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Calculated 70-Meter Antenna Performance for Offset L-Band and C-Band Feeds

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This article summarizes a series of calculations that were carried out in order to determine the performance of the new dual-shaped 70-m antenna for feeds that are displaced from the focal ring. Calculations were carried out at 1.68 GHz (L-band) and 5.0 GHz (C-band) for a number of feed/subreflector configurations. The effects of feed displacement, feed pointing angle, subreflector tilt, and lateral subreflector movement are summarized. Of specific interest are gain, beam squint, and spillover noise temperature for each of the feed/subreflector configurations described above.

I. Introduction

In order to support the Soviet Mars Orbiter/Phobos Lander mission with an uplink as well as a downlink capability, a 5-GHz (C-band) transmit feed will be added to the existing 1.68-GHz (L-band) receive feed at DSS 14. Due to lack of focal ring space, the L-band feed is radially displaced from the ring, causing a slight drop in gain and a small beam squint. In order for the transmit and receive beams to be coincident, the C-band feed's phase center should coincide with that of the L-band feed. Unfortunately, the rather large radial displacement (in terms of wavelengths) at C-band causes a significant drop in gain. Existing computer programs (T. Veruttipong, D. Rochblatt, W. A. Imbriale and V. Galindo, *Dual-Shaped and Conic GTD/Jacobi-Bessel Analysis Programs: A User Manual*. JPL Internal Document D-2583, Jet Propulsion Laboratory, Pasadena, California) were used to determine the C-band and L-band gain loss, and to determine beam squint as a function of radial feed displacement for the upgraded dual-shaped 70-m antenna system (A. G. Cha and W. A. Imbriale, *Computer Programs for the Synthesis and Interpolation of 70M Antenna Reflector Surfaces*, JPL Internal Document D-1843, Jet Propulsion Laboratory, Pasadena, California, November 1984). In an effort to retrieve some of the gain loss, the effects of feed pointing, subreflector tilt, and lateral subreflector movement were examined. The results of these parameter sweeps are summarized, and spillover noise temperatures and antenna patterns are presented for a few cases. The next section compares the antenna performance for feeds placed at the present L-band location (henceforth called the nominal configuration) to that which could be obtained for feeds placed on the focal ring. Subsequent sections present results for the parameter sweeps described above.

II. Nominal Configuration

The geometry of the dual-shaped 70-m system is shown in Fig. 1. Point N represents the position of the phase center for a feed location on the focal ring. The pointing angle of such a feed with respect to the main reflector axis is shown as θ_N = 5.73722 degrees. Also shown is the location of the phase center for the offset L-band feed, point L. This point is displaced radially about 24 inches from the focal ring and displaced about 3 inches toward the subreflector from point N. The L-band pointing angle, θ_L = 8.617 degrees, is also shown. For

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the calculation of antenna gain, the same feed pattern was used for both frequencies—that of a 22.4-dB corrugated horn. It is assumed to be a good representation of both the dual-mode L-band horn near its center frequency and the C-band feed that is yet to be developed.

Table 1 summarizes calculated dual-reflector gain and beam position for both frequencies at both feed locations. The first line, labeled directivity, represents the calculated gain from the dual-reflector analysis program. This gain value is modified due to quadripod blockage, VSWR, surface tolerance, and horn and waveguide loss. Pointing loss at C-band assumes a 0.005 degree pointing accuracy, and pointing loss at L-band assumes a 0.005 degree pointing accuracy and L-band squint relative to C-band. Calculated beam position for the four cases is also shown in the table. Far-field patterns (asymmetric plane) are shown for the offset feed position at L-band and C-band in Figs. 2 and 3.

As can be seen from the first line of Table 1, a severe gain loss of over 2.7 dB is suffered when the C-band feed is displaced from the focal ring, while the L-band loss is a tolerable 0.42 dB. Examination of the main reflector current indicates that a severe phase error is responsible for the gain loss. The phase error is, of course, a function of the feed displacement in terms of wavelengths. The beam position is about 0.19 degrees for the offset feed at both frequencies. Figures 2 and 3 show the comma lobes generated by the offset feeds—about -12.5 dB at L-band and -10 dB at C-band. Due to the large gain loss incurred by displacing the feed, particularly at C-band, some investigations were carried out to determine the effects of feed angle and subreflector position on this gain loss. The next few sections summarize the calculations made to determine these effects.

III. Feed Displacement

Antenna gain and beam position were calculated as a function of purely radial feed displacement for both frequencies of interest. The geometry is depicted in Fig. 4. The radial feed displacement (ΔR) was varied with a fixed feed angle of θ_F = 5.73722 degrees. Calculated antenna directivity (line 1 of Table 1) is plotted as a function of ΔR for L-band in Fig. 5 and C-band in Fig. 6. The calculated beam position is essentially identical for both frquencies and is plotted in Fig. 7.

From Fig. 6, we see that at 5-GHz a gain loss of about 0.5 dB occurs for an 8-inch offset, and about 1 dB for a 12-inch offset. On this plot, the current L-band feed location is well represented by a 24-inch offset and a gain loss of 2.7 dB, even though the feed angle used for this plot is 5.7 degrees as opposed to 8.6 degrees. Feed angle has only a small influence on antenna gain, and these effects are described next. Figure 7 shows that beam position is essentially a linear function of feed displacement.

IV. Feed Angle

Feed pointing angle effects were examined for a fixed feed position. The position chosen was an offset of 14 inches (ΔR = 14 inches). This distance represents the minimum distance the phase center of the L-band feed must be from the focal ring due to mechanical considerations. Gain versus feed angle is plotted in Fig. 8 for L-band and in Fig. 9 for C-band. Beam position is insensitive to feed angle and is essentially constant at 0.121 degrees. These figures indicate that gain is a weak function of feed angle (note the scale of 0.05 dB per division). We will later show that spillover noise temperature is affected significantly by this parameter. From Fig. 9, we note that the optimum feed angle (in terms of gain) for a 14-inch offset is very nearly the focal ring feed angle of 5.7 degrees.

V. Subreflector Tilt

For a study of subreflector tilt, the feed was placed at the present L-band location with a pointing angle of 5.73722 degrees. The geometry for subreflector tilt is depicted in Fig. 10. The subreflector system was rotated through an angle ($\theta' - \theta_0$) about the point B, which is located at Z_m = 644 inches. This particular rotation point was chosen since excellent results have been obtained using this point when analyzing a similar problem [1]. Also, following the results of [1], the nominal angle of rotation was taken to be one-half the difference between the offset feed location and the focal ring location. Gain at L-band and C-band for several subreflector tilt angles near the optimum point is shown in Figs. 11 and 12. The corresponding beam position, identical for both frequencies, is shown in Fig. 13.

As was previously reported [1], these calculations indicate that nearly all of the gain lost due to displacing the feed can be recovered by tilting the subreflector. For approximately 1.2 degrees of subreflector tilt, all but 0.13 dB of the gain lost at C-band is recovered, and all but 0.11 dB at L-band. Unfortunately, the mechanical controls required to tilt the subreflector between tracks are not part of the present design.

VI. Lateral Subreflector Movement

As an alternative to subreflector tilt, the effect of lateral subreflector movement on antenna gain was investigated. Unlike subreflector tilt, the mechanical controls required for lateral subreflector movement are part of the present design.

For these calculations, a feed located at the present L-band position and pointed at the present L-band feed angle (8.617 degrees) was used. The subreflector was moved in a purely ($-X_m$) direction (see Fig. 10). Gain at L-band and C-band for subreflector displacements up to 5 inches is shown in Figs. 14 and 15, with the corresponding beam position shown in Fig. 16. Figures 17 and 18 show antenna patterns for a subreflector displacement of 5 inches.

Again, a substantial increase in gain, particularly at C-band, can be obtained for offset feeds by a lateral displacement of the subreflector. For a 3-inch subreflector movement, the gain lost relative to that for a feed on the focal ring is about 1 dB, and about 0.5 dB for a 5-inch subreflector movement. These losses should be compared to 2.7 dB for a non-displaced subreflector. For L-band, all but about 0.1 dB of the gain loss is recovered for a subreflector offset of 3 inches. Figures 17 and 18 show how the pattern symmetry is improved and the comma lobe is reduced for a 5-inch subreflector displacement.

VII. Spillover Noise Temperature

Since lateral displacement of the subreflector appears to be a reasonable method of obtaining acceptable gain loss for offset C-band and L-band feeds, spillover noise temperature was calculated as a function of subreflector displacement. Computer programs used in the analysis are described elsewhere (A. G. Cha, *Physical Optics Analysis of NASA/JPL Deep Space Network Antennas*, JPL Internal Document D-1853, Jet Propulsion Laboratory, Pasadena, California, November 1984) and the results are summarized in Table 2. For both frequencies, spillover noise is reduced for larger subreflector displacements. Therefore, both increased gain and reduced noise can be obtained by laterally displacing the subreflector.

Finally, the influence of feed tilt angle on spillover noise was examined for the case of a 5-inch lateral subreflector displacement. Spillover noise at L-band versus feed tilt angle is plotted in Fig. 19. At the present feed angle (8.617 degrees), spillover noise is about 4.8 K, but could be reduced to about 2.0 K if the feed were repointed to an angle between 3 degrees and 5.5 degrees.

VIII. Conclusion

The results of calculations of gain for the 70-m dual-shaped antenna for several different feed and subreflector configurations at L-band and C-band have been presented. For a C-band feed located at the current L-band location, a severe gain loss of 2.7 dB occurs. Tilting the subreflector can reduce this loss to about 0.1 dB. A lateral displacement of the subreflector of 3 inches can reduce the loss from 2.7 dB to about 1 dB. Feed pointing angle was shown to have only a small effect on antenna gain, but a larger effect on spillover noise temperature.

Acknowledgements

The authors would like to acknowledge the assistance of the Antenna and Microwave Development Group, particularly Dr. T. Veruttipong, throughout this study.

References

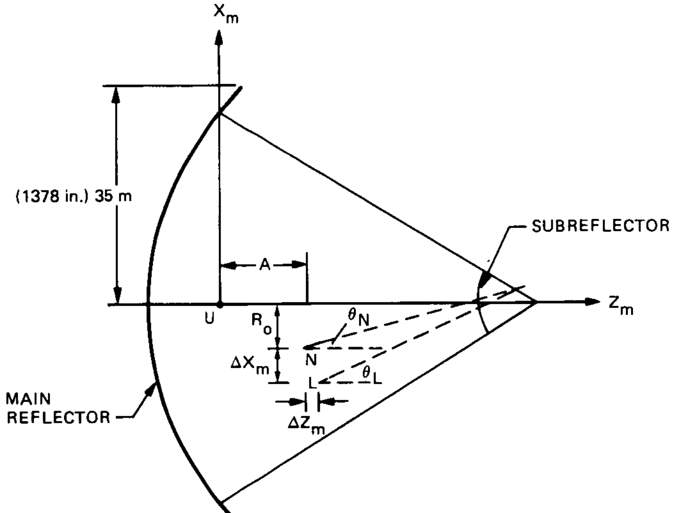
[1] T. Veruttipong, V. Galindo-Israel and W. A. Imbriale, "Low Loss Off-Axis Feeds for Symmetric Dual-Reflector Antennas," *TDA Progress Report 42-84*, vol. Oct.–Dec. 1985, pp. 35–59, Jet Propulsion Laboratory, Pasadena, Calif., February 15, 1986.

Table 1. 70-m theoretical performance

Parameter	5-GHz (C-Band)		1.68-GHz (L-Band)	
Feed location (Fig. 1)	N	L	N	L
Directivity	70.85	68.11	61.29	60.87
Quad (0.922)	–0.35	–0.35	–0.35	–0.35
VSWR (1.2)	–0.04	–0.04	–0.04	–0.04
Surface tolerance (0.0208 in.)	–0.05	–0.05	–0.01	–0.01
Horn loss	–0.22	–0.22	–0.10	–0.10
Waveguide loss	–0.18	–0.18	–0.07	–0.07
Pointing loss	–0.07	–0.07	–0.01	–0.08
Gain (dBi) at system η	69.94	67.20	60.71	60.22
η%	72.7	38.7	77.8	69.5
Gain (dBi) at 100% η	71.32	71.32	61.80	61.80
Beam position, deg	0.0	0.186	0.0	0.194

Table 2. Spillover noise temperatures

Subreflector Displacement, in.	Spillover Noise (C-Band), K	Spillover Noise (L-Band), K
0	11.7	9.4
3	8.7	7.6
5	5.9	4.8



U	ORIGIN OF SHAPER PROGRAMS
N	FOCAL RING FEED LOCATION
A	101.6 in.
R_o	42.523 in.
θ_N	FEED ANGLE 5.73722°
L	L-BAND FEED LOCATION
ΔX_m	23.674 in.
ΔZ_m	2.981 in.
θ_L	L-BAND FEED ANGLE (8.617°)

Fig. 1. 70-m antenna geometry

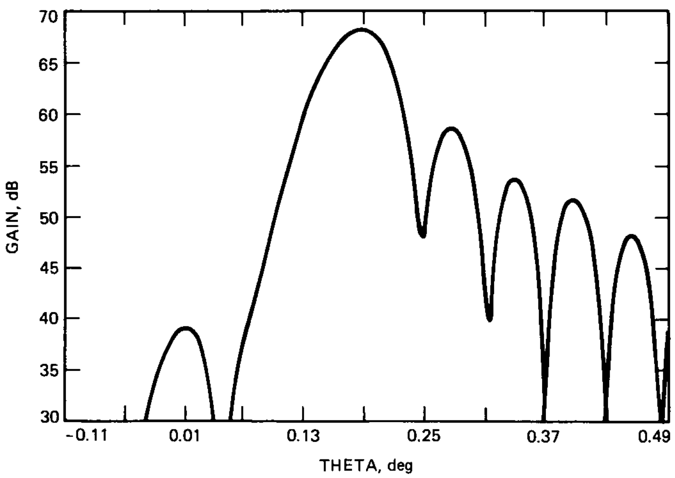


Fig. 2. C-band pattern, present L-band feed location

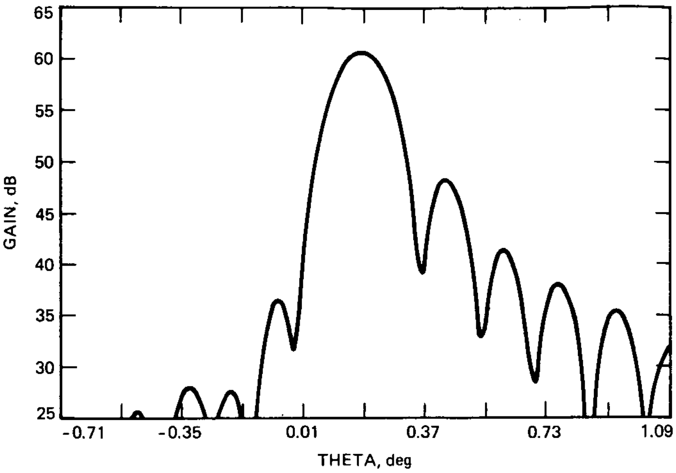
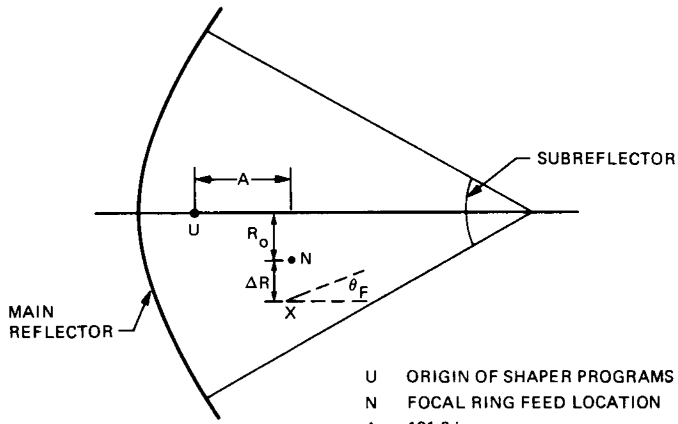


Fig. 3. L-band pattern, present L-band feed location



U	ORIGIN OF SHAPER PROGRAMS
N	FOCAL RING FEED LOCATION
A	101.6 in.
R_o	42.523 in.
X	OFFSET FEED LOCATION
ΔR	RADIAL FEED DISPLACEMENT
θ_F	5.73722°

Fig. 4. Geometry for radial feed displacement

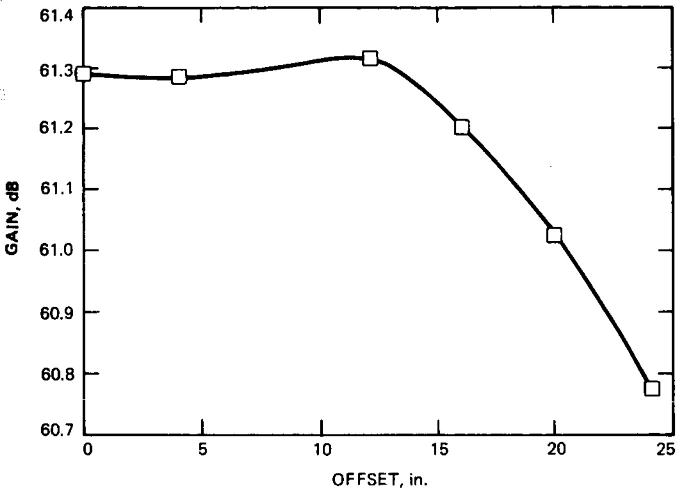


Fig. 5. Gain vs. radial feed displacement (L-band)

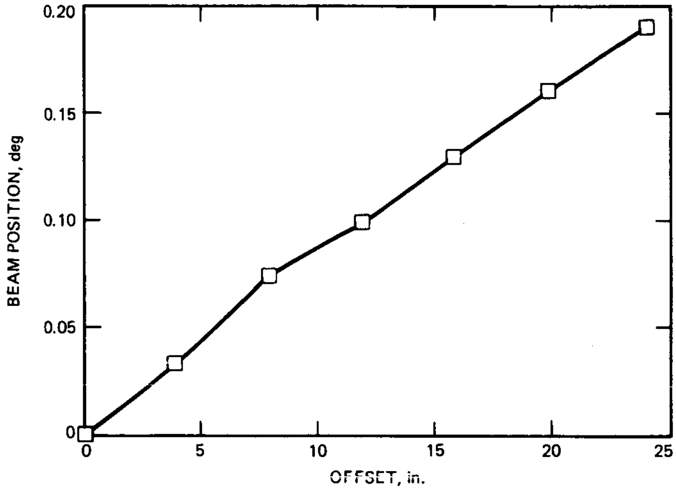


Fig. 7. Beam position vs radial feed displacement

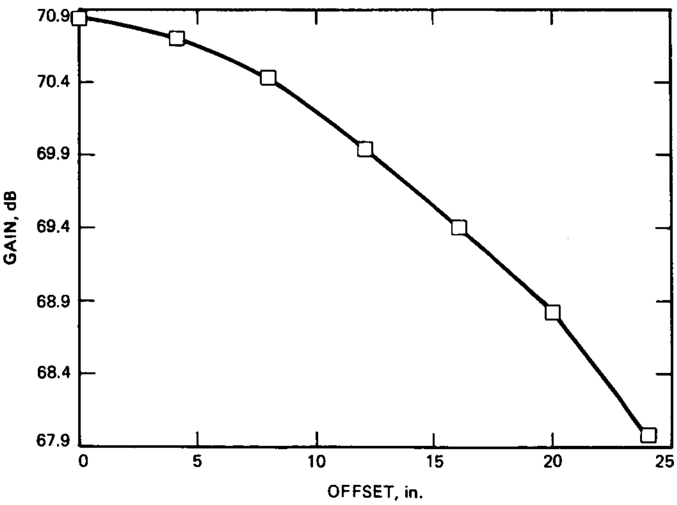


Fig. 6. Gain vs. radial feed displacement (C-band)

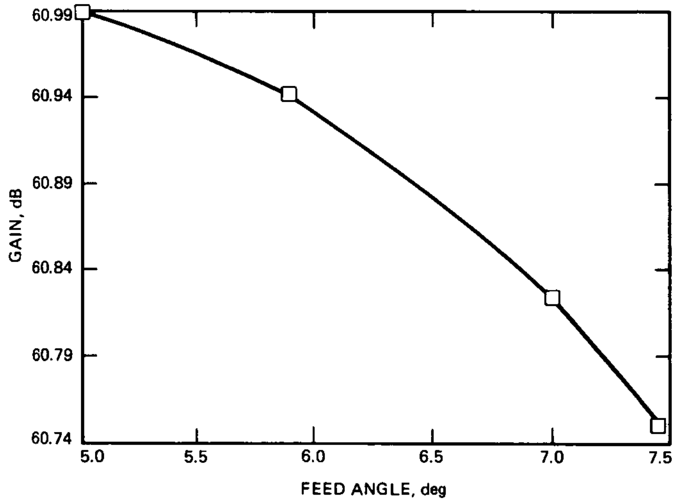


Fig. 8. Gain vs. feed angle (L-band)

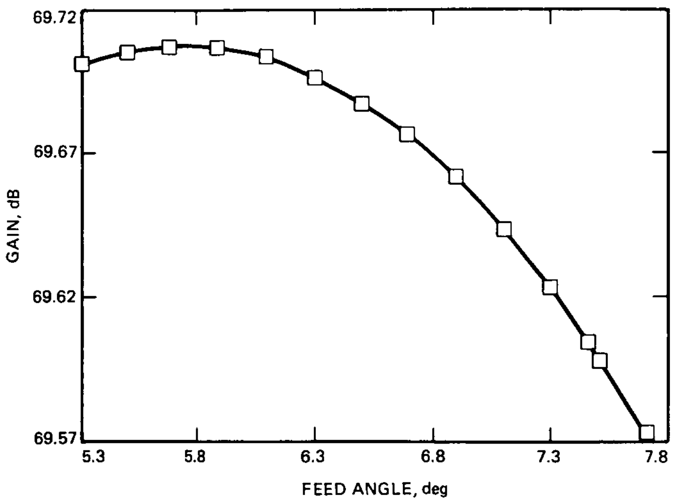


Fig. 9. Gain vs. feed angle (C-band)

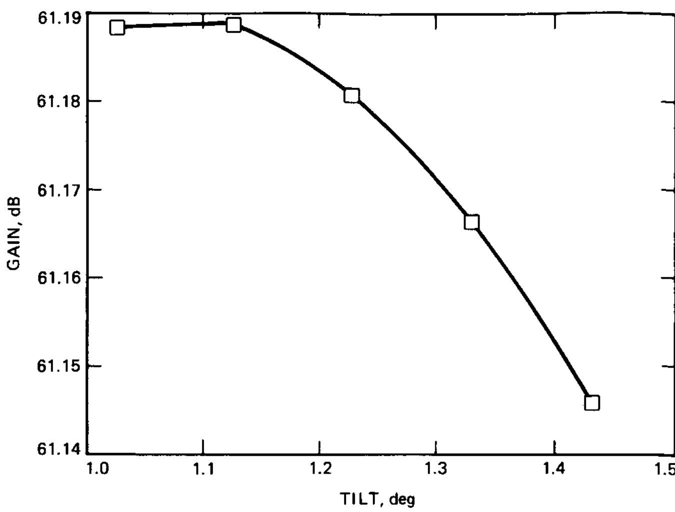


Fig. 11. Gain vs. subreflector tilt (L-band)

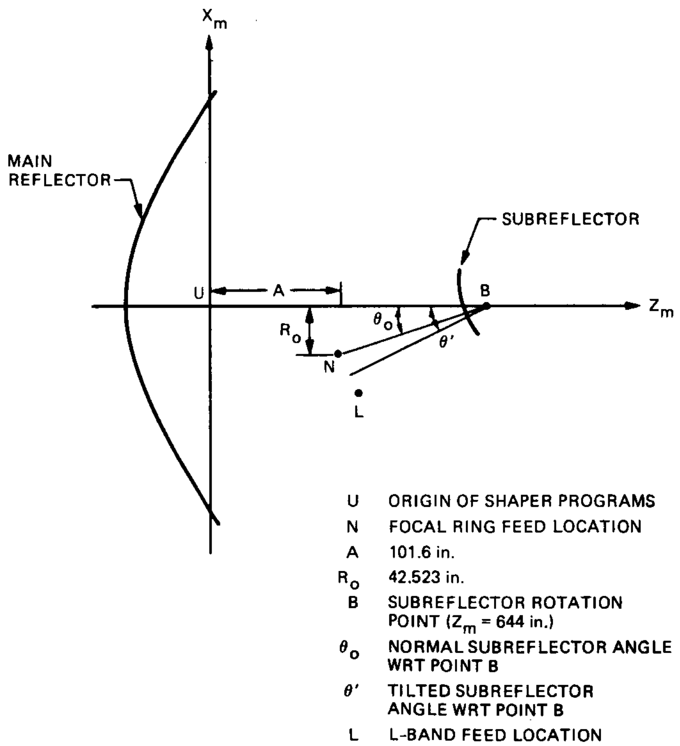


Fig. 10. Geometry for subreflector tilt

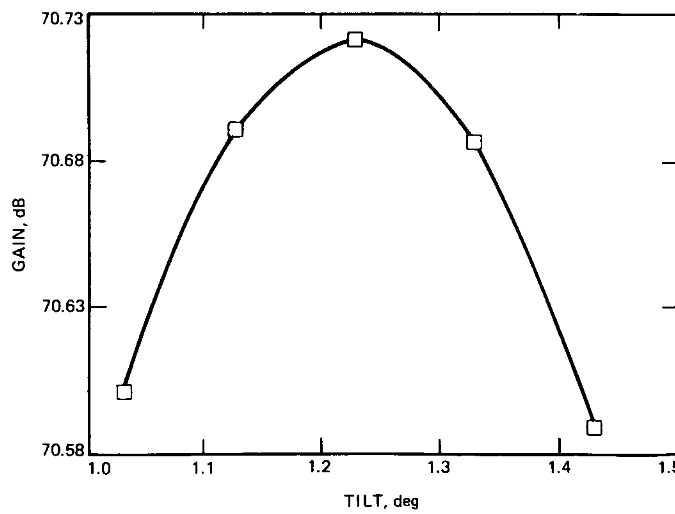


Fig. 12. Gain vs. subreflector tilt (C-band)

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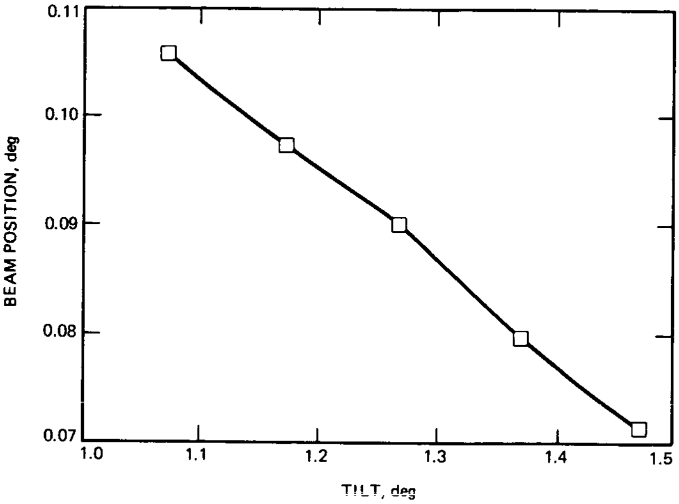

Fig. 13. Beam position vs subreflector tilt

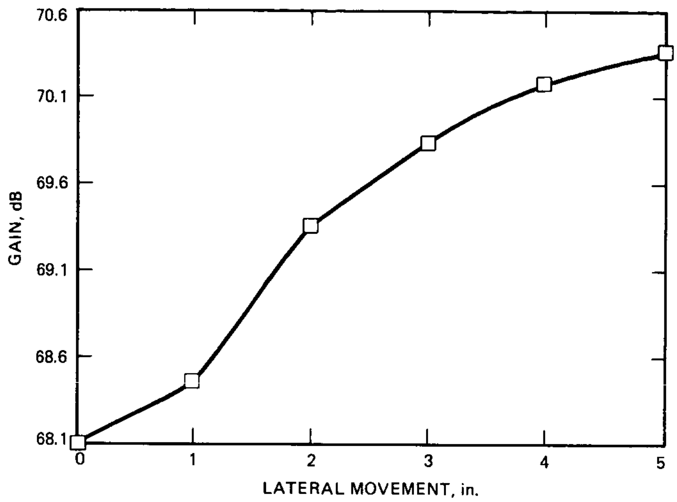

Fig. 15. Gain vs. lateral subreflector movement (C-band)

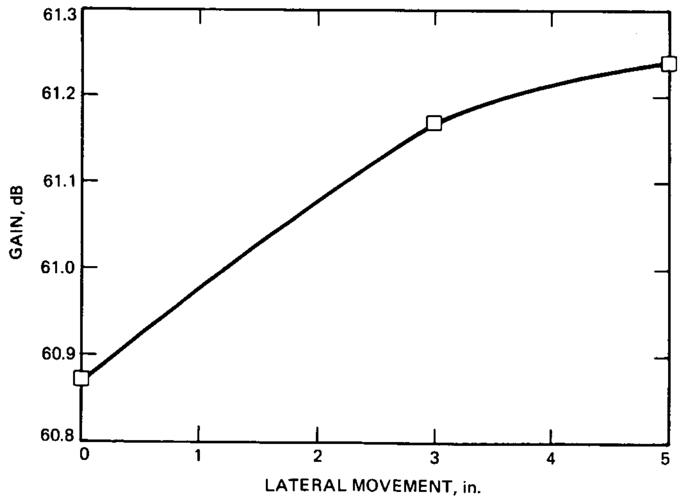

Fig. 14. Gain vs. lateral subreflector movement (L-band)

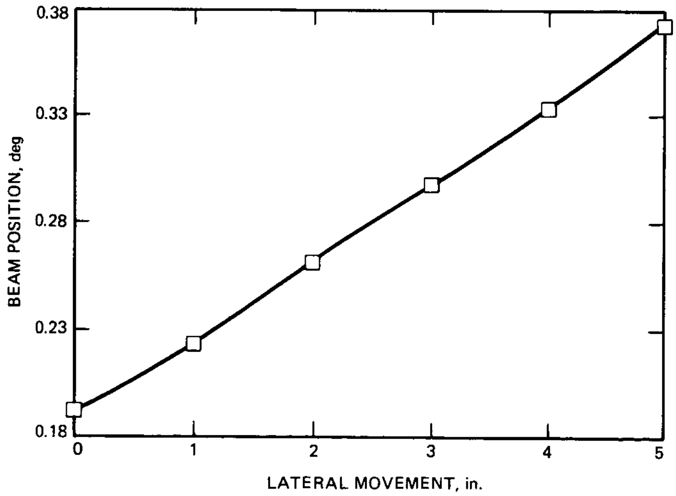

Fig. 16. Beam position vs. lateral subreflector movement

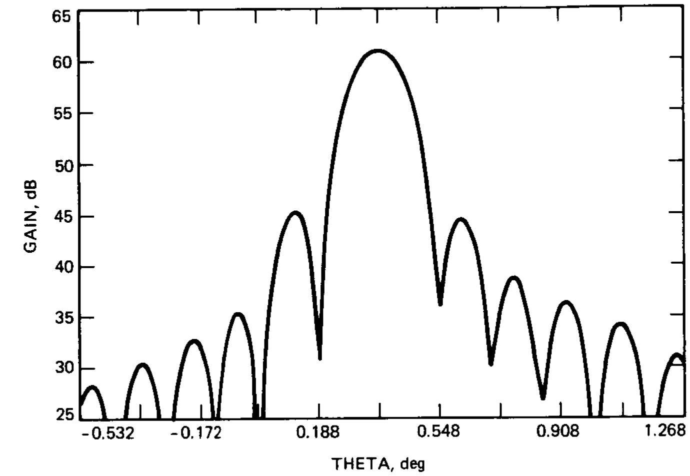

Fig. 17. L-band pattern 5-inch subreflector offset

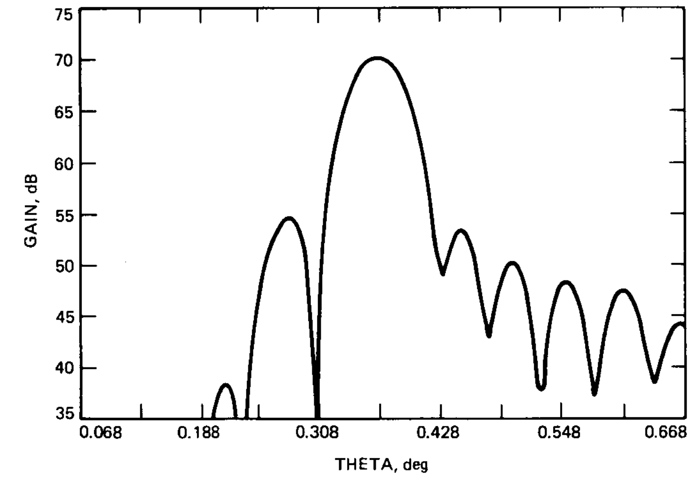

Fig. 18. C-band pattern 5-inch subreflector offset

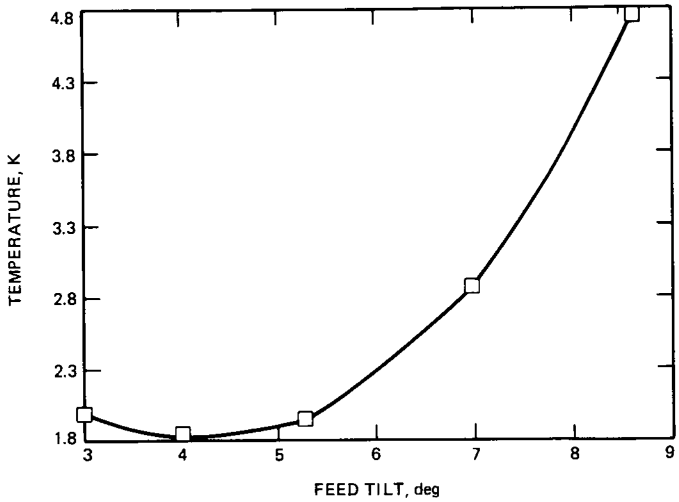

Fig. 19. Spillover noise temperature vs. feed tilt angle