



Report ITU-R S.2196
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**Methodology on the modelling of earth
station antenna gain in the region of
the antenna main-lobe and the
transition region between the minimum
angle of the reference antenna pattern
and the main-lobe**

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Methodology on the modelling of earth station antenna gain in the region of the antenna main-lobe and the transition region between the minimum angle of the reference antenna pattern and the main-lobe

1 Modelling of the antenna main-lobe

The gain of an elliptical aperture antenna in the main-lobe for a specific angle of rotation with respect to the major axis depends on both the off-axis angle and the D/λ ratio for the *plane of interest*¹. The derivation which follows is the simplified case that assumes the antenna major axis dimension of the antenna aperture is parallel to the *GSO plane*². Models for calculating the D/λ ratio for the plane of interest for other antenna shapes and for elliptical antennas which do not conform to this simplified case can also be developed. The model for the simplified case of an elliptical antenna is developed below:

The dimensions of the antenna aperture in the GSO plane and the plane perpendicular to the GSO plane can be related to one another and to the equivalent diameter using the defined ratio K where:

$$D_{GSO} = \sqrt{K} \cdot D_{eq} \quad (1)$$

$$D_{\perp GSO} = \frac{D_{GSO}}{K} \quad (2)$$

where:

D_{GSO} is the antenna dimension in the geostationary orbit plane;

$D_{\perp GSO}$ is the antenna dimension in the plane perpendicular to D_{GSO} ;

D_{eq} is the equivalent circular diameter of the physical antenna;

K is the ratio of the perpendicular dimensions D_{GSO} to $D_{\perp GSO}$ and the antenna boresight is normal to the plane containing the dimensions D_{GSO} and $D_{\perp GSO}$.

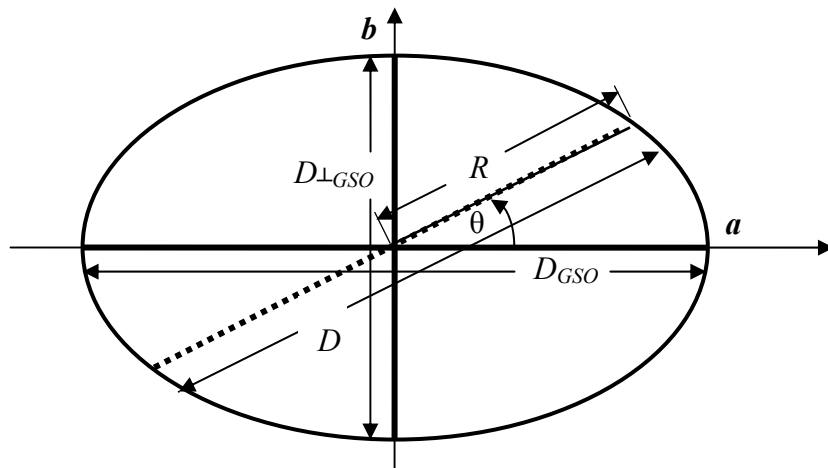
For elliptical antenna pattern, the values of D_{GSO} and $D_{\perp GSO}$ can be applied to an ellipse equation to calculate the antenna dimension D in the plane of interest. Figure 1 shows the relationship between D (represented by dotted line) and the ellipse in the plane of interest given by the angle θ .

Figure 1

¹ The plane of interest is the plane passing through the antenna boresight and the direction of interest.

² The term “GSO plane”, which is used throughout shall be interpreted as the plane containing the tangent to the part of the GSO arc aligned with D_{GSO} (see Figure 1) and the earth station.

FIGURE 1



D_{GSO} and $D_{\perp GSO}$ are the dimensions of major axis and minor axes respectively of the elliptical antenna. Replace the semi-major axis a and semi-minor axis b of the ellipse equation with $\frac{D_{GSO}}{2}$ and $\frac{D_{\perp GSO}}{2}$ respectively, so that in rectangular coordinates:

$$\frac{x^2}{\left(\frac{D_{GSO}}{2}\right)^2} + \frac{y^2}{\left(\frac{D_{\perp GSO}}{2}\right)^2} = 1 \quad (3)$$

Assuming the major axis of the antenna is aligned with the geostationary orbit plane and θ represents the angle of rotation in a counter-clockwise direction about the main beam direction, the antenna “dimension” (of the antenna aperture in the plane parallel to the boresight axis, passing through the direction of interest and the boresight axis) can be expressed as a function of the rotation angle θ . Therefore, x and y in (3) can be expressed as:

$$x = R \cdot \cos \theta \quad (4)$$

$$y = R \cdot \sin \theta \quad (5)$$

where:

- D the dimension, in metres, of the antenna aperture in the *plane of interest* as shown in Figure 1;
- R the “radius” of the antenna aperture in the *plane of interest* ($=D/2$);
- θ the angle, in degrees, between the plane containing the boresight and the dimension D_{GSO} and the *plane of interest*, where the *plane of interest* passes through the boresight and the direction of interest (see Figure 1).

Replacing x and y in (3) by (4) and (5), and R with $D/2$, the antenna dimension D in the plane of interest can be expressed as follows:

$$D = \frac{D_{\perp GSO}}{\sqrt{\sin^2 \theta + \left(\frac{D_{\perp GSO}}{D_{GSO}} \right)^2 \cos^2 \theta}} \quad (6)$$

Substitute equation (2) into equation (6), it gives:

$$D = \frac{D_{\perp GSO}}{\sqrt{\sin^2 \theta + \left(\frac{1}{K} \right)^2 \cos^2 \theta}} \quad (7)$$

To simplify the notation, the denominator of equation (7) is defined as rotation factor F , which is a function of the rotation angle θ and the D_{GSO} to $D_{\perp GSO}$ ratio K . Therefore,

$$D = \frac{D_{\perp GSO}}{F} \quad (8)$$

where:

$$F(\theta, K) = \sqrt{\sin^2 \theta + \left(\frac{1}{K} \right)^2 \cos^2 \theta} \quad (9)$$

For a given antenna, having a major-to-minor axis ratio K , the value of F can be expressed as a function of the rotation angle θ . Therefore, in a plane of interest of a given antenna, having a major-to-minor axis ratio K , D is simply a function of θ .

2 Modelling the antenna main-lobe given a side-lobe reference pattern

Modelling the transition region between the main-lobe of an antenna and the side-lobe envelope requires knowledge of the reference pattern depicting the antenna's side-lobe envelope. The main-lobe of an antenna and the transition region between the main-lobe and the side-lobe envelope can be modelled for two types of side-lobe reference patterns. The methodologies in this Report may be used with either Recommendation ITU-R S.465-6 or Recommendation ITU-R S.1855. Although the intersection point in this model where the envelope of the side-lobe reference pattern intersects the antenna main lobe is equal to the main-lobe gain in equation (10), the actual gain in this vicinity may be considerably less. In fact, the first null of a parabolic reflector type antenna occurs very near this intersection point. The actual location of the null will be determined by a number of factors including type of illumination. The antenna main lobe model in equation (10) assumes a uniform illumination resulting in a wider main lobe and thus results in a conservative estimate of gain at the intersection point. The very small transition region between this intersection point and the minimum angle applicable to the side-lobe reference pattern follows the applicable side-lobe reference pattern.

2.1 Modelling the antenna main-lobe assuming a side-lobe reference envelope of Recommendation ITU-R S.465-6

2.1.1 Main-lobe definition

Using the main-lobe definition that can be found in Annex 3 of RR Appendix 8:

$$G(\varphi) = G_{\max} - 0.0025 \left(\frac{D}{\lambda} \varphi \right)^2 \quad \text{for } 0 < \varphi < \varphi_m \quad (10)$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi \leq \varphi_p \quad (11)$$

where:

$$G_1 = 2 + 15 \log \left(\frac{D}{\lambda} \right) \quad \text{dBi} \quad (12)$$

$$\varphi_m = \frac{20\lambda}{D} \sqrt{G_{\max} - G_1} \quad \text{degrees} \quad (13)$$

$$\varphi_r = 15.85 \left(\frac{D}{\lambda} \right)^{-0.6} \quad \text{degrees} \quad (14)$$

$$\varphi_p = \text{Max} (\varphi_r ; 100 \lambda/D) \quad \text{degrees} \quad (15)$$

For further calculation, we may approximate $G_{\max}$ by the formula:

$$G_{\max} = 10 \log \left(\eta \pi^2 \left(\frac{D}{\lambda} \right)^2 \right) \quad (16)$$

where:

η = antenna aperture efficiency (fraction <1).

2.1.2 Intersection φ_{int} between the main-lobe or the first side-lobe G_1 and the side-lobe envelope

For larger values of D/λ (where $\varphi_r > \varphi_m$), the intersection that occurs is between the first side-lobe G_1 and the side-lobe envelope ($32 - 25 \log(\varphi)$) and is defined by:

$$G_1 = 32 - 25 \log(\varphi_r) \quad (17)$$

$$\varphi_r = 15.85 \left(\frac{D}{\lambda} \right)^{-0.6} \quad (18)$$

However, this value is correct provided that φ_r is greater than φ_m . In the case that φ_r is less than φ_m , the intersection (φ_{int}) between the main-lobe and the side-lobe envelope ($32 - 25 \log(\varphi)$) is then determined by solving the following expression:

$$G_{\max} - 0.0025 \left(\frac{D}{\lambda} \varphi_{\text{int}} \right)^2 = 32 - 25 \log(\varphi_{\text{int}}) \quad (19)$$

Figures 2 and 3 below show that φ_{int} is greater than φ_m for D/λ varying between 45.00 and 54.45, according to the value of the aperture efficiency.

FIGURE 2

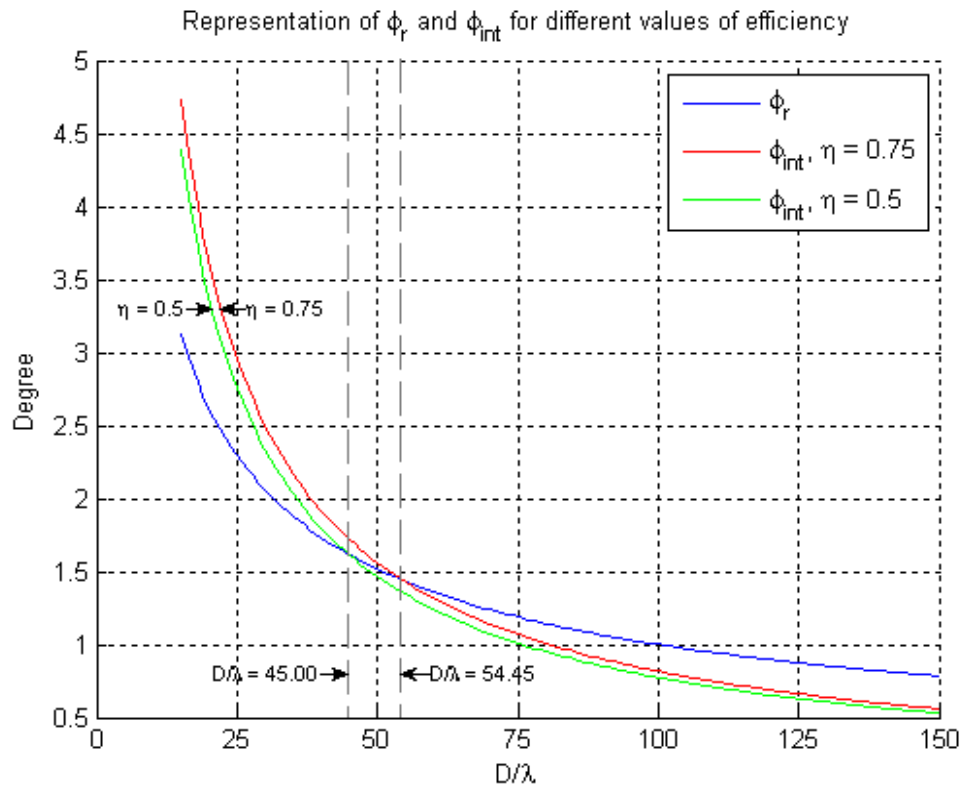


FIGURE 3

