RECOMMENDATION ITU-R S.1430

DETERMINATION OF THE COORDINATION AREA FOR EARTH STATIONS OPERATING WITH NON-GSO SPACE STATIONS WITH RESPECT TO EARTH STATIONS OPERATING IN THE REVERSE DIRECTION IN FREQUENCY BANDS ALLOCATED BIDIRECTIONALLY TO THE FSS

(Questions ITU-R 253/4, ITU-R 231/4 and ITU-R 212/1)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that some frequency bands are allocated to the FSS for use by non-GSO systems in both the Earth-to-space and the space-to-Earth direction of transmission;

b) that these frequency bands are also available for use by GSO systems;

c) that, therefore, there is a possibility of mutual interference between earth stations operating to space stations in both GSO and non-GSO orbits;

d) that such potential interference may be alleviated or avoided through the coordination of such earth stations;

e) that it is desirable to limit the number of coordinations that may have to be undertaken;

f) that it is possible to define an area around a transmitting earth station outside of which a receiving earth station would be subject to only negligible interference;

g) that Radiocommunication Study Group 1 is drawing together the results of studies from all concerned Study Groups in the development of comprehensive texts that may be used to revise RR Appendix S7;

h) that Recommendation ITU-R P.620 contains a propagation model that is intended for coordination of earth stations,

recommends

1 that, in frequency bands allocated to the FSS in both the space-to-Earth and the Earth-to-space direction of transmission and utilized by both non-GSO and GSO FSS systems, a bidirectional coordination area be determined for each transmitting earth station;

2 that, for that purpose, Annex 1 to this Recommendation should be used.

ANNEX 1

Determination of the coordination area for earth stations operating with non-GSO space stations with respect to earth stations operating in the reverse direction in frequency bands allocated bidirectionally to the FSS

1 Introduction

This procedure has been developed for the determination of the bidirectional coordination area around an earth station operating with a non-GSO space station in frequency bands used bidirectionally by earth stations operating to non-GSO space stations and GSO earth stations.

The operation of transmitting and receiving non-GSO and GSO earth stations in bidirectionally allocated frequency bands may give rise to interference between stations of the two FSS applications. 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 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 earth stations located outside the coordination area the probability of causing or experiencing significant interference is considered to be negligible.

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.

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 receiving earth stations, while the pertinent parameters of the transmitting earth stations are known.

Once the coordination area around an earth station has been computed, it can be stated, regarding another earth station to be operated in the reverse direction:

– if the earth station is to be located outside the coordination area, then there will be little risk of interference;

– if the earth station is to be located within the coordination area, then it will be necessary to carry out a detailed coordination.

The coordination area will normally be determined for the case where the non-GSO earth station is transmitting and hence capable of interfering with the reception of other earth stations. It may also be necessary to determine the coordination area for the case where the non-GSO earth station is receiving and hence capable of being interfered-with by emissions from other earth stations.

The procedure in this Annex describes the case in which the non-GSO earth station is transmitting. The methodologies apply equally to the case in which the non-GSO earth station is receiving. For the calculation of the coordination area of transmitting earth station the necessary parameters can be found in Recommendation ITU-R SM.1448. For a receiving earth station the methodologies can be used on bilateral basis only, since the parameters of the transmitting earth station with respect to which the coordination area is established will have to be provided by the responsible administration.

The coordination area of an earth station operating with a GSO space station in a slightly inclined GSO orbit should be determined for the minimum angle of elevation and the associated azimuth at which the space station is visible to the earth station.

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 GSO earth 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 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 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.

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.

The coordination distance can then be determined using a suitable propagation model. The ITU-R has developed propagation models suitable for the determination of the coordination area of earth stations operating with the non-GSO 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 time; this value must be exceeded by the actual or predicted basic transmission loss for all but p% of time

G_t: gain of the transmitting antenna of the interfering station towards the physical horizon on a given azimuth (dBi). If the interfering station is an earth station operating to non-GSO space station, then G_t is a time-varying function

G_r: gain of the receiving antenna of the interfered-with station towards the physical horizon at a given azimuth (dBi). If the interfered-with station is an earth station operating to non-GSO space station, then G_r is a time-varying function.

2.3 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 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)

N_L: link noise contribution (see Note 2)

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

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) (see Note 3)

W: 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 4).

NOTE 1 – The following earth station receiving system noise temperatures should be used since the location and precise characteristics of the station are unknown:

Frequency range (GHz)	T_e (K)
1-10	75
10-17	150
> 17	300

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. In the absence of specific interference data, it is assumed $N_L = 1$ dB for fixed-satellite links.

NOTE 3 – M_s is the factor by which the link noise under clear-sky conditions would have to be raised to produce the specified minimum performance. It is the dB sum of two margins M_0 (the natural performance margin) and ΔM (the operational excess margin). The natural performance margin M_0 is the dB difference between the two C/N values that would just produce the specified nominal (long term) and the specified minimum (short term) performances, respectively. The excess margin ΔM is the dB difference between the actual clear-sky C/N and the value which would produce the nominal specified performance; it may be equal to 0 dB. Thus, M_s is the real fade margin but it is also the margin by which the clear-sky noise floor could be raised (e.g. as the result of interfering emissions) to produce minimum performance conditions.

In analogue systems of the FSS, M_0 is given by $M_0 = 10 \log (50\,000/10\,000) = 7$ dB. Since this is sufficient to deal with fading at least below about 17 GHz, ΔM is taken as 0 dB, and $M_s = 7$ dB. For frequencies above about 17 GHz, ΔM may have to assume some value greater than 0 dB.

In digital systems of the FSS, M_0 can be as little as 1 dB for practical satellite circuits. In real satellite circuits, due to the presence of FEC codes, the BER versus C/N curve is very steep. In addition, at BER as low as 1×10^{-5}, the modem's decoder can lose synchronization to the incoming bit stream as the modem FEC algorithm begins to break down. Especially for very low bit rates, the recovery time could be significantly large. Thus, a degradation in C/N as small as 1.0 dB, when the BER is 1×10^{-7}, could result in degraded performance and/or downtime to the end-user anywhere from a few seconds to several minutes. The low value of M_0, i.e. 1 dB, is not likely to be sufficient to deal with fading on real links, hence, M_s is to be estimated directly from the expected fading depth for the real percentages of the time of concern. Practical values for M_s are therefore:

F (GHz)	M_s (dB)
< 10	2
10-17	4
> 17	6

NOTE 4 – 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 earth station

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

Using computer simulations, a procedure for calculating the time-varying gain of the transmitting or the receiving antenna of an earth station operating to a non-GSO space 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 and elevation angle 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 distribution 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. $G = \{G_{min}, G_{min} + s, G_{min} + 2s, ..., G_{max}\}$. A value of $s = 0.1$ to 0.5 dB is recommended.

– 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.

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

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

$$\varepsilon_t = \arcsin\left\{ \left(r_s \cos(\psi) - r_g \right) / \left(r_s{}^2 + r_g{}^2 - 2 r_s r_g \cos(\psi) \right)^{0.5} \right\} \quad (4)$$

where:

$$\cos(\psi) = \cos(\xi_t)[\cos(\dot{\theta}\, t + \lambda_g - \lambda_s)\cos(\omega + f) + \sin(\dot{\theta}\, t + \lambda_g - \lambda_s)\cos(i_s)\sin(\omega + f)] + \sin(\xi_g)\sin(i_s)\sin(\omega + f)$$

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

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

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

ψ: 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 node of the non-GSO satellite orbit at time $t = 0$ (degrees)

i_s: operational inclination angle of the non-GSO satellite orbit (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, ξ_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:

$$r_s = r_s \begin{bmatrix} x \\ y \\ z \end{bmatrix} = r_s \begin{bmatrix} \sin(\dot{\theta} t - \lambda_s)\cos(i_s)\sin(\omega + f) + \cos(\dot{\theta} t - \lambda_s)\cos(\omega + f) \\ \cos(\dot{\theta} t - \lambda_s)\cos(i_s)\sin(\omega + f) - \sin(\dot{\theta} t - \lambda_s)\cos(\omega + f) \\ \sin(i_s)\sin(\omega + f) \end{bmatrix} \quad (5)$$

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

$$\lambda_t = \text{arc}\tan(y/x) \qquad \xi_t = \text{arc}\sin(z) \quad (6)$$

The azimuth, α_s, of the non-GSO satellite as seen from the earth station operating to non-GSO space station is:

$$\alpha_s = \left\{ \frac{\cos(\xi_t)\sin(\delta)}{\sin(\xi_g)\cos(\xi_t)\cos(\delta) - \cos(\xi_g)\sin(\xi_t)} \right\} \quad (7)$$

where:

$$\delta = \lambda_g - \lambda_t \quad (8)$$

The angle $\varphi(\alpha_s)$ (between the boresight of the antenna and the horizon direction) corresponding to a pertinent azimuth α_s, expressed as a function of the boresight azimuth and elevation angles (α_s, ε_t) and the azimuth and elevation angles (α_0, ε_0) in the pertinent direction, is given by:

$$\varphi(\alpha_s) = \text{arc}\cos\left\{\cos(\alpha_s - \alpha_0)\cos(\varepsilon_t)\cos(\varepsilon_0) + \sin(\varepsilon_t)\sin(\varepsilon_0)\right\} \quad (9)$$

when $\varepsilon_0 = 0°$:

$$\varphi(\alpha_s) = \text{arc}\cos\left\{\cos(\alpha_s - \alpha_0)\cos(\varepsilon_t)\right\} \quad (10)$$

Appendix 1 to Annex 1 shows examples of calculating the horizon antenna gain of a non-GSO earth station.

4 Determination of the horizon antenna gain for unknown station

4.1 Determination of G_r of a GSO earth station

Since not only the precise characteristics of the receiving earth station are unknown but also its precise location, use is made of the fact that the receiving earth station must be assumed to lie anywhere on the boundary of the bidirectional coordination area, and that this places it relatively close, in global geometric terms, to the transmitting earth station. Hence the simplifying assumptions are made that plane rather than spherical geometry between the two earth stations can be used, and that the receiving earth station site has the same latitude as the transmitting earth station around which the coordination area is to be determined.

As prescribed by equation (2), the horizon antenna gains of the transmitting and receiving antennas must be added for each azimuth. This allows the transmitting antenna gain to be directly plotted versus its azimuth, but a given azimuth at the transmitting antenna's locations is the opposite or back azimuth at the receiving antenna's location. Therefore to a value of G_t found for each azimuth α at the transmitting non-GSO earth station must be added a value of G_r which is found for the azimuth $\alpha' = (\alpha + 180°)$.

The determination of the antenna gain G_r of the receiving earth station recognizes that:

– The main beam is not directed towards the physical horizon but towards a satellite at some, perhaps a large, elevation angle.

– The direction of the main beam is constrained by the possible locations of GSO satellites.

Hence, to determine G_r of a GSO earth station, in the absence of any knowledge regarding the location of a receiving earth station, the procedure described in Appendix 2 to Annex 1 is used.

Since it is not known beforehand towards which orbit location a receiving earth station antenna beam is directed, the horizon antenna gain must be determined for all geostationary-orbit locations. Also, since the horizon elevation is not known, 0° is used for all azimuths. Finally, the assumption that the latitude of the receiving earth station is the same as that of the transmitting earth station for which the coordination area is being determined, is a simplifying assumption which introduces generally negligible errors which, in any case, will not exceed 2 dB.

Thus the procedure given in Case 2 in Appendix 2 to Annex 1 for calculating the antenna gain in the direction of the earth-station horizon has to be carried out for each counter-azimuth α' at a 0° horizon elevation angle.

The assumption of 0° horizon elevation angle is conservative since the increase in antenna gain due to a raised horizon would, in practice, be more than offset by any real site shielding which, for the receiving antenna site, must be assumed to be zero. It should be noted that while no site shielding can be assumed for the receiving earth station, any site shielding that may exist at the transmitting earth station is considered in the normal fashion.

An example of how the antenna gains G_t and G_r are to be added on a common azimuth plot is given below:

$$\alpha = 192°$$

$$\alpha + 180° = 372° = 360° + 12°$$

$$\alpha' = 12°$$

One obtains $G_t + G_r$ from:

$$G_t + G_r = G_t(\alpha) + G_r(\alpha') \qquad \text{dB} \tag{11}$$

for each azimuth α at a transmitting earth station to be used in equation (2). When determining $G_r(\alpha')$ using equation (28) of Appendix 2 of Annex 1 and the equations following it, G_{max} shall be taken to be 42 dBi.

4.2 Determination of G_r for a non-GSO earth station

When the unknown earth station operates to non-GSO space stations the antenna gain in the direction of the horizon on any azimuth would normally be expected to vary with time. By definition, it is impossible to have any knowledge of the statistics of the gain variations of the unknown station, and a simplifying assumption must therefore be made.

In the time-invariant gain method, the actual value of the horizon antenna gain is based on the maximum assumed variation in horizon antenna gain on each azimuth. The values of horizon antenna gain defined below should be used for each required azimuth:

$$G_e = G_{max} \qquad \text{for} \qquad (G_{max} - G_{min}) \leq 20 \quad \text{dB}$$

$$G_e = G_{min} + 20 \qquad \text{for } 20 \text{ dB} < (G_{max} - G_{min}) < 30 \quad \text{dB}$$

$$G_e = G_{max} - 10 \qquad \text{for} \qquad (G_{max} - G_{min}) \geq 30 \quad \text{dB}$$

where:

G_e : horizon antenna gain of the unknown earth station (dBi) for a particular azimuth use G_t or G_r as appropriate for a transmitting or receiving earth station in the equation

G_{max}, G_{min} : maximum and minimum values of horizon antenna gain (dBi), respectively, on the azimuth under consideration.

Representative system characteristics of the unknown earth station are required to derive G_{min} and G_{max}.

5 Determination of coordination areas

Having assembled characteristics for the known and unknown earth stations, one of the two methods described in § 5.1 and 5.2 may be applied to determine the coordination area for the earth station.

The method in § 5.1 makes certain approximations to avoid the need to convolve the statistics of transmission loss and antenna gain. These approximations result in identical or smaller coordination distances than would be given by a full convolution. The truncation of the transmission loss model at values less than 100% will introduce small or negligible errors. The advantage of this method is that the algorithms required are straightforward and the need to derive distribution functions of transmission loss is avoided. The simplicity of this method helps to ensure the repeatability of results between different software implementations. This method is less sensitive to errors stemming from the sizes of the bins used in the gain and loss distributions.

The method in § 5.2 is based on a conceptually more accurate principal though it is more complex to implement. The potential accuracy may not be achieved in practice for two principal reasons. Firstly, the current propagation model of Recommendation ITU-R P.620 is valid for percentage-times only below 50% and above 0.001%: it is therefore necessary to approximate some parts of the transmission loss distribution function, with consequent loss of accuracy. Secondly, the discrete convolution and the subsequent search for the required coordination distance require finite values of iteration step-size and convergence criteria. As in the method of § 5.1, the use of too large iteration step-size will result in an overestimate or underestimate of the required coordination distance. However the greater complexity of the method of § 5.2 may encourage the use of large step sizes and convergence criteria to reduce computer run-times. The smaller values given in § 5.2 are recommended.

Practical implementations have shown that the two methods give comparable results, with the method in § 5.1 yielding slightly smaller coordination distances.

5.1 Determination of the coordination distance using method 1

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.

The methodology used here requires knowledge of the statistics of the time-varying horizon antenna gain of the earth station operating to a non-GSO space station, but 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:

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

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 $\{P_t + G_r - P_r(p)\}$ 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 satisfy $p = p'\ p_i$ 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 time. At each such step the values of G_{ti} and p_i are fixed. Then equation (12) can be rewritten as follows:

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

The $L_{bi}(p')$ calculations are repeated for all G_{ti} gain levels as described in the implementation steps below. From the values of $L_{bi}(p')$ and associated distances, the distance corresponding to the maximum 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 horizon antenna gain of the earth station operating to non-GSO space station at 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_{tmin}, and the maximum gain value, G_{tmax}. Choose a gain increment s dB and divide this gain range into a number of gain levels $\{G_{tmin}, G_{tmin} + s, G_{tmin} + 2s, ..., G_{tmax}\}$. A value of $s = 0.1$ to 0.5 dB is recommended.

Step 3: Determine the percentage of time, p_i, associated with each 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 transmission 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 propagation mode (1) model in Recommendation ITU-R P.620.

Step 7: Repeat Steps 3-6 for each gain level G_{ti} over the range G_{tmin} to G_{tmax}. 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 the coordination distance d (km) is shorter than the minimum coordination distance limit, d_{min}, or longer than the maximum coordination distance limit, d_{max}:

If $d < d_{min}$ set $d = d_{min}$

If $d > d_{max}$ set $d = d_{max}$

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

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

An example for calculating the coordination distance contour using this methodology is given in Appendix 3 to Annex 1.

5.2 Determination of the coordination distance using method 2

5.2.1 Introduction

In this method, the coordination contour is determined using calculations that apply the time varying statistics associated with the predicted basic transmission loss and the horizon antenna gain of an earth station. This method accounts for the joint statistics of propagation loss and antenna gain by convolving their pdf.

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

For this method, equation (2) is replaced by the following condition:

$$(L_c - G_\alpha)(p) > P_t + G_b - P_r(p) \qquad (13)$$

where:

$(L_c - G_\alpha)(p)$: combination of basic transmission loss at distance d (km) and horizon antenna gain not exceeded for $p\%$. 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 a potentially interfering station

G_b: antenna gain of the unknown 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 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 successively to 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 $L_c - G_\alpha(p)$ 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%; and

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

If this 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% (see § 5.2.2.3) 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:

5.2.2 Calculation methodology

5.2.2.1 Nomenclature

The following nomenclature is used in the description:

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

X_i: *ith* 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. $\mathrm{r}_L(L_i)$ 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 pdfs. 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.

5.2.2.2 Calculation methodology – core

a) In accordance with section 3, 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. $\boldsymbol{G}$ = {–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:

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

Step 2: Starting with distance d1, carry out the following steps:

Step 2.1: determine probability distribution of the basic transmission loss $q_L(\boldsymbol{L})$ as described in § 5.2.2.3;

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 § 5.2.2.4;

Step 2.3: the value of $(L_c - G_\alpha)(p)$ is the value not exceeded by the cumulative distribution of the combined basic transmission loss and horizon antenna gain for p% 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.

5.2.2.3 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 $r(L_i)$ varies depending on the value of L_i, as indicated in the Table 1:

TABLE 1

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

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

5.2.2.4 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 ***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 ***L*** and ***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:

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

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

APPENDIX 1

TO ANNEX 1

Antenna gain distribution examples

1 General

This Appendix presents examples for the determination of the statistics of the transmitting antenna gain 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 operating to non-GSO space station:

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

where:

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

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

D: antenna diameter

λ: wavelength expressed in the same unit as D

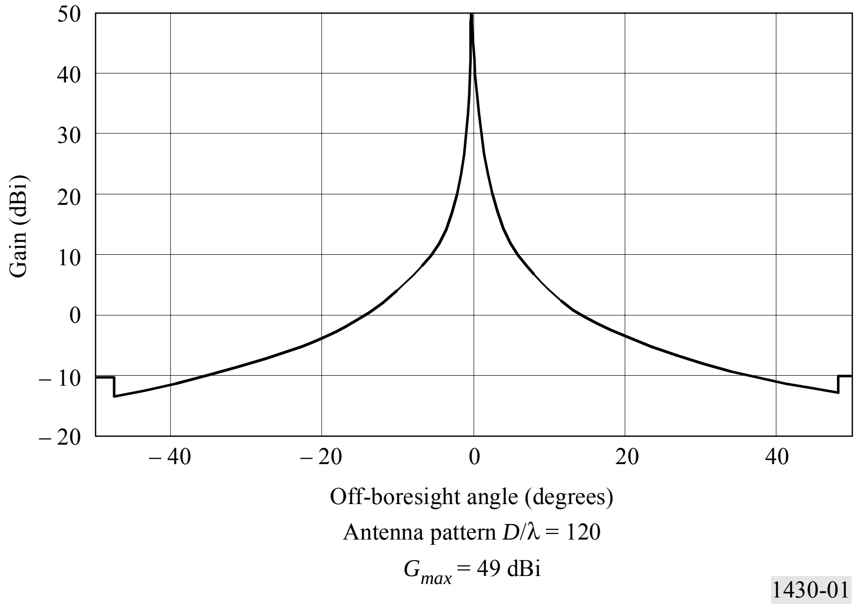
G_{max}: maximum gain of antenna (dBi)

φ: off-boresight angle (degrees).

This antenna pattern is shown in Fig. 1 for an antenna diameter to wavelength ratio, D/λ, of 120 and a maximum gain, G_{max}, of 49 dBi (approximately 55% efficiency). This pattern has a beamwidth of approximately 0.5°.

FIGURE 1

Antenna pattern used in the examples



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 operating to non-GSO space 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, *i*, of 98.2°.

Figure 2 shows typical horizon 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 yields a smoother curve like the one generated with a resolution of 0.1° in azimuth and elevation angles.

FIGURE 2

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

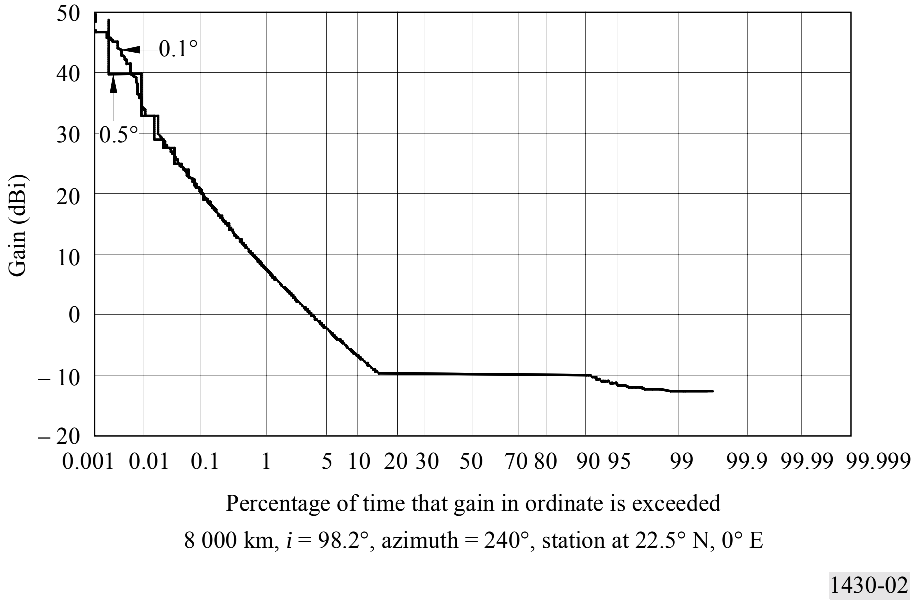
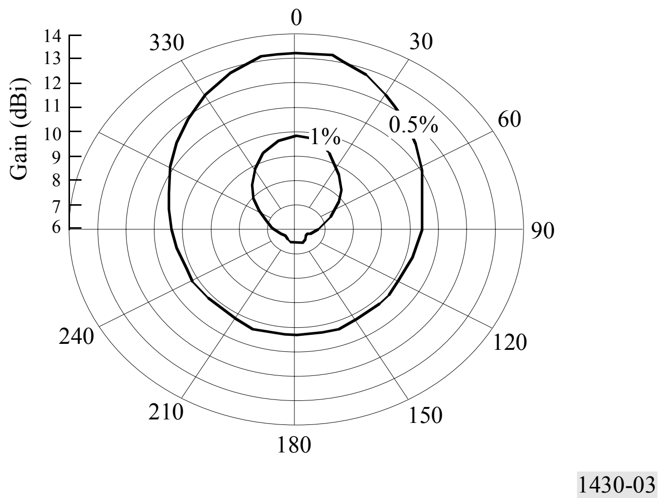


Figure 3 shows the gain that is exceeded 0.5% and 1% of the time as a function of the azimuth angle. These results were generated with a step-size resolution of 0.5° in elevation and azimuth angles.

FIGURE 3

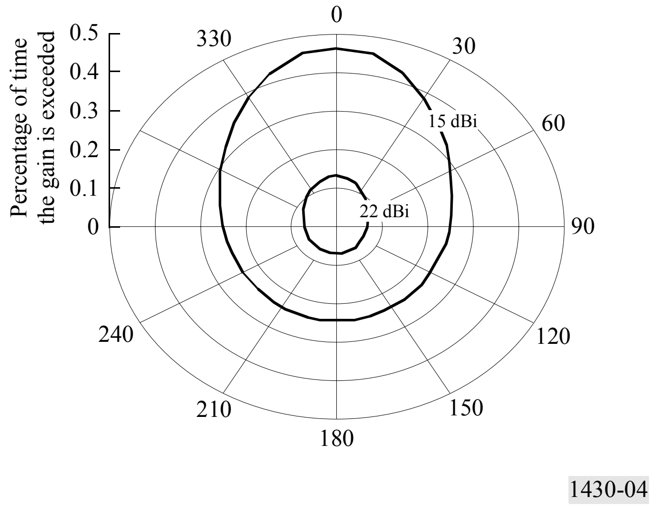
Gain contours of example 1 for 0.5% and 1% of time



In Fig. 4, the horizon gain is fixed and the percentage of 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 step size resolutions of 0.5°.

FIGURE 4

Contours giving the percentage of time a specific gain value is exceeded



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

Figure 5 shows two gain exceedance distributions at azimuth angles 0° and 140°. The difference in gain at percentage of time around 1% is significant. 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.

FIGURE 5

Gain exceedance distributions for two azimuth angles 0° and 140°

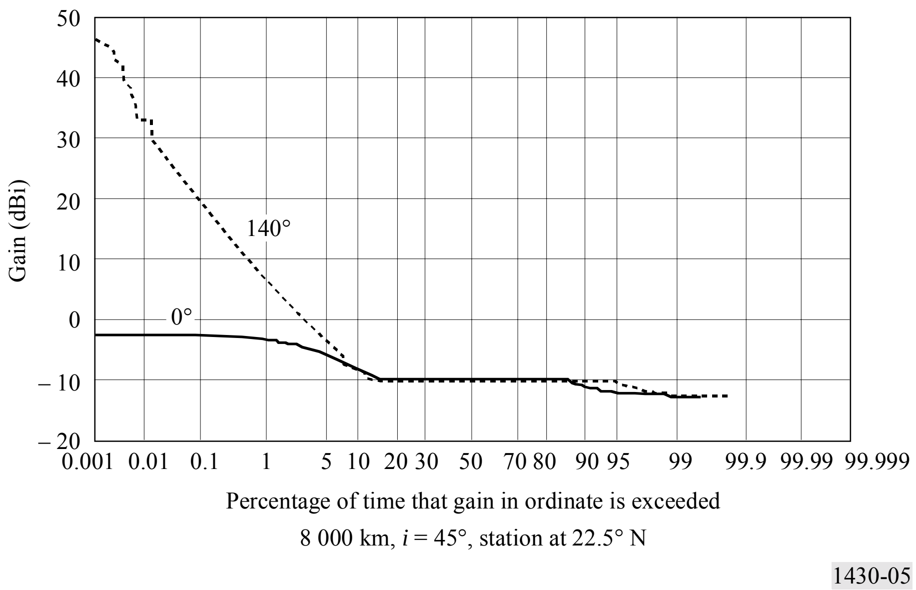
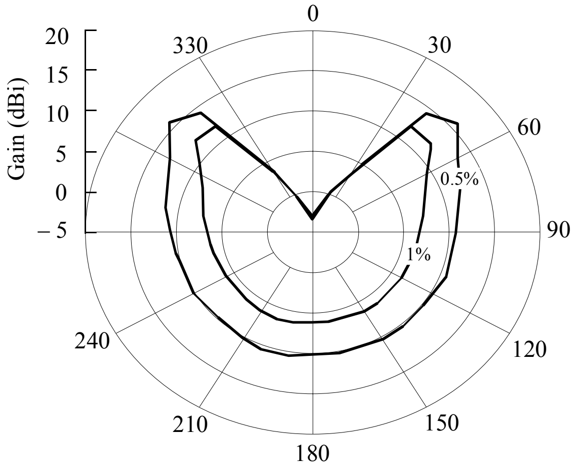


FIGURE 6

Gain contours of example 2 with 0.1° resolution



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APPENDIX 2*

TO ANNEX 1

Antenna gain of a geostationary earth station in the direction of the horizon

1 General

The gain component of the antenna of an earth station in the direction of the physical horizon around an earth station is a function of the angular separation between the antenna main beam axis and the horizon in the direction under consideration. When the earth station is used to transmit to more than one space station along the geostationary orbit, or to one or more space stations in slightly inclined orbits, all possible pointing directions of the antenna main beam axis must be considered. For earth station coordination, knowledge of $\varphi(\alpha)$, the minimum possible value of the angular separation that will occur during the operation of the space station, is required for each azimuth.

When a geostationary satellite maintains its location close to its nominal orbital position, its elevation ε, and azimuth α, as seen from an earth station at a latitude ξ_g are uniquely related. Figure 7 shows the possible location arcs of positions on the geostationary orbit in a rectangular azimuth/elevation plot. It shows arcs corresponding to a set of earth-station latitudes and the intersecting arcs correspond to points on the orbit with a fixed difference in longitude East or West of the earth station. Figure 7 also shows a portion of the horizon profile $\varepsilon(\alpha)$. The off-beam angle $\varphi(\alpha)$ between the horizon profile at an azimuth of 190° and a space station located 28° W of an earth station at 43° N latitude is indicated by the great-circle arc shown dashed on Fig. 7.

When the North-South station-keeping of a geostationary satellite is relaxed, the orbit of the satellite becomes inclined with an inclination that increases gradually with time. As viewed from the Earth, the position of the satellite traces a figure eight during each 24 h period. Figure 8 shows the trajectories of a set of satellites, each with 10° inclination, spaced by 3° along the geostationary orbit from 28° W to 44° E of an earth station at 43° N longitude. For purposes of coordination area determination, only a bounding envelope of these trajectories needs to be considered. A simple bounding envelope based on the maximum excursions in latitude and longitude of the sub-satellite points of satellites at all possible positions along the arc, as shown in Fig. 8, may be used. Figure 8 also shows, with a dashed curve, the great-circle arc corresponding to the minimum off-beam angle $\varphi(\alpha)$ between this envelope and the horizon profile at an azimuth of 110°.

* This Appendix is copied from Appendix 1 to Annex 1 of Recommendation ITU-R IS.847.

2 Determination of φ(α)

For the determination of the off-beam angle φ(α), four cases may be distinguished. These depend on whether a single space station or a portion of the geostationary orbit is to be considered, and whether or not the earth station will operate with space stations in slightly inclined orbits. The following equations may be used in all of these cases:

$$\psi_s\,(i,\delta) = \text{arc cos}\left(\sin\xi_g\,\sin i + \cos\xi_g\,\cos i\cos\delta\right) \tag{14}$$

$$\varepsilon_s\,(i,\delta) = \text{arc sin}\left(\frac{K\cos\psi_s\,(i,\delta) - 1}{\left(1 + K^2 - 2K\cos\psi_s\,(i,\delta)\right)^{1/2}}\right) \tag{15}$$

$$\alpha'_s\,(i,\delta) = \text{arc cos}\left[\frac{\sin i - \cos\psi_s\,\sin\xi_g}{\sin\psi_s\,\cos\xi_g}\right] \tag{16}$$

$$\alpha_s\,(i,\delta) = \alpha'_s\,(i,\delta) \qquad \text{for space stations located East of the earth station } (\delta \geq 0) \tag{17}$$

$$\alpha_s\,(i,\delta) = 360^\circ - \alpha'_s\,(i,\delta) \qquad \text{for space stations located East of the earth station } (\delta \leq 0) \tag{18}$$

$$\varphi(\alpha, i, \delta) = \text{arc cos}\,\left[\cos\varepsilon(\alpha)\cos\varepsilon_s\,(i,\delta)\cos(\alpha - \alpha_s\,(i,\delta)) + \sin\varepsilon(\alpha)\sin\varepsilon_s\,(i,\delta)\right] \tag{19}$$

where:

ξ_g: latitude of the earth station (positive for North; negative for South)

δ: difference in longitude from the earth station to the space station

i: latitude of the sub-satellite point (positive for North; negative for South)

$\psi_s(i, \delta)$: great-circle arc between the earth station and the sub-satellite point

$\alpha_s(i, \delta)$: space station azimuth as seen from the earth station

$\varepsilon_s(i, \delta)$: space station elevation angle as seen from the earth station

$\varphi(\alpha, i, \delta)$: angle between the main beam and the horizon direction corresponding to the pertinent angle, α, when the main beam is steered towards a space station with a sub-satellite point at latitude *i* and longitude difference δ

α: azimuth of the pertinent direction

$\varepsilon(\alpha)$: elevation angle of the horizon in the pertinent azimuth, α

$\varphi(\alpha)$: angle to be used for horizon gain calculation at the pertinent azimuth, α

K: orbit radius/Earth radius, assumed to be 6.62.

All arcs mentioned above are in degrees.

Case 1: Single space station, no orbital inclination.

For a single space station operating with no orbital inclination at an orbital position with difference in longitude δ_0, equations (14) to (19) may be applied directly, using $i = 0$, to determine $\varphi(\alpha)$ for each azimuth α. Thus:

$$\varphi(\alpha) = \varphi(\alpha, 0, \delta_0) \tag{20}$$

where δ_0 is the longitude difference from the earth station to the space station.

Case 2: Space stations on a portion of the geostationary orbital arc, no orbital inclination.

For space stations operating with no orbital inclination on a portion of the geostationary orbital arc, equations (14) to (19) may be applied directly, $i = 0$ to develop the minimum value of off-axis angle. For each azimuth α, the angle $\varphi(\alpha)$ is the minimum value of $\varphi(\alpha, 0, \delta)$ for any position along the arc. Thus:

$$\varphi(\alpha) = \min_{\delta_w \leq \delta \leq \delta_e} \varphi(\alpha, 0, \delta_0) \tag{21}$$

where:

δ_e : difference in longitude at the eastern extreme of the operational portion of the orbital arc

δ_w : difference in longitude at the western extreme of the operational portion of the orbital arc.

Case 3: Space stations on a portion of the geostationary orbital arc, with orbital inclination.

For space stations operating in slightly inclined orbits on a portion of the geostationary arc with nominal longitude difference between δ_e, and δ_w, the maximum orbital inclination over their lifetimes, i_s, must be considered. equations (14) to (19) may be applied to develop the minimum off-axis angle to each of four arcs in azimuth/elevation space that bound the trajectory of the space station in azimuth and elevation. The bounding arcs correspond to the maximum and minimum latitudes of the sub-satellite points and the extremes of the difference in longitude between the earth and space stations when the space station is operating at its maximum inclination. Thus:

$$\varphi(\alpha) = \min_{1 \leq n \leq 4} \varphi_n(\alpha) \tag{22}$$

with:

$$\varphi_1(\alpha) = \min_{\delta_w - \delta_s \leq \delta \leq \delta_e + \delta_s} \varphi(\alpha, -i_s, \delta) \tag{23}$$

$$\varphi_2(\alpha) = \min_{\delta_w - \delta_s \leq \delta \leq \delta_e + \delta_s} \varphi(\alpha, i_s, \delta) \tag{24}$$

$$\varphi_3(\alpha) = \min_{-i_s \leq i \leq i_s} \varphi(\alpha, i, \delta_w - \delta_s) \tag{25}$$

$$\varphi_4(\alpha) = \min_{-i_s \leq i \leq i_s} \varphi(\alpha, i, \delta_e + \delta_s) \tag{26}$$

$$\delta_s = (i_s / 15)^2 \tag{27}$$

where:

i_s : maximum operational inclination angle of the satellite orbit

δ_s : maximum longitude change from nominal value of the sub-satellite point of a satellite with orbital inclination i_s.

Case 4: Single space station, with inclined orbits.

For a single space station, operating at a nominal longitude difference of δ_0, with a maximum orbital inclination of i_s over its lifetime, the determination of $\varphi(\alpha)$ is the same as for Case 3, except that here $\delta_e = \delta_w = \delta_0$.

It should be noted that the determination of the minimum off-axis angles in equations (21), (23), (24), (25) and (26) may be made by taking increments along a bounding contour. The step size in i or δ should be between 0.5° and 1.0° and the end points of the respective ranges should be included in the determination.

Note that the horizon profile $\varepsilon(\alpha)$ used in the determination of $\varphi(\alpha)$ should be specified at increments in azimuth α that should not exceed 5°.

3 Determination of antenna gain

The relationship $\varphi(\alpha)$ may be used to derive a function for the horizon antenna gain, G(dB) as a function of the azimuth α, by using the actual earth-station antenna pattern, or a formula giving a good approximation. For example, in cases where the ratio between the antenna diameter and the wavelength is not less than 35, the equation (28) should be used:

$$G(\varphi) = \begin{cases} G_{max} - 2.5 \times 10^{-3} \left(\dfrac{D}{\lambda} \varphi \right)^2 & \text{for } 0 < \varphi < \varphi_m \\ G_1 & \text{for } \varphi_m \le \varphi < \varphi_r \\ 29 - 25 \log(\varphi) & \text{for } \varphi_r \le \varphi < 36^\circ \\ -10 & \text{for } 36^\circ \le \varphi \le 180^\circ \end{cases} \tag{28}$$

where:

D: antenna diameter

λ: wavelength expressed in the same unit as D

G_1: gain of the first side lobe

$$G_1 = \begin{cases} -1 + 15 \log(D/\lambda) & \text{dBi} \quad \text{for } D/\lambda \ge 100 \\ -21 + 25 \log(D/\lambda) & \text{dBi} \quad \text{for } D/\lambda < 100 \end{cases}$$

$$\varphi_m = \frac{20\,\lambda}{D} \sqrt{G_{max} - G_1} \quad \text{degrees}$$

$$\varphi_r = \begin{cases} 15.85\,(D/\lambda)^{-0.6} & \text{degrees} \quad \text{for } D/\lambda \ge 100 \\ 100\,(\lambda/D) & \text{degrees} \quad \text{for } D/\lambda < 100 \end{cases}$$

The above patterns may be modified as appropriate to achieve a better representation of the actual antenna pattern.

In cases where D/λ is not given, it may be estimated from the expression:

$$20 \log \frac{D}{\lambda} \approx G_{max} - 7.7$$

where G_{max} is the main lobe peak antenna gain (dB).

FIGURE 7

Position arcs of geostationary satellites with horizon and the arc from the horizon at azimuth 190° to a satellite 28° W of an earth station at 43° N latitude

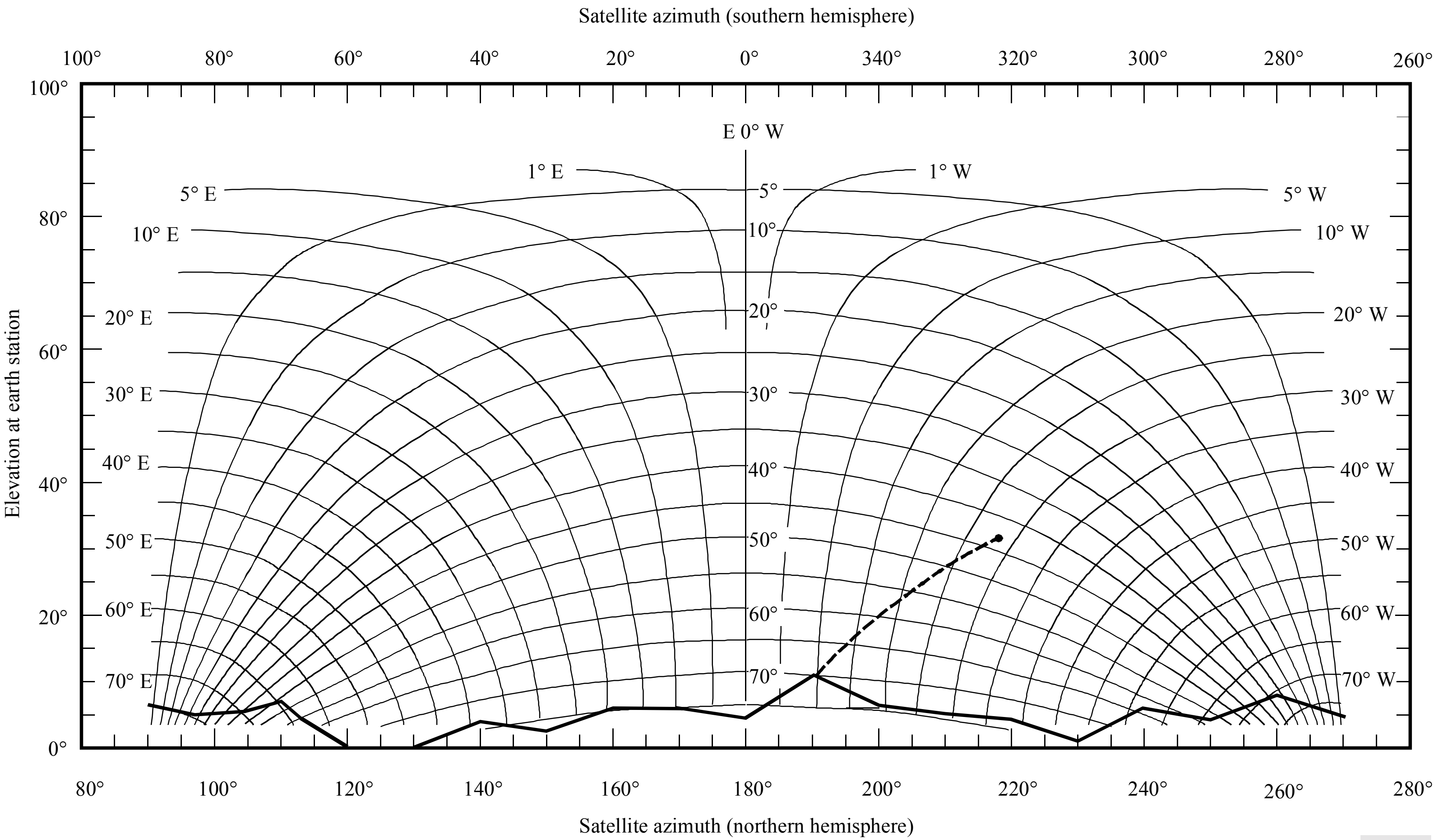

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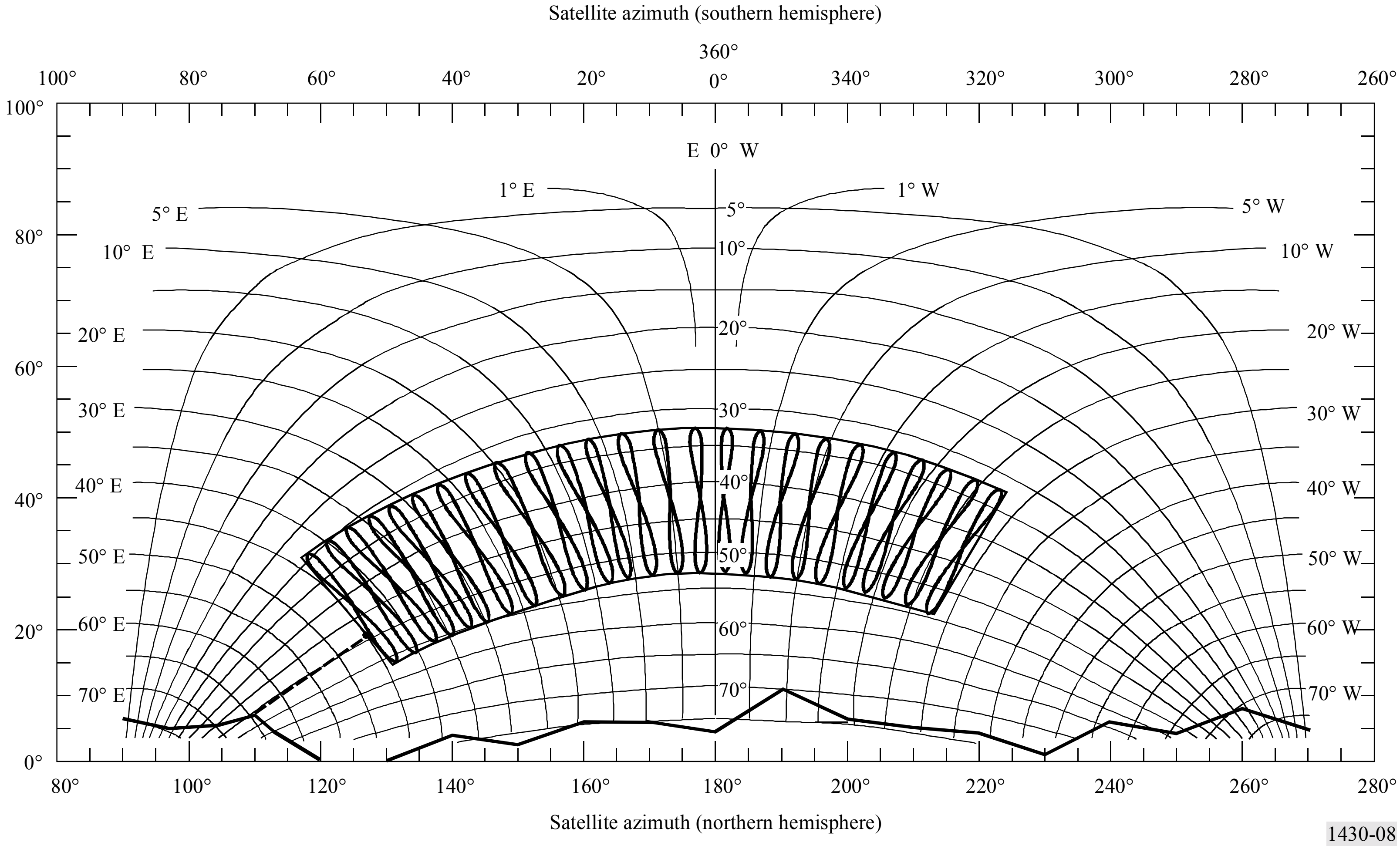
FIGURE 8

Position arcs of geostationary satellites with horizon and the arc from the horizon at azimuth 110° to the envelope of satellites with 10° inclination on the geostationary orbital arc from 28° W to 44° E of an earth station at 43° N latitude



APPENDIX 3

TO ANNEX 1

Coordination distances for a transmitting earth station operating to a non-GSO space station interfering with a receiving GSO earth station using the method in § 5.1

1 General

This Appendix presents an example for the determination of the coordination area using the method in § 5.1, between a transmitting earth station operating to a non-GSO space station interfering with a receiving GSO earth station in the 6 700-7 075 MHz frequency band.

2 Systems parameters

The systems parameters of the transmitting earth station operating to a non-GSO space station and the receiving GSO earth station are as given in Table 2.

TABLE 2

Non-GSO transmitting earth station and satellite orbit parameters used to determine coordination distance with a receiving GSO earth 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	Rec. ITU-R IS.465
Non-GSO transmitting station:	
Transmit antenna gain (dBi)	50
e.i.r.p./carrier (dBW)	56.5
Transmission bandwidth (kHz)	1 230
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 (dB)	42
Reference bandwidth (MHz)	1
T_e (K)	75
$P_r(p)$ (dBW)	–151.2

3 Coordination distance

Figure 9 shows the horizon antenna gain complementary cdf of the transmitting earth station operating to a non-GSO space station at different azimuth values. This function gives the percentage of time that a specific gain value is exceeded. Figure 10 shows an example of transmit and receive horizon antenna gains calculated on common azimuths as described in § 3.

FIGURE 9

Non-GSO horizon antenna gain complementary cdf for azimuths 0°, 60° and 180°

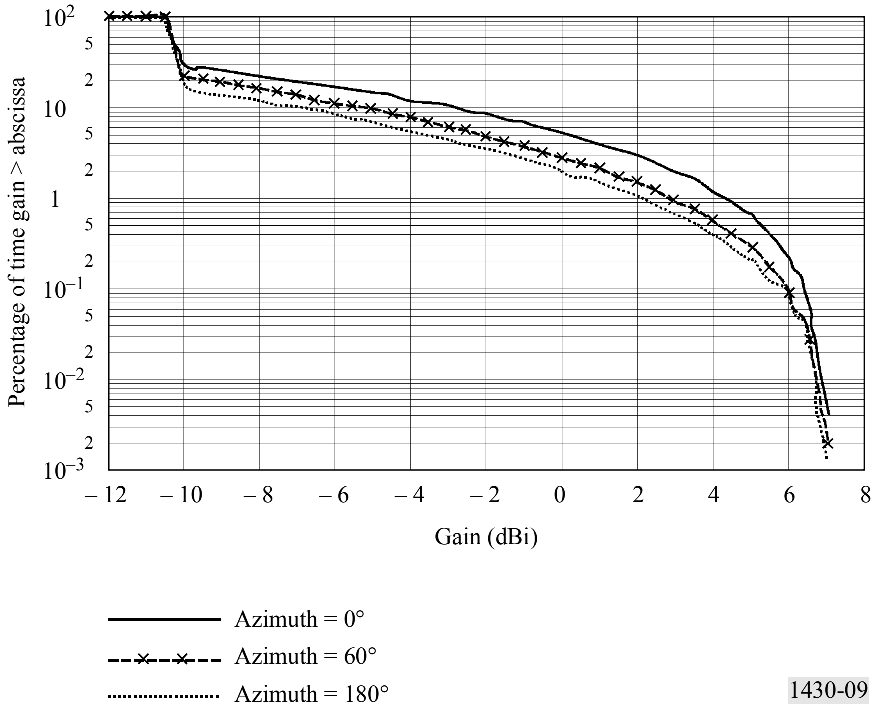


FIGURE 10

Composite horizon antenna gain $G_t + G_r$ of the transmitting earth station operating to a non-GSO space station and the receive GSO earth station

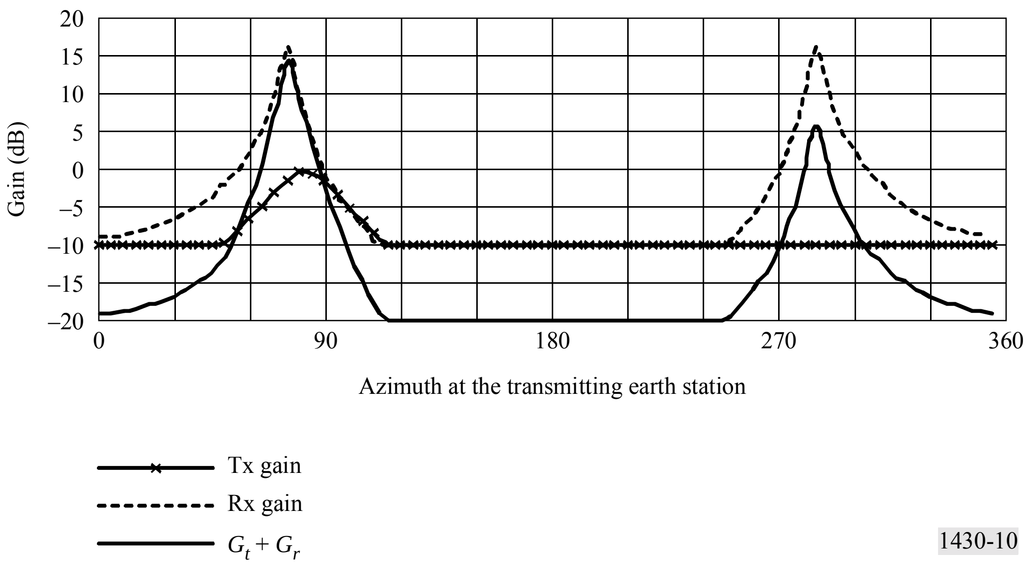


Table 3 shows an example for the determination of the coordination distance between the transmitting earth station operating to a non-GSO space station and the receiving GSO earth station listed in Table 2. The estimated distances are shown for a step size increment of 0.5 dB over the whole range of the horizon antenna gain and for 0° horizon elevation angle. The distance calculations are based on the methodology described in § 5 and the propagation mode (1) model of Recommendation ITU-R P.620. The largest value (marked in bold) in column d_i (km) of Table 3 is selected as the coordination distance at the specified azimuth.

TABLE 3

Coordination distance of a transmitting earth station operating to a non-GSO space station interfering with a receiving GSO earth station (minimum operating elevation angle = 10° and azimuth elevation = 0°)

Gain level, i	Tx antenna gain G_{ti} (dBi)	Gain pdf	Gain cdf	$p' = p/p_i$	Required loss (dB)	Coordination distance, d_i (km)
1	–10.5	0.709370	1.000000	0.000020	138.3	104.43
2	–10.0	0.016990	0.290630	0.000069	138.8	104.43
3	–9.5	0.016410	0.273640	0.000073	139.3	104.43
4	–9.0	0.015890	0.257230	0.000078	139.8	104.43
5	–8.5	0.015360	0.241340	0.000083	140.3	104.43
6	–8.0	0.014800	0.225980	0.000089	140.8	104.43
7	–7.5	0.014190	0.211180	0.000095	141.3	104.43
8	–7.0	0.013670	0.196990	0.000102	141.8	104.43
9	–6.5	0.013100	0.183320	0.000109	142.3	104.43
10	–6.0	0.012570	0.170220	0.000118	142.8	104.43
11	–5.5	0.012040	0.157650	0.000127	143.3	104.43
12	–5.0	0.011530	0.145610	0.000137	143.8	104.43
13	–4.5	0.011030	0.134080	0.000149	144.3	104.43
14	–4.0	0.010510	0.123050	0.000163	144.8	104.43
15	–3.5	0.009990	0.112540	0.000178	145.3	104.43
16	–3.0	0.009480	0.102550	0.000195	145.8	104.43
17	–2.5	0.008970	0.093070	0.000215	146.3	104.43
18	–2.0	0.008500	0.084100	0.000238	146.8	105.03
19	–1.5	0.007950	0.075600	0.000265	147.3	107.43
20	–1.0	0.007460	0.067650	0.000296	147.8	109.73
21	–0.5	0.007040	0.060190	0.000332	148.3	111.83
22	0.0	0.006540	0.053150	0.000376	148.8	113.73
23	0.5	0.006190	0.046610	0.000429	149.3	115.33
24	1.0	0.005640	0.040420	0.000495	149.8	116.63
25	1.5	0.005330	0.034780	0.000575	150.3	117.63
26	2.0	0.004850	0.029450	0.000679	150.8	118.23
27	2.5	0.004450	0.024600	0.000813	151.3	**118.33**
28	3.0	0.004060	0.020150	0.000993	151.8	117.83
29	3.5	0.003610	0.016090	0.001243	152.3	116.43
30	4.0	0.003220	0.012480	0.001603	152.8	114.03
31	4.5	0.002830	0.009260	0.002160	153.3	110.13
32	5.0	0.002370	0.006430	0.003110	153.8	104.43
33	5.5	0.001940	0.004060	0.004926	154.3	104.43
34	6.0	0.001440	0.002120	0.009434	154.8	104.43
35	6.5	0.000640	0.000680	0.029412	155.3	104.43
36	7.0	0.000040	0.000040	0.200000	155.8	104.43

Table 4 shows estimated distance for azimuths over the range 0° to 180°. These estimated distances are shown for a step size increment of 0.5 dB over the whole range of the horizon antenna gain and for 0° horizon elevation angle. The minimum coordination distance in this example is 104.43 km. The largest distance value (marked in bold) represents the coordination distance at the specified azimuth.

TABLE 4

Coordination distance at different azimuths

Non-GSO Tx earth station horizon antenna gain (dBi)	Coordination distance d_i (km) at azimuth (degrees)						
	0°	30°	60°	90°	120°	150°	180°
–10.5	104.43	104.43	155.63	131.93	104.43	104.43	104.43
–10.0	104.43	104.43	142.03	117.83	104.43	104.43	104.43
–9.5	104.43	104.43	145.13	120.93	104.43	104.43	104.43
–9.0	104.43	104.43	148.13	124.03	104.43	104.43	104.43
–8.5	104.43	104.43	151.03	127.03	104.43	104.43	104.43
–8.0	104.43	104.43	153.83	129.83	104.43	104.43	104.43
–7.5	104.43	104.43	156.63	132.63	104.43	104.43	104.43
–7.0	104.43	104.43	159.23	135.43	104.43	104.43	104.43
–6.5	104.43	104.43	161.83	138.03	104.43	104.43	104.43
–6.0	104.43	104.43	164.23	140.53	104.43	104.43	104.43
–5.5	104.43	104.43	166.53	142.83	104.43	104.43	104.43
–5.0	104.43	104.43	168.73	145.13	104.43	104.43	104.43
–4.5	104.43	106.73	170.83	147.23	104.43	104.43	104.43
–4.0	104.43	109.43	172.73	149.23	104.43	104.43	104.43
–3.5	104.43	112.03	174.53	151.13	104.43	104.43	104.43
–3.0	104.43	114.53	176.13	152.73	104.43	104.43	104.43
–2.5	104.43	116.83	177.63	154.23	104.43	104.43	104.43
–2.0	105.03	119.03	178.83	155.53	104.43	104.43	104.43
–1.5	107.43	121.03	179.83	156.63	104.43	104.43	104.43
–1.0	109.73	122.83	180.63	157.43	104.43	104.43	104.43
–0.5	111.83	124.43	181.23	158.03	104.43	104.43	104.43
0.0	113.73	125.73	**181.43**	**158.23**	**104.43**	**104.43**	**104.43**
0.5	115.33	126.83	181.33	158.13	104.43	104.43	104.43
1.0	116.63	127.53	180.73	157.53	104.43	104.43	104.43
1.5	117.63	**127.83**	179.73	156.53	104.43	104.43	104.43
2.0	118.23	127.73	178.13	154.83	104.43	104.43	104.43
2.5	**118.33**	127.03	175.83	152.53	104.43	104.43	104.43
3.0	117.83	125.53	172.53	149.23	104.43	104.43	104.43
3.5	116.43	123.13	168.13	144.73	104.43	104.43	104.43
4.0	114.03	119.53	162.13	138.63	104.43	104.43	104.43
4.5	110.13	114.13	153.93	130.33	104.43	104.43	104.43
5.0	104.43	106.13	142.03	118.33	104.43	104.43	104.43
5.5	104.43	104.43	124.43	104.43	104.43	104.43	104.43
6.0	104.43	104.43	104.43	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 shows coordination distance values over the azimuth range 0° to 360°. Figure 11 plots the coordination contour of the distances in Table 5.

TABLE 5

Coordination distances for a transmitting earth station operating to a non-GSO space station interfering with a receiving GSO earth station

Azimuth (degrees)	Coordination distance (km)	Azimuth (degrees)	Coordination distance (km)
0	118.33	180	104.43
10	119.03	190	104.43
20	121.93	200	104.43
30	127.83	210	104.43
40	138.13	220	104.43
50	154.73	230	104.43
60	181.43	240	104.43
70	229.33	250	104.43
80	228.03	260	119.83
90	158.23	270	158.23
100	119.93	280	228.03
110	104.43	290	229.33
120	104.43	300	181.33
130	104.43	310	154.73
140	104.43	320	138.13
150	104.43	330	127.93
160	104.43	340	121.93
170	104.43	350	119.03
180	104.43	360	118.33

FIGURE 11

Coordination contour for a transmitting earth station operating to a non-GSO space station interfering with a receiving GSO earth station using the method in § 5.1