

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**

(Questions ITU-R 253/4 and ITU-R 219/9)

(2000)

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.

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

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):

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

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:

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

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:

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

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:

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

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:

$$N_L = 1 \text{ dB} \quad \text{for FSS links}$$

$$N_L = 0 \text{ dB} \quad \text{for terrestrial links}$$

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., $G = \{G_{min}, G_{min} + s, G_{min} + 2s, \dots, G_{max}\}$.
- 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:

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

where:

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

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

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 node 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, ζ_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:

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

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

$$\lambda_t = \tan^{-1} (y / x) \quad \zeta_t = \sin^{-1} (z) \quad (7)$$

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

$$\alpha_t = \tan^{-1} \left\{ \frac{\cos(\zeta_t) \sin(\Delta\lambda)}{\sin(\zeta_g) \cos(\zeta_t) \cos(\Delta\lambda) - \cos(\zeta_g) \sin(\zeta_t)} \right\} \quad (8)$$

where:

$$\Delta\lambda = \lambda_g - \lambda_t \quad (9)$$

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:

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

when $\chi_0 = 0^\circ$:

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

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:

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

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:

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

$G_t(p_i)$ 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:

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

The $L_{bi}(p')$ calculations are repeated for all G_{ti} gain levels as described in the implementation steps below. From the values of $L_{bi}(p')$, 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 $\{G_{t_{min}}, G_{t_{min}} + s, G_{t_{min}} + 2s, \dots, G_{t_{max}}\}$. 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 :

$$\begin{aligned} p' &= p/p_i & \text{if} & & p/p_i \leq Z\% \\ p' &= Z\% & \text{if} & & p/p_i > Z\% \end{aligned}$$

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:

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

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:

$$\begin{aligned} \text{if } d_i \text{ (km)} < d_{min} & \quad \text{set} & \quad d_i \text{ (km)} &= d_{min} \\ \text{if } d_i \text{ (km)} > d_{max} & \quad \text{set} & \quad d_i \text{ (km)} &= d_{max} \end{aligned}$$

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