RECOMMENDATION ITU-R S.1781

Possible methodology for frequency sharing between bidirectional geostationary fixed-satellite service networks comprising ubiquitously deployed earth stations

(Question ITU-R 209/4)

(2007)

Scope

This Recommendation provides a methodology to establish frequency compatibility, based on area coordination, between two fixed-satellite service (FSS) systems when one or both systems involve large numbers of ubiquitously deployed ground terminals and the terminals of one system are transmitting while the terminals of the other system are receiving in the same frequency bands allocated bidirectionally to the FSS.

The ITU Radiocommunication Assembly,

considering

a) that there is a growing interest in the ubiquitous deployment of very small aperture terminal (VSAT)-type fixed-satellite service (FSS) earth stations, i.e. in the installation and operation of earth stations without individual licences but under the overall licence for the system in which they operate;

b) that in such cases the precise locations of particular earth stations would not be known at the time that frequency coordination is carried out for the system;

c) that the need to deploy the earth stations in large numbers would make their coordination on a site-by-site basis difficult;

d) that some frequency bands in which such deployment would be desirable are allocated to the FSS on a bidirectional basis;

e) that some of the bands allocated to the FSS on a bidirectional basis are also subject to specific regulatory provisions, for example, provisions of the FSS Allotment Plan or of the Radio Regulations (RR) Appendix 30A Plan;

f) that some administrations may opt for some form of area coordination within which VSAT-type FSS earth stations may operate in a single direction of transmission;

g) that in such cases as described in *considering* f) it may be helpful for administrations to have methodologies for determination of the overall coordination area based on technical criteria of their choice,

noting

a) that the coordination contour around the region within which an administration wishes to implement area coordination may border other areas of coordination contained in the territory of the same administration or international borders;

b) that administrations would need to take necessary steps to identify the frequency bands and associated geographical areas where any coordination method involving a large number of terminals operating in the same band would be implemented,

recognizing

a) that administrations are free to pursue bilateral agreements outside of the scope of the RR;

b) that administrations are free to choose the level of protection to be afforded to the VSAT-type FSS earth stations deployed in their territory;

c) that, in the case of international coordination, administrations would have to agree on earth station and protection characteristics to be considered;

d) that factors such as the protection of receiving earth stations with respect to higher-powered transmitting earth stations located in the territory of administrations not included in a bilateral agreement may indicate the desirability of recording receiving earth stations with the Radiocommunication Bureau, whether or not they are covered by a bilateral agreement;

e) that for the case of earth stations planned to operate in bands allocated to the FSS on a bidirectional basis subject to specific regulatory provisions, these provisions must also be taken into account by administrations when planning their deployment,

recommends

1 that administrations intending to license within their territory, based on area coordination, ubiquitously deployed VSAT-type FSS earth stations operating in bands allocated bidirectionally to the FSS, should consider the use of the guidelines contained in Annex 1 to this Recommendation.

Annex 1

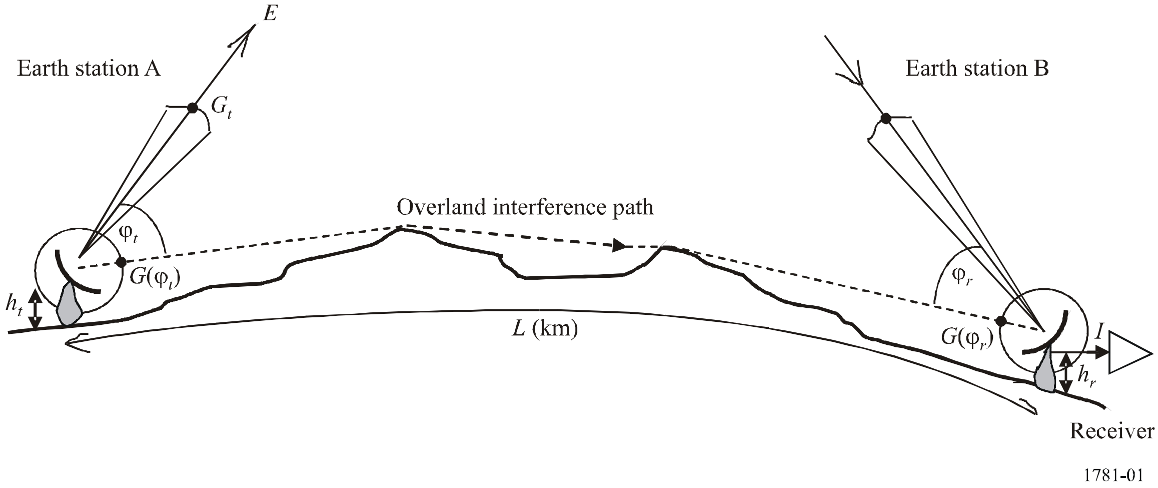
1 Introduction

This Annex contains the elements of a methodology to establish frequency compatibility between two FSS systems when one or both systems involve large numbers of ubiquitously deployed ground terminals, and the terminals of one system are transmitting while the terminals of the other system are receiving.

The analysis developed in this Annex is based on system parameters used in the band 12.5-12.75 GHz. Since the bidirectional FSS allocations apply only in Region 1 in that band, it is necessary to use Region 1 countries as a basis for the examples. The methodology, however, is general and can be applied to any bands where there is bidirectional FSS sharing.

2 Methodology

FIGURE 1



In the example illustrated in Fig. 1, earth station A operates to a geostationary satellite equipped to use the 12.5-12.75 GHz FSS (Earth-to-space) allocation, while earth station B operates to another geostationary satellite using the 12.5-12.75 GHz FSS (space-to-Earth) allocation. Earth station A transmits a PSK carrier centred on 12.625 GHz, with an e.i.r.p. spectral density of E dB(W/MHz), and interferes via an overland path with the reception by earth station B of another phase shift keying (PSK) carrier centred on 12.625 GHz. The interference spectral density, I, at the input to the receiver in earth station B is then given by:

$$I = E - G_t + G(\varphi_t) - pl + G(\varphi_r) \qquad \text{dB(W/MHz)} \qquad (1)$$

where:

G_t: on-axis gain of the antenna at earth station A (dBi)

$G(\varphi_t)$: earth station A antenna gain toward the horizon in the direction of earth station B (dBi)

pl: path loss between the two stations (dB)

$G(\varphi_r)$: earth station B antenna gain toward the horizon in the direction of earth station A (dBi)

φ_t: off-axis angle at earth station A toward the horizon in the direction of earth station B (degrees), and

φ_r: off-axis angle at earth station B toward the horizon in the direction of earth station A (degrees).

Instead of using absolute case assumptions, it is possible to generate contours within which deployment of FSS stations operating in opposite directions of transmission in the same bands would be compatible for any given percentage of cases by appropriate selection of the parameters to be used with equation (1).

For example, during 2002, an ITU-R survey of existing and planned FSS earth stations produced statistics of diameters of antennas, their e.i.r.p. and the bandwidth of the carriers transmitted. The survey included almost 127 000 terminals with antennas in the diameter range 1.5 to 2.1 m. Although the survey concentrated mainly on earth stations designed to transmit in the band

14-14.5 GHz, it may be assumed that a survey concentrating on the band 12.5-12.75 GHz would yield similar statistics, albeit from a smaller database. These results could be used to make reasonable assumptions for the parameters E and G_t in equation (1).

The values of φ_t or φ_r depend on the latitude and longitude of the earth station, the longitude of the satellite to which it is operating, and the azimuth bearing of the other earth station. The variation in φ with these parameters is calculated in Appendix 1, which also shows how cumulative distribution functions of off-axis angles for interference between earth stations operating in opposite directions of transmissions can be developed so that adequate values of φ_t and φ_r may be chosen for use with equation (1).

2.1 Methodology applied to an international example

The ITU-R survey of existing and planned FSS earth stations in 2002 revealed that the most popular diameter of antennas installed up to then and operating in the band 14-14.5 GHz was around 1.8 m, and that 98% of such antennas transmitted carriers whose e.i.r.p.s did not exceed 52 dBW and whose bandwidths do not exceed 1 MHz. The values of $E = 52$ dB(W/MHz) and $G_t = 10 \log ((0.65)\{\pi.(1.8)/\lambda\}^2) = 45.7$ dBi were therefore selected for the present example.

As shown in Appendix 1, for about 96% of the earth stations φ_t and φ_r will not be less than 25°, and therefore $G(\varphi_t)$ and $G(\varphi_r)$ will not be greater than −3 dBi. Appendix 1 also shows that, if $G(\varphi_t) \cong -3$ dBi, then it is sufficiently conservative to assume that $G(\varphi_r) \cong -10$ dBi, and vice versa.

Taking these values for E, G_t, $G(\varphi_t)$ and $G(\varphi_r)$ as representing a quasi-worst-case, equation (1) becomes:

$$I = -6.7 - pl \qquad \text{dB(W/MHz)} \tag{2}$$

According to Recommendation ITU-R S.1323, a GSO FSS link should be designed on the basis that "*the aggregate interfering power from the earth and space station emissions from all other GSO FSS networks … does not exceed, at the input to the demodulator, ... 20% of the total system noise power under clear-sky conditions...*". For the present example it is assumed that the aggregate interference comprises equal contributions from the uplink and downlink emissions of all co-directional and bidirectional GSO FSS systems in a 1 MHz band centred on 12.625 MHz. Hence the aggregate interference received at earth station B from all earth stations using this 1 MHz band in the Earth-to-space direction is limited here to a maximum of 5% of the link noise budget.

With the exception of CDMA networks, only one earth station can transmit to a given satellite at a given carrier frequency and sense of polarization, at the same time, within the coverage of a given receive beam, since the uplinks of multiple co-frequency carriers to the same beam would interfere grossly with each other. (Although CDMA allows n such carriers to coexist under these circumstances, the carrier e.i.r.p. of each earth station in that case is only about $1/n$-th of the e.i.r.p. of a single earth station employing FDMA.) At latitudes near 50° the GSO is above 10° elevation at any single point on the Earth's surface over a longitude range of about 120° (i.e. ±60°). The minimum spacing between co-frequency, co-coverage satellites in ITU Regions 1 and 3 is about 3°, and in Region 2 it is about 2°. It follows that, in the limit, 40 to 60 earth stations in a given coverage area could transmit on the same carrier frequency and polarization to different satellites in the GSO, the interference between their uplinks being within acceptable limits owing to the discrimination provided by their antenna transmit patterns.

However, even if in the carrier band considered the GSO spectrum resource was fully utilized in this manner, it is highly unlikely that all the earth stations transmitting in the common coverage area would be located sufficiently near to a given earth station receiving a co-frequency carrier to cause significant interference to that earth station. For one thing, it is likely that the resource would be divided among several countries because a typical satellite beam operating in the band 14-14.5 GHz is dimensioned for continental, rather than national, coverage. Hence an allowance for ten earth stations transmitting in the 1 MHz band at 12.625 GHz and interfering with the same earth station receiving at this frequency is deemed to be sufficiently conservative for present purposes. In this study the maximum interference from a single earth station A to earth station B in clear air is therefore limited to 0.5% of the system noise budget.

Since interference via overland paths is affected by propagation conditions, it is necessary to know the percentage of time for which "clear air" conditions apply. In Recommendation ITU-R S.1062 the long-term BER requirements are permitted to be exceeded for no more than 10% of the worst month, which corresponds to 4% of the average year. Hence the interference from earth station A to earth station B should not exceed 0.5% of system B noise for more than 4% of the time, i.e.:

$$I \leq 10 \log ((0.05)(k\,T\,B)) \qquad \text{dBW} \qquad (3)$$

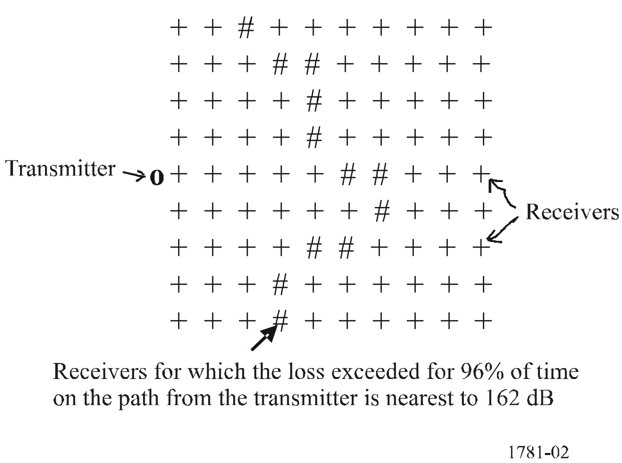
where:

- 10 log (k): −228.6 dB(W/Hz) per Kelvin (Boltzmann's constant)
- T: system noise temperature (> 200 K for most 14-14.5 GHz uplinks)
- B: 1 MHz as defined above.

By combining equations (2) and (3) it may be deduced that, for the band to be shared by bidirectional FSS networks, the loss on the interference path between earth stations A and B should be 162 dB or greater for at least 96% of the time.

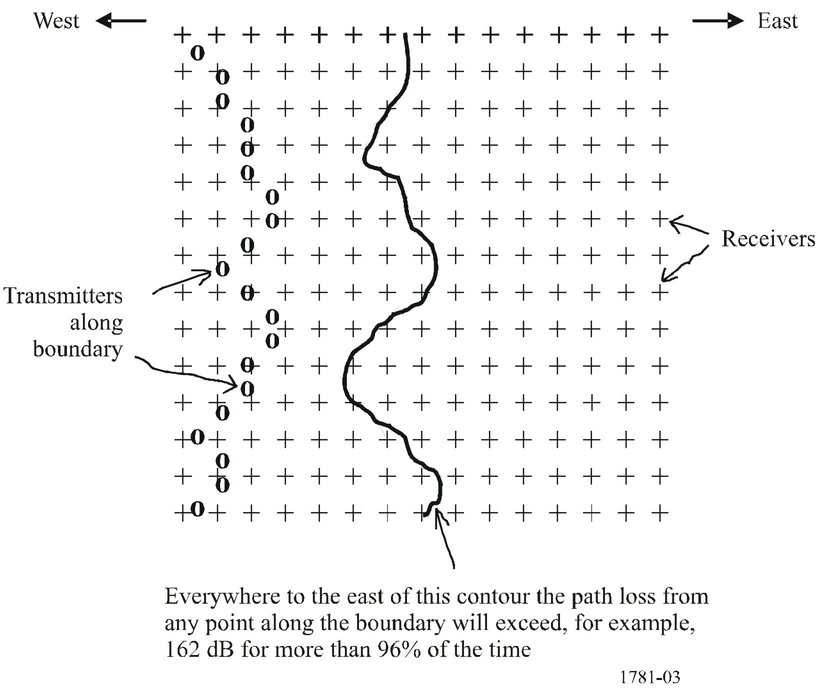
If a terrain database is available, i.e. a database containing the heights above sea level of the land at evenly distributed points over a given area, the information and algorithms in Recommendations ITU-R P.452 and ITU-R P.526 may be used to calculate the propagation loss exceeded for any given percentage of time over the Great Circle path between any two data points within that area. These Recommendations cover both line-of-sight and transhorizon paths, including atmospheric absorption and the diffraction, ducting and tropospheric scatter modes of propagation as appropriate. Thus if a software model comprising a single transmitter and a large number of evenly-spaced receivers is constructed, it is possible to compute the losses exceeded for a given percentage of time on the paths between the transmitter and each and every receiver, and thus to identify all the paths where the loss is close to a given value – see Fig. 2.

FIGURE 2



By adding further transmitters to the model, spaced at small intervals along any given boundary line within the geographical area concerned, and then selecting the maximum path length, *L*, from each transmitter corresponding to the path loss concerned, a contour may be drawn beyond which the loss will exceed the given value for the given percentage of time for a transmission anywhere along that boundary. The area between the boundary and this contour will be the maximum area within which the path loss could be inadequate for frequency sharing. The accuracy of the contour could be improved using linear interpolation between the appropriate pairs of adjacent receivers – see Fig. 3.

FIGURE 3



The shape of the contour depends partly on the shape of the boundary and partly on the nature of the terrain between contour and boundary.

From this analysis it is clear that, in this example, an earth station with a 1.8 m or larger antenna, transmitting an e.i.r.p. of up to 52 dB(W/MHz) in the band 12.5-12.75 GHz, could be located anywhere to the west of the boundary without exceeding a single-entry interference criterion of 0.5% of system noise at an earth station receiving at the same frequency anywhere to the east of the contour.

Using a proprietary software package, a model as described above was constructed for an example in which the boundary was the border between France and Germany. The terrain database used has a horizontal resolution of about 900 m and a vertical resolution of about 1 m. Accordingly, an interval between adjacent receiving earth stations of 5 km throughout eastern France and western Germany was adopted, with a similar resolution between adjacent transmitting earth stations along the border between the two countries. The height of the antenna above local ground level for each receiving earth station and each transmitting earth station (h_r and h_t in Fig. 1) was set at 5 m.

The results are given in Fig. 4, where the contours in both France and Germany are shown. This illustrates two cases, i.e.:

– when transmitting earth stations are deployed in France up to the international border, the interference criterion will be met at any earth station in Germany located on, or to the east of, contour G, and

– when transmitting earth stations are deployed in Germany up to the international border, the interference criterion will be met at any earth station in France located on, or to the west of, contour F.

To make the maximum use of both the uplink and downlink allocations in the band while affording equal access for both countries, it would be technically possible for France to use the whole band anywhere to the west of contour F, and to use half of the band anywhere between contour F and the border with Germany, while Germany could use the whole band anywhere to the east of contour G, and the other half of the band anywhere between contour G and the border with France. Such an arrangement would of course be subject to prior agreement between the administrations of the two countries. The areas in which the band restrictions would apply can be seen to be fairly modest proportions of the total areas of France and Germany respectively, and take no account of local site-shielding at either end of the interference paths.

The contours could be computed with greater accuracy if a terrain database with better resolution was used and/or by reducing the interval between adjacent earth stations in the computer model and increasing the numbers accordingly. In most cases this would lead to some reduction in the "restriction" areas. Additionally, on a case-by-case basis, local reductions in the "restriction" areas could be achieved by the use of site-shielding.

2.2 Methodology applied to a domestic example

In this case it is obviously inappropriate to use the border between one country and another as the boundary for bidirectional frequency sharing purposes. Within any given country it is necessary to define the boundary within which earth stations could transmit to certain satellites on the same frequency as earth stations outside the boundary, but still within the country concerned, were receiving from other satellites. It is theoretically possible to use local geographical borders for this purpose (e.g. county borders in England or canton borders in Switzerland), but such an exercise would not be useful because there is unlikely to be correlation between the deployment of VSAT systems and such borders geography. A more appropriate scheme is to define a hexagonal boundary, so that adjacent areas may share the frequencies bidirectionally throughout the country – similar to a cellular terrestrial system, but with larger "cells" – as illustrated in Fig. 5.

In this arrangement, if the area of the hexagon is sufficiently large, the majority of area A may be used for earth stations transmitting (to different satellites) on the same frequency as that on which earth stations in areas B, C, D, etc. are receiving, and vice versa. As in the international example, there will be an irregular strip of land immediately inside the hexagonal boundary of each area in which transmission will be restricted. The precise nature of the restriction will be a matter for the operators concerned and the national licensing authority. One possibility affording equal spectrum access to the restricted part of each hexagonal area would be as in Table 1.

FIGURE 4

Contours for sharing between ubiquitously deployed earth stations of two FSS networks in opposite transmission directions; International

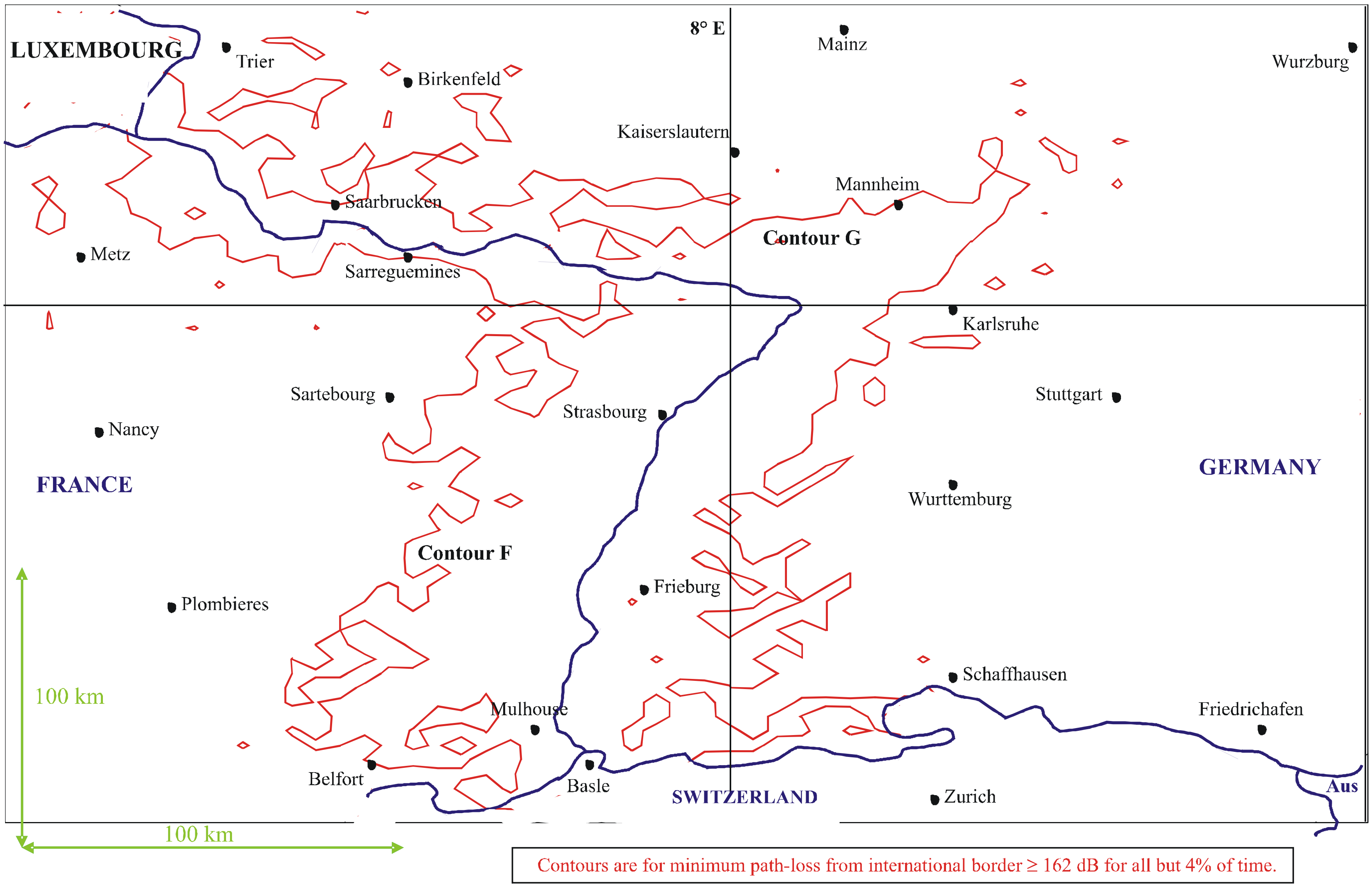


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FIGURE 5

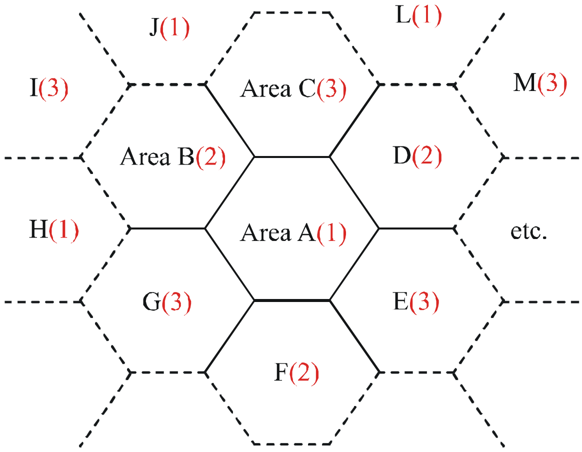

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TABLE 1

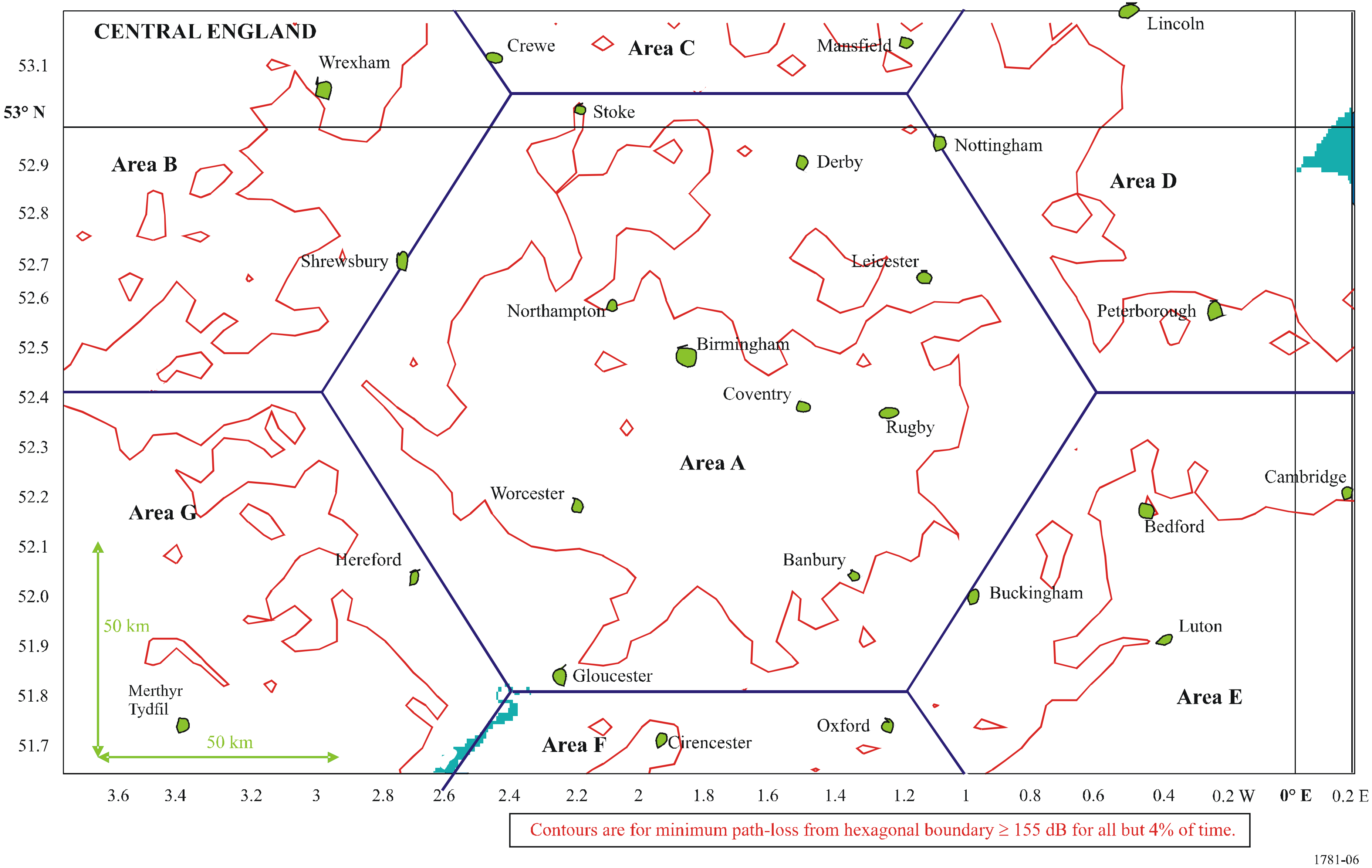
Possibility of dividing the band equally

<------------------- 12.5-12.75 GHz ---------------->		
f1 = 12.5-12.583 GHz (1) in Fig. 5	**f2 = 12.583-12.667 GHz (2) in Fig. 5**	**f3 = 12.667-12.75 GHz (3) in Fig. 5**
Restricted part of A transmitting on f1	Restricted part of B transmitting on f2	Restricted part of C transmitting on f3
Restricted part of H transmitting on f1	Restricted part of D transmitting on f2	Restricted part of E transmitting on f3
Restricted part of J transmitting on f1	Restricted part of F transmitting on f2	Restricted part of G transmitting on f3
Restricted part of L transmitting on f1		Restricted part of I transmitting on f3
		Restricted part of M transmitting on f3

An example of this arrangement has been modelled using the proprietary software package in the manner described in § 3 for a hexagonal area in central England, and the result is shown in Fig. 6. Again, the separation between adjacent receiving earth stations, and also between adjacent transmitting earth stations, was 5 km, and the antennas at all stations were set at a height of 5 m. Transmitting earth stations were located around the central hexagonal boundary and also along each of the six straight lines separating the adjacent areas of equal size. The "grid" of receiving earth stations was dimensioned to cover the whole of the rectangular area encompassed by Fig. 6. This enabled the contour defining the restricted zone in the hexagonal area labelled "Area A" to be drawn, and also the parts of the corresponding contours in the adjacent areas B, C, D, E, F and G falling within the region modelled.

FIGURE 6

Contours for sharing between ubiquitously deployed earth stations of two FSS networks in opposite transmission directions; National



For frequency sharing within a country, especially within a relatively small country, it may be appropriate to use a rather less conservative interference criterion, in order not to result in "restriction" zones that are an inconveniently large proportion of their hexagonal areas. Therefore, for the present national example, the assumptions leading to equations (2) and (3) were revisited, and the following changes made:

– First, a review of the database compiled from the replies to the 2002 Questionnaire for VSATs operating in the band 14-14.5 GHz and having antennas in the diameter range 1.5 m-2.1 m revealed that, although 98% of the earth stations transmit no more than 52 dBW (per 1 MHz bandwidth), the percentage begins to fall significantly only for e.i.r.p. levels below about 49 dBW. In fact 97% of the earth stations transmit e.i.r.p.s no greater than 50 dBW.

– Second, since the frequency sharing in this case would be within the purview of a single administration, it is likely that there would be greater control over the interference environment than in the international example. Furthermore, in comparison with the international case, there are less likely to be as many as ten earth stations within "interfering" distance of a given earth station and transmitting on the same frequency as that on which the earth station is receiving. Hence, for the present example, a single-entry allowance of 1% of the system noise budget (rather than the 0.5% in § 2) is considered to be reasonable.

– Third, from Fig. 11 it may be deduced that for about 92% of the interference paths the off-axis angles at the transmitting or the receiving earth station will be greater than about 30° (rather than the 25° assumed in § 2). At 30° off-axis the antenna side-lobe gain will be −5 dBi. Hence the gain will be less than −5 dBi for about 92% of the interference paths, and in this example we will assume $G(\varphi_t) = -5$ dBi and $G(\varphi_r) = -10$ dBi.

Taking these three factors into account in equations (2) and (3) the path loss which must be exceeded for at least 96% of the time becomes 155 dB, in order to derive the contours.

Figure 6 suggests that, as in the international example, bidirectional FSS sharing of the whole 12.5-12.75 GHz band would be practicable in a national case for earth stations in a majority of the country. Within area A in Fig. 6, for example, there would be no restrictions on the use of the band for transmitting earth stations inside the contour, which comprises more than 50% of the area, and there are indications that this is likely to be true also in areas B, C, D, E and H. Employment of a terrain database having higher resolution than the one used here, and inclusion of local "clutter" (i.e. buildings, trees, etc.) would have the effect of "shifting" the contour toward the area boundary in many cases. Between the contour and the hexagonal boundary, additional means to facilitate sharing of the band would be needed, for example, restricting transmission to one third of the band in each hexagonal area as explained above

Appendix 1
to Annex 1

Variation in off-axis angle toward the interference path

The elevation angle of an earth station operating to a satellite in the geostationary orbit can be determined by the following expression:

$$E_S = \arctan\left((\cos(\alpha_E - \alpha_S).\cos(\lambda_E) - 0.1513) / \left(1 - \cos^2(\alpha_E - \alpha_S).\cos^2(\lambda_E)\right)^{1/2} \right) \qquad (4)$$

where:

E_S: elevation angle of the earth station antenna

α_E: longitude of the earth station

α_S: longitude of the satellite

λ_E: latitude of the earth station.

The azimuth of the earth station in the direction of the satellite can be determined by the following expression:

$$A_s = 180 + \arctan(\tan(\alpha_E - \alpha_S)/\sin(\lambda_E)) \tag{5}$$

Where A_S is the azimuth angle, measured in degrees from true north, towards the space station to which the earth station is operating.

The off-axis angle of an earth station operating according to the values of E_S and A_S determined above, in the direction of any other earth station towards which the azimuth, also measured in degrees from true north, is A_E, can be determined by the following expression assuming a zero degree horizon elevation[1]:

$$\alpha = \arccos(\cos(E_s)\cos(A_E - A_S)) \tag{6}$$

where:

φ: off-axis angle of the earth station antenna in the direction of the other earth station

A_E: azimuth angle, measured in degrees from true north, towards the other earth station.

In the international example in the main text of this Recommendation the mean latitude is about 49° N, and in Figs. 7 to 10 equations (4) to (6) have been used to plot φ, for $\lambda_E = 49°$, as a function of A_E for four values of the separation between the longitudes of the earth station and the geostationary satellite to which it is operating ($\alpha_E - \alpha_S$). From Fig. 7 it can be seen that, as might be expected, when the earth station and its satellite are on the same longitude, the variation in off-axis angle is symmetrical for easterly and westerly azimuth bearings. Similarly Figs. 8, 9 and 10 show asymmetrical easterly and westerly variations, with the minimum value of φ occurring when A_E corresponds to the azimuth of the transmitting earth station. If Figs. 8, 9 and 10 were recalculated for the corresponding cases where the satellite is to the west of the earth station, the mirror images (about $A_E = 0°$) of the three plots would result.

Again, as might be expected, the minimum value of φ is in each case equal to the elevation angle of the satellite as "seen" by the earth station. This may be verified by evaluating equation (4) and comparing the result with the minimum points on the curves in Figs. 7 through 10.

$\alpha_E - \alpha_S$ (degrees)	0	20	40	60
E_S (degrees)	33.78	30.58	22.11	10.60

Since most GSO FSS networks operating in the band 14-14.5 GHz do not operate at elevation angles below about 10°, Figs. 7 through 10 may be considered to encompass the full range of off-axis angles for interference between earth stations using opposite directions of transmission.

[1] The results of this Appendix would be slightly different if a non-zero horizon elevation was assumed, but the difference would be small because the earth station locations for which the horizon elevation exceeds 2º or 3º are rare.

Since earth stations may be located anywhere, the interference path between an earth station using the 12.5-12.75 GHz FSS (Earth-to-space) allocation and an earth station using the 12.5-12.75 GHz (space-to-Earth) allocation may lie in any direction on the Earth's surface. Hence all azimuth bearings (A_E) at any earth station either transmitting or receiving in the band can be considered equally likely. Similarly, for the purposes of the present exercise, all (practicable) difference angles between earth station and satellite longitude ($\alpha_E - \alpha_S$) are considered to be equally likely; (in practice small longitude differences are more common than large ones, but the present assumption simplifies the analysis and errs on the conservative side, i.e. the results are slightly pessimistic). Therefore, by producing results of the form in Figs. 7, 8, 9 and 10 for values of $\alpha_E - \alpha_S$ at 10º intervals from 0° to 60°, it was possible to generate a cumulative distribution function (CDF) of interference off-axis angles covering all geographical circumstances, based on the assumptions of equal likelihood and a mean latitude of 49°. This CDF is shown as the upper curve in Fig. 11.

For convenience the off-axis gain pattern for a 1.8 m antenna at 12.625 GHz (as included in the example in the main text of this Recommendation) has been added to Fig. 11 (lower curve) by inserting a right-hand vertical axis with an appropriate scale. This off-axis antenna gain pattern was calculated using the formulae in Recommendation ITU-R S.580. Thus it may be seen, for example, that an off-axis angle of 25° is exceeded by at least 96% of interference paths, and that the antenna gain is less than about –3 dBi for all off-axis angles greater than 25°. Since the maximum (i.e. on-axis) gain of such an antenna is 45.7 dBi assuming 65% efficiency, it follows that the antenna discrimination at either end of the interference path is at least 48.7 dB in 96% of such cases. Furthermore, the probability of the antenna gain in the direction of the interference path being close to –3 dBi for the antennas of both earth stations is very low – around $(0.04)^2$ or 0.16%, so for the purposes of the main text it is sufficiently conservative to assume that the off axis gain is –3 dBi at one end of the interference path and –10 dBi at the other end.

FIGURE 7

Interference off-axis angle vs. azimuth bearing from true north at 49° N earth station
Satellite on same longitude as earth station

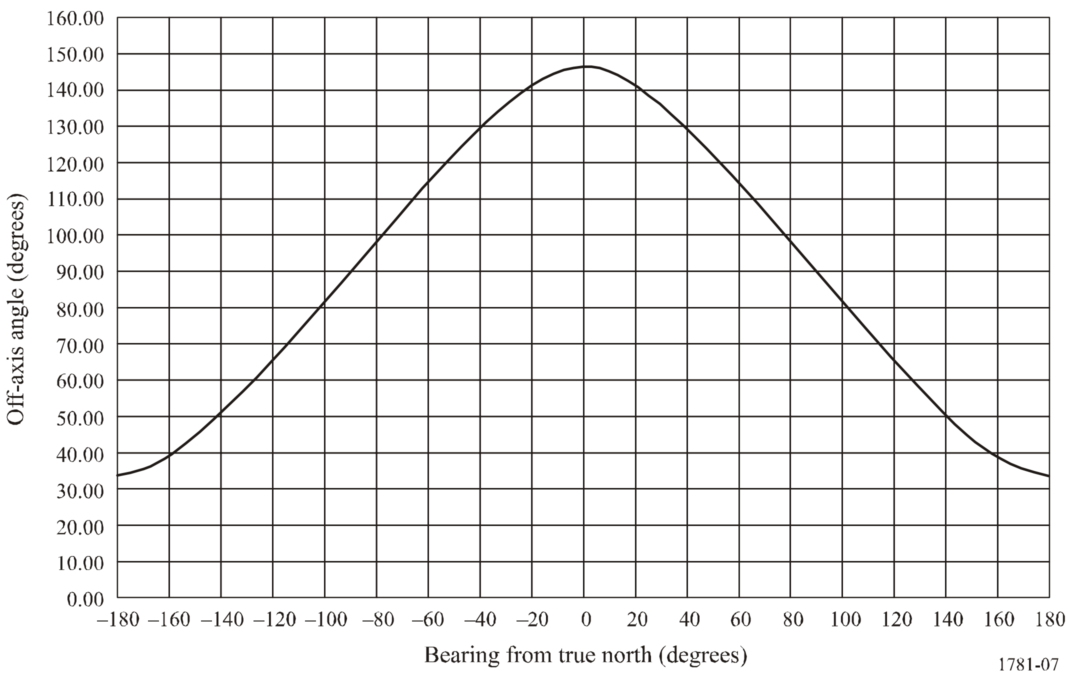


FIGURE 8

Interference off-axis angle vs. azimuth bearing from true north at 49° N earth station
Satellite 20º E of earth station

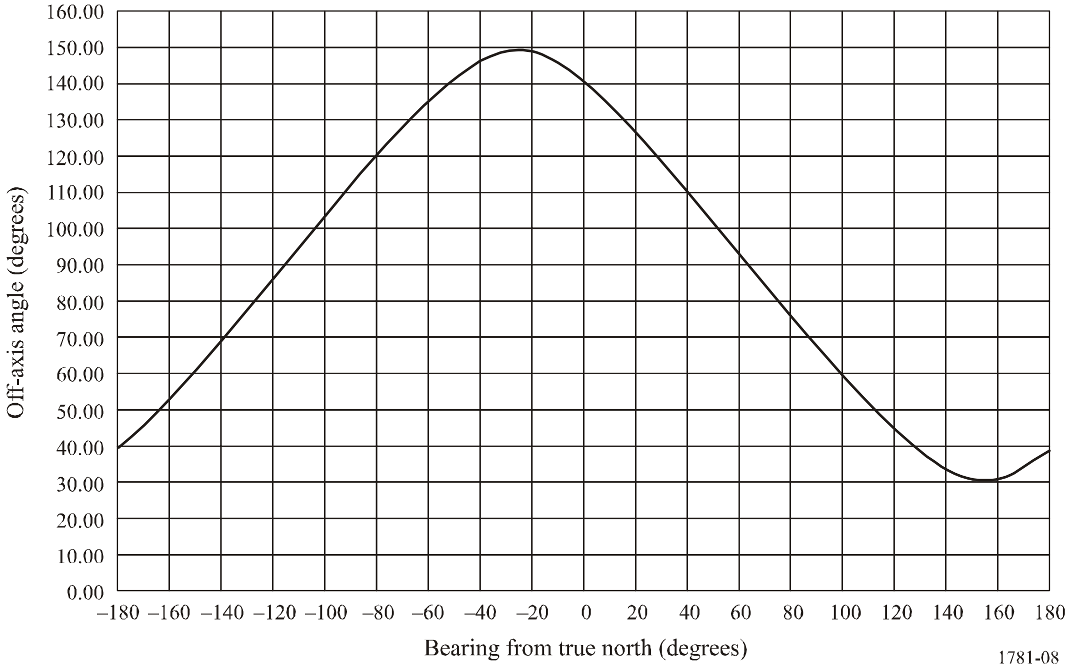


FIGURE 9

Interference off-axis angle vs. azimuth bearing from true north at 49° N earth station
Satellite 40º E of earth station

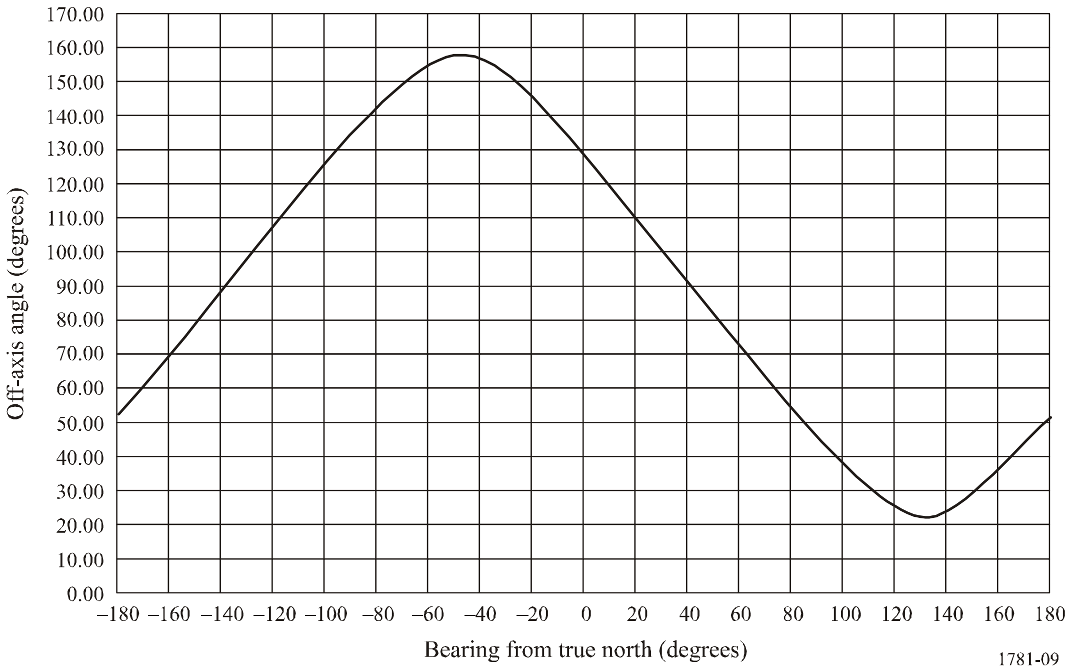


FIGURE 10

Interference off-axis angle vs. azimuth bearing from true north at 49° N earth station Satellite 60º E of earth station

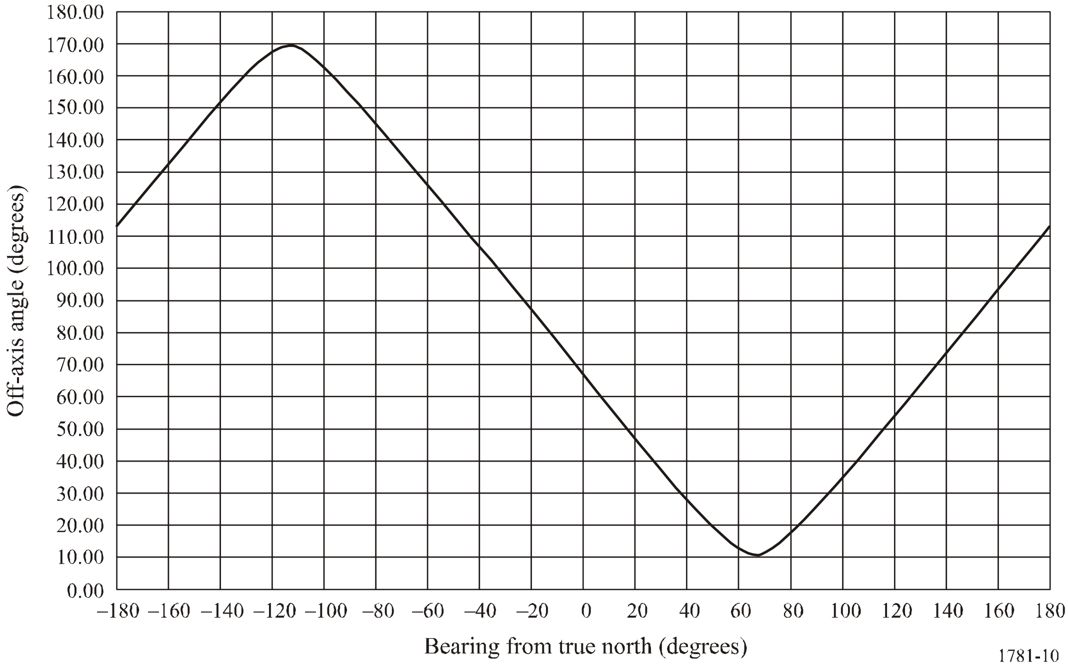


FIGURE 11

CDF of off-axis angles for interference between earth stations operating in opposite directions of transmission compared with Recommendation ITU-R S.580 off-axis pattern