

RECOMMENDATION ITU-R S.672-4

**SATELLITE ANTENNA RADIATION PATTERN FOR USE AS
A DESIGN OBJECTIVE IN THE FIXED-SATELLITE SERVICE
EMPLOYING GEOSTATIONARY SATELLITES**

(Question ITU-R 41/4)

(1990-1992-1993-1995-1997)

The ITU Radiocommunication Assembly,

considering

- a) that the use of space-station antennas with the best available radiation patterns will lead to the most efficient use of the radio-frequency spectrum and the geostationary orbit;
- b) that both single feed elliptical (or circular) and multiple feed shaped beam antennas are used on operational space stations;
- c) that although improvements are being made in the design of space-station antennas, further information is still required before a reference radiation pattern can be adopted for coordination purposes;
- d) that the adoption of a design objective radiation pattern for space-station antennas will encourage the fabrication and use of orbit-efficient antennas;
- e) that it is only necessary to specify space-station antenna radiation characteristics in directions of potential interference for coordination purposes;
- f) that for wide applicability the mathematical expressions should be as simple as possible consistent with effective predictions;
- g) that nevertheless, the expressions should account for the characteristics of practical antenna systems and be adaptable to emerging technologies;
- h) that measurement difficulties lead to inaccuracies in the modelling of spacecraft antennas at large off-axis angles;
- j) that the size constraints of launch vehicles lead to limitations in the D/λ values of spacecraft antennas, particularly at lower frequencies such as the 6/4 GHz band;
- k) that space-station antenna pattern parameters such as reference point, coverage area, equivalent peak gain, that may be used to define a space-station reference antenna pattern, are found in Annex 1;
- l) that two computer programs have been developed to generate coverage contours (see Annex 2),

recommends

- 1 that for single feed circular or elliptical beam spacecraft antennas in the fixed-satellite service (FSS), the following radiation pattern should be used as a design objective, outside the coverage area:

$$G(\psi) = G_m - 3 (\psi/\psi_b)^\alpha \quad \text{dBi} \quad \text{for} \quad \psi_b \leq \psi \leq a \psi_b \quad (1)$$

$$G(\psi) = G_m + L_N + 20 \log z \quad \text{dBi} \quad \text{for} \quad a \psi_b < \psi \leq 0.5 b \psi_b \quad (2a)$$

$$G(\psi) = G_m + L_N \quad \text{dBi} \quad \text{for} \quad 0.5 b \psi_b < \psi \leq b \psi_b \quad (2b)$$

$$G(\psi) = X - 25 \log \psi \quad \text{dBi} \quad \text{for} \quad b \psi_b < \psi \leq Y \quad (3)$$

$$G(\psi) = L_F \quad \text{dBi} \quad \text{for} \quad Y < \psi \leq 90^\circ \quad (4a)$$

$$G(\psi) = L_B \quad \text{dBi} \quad \text{for} \quad 90^\circ < \psi \leq 180^\circ \quad (4b)$$

where:

$$X = G_m + L_N + 25 \log(b \psi_b) \quad \text{and} \quad Y = b \psi_b 10^{0.04(G_m + L_N - L_F)}$$

$G(\psi)$: gain at the angle ψ from the main beam direction (dBi)

G_m : maximum gain in the main lobe (dBi)

ψ_b : one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)

L_N : near-in-side-lobe level in dB relative to the peak gain required by the system design

L_F = 0 dBi far side-lobe level (dBi)

z : (major axis/minor axis) for the radiated beam

L_B : $15 + L_N + 0.25 G_m + 5 \log z$ dBi or 0 dBi whichever is higher.

NOTE 1 – Patterns applicable to elliptical beams require experimental verification. The values of a in Table 1 are provisional.

TABLE 1

L_N (dB)	a	b	α
–20	$2.58 \sqrt{(1 - \log z)}$	6.32	2
–25	$2.58 \sqrt{(1 - 0.8 \log z)}$	6.32	2
–30	–	6.32	–

The numeric values of a , b , and α for $L_N = -20$ dB and -25 dB side-lobe levels are given in Table 1. The values of a and α for $L_N = -30$ dB require further study. Administrations are invited to provide data to enable the values of a and α for $L_N = -30$ dB to be determined;

2 that for multiple-feed, shaped beam, spacecraft antennas in the FSS, the radiation pattern to be used as a design objective shall be selected from the following formulae depending upon the class of antenna and the range of the scan ratio.

Definition of class of antennas

- Definition of class A antennas:

Class A antennas are those with the boresight location within the coverage area.

- Definition of class B antennas:

Class B antennas are those with the boresight location outside the coverage areas for one or more of the beams.

Definition of scan ratio

There are two definitions of the scan ratio:

The scan ratio δ in § 2.1 is defined as the angular distance between the centre of coverage (defined as the centre of the minimum area ellipse) and a point on the edge-of-coverage, divided by the beamwidth of the component beam.

Scan ratio S used in § 2.2. and 2.3 is defined as the angular distance between the antenna boresight and a point on the edge-of-coverage, divided by the beamwidth of the component beam.

In the initial determination of which *recommends* is applicable to a specific class A antenna, the δ scan ratio definition should be used;

2.1 For class A antennas with scan ratio values $\delta \leq 3.5$:

$$G_{\text{dBi}}(\Delta\psi) = \begin{cases} G_{ep} + 0.256 - 13.065 \left(\frac{\Delta\psi}{Q\psi_0} + 0.5 \right)^2 & \text{for } 0 \leq \frac{\Delta\psi}{\psi_0} \leq 0.8904 Q \\ G_{ep} - 25 & \text{for } 0.8904 Q < \frac{\Delta\psi}{\psi_0} \leq 1.9244 Q \\ G_{ep} - 25 + 20 \log \left(\frac{1.9244 Q \psi_0}{\Delta\psi} \right) & \text{for } 1.9244 Q < \frac{\Delta\psi}{\psi_0} \leq 18/\psi_0 \end{cases}$$

where:

 $\Delta\psi$: angle (degrees) from the convex coverage contour to a point outside the coverage region in a direction normal to the sides of the contour G_{ep} : equivalent peak gain (dBi)

$$= G_e + 3.0$$

 ψ_0 : the half-power beamwidth of component beams (degrees)

$$= 72(\lambda/D)$$

 λ : wavelength (m) D : physical diameter of the reflector (m)

$$Q = 10 \left(\frac{0.000075 (\delta - 1/2)^2}{[(F/D_p)^2 + 0.02]^2} \right)$$

 δ : scan ratio as defined in § 2 F/D_p : ratio of the reflector focal length F to parent parabola diameter D_p

$$D_p = 2(d + h)$$

 d : projected aperture diameter of the offset paraboloid h : offset height to the edge of the reflector.**2.2** that for class A antennas with scan ratio values $S \geq 5$:

$$G_{\text{dBi}}(\Delta\psi) = \begin{cases} G_e - B \left[\left(1 + \frac{\Delta\psi}{\psi_b} \right)^2 - 1 \right] & \text{for } 0^\circ \leq \Delta\psi \leq C \psi_b \\ G_e - 22 & \text{for } C \psi_b < \Delta\psi \leq (C + 4.5) \psi_b \\ G_e - 22 + 20 \log_{10} \left[\frac{(C + 4.5) \psi_b}{\Delta\psi} \right] & \text{for } (C + 4.5) \psi_b < \Delta\psi \leq 18^\circ \end{cases}$$

where:

 $\Delta\psi$: angle (degrees) from the convex coverage contour in a direction normal to the sides of the contour G_e : gain at the edge-of-coverage (dBi)

$$B = B_0 - (S - 1.25) \Delta B \text{ for } S \geq 5$$

$$B_0 = 2.05 + 0.5 (F/D - 1) + 0.0025 D/\lambda$$

$$\Delta B = 1.65 (D/\lambda)^{-0.55}$$

 ψ_b : beamlet radius

$$= 36 \lambda/D$$

 λ : wavelength (m) D : physical diameter of the reflector (m)

$$C = \sqrt{1 + \frac{22}{B}} - 1$$

S : scan ratio as defined in § 2

F/D : ratio of focal length over the physical diameter of the antenna;

2.3 that for class B antennas, which only use scan ratio S (for $S \geq 0$):

$$G_{\text{dBi}}(\Delta\psi) = \begin{cases} G_e - B \left[\left(1 + \frac{\Delta\psi}{\psi_b} \right)^2 - 1 \right] & \text{for } 0^\circ \leq \Delta\psi \leq C \psi_b \\ G_e - 17 + 18.7012 \log_{10} \left(\cos \left[\frac{(\Delta\psi - C \psi_b)}{\psi_b} \right] \right) & \text{for } C \psi_b < \Delta\psi \leq (C + 1) \psi_b \\ G_e - 22 & \text{for } (C + 1) \psi_b < \Delta\psi \leq (C + 4.5) \psi_b \\ G_e - 22 + 20 \log_{10} \left[\frac{(C + 4.5) \psi_b}{\Delta\psi} \right] & \text{for } (C + 4.5) \psi_b < \Delta\psi \leq 18^\circ \end{cases}$$

where:

$\Delta\psi$: angle (degrees) from the convex coverage contour in a direction normal to the sides of the contour

G_e : gain at the edge-of-coverage (dBi)

$B = B_0 - (S - 1.25) \Delta B$ for $S \geq 0$

$B_0 = 2.05 + 0.5 (F/D - 1) + 0.0025 D/\lambda$

$\Delta B = 1.65 (D/\lambda)^{-0.55}$

ψ_b : beamlet radius

$= 36 \lambda/D$

λ : wavelength (m)

D : physical diameter of the reflector (m)

$$C = \sqrt{1 + \frac{17}{B}} - 1$$

S : scan ratio as defined in § 2

F/D : ratio of focal length over the physical diameter of the antenna;

2.4 that for class A antennas with scan ratio values $\delta > 3.5$ and $S < 5$, the design objective is still under study. In particular, studies are required on the extension of the equations given in § 2.1 and 2.2 into this region. One possible method of extending the design objective into this region is described in Annex 1. For the definition of scan ratios δ and S and their application, see § 2;

2.5 that the following Notes shall be considered part of § 2.1 and 2.2:

NOTE 1 – The coverage area shall be defined as the contour constructed from the polygon points surrounding the service area, using the method given in Annex 2.

NOTE 2 – For the cuts, where the –3 dB gain contour is outside of the constructed coverage contour, the design objective pattern should originate from the –3 dB contour.

NOTE 3 – This Recommendation should be applied only in the direction of an interference sensitive system. That is, it need not be applied in directions where the potential for interference to other networks does not exist (e.g. off the edge of the Earth, unpopulated ocean regions). 10% of the cuts may exceed the design objective pattern.

NOTE 4 – This Recommendation does not apply to dual frequency band antennas. Antennas using the reflector induced phase error for beam broadening belong to this category and require further study.

ANNEX 1

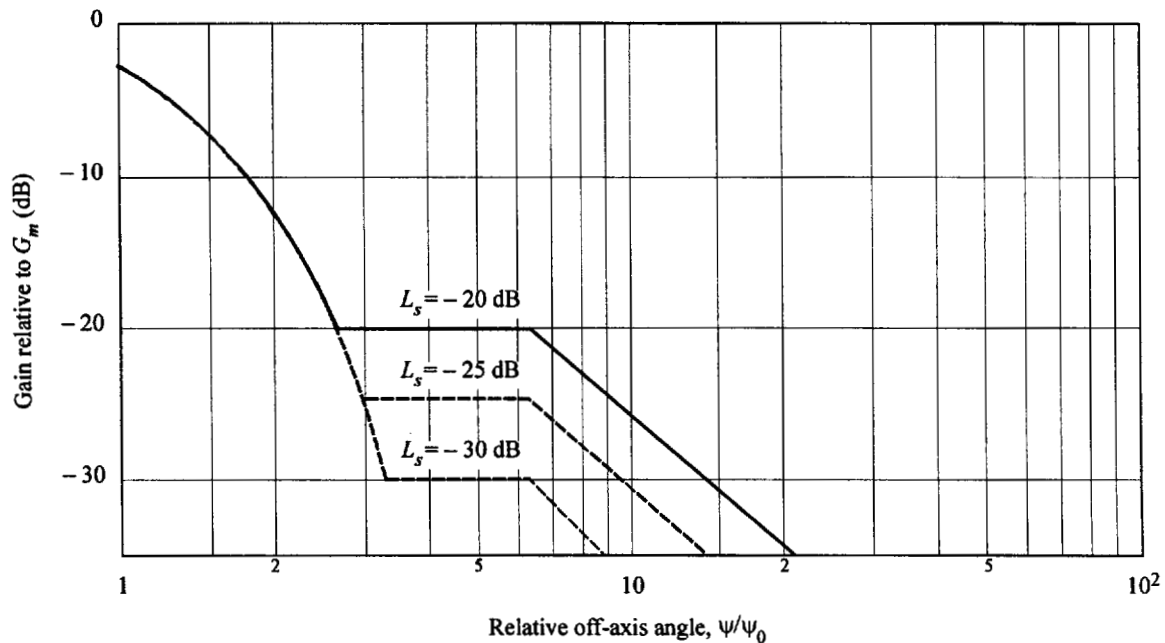
Satellite antenna patterns in the fixed-satellite service

1 Satellite antenna reference radiation patterns

1.1 Single feed circular beams

The radiation pattern of the satellite antenna is important in the region of the main lobe as well as the farther side lobes. Thus, the possible patterns commencing at the -3 dB contour of the main lobe are divided into four regions. These are illustrated in Fig. 1.

FIGURE 1
Radiation pattern envelope functions



$$\begin{aligned}
 G(\psi) &= G_m - 3(\psi/\psi_0)^2 & \text{dBi} & \quad \text{for} \quad \psi_0 \leq \psi \leq a\psi_0 & \quad \text{(I)} \\
 G(\psi) &= G_m + L_s & \text{dBi} & \quad \text{for} \quad a\psi_0 < \psi \leq b\psi_0 & \quad \text{(II)} \\
 G(\psi) &= G_m + L_s + 20 - 25 \log(\psi/\psi_0) & \text{dBi} & \quad \text{for} \quad b\psi_0 < \psi \leq \psi_1 & \quad \text{(III)} \\
 G(\psi) &= 0 & \text{dBi} & \quad \text{for} \quad \psi_1 < \psi & \quad \text{(IV)}
 \end{aligned}$$

where:

- $G(\psi)$: gain at the angle (ψ) from the axis (dBi)
 G_m : maximum gain in the main lobe (dBi)
 ψ_0 : one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)
 ψ_1 : value of (ψ) when $G(\psi)$ in equation (III) is equal to 0 dBi
 L_s : the required near-in-side-lobe level (dB) relative to peak gain
 a, b : the numeric values are given below:

L_s	a	b
-20	2.58	6.32
-25	2.88	6.32
-30	3.16	6.32

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Difficulties arise, however, in attempting to apply the postulated pattern to a non-circular beam. Administrations are therefore requested to submit measured radiation patterns for antennas with other than simple circular beams.

1.2 Single feed elliptical beams

The functions in Fig. 1 define a maximum envelope for the first side lobes at a level of -20 dB relative to peak gain and this pattern applies to antennas of fairly simple designs. However, in the interest of a better utilization of the orbit capacity, it may be desirable to reduce this level to -30 dB and to use antennas of more sophisticated design. The pattern adopted by the World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service, Geneva, 1977 (WARC BS-77) for broadcasting satellite antennas meets this requirement and is now being achieved and should therefore apply in that case. Additional studies may be desirable to ascertain the feasibility of achieving these reduced side-lobe levels in common practice, particularly with respect to the 6/4 GHz bands.

1.3 Multiple feed shaped beams

A similar pattern applicable to shaped beams must be based on analysis of several shaped beams and also on theoretical considerations. Additional parameters must be specified, such as the diameter of the elemental beamlet and the level of the first side lobe. In addition the cross-section and means of measuring angles form part of the pattern definition.

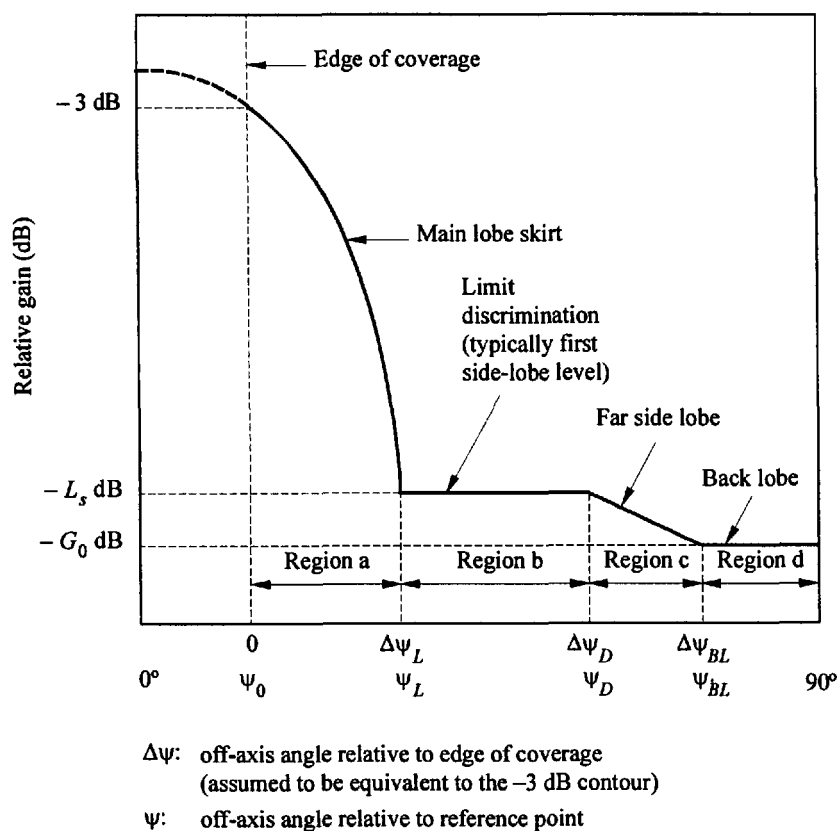
The important consideration in producing such a reference is the discrimination to be achieved from the edge of coverage of all types of antenna, including the most complex shaped beam antenna, as a function of angular separation of the coverage areas as seen from the orbit. The radiation pattern of a shaped beam antenna is unique and it is mainly determined by the following operational and technical factors:

- shape of the coverage area;
- satellite longitude;
- maximum antenna aperture;
- feed design and illumination taper;
- normalized reflector aperture diameter (D/λ);
- focal length to aperture diameter ratio (F/D);
- number of frequency re-use and independent beam ports;
- number of feed elements utilized;
- bandwidths;
- polarization orthogonality requirements;
- total angular coverage region provided;
- stability of feed element phase and amplitude excitations;
- reconfigurability requirements;
- number of orbital positions from which beam coverages must be provided;
- reflector surface tolerances achieved;
- beam pointing (i.e. derived from satellite or independent beam positioning via earth-based tracking beacons);
- component beam degradations due to scan aberrations that are related to the specific reflector or antenna configuration (i.e. single reflector, dual reflector, shaped reflector systems without a focal axis, direct radiating array, etc.).

In view of this, there may be some difficulties in developing a single reference radiation pattern for shaped beam antennas.

The reference pattern of Fig. 1 is unsatisfactory for shaped beam antennas, since a key parameter to the reference pattern is ψ_0 , the -3 dB half-beamwidth, whereas the beam centre of a shaped beam is ill-defined and largely irrelevant to the out-of-beam response. A simple reference pattern consisting of four segments, as illustrated in Fig. 2 might be more satisfactory for the basis of a reference pattern. The slope of the skirt of this pattern would be a function of the angular distance outside the average contour.

FIGURE 2
Possible form of reference radiation pattern



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The particular direction in which to measure this angular distance is also a parameter which needs definition. One method is to measure this angle orthogonally from the constant gain contour which corresponds most closely to the coverage area. Difficulties arise with this method where portions of the gain contours are concave such as occurs with crescent-shaped patterns. For this type of pattern, the orthogonal direction away from a contour could intersect the coverage area again. From an antenna design standpoint, the difficulty in achieving good discrimination in the concave portion of a pattern increases with the degree of concavity. An alternative method which could circumvent these problems is to circumscribe the coverage area by a contour which has no concavity and then measure the angles orthogonally from this contour; this contour being considered as edge of coverage. Other methods of defining the direction of measurement are possible, e.g. the centre of a circumscribing ellipse could be used as a reference point (see § 2.1 and 2.2), but an unambiguous definition is needed for any reference pattern.

Once the direction is defined, the radiation pattern can be separated into four regions of interest:

Region a: Main lobe skirt (edge of coverage to angle of limit discrimination)

This region is assumed to cover what is considered to be adjacent coverage regions. The required isolation between satellite networks would be obtained from a combination of satellite antenna discrimination and orbital separation.

A simple function which could be applied to this region could be in a form similar to that given in equation (I) of Fig. 1.