RECOMMENDATION ITU-R IS.849-1

DETERMINATION OF THE COORDINATION AREA FOR EARTH STATIONS OPERATING WITH NON-GEOSTATIONARY SPACECRAFT IN BANDS SHARED WITH TERRESTRIAL SERVICES*

(Questions ITU-R 3/12, ITU-R 4/12, ITU-R 5/12 and ITU-R 6/12)

(1992-1993)

The ITU Radiocommunication Assembly,

considering

a) that in certain space systems using non-geostationary space stations, the gain of earth station antennas towards the horizon may vary substantially over time in a consistent and predictable manner;

b) that in cases where earth station antenna gain towards the horizon varies significantly over time, the occurrences of relatively high gain towards the horizon and relatively low basic transmission loss in the same azimuth can be treated as independent statistical events that will occur simultaneously for only small percentages of time;

c) that the limits on the minimum elevation angle of an antenna main beam and the maximum equivalent isotropically radiated power (e.i.r.p.) towards the horizon prescribed for earth stations in Article 28 of the Radio Regulations (RR) help limit the maximum extent of coordination distances;

d) that the method of Recommendation ITU-R IS.847 for determining coordination distances assumes a constant earth station antenna gain towards the horizon,

recommends

1. that earth stations using antennas that track non-geostationary space stations be operated with the highest practical values of minimum antenna elevation angles consistent with operational requirements and the elevation angle and e.i.r.p. limits specified in RR Article 28;

2. that coordination areas for earth stations operating with non-geostationary space stations be determined using one of the following methods, whichever results in the smaller coordination distance (Note 1). These methods should be applied using the receiving earth station parameters specified in Table 1, where appropriate, in place of those specified in Table 2 of Annex 1 to Recommendation ITU-R IS.847 (Note 2);

2.1 Statistical methods

The 3% method – Where the statistics of horizon antenna gain can be determined in accordance with Annex 1, the value of horizon antenna gain (i.e. $G_{t'}$ or G_r as appropriate) exceeded for 3% of the time, as determined for each azimuth by the method in Annex 1, should be used in conjunction with the method of Annex 1 to Recommendation ITU-R IS.847 for propagation Mode 1 distances.

The composite method – When a potentially affected terrestrial station of another administration is identified within the coordination area that has been determined in accordance with the 3% method, upon agreement between administrations this coordination contour may be replaced by the coordination contour determined in accordance with the composite method of Annex 2. The composite method accounts for the joint statistics of propagation loss and antenna gain by convolving their probability density functions (Note 3).

* The procedure described in this Recommendation applies to situations where the coordination area is to be determined from specified threshold levels of interference power. For cases where the coordination distances are predetermined refer to Recommendation ITU-R IS.850. Recommendation ITU-R IS.850 should, in any case, be consulted prior to application of this Recommendation.

2.2 Time-invariant gain (TIG) method

Where the statistics of horizon antenna gain cannot be reliably determined, the values of horizon antenna gain defined below for each azimuth should be used with the method of Annex 1 to Recommendation ITU-R IS.847 for propagation Mode 1 distances (Note 4):

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

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

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

where:

G_e : horizon antenna gain of the earth station (dBi) for a particular azimuth for use as $G_{t'}$ or G_r in equation (2) of Annex 1 to Recommendation ITU-R IS.847

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

3. that in the event an earth station is intended to operate at times with satellites in geostationary orbit and at other times with non-geostationary satellites, the coordination distance for each azimuth is the greater of the coordination distances determined for each type of operation in accordance with all applicable provisions of this Recommendation and Recommendation ITU-R IS.847 (Note 5);

4. that published coordination contours for earth stations that operate with non-geostationary space stations be supplemented with the following data:

– an indication of which of the methods in § 2 or 3 was used to determine the coordination area;

– a diagram or table furnishing for each azimuth the minimum operational elevation angles; and

– a list of antenna horizon gain values used in the calculation of coordination distances.

5. that the following Notes should be considered to be part of this Recommendation:

Note 1 – Both the statistical and time-invariant gain (TIG) methods of § 2 have been found to provide coordination distances that are consistent with the purpose of coordination areas. In the practical cases considered in developing this Recommendation, the statistical method has been found to result generally in smaller coordination distances than the TIG method. Thus, the coordination distance will be the value determined by the statistical method unless the values determined by the TIG method are smaller for all azimuths, in which case the values from the TIG method should be used. Annex 3 provides example calculations of coordination distances using both methods.

Note 2 – Propagation Mode 2 (hydrometeor scatter) is not considered in § 2 because the probability of not exceeding the required level of transmission loss is greatly reduced by antenna motion in the case of earth-station antennas with relatively high gain or by the relatively high transmission losses associated with earth-station antennas having relatively low gain. In all cases, the propagation Mode 2 distances would be less than the propagation Mode 1 (great-circle) distances. However, the Mode 2 mechanism may produce significant interference at shorter separation distances than the Mode 1 coordination distance; thus, during coordination, it is necessary to consider the potential for interference via propagation Mode 2.

Note 3 – The composite method described in Annex 2 is a new procedure that administrations are encouraged to use. Tests of this procedure so far have indicated that it produces a coordination area that is sufficiently large, but smaller than that produced by either the statistical (3%) method or the TIG method in § 2.

Note 4 – The provisions of the TIG method allow some advantage to be taken of the time varying nature of the horizon antenna gain for earth stations using antennas that track non-geostationary space stations. However, no advantage can be applied reliably under this method for earth stations using low-gain antennas (i.e. antennas having a maximum gain less than about 23 dBi generally cannot produce 20 dB or greater differences between the minimum and maximum values of horizon antenna gain).

TABLE 1

Parameters for determination of coordination distance for receiving earth stations operating with non-geostationary space stations

Space radiocommunications service designations		Space research			Space operation		Earth exploration-satellite		Meteorological satellite		
		Near-Earth		Deep space							
		Unmanned	Manned								
Frequency bands (MHz) (1)		1 700-1 710 2 200-2 290		2 290-2 300	1 525-1 530	2 200-2 290	8 025-8 400		1 670-1 710 (14)		7 450-7 550
Modulation at earth station (2)		–	–	–	–	–	N	N	N	N	N
Earth station interference parameters and criteria	p_0 (%)	0.1	0.001	0.001	1.0	1.0	0.02	0.022	0.012	0.012	0.006
	n	2	1	1	1	2	2	2	2	2	2
	p (%)	0.05	0.001	0.001	1.0	0.5	0.01	0.011	0.006	0.006	0.003
	N_L (dB) (3)	–	–	–	–	–	–	–	–	–	1
	M_s (dB) (4)	–	–	–	–	–	–	–	–	–	24
	W (dB) (5)	–	–	–	0	0	0	0	0	0	0
Terrestrial station parameters	E (dBW) A	62 (6)	62 (6)	62 (6)	50	62 (7)	55	55	92 (7)	92 (7)	55
	E (dBW) N	–	–	–	37	–	42	42	–	–	–
	P_t (dBW) A	10 (6)	10 (6)	10 (6)	13	10 (7)	13	13	40 (7)	40 (7)	13
	P_t (dBW) N	–	–	–	0	–	0	0	–	–	–
	ΔG (dB)	10 (6)	10 (6)	10 (6)	–5	10 (7)	0	0	10 (7)	10 (7)	0
Reference bandwidth(8)	B (Hz)	1	1	1	10^3	10^3	100×10^6 (9)	40×10^6 (9)	5.33×10^6	1.334×10^6	10^6
Threshold interference level	$P_r(p)$ (dBW) in B	–216	–216	–222	–184	–184	–118 (10)	–126 (11)	–124 (12)	–144 (13)	–142

Notes to Table 1:

(1) The allocated frequency bands are given in RR Article 8.

(2) A: analogue modulation; N: digital modulation.

(3) (4) (5) See Notes 2, 3 and 4 in § 2.3.1 of Annex 1 to Recommendation ITU-R IS.847.

(6) In these bands, the parameters for the terrestrial stations associated with trans-horizon systems have been used.

For the space research service only, when trans-horizon systems are not considered, assuming that they are estimated for 1 Hz bandwidth and are 30 dB below the total power assumed for emission, the following values may be used:

$E = 20$ dB, $P_t = -17$ dBW, $\Delta G = -5$ dB for analogue terrestrial stations

$E = -23$ dB, $P_t = -60$ dBW, $\Delta G = -5$ dB for digital terrestrial stations.

(7) In these bands, the parameters for the terrestrial stations associated with trans-horizon systems have been used. If an administration believes that trans-horizon systems do not need to be considered, the line-of-sight radio relay parameters associated with the frequency band (1 525-1 530) MHz may be used to determine the coordination area.

(8) In certain systems it may be desirable to choose a reference bandwidth *B* that differs from the table entry when the system requirements indicate that this may be done. However, because the values of *E* and P_t should not be changed, a greater bandwidth will result in smaller coordination distances, and a later decision to reduce the reference bandwidth may require re-coordination of the earth station. It may also be desirable to decrease the value of the reference bandwidth; for example, for narrow-band transmissions the reference bandwidth *B* might be assumed to be equal to the narrower bandwidth occupied by the wanted transmissions.

(9) In certain cases it is necessary to consider a smaller reference bandwidth *B* due to the characteristics of the systems. For these cases, the reference bandwidth *B* should be assumed to be equal to the real bandwidth occupied or 1 MHz, whichever is greater, and the threshold interference criteria would be adopted proportionally (for example, if $P_r(p)$ is –118 dBW in 100 MHz, then $P_r(p)$ can be taken as –138 dBW in 1 MHz).

(10) This value applies for an earth station used for recorded data acquisition and with an antenna gain of 55.2 dBi (9 m diameter). For other antenna gains, the level of total permissible interference changes in direct proportion to the change in antenna gain.

(11) This value applies for an earth station used for direct data readout and with an antenna gain of 36.4 dBi (1 m diameter). For other antenna gains, the level of total permissible interference changes in direct proportion to the change in antenna gain.

(12) This value applies for an earth station with an antenna gain of 46.8 dBi (15.9 m diameter). For other antennas, in the range 39 dBi (6.5 m diameter) $< \sigma < 46.8$, $P_r(p) = \sigma - 170.8$ dBW.

(13) This value applies for an earth station with an antenna gain of 29.8 dBi (2.2 m diameter). For antennas having other gain values of σ ($\sigma \leq 38$ dBi), the appropriate values of $P_r(p)$ are as follows:

$P_r(p) = -144$	dBW	for	$\sigma \leq 30$ dBi (2.3 m diameter)
$P_r(p) = 2(\sigma - 30) - 144$	dBW	for 30 dBi	$< \sigma \leq 34$ dBi (3.6 m diameter)
$P_r(p) = \sigma - 170$	dBW	for 34 dBi	$< \sigma < 38$ dBi (5.8 m diameter)

(14) In the band 1 670-1 700 MHz, an additional contour for coordination with the meteorological aids service is required. See Table 2 of Recommendation ITU-R IS.850 for details of the calculation.

Note 5 – In cases where § 3 is applicable, propagation Mode 2 distances should be determined and applied for the geostationary-satellite operations as described in Recommendation ITU-R IS.847. In these cases, the coordination distance on any particular azimuth is the greater of the distances determined for geostationary-satellite operation (propagation Modes 1 and 2) and non-geostationary space station operation (propagation Mode 1 only).

ANNEX 1

Applicable statistics of horizon antenna gain

Cumulative distributions of horizon antenna gain are needed for each azimuth in order to determine:

– the horizon antenna gain exceeded for 3% of the time, and

– the probability densities of horizon antenna gain in cases where the coordination contour is to be calculated by the composite method.

These distributions are determined as indicated below. Space station flight simulation software, or other means, can be used to determine the statistics of earth station antenna pointing and, hence, the statistics of horizon antenna gain on particular azimuths. Reference or measured antenna radiation patterns may be used as described in Appendix 1 to Annex 1 of Recommendation ITU-R IS.847. Consistent with the purpose of this Recommendation, it is essential that the applied statistics of horizon antenna gain do not underestimate the actual statistical values.

In the case where the earth station is receiving, the applicable interference threshold $P_r(p)$ is specified with respect to the percentage of time during reception. Thus, the horizon antenna gain statistics are to be specified with respect to the total time that the receiver is in operation rather than the total elapsed time. The statistics pertain to all anticipated earth station operation for reception except that involving geostationary satellites. Thus, in considering earth station operations with space stations in various orbits or trajectories, the percentage of time during which a given horizon antenna gain is exceeded is the maximum of the percentages of time that the gain level is exceeded when operating with each space station. Because the temporal probabilities are normalized by total time of reception for each type of operation, there is some tolerance for overlooking certain earth station operations that may lead to higher values of horizon antenna gain exceeded for a given percentage of time. These omissions generally lead to at most a small underestimation of horizon antenna gain exceeded for 3% of the time (e.g. 1 dB error) and consequently the coordination contour remains reliable. Furthermore, in cases where a coordination contour is being calculated by the composite method, the effective error in the resulting coordination distance will be reduced by virtue of the convolution process (which applies conservatively low values of basic transmission loss).

In the case of a transmitting earth station, the antenna gain statistics are specified with respect to total elapsed time regardless of whether the earth station is being operated over all the elapsed time. This is necessary for consistency with the interference thresholds specified for terrestrial services.

Thus, it is essential that all envisaged earth station operations corresponding with the busiest foreseen operating schedule be carefully considered in a manner that yields worst-month statistics for horizon antenna gain. (Worst-month statistics of horizon antenna gain are the statistics associated with the 30 contiguous days of earth station operation that yield the highest level of horizon antenna gain exceeded for 3% of the time. In many cases, the most intensive possible earth station operational schedule and the types of associated space station orbits/trajectories can be defined to serve as a basis for calculating the worst-month statistics.)

ANNEX 2

Coordination area for earth stations with tracking antennas Determination by the composite method

1. Introduction

This Annex modifies the methodology of Annex 1 to Recommendation ITU-R IS.847 in order to obtain coordination distances that are consistent with the relatively low horizon antenna gain levels that occur for large percentages of the time in certain earth stations that operate with non-geostationary space stations.

Under the composite method, the coordination contour is determined using calculations that precisely apply the temporal statistics associated with the basic transmission loss and the horizon antenna gain of an earth station. Consequently, the distances determined with this approach are smaller than the coordination distances determined by the statistical (3%) method, which necessarily makes conservative assumptions for the purposes of simplification. 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.

The composite method requires use of relatively complex calculations which should only be applied by agreement with affected administrations. All terminology and parameter symbols used herein are defined in Recommendation ITU-R IS.847 except where definitions are included in this Annex.

The coordination contour determined by the composite method uses an alternative form of equation (2) of Recommendation ITU-R IS.847, which involves an iterative calculation that converges to the coordination distance. The equation upon which the iterations are based is expressed as:

$$I(p) = P_{t'} + G_{terr} + [G_{es} - L_b(d')]\,(p) \tag{1a}$$

$$e = P_r(p) - I(p) \tag{1b}$$

$$d_{m1} = d', \text{ when } 0 < e < 0.5 \text{ dB} \tag{1c}$$

where:

$I(p)$: interference power level (dBW) in the reference bandwidth predicted to occur for no more than p% of the time at the receiver antenna port

$P_{t'}$: transmitter power (dBW) in the reference bandwidth at the input to the antenna of the potentially interfering station (see more complete definition in Recommendation ITU-R IS.847)

G_{terr} : antenna gain (dBi) of the terrestrial station

G_{es} : antenna gain (dBi) of the earth station towards the physical horizon (i.e., the horizon antenna gain)

$L_b(d')$: basic transmission loss (dB) on a path of length d'

d' : estimated coordination distance (km)

e : amount (dB) by which the coordination threshold level of interfering signal power exceeds the level of interfering signal power predicted to occur at the estimated coordination distance

$P_r(p)$: coordination threshold level (dBW) of interfering signal power in the reference bandwidth

d_{m1} : coordination distance (km), which results from iterative application of equations (1a) and (1b).

2. Determination of values of the function $[G_{es} - L_b(d')](p)$

A value for the function $[G_{es} - L_b(d')](p)$ is determined from a cumulative distribution that is calculated from the convolution of the temporal probability densities of G_{es} and $L_b(d')$. These probability densities, in turn, are determined from the cumulative distributions of G_{es} and $L_b(d')$. The cumulative distribution of earth station antenna gain is determined in accordance with Annex 1.

The cumulative distribution of $L_b(d')$ is constructed from statistics calculated using the method of § 3 of Annex 1 to Recommendation ITU-R IS.847, as supplemented in § 4 of this Annex. Logarithmic interpolation is used to fashion a continuous cumulative distribution from the statistics calculated as follows.

$p \leq 0.0001$: $L_b(d') = L_b(0.001) - 10$ dB

$$\left.\begin{array}{l} p = 0.001 \\ p = 0.01 \\ p = 0.1 \\ p = 1.0 \\ p = 10.0 \end{array}\right\} \quad \text{Values are calculated using § 3 of Annex 1 to Recommendation ITU-R IS.847}$$

$p = 50.0$: $L_b(d')$ = calculated in accordance with § 4

$p = 90.0$: $L_b(d') = (2 \times L_b(50)) - L_b(10.0)$

$p = 99.0$: $L_b(d') = (2 \times L_b(50)) - L_b(1.0)$

$p = 99.9$: $L_b(d') = (2 \times L_b(50)) - L_b(0.1)$

$p \geq 99.99$ $L_b(d') = L_b(99.9) + 20$ dB

3. Iterative convergence on coordination distance under the composite method

The initial estimate of coordination distance d' should be taken as 95% of the coordination distance resulting from the statistical (3%) method of *recommends* 2. The initial and all successive coordination distance estimates d' are used in equations (1a) and (1b) to determine values for the parameter e, which, in turn, are used to determine the amount by which d' should be incremented. Because all variables and equations in these iterations behave monotonically, a variety of methods can be used to determine successive estimates of d' in order to converge on the coordination distance in accordance with equation (1c). With reference to the parameters distance d_n and specific attenuation β_n defined in § 3 of Annex 1 to Recommendation ITU-R IS.847, equations (15) and (16), one such method for making successive distance estimates is as follows:

$$L_n = d_n \beta_n \tag{2a}$$

$$d' = \frac{L_1 - 0.8\, e}{\beta_1} \qquad \text{for } n = 1 \tag{2b}$$

$$d' = \frac{L_n \text{ (from previous } d' \text{ value)}}{\beta_n \text{ (from previous } d' \text{ value)}} + \sum_{i=1}^{n-1} D_i \quad \text{km} \qquad \text{for } n > 1 \tag{2c}$$

where:

L_n : basic transmission loss component (dB) available from the nth section of the interfering signal path

d' : next value of estimated coordination distance (km) to be applied in equations (1a) to (1c).

4. Propagation loss exceeded for all but 50% of the time

The basic transmission loss exceeded for all but 50% of the time is calculated using:

$$L_b(50) = 137 + k(f) + 20 \log d' + 0.09 d' + 0.075 \left| \zeta \right| + A_g \tag{3}$$

where:

L_b (50): basic transmission loss (dB) exceeded for all but 50% of the time

$$k(f) = \begin{cases} 30 \log (f) & \text{for } f \leq 2 \text{ GHz} \\ 3 + 20 \log (f) & \text{for } f > 2 \text{ GHz} \end{cases}$$

f: frequency (GHz)

d': estimated coordination distance (km)

ζ: latitude of earth station (degrees)

A_g: gaseous attenuation (dB)

A_g = $(\beta_o + \beta_v) d'$

β_o, β_v are as defined in Recommendation ITU-R IS.847.

ANNEX 3

Example calculations of coordination distance for an earth station operating with satellites in low earth orbit

1. Introduction

This Annex presents example calculations of coordination distance for one azimuth using the methods of *recommends* 2. The parameters used in this example are provided in Table 2.

The cumulative distribution of horizon antenna gain generated for the azimuth under consideration in this example as required for the statistical method, is provided in Table 3.

2. Time-invariant gain (TIG) method

From the antenna pattern, minimum antenna elevation angle, and physical horizon angle specified for the earth station in Table 2, the difference between the maximum and minimum values for horizon antenna gain is found to be 30.6 – (–1.4) dB or 32 dB. Thus, the horizon antenna gain to be used in equation (2) of Recommendation ITU-R IS.847 is 20.6 dBi (30.6 dBi – 10 dB).

From equation (2) of Recommendation ITU-R IS.847 and the parameters in Table 2, above:

$$L_b(0.006) = 37 + 20.6 - (-144)$$

$$= 201.6 \text{ dB}$$

From § 3.2 of Annex 1 to Recommendation ITU-R IS.847:

$$L_1 = 201.6 - 120 - 20 \log 1.7 - \log 0.006 - 5(0.006)^{0.5} - \left(20 \log \left[1 + (4.5)(3)(1.72)^{0.5}\right] + 3(1.7)^{0.33}\right)$$

$$= 49.9 \text{ dB}$$

$$\beta_i (0.006) = 0.01 + \left[0.04 + 0.05 \log 1.7 + 0.16(0.006)^{0.1}\right] + 0.0 + 0.0$$

$$= 0.157 \text{ dB/km}$$

$$d_1 = 318 \text{ km.}$$

TABLE 2

Receiving earth station and satellite orbit parameters used to determine coordination distance with respect to a digital terrestrial station

Earth station type	Meteorological, receiving
Latitude (degrees)	37.5
Frequency (GHz)	1.70
Antenna diameter (m)	2.46
Minimum operating elevation angle (degrees)	3
Gain pattern (dBi): $G(\varphi) = \begin{cases} 30.6 - (2.5 \times 10^{-3})(14\,\varphi)^2 & \text{for } \varphi < 5.4° \\ 16.2 & \text{for } 5.4° \leq \varphi < 9.4° \\ 40.5 - 25 \log \varphi & \text{for } 9.4° \leq \varphi < 48° \\ -1.4 & \text{for } \varphi \geq 48° \end{cases}$	
Orbit parameters	
Multiple satellites with similar ephemerides	
Inclination (degrees)	98.89
Altitude (km)	825
Receiver parameters	
$P_r(p)$ (dBW)	–144
Percentage of time (p)	0.006
Terrestrial station	
Transmit power ($P_{t'}$) (dBW)	0
Mainbeam gain (G_{terr}) (dBi)	37
Gain adjustment (G) (dB)	–5
Analysis parameters	
Interferer azimuth (degrees)	90
Radio climatic zone	A2
Physical horizon (degrees)	3

TABLE 3

Statistics of horizon antenna gain for example receiving earth station

Earth station horizon antenna gain (dBi)	Percentage of reception time gain is exceeded (four significant digits)
30.6	0.0000
24.0	0.0195
23.0	0.0585
22.0	0.0975
21.0	0.0976
20.0	0.1365
19.0	0.6632
18.0	0.8192
17.0	1.1313
16.0	1.3068
15.0	1.6189
14.0	2.0285
13.0	2.4966
12.0	2.9647
11.0	3.5303
10.0	4.1935
9.0	5.0322
8.0	5.9294
7.0	6.8851
6.0	8.0164
5.0	9.3037
4.0	10.8250
3.0	12.4144
2.0	14.2383
1.0	16.2863
0.0	18.4708
–1.0	20.9674
–1.4	22.2157

3. Statistical method

From interpolation of the statistics of antenna horizon gain given in Table 3, the horizon antenna gain exceeded for 3% of the time is 11.9 dBi. This yields:

$$L_b(0.006) = 192.9 \text{ dB}$$

$$L_1 = 41.1 \text{ dB}$$

$$\beta_i(0.006) = 0.157 \text{ dB/km (as determined in § 2 above)}$$

$$d_1 = 262 \text{ km.}$$

4. Resulting coordination distance for example problem

Because the 262 km coordination distance determined by the statistical method is smaller than that determined by the time-invariant gain (TIG) method (318 km), the coordination distance in the azimuth under consideration is 262 km and the statistical method is to be used to determine coordination distances for all azimuths.