GBT Memo No. 48

NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

CORRECTING FOR GRAVITATIONAL MOTION OF FOCUS IN ELEVATION (SMALL SUBREFLECTOR)

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It has been estimated by the structures group that the feeds and subreflectors would travel by about a maximum of 8 inches (") in the elevation plane as the telescope moves from zenith to horizon, due to the deflection of the arm which supports the above on the GBT. This would result in the focus of the main reflector and one of the foci of the gregorian subreflector (which is coincident with the focus of the main reflector in the absence of deflection) to separate by a maximum of 8". It is anticipated that deflection of the main reflector surface would move its focus in the same direction and thus reduce this separation, but it is not known at this time how much this reduction would be. The small subreflector (4.07m x 4.33m) on the GBT would have provision for tilting about two orthogonal axes to compensate for higher frequency components of the pointing error spectrum. C. Brockway in GBT Memo No. 33 contemplates the compensation of focus travel by the tilt mechanism of the subreflector in lieu of translating it. This memo presents an analysis of the effects of focus travel and the amount of compensation that can be achieved by either tilting or translating the subreflector, while no correction is applied to the feed.

The analysis is done at 5 GHz and with the small subreflector. A Jacobi Bessel/GTD program is used in the analysis. Focus travels of 2", 4" and 8" are considered. Figure 1 shows the geometry of the feed and subreflector displacement. In the following discussions, a designation of +4" represents a travel of 4" towards the axis of the telescope in a direction normal to it, and -4" a travel away from the axis. The deflection of the arm would result in a very small component of travel in the telescope axial direction for the feed and subreflector. This could be corrected for by translating the subreflector axially. The 8" deflection could be offset, by positioning the feed and subreflector at their nominal positions when the telescope is at 45° elevation in which case they would displace to -4" at zenith and +4" at horizon. The effect of such a setting is also studied.

Figure 2 shows the far-field patterns of the telescope with zero displacement for the feed and subreflector relative to the main reflector (called the nominal case). For displacement of the feed and subreflector as a unit by distances of 2", 4" and 8", the beam patterns and gains are computed first. Table 1 lists the resulting performance and the beam patterns are given in Figures 3 and 4. The beam is scanned in elevation and the scan angle (in the YZ plane of Figure 1) is given in the table. Broken lines in the patterns indicate the telescope axis. For a travel of +4", the gain loss is 0.91 dB, while for -4", the loss is 1.29 dB. The reason for the difference is the uneven illumination taper at the far and near edges of the main reflector by the subreflector scattered pattern. For +8" travel, the gain loss is 3.91 dB. The -15 dB beamwidth relative to the nominal case is also shown in the table. The main beam has become wider and has overlapped with the first sidelobe. The effect is more pronounced in the elevation plane.

While trying to reason out the high loss in gain, the travel of the feed and subreflector could be thought of as travel of a prime focus feed. If the feed and subreflector are moved in the Y' direction in Figure 1, instead of Y (as in the deflection case above), the computed gain loss is 0.5 dB for 4" displacement and 2.0 dB for 8" displacement. For the same amount of displacements in the X' direction, the losses are 0.48 dB and 1.90 dB. The beam scanning angles are 1.88 half-power beamwidths (HPBW) and 3.7 HPBW's for the Y' displacement and 1.90 and 3.8 HPBW's for the X' displacements. Figure 5, reproduced from [1], gives the gain loss of offset prime focus reflectors (f/D = 1 and 0.75) for lateral feed displacements. The losses calculated above with additional data when plotted in Figure 5 places the gain loss curve for f/D = 0.6 just below the curve for f/D = 0.75. Also, the curve for the above data points falls in the right location in Figure 6 from [2] and shown in Section 5 of GBT Memo No. 3. For the above displacements, the scan angle to displacement ratio is 1.1 HPBW/wavelength. The travel of the feed and subreflector due to the deflection of the support arm has a component of movement along the Z' direction in Figure 1 that possibly accounts for the additional gain loss.

To compensate for the focus travel, first the subreflector is tilted (from the displaced location) about an axis behind it, in a direction that would translate its focus towards the prime focus. It is observed that at the optimum tilt angle for which the gain reaches a maximum, the subreflector focus has travelled beyond the prime focus by a small amount. Table 2 lists the tilt angles and the resulting performance. From Figures 7 and 8 of the far-field patterns, it is noted that the main beam is still distorted with significant difference between the beams in the two orthogonal planes. At +4" displacement, the gain loss is 0.2 dB, the main beam is wider than the nominal case by 12% and the cross-polarization level is up by about 2 dB.

Next, the subreflector is translated to compensate for the focus travel. In Table 3, the performance of the telescope, when the subreflector is translated by an amount equal to the deflection but in the opposite sense, is presented. The far-field patterns are shown in Figures 9 and 10. The gain loss is only 0.05 dB even for the 8" deflection. The beam patterns are identical in the two planes and compare well with the nominal case. Cross-polarization at +4" displacement is worse by about 2 dB compared to the tilted case above, but the copolar beam is much superior.

The conclusion of this memo is that translating the subreflector is the best method of compensating for focus travel, especially when the travel is of the order of 4" or more. The small subreflector would have a two-axes tilt mechanism for pointing corrections, which, if necessary, could be used in addition to translation at very high frequencies. It remains to be seen if any tilting would be required for the big subreflector.

References:

[1] P. G. Ingerson, "Off-Axis Scan Characteristics of Offset Fed Parabolic Reflectors," *IEEE Int. Symp. Digest AP-S* (Urbana, IL), June 1975, pp. 382-383.

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

TABLE 1. Feed and Subreflector Displaced.

Displacement d (ins)	Peak Gain G (dB)	Gain Loss $G_o - G$ (dB)	-15 dB Beamwidth Ratio BW/BW_o		Angle of Beam Scan α_1	Sky Beam Rotation to Displacement Ratio α_1/d (BW/λ)	Peak Cross-Polarization Below G (dB)
			Elev. Plane	Orth. Plane			
+2	72.950	0.184	1.083	0.991	1.6′	0.80	-53.2
+4	72.220	0.914	1.558	0.976	3.2′	0.78	-51.7
-4	71.844	1.290	1.580	1.007	-3.2′	0.78	-50.2
+8	69.221	3.913	2.364	1.687	6.4′	0.78	-50.0

NOTE: For feed and subreflector at nominal position:
peak gain G_o = 73.134 dB
peak cross-polarization below G_o = -53.1 dB
HPBW = 2.4′
-15 dB beamwidth (BW_o) = 4.98′

TABLE 2. Feed and Subreflector Displaced; Subreflector Tilted.

Displacement d (ins)	Tilt Angle ω	Peak Gain G (dB)	Gain Loss $G_o - G$ ** (dB)	-15 dB Beamwidth Ratio BW/BW_o **		Angle of Beam Scan α_2	Sky Beam Rotation to Subreflector Tilt Ratio $\frac{\alpha_1 - \alpha_2}{\omega}$ **	Peak Cross-Polarization Below G (dB)
				Elev. Plane	Orth. Plane			
+2	15.5′ CW*	73.132	0.002	1.028	0.992	25.2″	0.076	-53.6
+4	49.6′ CW*	72.939	0.195	1.121	0.991	-36.0″	0.076	-49.9
-4	1°26.8′ CCW*	73.091	0.043	1.012	0.999	3.2′	0.073	-45.5
+8	2°7.0′ CW*	72.246	0.888	1.501	1.013	-3.5′	0.077	-41.0

NOTE: *CW and CCW are clockwise and counterclockwise rotations in Figure 1.
**G_o, BW_o, and α_1 are from Table 1.

TABLE 3. Feed Displaced; Subreflector Translated Back.

Displacement d (ins)	Subreflector Translation d_s (ins)	Peak Gain G (dB)	Gain Loss $G_o - G$ * (dB)	-15 dB Beamwidth Ratio BW/BW_o *		Angle of Beam Scan α_3	Sky Beam Rotation to Subreflector Translation Ratio $\frac{\alpha_1 - \alpha_3}{d_s}$ * (BW/λ)	Peak Cross-Polarization Below G (dB)
				Elev. Plane	Orth. Plane			
+2	-2	73.130	0	1.004	1.000	-32.4"	1.06	-50.5
+4	-4	73.134	0	1.003	1.001	-1.1′	1.05	-47.8
-4	+4	73.110	0.024	0.998	1.000	1.1′	1.05	-47.4
+8	-8	73.081	0.053	1.015	0.996	-2.2′	1.05	-42.9

NOTE: $^*G_o$, BW_o, and α_1 are from Table 1.

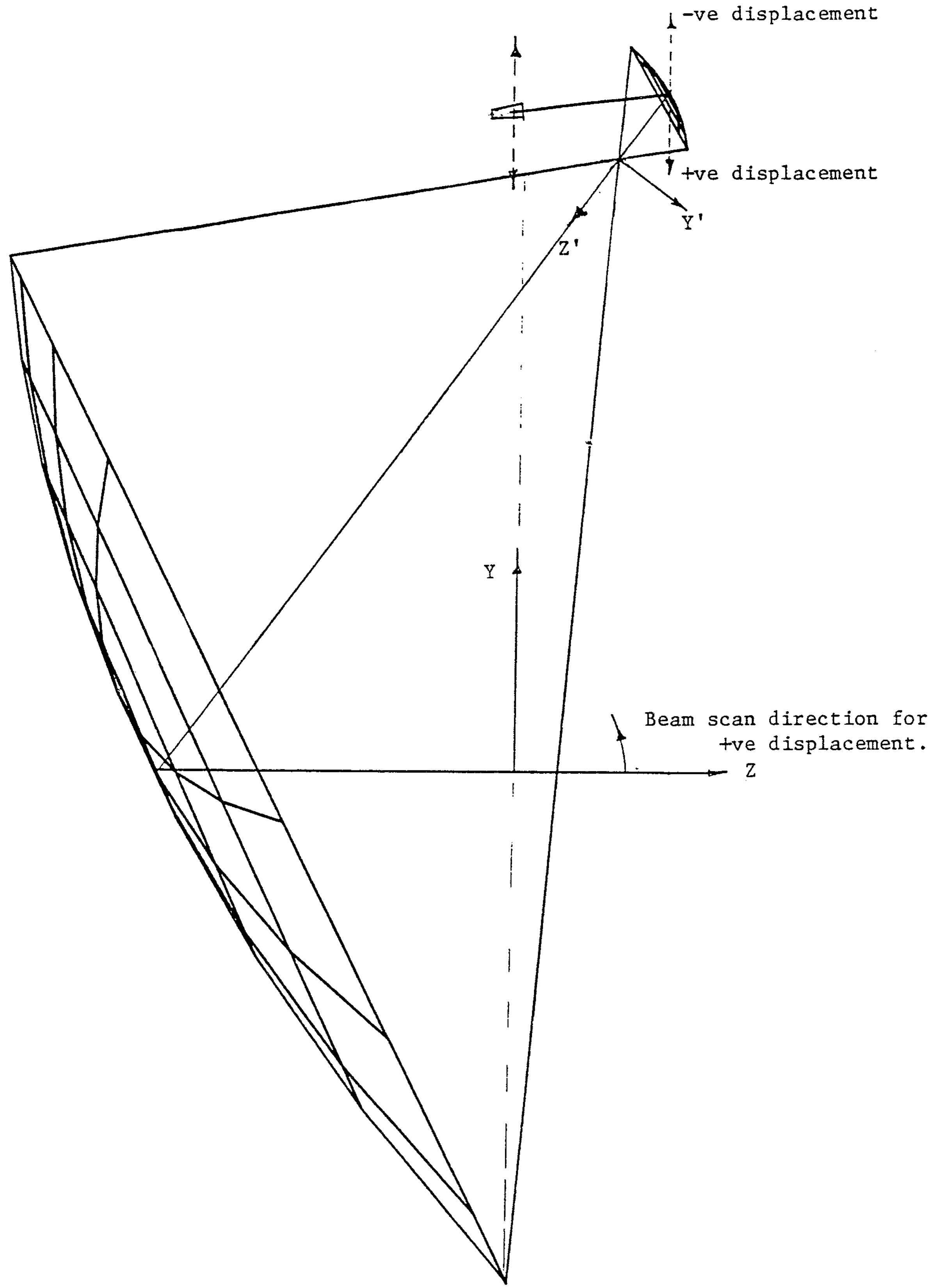
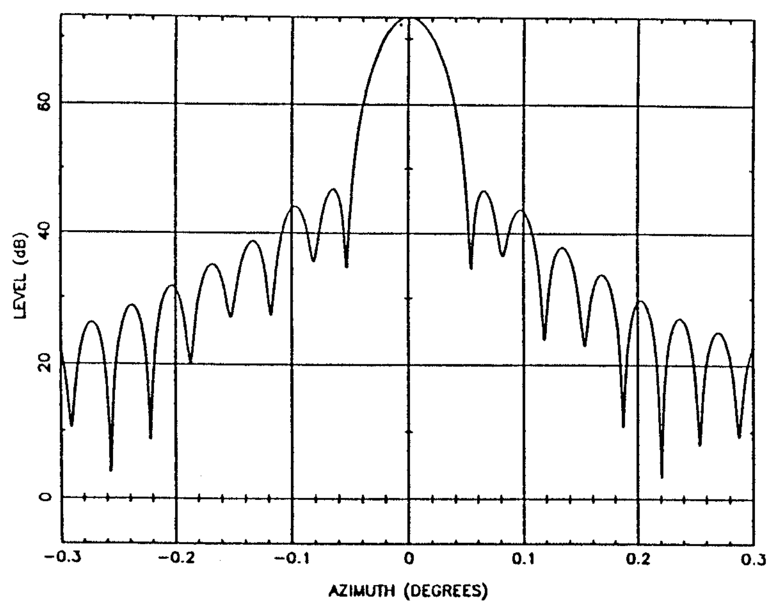
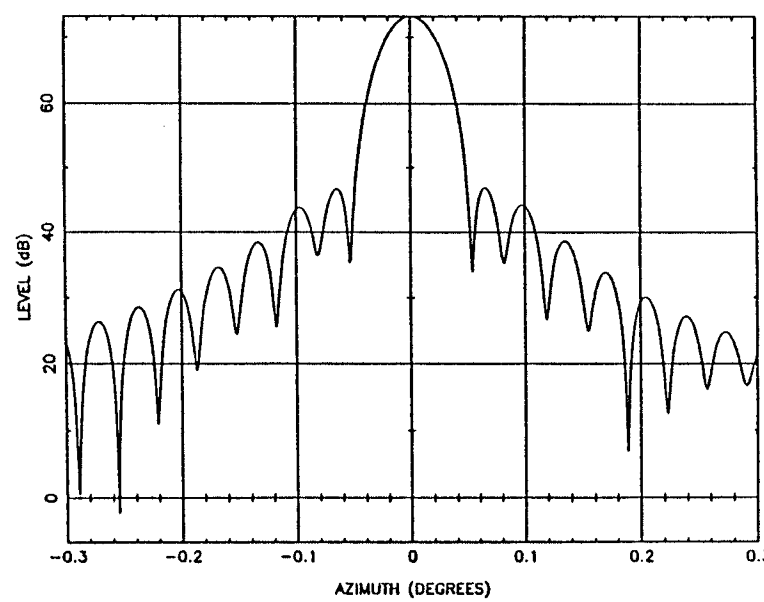


Fig. 1. Geometry of feed and subreflector travel.

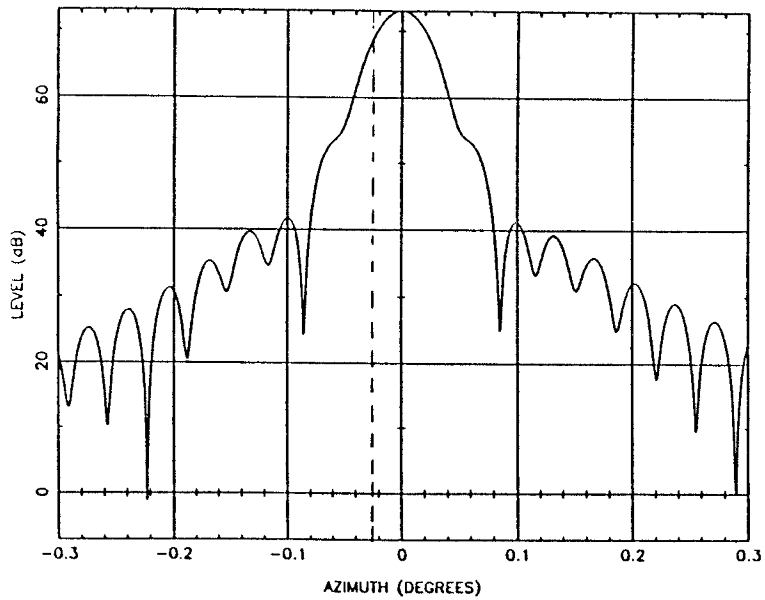


Elevation Plane

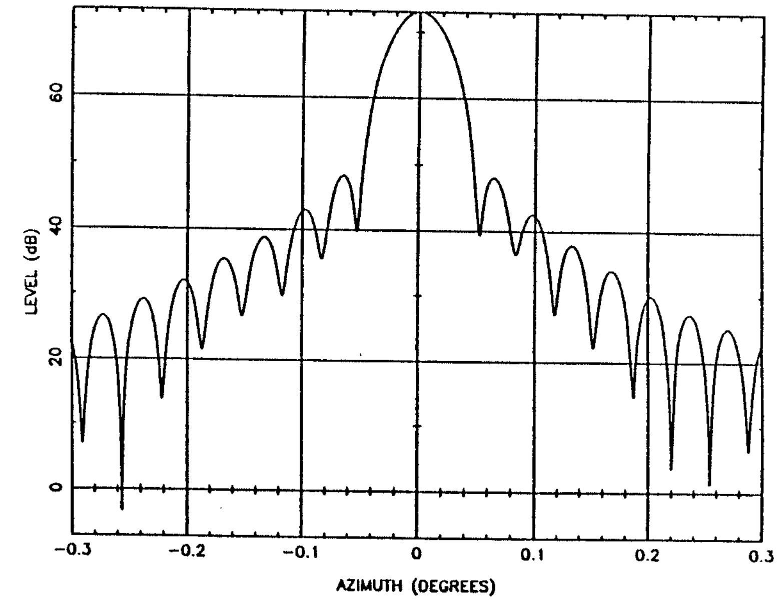


Orthogonal Plane

Fig. 2. Far-field patterns; feed and subreflector at nominal position.

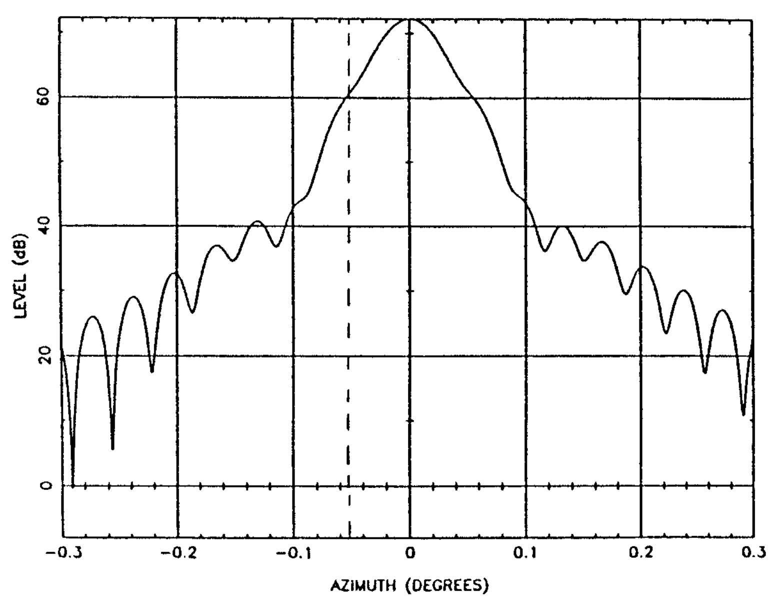


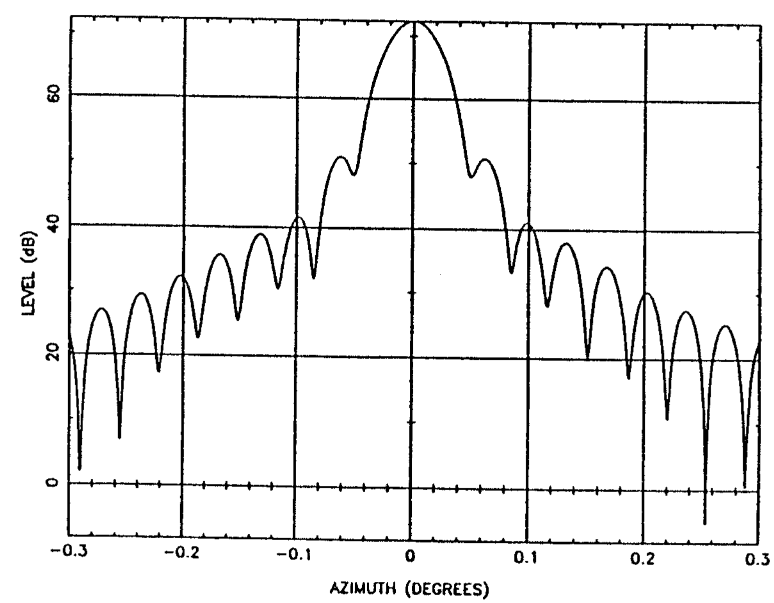
Elevation Plane



Orthogonal Plane

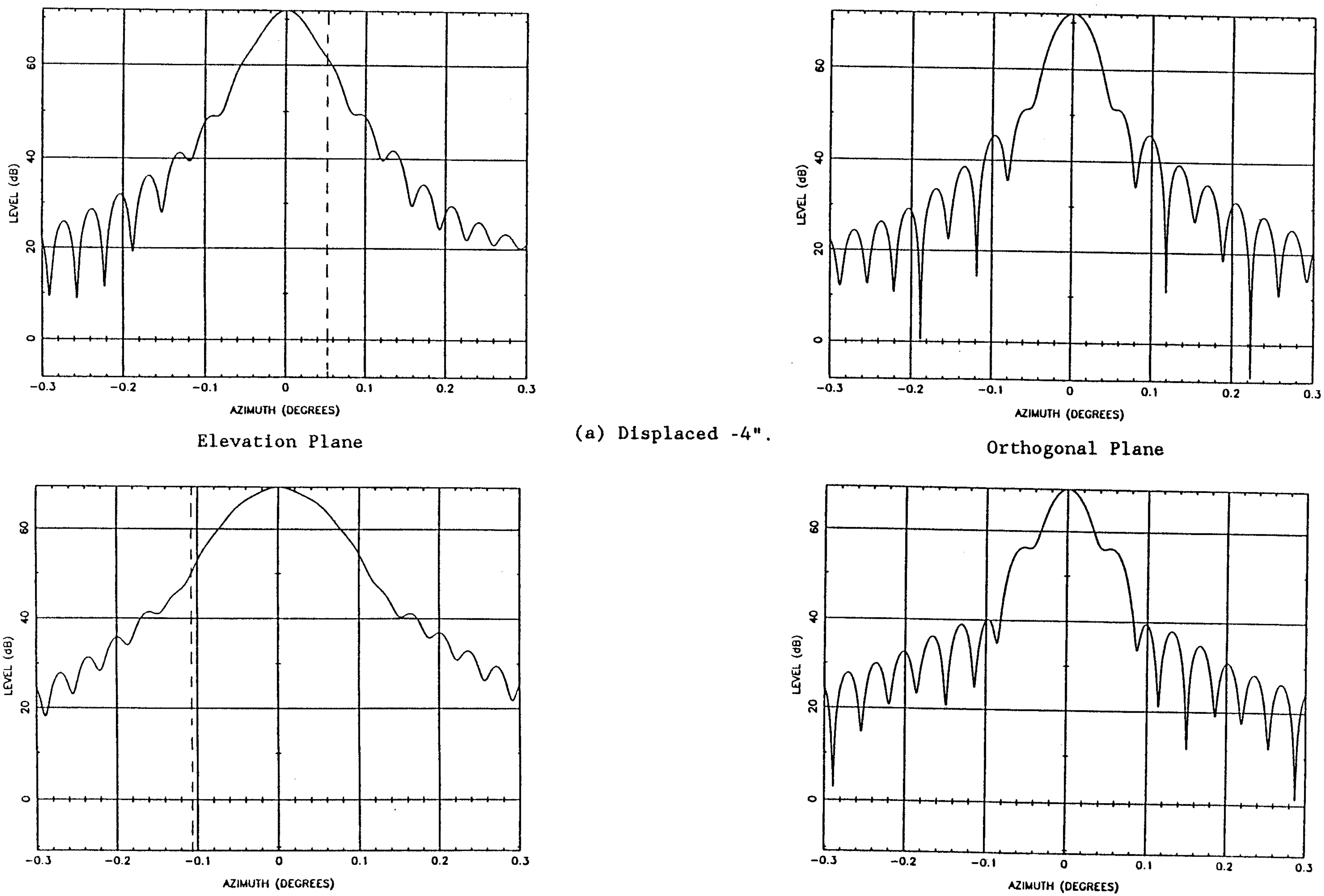
(a) Displaced +2".





(b) Displaced +4".

Fig. 3. Far-field patterns; feed and subreflector displaced.



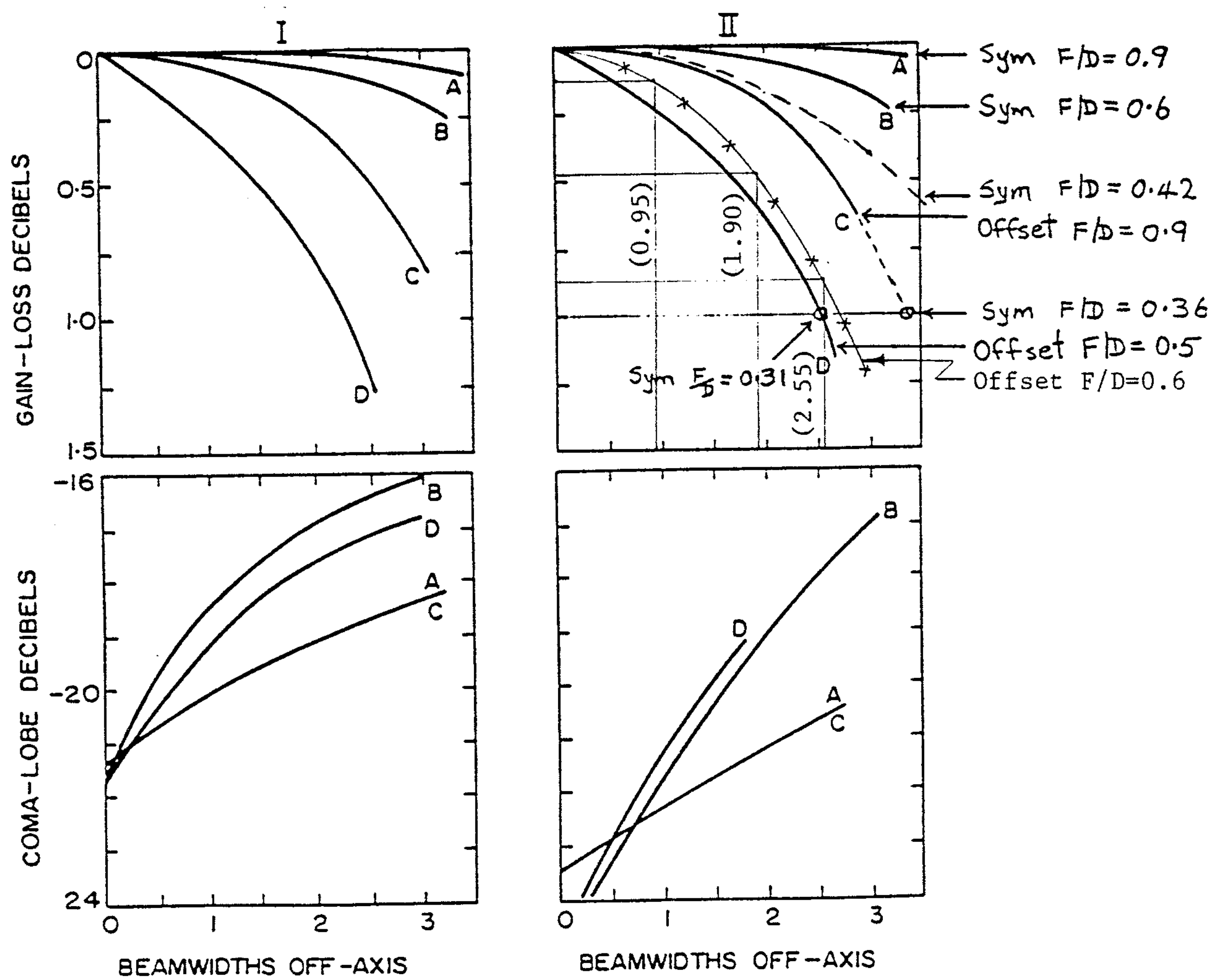
Elevation Plane

(a) Displaced -4".

Orthogonal Plane

(b) Displaced +8".

Fig. 4. Far-field patterns; feed and subreflector displaced.



Beam-scanning gain loss and coma-lobe levels. illumination tapers of −6dB (column I *and −10dB (column* II.

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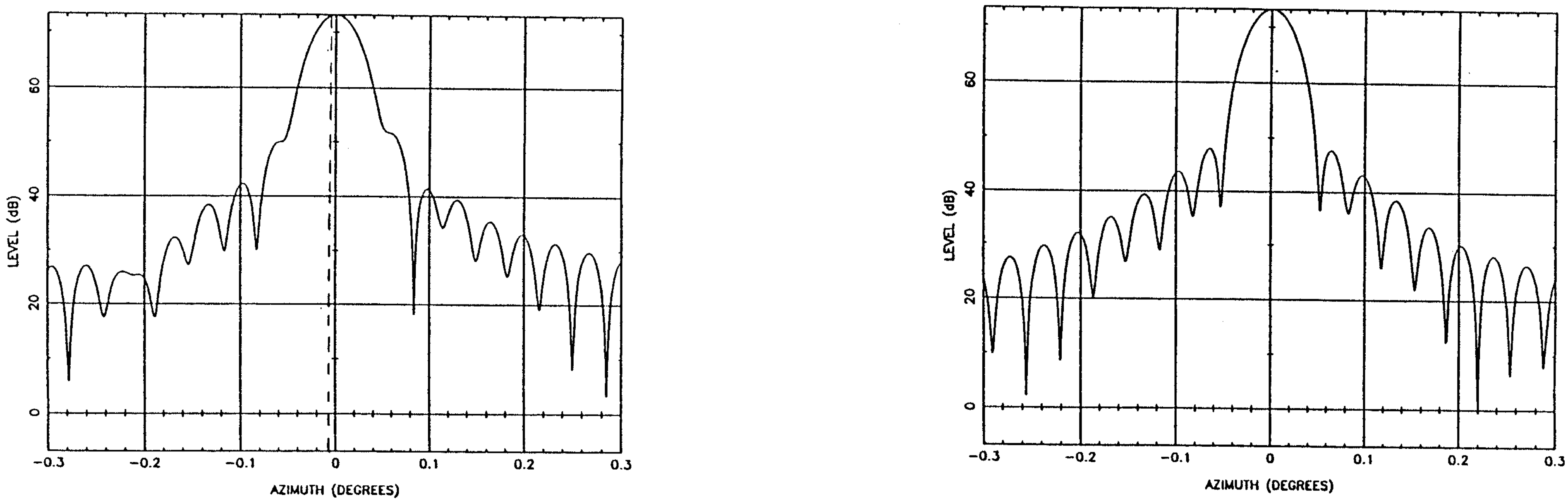
a $\theta^* = 30^\circ, \theta_0 = 0$
b $\theta^* = 45^\circ, \theta_0 = 0$
c $\theta^* = 30^\circ, \theta_0 = 45^\circ$
d $\theta^* = 45^\circ, \theta_0 = 45^\circ$

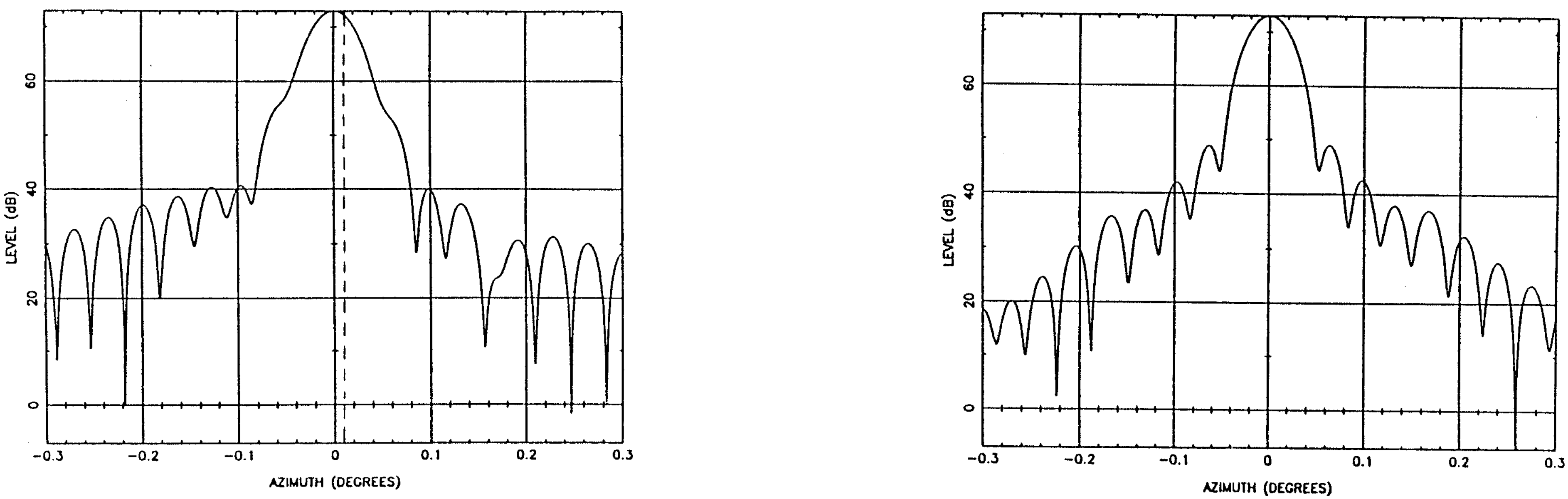
Fig. 6. Beam scan gain loss for displacement in X′ direction.



(a) Displaced +2"; subreflector tilted 15.5′ (CW).

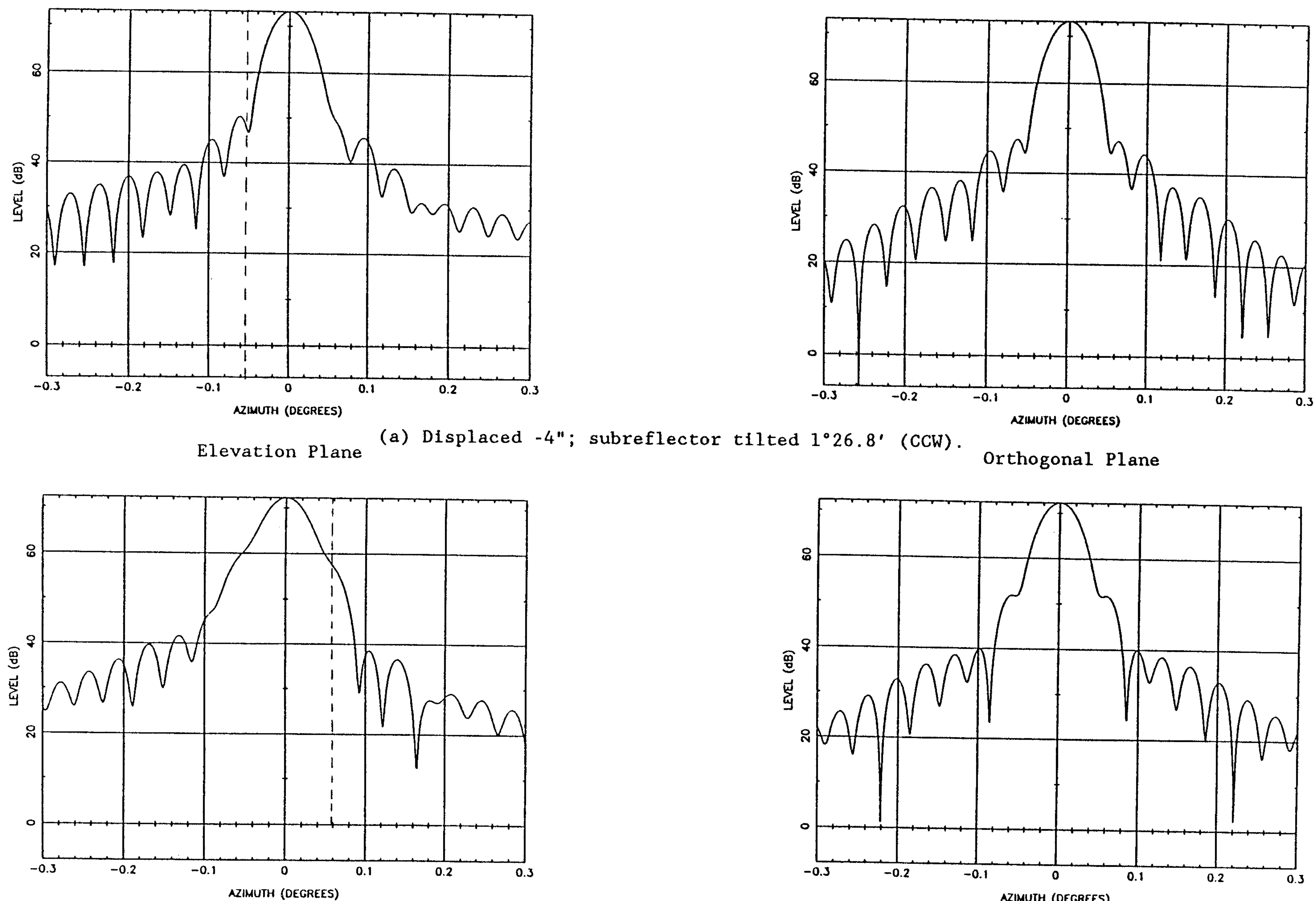
Elevation Plane

Orthogonal Plane



(b) Displaced +4"; subreflector tilted 49.6′ (CW).

Fig. 7. Far-field patterns; feed and subreflector displaced; subreflector tilted.



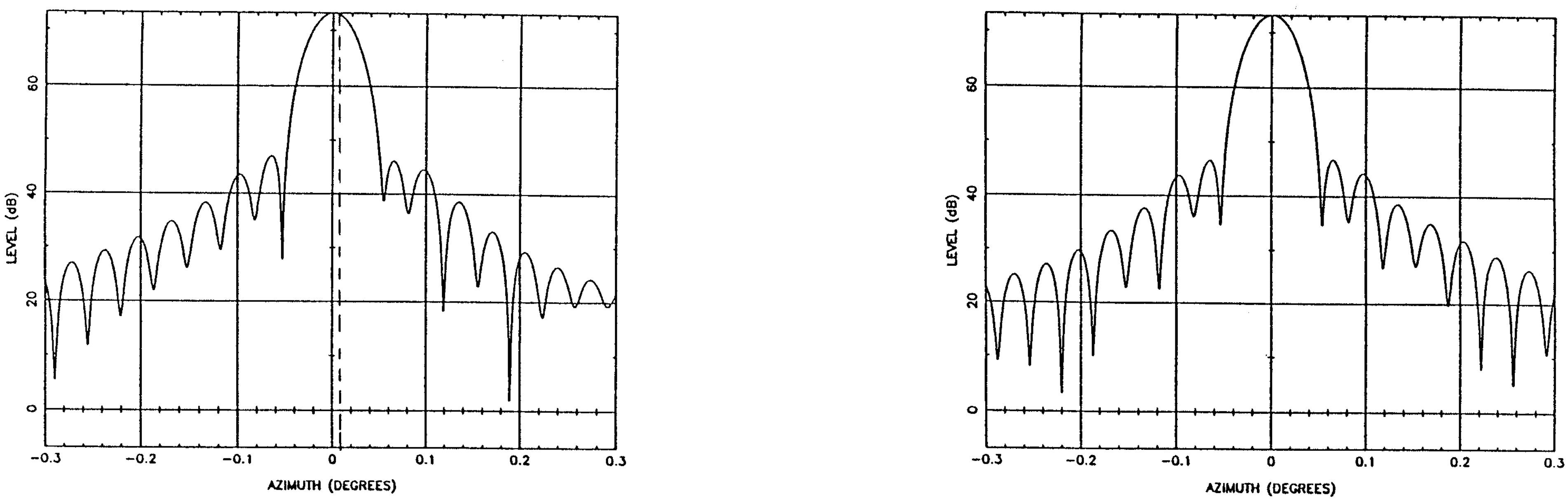
(a) Displaced -4"; subreflector tilted 1°26.8′ (CCW).

Elevation Plane

Orthogonal Plane

(b) Displaced +8"; subreflector tilted 2°7′ (CW).

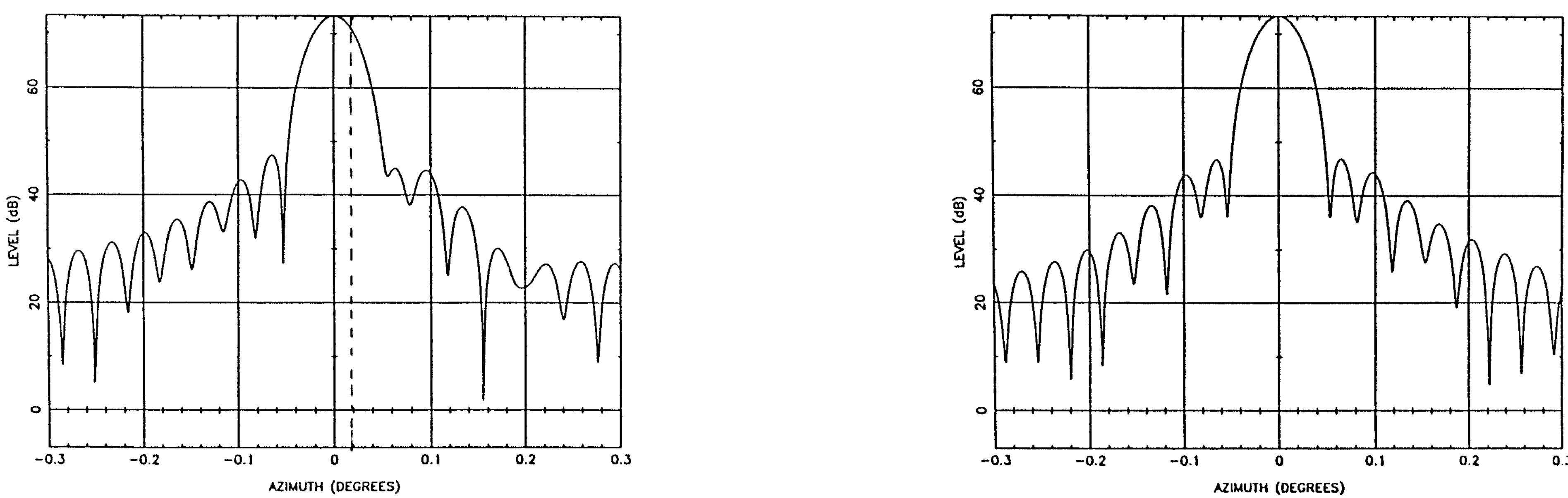
Fig. 8. Far-field patterns; feed and subreflector displaced; subreflector tilted.



(a) Displaced +2"; subreflector translated -2".

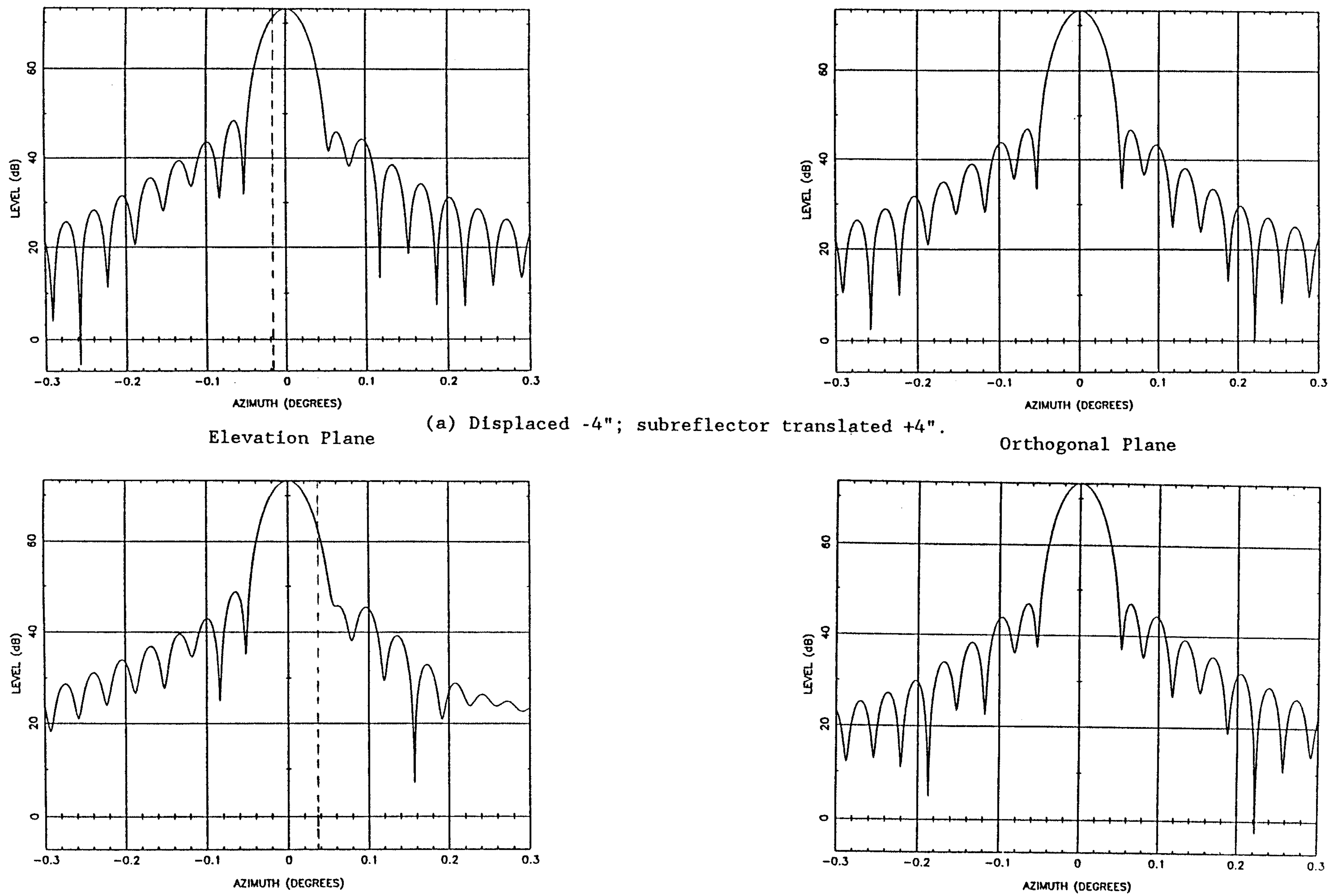
Elevation Plane

Orthogonal Plane



(b) Displaced +4"; subreflector translated -4".

Fig. 9. Far-field patterns; feed displaced; subreflector translated back.



(a) Displaced -4"; subreflector translated +4".

(b) Displaced +8"; subreflector translated -8".

Fig. 10. Far-field patterns; feed displaced; subreflector translated back.