RECOMMENDATION ITU-R BO.1443-2

Reference BSS earth station antenna patterns for use in interference assessment involving non-GSO satellites in frequency bands covered by RR Appendix 30*

(Question ITU-R 73/6)

(2000-2002-2006)

Scope

This Recommendation intends to provide tri-dimensional reference earth station antenna patterns for the broadcasting-satellite service (BSS) that can be used for the calculation of interference generated by non-GSO FSS satellites into BSS earth station antennas.

The ITU Radiocommunication Assembly,

considering

a) that for earth station antennas in the BSS the reference antenna radiation patterns for GSO BSS receive antennas in Annex 5 to RR Appendix 30 were used to develop the BSS Plans and prescribe a reference radiation pattern which represents an envelope of the side lobes;

b) that such reference radiation patterns are necessary for interference calculations involving fixed or transportable BSS receivers and GSO satellites to ensure adequate protection of the BSS Plans;

c) that in circumstances where there are multiple interfering sources whose positions vary substantially with time, the level of interference received inevitably depends on the troughs as well as the peaks in the gain pattern of the victim BSS earth station antenna;

d) that for BSS earth stations, suitable reference radiation patterns are needed for use in assessing interference from non-GSO FSS systems;

e) that to facilitate computer simulations of interference, the reference patterns should cover all off-axis angles from 0° to ±180° in all planes;

f) that the reference patterns should be consistent with the results of measurements on a wide range of consumer BSS earth station antennas;

g) that it is appropriate to establish different reference patterns for different ranges of antenna sizes;

h) that the patterns may exhibit characteristics that may be important when modelling non-GSO interference, for example in the case of small offset-fed antennas,

* The basis for the patterns contained in this Recommendation, including the methodology for analysing and plotting the data which measures the goodness of fit of the data sets to the recommended pattern are contained in Report ITU-R BO.2029 – Broadcasting-satellite service earth station antenna pattern measurements and related analyses. This Report along with the raw data sets and the spread sheets used to perform the graphical analysis are contained on a CD-ROM available from ITU.

recommends

1 that for calculations of interference generated by non-GSO FSS satellites into BSS earth station antennas, the reference earth station antenna radiation patterns described in Annex 1 should be employed;

2 that the methodology described in Annex 2 be used to convert the relative azimuth and elevation angle of the non-GSO satellite under investigation into the same coordinate system as employed for the three-dimensional antenna pattern;

3 that the following Notes be considered part of this Recommendation:

NOTE 1 – The cross-polarization radiation pattern may be of importance in non-GSO interference calculations. This issue requires further study.

NOTE 2 – This Recommendation is based on measurements and analysis of paraboloid antennas. If new earth station antennas are developed or are considered for use in the BSS, the reference antenna patterns in this Recommendation should be updated accordingly.

Annex 1

Reference BSS antenna radiation patterns

For $11 \leq D/\lambda \leq 25.5$

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D\varphi}{\lambda} \right)^2 \qquad \text{for} \qquad 0 \leq \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad \text{for} \qquad \varphi_m \leq \varphi < 95\lambda/D$$

$$G(\varphi) = 29 - 25 \log(\varphi) \qquad \text{for} \qquad 95\lambda/D \leq \varphi < 36.3°$$

$$G(\varphi) = -10 \qquad \text{for} \qquad 36.3° \leq \varphi < 50°$$

for $56.25° \leq \theta < 123.75°$

$$G(\varphi) = M_1 \cdot \log(\varphi) - b_1 \qquad \text{for} \quad 50° \leq \varphi < 90°$$

$$G(\varphi) = M_2 \cdot \log(\varphi) - b_2 \qquad \text{for} \quad 90° \leq \varphi < 180°$$

where:

$$M_1 = \frac{2 + 8 \cdot \sin(\theta)}{\log\left(\frac{90}{50}\right)} \qquad \text{and} \qquad b_1 = M_1 \cdot \log(50) + 10$$

where:

$$M_2 = \frac{-9 - 8 \cdot \sin(\theta)}{\log\left(\frac{180}{90}\right)} \qquad \text{and} \qquad b_2 = M_2 \cdot \log(180) + 17$$

for $0° \le \theta < 56.25°$ and $123.75° \le \theta < 180°$

$$G(\varphi) = M_3 \cdot \log(\varphi) - b_3 \qquad \text{for} \quad 50° \le \varphi < 120°$$

$$G(\varphi) = M_4 \cdot \log(\varphi) - b_4 \qquad \text{for} \quad 120° \le \varphi < 180°$$

where:

$$M_3 = \frac{2 + 8 \cdot \sin(\theta)}{\log\left(\frac{120}{50}\right)} \qquad \text{and} \qquad b_3 = M_3 \cdot \log(50) + 10$$

where:

$$M_4 = \frac{-9 - 8 \cdot \sin(\theta)}{\log\left(\frac{180}{120}\right)} \qquad \text{and} \qquad b_4 = M_4 \cdot \log(180) + 17$$

for $180° \le \theta < 360°$

$$G(\varphi) = M_5 \cdot \log(\varphi) - b_5 \qquad \text{for} \quad 50° \le \varphi < 120°$$

$$G(\varphi) = M_6 \cdot \log(\varphi) - b_6 \qquad \text{for} \quad 120° \le \varphi < 180°$$

where:

$$M_5 = \frac{2}{\log\left(\frac{120}{50}\right)} \qquad \text{and} \qquad b_5 = M_5 \cdot \log(50) + 10$$

where:

$$M_6 = \frac{-9}{\log\left(\frac{180}{120}\right)} \qquad \text{and} \qquad b_6 = M_6 \cdot \log(180) + 17$$

where:

D: antenna diameter

λ: wavelength expressed in the same unit as the diameter

G: gain

φ: off-axis angle of the antenna relative to boresight (degrees)

θ: planar angle of the antenna (degrees) (0° azimuth is the horizontal plane).

$$G_{max} = 20 \log\left(\frac{D}{\lambda}\right) + 8.1 \qquad \text{dBi}$$

$$G_1 = 29 - 25 \log\left(95 \frac{\lambda}{D}\right) \qquad \text{dBi}$$

$$\varphi_m = \frac{\lambda}{D} \sqrt{\frac{G_{max} - G_1}{0.0025}} \qquad \text{degrees}$$

For $25.5 < D/\lambda \le 100$

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} (D\varphi/\lambda)^2 \qquad \text{dBi} \qquad \text{for} \qquad 0 < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad \text{for} \qquad \varphi_m \le \varphi < (95\lambda/D)$$

$$G(\varphi) = 29 - 25 \log \varphi \qquad \text{dBi} \qquad \text{for} \qquad (95\lambda/D) \le \varphi < 33.1°$$

$G(\varphi) = -9$	dBi	for	$33.1° < \varphi \leq 80°$
$G(\varphi) = -4$	dBi	for	$80° < \varphi \leq 120°$
$G(\varphi) = -9$	dBi	for	$120° < \varphi \leq 180°$

where:

$$G_{max} = 20 \log (D/\lambda) + 8.1 \quad \text{dBi}$$

$$G_1 = 29 - 25 \log (95\lambda/D) \quad \text{dBi}$$

$$\varphi_m = (\lambda/D) \sqrt{\frac{G_{max} - G_1}{0.0025}}$$

For D/λ > 100

$G(\varphi) = G_{max} - 2.5 \times 10^{-3} (D\varphi/\lambda)^2$	dBi	for	$0 < \varphi < \varphi_m$
$G(\varphi) = G_1$		for	$\varphi_m \leq \varphi < \varphi_r$
$G(\varphi) = 29 - 25 \log \varphi$	dBi	for	$\varphi_r \leq \varphi < 10°$
$G(\varphi) = 34 - 30 \log \varphi$	dBi	for	$10° \leq \varphi < 34.1°$
$G(\varphi) = -12$	dBi	for	$34.1° \leq \varphi < 80°$
$G(\varphi) = -7$	dBi	for	$80° \leq \varphi < 120°$
$G(\varphi) = -12$	dBi	for	$120° \leq \varphi < 180°$

where:

$$G_{max} = 20 \log (D/\lambda) + 8.1 \quad \text{dBi}$$

$$G_1 = -1 + 15 \log (D/\lambda) \quad \text{dBi}$$

$$\varphi_m = (\lambda/D) \sqrt{\frac{G_{max} - G_1}{0.0025}}$$

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

Annex 2

Geometric conversions for use with the 3-D antenna model

Definition of θ

θ is defined as the planar angle of the non-GSO satellite relative to the zero degree plane of the antenna model (corresponding to the standard bottom-mounted offset feed assembly). As seen by the earth station, the θ = 0 line is to the right, and θ increases in an anticlockwise direction.

Calculation approach

Figure 1 shows a geometric approach to calculate the planar angle θ. All calculations are shown using degrees, though typically these must be converted into radians when computing trigonometric values.

Inputs

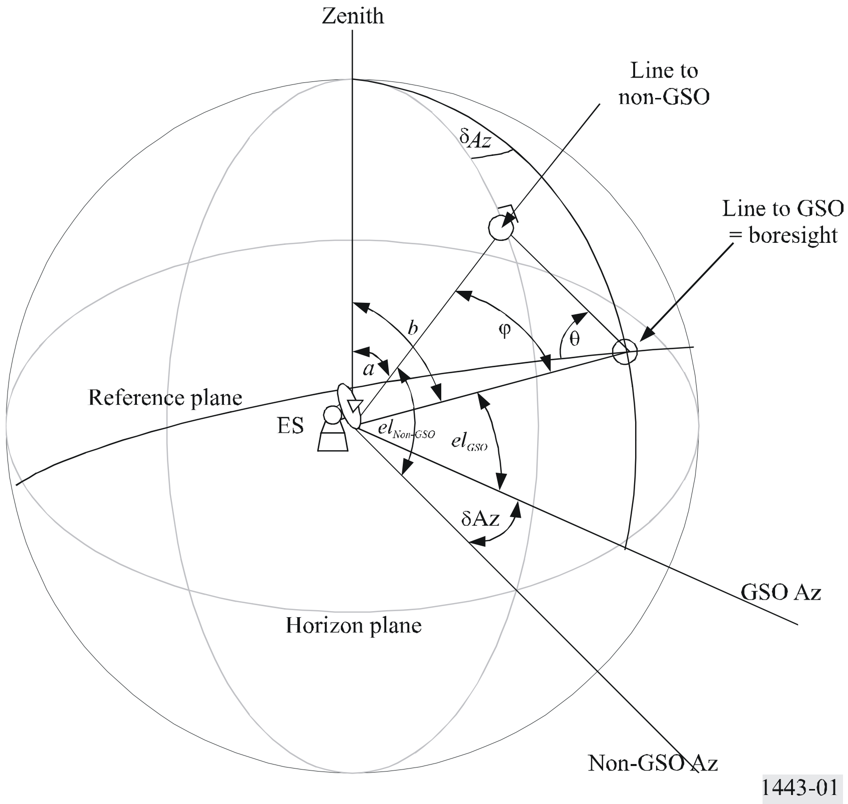
GSO satellite (az, el)

Non-GSO satellite (az, el)

NOTE 1 – What is required is the difference in azimuth, so if that is available the actual azimuths would not be needed.

The following section shows how to calculate these parameters from the vectors of each station.

FIGURE 1



From Fig. 1:

$$a = 90 - el_{non-GSO}$$

$$b = 90 - el_{GSO}$$

$$\delta Az = Az_{non-GSO} - Az_{GSO}$$

δAz should be set to be in the range {–180 to +180}

Then the off-axis angle φ (topocentric separation angle between the satellites) can be calculated by using the spherical geometry formula:

$$\cos(c) = \cos(a)\cos(b) + \sin(a)\sin(b)\cos(C)$$

with $C = \delta Az$ and $c = \varphi$.

The same formula can be used to define an angle B:

$$\cos(B) = \frac{\cos(b) - \cos(c)\cos(a)}{\sin(c)\sin(a)}$$

from which the planar angle θ can be derived:

if ($\delta Az > 0$ and $B < 90$) $\theta = 90 - B$

if ($\delta Az > 0$ and $B > 90$) $\theta = 450 - B$

if ($\delta Az < 0$) $\theta = 90 + B$

In the case that both satellites have the same azimuth and so $\delta Az = 0$, then

$$\varphi = \left| el_{GSO} - el_{non-GSO} \right|$$

if $el_{GSO} > el_{non-GSO}$ $\theta = 270$

else $\theta = 90$

Example data

For the following positions:

Station	Latitude (degrees)	Longitude (degrees)	Height (km)
Earth station	10	20	0
GSO sat	0	30	35 786.055
Non-GSO sat	0	–5	1 469.200

Then for the earth station the following az/els can be calculated (with respect to the earth station horizon and north direction):

Station	Azimuth (degrees)	Elevation (degrees)
GSO sat	134.5615	73.4200
Non-GSO sat	–110.4248	10.0300

Hence the off-axis angles and planar angles are:

Station	φ (off-axis) (degrees)	θ (planar) (degrees)
Non-GSO sat	87.2425	26.69746

Calculation of azimuth and elevation

The following can be used to calculate azimuth and elevation from the vectors involved.

Given:

Position vector of earth station: $\underline{r}_G$

Position vector of GSO satellite: $\underline{r}_S$

Position vector of non-GSO satellite: $\underline{r}_N$

Then create:

Vector from earth station to GSO $\underline{r}_{GS} = \underline{r}_S - \underline{r}_G$

Vector from earth station to non-GSO $\underline{r}_{GN} = \underline{r}_N - \underline{r}_G$

Unit vector of earth station position vector $\hat{\underline{r}}_G$

Then the elevation angles are:

$$el_S = 90 - \angle(\underline{r}_{GS}, \underline{r}_G)$$

$$el_N = 90 - \angle(\underline{r}_{GN}, \underline{r}_G)$$

To calculate the difference in azimuth, convert vectors from earth station to GSO/non-GSO to be in the horizontal plane that is perpendicular to the zenith vector, i.e.

$$\underline{r}'_{GS} = \underline{r}_{GS} - \left(\hat{\underline{r}}_G \cdot \underline{r}_{GS}\right)\hat{\underline{r}}_G$$

$$\underline{r}'_{GN} = \underline{r}_{GN} - \left(\hat{\underline{r}}_G \cdot \underline{r}_{GN}\right)\hat{\underline{r}}_G$$

Then:

$$\delta Az = \angle(\underline{r'_{GS}}, \underline{r'_{GN}})$$

The sign of δAz will be the same as the sign of the difference in longitude of the two satellites.