22, 1.83 and 2.44 m (2, 4, 6 and 8 ft). The appropriate antenna is selected for the distance from the transmitter. The receiver noise figure in many of the systems is 9 dB. However, recent technological advances will permit use of receivers with noise figures as low as 3.5 dB.

Frequency-sharing in the vicinity of 2600 MHz between a broadcasting-satellite system and an ITFS system is technically feasible under certain conditions. A limit on the power flux-density of the satellite signal would have to be specified to protect the ITFS service and a "hole" or an area of interference within the satellite service zone would be created due to interference from the ITFS operation. The size of this area of interference depends on the transmitter power and height of the transmitting antenna of the ITFS system, the angular discrimination of the earth receiving antennas of the broadcasting-satellite system, and the angle of elevation of the satellite.

4.1.3.1 *Protection of the ITFS system*

The television broadcasting-satellite service using wideband frequency-modulation can share frequencies with ITFS in the 2600 MHz band provided the satellite power flux-density for each channel is limited in accordance with the values shown in Fig. 3.

It can be shown that the allowable interfering power flux-density ρ_i is:

$$\rho_i = \frac{C/N}{C/I} \cdot \frac{4\pi kTB}{\lambda^2} \cdot \frac{1}{G(\varphi)} \tag{3}$$

where $G(\varphi)$ is the ITFS antenna gain at an off-axis angle φ.

In Fig. 3 curves are provided for each ITFS antenna aperture, for noise figures of 9 and 3.5 dB, and for a luminance signal-to-unweighted r.m.s. noise ratio of 43 dB, representing the likely range of system performance. The dashed line shows the PFD for the broadcasting-satellite system based on Table II (i.e. -115 dB(W/m^2) beam centre).

TABLE III – *Example of characteristics for a typical ITFS system (operating in the vicinity of 2600 MHz)*

Amplitude modulation, vestigial sideband, System M (USA and Canada)		Omnidirectional
E.i.r.p.	(dBW)	20
Service range (approximate)	(km)	50
Received signal to be protected	(dB(μV/m))	56
Luminance signal-to-unweighted r.m.s. noise	(dB)	43
Receiving antenna gain: for diameter (m): 0.61 1.22 1.83 2.44	(dB)	 21.5 27.5 31 33.5
Receiving antenna discrimination: where: φ : angle off the main beam axis, φ_0: angle between the half-power points.	(dB)	$10.5 + 25 \log(\varphi/\varphi_0)$
Required protection ratio from satellite signals	(dB)	50
Receiving antenna beamwidth	(degrees)	12.8; 6.4; 4.3 and 3.2

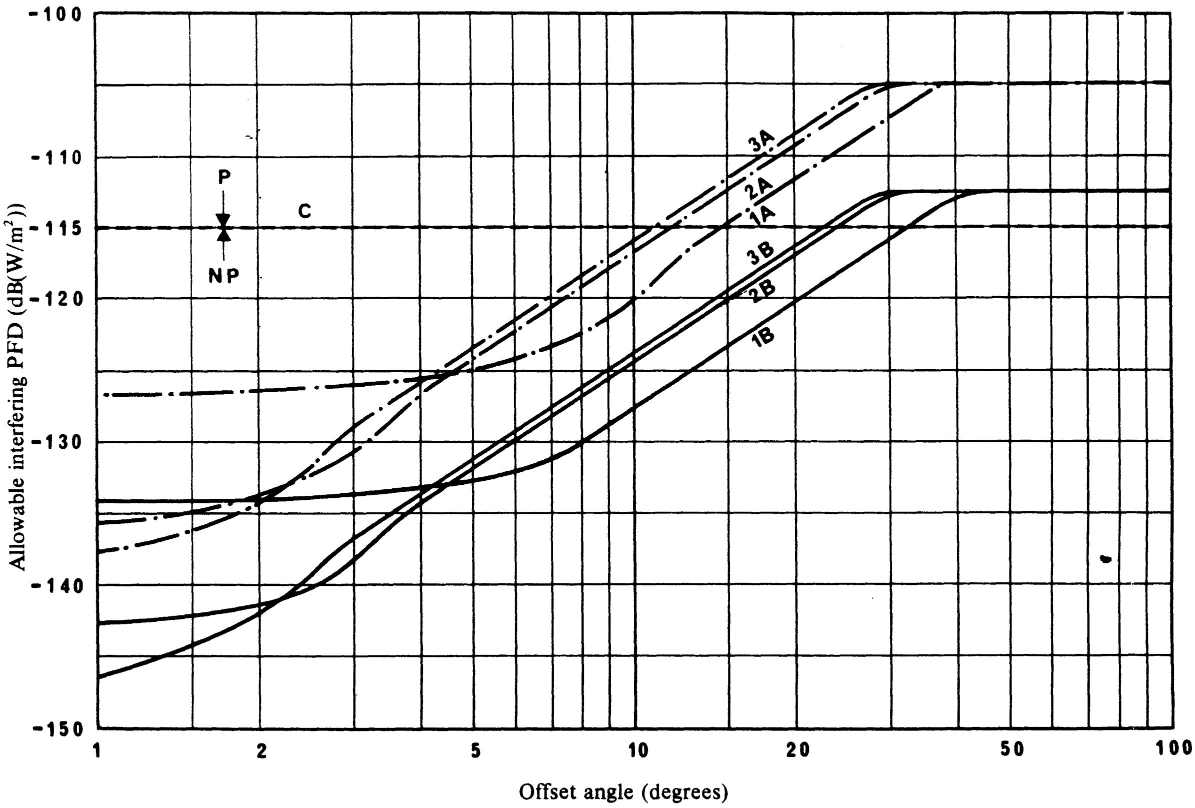


FIGURE 3 – *Allowable interfering broadcasting satellite power flux-density as a function of offset angle (for protection of the ITFS system)*

Curve	Diameter, *D* (m)	Noise figure (dB)
1A	0.6	9
1B	0.6	3.5
2A	1.83	9
2B	1.83	3.5
3A	2.44	9
3B	2.44	3.5

Note. – *S/N* = 43 dB and *C/I* = 50 dB for all curves.

C — — — — Signal to be protected (beam centre PFD, –115 dB(W/m²))
P : protected
NP: not protected

For the contiguous United States, angles of elevation are almost always greater than 30° for satellites in mid-continental locations. Note also that the offset angle (between the main beam of the broadcasting-satellite earth-station antenna and a terrestrial station antenna) will never be less than the angle of elevation to the satellite, regardless of terrestrial system azimuths. Therefore, as can be seen from Fig. 3, a broadcasting-satellite system would not cause interference to a 43 dB *S/N* ITFS system having the characteristics shown in Table III even if the ITFS receiver has a noise figure as low as 3.5 dB (as can be seen in Curves 1A, 2A, 3A, 1B, 2B and 3B).

ITFS systems having higher *S/N* objectives, say 45 or 49 dB, would be protected against interference with even smaller offset angles. Similarly, lower protection ratios, which might be acceptable for interfering BSS signals of higher peak-to-peak deviation (as discussed in Report 634, § 1.6) would also result in smaller offset angles to achieve the desired level of protection.

4.1.3.2 *Protection of the television broadcasting-satellite system*

An earth receiving installation for community reception can be protected from ITFS interference provided that the power flux-density of the latter is limited to a maximum of -115 dB(W/m^2) as seen from Fig. 4. This protection is achievable at a minimum angle of elevation for the satellite of 31°.

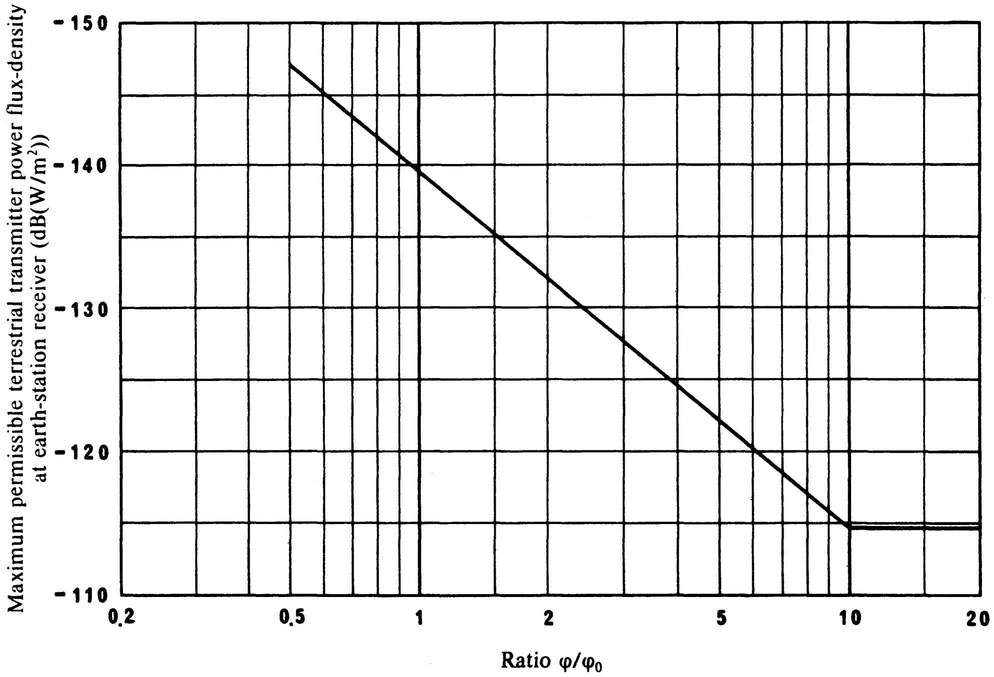


FIGURE 4 – *Example of maximum permissible power flux-density from terrestrial station transmitters to protect BSS earth-station receivers*
(ITFS at 2.6 GHz)

φ : direction of satellite relative to axis of main beam of terrestrial receiving antenna
φ_0: 3 dB beamwidth of terrestrial receiving antenna

The necessary separation between the earth receiving installation location and the ITFS transmitter for different values of the ITFS power flux-density and angles of discrimination in the range from 60 km to over 140 km is shown in Fig. 5. These values assume no site shielding, and were calculated from the following formula:

$$E_t(d, r) = \text{e.i.r.p.}_t - 10 \log (4\pi d^2) - L_t(d, r) + 145.8 \qquad (4)$$

where,

$E_t(d, r)$: signal emitted by terrestrial transmitter at distance, d, with probability, r(%), (dB(μV/m))

d : distance from terrestrial transmitter,

$L_t(d, r)$: attenuation in excess of the spreading loss at distance, d, not exceeded for r% of the time (here, assumed 1%).

Note that a protection ratio of 30 dB was used in this example, which is consistent with Report 634 and the value of $L_t(d, r)$ is consistent with Report 569 and assumes a value of H = 200 m.

The separation distances shown in Fig. 5 are theoretical, worst-case values. Some observations have been made of interference from ITFS transmitters to receivers similar to those that might be used in the broadcasting-satellite service. These interference values were obtained from experiments conducted with the ATS-6 spacecraft and a multiplicity of small receiving installations, some of which were sited near ITFS transmitters or at various locations within their antenna patterns.

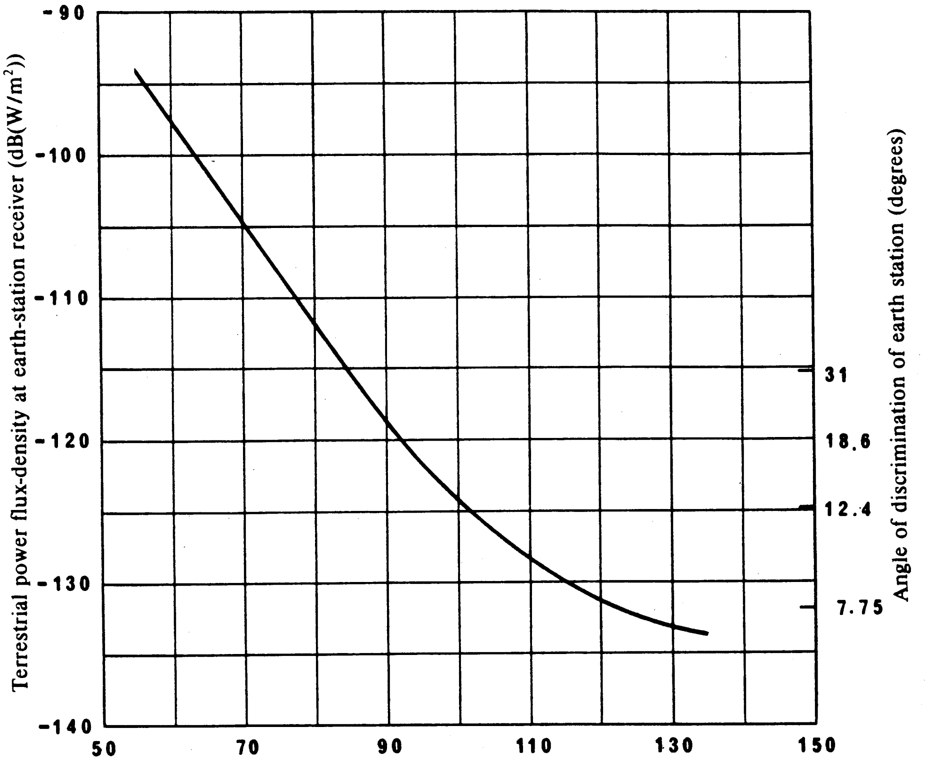


FIGURE 5 – *Example of separation distance to protect earth-station receivers from terrestrial transmitters*
(ITFS at 2.6 GHz)
E.i.r.p.: 20 dBW

Although the actual separation distances and discrimination angles were not, in several cases, sufficient to ensure interference-free reception based on the criteria of this Report, no interference was noted even though such receivers were quite close to the transmitter or almost in its main beam.

Although these observations were not sufficiently detailed or extensive enough to dictate changes in the methods of calculation described in this Report, they do suggest that the methods herein are conservative, and that there may be more interference-free locations and areas than indicated by the curves in this Report.

Results and conclusions in this section are based on theoretical considerations. Precise measurements of interference in the vicinity of terrestrial systems in the band 2500 to 2690 MHz are needed to confirm these predictions.

4.2 *Energy dispersal*

The use of energy dispersal in the 2.6 GHz band has been examined by one administration. Calculation of the required bandwidth and corresponding signal-to-noise ratio lead to the conclusion that the performance of a 2.6 GHz broadcasting-satellite system using small receiving antennas can be severely limited by the need to provide energy dispersal.

4.3 *Sharing with the radioastronomy service*

Report 224 discusses sharing between the radioastronomy service and the broadcasting-satellite service. In the shared band, the possibilities of geographical sharing need to be explored. In making assignments, the attention of administrations is drawn to the adjacent band problems discussed in Reports 224 and 807.

5. Sharing in band 11.7 to 12.75 GHz

This section presents the conditions for frequency-sharing in the 12 GHz band between the broadcasting-satellite and terrestrial services. Sharing between the broadcasting-satellite service and the fixed-satellite service in the band 11.7 to 12.2 GHz (applicable to Region 2) is considered in Reports 561 and 809.

Rainfall attenuation in some climates may require large propagation margins if high service reliability is desired. The effect of this margin should be taken into account when considering sharing problems.

5.1 *Conditions for the protection of terrestrial systems against interference from broadcasting satellites*

5.1.1 *General considerations*

The bandwidth of a 625-line broadcasting-satellite emission is given as an example in Report 215 as 27 MHz. For conditions where no video information is present or where the video information is repetitive in certain ways, the power can collect itself in the form of spikes of energy. Since some terrestrial services may be affected by power spectral density rather than total interfering power it is important to try and relate the power of a broadcasting satellite emission to the power in different bandwidth values. This leads to consideration of applying energy dispersal to the broadcasting-satellite emission or interfered-with service.

For terrestrial systems carrying analogue FDM-FM telephony, in which a 4 kHz bandwidth is considered when assessing interference levels, the advantages of energy dispersal are significant. Studies of energy dispersal in the broadcasting-satellite service have shown that "natural" dispersion values on the order of 10 dB exist [CCIR, 1974-78a, b and c].

The WARC-BS-77 adopted the use of energy dispersal for the broadcasting-satellite service specifying the value of 600 kHz. The WARC ORB-85 in incorporating the RARC SAT-83 broadcasting-satellite service Plan for Region 2 into the Radio Regulations, required the use of energy dispersal such that the spectral power flux-density, measured in a 4 kHz bandwidth, be reduced by 22 dB in relation to that in the centre bandwidth. This reduction corresponds to a peak-to-peak deviation of approximately 600 kHz.

With such a value the advantage for terrestrial systems carrying television signals would appear to be negligible. The subjective effect of a dispersed FM-signal on an AM-TV signal actually gives a reduction in protection ratio of about 1.5 dB per MHz peak-to-peak deviation of the dispersed signal (see Report 634).

It is unlikely that there will be widespread use of energy dispersal by terrestrial services such as the fixed service.

The power flux-density in a 4 kHz bandwidth from a broadcasting satellite emission can be simply obtained by subtracting the appropriate value in Table IV from the total power flux-density in the 27 MHz bandwidth.

TABLE IV — *Energy dispersal advantage relative to a 4 kHz band*

Condition of dispersal	Energy dispersal (dB)
Natural	10
600 kHz (WARC-BS)	22
1 MHz	25
2 MHz	27
4 MHz	30

An additional protection advantage also dependent on the spectrum of a broadcasting-satellite emission may be obtained in certain circumstances by offsetting the terrestrial channels from the broadcasting satellite channels. Such protection will of course depend on the terrestrial emission having a bandwidth equal to, or less than, the spacing between the satellite broadcast channels; and the precise advantage will depend on the spectrum of the two signals. Further study is required to produce numerical values but they may lie in the range 0 to 10 dB depending on the aforementioned factors. Since Report 634 indicates that energy dispersal has an adverse effect on protection ratios it would appear to follow that energy dispersal would have an adverse effect on the advantage to terrestrial services from offsetting their emissions from those of broadcasting satellites.

Both the WARC-BS-77 and RARC SAT-83 adopted circular polarization for the broadcasting-satellite service. Terrestrial systems employing linear polarization should not rely on more than 3 dB of polarization discrimination.

5.1.2 *Interference to terrestrial broadcasting from the BSS*

Interference to terrestrial broadcasting from broadcasting satellites is treated in this section as depicted in Fig. 6. The figure shows the two essential elements of sharing in this situation: that of the satellite antenna discrimination (which can be expressed as a function of the off-axis angle, φ) and that of the terrestrial receiver antenna discrimination (which can be expressed as a function of the angle of arrival, θ).

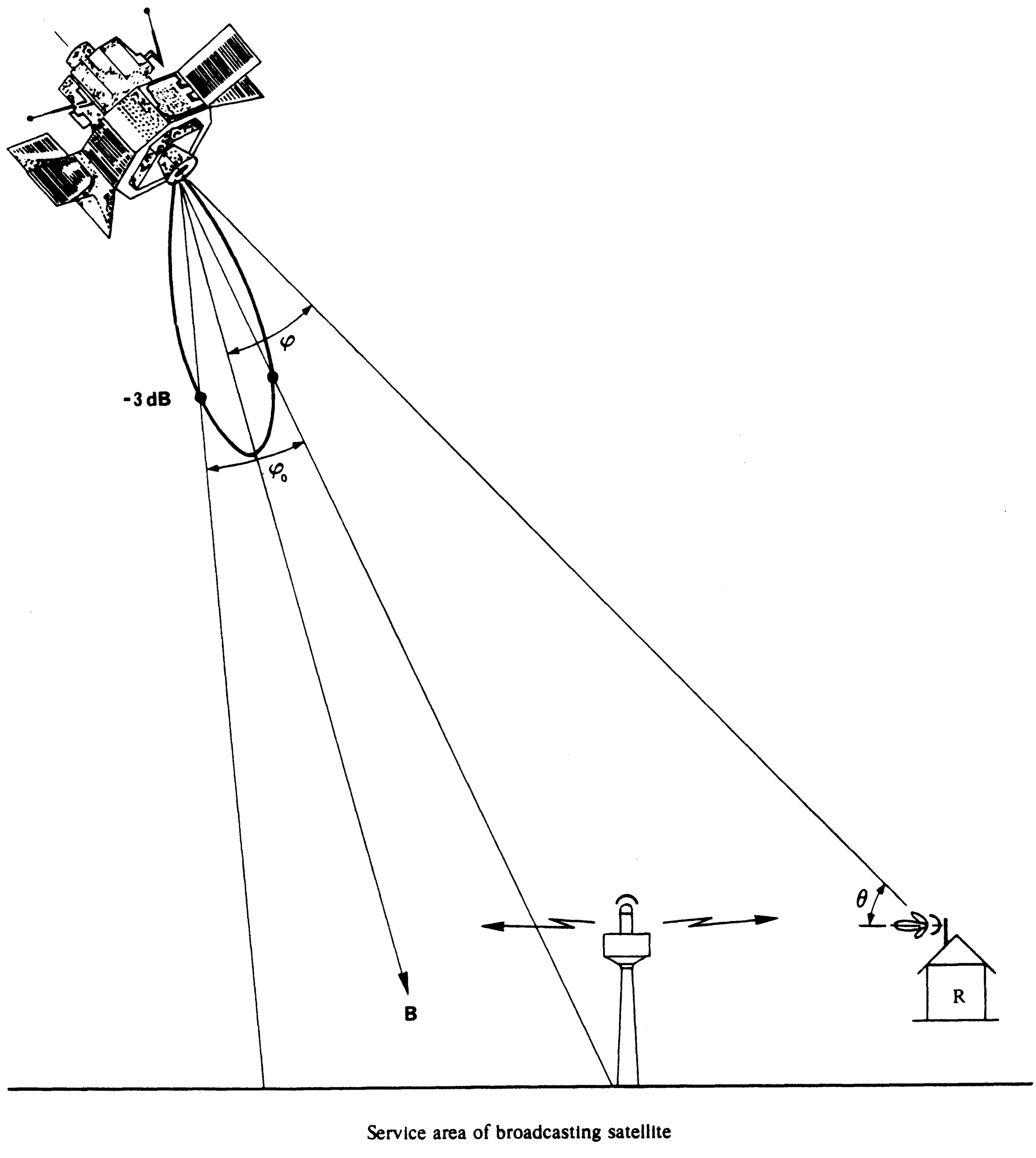


FIGURE 6 — *Interference to receiver of terrestrial broadcast from broadcasting-satellite transmitter*

φ : off-axis angle of satellite antenna

B : beam centre

θ : angle of arrival

R : terrestrial receiver

To illustrate the concepts of this sharing model, the beam centre indicated in Fig. 6 is assumed to be aimed at a point 40° north and the beamwidth of the satellite antenna is assumed to be 2°. The resulting power flux-density at that longitude is shown in Fig. 7 by the solid line. The different values result from the satellite antenna discrimination. The dashed line indicates for the example of a radio relay system carrying television (line 2 in Table V), the interfering power flux-density which can be accepted. The different values result from the radio relay antenna discrimination. Where the dashed line is above the solid line, sharing is feasible for any direction of azimuth of the terrestrial receiver. Where the solid line is above the dashed line, sharing is only feasible when the radio-relay antenna is displaced in azimuth by a suitable amount from the satellite position on the geostationary orbit. This same example is plotted in Fig. 8 in the form of a contour map showing that with this particular example of terrestrial systems sharing is feasible in the non-hatched portions with no restrictions. Sharing is feasible in the hatched portions only with restrictions on the pointing direction of the radio-relay antenna.

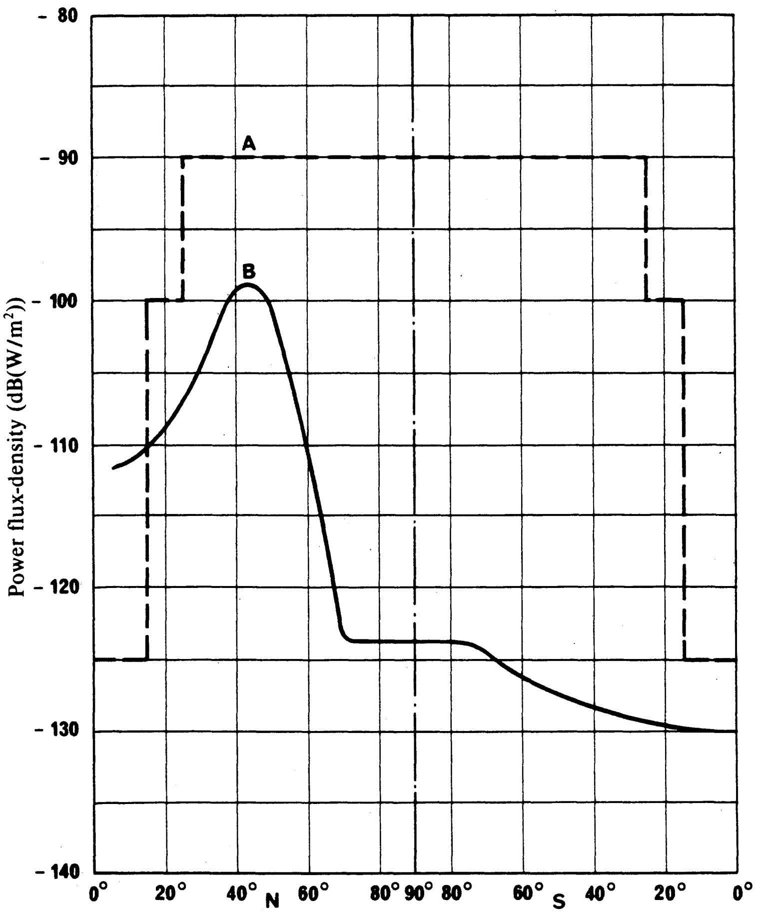


FIGURE 7 – *Example for sharing model 2 showing feasibility of frequency sharing between a broadcasting satellite providing individual reception and a radio relay system carrying television*

———— Power flux-density from broadcasting satellite;
– aiming point of satellite beam 40° N
– satellite antenna beamwidth 2°

— — — Maximum acceptable interfering power-flux density into a radio relay system carrying television (example in [CCIR, 1974-78e]).

—·—·— Equator

Curves A: terrestrial system
B: satellite

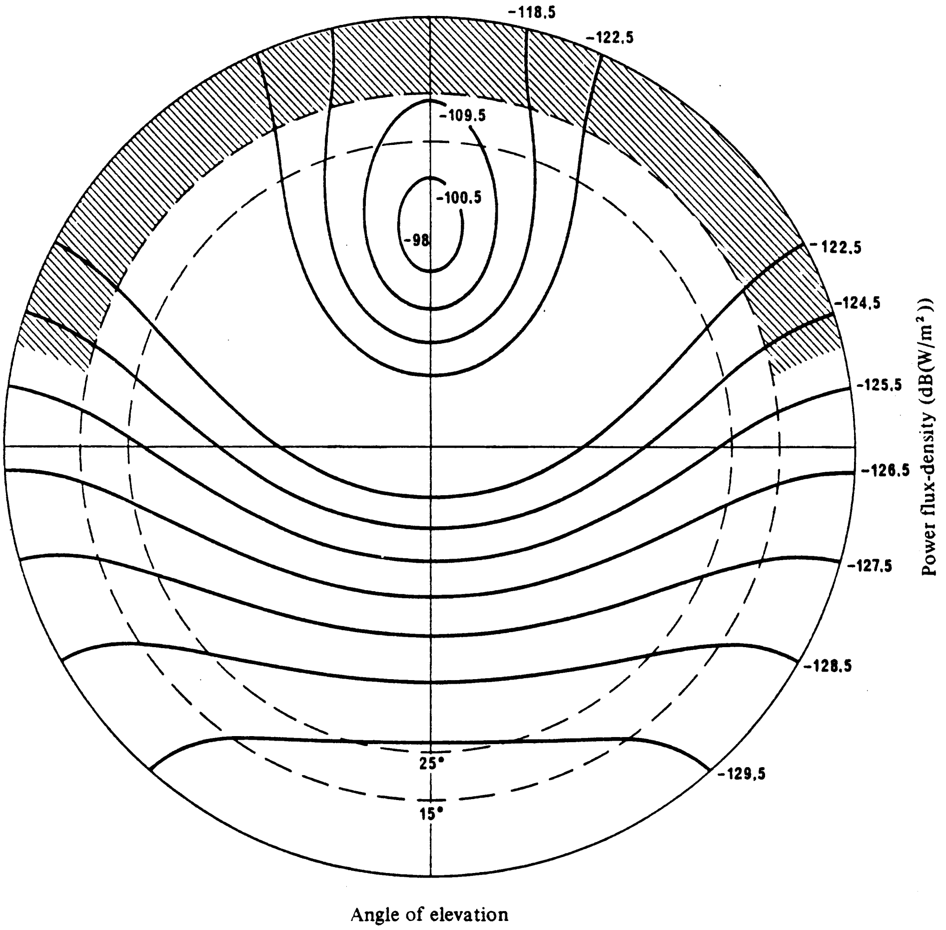


FIGURE 8 – *Power flux-density from a broadcasting satellite with a 2° beam aiming at a latitude of 40° N*

Note. – The hatched regions in the above diagram indicate the area of the surface of the Earth where the maximum permissible interference power flux-density into a television radio-relay link is exceeded, limits from [CCIR, 1974-78 f].

TABLE V – *Examples for interfering power flux-densities acceptable by systems in the 12 GHz band*
(From [CCIR, 1974-78a])

Wanted system	Percentage of time	Maximum interfering power flux-density (dB(W/m²)) for angle of arrival of 0° relative to the main axis of terrestrial antenna	Antenna off-beam discrimination(¹)
1	2	3	4
Line-of-sight FM-radio relay links carrying telephony (³)	99.9	—128/4 kHz (²) at any angle of arrival	35-25 log φ
Line-of-sight FM-radio relay links carrying television programmes(³)	99.9	—125/5 MHz	$10.5 + 25 \log(\varphi/\varphi_0)$
Line-of-sight AM multi-channel systems carrying television programmes(³)	99.9	—134/5 MHz	$10.5 + 25 \log(\varphi/\varphi_0)$
Terrestrial AM television system	99	—130/5 MHz	$9 + 20 \log(\varphi/\varphi_0)$
Terrestrial FM television system	99	—130/27 MHz	$9 + 20 \log(\varphi/\varphi_0)$
Broadcasting-satellite system (individual reception)	99	—131/27 MHz	$-(9 + 20 \log(\varphi/\varphi_0))$ (²) for $0.707\varphi_0 < \varphi \leq 1.26\varphi_0$ $-(8.5 + 25 \log_{10}(\varphi/\varphi_0))$ for $1.26\varphi_0 < \varphi \leq 9.55\varphi_0$

(¹) Antenna off-beam gain.

(²) See Report 810.

(³) For further information on parameters of these systems consult Report 608 (Kyoto, 1978).

It should be noted that the above example only considers the case of a single satellite beam. Whilst a 2° beam at 40° N is considered a fairly worst case example, the precise geographical area over which sharing is feasible will depend on the outcome of the actual orbit position/frequency assignment plan which is established. The geographical area will also depend significantly on the sensitivity of the particular terrestrial services using the band.

The above example is for a single value of satellite antenna beamwidth. A more general way of expressing the sharing criteria for any satellite beamwidth is illustrated below for the example of a terrestrial broadcasting system [CCIR, 1974-78d].

In the example the necessary value for the protection ratio for just perceptible interference, PR_0, is 56 dB (wanted signal AM-VSB, 625 lines; unwanted signal FM, nominal peak-to-peak frequency deviation 8 MHz). However, taking into account the masking of interference by random noise, a lower value, PR_1, for the protection ratio, calculated according to the formula:

$$PR_1 = PR_0 - (49 - S/N) \qquad (5)$$

has been adopted in our calculations, where S/N is the peak-to-peak luminance signal-to-r.m.s. weighted noise, exceeded for 99% of the time at the edge of the coverage area in the terrestrial broadcasting system. This signal-to-noise ratio is assumed to be 39 dB.

Thus,

$$PR_1 = 56 - (49 - 39) = 46 \text{ dB} \qquad (6)$$

The minimum power flux-density of the wanted signal at the edge of the coverage area in the terrestrial broadcasting system, exceeded for 99% of the time is -85.5 dB(W/m^2). Thus, the interfering power flux-density of a signal arriving from the least favourable direction in the horizontal plane should not exceed -131.5 dB(W/m^2).

On the assumption that a typical power flux-density produced on earth by the broadcasting-satellite at the beam-centre in clear weather is -98 dB(W/m^2), a discrimination of about 33.5 dB must be ensured.

The envelope side-lobe diagram of the receiving antenna in the terrestrial broadcasting system is assumed to comply with the reference curve A given in Report 810, Fig. 2. Values for the antenna gain according to this reference curve are shown in Table VI.

It appears from Table VI that the required discrimination of 33.5 dB cannot be obtained from the angular response of the receiving antenna in the terrestrial broadcasting system alone. Thus, co-channel operation of the terrestrial service using amplitude modulation within the broadcasting-satellite service area is not possible.

TABLE VI – *Gain and angular discrimination for receiving antennas in the terrestrial broadcasting system*

Off-axis angle (θ) (degrees)	Antenna gain (dB)	
	Relative to isotropic radiator	Relative to maximum main-lobe gain (34.5 dB)
10	13.5	−21.0
15	8.0	−26.5
20	5.5	−29.0
25	3.0	−31.5
⩾ 29.65	1.5	−33.0

However, outside the broadcasting-satellite service area additional angular discrimination is obtained, due to the angular discrimination of the broadcasting-satellite transmitter antenna (see Fig. 6).

The relative gain of the broadcasting-satellite transmitter antenna is assumed to comply with Report 810, Fig. 1, curve A. The required value of φ/φ_0 (Fig. 6) to obtain sufficient additional angular discrimination has been calculated and is shown in Table VII.

TABLE VII – *Required value of additional angular discrimination of BC-SAT transmitter antenna*

BC-SAT elevation angle at receiving point (degrees)	Required value for the angular discrimination of the BC-SAT transmitter antenna (dB)	Required value for φ/φ_0
10	12.5	0.98
15	7.0	0.60
20	4.5	0.54
25	2.0	0.33
≥29.65	0.5	0.25

Another example of a terrestrial broadcasting system in which the minimum power flux-density at the fringe of the service area is assumed to be −78.2 dB(W/m^2), can accept an interfering power flux-density arriving from the least favourable direction in the horizontal plane not exceeding −124.2 dB(W/m^2). Such a value would enable feasible sharing over larger geographical areas than is indicated for the example in Table VII.

Other examples are given in [CCIR, 1974-78g, h, i, j and k].

As a result of experiments with NTSC 525-line television signals in Japan [CCIR, 1978-82a] it was found that satellite broadcasting signals did not cause harmful interference to a 12 GHz AM-VSB terrestrial broadcasting system within its coverage area even with overlapping channels in the case where the PFD from the BSE satellite was −106 dB(W/m^2) at about 40° elevation, while the terrestrial service is assumed to have a maximum range corresponding to a PFD of −70 dB(W/m^2).

5.1.3 *Interference to the fixed service from the BSS*

Interference to terrestrial radio-relay systems can result from broadcasting-satellite transmissions. The power flux-density at the surface of the Earth produced by any space station in the broadcasting-satellite service on the territory of other countries is limited to a value of the order of −128 dB(W/(m^2 · 4 kHz)) independent of the angle of arrival.

Under these conditions it is possible to formulate restrictions on the choice of a radio-relay path with which the associated interference power in the telephone channel of a reference 50 station radio-relay link does not exceed 1000 pW with the power flux-density at the surface of the Earth being −128 dB(W/(m^2 · 4 kHz)) independent of an angle of arrival.

The following approximation is used in the calculations:

$$P = P_{tn} \cdot W \cdot (G(\theta)/S_i)^{*} \qquad (7)$$

where,

W: permissible power flux-density at the surface of the Earth, assumed in this case to be equivalent to −128 dB(W/(m^2 · 4 kHz));

P: interference power of the telephone channel (W);

P_{tn}: thermal noise in the telephone channel assumed to be 20 pW;

* Care must be taken to use consistent units in the calculations.

$G(\theta)$: radio-relay receiving antenna gain in the direction of the interfering signal arriving from a space station:

$$10 \log G(\theta) = 35 - 25 \log (\theta)$$

$$S_i = 4\pi kTB/\lambda^2$$

$k = 1.38 \times 10^{-23}$

$\lambda = 2.5$ cm

$T = 890$ K

$B = 4$ kHz.

As the calculations show, with the assumptions adopted, the associated interference power does not exceed 1000 pW if, for example, the direction of one radio-relay receiving antenna differs from that to the interfering space station by 3° and the directions of other antennas differ from the direction to interfering space stations by 16°, or if the directions of all antennas differ from the directions to interfering space stations by approximately 13°.

The limitations given can be realized both in low and high latitudes. It is also natural that restrictions on the choice of radio-relay paths are different in high and low latitudes.

5.1.3.1 *Interference to a terrestrial radio-relay system carrying FDM-FM*

As discussed in a study conducted in the United States [Akima, 1980] from which much of the material in this section is taken, many short-range FDM-FM telephony systems are in operation in the fixed service in this band in the United States.

Typical receiver bandwidths are 12 MHz and 20 MHz. In an FDM-FM telephony system, degradation of the system performance caused by an interfering signal depends on the power spectral density of the interfering signal as well as the total power of the interfering signal. Even if the total interfering signal power is so small that the wanted FDM-FM system continues to operate above its threshold, some telephone channels may be degraded severely if the power spectral density of the interfering signal is very high in these channels.

First, we will compare the total power of the interfering BSS signal with that of the noise. The total noise power is −123 dBW in a 12 MHz bandwidth, and −121 dBW in a 20 MHz bandwidth. These values are several decibels higher than −127 dBW, which is the interfering BSS signal power in the worst case given in Table VIII. This Table shows the *maximum* value of BSS signal power at a fixed service receiver for various values of off-axis angles and for several different receiving antenna diameters. Values given in this Table have been derived using the reference antenna pattern given in Report 614 and an assumed Region 2 PFD of −102 dB(W/m²) for not less than 99% of the worst month. Typical interfering powers will be assumed as 3.8 dB lower. These maximum values are based on the variation in PFD from one BSS service area to another observed in the WARC-BS-77 Plan for Regions 1 and 3. Such variations are probably typical of those to be found in such allotment plans. The total power of noise plus interfering signal is only one decibel higher, at most, than the noise power alone in this case. Therefore, the operation of the wanted FDM-FM system should remain above the threshold in all cases if the system is designed with a reasonable margin in S/N.

TABLE VIII – *Maximum value of the BSS signal power at an FS receiver*
(θ denotes the off-axis angle, and D denotes the FS receiving antenna diameter)
(A receiver noise figure of 10 dB is assumed.)

θ (degrees)	Signal power (dBW)				
	D = 0.6 m	1.0	1.5	2.0	≥ 2.41
20	−134.5	−136.7	−138.4	−139.7	−140.0
15	−131.4	−133.6	−135.3	−136.6	−137.4
10	−127.0	−129.2	−130.9	−132.2	−133.0

Next, we will compare the power spectral density of the interfering signal with that of noise. The WARC-BS-77 specified that energy dispersal which corresponds to a peak-to-peak deviation of 600 kHz be employed by broadcasting satellites in the Geneva Plan for Regions 1 and 3. The WARC ORB-85, in incorporating the RARC SAT-83 Plan for Region 2, required the use of energy dispersal as discussed in § 5.1.1. Thus, we will assume as a worst case that the entire power of the BSS signal is contained in a 600 kHz bandwidth.

The noise power in a 600 kHz bandwidth is estimated to be $-134 + 10 \log 0.6 = -136.2$ dBW including a 10 dB contribution from receiver noise. Since this value is about the same order as the values of the BSS signal power given in Table VIII, the effect of the interfering BSS signal is not considered negligible. The post-demodulation baseband noise power in a telephone channel is 3 dB higher with the noise plus interference, than with the noise alone if the power spectral density of the interfering signal is equal to that of the noise. Tables IX and X show the increases in the baseband noise power caused by the interfering BSS signal, calculated with Table VIII. These tables show the relations among: the off-axis angle of the BSS satellite from the main beam of the FS receiving antenna, the FS receiving antenna diameter, and the required system margin against the interference in the design of the FS system. In the worst case of $\theta = 10°$ and $D = 0.6$ m considered in Table X a margin of 10 dB is required. The required system margin decreases as the off-axis angle and/or the antenna diameter increases. In the receiving site where the elevation angle of the BSS satellite is 20°, the required system margin is less than 4 dB regardless of the antenna diameter. When the antenna diameter is equal to or greater than 2.4 m, the required system margin is less than 5 dB even if the angle of elevation is 10°.

TABLE IX – *Increase in the baseband noise power due to the interfering BSS signal*
(Typical values of BSS signal power, 3.8 dB below those shown in Table VIII have been used.
θ denotes the off-axis angle, and D denotes the diameter of the FS receiving antenna.)

θ (degrees)	Increase in baseband noise power (dB)				
	$D = 0.6$ m	1.0	1.5	2.0	⩾2.41
20	2.1	1.4	1.0	0.7	0.7
15	3.5	2.4	1.8	1.4	1.2
10	6.5	4.9	3.8	3.1	2.7

TABLE X – *Increase in the baseband noise power due to the interfering BSS signal*
(Maximum values of BSS signal power shown in Table VIII are used.
θ denotes the off-axis angle, and D denotes the diameter of the FS receiving antenna.)

θ (degrees)	Increase in baseband noise power (dB)				
	$D = 0.6$ m	1.0	1.5	2.0	⩾2.41
20	3.9	2.8	2.0	1.6	1.5
15	5.3	4.5	3.5	2.8	2.5
10	9.3	7.8	6.4	5.5	4.9

5.1.3.2 *Interference to a radio-relay system carrying FM-TV*

An FM-TV relay system of a small number of hops (not more than five hops) is considered as an FS system in this band. The channel bandwidth considered in this system is 27 MHz. (The FS system considered in the preceding section is used also to transmit an FM-TV signal in the USA.) Consideration of interference to an FM-TV system is essentially the same as that of interference to an FDM-FM telephony system in that both the total power and the power spectral density of the interfering signal must be considered.

Insofar as the total interfering signal power is concerned, the discussion of the FDM-FM telephony system given in the preceding section also applies. Even with the interfering signal, the system remains operating above its threshold.

Since the power spectrum of the BSS signal is considered to be uniform in a 600 kHz bandwidth for the purpose of interference analysis, the discussion of the interference to the FDM-FM telephone system given in the preceding section also applies to the interference to an FM-TV system. The interfering BSS signal causes the baseband noise power spectral density in the victim FM-TV system to increase in a part of the baseband by the ratio given in Tables IX and X. If the system margin is greater than this ratio, the interference is considered tolerable.

5.1.3.3 *Interference to radio-relay systems carrying AM-VSB TV*

The conditions for protection of TV radio-relay using AM-VSB against interference from broadcasting satellites are given in Report 789. The maximum allowable interfering power flux-density should not exceed:

$$-134 \text{ dB(W/(m}^2 \cdot 5 \text{ MHz))} \qquad \text{for angle of arrival } \theta = 0° \qquad (8)$$

$$-134 + 10.5 + 25 \log (\theta/\theta_0) \qquad \text{for } \theta > \theta_0/2 \text{ for receiver antenna gains of 40.5 dBi} \qquad (9)$$

The CPM for the RARC SAT-83 proposed that within the main beam of the radio-relay antenna a PFD of:

$$-134 + 12 (\theta/\theta_0)^2 \text{ (dB(W/(m}^2 \cdot 5 \text{ MHz)))} \qquad \text{for } 0 \leqslant \theta \leqslant \theta_0/2 \qquad (10)$$

(where θ_0 is the half-power beamwidth of the receiving antenna), would be appropriate to protect radio-relay systems with the specific characteristics assumed in Report 789 and using AM-VSB.

At present, there is no standard method for determining the PFD in a band as wide as 5 MHz, the reference bandwidth of concern to the terrestrial broadcasting service (using AM-VSB) and TV radio-relay using AM-VSB. A worst-case assumption would include the entire BSS satellite power in a 5 MHz band. Power extrapolation methods are commonly used to derive this measurement. However, some standard methods should be developed and adopted.

It is expected that the wide geographical separation between the Region 2 and the Regions 1 and 3 service areas will in most situations create favourable coexistence of the FS and BSS services.

As an example, the PFD values in a 4 kHz bandwidth produced in Region 1 territory of Senegal from a satellite positioned to serve the most easterly parts of Region 2 (i.e 65° W to 95° W serving Brazil) are found to be in compliance with the limits of Annex 5 of Appendix 30 of the Radio Regulations, 1982, by more than 16 dB. Similarly, for satellites restricted to orbital positions east of 85° W, protection of the AM-VSB broadcasting service in Senegal is also provided. Between 85° W and 95° W, the use of shaped beams and the higher attenuation which can be expected for lower angles of arrival could also lead to compliance. It is noted that BSS satellite positions west of 86° W covering the north-east part of Brazil would probably be avoided since the low elevation angle of receiving earth stations would lead to large values of rainfall attenuation.

However, the most westerly positioned Region 2 BSS satellites would be more likely to cause interference to the fixed-service systems in the eastern part of Region 1.

For example, Fig. 9 shows the PFD values which would be produced in the most eastern part of Region 1, i.e. on USSR territory by a Region 2 BSS satellite positioned at 175° W to serve Alaska with a 3° × 1° elliptical beam antenna on the satellite using the WARC-BS-77 satellite transmitting reference pattern.

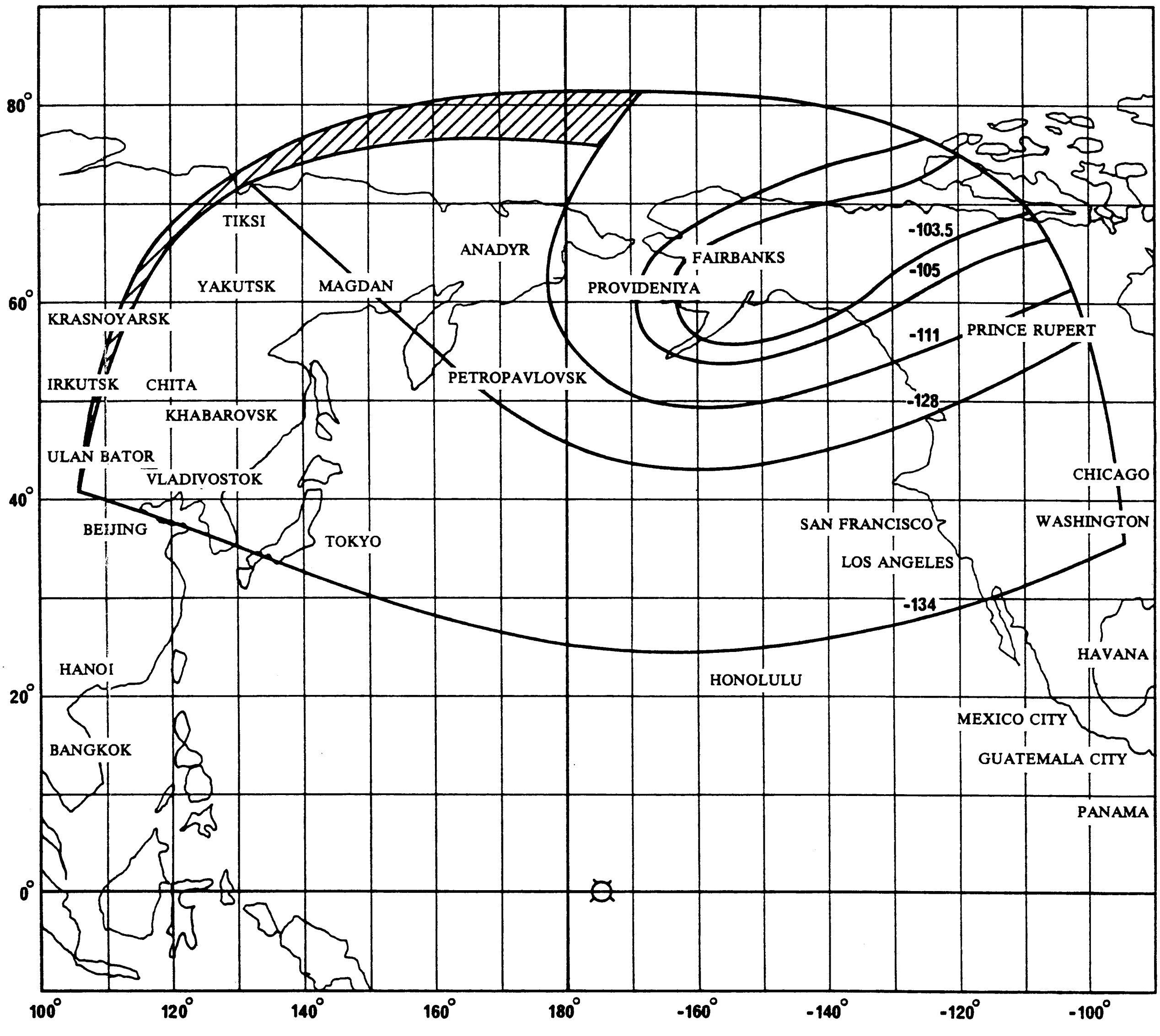


FIGURE 9 – *PFD contours of a Region 2 BSS satellite positioned at 175° W (3° × 1° elliptical beam antenna)*

There is an area (shaded in Fig. 9) where the PFD limits given in equations (8), (9) and (10) for radio-relay links carrying AM-VSB signals would be exceeded.

The conclusions of the CPM for the RARC SAT-83 on the possibilities of improving sharing and their impact are summarized in Table XI.

TABLE XI – *Possibilities for improving inter-regional sharing and their impact*

	Possibilities for improving sharing	Impact
1	Reduce BSS satellite e.i.r.p.	Larger ground receiver antenna required; individual reception may not be possible
2	Reduce coverage by use of small area beams	Entire population of desired service areas may not be served
3	Use individual reception only in highly populated areas well away from regional interface	Would require community reception in other parts of the desired service area
4	Beam shaping of satellite transmitting antenna	More uniform PFD in service area and less outside
5	Relocate satellite position	This may increase antenna discrimination at FS receivers in potential interference areas
6	Assign only certain frequency segments to BSS on one side of the regional interface and assign (or reassign) other frequencies to FS systems on the other side of the interface	Requires ITU or bilateral coordination but eliminates all interference considerations
7	Use satellite polarization orthogonal to FS receive antenna	With the use of circular polarization for the BSS and linear polarization for the FS, up to 3 dB of discrimination can be expected
8	Better fixed-service receive antenna pattern	Reduced coupling to BSS transmissions
9	Avoidance of orbit by FS receiving antenna	As much as 40 dB of discrimination can be obtained
10	Energy dispersal	Effective in spreading interference over the reference bandwidth of the interfered-with signal. For a reference bandwidth of 4 kHz, 22 dB of dispersal can be obtained with 600 kHz of spreading ([1])

([1]) This is not effective in protecting a 5 MHz AM-VSB signal.

Gaseous absorption can be a significant factor in reducing interference on satellite terrestrial paths where frequencies above 10 GHz are used and the signal arrives at the Earth with low elevation angles.

It can be concluded that sharing between the BSS and FS is generally feasible. There are some cases in which difficulties might arise. For these cases, technical solutions (beam shaping, antenna polarization discrimination, improvement in terrestrial antenna design, reduced satellite e.i.r.p., fixed-service pointing restrictions, frequency planning, reduced service areas) are possible, but bilateral or multilateral discussions among the administrations concerned may be necessary.

5.1.3.4 *Summary regarding interference from the BSS to the fixed service*

Taking into account the assumptions used, results of studies and the analysis given in this section indicate that, with proper coordination, interference from the BSS to terrestrial fixed services will not be a serious problem.

5.2 *Interference to the BSS from terrestrial services*

Typical values of e.i.r.p. for some terrestrial services which use or may use the band 11.7 to 12.5 GHz and which may cause interference to an earth-station receiver of the broadcasting-satellite service are indicated in Table XII.

TABLE XII – *Examples for e.i.r.p. of transmitters in the 12 GHz band*

Service	e.i.r.p. (dBW)
Line of sight radio-relay links:	
Telephony	36
Television programme distribution	41
Television multi-channel	23.5 to 46
Broadcasting:	
Amplitude-modulation	23.5 to 38
Frequency-modulation	26
Frequency-modulation (satellite system)	67.5

Equation (1) is also applicable for the case of protection for the satellite system provided that the factors are changed as necessary to represent the appropriate parameters of the satellite system.

Where the appropriate protection ratio is unknown an alternative approach may be used for the determination of the maximum interfering power flux-density at the earth station receiver, based on the effective receiver input noise power. If the maximum acceptable level of interference is limited to 10% of the effective receiver input noise power, then even under conditions of a severe fade of the wanted signal, the interference will not further degrade the output signal-to-noise ratio of the receiver, provided that the fade does not cause the wanted signal to fall below the carrier threshold level.

If the protection ratios are known, similar curves to those given in Fig. 8 can be drawn. An example for a 625-line system is given in Fig. 10 and is based on a power flux-density of -103 dB(W/m^2) and a single-entry protection ratio of 35 dB against frequency-modulation interfering signals for reception in the broadcasting-satellite service. From Fig. 10 the maximum tolerable interfering power flux-densities can be determined depending on the elevation angle of the earth station receiving antenna and the difference in azimuth of the directions of the satellite and the interfering signal. (These values of PFD are specified by the WARC-BS-77 for Regions 1 and 3.)

It should be noted that the expression $D_d = 8.5 + 25 \log (\varphi/\varphi_0)$ dB for the antenna discrimination represents the envelope of the maxima of the antenna side-lobes and thus the minimum discrimination (see Report 810, Fig. 2).

If it is assumed that the mean discrimination at an angle is some 3 dB greater than the minimum discrimination at that angle, then it can be stated that, for example, in 90% of locations the interfering signal strength will not exceed a level 1.7 dB below the maximum permitted.

When the maximum acceptable power flux-density for any particular direction at the earth-station receiver has been determined from Fig. 10, then the separating distance required between an outside broadcasting link and the earth-station receiver may be determined from Fig. 11.

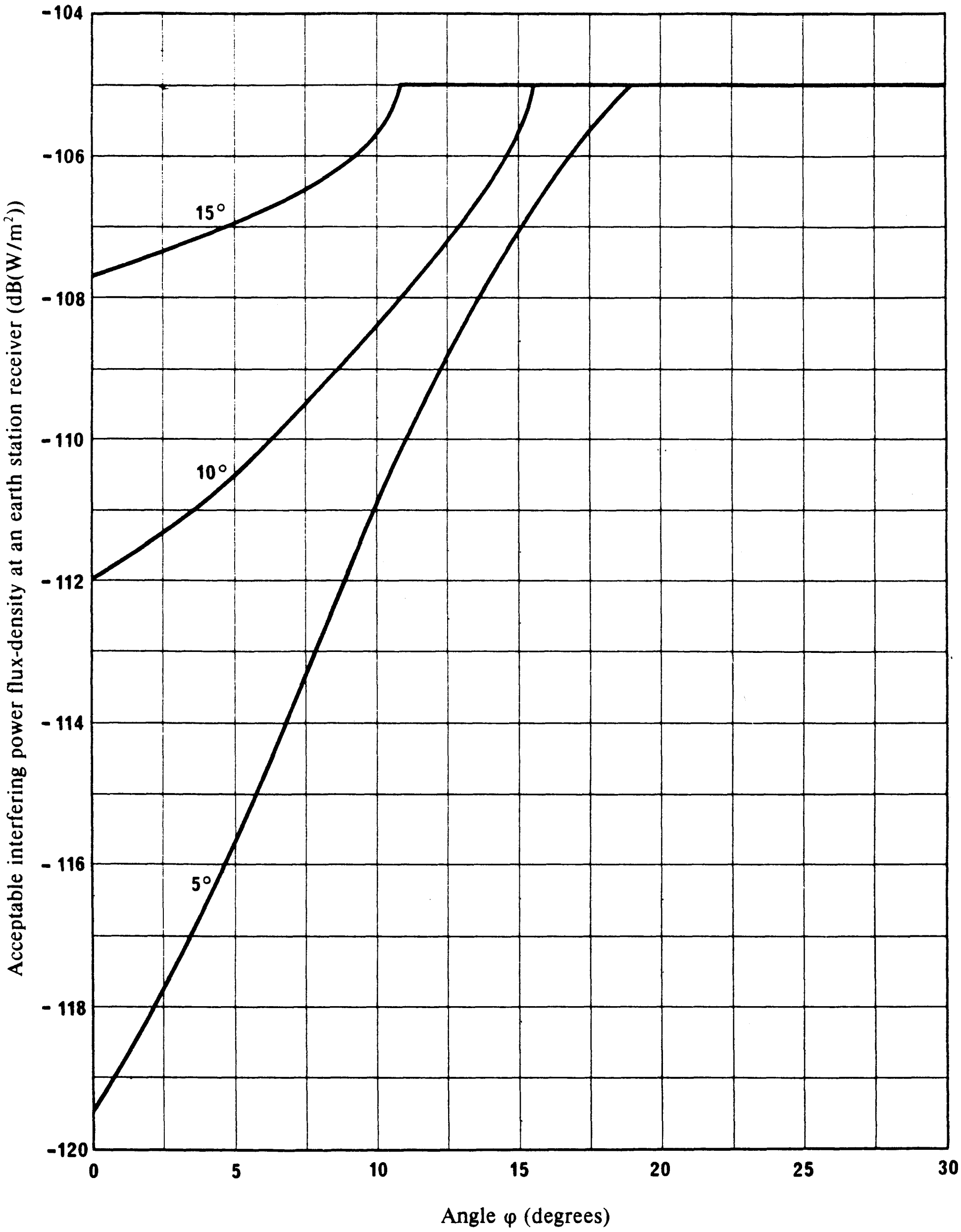


FIGURE 10 – *Acceptable interfering power flux-density from a terrestrial transmitter not to be exceeded for 99% of the time at an earth receiver (individual reception) for the example given in § 5.2*

(The angle of elevation of the satellite is shown as a parameter)

φ: Difference in azimuth between the directions of the satellite and the interfering signal.
Earth-receive antenna maximum off-beam gain: see Report 810, Fig. 2, curve A,
where: φ_0: Antenna 3 dB beamwidth
= 2.0° (for individual reception in Region 3) from Final Acts WARC-BS-77

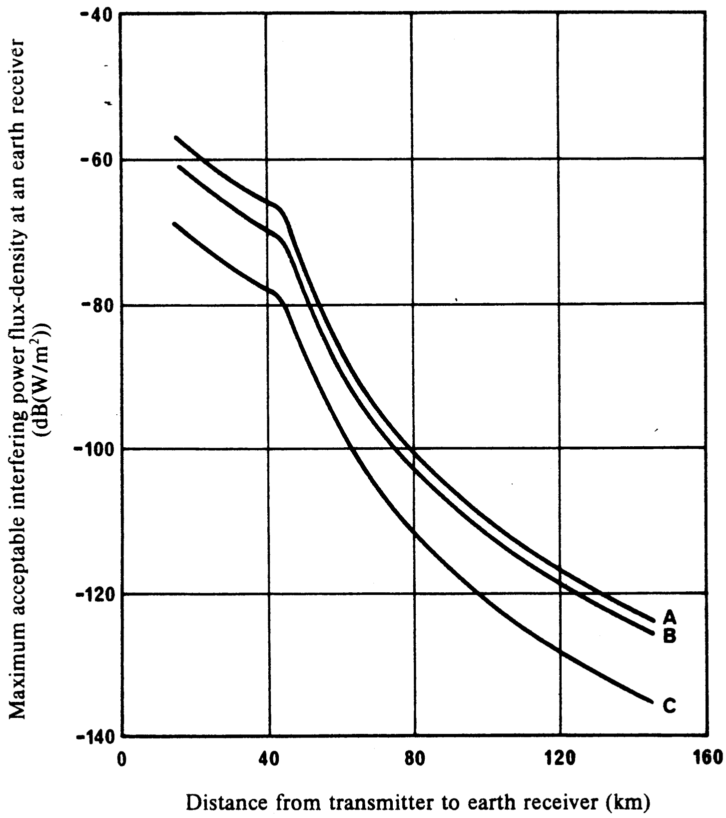


FIGURE 11 – *Required separation distance to protect an earth receiver from terrestrial transmitters*

(based on propagation curves for 50% of locations and 1% of time)

Power flux-density produced by:
A: Outside broadcast transmitter (e.i.r.p.: 34 dBW)
B: Amplitude-modulation television terrestrial broadcasting (e.i.r.p.: 38 dBW; transmitting antenna 75 m above the ground)
C: Frequency-modulation television terrestrial broadcasting (26 dBW; transmitting antenna 75 m above the ground)

Figure 11 also gives the separation distances required for a given value of power flux-density between an earth station receiver and transmitters of an amplitude-modulation terrestrial broadcast and a frequency-modulation terrestrial broadcast. The Schmeller and Ulonska propagation curve for 50% of locations and 1% of the time [Goes *et al.*, 1968] has been used in the preparation of Fig. 11.

To protect a higher percentage of locations for the broadcasting-satellite service, which might be necessary because of the uniform distribution of the wanted power flux-density in the service area, a correction to the maximum acceptable interfering power flux-density should be applied similar to that given in Fig. 12 of Recommendation 370.

The value of M_i, the margin for possible multiple interference entries, depends on the number and type of possible interferers. In the band 12.2 to 12.7 GHz, interference to the BSS may be caused by other BSS transmitters, by satellite transmitters in the FSS, and by fixed, mobile and broadcasting transmitters. Further work is required to determine how the total allowable interference should be allocated.

It is evident from Fig. 11 that, for large areas, frequency sharing within a given broadcasting-satellite service area would best be accomplished over an appreciable portion of that area if the terrestrial service operated in portions of the band not used by the broadcasting-satellite service within that service area as suggested in [CCIR, 1974-78l]. Experimental work in Japan for the case of an AM-VSB terrestrial broadcasting service has given an example of frequency separation that would provide a useful degree of protection [CCIR, 1978-82a and b]. The satellite signal receiver employed a mixer input stage [Konishi, 1980] and an IF bandwidth of about 25 MHz. In one example, reception was free of interference when the satellite (BSE) transmission was separated by 16 MHz (band-edge to band-edge) from the nearest of a series of seven AM-VSB transmissions in alternate 6 MHz channels, and the ratio of wanted signal to interfering signal was 0 dB at the receiver input. It appeared from further experiments in the laboratory that intermodulation in the receiver was not a primary limitation. Further measurements are required with a range of typical receivers to provide better selectivity data. From this, guidance on the frequency separation required to protect satellite broadcast reception could be deduced, taking into account the antenna directivity, the signal characteristics and the levels of signal that would apply in practical cases.

5.2.1 *Interference from the fixed service to the BSS*

The subject of interference from the fixed service to broadcasting satellite receivers, including a method of determining, in general, the interfering power flux-density at the edge of a BSS service area, is contained in Annex 3 to Appendix 30 to the Radio Regulations.

This section considers interference arising specifically from typical fixed service transmitters in operation in the United States and calculates the required separation distances to permit operation of broadcasting-satellite receivers without harmful interference.

Interference from the fixed to the broadcasting-satellite service (i.e. from fixed service transmitter to broadcasting-satellite receiver) is not uniform in a service area of the BSS, depending on the receiver location relative to the location and main-beam direction of the fixed station transmitting antenna.

The maximum permissible interfering signal power depends on the wanted BSS signal power and the required protection ratio.

First, determine the wanted signal power. The PFD to be exceeded for 99% of the worst month at the edge of the service area was specified by the WARC-BS-77 as -105 dB(W/m^2) as an interim value in Region 2. The received power can be determined using the effective area of the BSS receiving antenna.

For individual reception in Region 2, the receiving antenna half-power beamwidth is specified as 1.8°. This corresponds to a main-beam gain of 39.3 dBi. At 12 GHz, this requires an effective aperture of 0.4m^2 (i.e. an actual diameter of about 1 m for circular, parabolic antennas with efficiencies of 55%).

Thus, the wanted signal at the input to the BSS receiver, at the edge of the service area is:

$$-105 \text{ dB(W/m}^2) - 4 \text{ dB(m}^2) = -109 \text{ dBW}$$

Annex 6 to Appendix 30 to the Radio Regulations (ORB-85) specifies the required co-channel protection ratio as 35 dB (single-entry) decreasing linearly to 0 dB for interfering signals 35 MHz away from the desired signal. Therefore, the protection ratio is reduced to 22.1 dB when the interfering signal is at the centre of the adjacent BSS channel (i.e. 19.18 MHz away), and 0 dB when the interfering signal is two or more channels (38.4 MHz) away. Thus, only co-channel and the next adjacent channel interference need be considered.

Maximum permissible interfering signal powers then become:

-109 dBW -35 dB $= -144$ dBW, co-channel, and

-109 dBW -22.1 dB $= -131.1$ dBW, adjacent channel.

The interfering signal power depends on the interfering transmitter power, transmitting antenna gain in the direction of the BSS receiver, propagation loss and the BSS receiving antenna gain in the direction of the interfering fixed transmitter.

Transmitter power varies from system to system. (When the interfering signal bandwidth is wider than the BSS receiver bandwidth, only the power in the latter's bandwidth need be considered.)

Reference radiation patterns for circular antennas used in fixed radio-relay systems are given in Report 614. On-axis gain is a function of D/λ and the side-lobe envelope pattern is a function of D/λ and φ, where D is the antenna diameter, λ is the wavelength, and φ is the off-axis angle. Gain in the far side lobes is assumed to fall to isotropic (0 dBi). The close-in side-lobe envelope pattern given in Report 614 is applicable between the first side lobe and the point where the gain has fallen to isotropic. For simplicity, assume that the gain near the main lobe (expressed in dB) is parabolic with respect to the off-axis angle down to the first side-lobe gain, constant at the gain of the first side lobe out to the angle where the gain would be isotropic, and isotropic everywhere else. This is a conservative simplifying assumption, because the actual gain will be equal to, or less than, the values assumed.

The relationship between propagation loss, path length and type of path is also given in Appendix 30 to the Radio Regulations. Here, we assume all paths are over land.

The reference pattern for the BSS receiving antenna in Region 2 is given in the form of off-axis gain relative to the on-axis gain (39.3 dB). Thus, the gain at off-axis angles of 10, 15, 20 and 27 degrees is 12.2 dB, 7.8 dB, 4.7 dB and 0 dB, respectively.

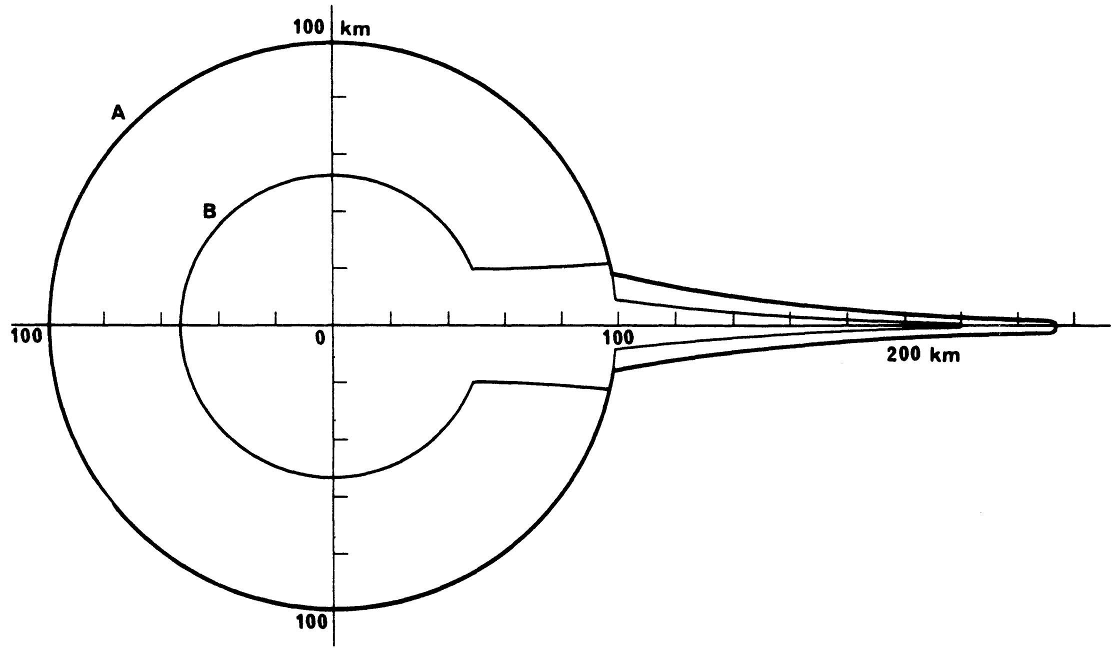
With these relations, the interfering signal power can be calculated, or the required separation distances can be determined. For each interfering transmitter, plot the minimum distance between the two locations against the off-axis angle of the interfering transmitter antenna with the location of the interferer at the origin. The resulting curve is the distance contour where the received, interfering signal reaches the permissible limit. The area inside the contour will have signals above the limit. Figure 12 is an example of such contours. These curves have been plotted for a typical US terrestrial system with a 1 W transmitter and a 1.8 m diameter antenna. Figure 12*a)* shows the co-channel case, and Fig. 12*b)* shows the case of adjacent-channel interference.

In Figs. 12*a)* and 12*b)*, the outer contours are for the worst case, in which elevation angles of the BSS receiving antennas are 15°. The inner contours describe a more favourable case in which the BSS elevation angles are above 27°, where the gain has fallen to isotropic. (The difference between the inner and outer contours can be interpreted as representing the effect of the discrimination of the BSS receiving antenna.)

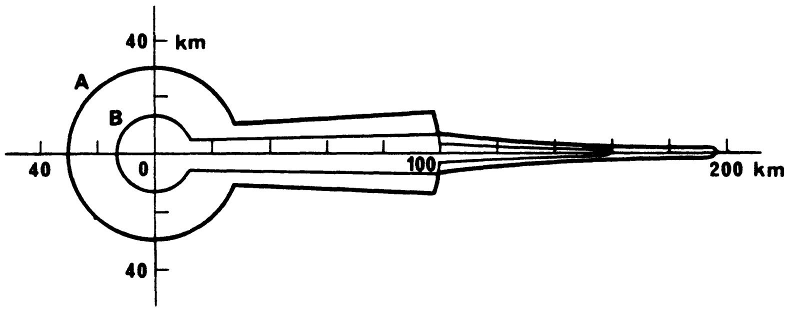
Each contour has a sharp peak in the on-axis direction of the interfering antenna, while it is a circular arc for angles well outside the main beam. Distances corresponding to these two regions are shown in Tables XIII and XIV for both co-channel and adjacent-channel cases, for both the 1 W system shown in Fig. 12, and for a lower e.i.r.p. system (type "B") employing a 10 mW (−20 dBW) transmitter and a 0.6 m diameter antenna.

TABLE XIII – *Minimum separation distances necessary in the case of co-channel interference from FS to BSS*

FS system (typical of US usage)	Antenna diameter (m)	Transmitter power (dBW)	Distance (km)			
			Worst case		Most favourable case	
			On-axis	Distant	On-axis	Distant
Type "A"	1.8	Typical 0.0 Max. 10.0	254.0 297.0	100.0 104.1	220.4 263.4	53.1 100.0
Type "B"	0.6	Typical −20.0 Max. −3.0	126.8 200.0	13.0 92.2	100.0 166.4	5.3 37.6



a) Co-channel interference



b) Adjacent-channel interference

FIGURE 12 – *Contours on which the received interfering FS signal power is equal to its maximum permissible limits for a 1 W (0 dBW) US fixed-service system*

BSS earth station elevation angle, θ :
A: θ = 15° (outer contour)
B: θ = 27° (inner contour)

TABLE XIV – *Minimum separation distances necessary in the case of adjacent-channel interference from FS to BSS*

FS system (typical of US usage)	Antenna diameter (m)	Transmitter power (dBW)	Distance (km)			
			Worst case		Most favourable case	
			On-axis	Distant	On-axis	Distant
Type "A"	1.8	Typical 0.0 Max. 10.0	198.4 241.5	29.5 93.3	164.9 207.9	12.0 38.0
Type "B"	0.6	Typical −20.0 Max. −3.0	100.0 144.5	3.0 20.9	69.8 110.9	1.2 8.5

5.2.2 *Summary concerning interference from terrestrial services to the BSS*

From the analyses shown here and the studies quoted, it can be seen that interference from fixed services to broadcasting-satellite earth stations will be a serious problem.

The two services can share the same frequencies (in accordance with the limits of harmful interference set forth in Appendix 30 to the Radio Regulations) by keeping terrestrial transmitters a sufficient distance from the service area of a broadcasting-satellite beam.

Such sharing can be accomplished by using some of the frequencies in a given geographic area for the broadcasting-satellite service, and the remainder of the frequencies in the band for terrestrial services.

5.3 *Effects of propagation*

In making calculations of interference, the effects of propagation should be taken into account using the latest relevant methods of the CCIR. In particular, the effects of atmospheric absorption due to oxygen and water vapour should be included. Appendix 30 of the Radio Regulations and the Final Acts of the RARC SAT-83, Part I, in their respective Annexes (concerning modifications to the respective Plans) provide the PFD levels from the BSS in one region into the other which would trigger coordination with respect to the fixed service. Also Annex 5 of Appendix 30 of the Radio Regulations (1982) sets forth the PFD levels for the protection of terrestrial services in Regions 1 and 3 from the BSS and FSS in Region 2. The Regional Administrative Radio Conference, RARC SAT-83, adopted in principle the use of atmospheric absorption in calculations for determining whether the specified coordination criteria and PFD limitations are met. Also, Resolution No. 9 of the RARC SAT-83 is directed towards the adoption of the use of atmospheric absorption in all intraregional and inter-regional coordination. The calculations in the directions from Regions 1 and 3 to Region 2 are based on the use of atmospheric absorption. Resolution No. 9 is directed, *inter alia*, towards the use of atmospheric absorption in the reverse direction as well.

Report 719 discusses the phenomenon of atmospheric absorption and how it can be modelled. At 12 GHz, atmospheric absorption for angles of arrival, θ, and water vapour density at the receiving station, $\rho(\text{gm/m}^3)$, is given by:

$$A_a = (7.226 \times 10^{-3} + 12.75\,\rho \times 10^{-4})\,R_0 \quad \text{dB} \qquad \text{for } \theta \simeq 0°$$

$$A_a = \frac{0.1156}{\sin\theta + \sqrt{\sin^2\theta + 0.0019}} + \frac{0.00511\,\rho}{\sin\theta + \sqrt{\sin^2\theta + 0.0005}} \qquad \text{for } 0° < \theta \leqslant 10°$$

$$A_a = \frac{0.0578 + 25.502\,\rho \times 10^{-4}}{\sin\theta} \qquad \text{for } \theta > 10°$$

where:

R_0 : horizontal path distance ($\theta \simeq 0°$).

Figure 13 gives the atmospheric absorption for low elevation angles for three values of ρ: 2, 7.5 and 11.1 gm/m³. The first represents winter conditions in the higher latitude land masses and the second represents summer conditions (Figs. 9 and 10 of Report 563), and the last represents a global average, as used in Report 719. Note that in general, values of ρ = 25 to 30 gm/m³ can be encountered.

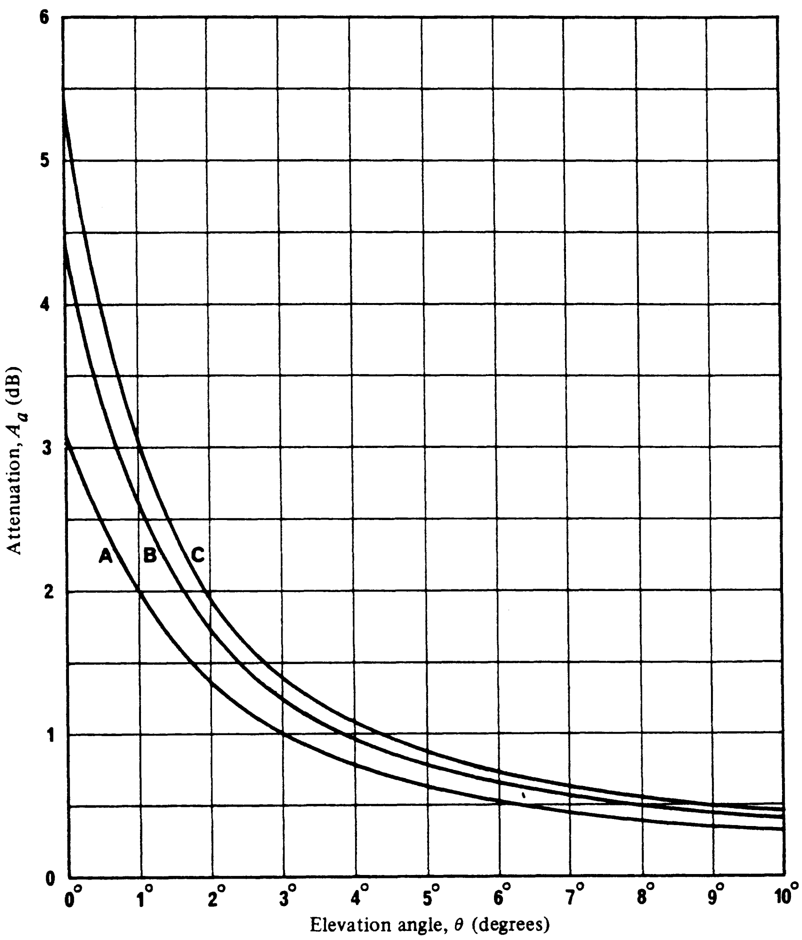


FIGURE 13 – *Atmospheric attenuation (A_a) versus elevation angle θ*

Curves A: $\rho = 2.0$ g/m³

B: $\rho = 7.5$ g/m³

C: $\rho = 11.1$ g/m³

ρ denotes water vapour density

Report 719 indicates that for completely dry atmospheres, about 2 dB of attenuation will be present on 12 GHz space-Earth paths at near zero angle of arrival and about 3 dB on 22 GHz paths. With significant amounts of water vapour present, as is the case during most of the year, the atmospheric absorption at 22 GHz would be very large.

5.3.1 *Conclusions on atmospheric absorption on nearly horizontal paths*

Above 10 GHz, Earth-space and space-Earth paths at nearly horizontal incidence will experience significant attenuation due to the presence of gases in the atmosphere.

Even in completely dry atmospheres at least 2 dB can be expected at 12 GHz due to oxygen alone. At 22 GHz at least 3 dB can be expected.

The presence of this attenuation was not taken into account in the establishment of inter-regional and inter-service limits on power flux-density.

Therefore, this attenuation can safely be taken into account in the determination of the levels of interfering signals to be expected on space-Earth paths around 12 GHz and 22 GHz.

The amount of attenuation to be expected should be determined using the current version of Report 719.

6. Sharing in bands above 12.75 GHz

The WARC-79 allocated three frequency bands above 12.75 GHz to the broadcasting-satellite service: 22.5 to 23, 40.5 to 42.5 and 84 to 86 GHz. In the band 40.5 to 42.5 GHz, the broadcasting-satellite service is the only primary allocation and therefore frequency-sharing from the BSS viewpoint is not necessary. In the band 84 to 86 GHz, the BSS, fixed, mobile and broadcasting services are all allocated on a primary basis. However, footnote No. 907 of the Radio Regulations applying to this band, states that stations in these other services "shall not cause harmful interference to broadcasting-satellite stations operating in accordance with the decisions of the appropriate frequency assignment planning conference for the broadcasting-satellite service". This footnote, plus lack of detailed information concerning the technical characteristics of systems which may operate in this band make it difficult to set forth a detailed sharing analysis for this portion of the spectrum.

6.1 *Sharing in the band 22.5 to 23 GHz between the BSS and other services*

6.1.1 *Interference between the broadcasting-satellite service and the inter-satellite service*

Interference between the BSS and the ISS is treated in Report 951.

6.1.2 *Sharing between broadcasting-satellite and fixed services*

6.1.2.1 *Characteristics of the terrestrial fixed system*

In North America, the band 22.5-23.0 GHz has not yet been extensively used by the fixed service. Typical applications of systems operating in this band fall mainly into two categories, namely, the provision of:

- low capacity telephony circuits such as PABX central office connections. Typical system capacities are 24/48 voice circuits employing digital transmission techniques;
- video links such as remote surveillance, electronic news gathering (ENG) pick-ups, etc. employing analogue transmission techniques (amplitude modulation). System lengths are typically a few kilometres.

A typical terrestrial radio system could exhibit the following characteristics:

Frequency (GHz)	22.4-23.0
Transmit power (mW)	100
Antenna gain (dBi)	34-40
Antenna beamwidth (degrees)	2-3
Receiver noise figure (dB)	8.0
RF bandwidth (channel spacing) (MHz)	50
Modulation: digital (AM/FSK)	voice/data
analogue (FM)	video
System length (km)	0.5-8

6.1.2.2 *BSS transmission system characteristics*

The type of broadcasting-satellite service considered here is high definition television (HDTV). It is still in the development stage, thus there are no established transmission standards defining signal format, modulation and system performance requirements.

However, Report 1075 considers the transmission aspects of HDTV by satellite with Table II of the Report containing examples of analogue and digital HDTV systems using the 22.5-23.0 GHz band. Table XV lists certain of the parameters that are pertinent to sharing.

TABLE XV – *Examples of possible HDTV systems using 22.5-23.0 GHz band*
(from Table II of Report 1075)

Parameter	Analogue	Digital
Type of modulation	FM-TDM	DPCM
RF bandwidth (MHz)	60	195
PFD (at edge of service area) (dB(W/m^2))	– 104.7	– 93.2
Rain attenuation (99% of the worst month) (dB)	4.5	4.5
BSS receiver antenna diameter (m)	2.5	0.62
Satellite e.i.r.p. (boresight) (dBW)	66.3	78.0

The analogue HDTV example with its larger TVRO antenna size and lower satellite power requirement could be used for community reception applications whereas the digital HDTV example, which assumes a small antenna, could correspond to individual reception systems which would be further into the future due to present technological constraints.

These two system examples along with the parameters assumed for the terrestrial radio systems given in § 6.1.2.1 will be used to determine coordination distances required with respect to a BSS receiving location.

6.1.2.3 *Coordination areas for a BSS receiving location*

An indication of the feasibility of sharing on a geographical basis between the BSS and FS can be obtained by determining the coordination area required around a BSS receiving location. (For the case of community reception the coordination distance can be considered with respect to a particular BSS receiving location whereas for direct reception the coordination distance should be considered with respect to the edge of the service area.)

The coordination area provides a conservative estimate of the separation distance required since worst-case assumptions are used to generate the contours. Factors that could alleviate the interference such as:

– off-axis discrimination of the terrestrial transmitting antenna,

– site shielding from natural terrain and local buildings,

are not considered. Furthermore, worst-case propagation parameters are used.

The method of generating the coordination contours is given in Appendix 28 of the Radio Regulations. The path loss between the interfering transmit station and the BSS receiving location that must be exceeded for p% of the time, $L(p\%)$, can be expressed as:

$$L(p\%) = P_t - P_r(p\%) \tag{11}$$

where:

P_t : boresight e.i.r.p. of the interfering transmit station,

$P_r(p\%)$: permissible level of interfering power at the input to the BSS receiver not to be exceeded for p% of the time.

$P_r(p\%)$ is related to the wanted signal level, $P_w(p\%)$, and the desired protection ratio, R, by the following:

$$P_r(p\%) = P_w(p\%) - R \tag{12}$$

Using the values for the system parameters given in § 6.1.2.1 and 6.1.2.2, the required path loss is given by the following:

$$L_p = R - PFD_w(p\%) - D(\varphi) + 78.5 \qquad (13)$$

where:

$PFD_w(p\%)$: power flux-density of wanted signal at BSS receiver exceeded for p% of the time,

$D(\varphi)$: BSS receiver antenna discrimination at an off-axis angle of φ degrees.

In the determination of path loss, the following assumptions were made:

- for coordination distances greater than 100 km, mode 1 propagation (i.e. great circle) was used;
- for distances less than 100 km, line-of-sight propagation was used;
- single climatic zone (Zone A2) assumed;
- horizon elevation factor of 0 dB (worst case);
- water vapour density: 1 g/m^3;
- frequency of 22.5 GHz;
- percentage of time: $p = 0.29\%$ (equivalent to 1% of the worst month).

In developing the coordination contours for both analogue and digital BSS systems two situations were considered, namely:

Case A assumptions: (best case)

- interfering signal attenuated by rain in the same amount as the wanted signal;
- BSS receiver located at centre of service area.

Case B assumptions: (worst case)

- interfering signal not attenuated by rain;
- BSS receiver located at edge of service area.

6.1.2.4 *Coordination area for analogue HDTV BSS*

BSS receive antenna characteristics

For the antenna diameter of 2.5 m ($D/\lambda > 100$), assumed for this case, the off-axis co-polar gain is given by the following (Appendix 28 of the Radio Regulations):

$$G(\varphi) = \begin{cases} 53.2 - 89.9\,\varphi^2 & \text{for } 0 < \varphi \leq 0.44 \\ 36.1 & \text{for } 0.44 < \varphi \leq 0.686 \\ 32.0 - 25\log(\varphi) & \text{for } 0.686 < \varphi \leq 48.0 \\ -10 & \text{for } \varphi > 48.0 \end{cases} \text{ dBi}$$

where φ is the off-axis angle in degrees.

Protection ratio required

As no data are available on protection ratio requirements for HDTV, data pertaining to conventional TV systems were assumed to be applicable. Based on data contained in Annex I to Report 634, the following protection ratios would appear to be appropriate:

Type of interference	*Protection ratio*
Coherent (e.g. AM-VSB TV)	35 dB
Non-coherent (e.g. digital)	25 dB

Figure 14 shows the coordination areas for both best case (case A) and worst case (case B) assumptions and for coherent and non-coherent interference. Table XVI summarizes the upper and lower limits for the coordination distances.

Although maximum coordination distances, which correspond to directions near the boresight, are quite large, these values correspond to a 0° elevation angle. For practical elevation angles of 10° or more these distances reduce to 100 km or less.

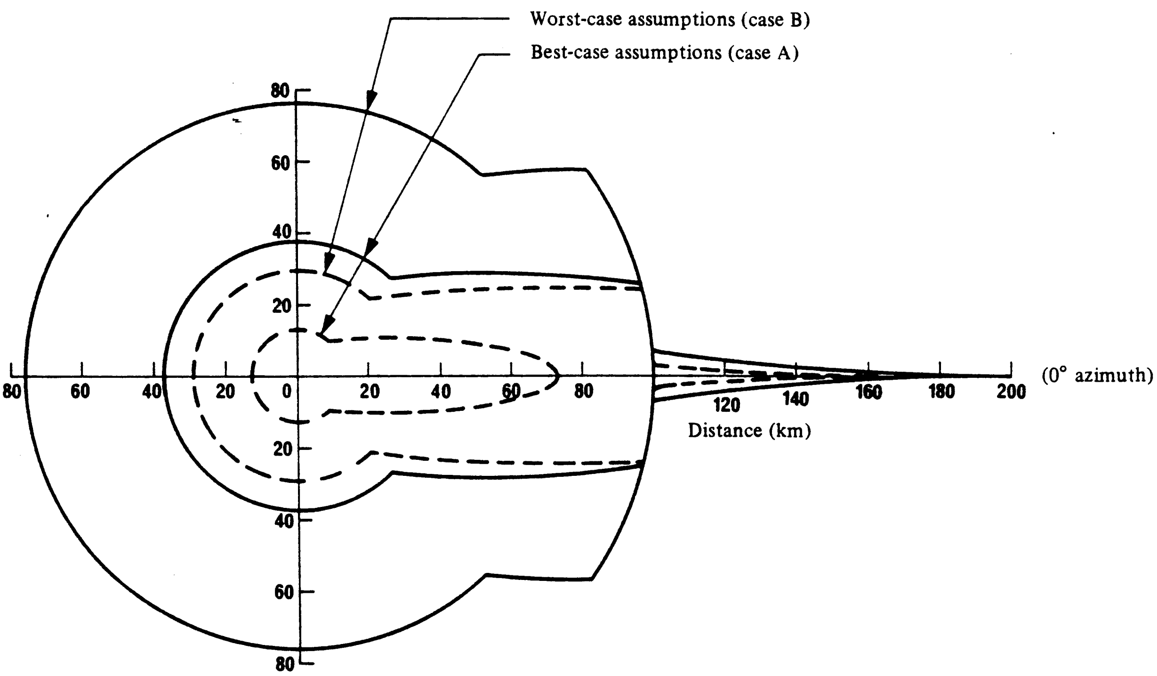


FIGURE 14 – *Coordination areas for analogue HDTV systems*

——— coherent interference (e.g. AM-VSB TV)

– – – non-coherent interference (e.g. digital telephony)

TABLE XVI – *Summary of coordination distances (km) for analogue HDTV*

	Coherent		Non-coherent	
	Maximum	Minimum	Maximum	Minimum
Best case (case A)	100	37	73.4	12.9
Worst case (case B)	197	75.6	168	28.9

6.1.2.5 *Coordination areas for digital HDTV*

BSS receiving antenna characteristics

The antenna diameter assumed for digital HDTV is 0.62 m ($D/\lambda < 100$). Thus the co-polar off-axis gain is given by the following (Appendix 28 of the Radio Regulations):

$$G(\varphi) = \left\{\begin{array}{l} 41.0 - 5.41\,\varphi^2 \\ 27.0 \\ 35.3 - 25\log(\varphi) \\ -6.7 \end{array}\right\} \text{dBi} \quad \begin{array}{l} \text{for } 0 < \varphi \leq 1.61 \\ \text{for } 1.61 < \varphi \leq 2.15 \\ \text{for } 2.15 < \varphi \leq 48.0 \\ \text{for } \varphi > 48.0 \end{array}$$

Protection ratio requirement

Based on data for digitally-coded conventional television systems (System M/NTSC), the required protection ratio for "just perceptible" interference is approximately 25 dB (see Report 634, Annex I). This value of protection ratio is assumed for the digital HDTV case as well.

Multiple interferers

The necessary bandwidth for the digital HDTV system is large compared to bandwidths used by terrestrial systems (typically 50 MHz spacing between RF channels). Furthermore, since the interference will be noise-like (i.e. non-coherent), its impact on picture degradation is not expected to be dependent on the interfering carrier off-set (i.e. co-channel or non co-channel interference). Therefore to take into consideration the possibility of more than one interferer falling within the HDTV channel, a multiple exposure factor of 10 log (195/50) = 5.9 dB is assumed as a worst-case situation.

Figure 15 shows the coordination areas for the digital HDTV systems assuming best case (case A) and worst case (case B) scenarios and for single and multiple exposure factors. Table XVII summarizes the maximum and minimum coordination distances for all these cases.

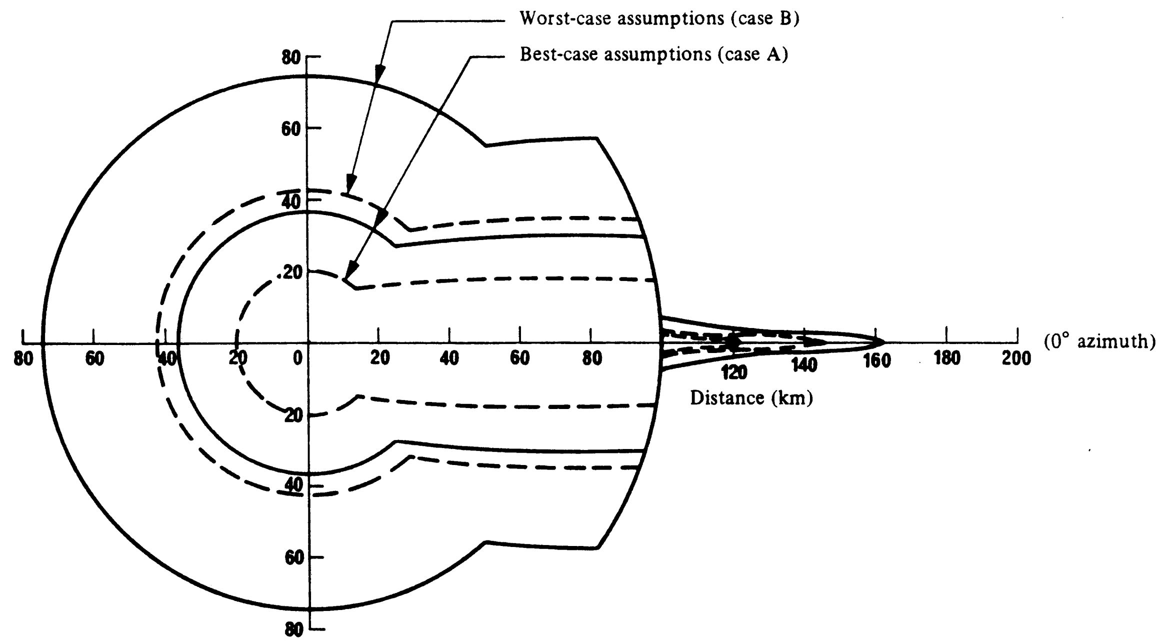


FIGURE 15 – *Coordination areas for digital HDTV systems*

——— multiple exposure factor: 5.9 dB

– – – multiple exposure factor: 0 dB

TABLE XVII – *Coordination distances for digital HDTV receivers*

	Single exposure		Multiple exposure	
	Maximum	Minimum	Maximum	Minimum
Best case (case A) (km)	123.4	19.7	140.7	36.4
Worst case (case B) (km)	145.4	42.6	162.7	74.8

As in the analogue HDTV case, the large values of coordination distances correspond to small off-axis angles and/or low elevation angles. For practical elevation angles of 10° or more the maximum coordination distance reduces to 100 km or less.

In comparison to the analogue HDTV case of Fig. 14, the coordination areas for digital HDTV lie between the worst-case (coherent) and best-case (non-coherent) analogue HDTV coordination areas.

6.1.2.6 *Interference from BSS into terrestrial systems*

As an indication of the sensitivity of terrestrial radio to interference from BSS, the ratio of interfering power to noise power in an RF channel bandwidth at the receiver input is determined in Table XVIII below. The digital HDTV BSS case is assumed to be the worst case due to its high PFD level and the terrestrial radio system parameters used are considered typical for video transmission applications (AM-VSB TV transmission).

TABLE XVIII – *Example of BSS interference into terrestrial radio-relay systems*

RF bandwidth of terrestrial channel (MHz)	5
Receiver noise figure (dB)	8
Boresight antenna gain (dBi)	34
Noise power at receiver input (kTB) (dBW)	–127.7
PFD of HDTV at boresight (clear air) (dB(W/m^2))	–85.7
Satellite transmitting antenna discrimination ([1]) (dB)	12.7
Bandwidth factor ([2]) (dB)	15.9
Atmospheric attenuation (clear air) (dB)	4.0
Gain of 1 m^2 (effective antenna aperture) at 22.5 GHz (dB)	48.5
Interference level at receiver input (dBW)	–132.8
(Interference/noise) ratio (dB)	–5.1

([1]) Assumes a minimum elevation angle of 20° at the *edge* of the BSS coverage area and a 1° satellite transmit antenna beamwidth.

([2]) For digital modulation the energy is assumed to be spread uniformly over the total bandwidth of the HDTV channel resulting in a reduction of interference power by 10 log (195/5) = 15.9 dB.

An analysis of interference to a terrestrial, medium-capacity system employing 4-phase DPSK modulation and capable of providing up to 672 voice channels for each RF carrier was carried out. Assumptions and system characteristics are given in Annex II.

This analysis indicates that a minimum BER of 1×10^{-7} can be met during median (clear-sky) conditions with excess C/I margins. The amount of excess margin depends on the path length of the digital system and the type of HDTV BSS interference. Lower margins can be expected on the longer path lengths (8 km) and from interfering signal analogue HDTV signals with p.f.d. levels designed for individual reception. However, these excess C/I margins imply that no restrictions in terms of terrestrial receive antenna location or orbit avoidance is required with respect to this mode of interference. These positive margins also imply that the assumption of the minimum elevation angle at the edge of the BSS coverage area (i.e. 20°) could be relaxed and still meet the protection criterion for all but the longest path lengths. The margins will be even greater in the case of community reception for HDTV BSS due to the lower p.f.d. levels.

The effect of interference on system performance during rain fading conditions will be to reduce slightly the fade margin to the receive BER threshold. Assuming that the satellite signal will also be faded by at least the same amount as the terrestrial signal, the reduction in the path fade margin will be less than 1 dB.

It should be noted, however, that these conclusions apply only to digital systems employing this level and type of modulation, and similar system characteristics. For example, these conclusions may <u>not</u> apply to systems currently being deployed and under development using a higher level of modulation such as 64 QAM, which is more sensitive to interference, or employing sectorial receiving antennas in which case the rain fades along the two paths may <u>not</u> be fully correlated.

6.1.2.7 *Summary and conclusions*

The feasibility of sharing between the BSS and FS has been examined, and the following conclusions may be drawn:

- analysis of coordination distances for the analogue HDTV BSS case (community reception) indicates that, for elevation angles greater than approximately 10° the maximum coordination distance lies between 73 and 100 km corresponding to azimuths near the boresight direction, and minimum coordination distances between 13 and 37 km for azimuths corresponding to the back lobe of the receiving antenna;
- coordination distances for the digital HDTV case (individual reception case) fall within the maximum and minimum coordination contours for the analogue HDTV case;
- considering the relatively smaller coordination areas required for this band, sharing on a geographical basis will be somewhat easier than in the 12 GHz band;
- the analysis of interference into terrestrial radio-relay systems from the broadcasting satellite given in § 6.1.2.6 indicates that, under worst-case assumptions, an (I/N) ratio of -5.1 dB would result. Further study is needed to determine if this margin is adequate for the types of terrestrial services envisaged for this band.

6.2 <u>Sharing between radioastronomy and the BSS in the region of 22 GHz</u>*

Radioastronomy (RA) has an interest in several bands around 22 GHz:

22.01 to 22.21 GHz
22.21 to 22.50 GHz
22.81 to 22.86 GHz
23.07 to 23.12 GHz

These bands are also of interest to the BSS for wide RF-band HDTV emissions (see Resolution 521).

The protection required by radioastronomy and the width of guard bands that would be required to provide full protection to RA is discussed in this section.

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* This section should be brought to the attention of CCIR Study Group 2.

6.2.1 Required power flux density limits

The power flux density (pfd) limits required to protect radioastronomy (RA) observations are given in Report 224. The limits tabulated are based on the assumption that an isotropic antenna is being used. Since in practical RA observations highly directional antennas are used, an additional factor of 15 dB (over the pfd limits tabulated) may be assumed. This assumption is based on the use of the reference antenna pattern 32-25 log φ to represent the side lobe gain in dBi of the RA antenna.It is further assumed here that the RA antenna will not be pointed closer than 5° from the geostationary satellite orbit (GSO) so that the gain of the RA antenna towards the GSO will not exceed
32-25 log(5°) ≅ 15 dBi.

The relevant pfd limit in this frequency band is calculated as follows: Table I of CCIR Report 224 indicates a spectral power flux-density of −233 dB(W/(m^2·Hz)) which corresponds to an assumed 0 dBi antenna gain.

This power flux-density level is further decreased by 15 dB (to −248 dB(W/(m^2·Hz)) to permit RA observations up to 5° off the geostationary satellite orbit as discussed above.

Report 1075 indicates that the free space pfd of an HDTV satellite service will be of the order of −90 to -100 dB(W/m^2) in the service area. Table XIX shows the spectral power flux density in a 1 Hz bandwidth assuming either uniform spectral distribution (as would be achieved by a digital transmission) or energy dispersal over 4 MHz (as would be achieved with a FM transmission). Further study may be needed to determine whether the standard type of energy dispersal used in FM systems would be adequate to protect the RA service.

Table XIX: Power flux density (pfd) in a 1 Hz bandwidth in dB(W/(m^2.Hz))

Bandwidth over which the energy is spread (MHz)	Spectral pfd dB(W/(m^2.Hz))	
	HDTV pfd = -90 dB(W/m^2)	HDTV pfd = -100 dB(W/m^2)
4	-156	-166
40	-166	-176
50	-167	-177
100	-170	-180

From the results in this table it can be seen that a significant attenuation of the HDTV signal is needed before it can operate in the RA band without causing excessive interference.

6.2.2 Implications

The levels of out-of-band interference should be lower. The modulation systems employed will have spectral shaping, and there can be attenuation from the satellite output filter.

To achieve the desirable level of -248 dB(W/(m^2·Hz)), between 68 and 92 dB of additional attenuation would be required.

6.2.2.1 FM systems

FM systems will have a spectrum which drops off fairly rapidly out of the band. Fig. 16 shows a typical example of a representative spectrum mask. This spectrum is deduced from information in CCIR Report 807-2. This Report gives a radio-frequency spectrum for a typical out-of-band radiation from a television broadcasting satellite. The assumption that a conventional television standard is used represents a near worst case. To extrapolate from conventional standards to HDTV standards, it is necessary to make some approximations. Frequency scaling of signals is valid under some conditions. Calculations were done both for r.f. bandwidths of 54 MHz (see system B in Table IX of Report 1075 ———) and 100 MHz. Thus the frequency scaling can be assumed to be a factor of two in the first example, and four in the second example.

It can be seen from the curves in Fig. 16 that some additional attenuation is necessary to protect the RA*. Fig. 16 also shows that, for an FM system with no additional filtering, the guard band must be between 65 and 120 MHz, depending on which example is used. Futher filtering on the output would be useful.

6.2.2.2 Digital systems

There is a wide range of possible digital systems under study. Some have a constant envelope and can be engineered to provide a spectrum which is not degraded when the signal is passed through a non-linear amplifier. Other digital systems do not have a constant amplitude envelope, the spectrum can be modified by non-linearities, especially in a TWTA, resulting in an increase in the out-of-band spectral components. Two of the examples from Report 1075, QPSK and 16 QAM, can be considered as limiting cases. Fig. 17 shows that a simple QPSK system will have levels of out-of-band radiation too high to allow the RA users to operate properly. Similarly, with the assumptions made, there will be problems with 16 QAM (Spectral envelopes of Fig.17 correspond to post-TWTA signals and 50% cosine roll-off (CRO). Extra filtering is therefore essential for digital systems.

6.2.2.3 Requirements for guard bands and filtering

It is possible to deduce the filtering necessary to protect the RA at minimum frequency separations from the HDTV BSS.

From a study of Fig.16 we can see that the FM systems used in the examples require filters with pass-bands of 50 and 100 MHz. Some rejection is desirable at a frequency offset by about the bandwidth away from channel centre frequency. An attenuation of 20 dB is assumed as a stringent, but probably achievable target, in order to improve the spectrum efficiency.

The output filter needs to provide attenuation to bring the residual levels of out-of-band radiation down to those proposed to protect the RA. From Fig.17 it can be seen that figures for attenuation of about 50 dB are required.

More specifically, a 140 Mbit/s QAM channel would need at least 50 dB attenuation at a minimum frequency offset from channel center of 68 MHz whereas an 140 Mbit/s QPSK channel would need at least 60 dB attenuation at a minimum frequency offset of 70 MHz.

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* The values in Fig. 16 assume energy dispersal.

6.2.2.4 Example calculation: 140 Mbit/s QPSK for the frequency region near 22 GHz

For this latter case, we can derive the total frequency band to be left free for RA operations:

- RA band: 50 MHz
- Minimum band between RA band edge and center frequency of nearest HDTV channel: 70 MHz
- Half channel RF width for an 140 Mbit/s QPSK signal with 50% CRO: 52.5 MHz

$$B(free) = 50 + 2 \times 70 - 2 \times 52.5 = 85 \text{ MHz}.$$

This leads to a large unoccupied band and to very stringent filters specifications.

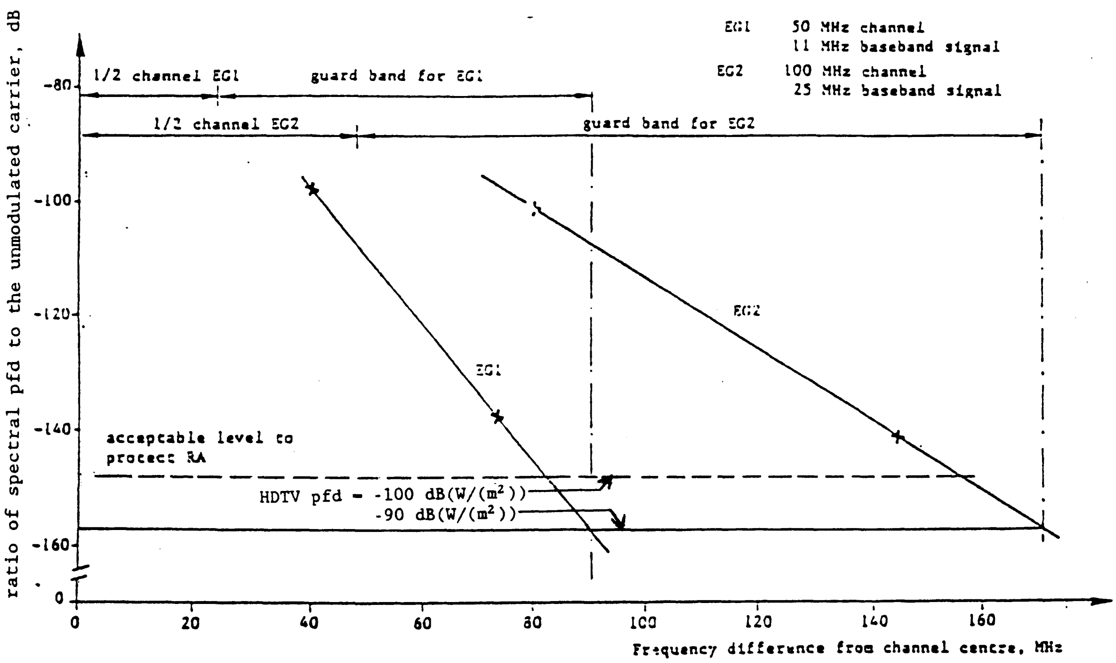

FIGURE 16

Spectrum mask for FM systems

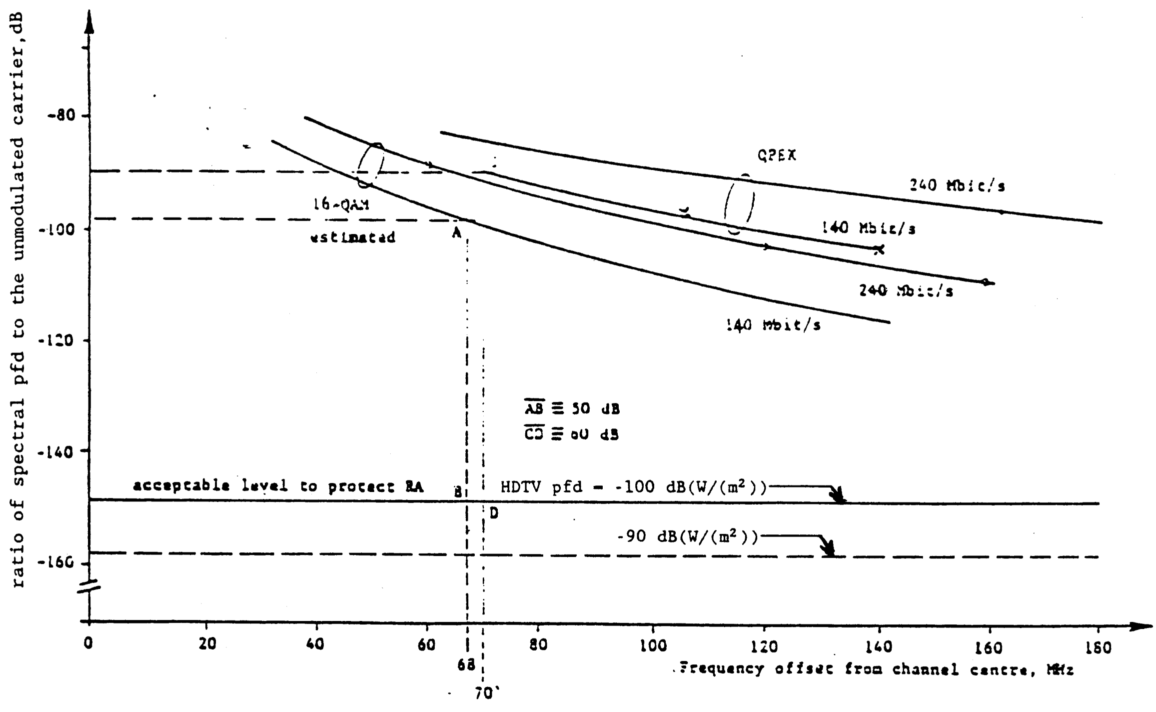

FIGURE 17

Spectral envelope for digital systems

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[1974-78]: **a.** 11/112 (Germany (Federal Republic of)); **b.** 11/415 (France); **c.** 11/420 (France); **d.** 11/172 (Netherlands); **e.** 11/142 (United Kingdom); **f.** 9/83 (United Kingdom); **g.** 11/170 (Netherlands); **h.** 11/143 (ESA); **i.** 11/163 (Switzerland); **j.** 9/92 (Germany (Federal Republic of)); **k.** 11/152 (USSR); **l.** 11/174 (Australia).

[1978-82]: **a.** 11/247 (Japan); **b.** 10-11S/114 (Japan).

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[1978-82]: 10-11S/11 (EBU); 10-11S/12 (United Kingdom); 10-11S/25 (USA); 10-11S/53 (USSR); 11/116 (USSR).

ANNEX I

EXAMPLES OF POWER FLUX-DENSITY LIMITS REQUIRED TO PROTECT THE LAND MOBILE SERVICE AT ABOUT 800 MHz

For a single broadcasting geostationary satellite in a visible orbit position, the acceptable value of power flux-density produced on the surface of the Earth by the satellite is:

- to protect a high grade service:
  - -133 dB(W/(m^2 · 16 kHz)) at the receiving antenna of the mobile station;
  - -146 dB(W/(m^2 · 16 kHz)) at the receiving antenna of the base station;
- to protect a minimum grade service:
  - -127 dB(W/(m^2 · 40 kHz)) at the receiving antenna of the mobile station;
  - -134 dB(W/(m^2 · 40 kHz)) at the receiving antenna of the base station.

These values are applicable only for the land mobile service at about 800 MHz.

The value of -146 dB(W/(m^2 · 16 kHz)) is based on currently available information and is, for example, necessary to protect a system operating in the land mobile service at about 800 MHz having the following characteristics:

- channel spacing: 25 kHz;
- receiver bandwidth: 16 kHz;
- receiver noise factor: 10 dB;
- improvement factor: 12 dB;
- antenna gain: 15 dBi;
- radio-frequency protection ratio: 18 dB;
- polarization discrimination: 3 dB.

For different or additional characteristics, the power flux-density mentioned will change accordingly. This value takes into account low elevation angles of the broadcasting satellite.

It should be noted that if several broadcasting geostationary satellites are in visible orbit positions, the power flux-density produced by each satellite must be correspondingly lower than that quoted above.

It would be desirable to obtain more data on parameters of systems in operation or under development from other administrations before a general value of protection to systems in the land mobile service can be arrived at. Further studies should therefore be undertaken on receipt of additional data.

At the present time it seems premature to judge whether sharing between the broadcasting-satellite service and the land mobile is feasible at about 800 MHz.

ANNEX II

CHARACTERISTICS OF A 23 GHz DIGITAL TERRESTRIAL SYSTEM AND INTERFERENCE CONSIDERATIONS

This Annex provides the details on the characteristics of the digital terrestrial system discussed in § 6.1.2.6. The assumptions and the method used for the analyses of the impact of interference are also included.

1. 23 GHz digital radio systems for voice/data transmission

With the rapid evolution of the digital voice/data network, the use of the 23 GHz band for voice/data transmission will most likely employ digital transmission techniques. Current device performance limitations at these frequencies will likely limit the choice of modulation to constant envelope techniques (e.g. 2- or 4-PSK) permitting operation near or at device saturation. Such modulation schemes will provide voice data capacity ranging from 96 voice channels (low capacity) up to approximately 672 voice channels (medium capacity) in one RF channel. The basic radio system transmission parameters for these systems are assumed to be as given in § 6.1.2.1 of the present Report.

Typical applications of these systems could be for interlinking buildings within metropolitan areas thus using relatively short paths (1-8 km) in order to limit path fading due to precipitation which can be severe at these frequencies. Considering possible path geometry, elevation angles of the terrestrial radio transmit/receive antennas could range up to ten degrees. The elevation angle of the digital radio receive antenna is important as it affects the location at which the terrestrial receive antenna boresight could possibly be directed towards the interfering satellite.

2. Sharing considerations and interference analyses

At these higher frequencies and with systems employing relatively short path lengths the major factor contributing to path availability will be rain fades. Furthermore, satellite interference of any concern will be in those cases where the terrestrial signal path is near the same azimuth and elevation angles as the interfering satellite signal path, otherwise there will be sufficient discrimination provided by the terrestrial receiving antenna. Hence it is reasonable to assume that the satellite signal will be faded by at least the same amount and at the same time as the terrestrial signal during rain conditions.

The sharing analysis presented herein is based on meeting a required carrier-to-interference ratio (C/I) to insure acceptable system error performance during median or clear sky propagation conditions.

(This approach is different from that used in § 6.1.2.6 of the present Report, which is based on achieving an acceptable interference-to-noise (I/N) ratio thus implying at least partial signal fading independence between the wanted and interfering paths.)

Assuming that the impact of the interference on the system BER is equivalent to that of Gaussian noise, then for 4-phase DPSK modulation a C/I of 13.8 dB will result in a theoretical BER of 1×10^{-7}. Allowing for a 3 dB implementation margin the required C/I in the absence of thermal noise ($C/N = \infty$) is 16.8 dB.

Similarly, assuming a threshold BER of 1 in 10^3 as minimum acceptable performance (i.e. system outage) corresponds to a faded C/N value of 9.8 dB for 4-phase DPSK. This threshold C/N value is in the absence of interference. The presence of interference in the faded condition will have the effect of increasing this threshold C/N value slightly which results in a slightly reduced fade margin. For example, assuming that the satellite signal will fade the same amount as the terrestrial signal, then for a $C/I = 16.8$ dB the required C/N for a 1 in 10^3 BER is approximately 10.3 dB, which represents a 0.5 dB reduction in the fade margin.

Table XX gives the terrestrial system path characteristics for path lengths ranging from 2 to 8 km and for two sizes of terrestrial transmit/receive antennas. The maximum allowable interfering pfd level at the terrestrial receiver location is based on the C/I given above and assumes no terrestrial antenna discrimination towards the interfering satellite.

TABLE XX - *Terrestrial system path parameters*

Path length (km)	Median receive signal level[1] (dBW)		Fade margin[2] above threshold (dB)		Allowable interference level[3] (dBW)		Allowable interference PFD (dBW/m^2)	
	30 cm	68 cm	30 cm	68 cm	30 cm	68 cm	30 cm	68 cm
2	-74.8	-60.6	34.7	48.9	-91.6	-77.4	-77.1	-70.0
4	-81.1	-66.9	28.4	42.6	-97.9	-83.7	-83.4	-76.3
6	-84.8	-70.6	24.7	38.9	-101.6	-87.4	-87.1	-80.0
8	-87.6	-73.4	21.9	36.1	-104.4	-90.2	-89.9	-82.5

(1) Assumes transmitter output level P_t = 13 dBm
(2) Assumes NF = 8 dB: BER = 1 in 10^3 (threshold): (C/I) = ∞
(3) Assumes median (C/I) = 16.8 dB (≈ 1 in 10^7 BER + 3 dB margin)

TABLE XXI - *HDTV BSS (individual reception) interference levels*

Parameter	Digital	Analogue	
PFD at edge of coverage area	-94.3	-94.7	$dB(W/m^2)$
RF bandwidth	195	60	MHz
Rain margin	4.5	4.5	dB
Satellite transmit antenna beamwidth	1.0	1.0	deg
Minimum elevation angle at edge of coverage area	20.0	20.0	deg
Maximum elevation angle, terrestrial receiving antenna	10.0	10.0	deg
Boresight PFD (clear air)	-86.8	-87.2	$dB(W/m^2)$
Satellite transmit antenna discrimination towards terrestrial receiver	9.6	9.6	dB
Additional clear air attenuation	1.26	1.26	dB
Bandwidth dispersal factor[1]	5.9	0	dB

	Terrestrial receiving antenna diameter				
Excess C/I for: Path length (km)	30	68	30	68	cm
2	26.6	33.7	21.0	28.1	dB
4	20.3	27.4	14.7	21.8	
6	16.6	23.7	11.0	18.1	
8	13.8	21.2	8.2	15.6	

(1) Bandwidth dispersal factor applicable to digital HDTV BSS .

Note.- There are some differences between Report 951, sharing between the ISS and the BSS around 23 GHz, and section 7.3.2.2.7 of the report of JIWP 10-11/3 which treats interference from the BSS to the ISS.