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Recommendation ITU-R SF.1485

(05/2000)

Determination of the coordination area for Earth stations operating with non-geostationary space stations in the fixed-satellite service in frequency bands shared with the fixed service

SF Series

Frequency sharing and coordination between fixed-satellite and fixed service systems

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R SF.1485*, **

DETERMINATION OF THE COORDINATION AREA FOR EARTH STATIONS OPERATING WITH NON-GEOSTATIONARY SPACE STATIONS IN THE FIXED-SATELLITE SERVICE IN FREQUENCY BANDS SHARED WITH THE FIXED SERVICE

(2000)

Scope

This Recommendation addresses the determination of coordination area for earth stations operating with non-geostationary satellites in the fixed-satellite service in frequency bands shared with the fixed service. Annex 1 describes the determination using a method sometimes called the time-varying gain (TVG) method and provides examples of its application in the Appendices to Annex 1 (See also Recommendation ITU-R SM.1448, Annex 1, § 2.2.2). Annex 2 provides a description of the determination of coordination area using a method sometimes called the composite method.

The ITU Radiocommunication Assembly,

considering

a) that WRC-95 allocated spectrum to satellite services, on a primary basis, that is used by the FS;

b) that the satellite services may operate with space stations in non-GSO orbits;

c) that emissions from earth stations operating with space stations in non-GSO orbits may produce interference to FS receivers and vice versa;

d) that Radiocommunication Study Group 1 is drawing together the results of studies from all concerned Study Groups in the development of text that may be used to revised RR Appendix S7;

e) that it is possible to define an area around a non-GSO earth station outside of which a FS station would cause or be subject to only negligible interference;

f) that the pointing of the antenna of an earth station operating with a space station in a non-GSO orbit varies with time and in accordance with the orbital parameters of the operational non-GSO satellite and the location of the earth station;

g) that procedures, similar to those which currently exist, should be established for the determination of coordination area around earth stations operating with non-GSO orbits,

recommends

1 that the determination of the coordination area around a non-GSO satellite system earth station takes into account the percentage of time that the earth station is pointing in the direction of interest;

2 that, when calculating the basic transmission loss, $L_b(p)$, the percentage of the time, p, during which the interfering power into the FS station receiver is allowed to exceed the maximum allowable level, $P_r(p)$, is modified by the percentage of time that the non-GSO earth station antenna is pointing in the direction of interest;

3 that the determination of the coordination area should take into account the orbital parameters of the space stations operating with the non-GSO earth station;

4 that the methods in Annex 1 or Annex 2 should be considered by administrations in determining the coordination area (see Note 1).

NOTE 1 – The orbital equations in the procedure of Annex 1 are applicable to circular orbits only.

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* This Recommendation should be brought to the attention of Radiocommunication Study Groups 1 and 3.

** Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

ANNEX 1

Determination of the coordination area for earth stations operating with non-GSO space stations in the FSS in frequency bands shared with the FS

1 Introduction

This procedure has been developed for determining the coordination area around an earth station operating with a non-GSO space station in frequency bands shared with terrestrial radiocommunication services.

The operation of transmitting and receiving non-GSO earth stations and terrestrial stations in shared frequency bands may give rise to interference between stations of the two services. The magnitude of such interference depends on the transmission loss along the interfering path which, in turn, depends on factors such as length and general geometry of the interference path, the minimum operational elevation angle, antenna gain distribution as a function of time, radio climatic conditions and the percentage of time during which the transmission loss should be exceeded.

The described procedure allows the determination, in all azimuth directions from a transmitting or receiving earth station, of a distance beyond which the transmission loss would be expected to exceed a specified value for all but a specified percentage of the time. A distance so determined is called the coordination distance. The end points of coordination distances determined for all azimuths define a coordination contour around the earth station, which contains the coordination area. For terrestrial stations located outside the coordination area the probability of causing or experiencing significant interference is considered to be negligible.

Although based on technical data, the coordination area is an administrative concept. Since the coordination area is determined before any specific cases of potential interference are examined in detail, it must therefore rely on assumed parameters of the terrestrial systems, while the pertinent parameters of the transmitting earth stations are known.

Stations located outside the coordination area of a given planned station are eliminated from any coordination consideration. Consequently, the coordination requirements of a station may be strictly domestic, if the coordination area of the planned station lies entirely in the territory of the notifying administration or, domestic and international if the coordination area also includes the territory of another administration in which case the coordination agreement of that administration is required.

Stations located in the coordination area of a planned station need to be examined on a case-by-case basis initially, taking into account the antenna discrimination, separation distance and path profile if necessary.

For the determination of the coordination area, two cases may have to be considered:

a) the non-GSO earth station is transmitting and hence capable of interfering with the reception of terrestrial stations;

b) the non-GSO earth station is receiving and hence capable of being interfered-with by emissions from terrestrial stations.

Whilst this Annex describes case a) in which the non-GSO earth station is transmitting and the terrestrial station is receiving, the methodologies are applicable to case b) in which the terrestrial station is transmitting and the non-GSO earth station is receiving.

2 General considerations

2.1 Concept of minimum permissible transmission loss

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

The amount of attenuation required between an interfering transmitter and an interfered-with receiver is given by the minimum permissible transmission loss for $p\%$ of the time, a value of transmission loss which should be exceeded by the actual or predicted transmission loss for all but $p\%$ of the time (when p is a small percentage of time, in the range 0.001% to 1.0%, it is referred to as short-term; if $p \geq 20\%$, it is referred to as long-term):

$$L(p) = P_t - P_r(p) \qquad \text{dB} \qquad (1)$$

where:

P_t: maximum available transmitting power level (dBW) in the reference bandwidth at the input to the antenna of an interfering station

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

P_t and $P_r(p)$ are defined for the same radio-frequency bandwidth (the reference bandwidth) and $L(p)$ and $P_r(p)$ for the same percentage of the time, as dictated by the performance criteria of the interfered-with system.

Only small percentages of the time are of interest here. Considering a specific mechanism of propagation for the interfering emission, the coordination distance can be determined. The ITU-R is currently developing propagation models suitable for the determination of the coordination area for earth stations operating with non-GSO satellite networks.

2.2 The concept of minimum permissible basic transmission loss

The transmission loss is defined in terms of separable parameters, vis-à-vis basic transmission loss (i.e. attenuation between isotropic antennas) and the effective antenna gains at both ends of an interference path. The minimum permissible basic transmission loss may then be expressed as:

$$L_b(p) = P_t + G_t + G_r - P_r(p) \qquad \text{dB} \qquad (2)$$

where:

$L_b(p)$: minimum permissible basic transmission loss (dB) for $p\%$ of the time; this value must be exceeded by the actual or predicted basic transmission loss for all but $p\%$ of the time

G_t: gain of the transmitting antenna of the interfering station (dBi). If the interfering station is a non-GSO earth station, this is the time-varying antenna gain towards the physical horizon on a given azimuth; in the case of a terrestrial station the maximum expected antenna gain is to be used

G_r: gain of the receiving antenna of the interfered-with station (dBi). If the interfered-with station is a non-GSO earth station, this is the time-varying gain towards the physical horizon on a given azimuth; in the case of a terrestrial station, the maximum expected antenna gain is to be used.

2.3 Derivation of interference parameters

2.3.1 Determination of the threshold interference level $P_r(p)$ of an interfering emission

The threshold interference level (dBW) of the interfering emission in the reference bandwidth, to be exceeded for no more than $p\%$ of the time at the receiving antenna terminals of a station subject to interference, from each source of interference, is given by the general formula below:

$$P_r(p) = 10\log(k\, T_e\, B) + N_L + 10\log\left(10^{M_s/10} - 1\right) - W \qquad \text{dBW} \qquad (3)$$

where:

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

T_e: thermal noise temperature of the receiving system (K), at the terminal of the receiving antenna (see Note 1)

B: reference bandwidth (Hz), i.e. the bandwidth in the interfered-with system over which the power of the interfering emission can be averaged

N_L: link noise contribution (see Note 2)

p: percentage of time during which the interference from one source may exceed the threshold value; since the entries of interference are not likely to occur simultaneously: $p = p_0/n$

p_0: percentage of time during which the interference from all sources may exceed the threshold value

n: number of equivalent equal level, equal probability entries of interference, assumed to be uncorrelated for small percentages of time

M_s: link performance margin (dB)

W: an equivalence factor (dB) relating interference from interfering emissions to that caused, alternatively, by the introduction of additional thermal noise of equal power in the reference bandwidth (see Note 3).

NOTE 1 – The noise temperature (K) of the receiving system, referred to the output terminals of the receiving antenna, may be determined from:

$$T_e = T_a + (e - 1)\,290 + eT_r \qquad \text{K} \tag{4}$$

where:

T_a: noise temperature (K) contributed by the receiving antenna

e: numerical loss in the transmission line (e.g. a waveguide) between the antenna terminal and the receiver front end

T_r: noise temperature (K) of the receiver front end, including all successive stages at the front end input.

For radio-relay receivers and where the waveguide loss of a receiving earth station is not known, a value of $e = 1.0$ should be used.

NOTE 2 – The factor N_L is the noise contribution to the link. In the case of a satellite transponder, it includes the up-link noise, intermodulation, etc. For example, in the absence of specific interference data, it is assumed:

$N_L = 1$ dB for FSS links

$N_L = 0$ dB for terrestrial links

NOTE 3 – The factor W (dB) is the level of the radio-frequency thermal noise power relative to the received power of an interfering emission which, in the place of the former and contained in the same (reference) bandwidth, would produce the same interference (e.g. an increase in the voice or video channel noise power, or in the BER). The factor W generally depends on the characteristics of both the wanted and the interfering signals. The factor W is positive when the interfering emissions would cause more degradation than thermal noise. When the wanted signal is digital, W is usually equal to or less than 0 dB, regardless of the characteristics of the interfering signal.

3 Determination of the antenna gain of the non-GSO satellite system earth station

For an earth station operating with a non-GSO satellite, the gain of the antenna varies as a function of time. The statistics of the horizon gain of the antenna of a non-GSO earth station can either be provided by administrations or derived based on computer simulations.

Using computer simulations, a methodology for calculating the time-varying gain of the antenna of a non-GSO earth station is as follows:

– Simulate the non-GSO satellite constellation over a sufficiently long period (e.g. one repetition cycle of the constellation) with a time step appropriate for the orbit altitude to have a valid representation of the antenna gain variations.

– At each time step, record the earth station azimuth and elevation angles of all satellites which are visible at the earth station and are above the minimum operational elevation angle. Criteria in addition to elevation angle could be used to avoid certain geometries, e.g. geostationary orbit arc avoidance.

– Use the actual earth station antenna pattern or a formula giving a good approximation of it to calculate the gain towards the horizon at each azimuth around the earth station.

– For each azimuth on the horizon around the earth station, calculate the percentage of time each gain value occurs. The probability density function (pdf) of the horizon antenna gain varies over the range G_{min} to G_{max}. It is recommended that increments of s (dB) are used between G_{min} and G_{max}, i.e., $G = \{G_{min}, G_{min} + s, G_{min} + 2s, ..., G_{max}\}$.

– Derive the gain cumulative distribution function (cdf) by integrating the gain density function; this cdf gives the percentage of time that the gain is less than or equal to a specific value.

3.1 Determination of the antenna geometry

The following equations are used in the above algorithmic approach to describe the geometry of the boresight of the antenna of the non-GSO earth station as a function of time.

For a spherical earth and a circular orbit, the elevation angle (χ_t) to a non-GSO satellite as seen from the non-GSO earth station is given by:

$$\sin(\chi_t) = \frac{r_s \cos(\beta) - r_g}{\sqrt{(r_s^2 + r_g^2 - 2 r_s r_g \cos(\beta))}} \tag{5}$$

where:

$$\begin{aligned}\cos(\beta) = \cos(\varsigma_g)\left[\cos(\dot{\theta}t + \lambda_g - \lambda_s)\cos(\omega + f) + \sin(\dot{\theta}t + \lambda_g - \lambda_s)\cos(i)\sin(\omega + f)\right] \\ + \sin(\varsigma_g)\ \sin(i)\sin(\omega + f)\end{aligned} \tag{5a}$$

$\dot{\theta} = \omega_e - \dot{\Omega}$

ω_e: earth rotation rate = 0.004178 (degrees/s)

$\dot{\Omega}$: rate of precession of the nodes of the non-GSO satellite (degrees/s)

β: angle between the vectors from the earth's centre to the non-GSO satellite and from the earth's centre to the non-GSO earth station (degrees)

r_s: distance from the earth's centre to the non-GSO satellite (km)

r_g: distance from the earth's centre to the non-GSO earth station (km)

λ_s: longitude of ascending mode of the non-GSO satellite orbit at time $t = 0$ (degrees)

i: orbit inclination of the non-GSO satellite (degrees)

ω: argument of perigee of the non-GSO satellite orbit at time t (degrees)

f: true anomaly of the non-GSO satellite in its orbit at time t (degrees)

λ_g, ς_g: longitude and latitude of the non-GSO earth station (degrees)

t: time (s).

The satellite vector from the earth's centre as a function of time is given by:

$$\vec{r}_s = r_s \begin{bmatrix} x \\ y \\ z \end{bmatrix} = r_s \begin{bmatrix} \sin(\dot{\theta}t - \lambda_s)\cos(i)\sin(\omega + f) + \cos(\dot{\theta}t - \lambda_s)\cos(\omega + f) \\ \cos(\dot{\theta}t - \lambda_s)\cos(i)\sin(\omega + f) - \sin(\dot{\theta}t - \lambda_s)\cos(\omega + f) \\ \sin(i_s)\sin(\omega + f) \end{bmatrix} \tag{6}$$

The sub-satellite longitude, λ_t, and latitude, ς_t, as functions of time are:

$$\lambda_t = \tan^{-1}(y / x) \qquad \varsigma_t = \sin^{-1}(z) \tag{7}$$

The azimuth, α_t, at which the satellite is seen from the non-GSO earth station is:

$$\alpha_t = \tan^{-1}\left\{ \frac{\cos(\varsigma_t)\sin(\Delta\lambda)}{\sin(\varsigma_g)\cos(\varsigma_t)\cos(\Delta\lambda) - \cos(\varsigma_g)\sin(\varsigma_t)} \right\} \tag{8}$$

where:

$$\Delta\lambda = \lambda_g - \lambda_t \tag{9}$$

The angle $\varphi(\alpha_t)$ (between the boresight of the antenna and the horizon direction) corresponding to a pertinent azimuth α_t, expressed as a function of the boresight azimuth and elevation angles (α_t, χ_t) and the azimuth and elevation angles (α_0, χ_0) in the pertinent direction, is given by:

$$\varphi(\alpha_t) = \cos^{-1}\{\cos(\alpha_t - \alpha_0)\cos(\chi_t)\cos(\chi_0) + \sin(\chi_t)\sin(\chi_0)\} \tag{10}$$

when $\chi_0 = 0°$:

$$\varphi(\alpha_t) = \cos^{-1}\{\cos(\alpha_t - \alpha_0)\cos(\chi_t)\} \tag{11}$$

The antenna gain component towards the horizon can be derived using the actual antenna pattern of the earth station, or from a formula giving a good approximation of it. Appendix 1 to Annex 1 shows examples of calculating the horizon antenna gain of a non-GSO earth station.

4 Determination of the coordination distance

The coordination distance for a specific propagation model is that distance d (km), which will result in a value of available basic transmission loss which is equal to the minimum permissible basic transmission loss as defined in § 2.2.

In cases where the terrestrial station is the unknown station, then the following methodology can be used for the determination of the coordination area. The methodology used here requires knowledge of the statistics of the time-varying horizon antenna gain of the non-GSO earth station, it does not require a derivation of the distribution function of the transmission loss.

The solution to equation (2) of the minimum permissible basic transmission loss which is given below is based on the case for a transmitting earth station operating to a non-GSO space station. A similar procedure can be adopted for a receiving non-GSO earth station where the antenna gain, G_r, varies with time.

The minimum permissible basic transmission loss equation can be re-written as follows:

$$L_b(p') - G_t(p_i) = P_t + G_r - P_r(p) \qquad \text{dB} \tag{12}$$

where:

P_t, $P_r(p)$ and G_r are as defined in equations (1) and (2) where p is the percentage of time at which the interference level allowed to exceed the interference threshold $P_r(p)$

p_i and p' are defined by the following probabilities:

$$p(G_t \geq G_{ti}) = p_i$$
$$p(L_b \leq L_{bi}) = p'$$

$G_t(p_i)$ is the time-varying transmitting antenna gain (dBi) towards the physical horizon in a given azimuth of the interfering earth station that is operating to a non-GSO space station.

Under the assumption that the path loss, L_b, and the antenna gain, G_t, are independent variables, the total percentage of time, p, that $\{L_b - G_t\}$ is allowed to be less than or equal to $\{P_t + G_r - P(p)\}$ is equal to the product of p' and p_i:

$$p(L_b - G_t \leq L_{bi} - G_{ti}) = p' p_i$$

For each pair of p' and p_i values that satisfies $p = p' p_i$ there exists a family of values L_b and G_t that satisfy equation (12). By using the cdf of the antenna gain G_t, for each azimuth, a value G_{ti} is selected such that G_t exceeds G_{ti} for only p_i% of the time. At each such step the values of G_{ti} and p_i are fixed. Then equation (12) can be re-written as follows:

$$L_{bi}(p') = P_t + G_{ti}(p_i) + G_r - P_r(p) \qquad \text{dB}$$

The $L_{bi}(p')$ calculations are repeated for all G_{ti} gain levels as described in the implementation steps below. From the values of $L_{bi}(p')$, the one corresponding to the maximum distance value is selected as the coordination distance at the specified azimuth.

The coordination distance is determined as described in the following steps:

Step 1: Compute the cdf of the earth station horizon antenna gain for a specific azimuth as described in § 3. This function may also be provided by administrations.

Step 2: From the cdf of the horizon antenna gain, determine the minimum gain value, $G_{t_{min}}$, and the maximum gain value, $G_{t_{max}}$. Choose a gain increment s (dB) and divide this gain range into a number of gain levels $\{G_{t_{min}}, G_{t_{min}} + s, G_{t_{min}} + 2s, ..., G_{t_{max}}\}$. A value of s = 0.1 to 0.5 dB is recommended.

Step 3: Determine the percentage of time, p_i, associated with the i-th gain level G_{ti}. This p_i represents the percentage of time the horizon antenna gain is greater than or equal to G_{ti}.

Step 4: Determine the percentage of time p' of the minimum required loss associated with each p_i:

$$p' = p/p_i \quad \text{if} \quad p/p_i \leq Z\%$$

$$p' = Z\% \quad \text{if} \quad p/p_i > Z\%$$

where the recommended value for Z is Z = 20%, and p' is defined over the range $0 \leq p' \leq 100\%$. If p' is greater than 100% then it should be ignored.

Step 5: Calculate the minimum required loss for the interfering emission:

$$L_{bi}(p') = P_t + G_{ti}(p_i) + G_r - P_r(p) \qquad \text{dB}$$

Step 6: Determine the distance, d_i (km), between the interfering station and the station that is subject to interference using an appropriate propagation model such as the models in Recommendation ITU-R P.620.

Step 7: Repeat Steps 3 to 6 for each gain level G_{ti} over the range $G_{t_{min}}$ to $G_{t_{max}}$. From the distance d_i (km) values calculated in Step 6, select the one corresponding to the maximum distance as the coordination distance at the specified azimuth.

Step 8: Check if d_i (km) falls between the minimum, d_{min}, and the maximum, d_{max}, coordination distance limits:

$$\text{if } d_i \text{ (km)} < d_{min} \qquad \text{set} \qquad d_i \text{ (km)} = d_{min}$$

$$\text{if } d_i \text{ (km)} > d_{max} \qquad \text{set} \qquad d_i \text{ (km)} = d_{max}$$

where d_{min} and d_{max} are as defined in Recommendation ITU-R P.620.

Step 9: Repeat Steps 1 to 8 for each azimuth around the earth station. In practice, it may generally suffice to do this repetition in an increment of 5°.

Examples of coordination distance contours calculated using this methodology are given in Appendix 2 to Annex 1.

APPENDIX 1

TO ANNEX 1

Antenna gain distribution examples

1 General

This Appendix presents examples for the determination of the transmitting antenna gain statistics of an earth station operating with non-GSO satellites. All examples presented here use the following formula for the antenna pattern of the earth station:

$$G(\varphi) = \begin{cases} G_{max} - 2.5 \times 10^{-3} \left(\dfrac{D}{\lambda} \varphi \right)^2 & \text{for} \quad 0 < \varphi < \varphi_m \\ 2 + 15 \log (D / \lambda) & \text{for} \quad \varphi_m \leq \varphi < \varphi_r \\ 29 - 25 \log (\varphi) & \text{for} \quad \varphi_r \leq \varphi < 48° \\ -10 & \text{for} \quad 48° \leq \varphi \leq 180° \end{cases}$$

where:

$$\varphi_m = \frac{20 \lambda}{D} \sqrt{G_{max} - 2 - 15 \log (D / \lambda)} \qquad \text{degrees}$$

$$\varphi_r = 15.85 \, (D / \lambda)^{-0.6} \qquad \text{degrees}$$

D: antenna diameter

λ: wavelength expressed in the same unit as D

G_{max}: maximum gain of antenna (dBi)

φ: off-boresight angle (degrees).

This antenna pattern is shown in Fig. 1 for $D/\lambda = 120$ and $G_{max} = 49$ dBi (approximately 55% efficiency). This pattern has a beamwidth of approximately 0.5°.

The examples presented in this Appendix are for a circular orbit and use a spherical Earth for the calculation of the boresight azimuth and elevation angles of the earth station.

Example 1: This example considers an earth station at (22.5° N, 0° E) operating with a non-GSO satellite in a circular orbit with a semi-major axis of 8 000 km and an inclination of 98.2°.

Figure 2 shows typical gain exceedance distribution curves at resolutions of 0.1° and 0.5° in azimuth and elevation angles. Both curves are taken at an azimuth of 240°. As shown the 0.5° curve is quite noisy at low percentages of time, thus a 0.5° step represents a significant variation in the gain especially close to the main beam. A smaller resolution results in a smoother curve like the one generated with a resolution of 0.1° in azimuth and elevation angles.

FIGURE 1

Antenna pattern used in the examples

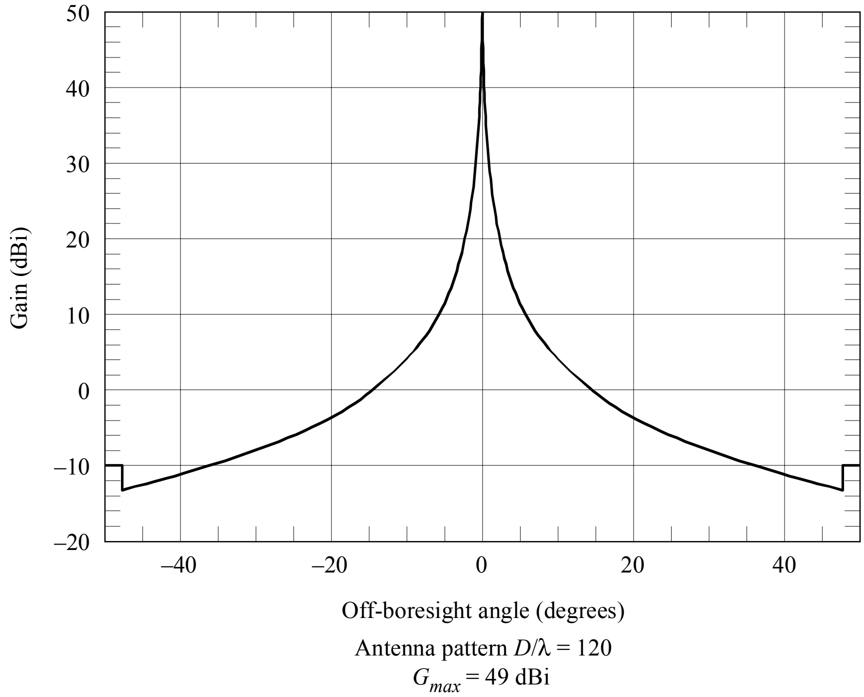

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FIGURE 2

Typical gain exceedance distribution at the horizon with 0.1° and 0.5° resolution in elevation and azimuth angles

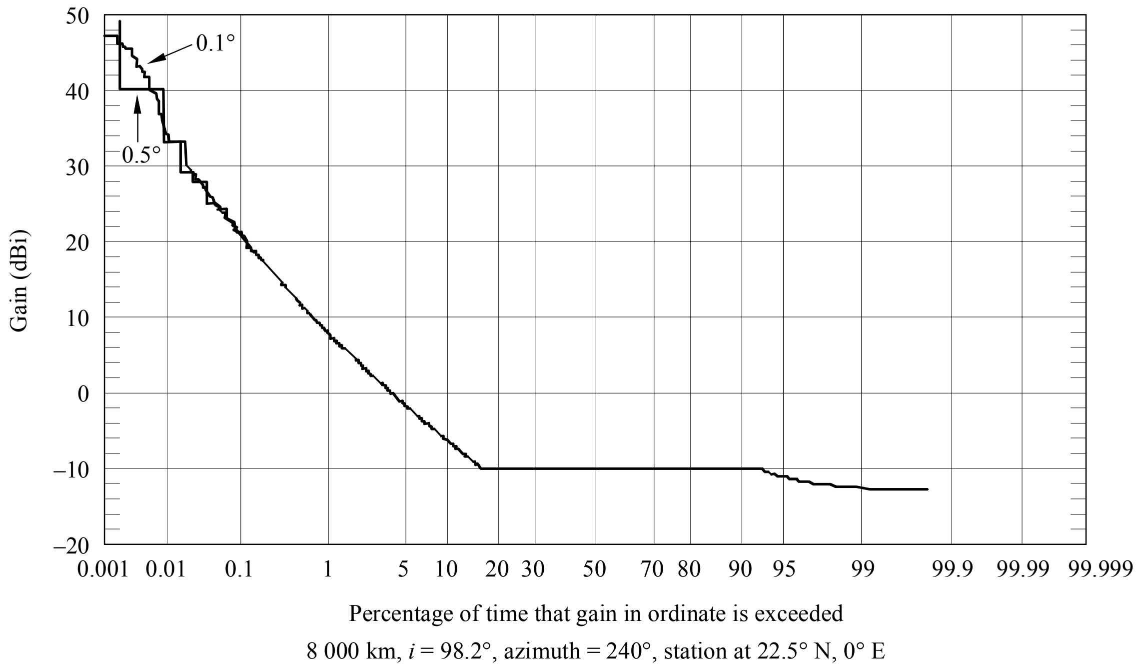

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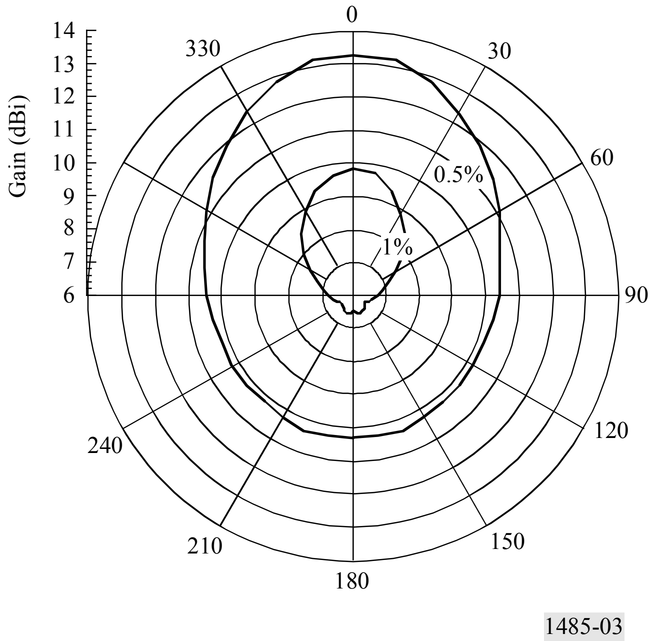
Figure 3 shows the gain that is exceeded 0.5% and 1% of the time as a function of the azimuth angle. These results were generated with a 0.5° step size resolution in elevation and azimuth angles.

FIGURE 3

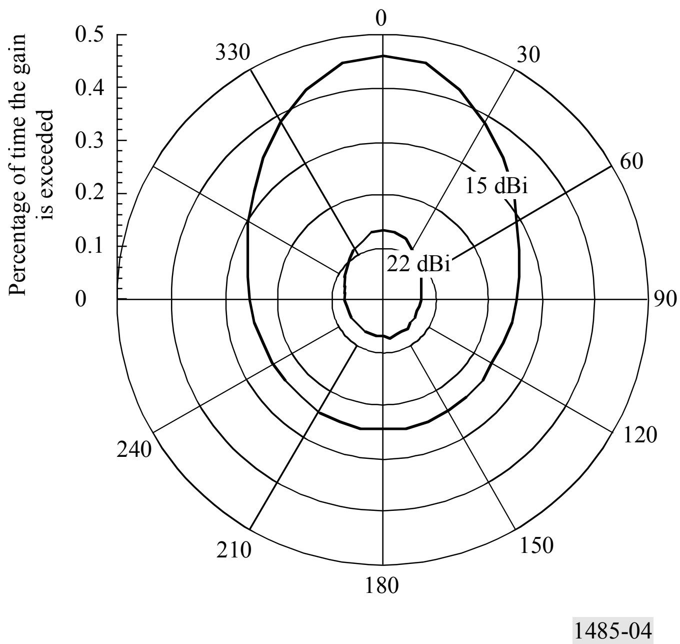
Gain contours of example 1 for 0.5% and 1% of time



In Figure 4, the gain is fixed and the percentage of the time that the gain is exceeded is shown as a function of azimuth. The contours are shown for gains of 15 dBi and 22 dBi generated with a step size resolution of 0.5°.

FIGURE 4

Contours giving the percentage of time a specific gain is exceeded at each azimuth angle



Example 2: This example is for the same non-GSO earth station and satellite described in Example 1 but the satellite orbit has an inclination of 45°.

Figure 5 shows the associated gain exceedance distributions at azimuth angles 0° and 140°. The difference at percentage of the time around 1% is significant in terms of gain. Figure 6 shows the gain that is exceeded 0.5% and 1% of the time as a function of the azimuth angle. The low dip at azimuth 0° is because the satellite is never seen in that direction. These results are generated with a step size resolution of 0.1° in elevation and azimuth angles.

FIGURE 5

Gain exceedance distributions for two azimuth angles 0° and 140° for an inclination of 45°

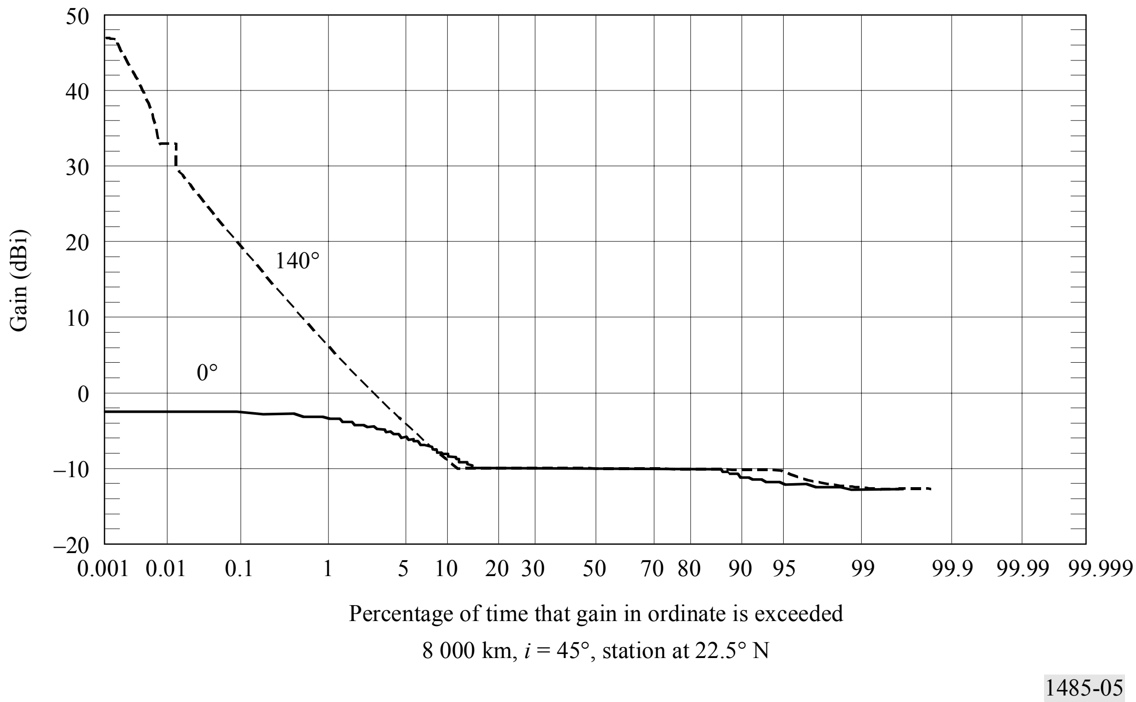
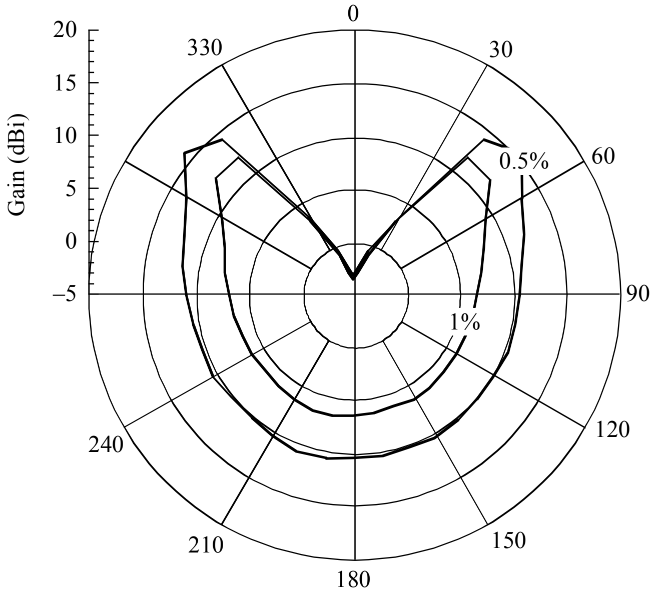


FIGURE 6

Gain contours of Example 2 for an inclination of 45°



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APPENDIX 2

TO ANNEX 1

Coordination distances for non-GSO earth stations with respect to terrestrial stations

1 General

This Appendix presents examples for the determination of the coordination area around non-GSO earth stations coordinating with terrestrial stations in the 6 700-7 075 MHz frequency band.

2 System parameters

The system parameters of the non-GSO earth stations and the terrestrial stations are given in Table 1 for a non-GSO transmitting earth station and a receiving terrestrial station and in Table 2 for a non-GSO receiving earth station and a transmitting terrestrial station.

TABLE 1

System parameters for the coordination of a transmitting non-GSO earth station and a receiving terrestrial station

Orbit parameters of the non-GSO satellites:	
Altitude (km)	1 414
Number of satellites	48
Inclination angle (degrees)	52
Non-GSO earth station type:	
Latitude (degrees)	50
Longitude (degrees)	0
Minimum operating elevation angle (degrees)	10
Antenna gain pattern	Recommendation ITU-R S.465
Non-GSO transmitting earth station:	
Transmit antenna gain (dBi)	50
e.i.r.p./carrier (dBW)	56.5
Transmission bandwidth (kHz)	1 230
Terrestrial receiving station:	
Modulation	Digital
Percentage of time, p%	0.002
Receive antenna gain (dBi)	47
Reference bandwidth (MHz)	1
$P_r(p)$ (dBW)	–103.0

TABLE 2

System parameters for the coordination of a receiving non-GSO earth station and a transmitting terrestrial station

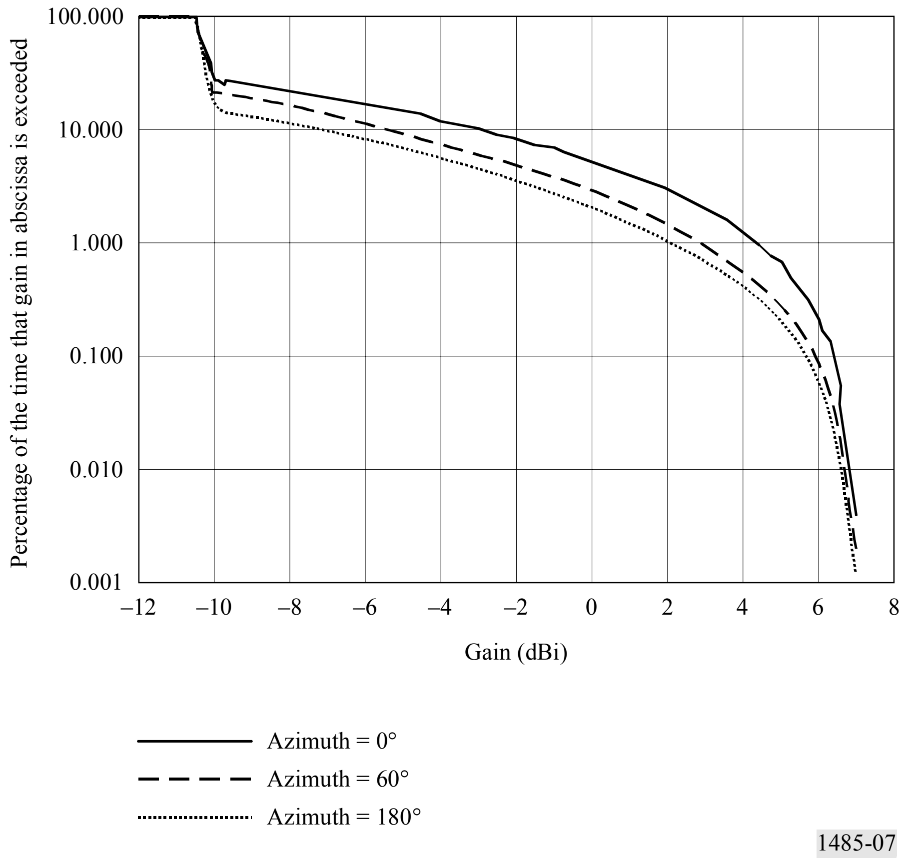
Orbit parameters of the non-GSO satellites:	
Altitude (km)	1 414
Number of satellites	48
Inclination angle (degrees)	52
Non-GSO earth station type:	
Latitude (degrees)	50
Longitude (degrees)	0
Minimum operating elevation angle (degrees)	10
Antenna gain pattern	Recommendation ITU-R S.465
Non-GSO receiving earth station:	
Modulation	Digital
Percentage of time, p%	0.002
M_s (dB)	2
N_L (dB)	1
W (dB)	0
Receive antenna gain (dBi)	50
Reference bandwidth (MHz)	1
T_e (K)	127.7
$P_r(p)$ (dBW)	–149.0
Terrestrial transmitting station:	
Transmit antenna gain (dBi)	42
e.i.r.p./carrier (dBW)	3

3 Coordination distance

Figure 7 shows examples of the cdf of the horizon antenna gain for the transmitting non-GSO earth station listed in Table 1.

FIGURE 7

Non-GSO earth station horizon antenna gain cdf at azimuths 0°, 60° and 180°



Tables 3 and 4 show examples for the determination of the coordination distance between the transmitting non-GSO earth station and the receiving terrestrial station listed in Table 1. The estimated distances are shown for a step size increment of 0.5 dB over the range of the horizon antenna gain and for 0° horizon elevation angle. These distances are calculated using the method described in § 4 and the propagation models of Recommendation ITU-R P.620. The largest value (marked in bold) in column *d* (km) of these tables is selected as the coordination distance at the specified azimuth.

Table 5 lists coordination distances for the transmitting/receiving non-GSO earth stations and the terrestrial receiving/transmitting stations listed in Tables 1 and 2. These coordination distances are plotted in Fig. 8.

TABLE 3

Determination of the coordination distance for a transmitting non-GSO earth station and a receiving terrestrial station at azimuth = 0°

Tx antenna gain, G_{ti} (dBi)	Gain pdf	Gain cdf	$p' = p/p_i$	Required loss (dB)	Coordination distance, d_i (km)
–12.0	0.000000	1.000000	0.000020	148.5	163.73
–11.5	0.000000	1.000000	0.000020	149.0	168.23
–11.0	0.000000	1.000000	0.000020	149.5	172.83
–10.5	0.709370	1.000000	0.000020	150.0	177.33
–10.0	0.016990	0.290630	0.000069	150.5	165.63
–9.5	0.016410	0.273640	0.000073	151.0	169.03
–9.0	0.015890	0.257230	0.000078	151.5	172.33
–8.5	0.015360	0.241340	0.000083	152.0	175.53
–8.0	0.014800	0.225980	0.000089	152.5	178.73
–7.5	0.014190	0.211180	0.000095	153.0	181.83
–7.0	0.013670	0.196990	0.000102	153.5	184.83
–6.5	0.013100	0.183320	0.000109	154.0	187.73
–6.0	0.012570	0.170220	0.000118	154.5	190.43
–5.5	0.012040	0.157650	0.000127	155.0	193.13
–5.0	0.011530	0.145610	0.000137	155.5	195.73
–4.5	0.011030	0.134080	0.000149	156.0	198.13
–4.0	0.010510	0.123050	0.000163	156.5	200.53
–3.5	0.009990	0.112540	0.000178	157.0	202.63
–3.0	0.009480	0.102550	0.000195	157.5	204.73
–2.5	0.008970	0.093070	0.000215	158.0	206.63
–2.0	0.008500	0.084100	0.000238	158.5	208.33
–1.5	0.007950	0.075600	0.000265	159.0	209.83
–1.0	0.007460	0.067650	0.000296	159.5	211.13
–0.5	0.007040	0.060190	0.000332	160.0	212.23
0.0	0.006540	0.053150	0.000376	160.5	213.03
0.5	0.006190	0.046610	0.000429	161.0	213.63
1.0	0.005640	0.040420	0.000495	161.5	213.83
1.5	0.005330	0.034780	0.000575	162.0	213.63
2.0	0.004850	0.029450	0.000679	162.5	212.93
2.5	0.004450	0.024600	0.000813	163.0	211.63
3.0	0.004060	0.020150	0.000993	163.5	209.63
3.5	0.003610	0.016090	0.001243	164.0	206.53
4.0	0.003220	0.012480	0.001603	164.5	202.23
4.5	0.002830	0.009260	0.002160	165.0	196.03
5.0	0.002370	0.006430	0.003110	165.5	186.63
5.5	0.001940	0.004060	0.004926	166.0	172.33
6.0	0.001440	0.002120	0.009434	166.5	147.23
6.5	0.000640	0.000680	0.029412	167.0	104.43
7.0	0.000040	0.000040	0.200000	167.5	104.43

TABLE 4

Coordination distance at different azimuths for a transmitting non-GSO earth station and a receiving terrestrial station

Tx antenna gain, G_{ti} (dBi)	Coordination distance d (km) at azimuth (degrees)						
	0°	30°	60°	90°	120°	150°	180°
–12.0	163.73	163.73	163.73	163.73	163.73	163.73	163.73
–11.5	168.23	168.23	168.23	168.23	168.23	168.23	168.23
–11.0	172.83	172.83	172.83	172.83	172.83	172.83	172.83
–10.5	177.33	177.33	177.33	177.33	177.33	177.33	177.33
–10.0	165.63	164.63	161.73	159.13	157.63	157.03	156.93
–9.5	169.03	167.83	164.83	162.03	160.53	160.03	159.83
–9.0	172.33	171.03	167.73	164.93	163.43	162.83	162.73
–8.5	175.53	174.13	170.63	167.73	166.23	165.63	165.53
–8.0	178.73	177.13	173.43	170.43	168.83	168.33	168.13
–7.5	181.83	180.03	176.13	173.03	171.43	170.83	170.73
–7.0	184.83	182.93	178.63	175.53	173.83	173.33	173.13
–6.5	187.73	185.63	181.13	177.83	176.23	175.63	175.53
–6.0	190.43	188.23	183.53	180.13	178.43	177.83	177.73
–5.5	193.13	190.63	185.73	182.23	180.53	179.93	179.83
–5.0	195.73	193.03	187.83	184.23	182.43	181.83	181.73
–4.5	198.13	195.23	189.73	186.03	184.23	183.63	183.53
–4.0	200.53	197.33	191.53	187.73	185.93	185.33	185.23
–3.5	202.63	199.23	193.23	189.23	187.33	186.73	186.73
–3.0	204.73	201.03	194.73	190.53	188.63	188.03	188.03
–2.5	206.63	202.53	196.03	191.73	189.73	189.13	189.03
–2.0	208.33	203.93	197.03	192.63	190.63	190.03	189.93
–1.5	209.83	205.13	197.93	193.33	191.23	190.63	190.53
–1.0	211.13	206.13	198.53	193.73	**191.63**	190.93	190.93
–0.5	212.23	206.83	198.93	**193.83**	191.63	**191.03**	**191.03**
0.0	213.03	207.23	**198.93**	193.73	191.33	190.73	190.73
0.5	213.63	**207.33**	198.53	193.13	190.73	190.13	190.13
1.0	**213.83**	207.03	197.73	192.03	189.53	188.93	188.93
1.5	213.63	206.33	196.53	190.53	187.93	187.33	187.33
2.0	212.93	205.03	194.63	188.33	185.53	185.03	184.93
2.5	211.63	203.13	192.03	185.43	182.43	181.93	181.83
3.0	209.63	200.33	188.43	181.53	178.33	177.83	177.63
3.5	206.53	196.43	183.63	176.23	172.73	172.33	172.13
4.0	202.23	191.03	177.13	169.23	165.43	165.13	164.93
4.5	196.03	183.53	168.33	159.63	155.63	155.23	154.93
5.0	186.63	172.63	155.63	146.03	141.53	141.13	140.93
5.5	172.33	155.93	136.73	125.93	121.23	120.83	120.43
6.0	147.23	127.53	105.63	104.43	104.43	104.43	104.43
6.5	104.43	104.43	104.43	104.43	104.43	104.43	104.43
7.0	104.43	104.43	104.43	104.43	104.43	104.43	104.43

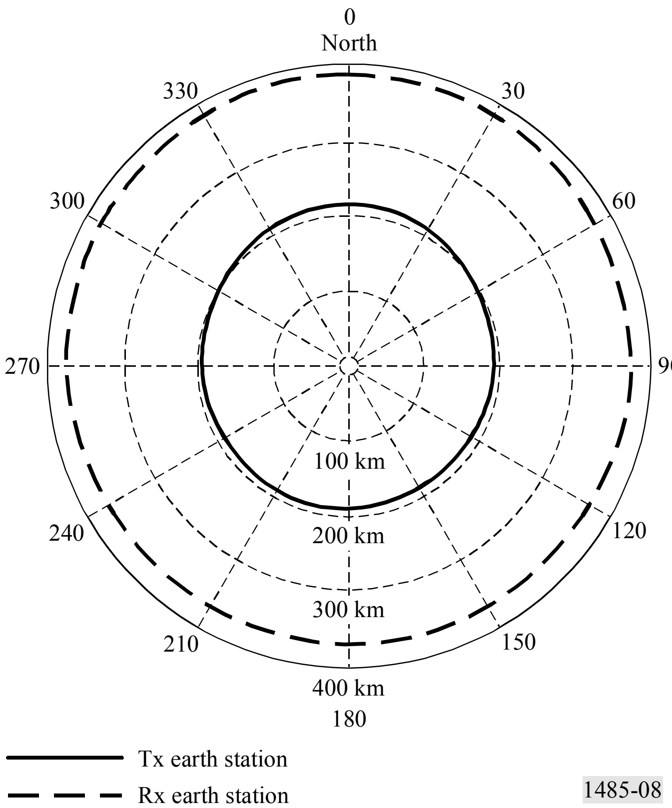
TABLE 5

Coordination distances between non-GSO earth stations and terrestrial stations

Azimuth (degrees)	Coordination distance *d* (km)		Azimuth (degrees)	Coordination distance *d* (km)	
	Tx earth station	Rx earth station		Tx earth station	Rx earth station
10	212.82	387.42	190	191.02	371.72
20	210.42	386.02	200	191.02	371.72
30	207.33	384.12	210	191.12	371.82
40	204.22	382.02	220	191.12	371.92
50	201.32	380.02	230	191.32	372.12
60	198.93	378.22	240	191.62	372.42
70	196.82	376.62	250	192.22	372.82
80	195.12	375.32	260	192.92	373.42
90	193.82	374.32	270	193.82	374.32
100	192.93	373.42	280	195.12	375.32
110	192.22	372.82	290	196.82	376.62
120	191.63	372.42	300	198.92	378.22
130	191.32	372.12	310	201.32	380.02
140	191.22	371.92	320	204.22	382.02
150	191.03	371.82	330	207.32	384.12
160	191.03	371.72	340	210.42	386.02
170	191.03	371.72	350	212.82	387.42
180	191.03	371.72	0 or 360	213.83	387.92

FIGURE 8

Coordination contours for non-GSO earth stations and terrestrial stations



ANNEX 2

Description of the composite method

1 Introduction

In the composite method (see Recommendation ITU-R SM.1448), the coordination contour is determined using calculations that precisely apply the time varying statistics associated with the predicted basic transmission loss and the horizon antenna gain of an earth station. The composite method accounts for the joint statistics of propagation loss and antenna gain by convolving their pfd's.

In cases where horizon antenna gain statistics are predictable with high confidence, the coordination contour determined by means of the composite method will assure that no terrestrial stations located outside it will cause or suffer unacceptable interference with respect to the earth station.

For the composite method, equation (2) in Annex 1 is replaced by the following condition:

$$(L_c - G_a)(p) > P_t + G_b - P_r(p) \tag{13}$$

where:

- $(L_c - G_a)(p)$: combination of basic transmission loss at distance d km and horizon antenna gain not exceeded for p% of the time. The method to evaluate this function is described below
- P_t: maximum available transmitting power level (dBW) in the reference bandwidth at the input to the antenna of an interfering station
- G_b: antenna gain of the terrestrial station (or, in the bidirectional case, the receiving earth station)
- $P_r(p)$: threshold interference level of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than p% of the time at the terminals of the receiving antenna of an interfered-with station, the interfering emission originating from a single source.

An iterative process is used to successively increment the coordination distance until the left-hand side of equation (13) exceeds the right-hand side. The first distance at which that condition is met is the coordination distance. For each distance increment, it is necessary to repeat the calculation of $(L_c - G_a)(p)$ by a process involving discrete convolution.

In the description here it is assumed that the propagation model meets two requirements:

a) that the model gives loss not exceeded for percentages of time in the range 0.001% to 50%;

b) that the model gives loss as a monotonically increasing function of distance.

If the composite method were used with a propagation model which did not meet the requirement a), the method of extending the cumulative distribution to percentages of time greater than 50% (§ 2.3 of this Annex) would need to be revised. If the propagation model did not meet the requirement b) (for example if it were used with Recommendation ITU-R P.452), the method of iteration used to determine the distance at which the interference threshold was just met would need to be revised. The propagation model in Recommendation ITU-R P.620 meets both requirements and hence may be used with the composite method as described here.

The process is described by the following steps:

2 Calculation methodology

2.1 Nomenclature

The following nomenclature is used in the description:

$\boldsymbol{X}$: set or array or values

X_i: i-th value in the set of values of $\boldsymbol{X}$

N_X: number of values in $\boldsymbol{X}$

$q_G(\boldsymbol{G})$: pdf of the horizon antenna gain; i.e. $q_G(G_i)$ denotes the probability that the horizon antenna gain is equal to G_i

$q_L(\boldsymbol{L})$: pdf of the path loss for a given distance; i.e. $q_L(L_i)$ denotes the probability that the path loss is equal to L_i

$r_L(\boldsymbol{L})$: cdf of the path loss for a given distance; i.e. $r_L(L_i)$ denotes the probability that the path loss is less than L_i

$q_C(\boldsymbol{C})$: pdf of the combined path loss – horizon antenna gain for a given distance; i.e. $q_C(C_i)$ denotes the probability that the combined path loss – horizon antenna gain is equal to C_i

$r_C(\boldsymbol{C})$: cdf of the combined path loss – horizon antenna gain for a given distance; i.e. $r_C(C_i)$ denotes the probability that the combined path loss – horizon antenna gain is greater than C_i

s: resolution of the horizon antenna gain and path loss pdf's. A value of $s = 0.1$ dB is recommended

d_{min}: minimum coordination distance, as defined in Recommendation ITU-R P.620

d_{max}: maximum coordination distance, as defined in Recommendation ITU-R P.620

d_s: path length increment for the iteration. A value from 0.1 km to 0.5 km is recommended.

2.2 Calculation methodology - core

a) In accordance with § 3 of Annex 1, determine the complete probability distribution of the horizon antenna gain $q_G(\boldsymbol{G})$, for each azimuth α. Each value in $\boldsymbol{G}$ must be an integer multiple of s dB, e.g. $q_G(\boldsymbol{G}) = \{-10.0, -9.9, -9.8, ...\}$ dBi

b) For each α, carry out the following steps:

Step 1: The distance under consideration is denoted d_i and is given by:

$$d_i = \{d_{min}, d_{min} + d_s, d_{min} + 2d_s, ...\} \qquad \text{km}$$

Step 2: Starting with distance d_1, carry out the following steps:

Step 2.1: determine probability distribution of the basic transmission loss $q_L(\boldsymbol{L})$ as described in § 2.3 of this Annex;

Step 2.2: the two probability distributions $q_L(\boldsymbol{L})$ and $q_G(\boldsymbol{G})$ are convolved and then integrated to give a cumulative probability distribution $r_C(\boldsymbol{C})$ as described in § 2.4 of this Annex;

Step 2.3: the value of $(L_c - G_a)(p)$ is the value not exceeded by the cumulative distribution of the combined basic transmission loss and horizon antenna gain for p percent of time. In other words, it is the value of C_i for which $r_C(C_i) = p$ where p is the percentage of time associated with the threshold interference level. Where there is not a value of $r_C(C_i)$ which exactly corresponds to p, it is generally acceptable to take the nearest value;

Step 2.4: if the inequality of equation (13) is false and $d_i < d_{max}$, increment d_i and repeat steps 2.1 to 2.4. Otherwise the coordination distance is d_i.

NOTE 1 – More efficient methods of iteration may be used which would converge more rapidly on the required coordination distance. Alternative methods of iteration may be used provided their solution converges with an error no greater than 0.5 km.

2.3 Determination of the probability distribution of the basic transmission loss

A pdf of basic transmission loss is required for the distance d_i. The range of values of basic transmission loss is denoted as $\boldsymbol{L}$ where:

$$\boldsymbol{L} = \{L_{min}, L_{min} + s, L_{min} + 2s, ..., L_{max}\} \qquad \text{dB}$$

and s denotes the step incremental value.

The minimum value, L_{min}, is the value of basic transmission loss corresponding to $p = 0.001\%$. The maximum value, L_{max}, is given by:

$$L_{max} = 2L_{mean} - L_{min} \qquad \text{dB}$$

where L_{mean} is the value of basic transmission loss corresponding to $p = 50\%$.

Values of L_{min} and L_{max} must be rounded to the nearest s dB. For each value in $\boldsymbol{L}$, it is necessary to associate a percentage of time representing the percentage of time that value of loss is not exceeded, $r_L(L_i)$. The method to determine $r_L(L_i)$ varies depending on the value of L_i, as indicated in Table 6:

TABLE 6

L_i	$r_L(L_i)$
L_{min}	0.001
$L_{min} < L_i < L_{mean}$	Determined by iteration; i.e. in the propagation model, the values of distance and basic transmission loss are fixed, and the corresponding value of p is solved by iteration
L_{mean}	50
$L_{mean} < L_i < L_{max}$	$100 - r_L(2L_{mean} - L_i)$
L_{max}	99.999

It is then necessary to derive the pdf of the basic transmission loss from the cumulative distribution. This is denoted $q_L(\boldsymbol{L})$ and can be determined from:

$$q_L(L_i) = r_L(L_i) \qquad \text{for } i = 1$$

and

$$q_L(L_i) = r_L(L_i) - r_L(L_{i-1}) \qquad \text{for } i > 1$$

2.4 Method to convolve the probability distributions

The following steps are used to determine the pdf and then cdf of the combined horizon antenna gain and basic transmission loss for distance d_i.

The maximum and minimum values of the combined distributions are given by:

$$C_{max} = L_{max} - G_{min} \qquad \text{dB}$$

and

$$C_{min} = L_{min} - G_{max} \qquad \text{dB}$$

The set of values of $\boldsymbol{C}$ is then:

$$\boldsymbol{C} = \{C_{min}, C_{min} + s, C_{min} + 2s \ldots, C_{max}\} \qquad \text{dB}$$

Let N_L and N_G be the number of values in each of $\boldsymbol{L}$ and $\boldsymbol{G}$ respectively.

For each value of C_i, a discrete convolution is performed to give the total probability of the path loss – horizon antenna gain equal to the value of C_i:

$$q_C(C_i) = \sum_{n=l}^{u} q_L(L_n) \cdot q_G(L_n - C_i)$$

The lower and upper limits to the summation are given by:

$$l = \begin{cases} i - N_G + 1 & \text{for } i > N_G \\ 1 & \text{otherwise} \end{cases}$$

$$u = \begin{cases} i & \text{for } i \le N_L \\ N_L & \text{otherwise} \end{cases}$$

The cumulative combined distribution of basic transmission loss and horizon antenna gain is given by:

$$r_C(C_i) = q_C(C_i) \qquad \text{for } i = 1$$

$$r_C(C_i) = r_C(C_{i-1}) + q_C(C_i) \qquad \text{for } i > 1$$