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Idealized Antenna Patterns for use in Communication-Satellite Interference Studies

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Abstract

Antenna patterns to represent earth station antennas of communication-satellite systems are derived from available published data. The patterns include an analytic expression describing the main beam and first side lobe. Higher order side lobes are specified in terms of smoothed mean power levels of these side lobes.

Key Words

Antenna, communication-satellite, earth station, interference idealized radiation pattern.

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Introduction

Recent work has shown that scattering from precipitation may be an important factor in determining the probability of interference between an earth station and a terrestrial radio-relay station operating on the same frequency [1, 2]. The authors have discussed a procedure for calculating rain-scattered radio wave power levels between such stations [3]. These calculations require a knowledge of the power gain and polarization characteristics of each antenna in any direction from which a signal may be expected. This article presents idealized principal polarization gain patterns for comparing various interference models when no particular antenna characteristics are specified.

Antenna Gain Characteristics

Figure 1 shows a set of polar coordinates, ϕ and θ, with ϕ the angle between the axis of the main beam of an antenna and any given direction and θ the azimuth angle measured in the xy plane from the positive x axis. The idealized antenna pattern is assumed to have axial symmetry about the main beam axis and hence the gain is independent of θ and may be expressed as a function of ϕ alone. Since antenna gains are dependent on antenna diameters, D, and operating wavelengths, λ, it turns out that ϕ is not the most convenient coordinate in which to specify the gain. A more natural parameter is derived from ϕ by the relation

$$u = \frac{\pi D}{\lambda} \sin \phi. \qquad (1)$$

This parameter is more useful because the entire antenna pattern can now be expressed in terms of one variable and the normalizing procedure, discussed below, is simplified considerably.

The idealized antenna pattern has a main beam and first side lobe described by

$$g_1 = \left(\frac{\pi D}{\lambda}\right)^2 (\sin u/u)^2. \qquad (2)$$

A graph of this function is shown in figure 2 which was taken from Silver [4]. As the curve indicates, the antenna pattern will be capable of allowing for the first major side lobe in an analytic way.

The function used to express the higher order side lobes was determined from studying graphs of smoothed mean power levels of currently operating earth station antennas given in an International Radio Consultative Committee (CCIR) document [5]. This document presents curves relating the gain versus log ϕ . Data for these curves were obtained from earth stations located at Andover, Maine [6, 7], Goldstone, California [8], Goonhilly Downs, England [9], Holmdel, New Jersey [10], Mill Village, Nova Scotia [11], Raisting, Germany [12], Wallops Island, Va., and the West Ford antennas at Camp Parks, California and Westford, Massachusetts [13].

Values of gain from the CCIR document were replotted as a function of log u. These curves were studied and the following function was accepted as a good fit to the data:

$$g_2 = K u^{-11/4}, \quad \phi_o \le \phi \le 90^\circ \qquad (3)$$

where

$$K = u_o^{3/4} (\sin u_o)^2 (\pi D/\lambda)^2 . \qquad (4)$$

The point u_o is determined from the normalization procedure described below and corresponds to the value of u where the gain g_1 is replaced by the gain g_2. The exponent of u in (3) was determined by comparing the slopes of the plotted data. Exponents ranged from -2.5 to -3.0 with a median of 2.75. The function g_2 was employed for ϕ's out to 90°. From 90° to 180° the value of g_2 at 90° was employed as the gain function. Thus

$$g_3 = K \left(\frac{\pi D}{\lambda}\right)^{-11/4} \qquad g_0^\circ \le \phi \le 180^\circ \qquad (5)$$

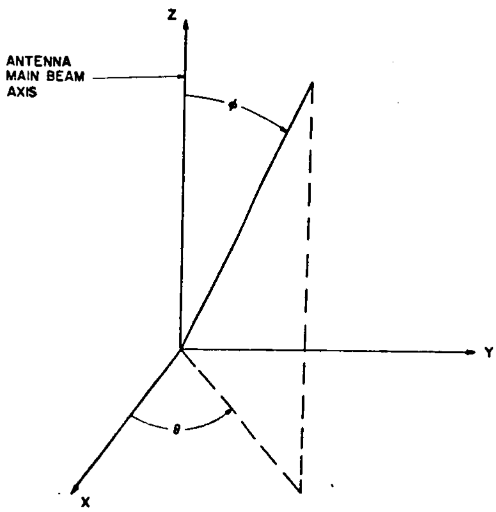

Fig. 1

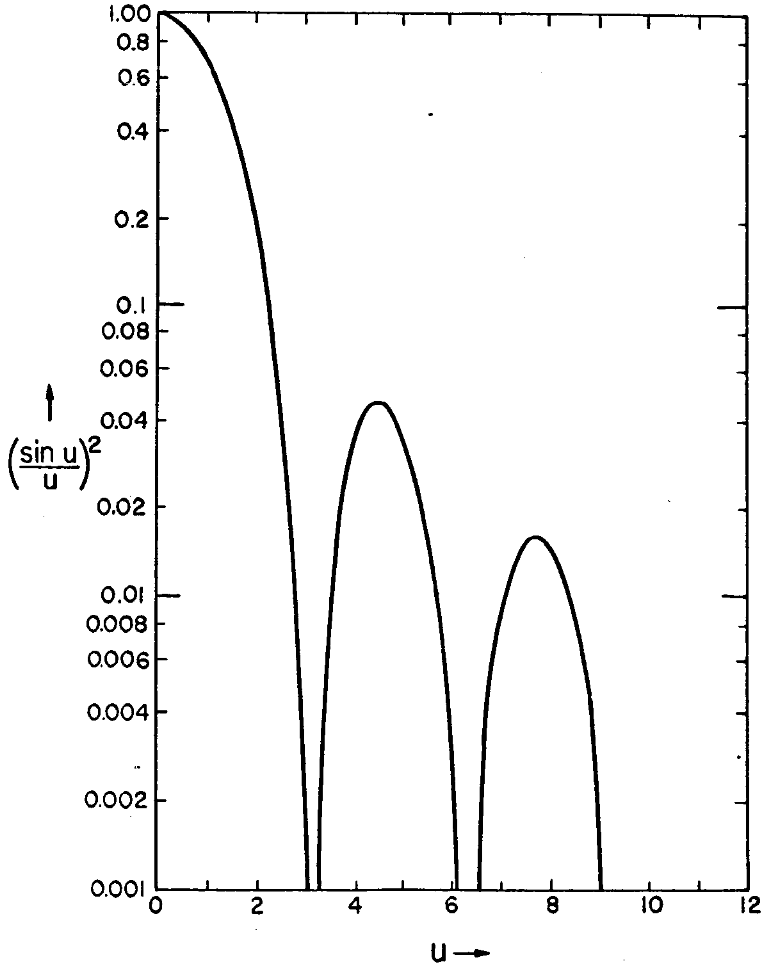
1.00
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
0.008
0.006
0.004
0.002
0.001
$\left(\frac{\sin u}{u}\right)^2$
0
2
4
6
8
10
12
u →

Fig. 2

Normalizing Procedure

The three components of the idealized antenna pattern outlined in the previous section must be combined smoothly over the entire range of ϕ. The resulting antenna pattern must then be normalized over all solid angles to insure that an antenna with a radiation efficiency, e, radiates this fraction of the power, p, put into its terminals. Referring to figure 1, the total power, ep, radiated from the antenna through a sphere of unit radius centered at the origin must satisfy the relation

$$ep \int_0^{2\pi} d\theta \int_0^{\pi} g \sin\phi \, d\phi = 4\pi ep. \tag{6}$$

By integrating (6) with respect to θ, the equation

$$\int_0^{\pi} g \sin\phi \, d\phi = 2. \tag{7}$$

is obtained. Using the gain functions given in the previous section 2, the gain in (7) can be divided into three components. Thus (7) becomes

$$\int_0^{\phi_o} \frac{(\sin(\pi D/\lambda)\sin\phi)^2}{\sin\phi} d\phi + K(\pi D/\lambda)^{-11/4} \int_{\phi_o}^{\pi/2} (\sin\phi)^{-7/4} d\phi + K(\pi D/\lambda)^{-11/4} = 2, \tag{8}$$

where the gain functions are expressed in terms of ϕ. The above equation can be solved for ϕ_o for any given D/λ where

$$\phi_o = \sin^{-1}\left[\frac{u_o}{\pi D/\lambda}\right]. \tag{9}$$

Results

Because of the complexity of the integrands in (8), the integration is done on an electronic computer for various trial ϕ_o's. Results of computations for various D/λ's are given in table 1 where the symbol eff

Table 1.

Critical Values for Various D/λ's

D/λ	u_o	ϕ_o	K	10 log K	eff	G
10	5.700	1.824×10^{-1}	1.104×10^{3}	30.430	0.7040	29.942
20	5.690	9.068×10^{-2}	4.545×10^{3}	36.575	0.7029	35.964
50	5.666	3.608×10^{-2}	3.036×10^{4}	44.823	0.7025	43.922
70	5.666	2.577×10^{-2}	5.951×10^{4}	47.746	0.7025	46.844
100	5.666	1.804×10^{-2}	1.214×10^{5}	50.842	0.7025	49.942
200	5.666	9.018×10^{-3}	4.858×10^{5}	56.865	0.7025	55.964
500	5.666	3.607×10^{-3}	3.036×10^{6}	64.823	0.7025	63.922
700	5.666	2.576×10^{-3}	5.951×10^{6}	67.746	0.7025	66.844
1000	5.655	1.800×10^{-3}	1.250×10^{7}	70.969	0.7025	69.942

stands for the aperture efficiency of the antenna, defined as the ratio of the radiated power for $\phi < \phi_1$ (the main beam) divided by the total radiated power. Using (7):

$$\text{eff} = \int [(\pi D/\lambda)^2 \ (\sin u/u)^2 \ \sin\phi \, d\phi] / 2 \qquad (10)$$

where

$$\phi_1 = \sin^{-1}(1.5 \ \lambda/D) \qquad (11)$$

is calculated from (2) with $u = 3\pi/2$. In table 1 the maximum gain, G, of the antenna was computed from the formula

$$G = 10 \log (\pi D/\lambda)^2 \text{ dB}. \qquad (12)$$

Note that the angle u_o and the aperture efficiency are nearly constant for all D/λ.

A sample idealized antenna pattern is represented as a function of u in figure 3 for a D/λ of 100 and for $0 < \phi < 90^o$. For $90^o < \phi < 180^o$ the gain is the constant -18.5 dB determined by (5).

Conclusion

We have presented an idealized pattern suitable for use in mutual interference studies with an estimated r.m.s. error for a "typical" antenna of 3-4 dB. The pattern is based on available data and approximates these data in the far side lobe region more closely than the curve recommended in the CCIR document [5]. The proposed pattern is normalized for each D/λ so that all of the power radiated from an antenna is accounted for.

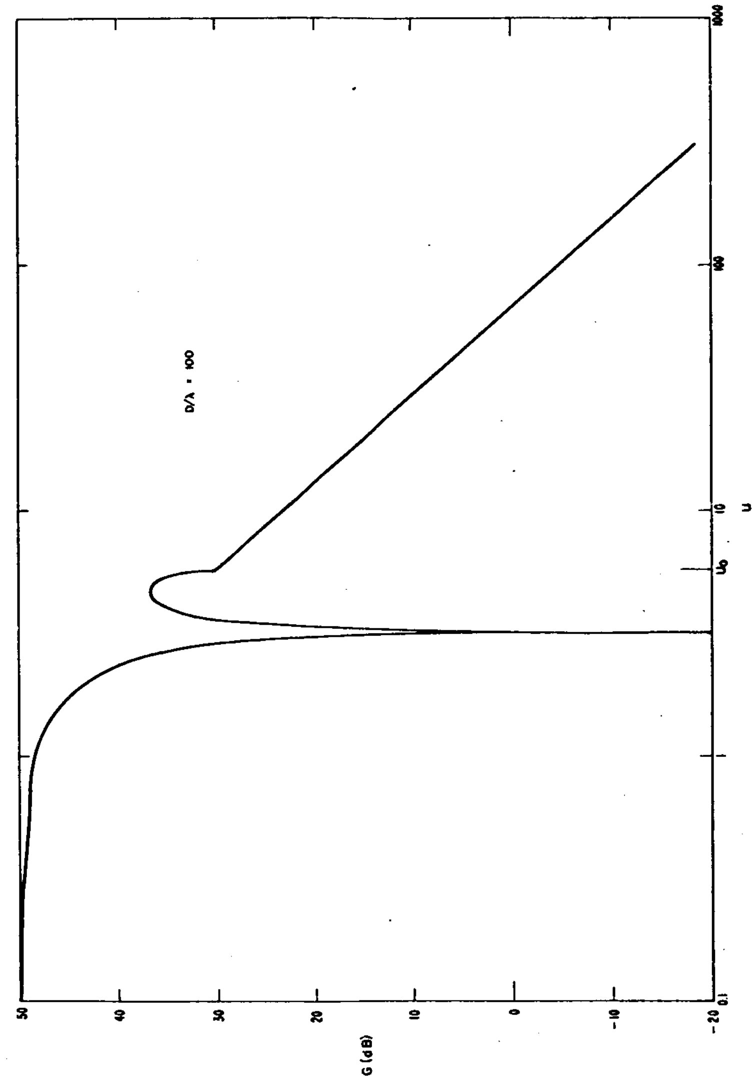

Fig. 8

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