GBT Memo No. 50

NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

AXIS OF NUTATION AND NUTATED PERFORMANCE

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The subreflector is nutated about an axis for the purpose of switching the telescope beam in the sky by about 3 half-power beam widths (HPBW), such that the beam is switched in a plane containing the telescope axis and orthogonal to the elevation plane. In other words, there is no component of switching in the elevation plane, which minimizes noise unbalance between the two beams. C. Brockway in GBT Memo No. 33 states that the nutation axis is normal to the telescope elevation axis. It is obvious that the nutation axis is also normal to the telescope axis in a symmetric antenna and not so obvious for the clear aperture GBT. This memo presents results of a study undertaken to fix the axis of nutation for the GBT, calculate the amount of rotation required for the subreflector (4.07m x 4.33m) for a 3 HPBW scan and analyze the performance of the telescope in the nutated position, using an analysis program.

As a first try, the axis of nutation was kept normal to both the elevation and telescope axes. Figure 1 illustrates the geometry of the subreflector in its nominal and nutated positions. The ratio of the beam rotation in the sky (ω) to subreflector rotation (α) is given by (from GBT Memo No. 33):

$$\frac{\omega}{\alpha} = \frac{BDf}{f}\left[2a + k\left(\frac{b + 2a}{b + a}\right)\right]$$

where:

BDf = beam deviation factor from prime focus

f = focal length

a = projected distance between subreflector vertex and focal plane

b = projected distance between feed phase center and focal plane

k = distance between axis of nutation and subreflector vertex

For the GBT, the parameters given in Figure 1 are used. With the axis of nutation at a distance of 1 meter behind the subreflector (k = 1m), ω/α = 0.081. For ω = 3 HPBW, the rotation angle of the subreflector α at different frequencies is calculated. Using these rotated geometries for the subreflector in the analysis program, the gain and beam patterns are computed. The telescope beam was found to be scanned more than 3 HPBW's and ω/α was found to be 0.085. (GBT Memo No. 34 gives $\omega/\alpha = 0.08$.) For $\omega = 3$ HPBW, the rotation angles were recalculated using the above value and the computations are repeated. The resulting performance is listed in Table 1. The performance for the non-switched case is listed in Table 2 for comparison. The results indicate that nutation of the subreflector about the above axis, which is normal to the elevation axis and normal to the axis of the parent paraboloid, results in very minute scan in the elevation direction at 5 GHz and zero scan at higher frequencies and, hence, is the obvious axis for nutation. Figures 2 through 7 show patterns for the non-switched and switched beams at 5, 20 and 40 GHz, respectively. These are patterns in the plane of switching and in the elevation plane. For the switched beams, the location of the axis of the telescope is indicated by broken lines. In the nutated position of the subreflector, in addition to the loss in peak gain, the first sidelobe in the plane of switching has increased by 5 dB as seen in the figures and the cross-polarization has increased by about 15 dB. The shape of the main beam for the switched case is essentially the same as the non-switched case. For rotation of the subreflector in the +x direction in Figure 1, the beam in the sky moves in the -x direction. As seen from Table 1, the maximum subreflector rotation angle in azimuth required for beam switching is ± 1.5°. In addition to this, rotation for pointing correction would be required. A rotation in azimuth of ± 3.0° would be more than adequate for both the tasks. If k = 2m, the maximum subreflector rotation required would be ± 1.2°. Hence, any suitable number for k between 1m and 2m could be chosen.

Table 3 lists the performance characteristics for a scan of 10 HPBW's at 40 and 100 GHz. At these frequencies, it may be necessary to scan more than 3 HPBW's while nutating. The ratio ω/α still holds good at 0.086. Figures 8 and 9 illustrate the switched beam patterns in the plane of switching and in the elevation plane at 40 and 100 GHz, respectively. The HPBW has increased by at least 20% as compared to the non-switched case.

Table 1. Performance for 3 HPBW's Switched Beam

Freq. (GHz)	Beam Rotation in Sky			Subreflector Rotation α	ω/α	Peak Gain G (dB)	Effic. η (%)	Peak Cross-Polarization Below G (dB)	First Sidelobe	
	Plane Normal to Elevation Plane		Elevation Plane						Level Below G (db)	No. of HPBW's Off Beam Max.
	ω	ω/HPBW								
5	7.2′	3.00	10.8"	1° 24.7′	0.085	72.82	69.84	-38.3	-21.6	1.60
20	1.8′	3.05	0	0° 21.5′	0.086	84.96	71.48	-50.1	-22.2	1.57
40	0′ 54.7"	2.99	0	0° 10.6′	0.086	90.99	71.57	-65.9	-22.7	1.57

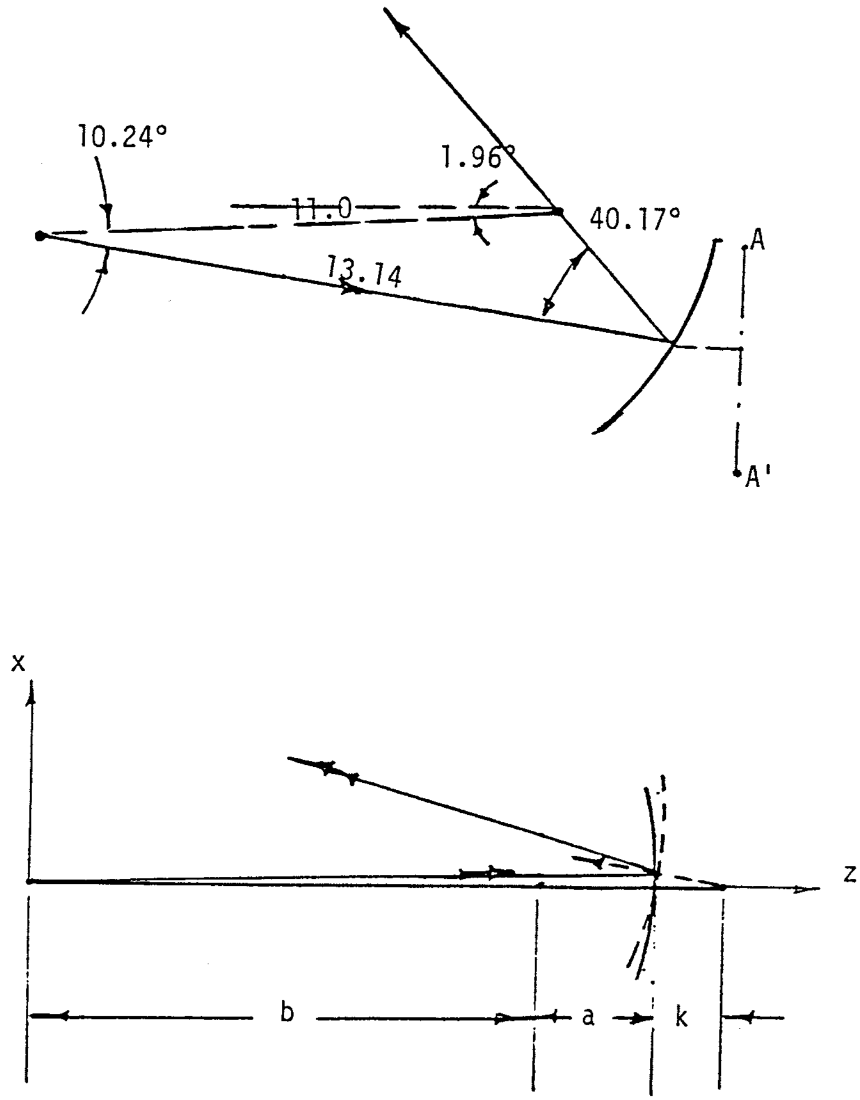
Table 2. Performance for Non-Switched Beam

Freq. (GHz)	HPBW	Peak Gain G (dB)	Efficiency η (%)	Peak Cross-Polarization Below G (dB)	First Sidelobe	
					Level Below G (db)	No. of HPBW's Off Beam Max.
5	2.4′	73.13	75.06	-53.1	-26.2	1.62
20	36.7"	85.26	76.54	-63.8	-26.0	1.57
40	18.3"	91.29	76.76	-66.9	-26.5	1.57
100	7.3"	99.25	76.81	-74.3	-26.8	1.57

Table 3. Performance for 10 HPBW's Switched Beam

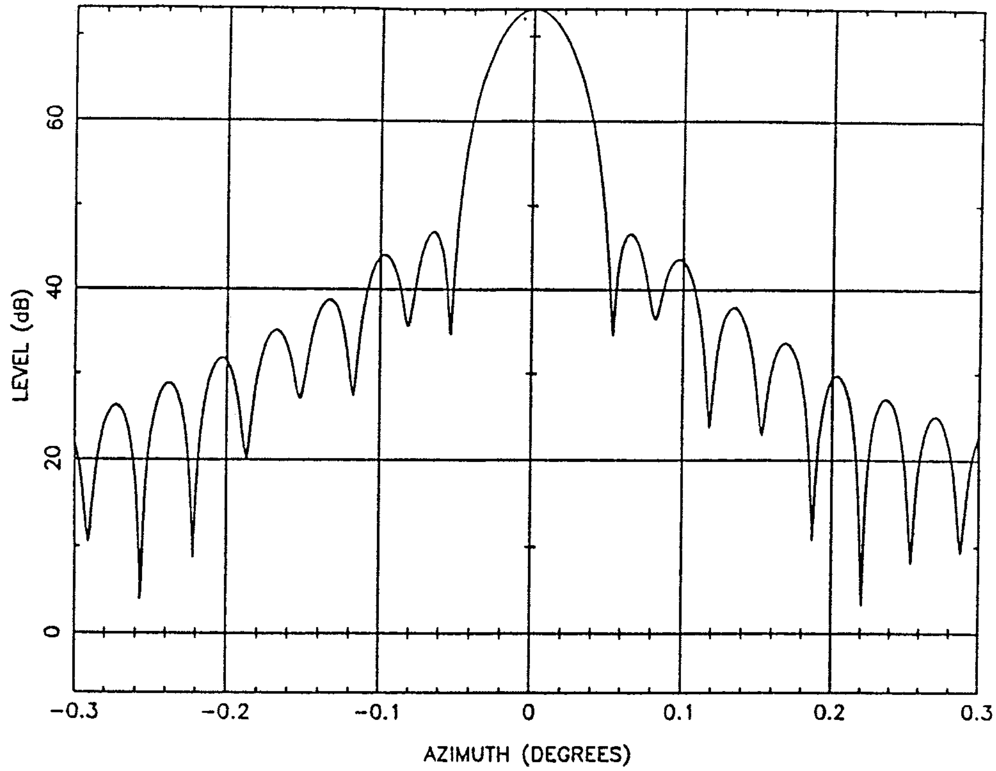
Freq. (GHz)	Beam Rotation in Sky		Subreflector Rotation α	ω/α	HPBW	Peak Gain G (dB)	Effic. η (%)	Peak Cross-Polarization Below G (dB)	First Sidelobe Below G (db)
	ω	ω/HPBW							
40	3.0′	10	35.4′	0.086	23.1"* 22.0"**	87.96	35.68	-48.6	-26.1
100	1.2′	10	14.2′	0.086	9.2"* 8.7"**	96.02	36.50	-57.2	-25.4

NOTE: *In the plane of switching.
**In the elevation plane.

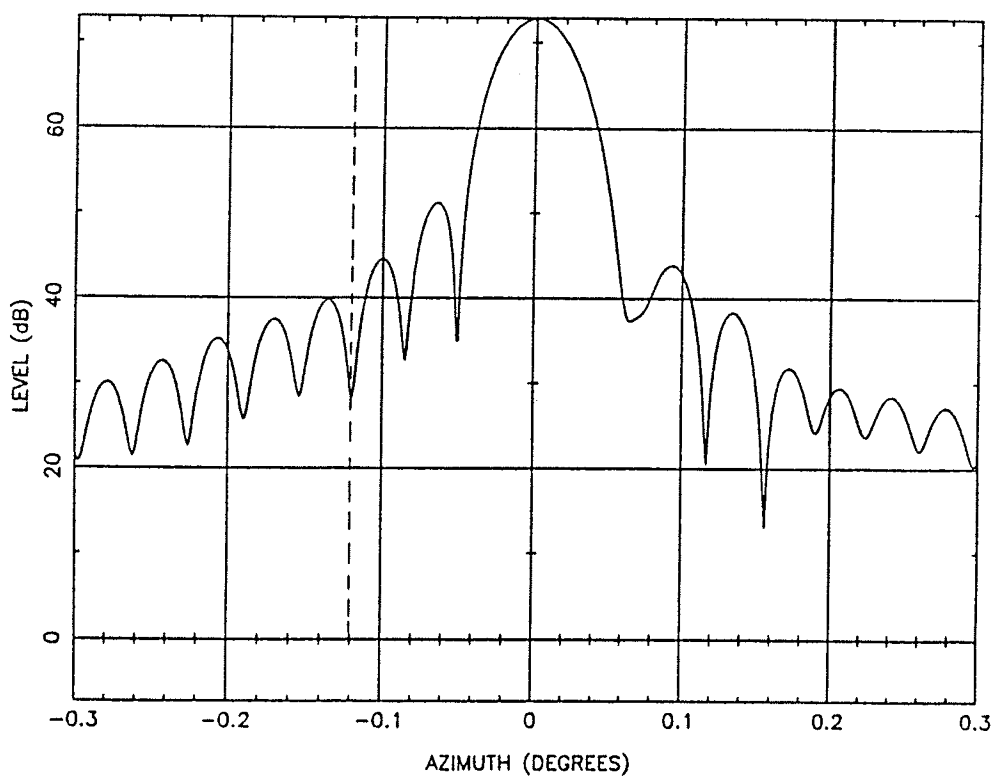


e = 0.68 (eccentricity)
b = 11 cos 1.96 = 10.994
p = 13.14 cos 8.28
a = p - b = 2.012
k = 1
BDf = 0.94
f = 60
AA' - Axis of nutation

Fig. 1. Geometry of nutation.

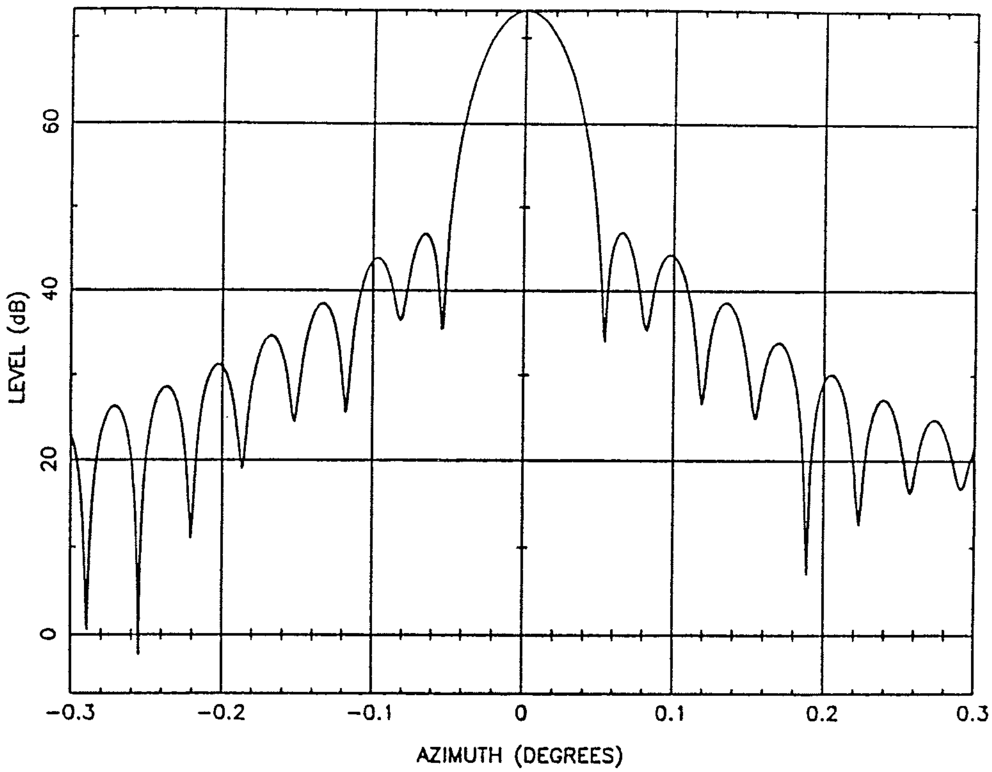


(a) Non-Switched Beam

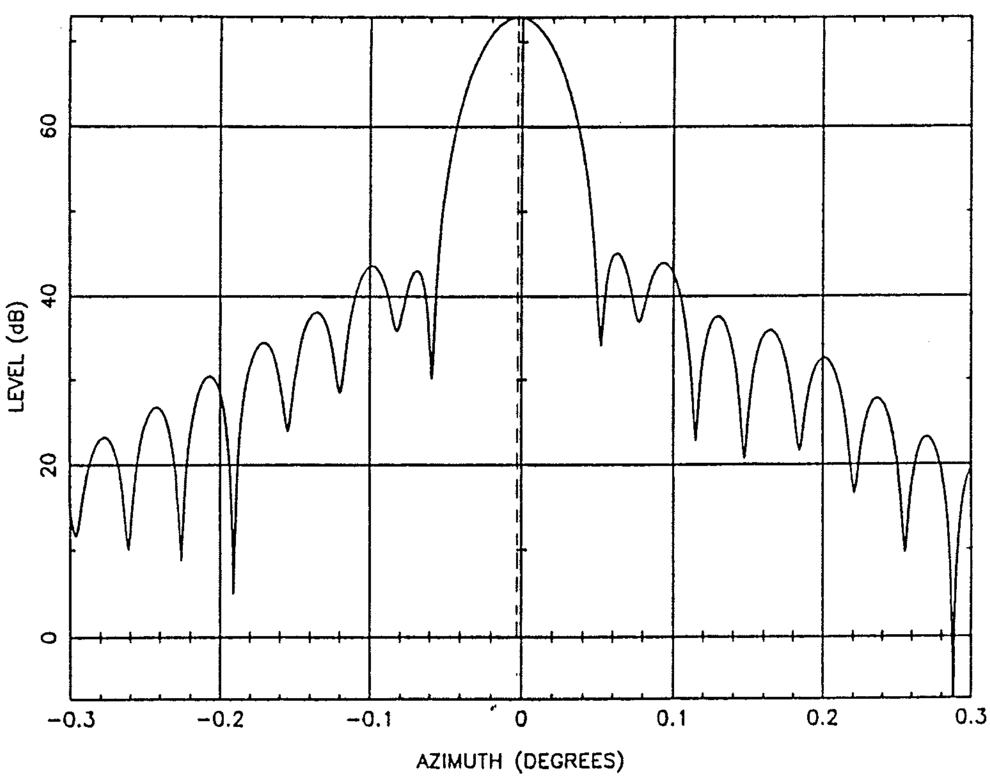


(b) Switched Beam - 3 HPBW's.

Fig. 2. Patterns at 5 GHz in the plane of switching.

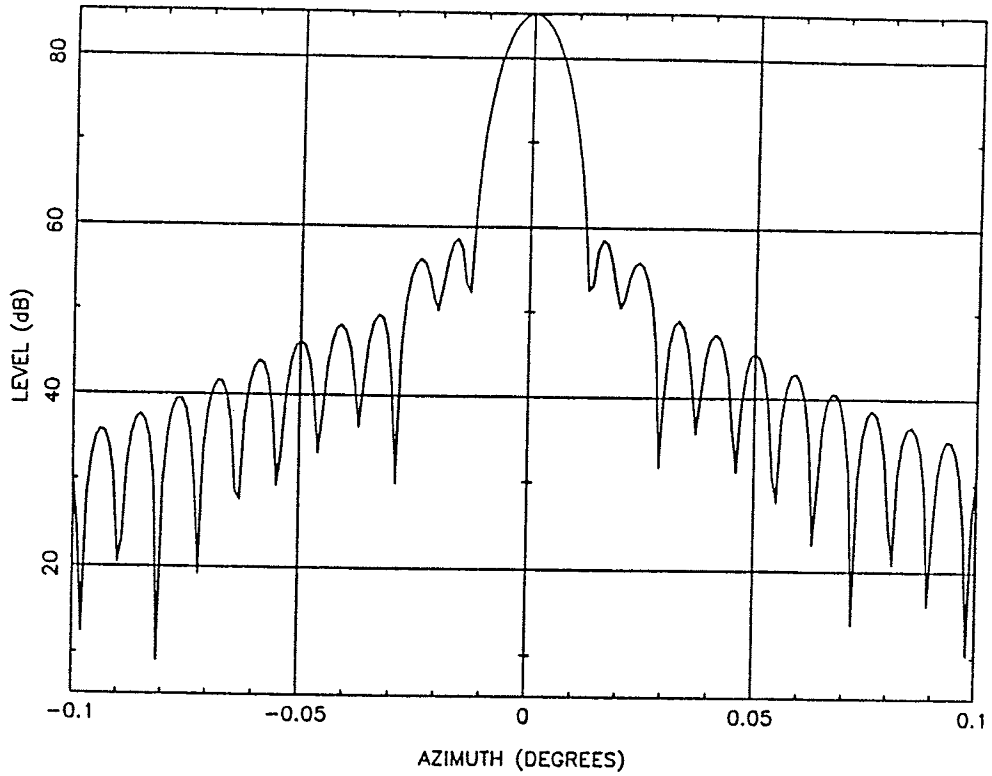


(a) Non-Switched Beam

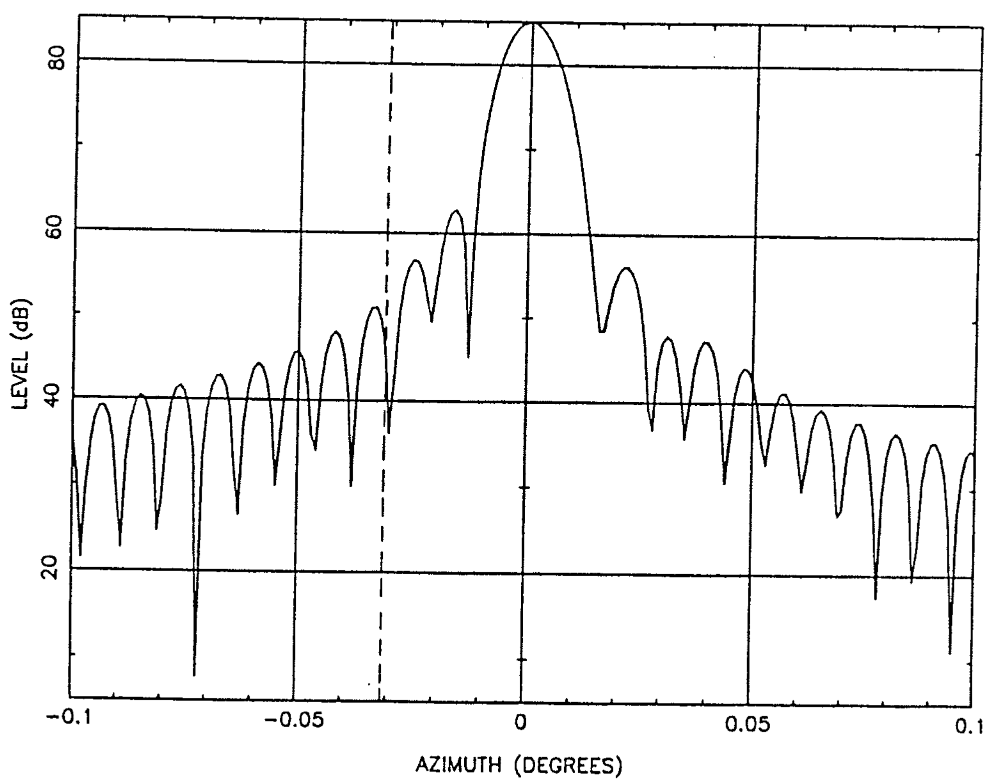


(b) Switched Beam - 3 HPBW's.

Fig. 3. Patterns at 5 GHz in the elevation plane.

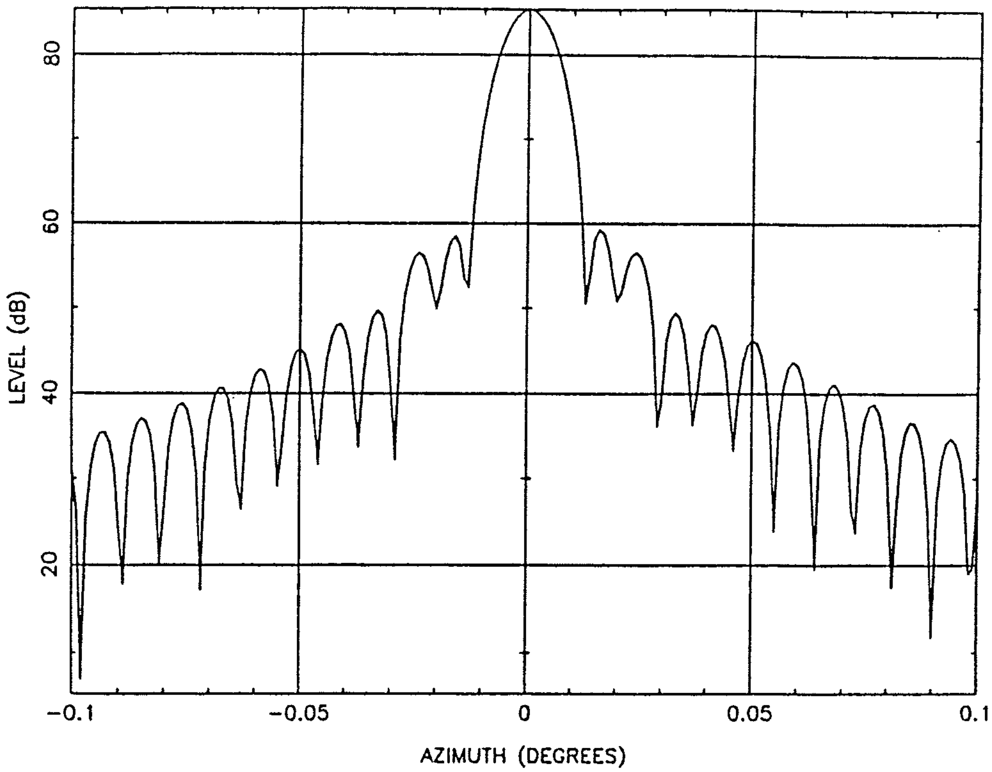


(a) Non-Switched Beam

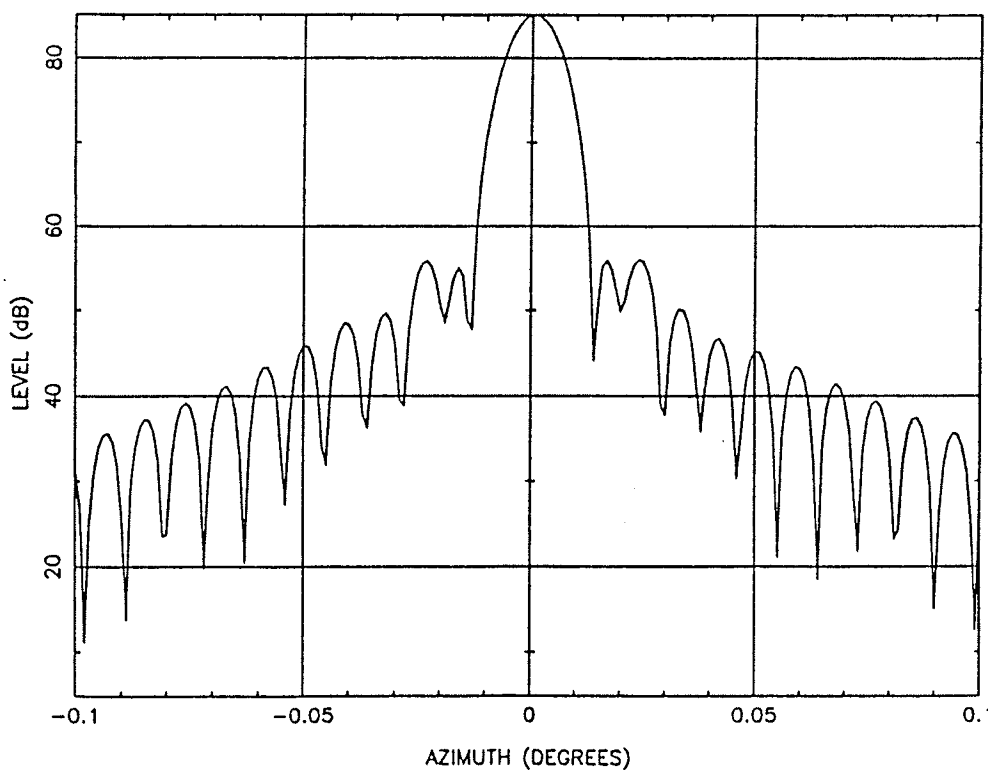


(b) Switched Beam - 3 HPBW's.

Fig. 4. Patterns at 20 GHz in the plane of switching.

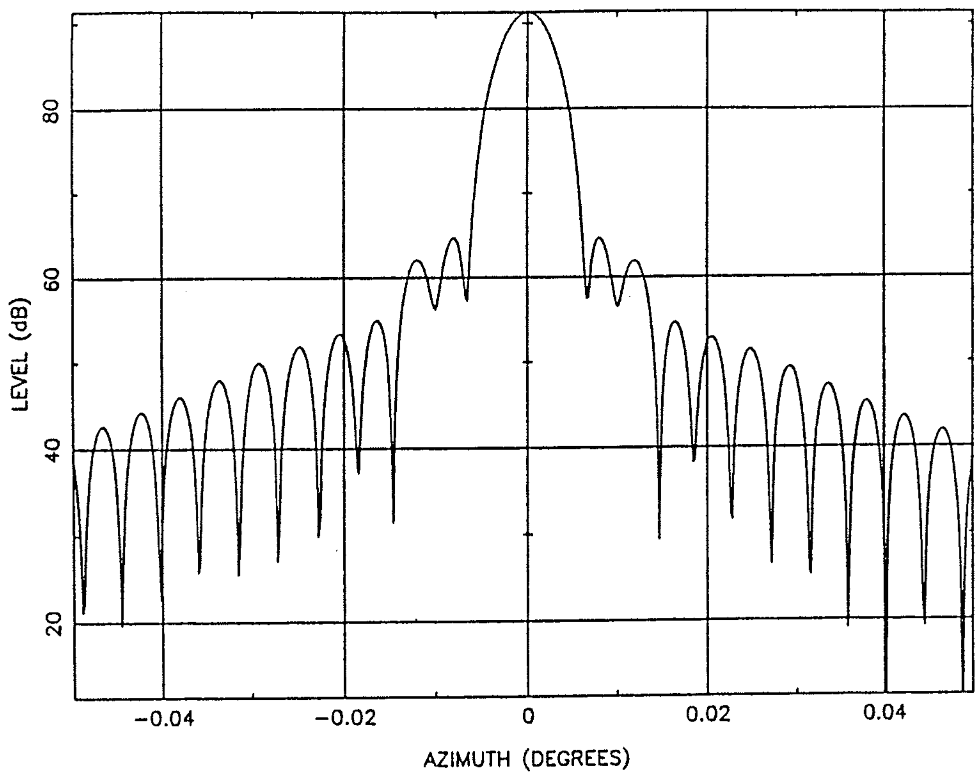


(a) Non-Switched Beam

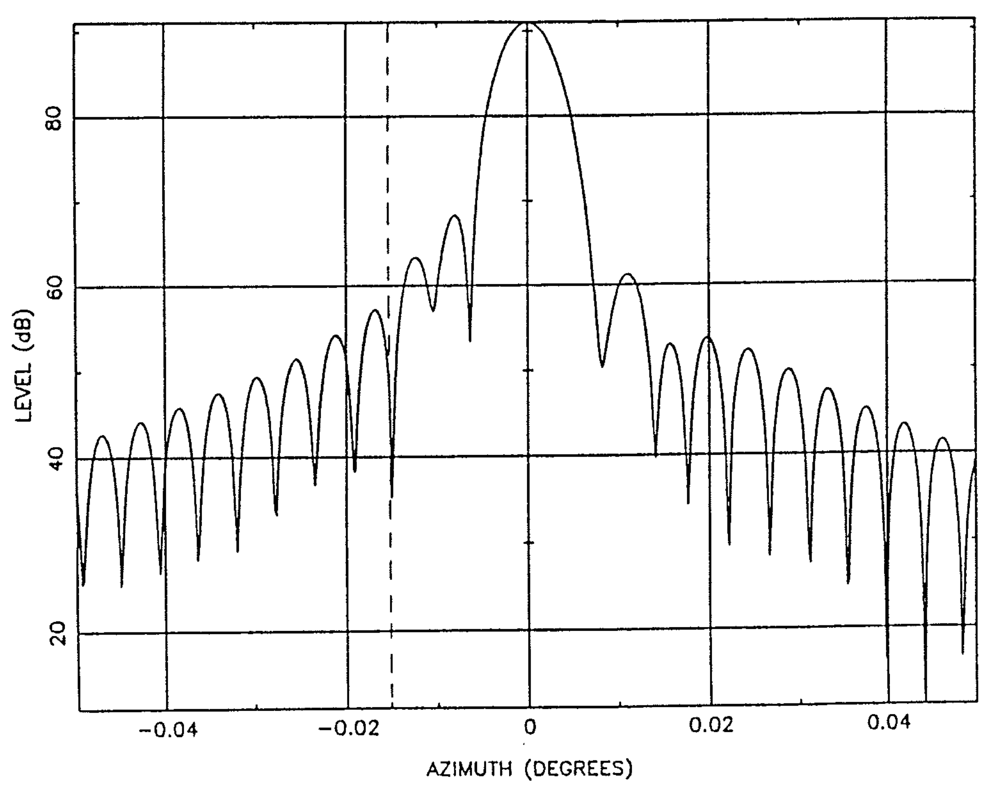


(b) Switched Beam - 3 HPBW's.

Fig. 5. Patterns at 20 GHz in the elevation plane.

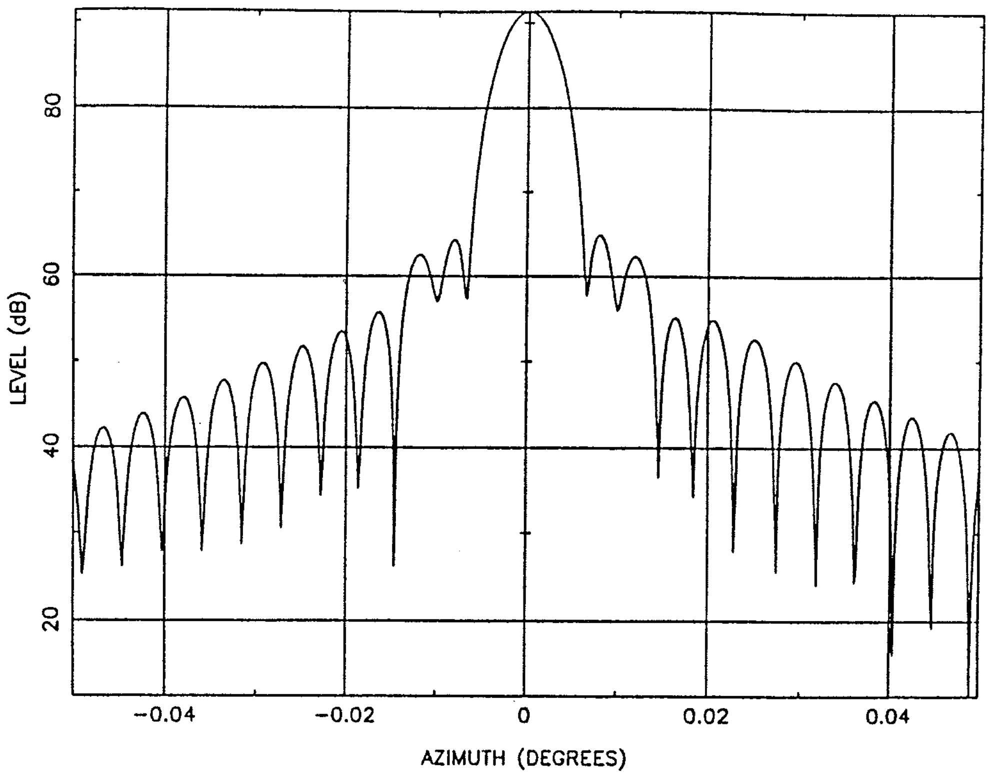


(a) Non-Switched Beam

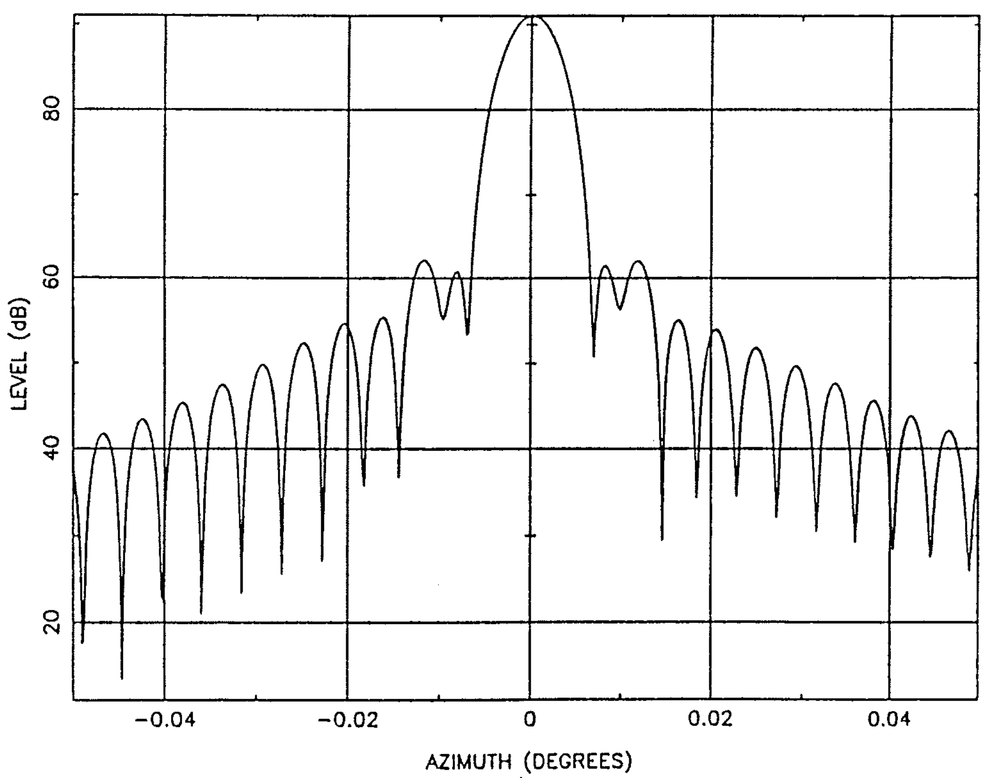


(b) Switched Beam - 3 HPBW's.

Fig. 6. Patterns at 40 GHz in the plane of switching.

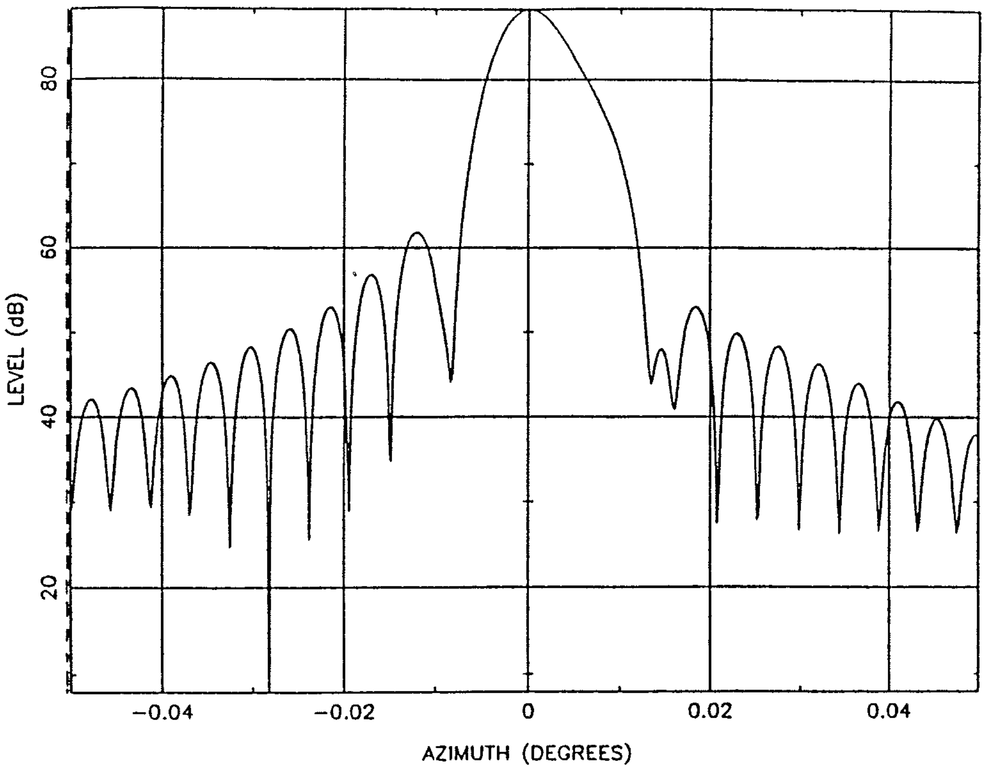


(a) Non-Switched Beam

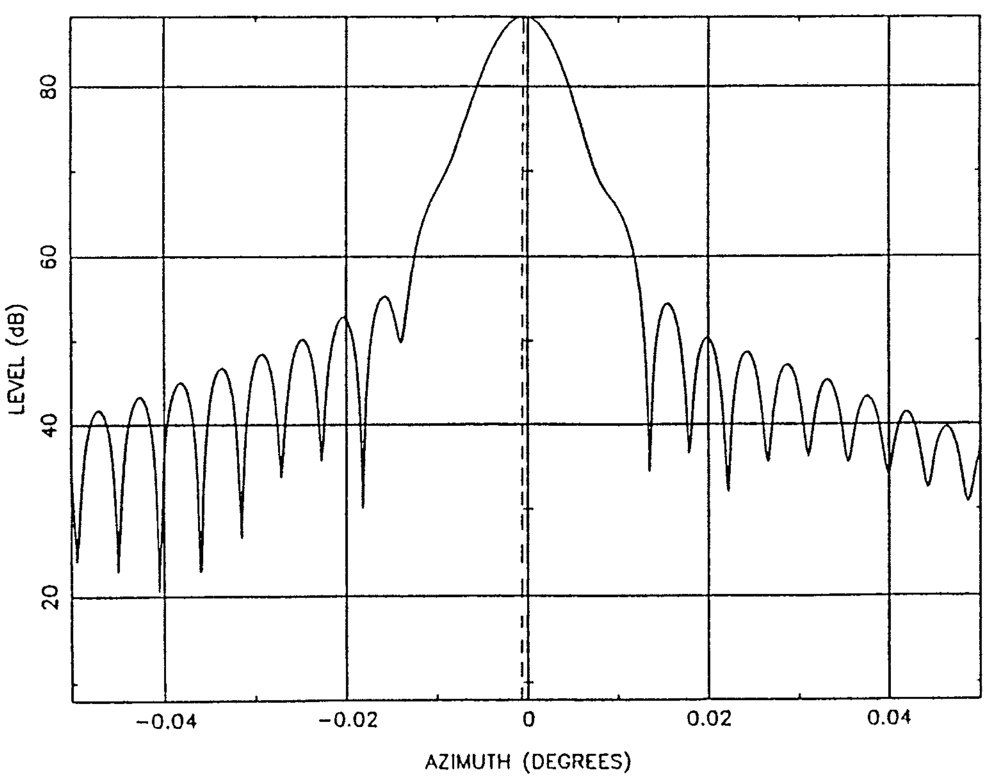


(b) Switched Beam - 3 HPBW's.

Fig. 7. Patterns at 40 GHz in the elevation plane.

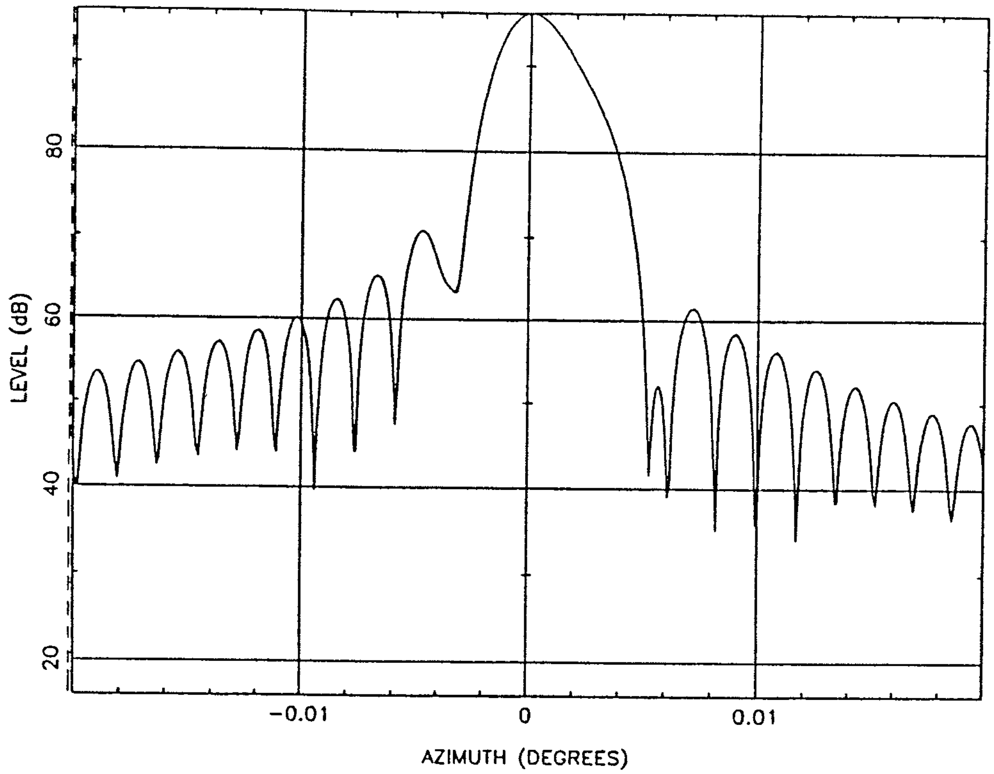


(a) Plane of Switching

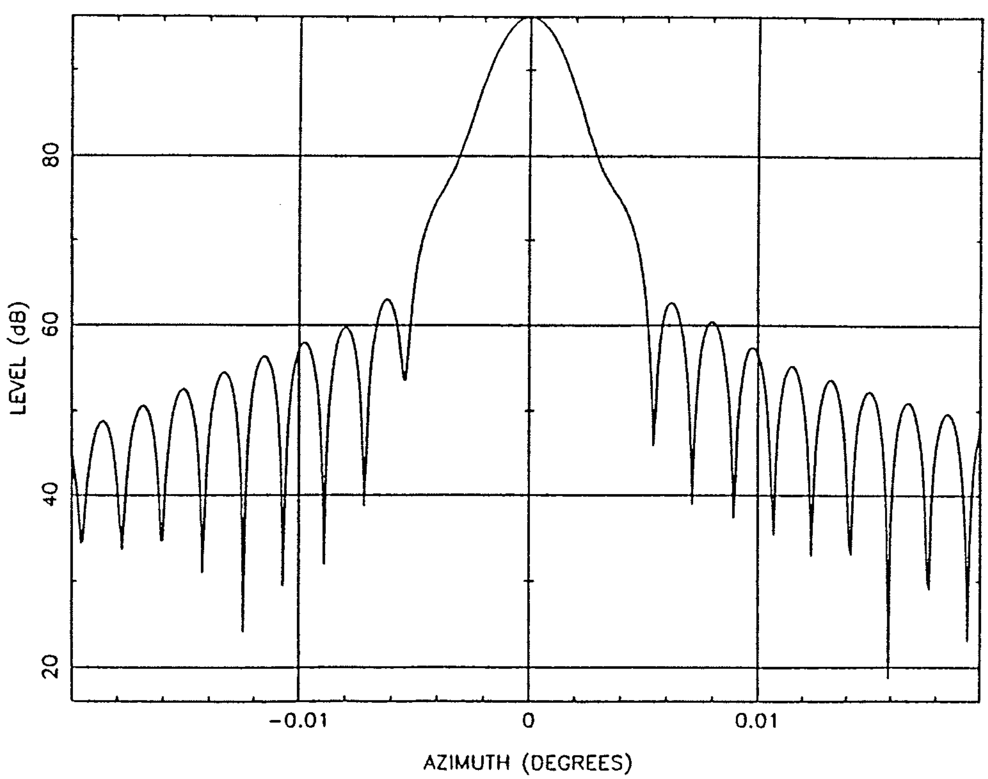


(b) Elevation Plane.

Fig. 8. Patterns at 40 GHz - Switched 10 HPBW's.



(a) Plane of Switching



(b) Elevation Plane.

Fig. 9. Patterns at 100 GHz - Switched 10 HPBW's.