RECOMMENDATION ITU-R SF.358-5*

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

(1963-1966-1974-1982-1993-1995)

The ITU Radiocommunication Assembly,

considering

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

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

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

d) that, nevertheless, any limitations of the power flux-density produced at the surface of the Earth should not be such as to place undue restrictions on the design of systems in the FSS;

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

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

recommends

1 that, in frequency bands in the range 2.5 to 27.5 GHz shared between systems in the FSS and line-of-sight radio-relay systems, the maximum power flux-density produced at the surface of the Earth by emissions from a satellite, including those from a reflecting satellite, for all conditions and methods of modulation, should not exceed:

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

–152	dB(W/m^2)	for	$\theta \le 5°$
–152 + 0.75 (θ – 5)	dB(W/m^2)	for	$5° < \theta \le 25°$
–137	dB(W/m^2)	for	$25° < \theta \le 90°$

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

–152	dB(W/m^2)	for	$\theta \le 5°$
–152 + 0.5 (θ – 5)	dB(W/m^2)	for	$5° < \theta \le 25°$
–142	dB(W/m^2)	for	$25° < \theta \le 90°$

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

–150	dB(W/m^2)	for	$\theta \le 5°$
–150 + 0.5 (θ – 5)	dB(W/m^2)	for	$5° < \theta \le 25°$
–140	dB(W/m^2)	for	$25° < \theta \le 90°$

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* Radiocommunication Study Groups 4 and 9 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

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

–148	dB(W/m^2)	for	$\theta \leq 5°$
–148 + 0.5 (θ – 5)	dB(W/m^2)	for	$5° < \theta \leq 25°$
–138	dB(W/m^2)	for	$25° < \theta \leq 90°$

1.5 in the bands 17.7 to 19.7 GHz, 22.55 to 23.55 GHz, 24.45 to 24.75 GHz and 25.25 to 27.5 GHz, in any 1 MHz band:

–115	dB(W/m^2)	for	$\theta \leq 5°$
–115 + 0.5 (θ – 5)	dB(W/m^2)	for	$5° < \theta \leq 25°$
–105	dB(W/m^2)	for	$25° < \theta \leq 90°$

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

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

3 that the information contained in Annex 1 should be used as guidance for the use of this Recommendation.

NOTE 1 – Definitive limits applicable in shared frequency bands are laid down in Table S21-4 of Article S21 of the Radio Regulations (RR). Study of these problems is continuing which may lead to changes in the recommended limits.

NOTE 2 – According to RR No. S21.16.4, the power flux-density limits in bands between 17.7 and 27.5 GHz shall apply until such time as modified by a competent world radiocommunication conference.

NOTE 3 – Recommendation ITU-R SF.1005 deals with the maximum allowable power flux-density values to be applied to the frequency bands above 10 GHz which may be bidirectionally allocated to the FSS on a shared basis with the fixed service by a future world radiocommunication conference.

ANNEX 1

Protection of terrestrial line-of-sight radio-relay systems against interference due to emissions from space stations in the fixed-satellite service in shared frequency bands between 1 and 27.5 GHz

1 Introduction

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

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

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

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

– the values should be low enough to avoid exceeding the recommended limits of maximum permissible interference to existing and future terrestrial radio-relay systems using the same frequencies;

– the values must be high enough to allow satisfactory operation of space communications systems.

2 Method of determining the maximum permissible power flux-density

2.1 Interference criteria

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

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

Maximum allowable values of interference from the FSS into digital radio-relay systems are laid down in Recommendation ITU-R SF.615. The effect of power flux-density limits on the design of digital radio-relay systems is discussed in § 6.

Since digitally-modulated signals have been shown to be affected by the total interference power within the occupied bandwidth, and since practical bandwidths are likely to be large, a reference bandwidth of 1 MHz has been adopted.

2.2 System models

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

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

The technical characteristics of model line-of-sight radio-relay systems are described by the parameters listed in Appendix 1.

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

2.2.2 Orbit model parameters for space systems

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

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

The effect of interference of emissions from space stations in non-GSO is considered in § 4.

2.3 Angle dependence of power flux-density limits

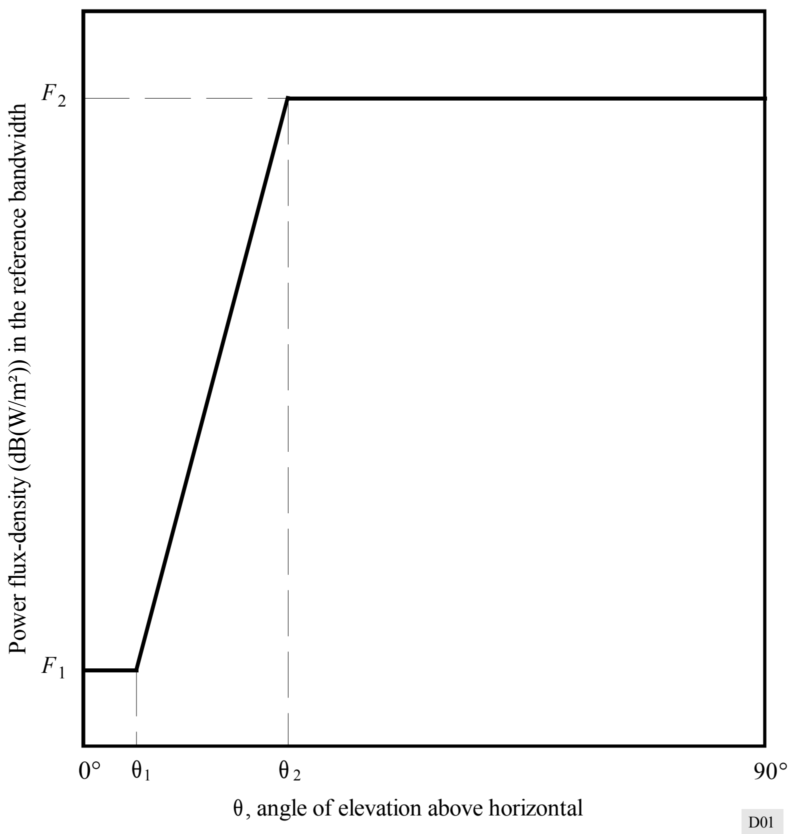
Radio-relay antennas are normally pointed in a nearly horizontal direction. Hence, normally, their greater sensitivity is to interfering power flux arriving in directions tangential (or nearly so) to the Earth's surface. As the angle of arrival of the interference increases, the radiation patterns of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

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

In this Recommendation, 5° has been chosen as the angle of arrival θ_1 in Fig. 1. This is because radio-relay antennas with elevation angles of 2° or 3° are not uncommon and the value of θ_1 should be large enough to protect these radio-relay systems adequately. On the other hand, the effect of the values of θ_1 below 5° on satellite system design is minimal. For example, the tilt angle of a geostationary satellite towards the Earth's surface with 0° arrival angle is 8.688° and that towards 5° arrival angle is 8.655° (see Fig. 2). The difference is as small as 0.033° (0.4% of the tilt angle). Thus the choice of $\theta_1 = 5°$ is a reasonable one.

FIGURE 1

Power flux-density limit vs. angle of arrival



2.4 Interference analysis

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

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

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

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

– the consequences of varying the North-South position limits.

The method followed in the statistical analyses is outlined in Appendix 1.

2.5 Frequency dependence of power flux-density limits

As frequency is increased from 4 to about 27.5 GHz, a number of factors have to be taken into account for the derivation of power flux-density limits:

– the receiving system noise temperatures in terrestrial model systems are expected to increase with frequency. Due to beamwidth restrictions in practice, the associated antenna gains are not likely to increase much beyond the maximum values at present in use at the lower frequencies. Fading, particularly at frequencies above 10 GHz, will increasingly be due to absorption by rain for small percentages of the time. When fading is due to rain, a certain correlation between the weakening of the wanted and the interfering signal can be expected, especially for on-beam exposures. These factors tend to increase the tolerable power flux-density. On the other hand, radio-relay systems may have lower feeder losses which would tend to reduce the permissible limit on power flux-density. The net effect of these considerations results in power flux-density limits which are only slightly higher in the frequency range 10 to 15 GHz, than those for frequencies below 10 GHz;

– at frequencies above about 15 GHz, terrestrial systems are likely to use digital modulation. Although for such systems the interference-additive characteristic of systems carrying analogue angle-modulated signals is no longer applicable, the generally lower sensitivity to interference of digital systems allows a substantial relaxation in the values of maximum permissible power flux-density. At such frequencies, furthermore, the fading will be mainly due to rain attenuation, and correlation between wanted and interfering signals will be appreciable. In addition, atmospheric absorption over the interference path from a space station can be substantial, in particular for low angles of arrival which includes the case of main beam exposures.

3 Limits of power flux-density

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

– in the frequency range between 1 and about 27.5 GHz, the frequency bands shared between the FSS and the fixed service are indicated in RR Article 8. For frequency bands shared between systems in the FSS and terrestrial line-of-sight radio-relay systems, the maximum power flux-density produced at the surface of the Earth by emissions from any one space station for all conditions and all methods of modulation should not exceed the values given in Table 1.

TABLE 1

Limits of power flux-density*

Frequency range (GHz)	Limit of power flux-density (dB(W/m^2))			
	$\theta \leq 5°$ (1)	$5° < \theta \leq 25°$	$25° < \theta \leq 90°$	Reference bandwidth
1.7-2.5 (2)	–154	–154 + 0.5 (θ – 5)	–144	in any 4 MHz band
2.50-2.69	–152	–152 + 0.75 (θ – 5)	–137	in any 4 MHz band
3-8	–152	–152 + 0.5 (θ – 5)	–142	in any 4 MHz band
8-11.7	–150	–150 + 0.5 (θ – 5)	–140	in any 4 MHz band
11.7-15.4	–148	–148 + 0.5 (θ – 5)	–138	in any 4 MHz band
15.4-27.5	–115	–115 + 0.5 (θ – 5)	–105	in any 1 MHz band

* According to RR No. S21.16.4, the power flux-density limits in bands between 17.7 and 27.5 GHz shall apply until such time as modified by a competent world radiocommunication conference.

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

(2) No frequency bands are at present allocated in the RR to the FSS between 1.7 and 2.5 GHz.

4 Interference from space stations in non-geostationary orbits

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

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

Results of a study of one possible model have indicated that the potential interference from space stations in low-circular orbits to FDM radio-relay systems in the shared 2 GHz band produces noise levels below the criteria established in Recommendation ITU-R SF.357. Further studies of interference to other types of system are required.

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

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

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

The characteristics typical of relatively simple receiving earth stations given in Table 2 are assumed:

TABLE 2

Receiving earth station characteristics

Frequency band (GHz)	Antenna diameter (m)	Antenna gain (dBi)	Reception system noise temperature (K)
4	7.5	47	500
12	6.0	55	700
20	4.5	57	1 000

Assuming free-space conditions and maximum allowable power flux-density for low elevation angles, the receiver power density can be compared with the thermal noise power density, at the input to the earth station receiver. Assuming further wide deviation angle modulation or digital modulation (Gaussian and raised cosine spectrum shapes, respectively), about 4 dB need be subtracted from the carrier/noise density ratio, leaving the available undegraded carrier/noise ratio as shown in Table 3.

TABLE 3

Undegraded carrier/noise ratios

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

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

In some cases higher values of carrier/noise ratio may be desirable. In such cases the higher power flux-density limits associated with the greater elevation angles of arrival are of considerable value in connection with narrow-beam space station antennas (see Appendix 2).

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

Interference from space stations below 10 GHz results in a small increase in the degradation of performance relative to that due to thermal noise alone. Since the allowable power flux-density limits which have been established were based upon analogue systems, and since the permissible degradation has been established in accordance with Recommendation ITU-R SF.615, it can be anticipated that there may be some constraints on the design of digital radio-relay links. Appendix 3 examines how orbital avoidance can be used.

7 Further considerations

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

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

In addition, the studies referred to in § 2.3 were made assuming antenna radiation diagrams of the form in Recommendation ITU-R F.699. These patterns are appropriate for circular apertures that display complete symmetry. However, some types of terrestrial radio-relay antennas do not exhibit circularly symmetrical radiation patterns and the patterns can be assumed to be similar to the reference patterns of Recommendation ITU-R F.699 only in the horizontal plane. Since the interference from space stations is received in all planes, additional studies are necessary. Studies have recently been made using a complete three-dimensional characterization of a pyramidal horn-reflector. The conclusions were similar to previous studies. Specifically, the limits given in § 3 are adequate to protect radio-relay systems, but the allowable interference may be exceeded in a small percentage of sensitive systems.

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

APPENDIX 1

TO ANNEX 1

Determination of power flux-density limits in the frequency band between 1 and 10 GHz

1 Introduction

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

2 Evaluation method

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

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

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

– a reasonable increase with the higher angles of arrival could be tolerated;

– non-geostationary and geostationary space stations could be accounted for under the same power flux-density limits;

– the maximum permissible interference power of Recommendation ITU-R SF.357 would be exceeded only in a relatively small fraction (≈ 10%) of the "high sensitivity" terrestrial systems, and somewhat lesser percentage for "average sensitivity" systems.

3 Model systems

The technical characteristics representative of radio-relay systems on which the analyses have been performed are shown in Table 4:

TABLE 4

Assumed parameters for model radio-relay systems

Frequency (GHz)	2.5	4	4
Type of system	High sensitivity	Average sensitivity	High sensitivity
Hop length (km)	60	50	50
Antenna gain (dBi)	38	40	42
Feeder loss (dB)	3	3	3
Receiver system noise temperature (K)	750	1 750	750
Channel thermal noise power per hop (pW0p)	25	25	10 and 25

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

$$G(\varphi) = G_1 - 25 \log \varphi \quad \text{dB} \quad \text{for } \varphi_0 \leq \varphi \leq \varphi_1 \qquad (1)$$
$$= G_2 \quad \text{dB} \quad \text{for } \varphi_1 < \varphi \leq 180°$$

where φ is the angle (degrees) from the main beam axis.

4 Results of the calculations

The calculations indicate that the power flux-density limits given in § 3 of Annex 1 would protect the average sensitivity model radio-relay systems adequately but would, in some cases, exceed the allowable values of Recommendation ITU-R SF.357 in the high sensitivity model systems.

The calculations also show that inclined satellite orbits have minimal effect on the aggregate level of interference into the fixed service as a function of North-South station-keeping accuracy. However, it should be noted that the statistical method, used here for studying the effects of interference into the fixed service from the FSS, although appropriate for FSS in equatorial orbits may require further consideration of time-sensitive elements in order to determine unavailability of the fixed service when the FSS is in inclined orbit.

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

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

APPENDIX 2

TO ANNEX 1

Use of "spot beam" antennas on geostationary satellites

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

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

Figure 2 shows the relationship between the tilt angle α at the satellite (defined as the angle between the geocentric radius vector and a ray to a point on the surface of the Earth) and the corresponding angle of arrival above the horizon of the satellite emissions. Figure 3 shows representative main beam patterns for satellite antennas. Three different beamwidths are shown in Table 5.

FIGURE 2

Tilt angle at the satellite versus angle of arrival above the horizon

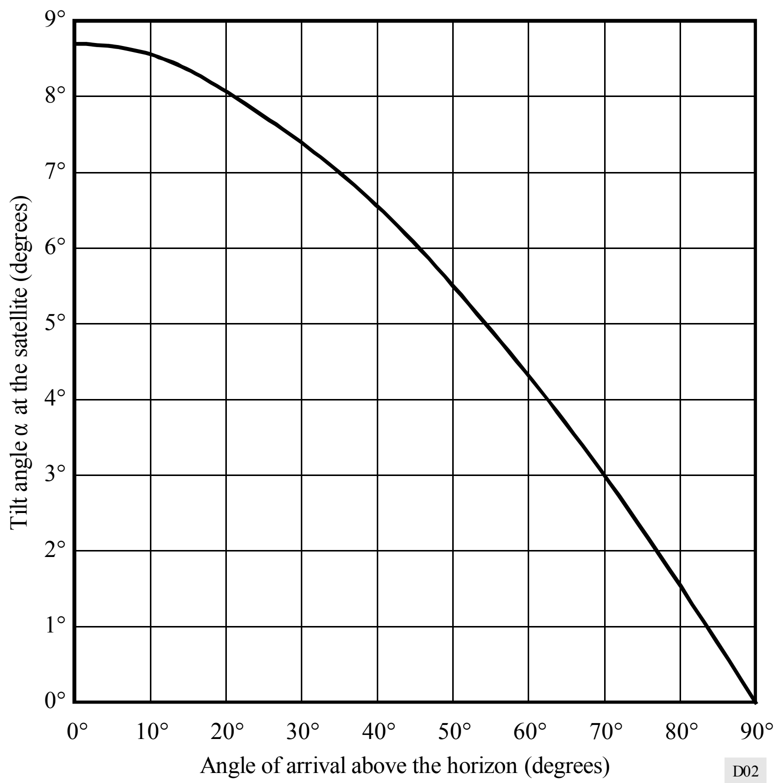


FIGURE 3

Representative main beam patterns for satellite antennas

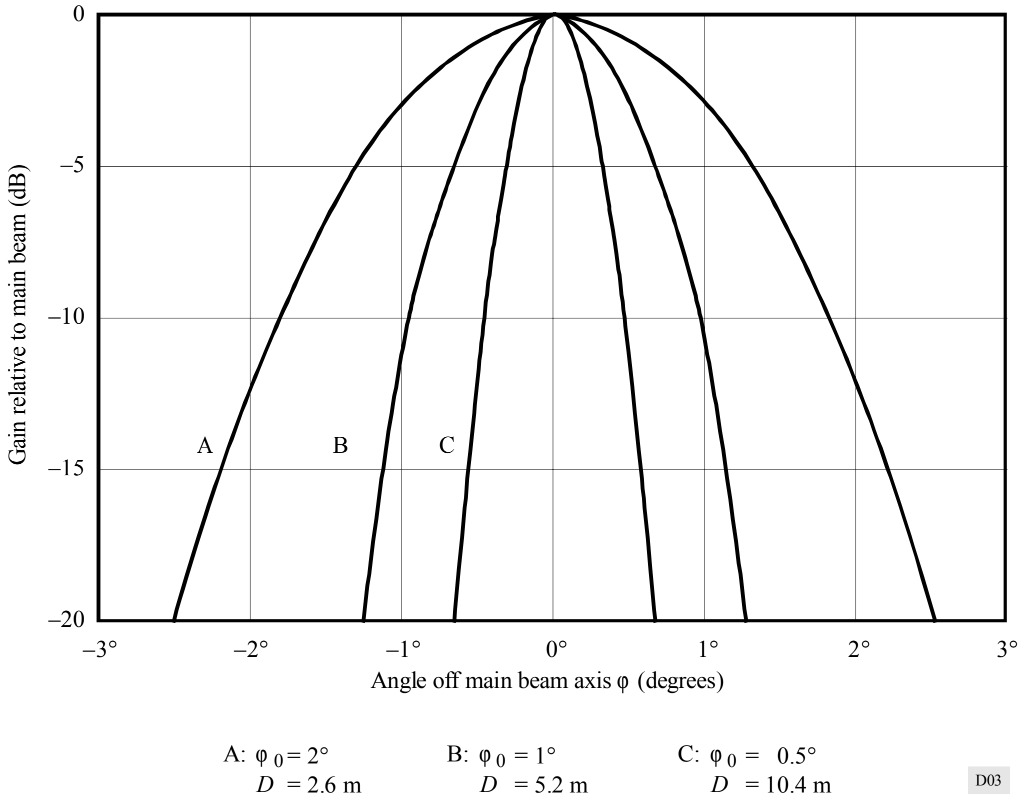


TABLE 5

Antenna beamwidths

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

The main beam patterns shown are of the general form:

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

where:

φ : angle from the main beam axis

φ_0 : half-power beamwidth.

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

FIGURE 4

Maximum power density at the centre of the beam without exceeding curve E

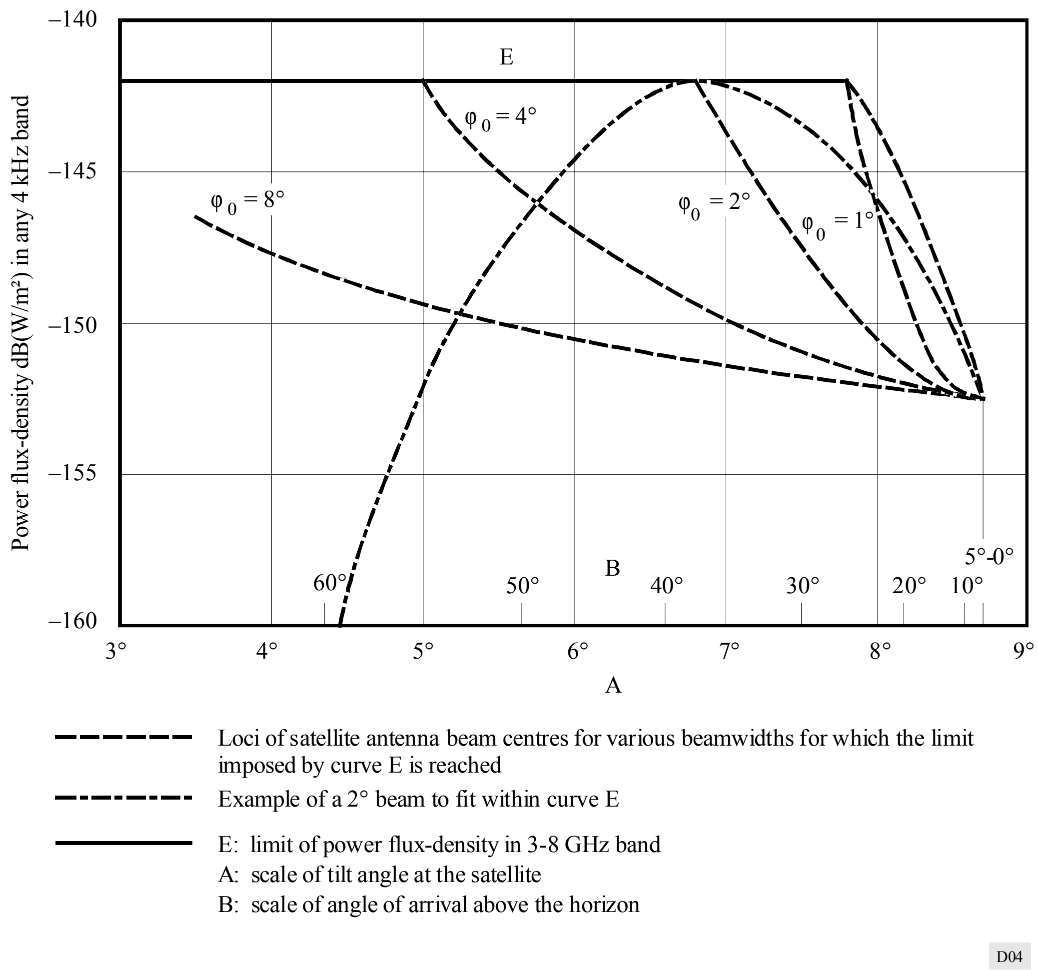


Figure 4 also shows the loci of satellite antenna beam centres for various beamwidths. Note that for a beam of given width, the flux-density at beam centre must be limited as shown by these curves so that no portion of the antenna beam exceeds the limit shown by the solid line.

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

APPENDIX 3

TO ANNEX 1

Use of orbital avoidance in the design of digital radio-relay systems

1 Introduction

Recommendation ITU-R SF.615 in effect allows 10% of the performance degradation in a digital radio-relay hypothetical reference digital path (HRDP) to be due to interference from fixed-satellite systems (FSS). At the same time, Article S21 of the RR and the present Recommendation specify the allowable power flux-densities due to FSS space stations in various bands.

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

2 Digital radio-relay analysis model

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

– frequency band: 4 GHz

– bandwidth: 20 MHz

– antenna: 4 m dish
 gain: 42 dBi
 pattern: $35 - 25 \log X$ dBi for $1.8 \leq X < 25$
 0 dBi for $X \geq 25$
 where X is the off-axis angle

– latitude: 50° N

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

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

– Category A: those radio-relay stations whose orbital avoidance is small, i.e. 2° to 10°;

– Category B: those radio-relay stations whose orbital avoidance is large, i.e. in excess of 10°.

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

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

3 Received interference power

When it is assumed that the orbital spacing between satellites is 3° and the power flux-density limits of RR Article S21 are met, the received aggregate interference power at a Category A station is found to be:

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

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

$$Pr_A = -131.1 \text{ dB(W/20 MHz)}$$

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

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

4 Degradation in performance due to interference

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

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

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

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

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

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

$$P_{0\,T} = \frac{0.9\,P_0}{n}$$

where:

P_0 : total permissible degradation in percentage of time (see Recommendation ITU-R F.594).

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

$$\begin{aligned} P_0 &= P_{0\,T} \times 1.38 \times nQ + P_{0\,T} \times 1.007 \times (1 - Q)n \\ &= 0.9\,P_0 \;(0.38\,Q + 1.007) \end{aligned}$$

Whence, $Q = 27\%$.

5 Discussion of results

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

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

6 Conclusion

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