GBT MEMO 102

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# POLARIZATION CHARACTERISTICS OF THE GBT

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In an axisymmetric antenna, the cross-polarized component of the radiated field is generated largely due to scattering by aperture blocking by the prime focus feed or subreflector and its supporting struts. The level of cross-polarization is low for such antennas when the (i) blockage is small, (ii) corrugated horns or dual-mode horns with circularly symmetric patterns are used as feed elements, and (iii) size of the primary reflector and/or subreflector is large in terms of wavelengths. At lower frequencies, when the size of corrugated horns warrants the use of dipole type of feeds, the performance of the antenna is limited by the characteristics of the feeds. In an asymmetric antenna like the GBT, the cross-polarization generating mechanisms are quite different. This memo presents some calculated results relevant to the GBT.

## Prime Focus:

The GBT is a clear aperture asymmetric antenna. When such an antenna is illuminated by a linearly polarized primary feed, though there is no aperture blockage causing the cross-polarization, the asymmetric primary reflector generates a cross-polarized component in the radiated field. The level of cross-polarization is a function of the offset angle $\theta_0$ (Figure 1) (angle between feed axis and the reflector axis) and half-angle $\theta^*$ subtended by the reflector at the focus (Figure 2) [1]. The peak cross-polar level is dependent by a large amount on parameters $\theta_0$ and $\theta^*$ and is relatively insensitive to the feed illumination taper [2]. The cross-polarized sidelobes are in the plane of asymmetry of the reflector. For the GBT $\theta_0 = 42.8°$ and $\theta^* = 39°$ and the cross-polarization is -21.5 dB (Figure 2). Table 1 lists the calculated peak copolar gain and the peak cross-polar level at different frequencies. At frequencies of 800 MHz and above, the feeding element is a corrugated horn, while at lower frequencies dipole type of feeds are used. Figure 3 gives the copolarized and cross-polarized patterns calculated at 300 MHz and 800 MHz, respectively. A special purpose aperture matched feed can be used to improve the cross-polarization by between 10 and 15 dB [2]. This feed has an aperture field which not only matches the copolar component of the focal field of the antenna but the cross-polar component as well. This is achieved by making use of higher order asymmetric waveguide modes. However, these feeds have only 4-5 percent bandwidth.

TABLE 1

| Frequency (MHz) | Peak Copolar Gain (dB) | Peak Cross-Polarization Below Peak Copolar Gain |
|---|---|---|
| 300 | 48.82 | -20.00 |
| 600 | 54.81 | -20.10 |
| 800 | 56.66 | -21.63 |
| 1070 | 59.19 | -21.64 |

When an asymmetric antenna is illuminated by a purely circularly polarized feed from prime focus, the asymmetric reflector does not depolarize the fields. Each of the linearly polarized components of the incident field effectively generates a cross-polarized component. The cross-polarized components are in phase quadrature with the copolar component. The combination of the two orthogonal copolarized vectors and the phase asymmetric pair of cross-polarized vectors rotate in the same direction. Although this results in a purely circularly polarized radiation, the beam is no more on the boresight axis. The beam squint is in the plane of asymmetry and the direction of movement is dependent on the sense of polarization. Figure 4 illustrates the relationship between the beam squint and the antenna parameters [1]. The beam squint for the GBT is 0.1 half-power beamwidth (HPBW).

## Secondary Focus:

The subreflector and the feed of the GBT have been positioned such that they do not block the aperture of the main reflector. Such an arrangement is the dual-offset-reflector configuration. Analyses of such a configuration [3]-[6] have shown that the dual-offset antenna can be designed such that, when fed by a conventional linearly polarized feed, the depolarization arising from the two offset reflectors can be made to cancel, thus providing an overall low cross-polarization. Analyses done on such reflectors [4]-[6] indicate that perfect cancellation can be achieved if the reflector system satisfies the following condition:

$$\tan \alpha = \frac{|1 - e^2| \sin \beta}{(1 + e^2) \cos \beta - 2e} \tag{1}$$

where $\alpha$ is the angle between the feed axis and rotation axis of the subreflector (Figure 5), $\beta$ is the angle between the rotation axis of the subreflector and that of the parabolic main reflector and e is the eccentricity of the subreflector. Later analysis [7] indicates that diffraction effects introduced by the finite-sized subreflector limit the polarization purity in spite of satisfying equation (1). In addition, the feed illumination taper and the eccentricity of the subreflector also have an effect on the polarization characteristics. To reduce cross-polarization levels below -40 dB, subreflector diameter should be greater than 25 wavelengths.

The GBT subreflector has a diameter of 7.5 meters in the asymmetric plane which is about 25 wavelengths at 1 GHz. Figure 6 shows the calculated results for the GBT, indicating the relationship between cross-polarization level and the subreflector transverse diameter in wavelengths ($d_s$ in Figure 5) for different values of feed illumination taper. The dimension $d_s$ is 33 wavelengths at 1.4 GHz. The illumination taper for the feed at 1.4 GHz is -15 dB as per [8]. From Figure 6 it is apparent that the cross-polarization is -42 dB at 1.15 GHz which is the lowest frequency at secondary focus and better than -42 dB for higher frequencies. For frequencies above 8.2 GHz, the feed illumination taper is -13 dB and extrapolating from Figure 6, the GBT will have cross-polarization below -50 dB. Figure 7 shows the calculated copolarized and cross-polarized patterns in the plane of asymmetry at 1.42 GHz and 5.00 GHz.

In order to achieve beam scanning or to provide multiple beams, radio telescopes employ lateral displacement of the feeds. The best focal surface to locate the feeds is found by examining the caustics of the reflector system [9]. The optimum location of the feed and the orientation of its axis with respect to the axis of the on-axis feed for various beam scans at 1.42 GHz and 5.00 GHz are given in Table 1 of [10]. Table 2 lists the cross-polarization levels with respect to the copolar peaks for various beam scans in the symmetric and asymmetric planes. These results are for a feed illumination taper of -15 dB. The first set of columns in Table 1 are for feed offset from axis but not tilted. The loss in aperture efficiency is given in parenthesis. The loss in efficiency is due to two reasons: (1) the phase error in the aperture and (2) the increase in spillover. The feed is tilted towards the center of the subreflector in order to reduce the spillover losses and these results are given in the second column. As can be seen, the loss in aperture efficiency decreases but the cross-polar levels get worse in the symmetric plane. This is because tilting the feed upsets the condition in equation (1) for cross-polar cancellation between the two asymmetric reflectors.

The loss in aperture efficiency is lower for beam scans in the asymmetric plane but cross-polarization is much worse in this plane. Hence, when only two beams are required, the feeds should be translated in the symmetric plane. At 1.42 GHz, it is obvious that only narrow bandwidth feeds can be used for providing multiple beams. A practical size for the feeds would be three wavelengths in aperture (25" diameter) and two such feeds, separated by one outer diameter of each other, can be located in the 48" diameter cutout on the turret. Each feed should be symmetrically displaced on either side of the feed circle and the beams in the sky would be separated by 2.6 HPBW's.

Table 3 lists beam scan, loss in aperture efficiency and cross-polarization level for feeds translated from the focus by one feed radius distance. The results are given for feeds translated in the symmetric and asymmetric planes at 5, 8 and 12 GHz. The cross-polar levels are better than -30 dB for translations in the symmetric plane even at 5 GHz. But in the asymmetric plane, better than - 30 dB cross-polarization can be obtained only for frequencies above 10 GHz.

## References:


[1] T. S. Chu and R. H. Turrin, "Depolarization Properties of Offset Reflector Antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-21, pp. 339-345, May 1973.

[2] A. W. Rudge and N. A. Adatia, "Offset-Parabolic-Reflector Antennas: A Review," *Proceedings of the IEEE*, vol. 66, no. 12, pp. 1592-1618, December 1978.

[3] N. A. Adatia, "Cross-Polarization of Reflector Antennas," Ph.D. dissertation, University of Surrey, England, December 1974.

[4] H. Tanaka and M. Mizusawa, "Elimination of Cross-Polarization in Offset Dual Reflector Antennas," *Elec. Commun.* (Japan), vol. 58, pp. 71-78, 1975.

[5] Y. Mizugutch, M. Alagawa and H. Yokoi, "Offset Dual Reflector Antenna," in *IEEE Int. Symp. AP-S*, Amherst, MA, pp. 2-5, October 1976.

[6] M. Muzusawa and T. Katagi, "The Equivalent Parabola of a Multi-Reflector Antenna and Its Application," *Mitsubishi Elec. Eng.*, no. 49, pp. 25-29, September 1976.

[7] N. A. Adatia, "Diffraction Effects in Dual Offset Cassegrain Antenna," *IEEE Int. Symp. AP-S*, Washington, DC, pp. 235-238, May 1978.

[8] S. Srikanth, "Gain/System Temperature Optimization at Secondary Focus," GBT Memo No. 87, October 6, 1992.

[9] C. J. Stetten, *Reflector and Lens Antenna - Analysis and Design Using Personal Computers*, Artech House, Inc., 1988.

[10] S. Srikanth, "Field of View of GBT - Unshaped," GBT Memo No. 55, June 6, 1990.

## TABLE 2

| PEAK CROSS-POLARIZATION LEVEL (dB) BELOW PEAK COPOLAR GAIN FOR SCANNED BEAM | | | | | | | |
|---|---|---|---|---|---|---|---|
| FREQ. (GHz) | PLANE | FEED OFFSET ONLY | | | FEED OFFSET AND TILTED | | |
| | | BEAM SCAN IN HPBW's | | | BEAM SCAN IN HPBW's | | |
| | | 2.8 | 6.0 | 10.0 | 2.8 | 6.0 | 10.0 |
| 1.42 | Symmetry | -22.2 (22.51) | -16.5 (75.03) | | -19.8 (3.84) | -13.8 (17.40) | |
| | Asymmetry | -12.8 (24.77) | -6.3 (83.35) | | -12.8 (2.61) | -6.2 (17.86) | |
| 5.00 | Symmetry | -33.1 (2.00) | -26.6 (11.57) | -22.64 (27.49) | -31.0 (0.14) | -24.5 (4.73) | -20.3 (10.00) |
| | Asymmetry | -23.7 (1.5) | -17.1 (9.73) | -12.7 (28.78) | -23.7 (0) | -17.1 (1.68) | -12.7 (6.79) |

NOTE: Numbers in parentheses are loss in aperture efficiency in percent.

# TABLE 3

| Feed at One Radius Distance from Focus | | | | | | |
|---|---|---|---|---|---|---|
| Freq. (GHz) | Plane | Direction of Translation | Beam Scan | | Aperture Efficiency (%) | Cross-Polarization Below Peak Gain (dB) |
| | | | Arcmin | HPBW's | | |
| 5 | | No translation | 0 | 0 | 68.3970 | -51.33 |
| | Symmetric | +Y | 6.29 | 2.47 | 67.3654 | -33.82 |
| | | -Y | 6.16 | 2.42 | 67.9449 | -34.31 |
| | Asymmetric | X | 6.23 | 2.44 | 67.3188 | -24.41 |
| 8 | | No translation | 0 | 0 | 61.7422 | -55.94 |
| | Symmetric | +Y | 4.30 | 2.71 | 61.0804 | -37.30 |
| | | -Y | 4.22 | 2.66 | 61.7422 | -37.55 |
| | Asymmetric | X | 4.26 | 2.68 | 61.6115 | -27.86 |
| 12 | | No translation | 0 | 0 | 51.1078 | -59.03 |
| | Symmetric | +Y | 2.04 | 1.98 | 51.1078 | -43.48 |
| | | -Y | 2.03 | 1.97 | 50.9222 | -43.93 |
| | Asymmetric | X | 2.03 | 1.97 | 51.1078 | -34.14 |

NOTE: +Y refers to translation towards main reflector axis in Fig. 5 and -Y away.

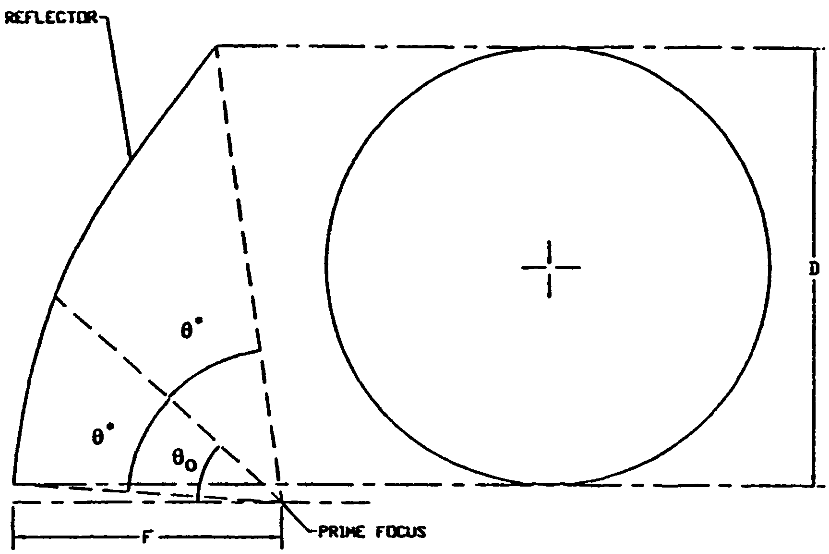



Fig. 1. Single-offset-reflector configuration.

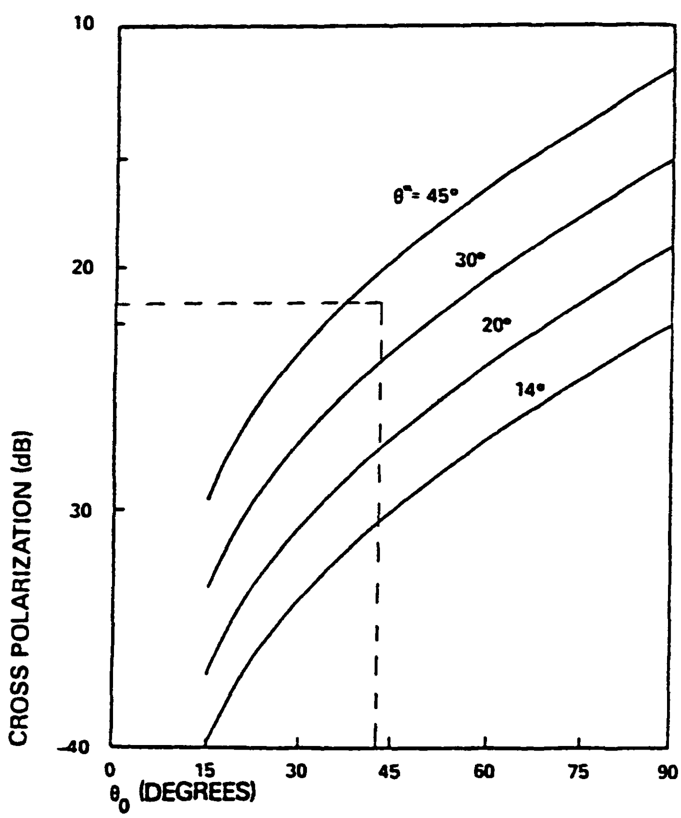
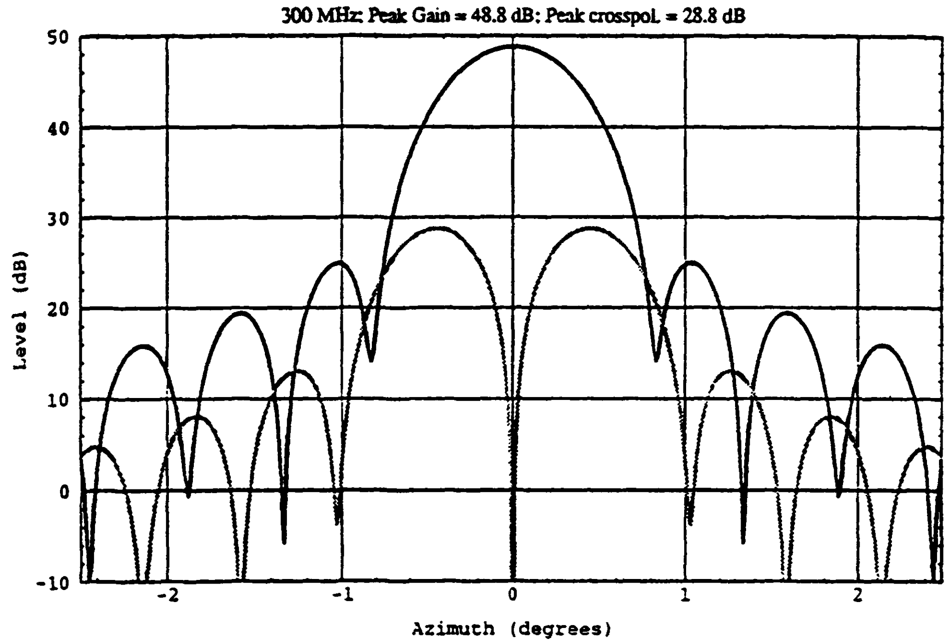
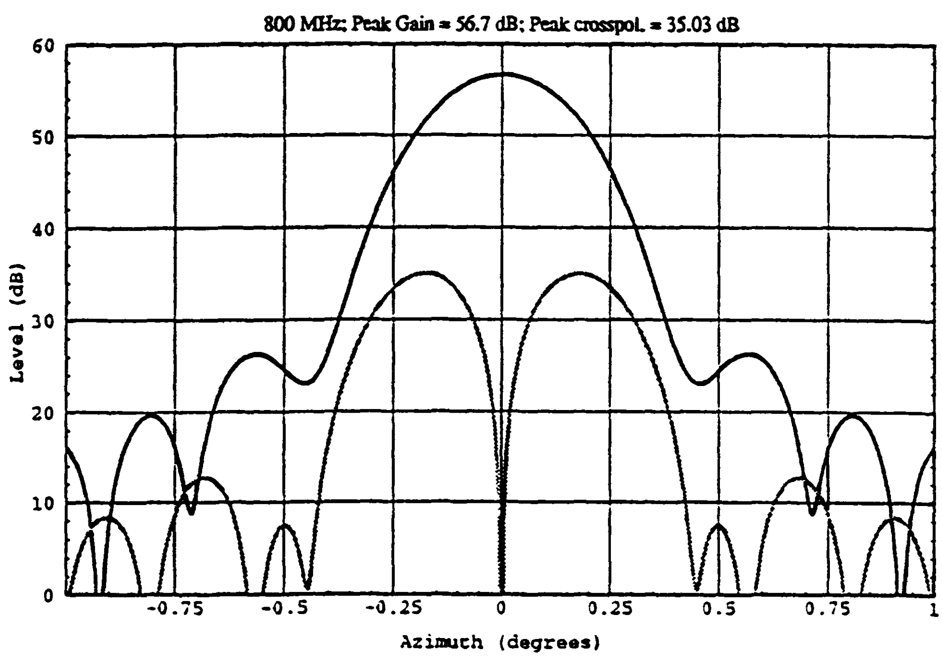



Fig. 2. Peak cross-polar levels in the plane of asymmetry as a function of offset-reflector parameters $\theta_o$ and $\theta^*$.




(a) 300 MHz




(b) 800 MHz

**Fig. 3. Calculated copolarized and cross-polarized radiation pattern in the plane of asymmetry (prime focus).**

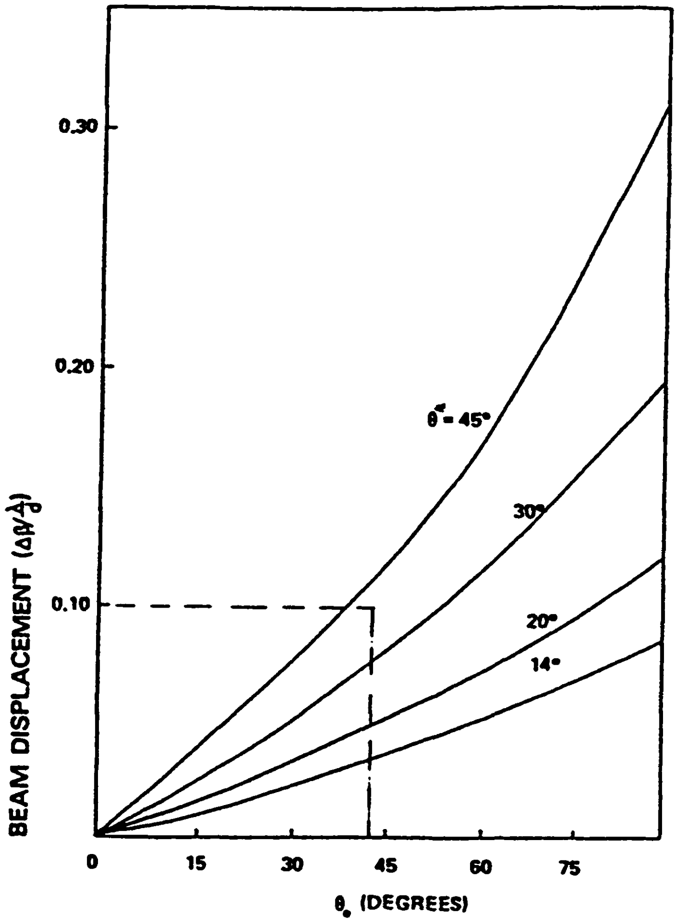



Fig. 4. Beam displacement as a function of offset-reflector parameters $\theta_o$ and $\theta^*$.

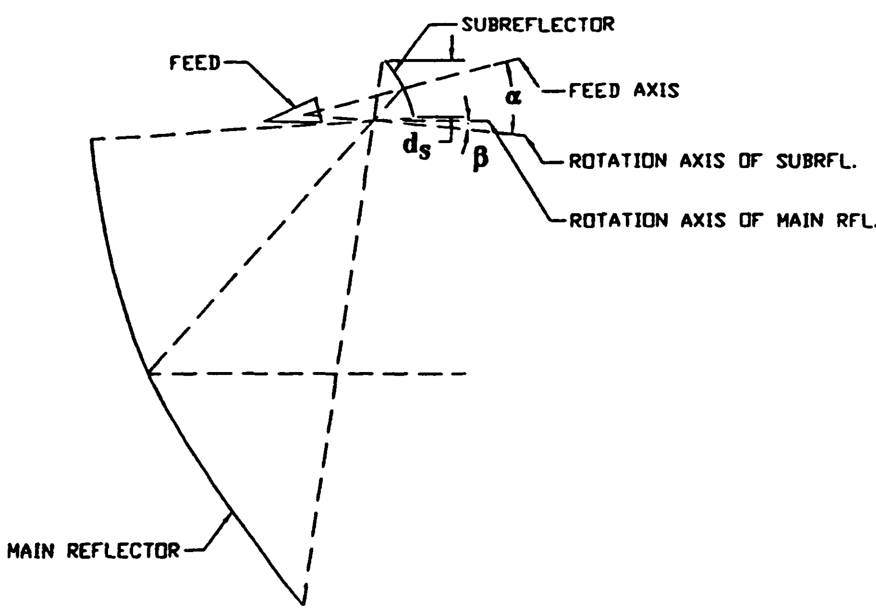



Fig. 5. Dual-offset-reflector configuration.

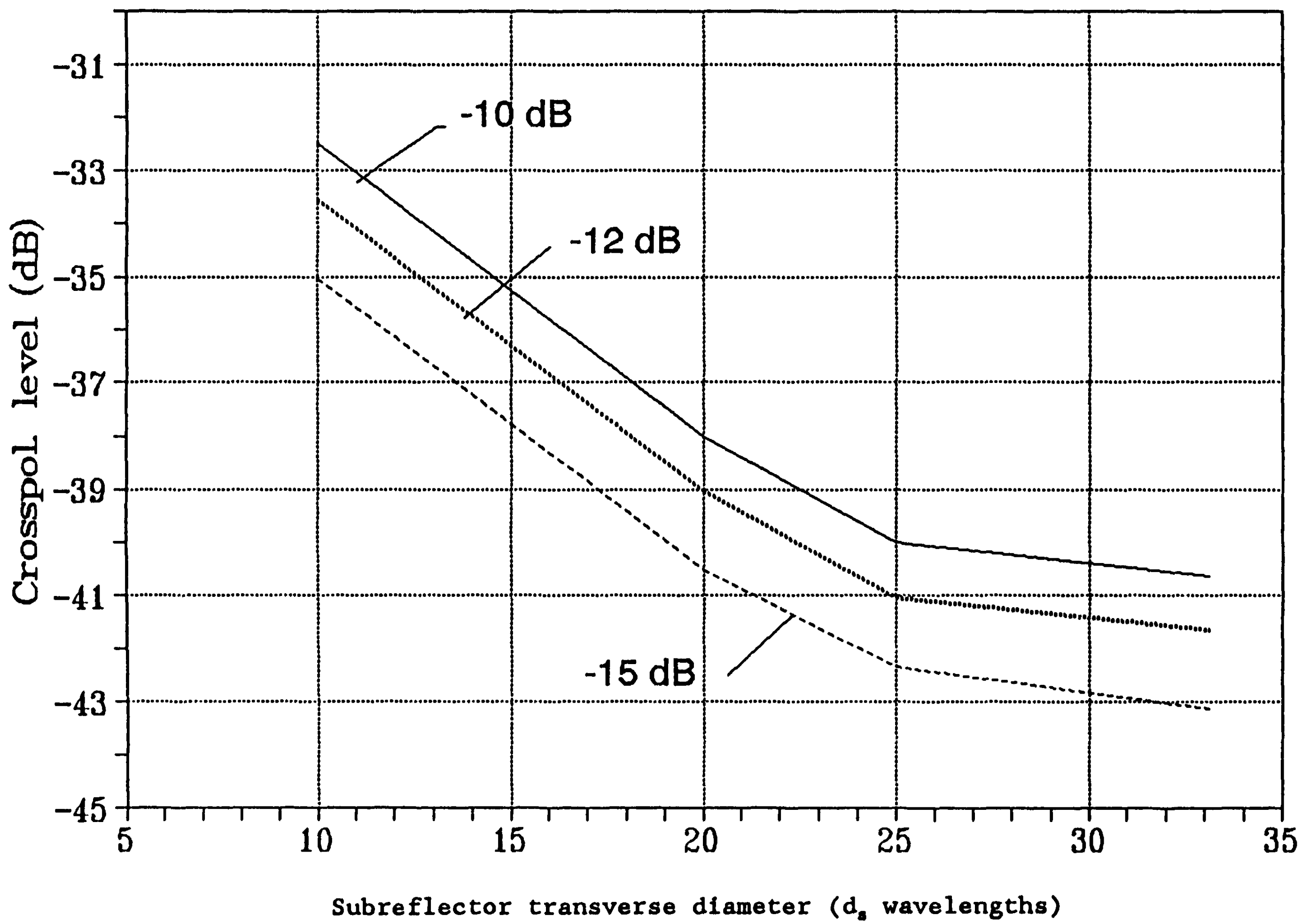
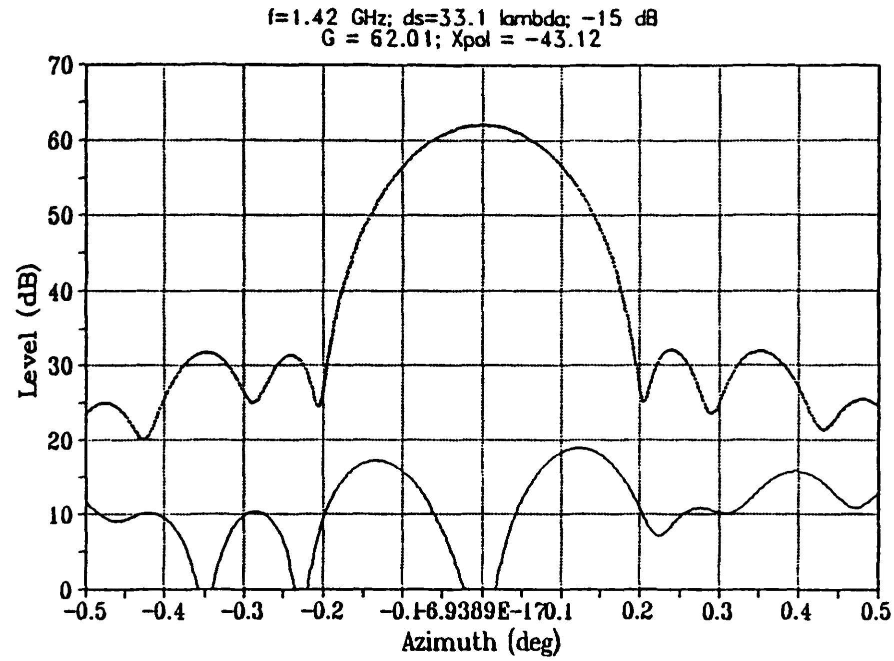
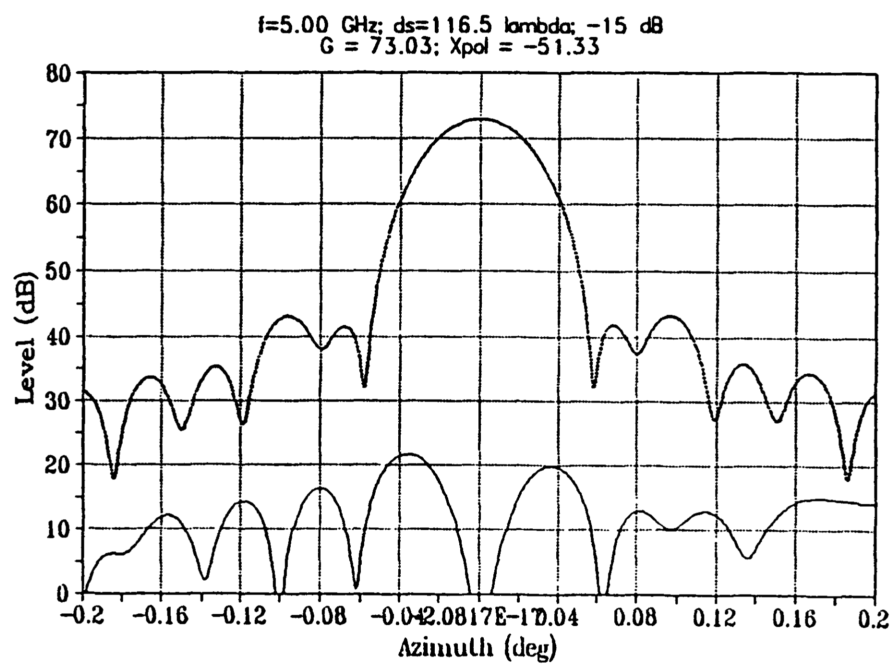



Fig. 6. Peak cross-polar levels as a function of subreflector dimension. Parameter is feed illumination taper.




(a) 1.42 GHz




(b) 5.00 GHz

Fig. 7. Calculated copolarized and cross-polarized radiation pattern in the plane of asymmetry (secondary focus).