CSIRO - Australia Telescope National Facility

The 1kT Project: Antenna Reference Radiation patterns for Array Elements for System Performance Evaluation: Part 1 - Reflector Antennas.

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Note: The reference radiation patterns deduced in this report for symmetric-beam reflectors have been developed from theoretical and measured patterns contained in Recommendations and Reports of the ITU (Fixed Satellite Service) and related contributions by the author.

1. Introduction

There is now an interest in using reference radiation patterns for general system studies requiring the development of antenna element parameters. In this Part 1, reflector antennas having symmetric (or near symmetric), beams are considered. The antennas can be symmetric or offset. Such antennas may be used for the 1kT array, particularly for the higher frequency range (say 0.8 to 20 GHz) or for SETI, and this preliminary study takes these possible applications into account.

The reference radiation patterns are defined in terms of a main lobe, a first sidelobe, and an envelope of the other sidelobe peaks. The main lobe and first sidelobe are a function of the diameter/ wavelength (D/λ), but the remaining sidelobe levels as a function of angle are, to a first approximation, independent of D/λ. For small D/λ less than about 100, the approximation may be improved by use of a second-order correction. Also, generally it is found that off-set antennas will have lower sidelobes than symmetric antennas due to the elimination of blockage. However, for very wideband operation where there is likely to be comprises in feed design, and hence illumination and spill-over efficiencies, the sidelobe levels will tend to be compromised.

2. The Antenna Parameters

Fig. 1 shows the range of D/λ for reflector sizes 5 to 30 m, and frequency range 0.8 to 20 GHz. Typically, D/λ would range from 30 to 1300 for D in the range 10 to 20 m where the above frequency range is applicable.

2.1 First-order approximation to radiation pattern envelope

The radiation pattern is divided into four major sections as illustrated in Fig.2 (where D/λ has been set at 100).

a) ***main beam***:
peak gain: $G_{max} \sim 20 \log D/\lambda + 7.7$, (dBi)
location of break-point: $\varphi_l = 100\lambda/D$, (degrees)

b) ***first side-lobe level***:
peak gain: G_1 = 15 log D/λ -2, (dBi)
location of second break-point φ_2 : $2\varphi_1$

c) ***side-lobe envelopes***:
G_2 (φ) = 29-25 log φ, (dBi): Curve A.
over the angular range φ_2 to 36°

G_3 (φ) = -10dBi: Curve B.
over the angular range 36° to 180°

Note that the Curves A and B are independent of D/λ, whereas the main-beam and first sidelobe are dependent on D/λ. This is shown in Fig.3, where the levels and locations of the first sidelobes for D/λ in the range 25 to 1000 are indicated. The horizontal dashes indicate the gain G_0. Note also that Curve A has been extended to small φ; for any given value of D/λ, this curve ends at the envelope defined by the first sidelobe.

In summary, to a first approximation, extraneous signals entering the antenna at angles greater than the second break point φ_2 will be independent of D/λ. To minimise the effect of interference compared to reception of the desired signal in the main beam, an antenna with maximum gain should be used, discrimination being proportional to the gain of the antenna. The exception is interference entering through the first sidelobe, where there is no significant benefit in an increased D/λ except that the volume of sky intercepted by the first sidelobe naturally decreases with increased D/λ. The effect of interfering sources in the three different sidelobe areas and as a function of D/λ will form part of the next study.

Finally, if required for calculations, the mean level of sidelobes can be assumed to be approximately 2dB below the defined peak envelope.

2.2 Second-order sidelobe characteristics

The first order approximation to the sidelobe envelope beyond the first sidelobe can be improved by considering the effect of:

a) D/λ, particularly when D/λ < 100, and
b) type of antenna, ie symmetrical or offset.

For either antenna type, the envelope of sidelobes tends to increase as D/λ decreases below 100.

For well-designed offset antennas, the sidelobe envelope is below that of the symmetric type by typically 6dB, although for wide band systems, comprises in feeding may reduce this advantage.

A more accurate representation for Curve A for optimally-designed feeding may be:

a) ***Offset antennas***: G_2 (φ) = 43 - 10 log D/λ - 25 log φ, for D/λ < 100
which reduces to:
G_2 (φ) = 23 - 25 log φ, for D/λ > 100
G_2 (φ) is also shown as Curve A^1 in Fig.3 for the case D/λ = 100. Curve A^1 will coincide with Curve A when D/λ = 25.

b) *Symmetric antennas*: $G_2(\varphi) = 49 - 10 \log D/\lambda - 25 \log \varphi$, for $D/\lambda < 100$
which reduces to:
$G_2(\varphi) = 29 - 25 \log \varphi$, for $D/\lambda > 100$

Curve A is a reasonable approximation to a typical engineering situation requiring moderate bandwidths where one would tend to use symmetric antennas for D/λ large, and offset antennas for D/λ small ($D/\lambda << 100$).

For overall system studies, the use of Curve A should represent a useful approximation for most practical purposes. Note that the model is easily extended to include a quasi-elliptical main beam, or non-constant first sidelobe level, varying as a function of circumferential angle (defined relative to the main beam peak).

Finally, the reference patterns defined here can be used as a bench-mark for comparing other antenna types in system studies, since a reflector antenna giving a symmetric beam and low sidelobes is usually considered as producing the most desirable pattern in practice.

3. References

The generalised curves have been based on measured patterns contained or summarised in the following Recommendations and Reports of the ITU-R (formerly CCIR) for the Fixed-Satellite Service (Study Group 4):

(a) Reports, 1990: Reports 391-6, 390-6, 998-1
(b) Recommendations, 1992: Rec. 731
(c) Recommendations, 1993: Rec. 580-4.

Appendix

Use of reflector antennas in the 1kT

It is interesting to consider the use of a prime-focus reflector for the 1kT. These thoughts continue on the discussions at the 1kT International Technical Workshop in December 1997.

Let us consider the following range of parameters:

- total frequency range: 0.8 to 20GHz
- feed/receiver frequency ranges:
  - * Band A: 0.8 to 1.8 GHz
  - * Band B: 1.8 to 4.05 GHz
  - * Band C: 4.0 to 9.0 GHz
  - * Band D: 8.95 to 20.14 GHz
- [feed]/LNA cooling temperature: 80K

(The paper entitled: "Noise temperature estimates for a next generation very large microwave array", Sander Weinreb, paper submitted to 1998 IEEE MTT-S Symposium, indicates that such parameters are not unreasonable. Also, the overall cost of an antenna and associated cooled receiver needs to be carefully studied, particularly in arriving at the optimum antenna diameter for overall minimum system cost).

The above proposal of say four bands raises the question of the feeding arrangements. In addition to having four different feeding systems in the focal-plane to cover the four bands, each feed-type (which may be different for Band A and Band D for example), must give efficient illumination across a 2.25:1 band. In addition, at the higher frequencies, multi-feeding will be possible for multi-beaming and interference excision. For example for Bands C and D, one could consider a group of 7 feeds (1 central and 6 outer feeds). Indeed, above 9 GHz the feeds for Band D could be arranged as a small focal-plane array to compensate for first-order main-reflector distortion, thus reducing the cost of the antenna through use of a lighter back-up structure. Note that the pointing direction of the central feed for each band would not be identical.

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BMT/ATNF/1.98

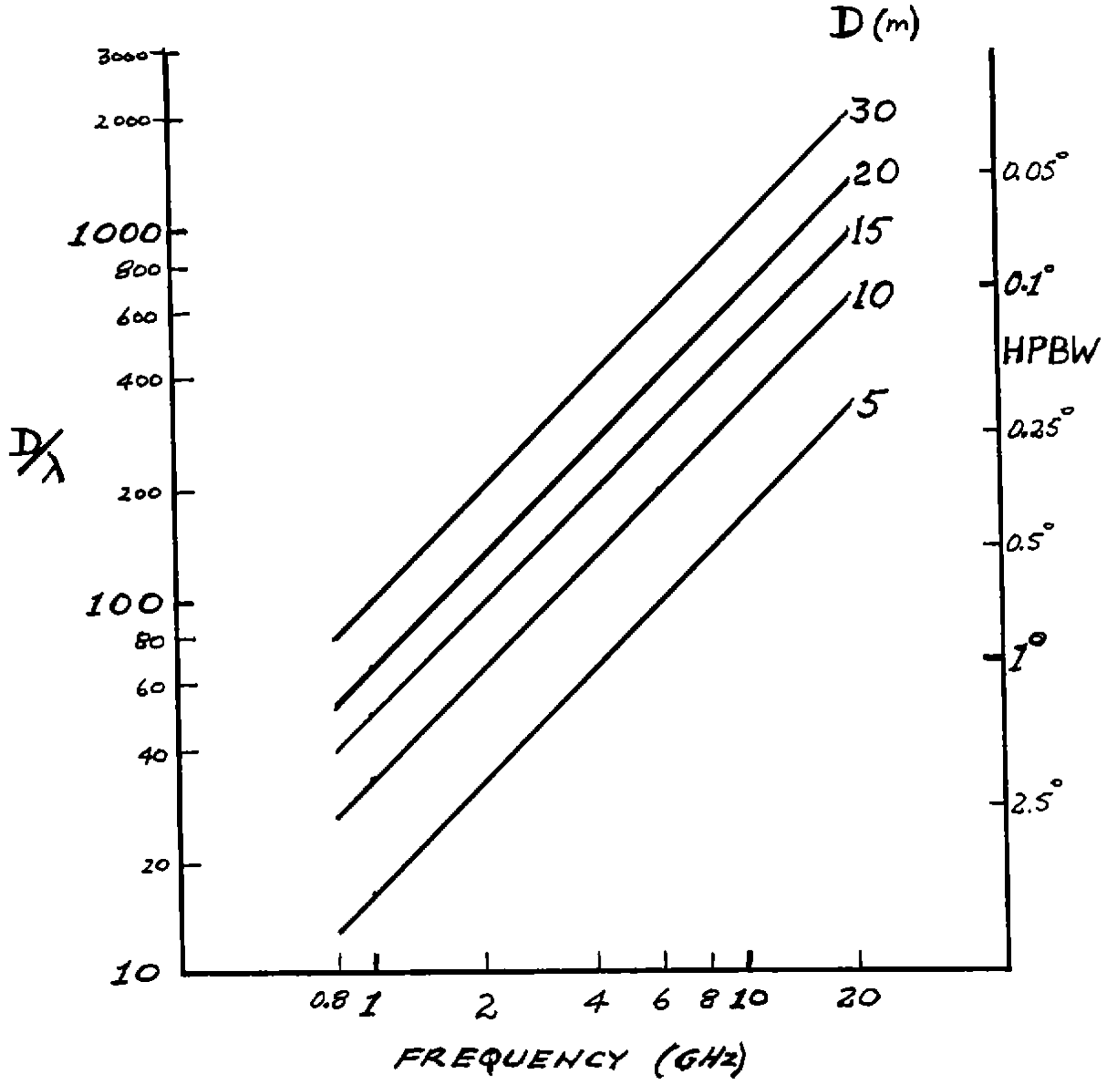
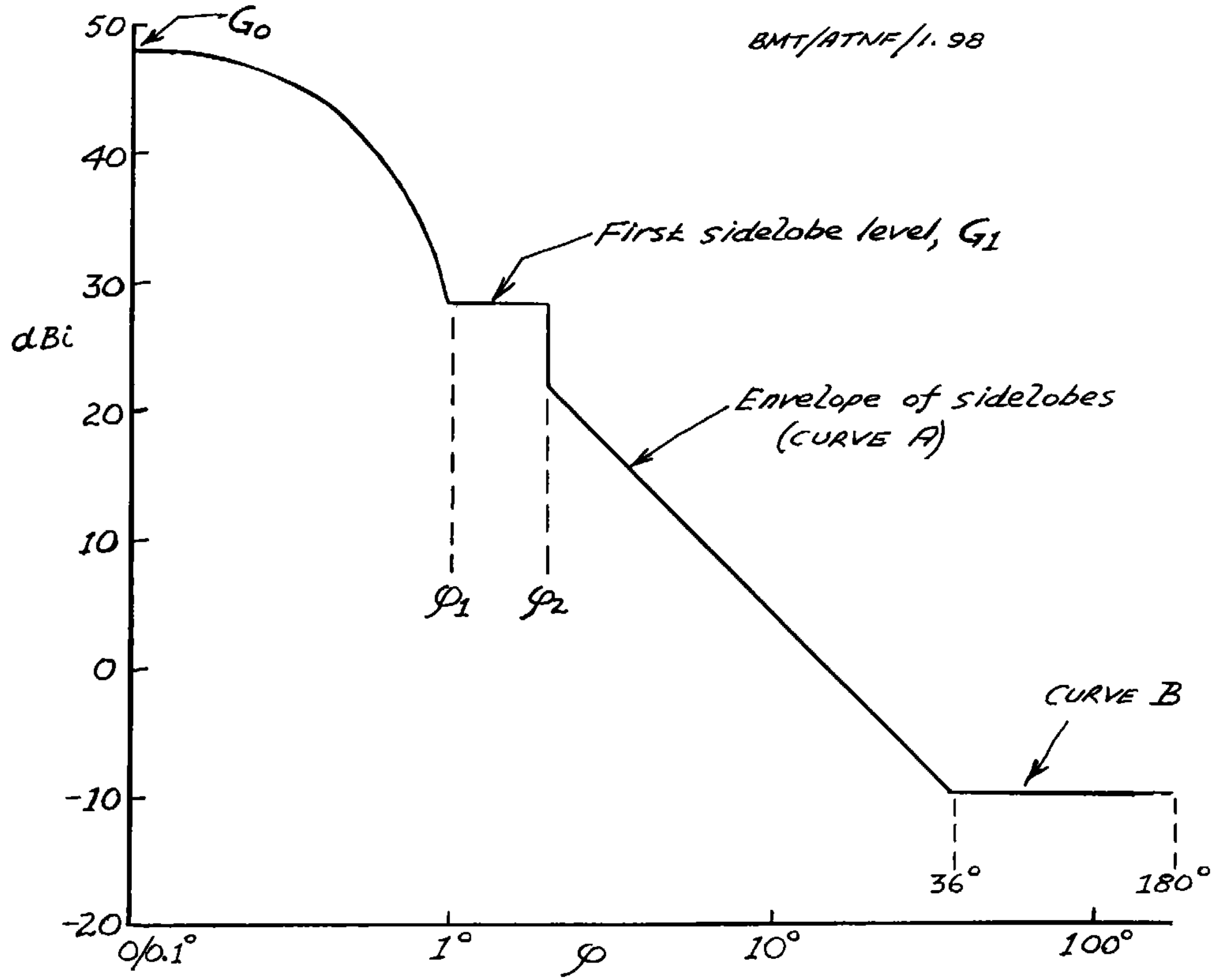
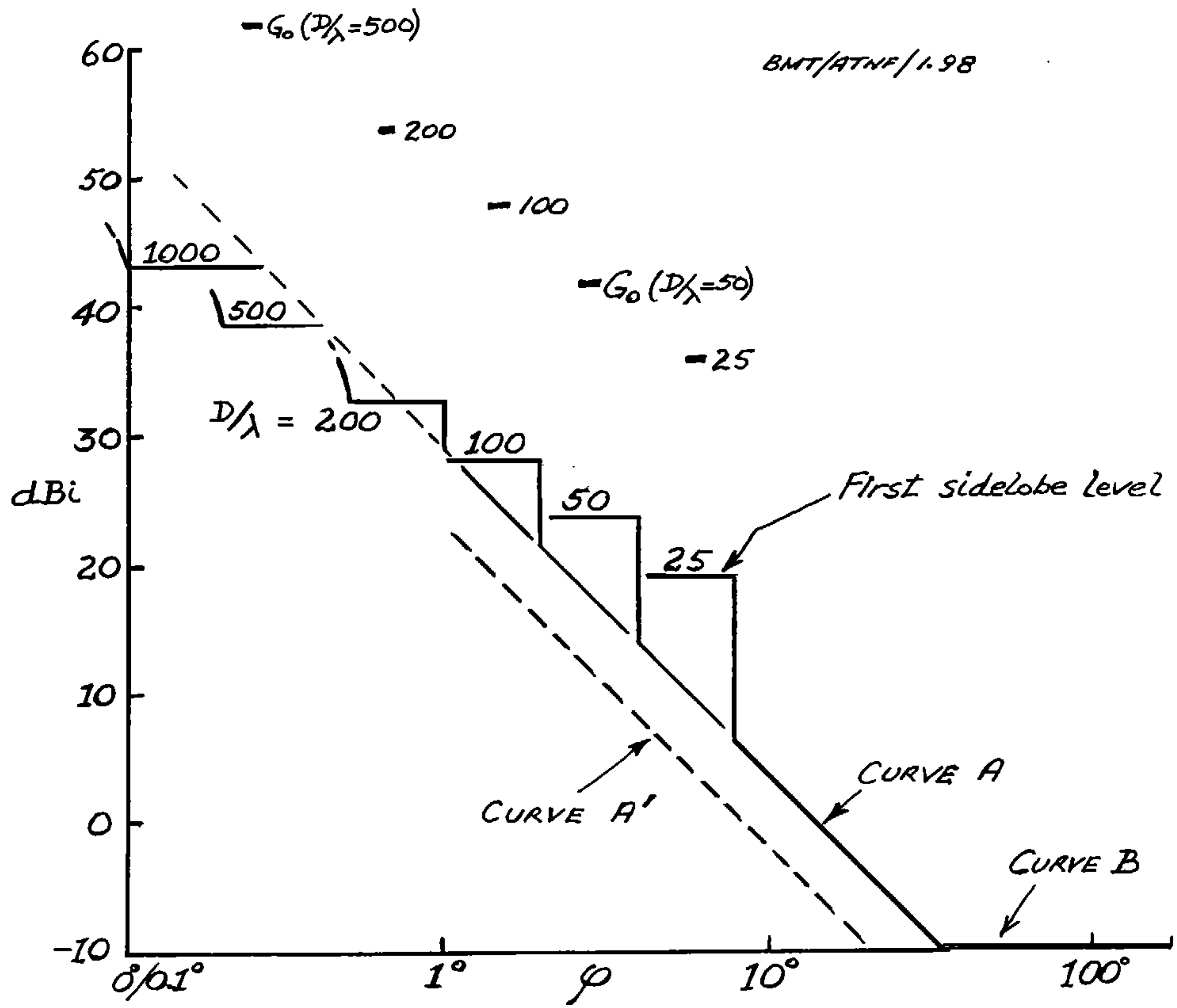


FIG. 1



G_0
BMT/ATNF/1.98
First sidelobe level, G_1
Envelope of sidelobes
(CURVE A)
CURVE B
dBi
50
40
30
20
10
0
-10
-20
φ_1
φ_2
36°
180°
0/0.1°
1°
φ
10°
100°

FIG. 2



BMT/ATNF/1.98
G_o (D/λ=500)
200
100
G_o (D/λ=50)
25
60
50
40
30
20
10
0
-10
dBi
1000
500
D/λ = 200
100
50
25
First sidelobe level
CURVE A
CURVE A'
CURVE B
0.1°
1°
10°
100°
φ

FIG. 3