GBT Memo No. 33

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, WV

MEMORANDUM

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To: GBT Memo Series

From: C. Brockway

Subj: GBT Lateral Focusing

Part of the pointing correction method for the GBT is to alter the subreflector orientation by either translation or rotation (tilting). It is likely that more accurate positioning and a faster servo response can be achieved by rotation. Response time is important if higher frequency components (in the neighborhood of 1 Hz or so) of the pointing error spectrum are to be compensated.

Figure 1 shows the geometry of subreflector lateral focus displacement as a result of subreflector tilt. The diagram is for a symmetric Gregorian but the principle is the same for the clear aperture case. From the figure:

$$\frac{Xt}{Al} = 2a + k\left(\frac{b + 2a}{b + a}\right)$$

where:

Xt = subreflector focus shift in focal plane due to tilt
Al = subreflector tilt angle (radians)
a = distance between subreflector vertex and focal plane
b = distance between feed phase center and focal plane
d = distance between subreflector tilt axis and focal plane
k = distance between subreflector tilt axis and vertex

The ratio of sky beam shift to subreflector rotation is given by:

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

where:

B, Al = sky beam shift, subreflector tilt angle (same units)
BDf, f = primary reflector beam deviation factor, focal length
BDf, f = 0.94, 60 meters for GBT

It is seen that Xt is linear with A1 and has two components, the first caused by subreflector rotation and the second because the feed does not move as a result of rotation. The effect of curvature on Xt in the focal plane is neglected for small subreflector tilt angles. The axial component must be considered since telescope gain is strongly dependent on axial de-focus.

It is possible to tilt the subreflector about a second axis, orthogonal to the first, so to force the subreflector focus to any location in the focal plane. For beam switching, the rotation axis is normal to the telescope elevation axis to minimize noise unbalance between the two beams. For tracking main reflector best fit focus and offset arm gravitational deformation, the rotation axis is parallel to the telescope elevation axis. For pointing compensation, simultaneous rotation about both axes is required since both azimuth and elevation components are expected.

A small tilt of the subreflector results in a rather large shift in focus. This is given in Figure 2 where the ratio of lateral focus change to subreflector rotation is plotted against the distance, k, between the rotation axis and subreflector. Figure 3 shows the effect of this distance on the ratio of sky beam shift to subreflector rotation. The k dimension is obviously not critical for the parameters under consideration for the GBT. Figure 4 gives the axial component of focus displacement against lateral focus change and Figure 5 shows telescope gain loss if the axial component is not compensated. At short wavelengths, compensation is required as gain loss is proportional to the fourth power of lateral change from rotation [1]. This is not seen as a problem because the required compensation is only a few millimeters and the axial focus mechanism will always be active anyway to correct for other effects. Of course, an axial focus mechanism cannot be expected to compensate for rapid subreflector rotations as needed for pointing corrections and, for the smaller subreflector, beam switching (nutation). Thus, Figure 5 gives an indication of the maximum pointing correction plus beam shift allowable from subreflector tilting. For example, gain loss is negligible for a sky beam displacement up to about 4 arc min at a frequency of 60 GHz. For a nutation beam shift of 3 HPBW, normally the maximum used, the beam shift displacement is only about .65 arc min so 3.35 arc min remains available for pointing correction and this would seem to be adequate.

It should be noted, that certain specifications of the fine pointing system, in particular the limits of correction and frequency response, require a dynamic analysis of the entire telescope structure but this can only be done for a somewhat complete structural design. However, tilting the subreflector to translate its focus appears to have the range needed for the anticipated maximum pointing corrections. Also, large scale surface deformations causing an aperture phase error of third order, apparently common in large telescopes even of homologous design, can be corrected by subreflector tilt so the possibility exists for tilt compensation instead of many panel adjustments. Unfortunately, a second order aperture phase error, also common in large telescopes, cannot be corrected at the subreflector without changing its shape.

There are a few cases in the literature implying the equivalency of subreflector translation and rotation. Zarghamee [2] considered subreflector positioning to correct for gravitational surface deformations of the Bonn 100 meter telescope and concluded that subreflector rotation plus translation was redundant for gain maximization. Ruze [3] uses superposition of translation and rotation for total lateral offset. The Green Bank 140 foot telescope uses a two axis tilting mechanism for lateral tracking of the best fit focus [1].

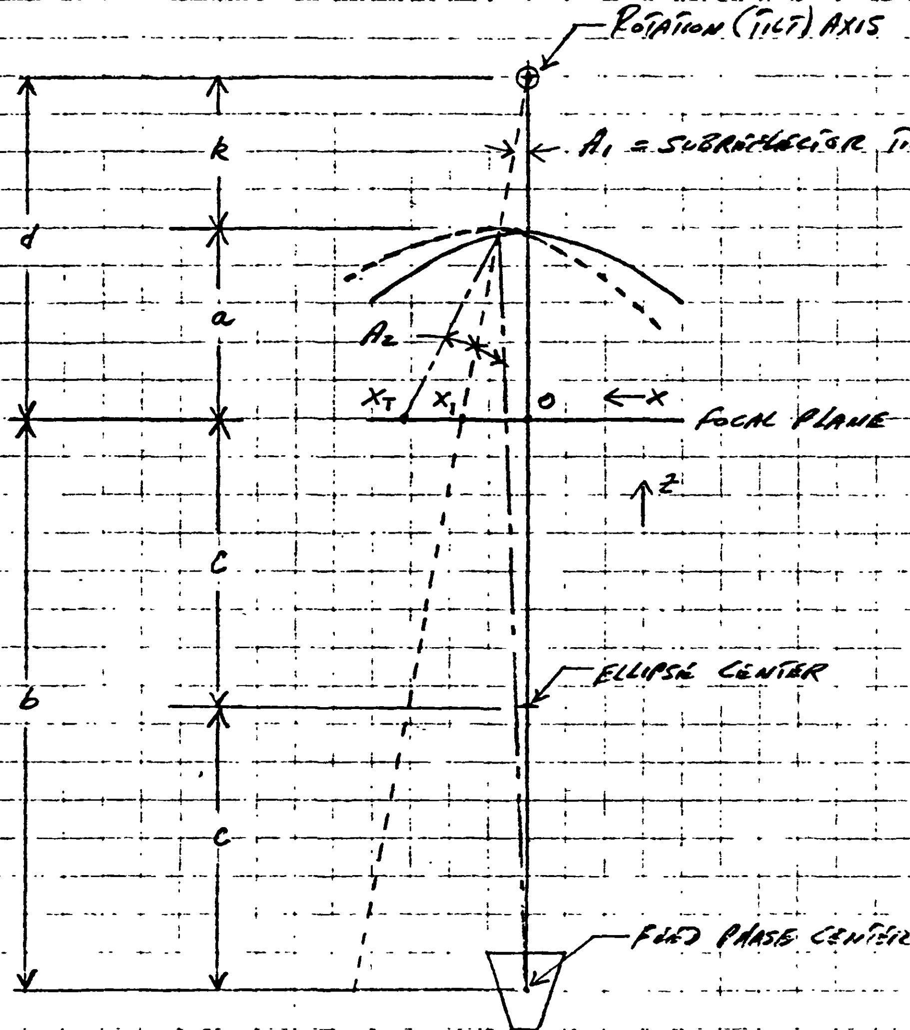
As for the GBT, it appears that a two axis tilting mechanism of fast response time is needed for pointing compensation. The same mechanism can be considered for lateral correction although a radiation pattern analysis seems appropriate to determine if there is a significant degradation of the main beam, sidelobe structure, or noise properties at the maximum tilt angle.

References

[1]. C. Brockway, "140 Foot Telescope Lateral Focus", NRAO Electronics Division Memorandum, March 1985.

[2]. M. Zarghamee and J. Antebi, "Surface Accuracy of Cassegrain Antennas", IEEE Transactions on Antennas and Propagation, AP-33, No. 8, 828-837, August 1985.

[3]. J. Ruze, "Small Displacements in Parabolic Reflectors", Lincoln Laboratory Memorandum, February 1969.



NEGLECT CURVATURE: (NOT TO SCALE)

$$X_1 = d A_1$$

$$X_T = a A_2 + d A_1 \qquad \text{AND:} \quad \frac{A_2}{A_1} = \frac{b+d}{b+a} > 1$$

$$X_T = A_1 \left[d + a\left(\frac{b+d}{b+a}\right)\right]$$

$$\boxed{\frac{X_T}{A_1} = 2a + k\left(\frac{b+2a}{b+a}\right)}$$

ϵ = ELLIPSE ECCENTRICITY

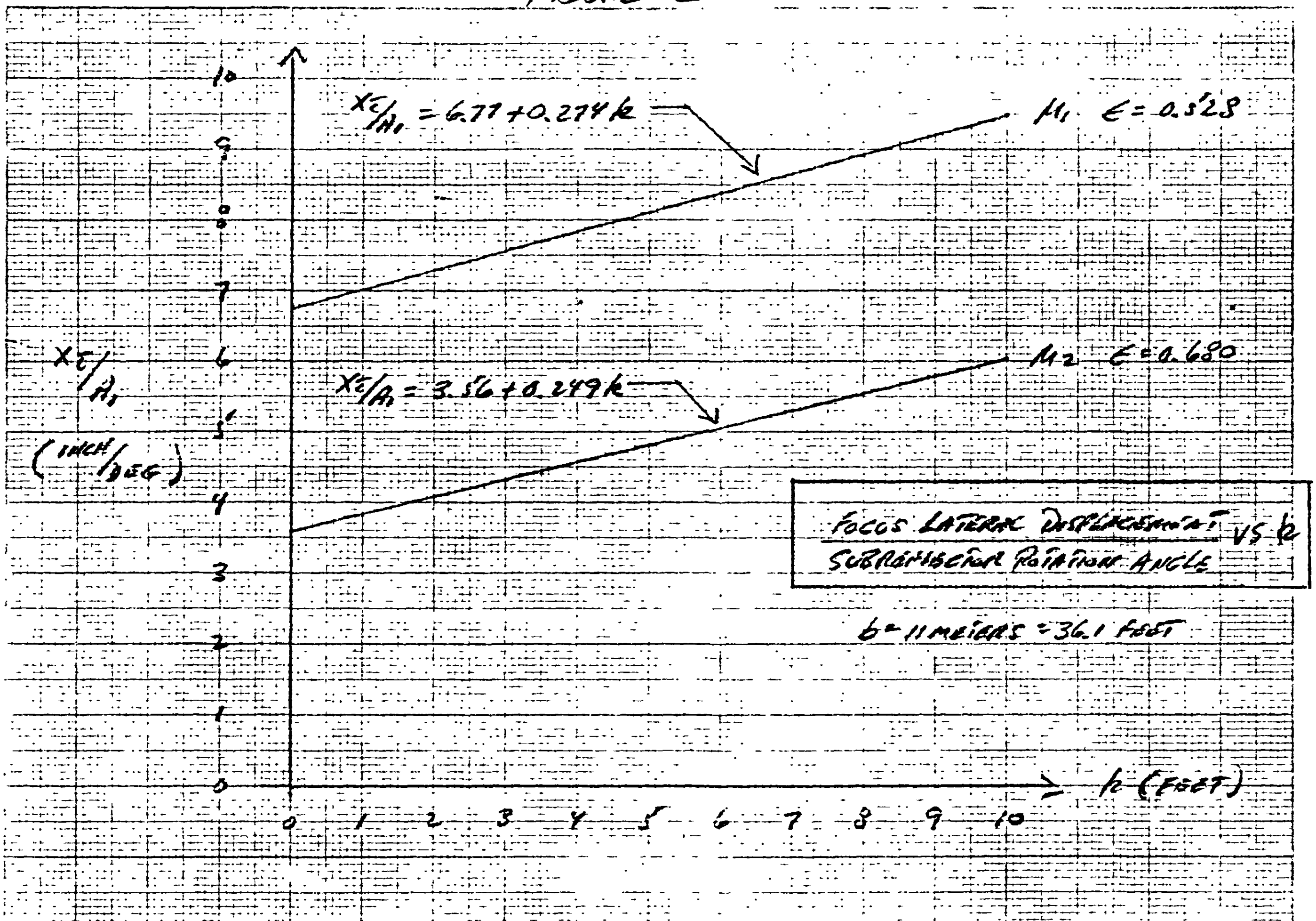
$$\epsilon = \frac{c}{a+c}$$

$$a = \frac{b}{2}\left(\frac{1}{\epsilon} - 1\right)$$

GBT b = 11 METERS		
SUBREF	ϵ	a (METERS)
M1	0.528	4.92
M2	0.680	2.59

FIGURE 1

FIGURE 2



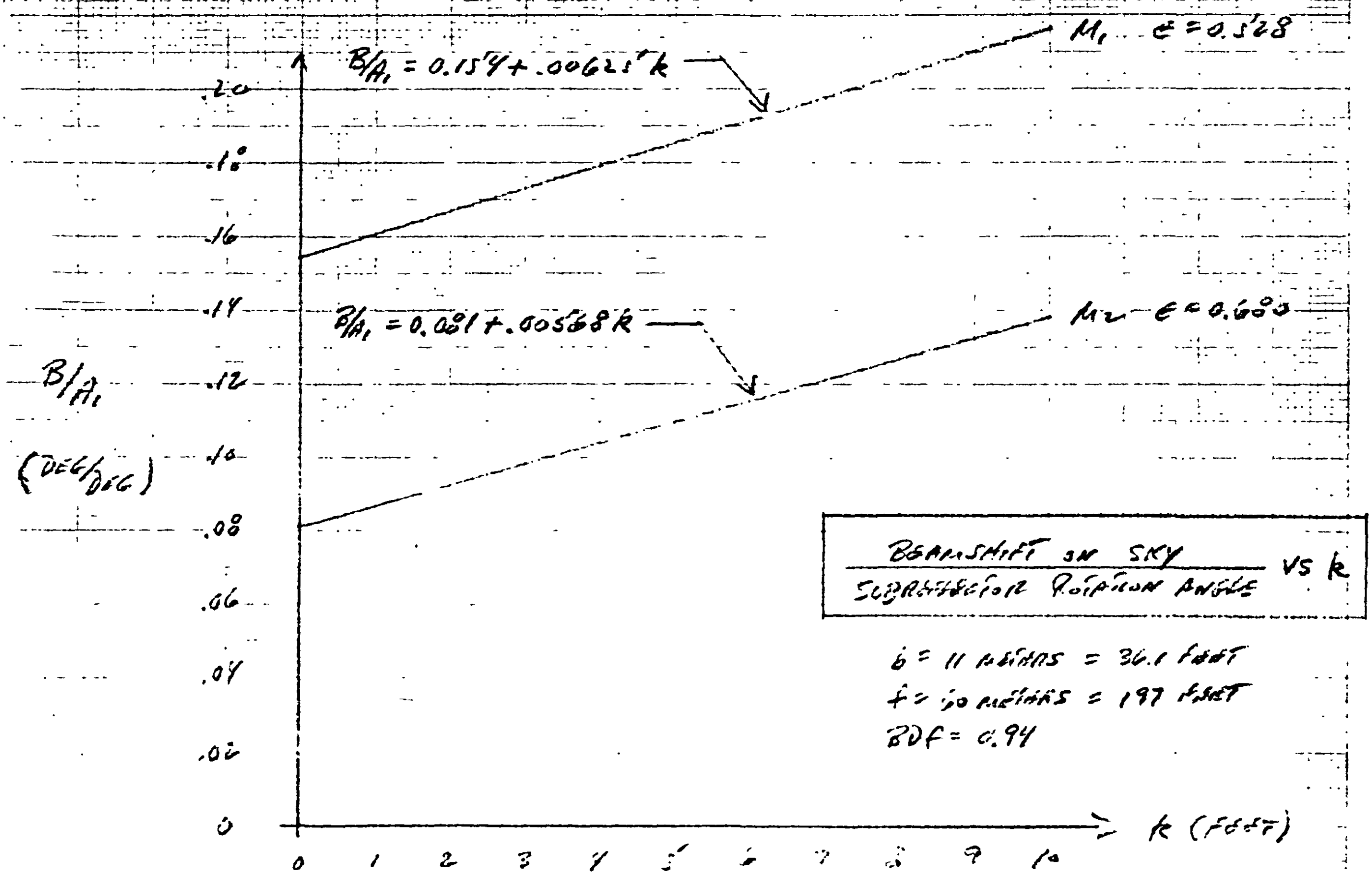
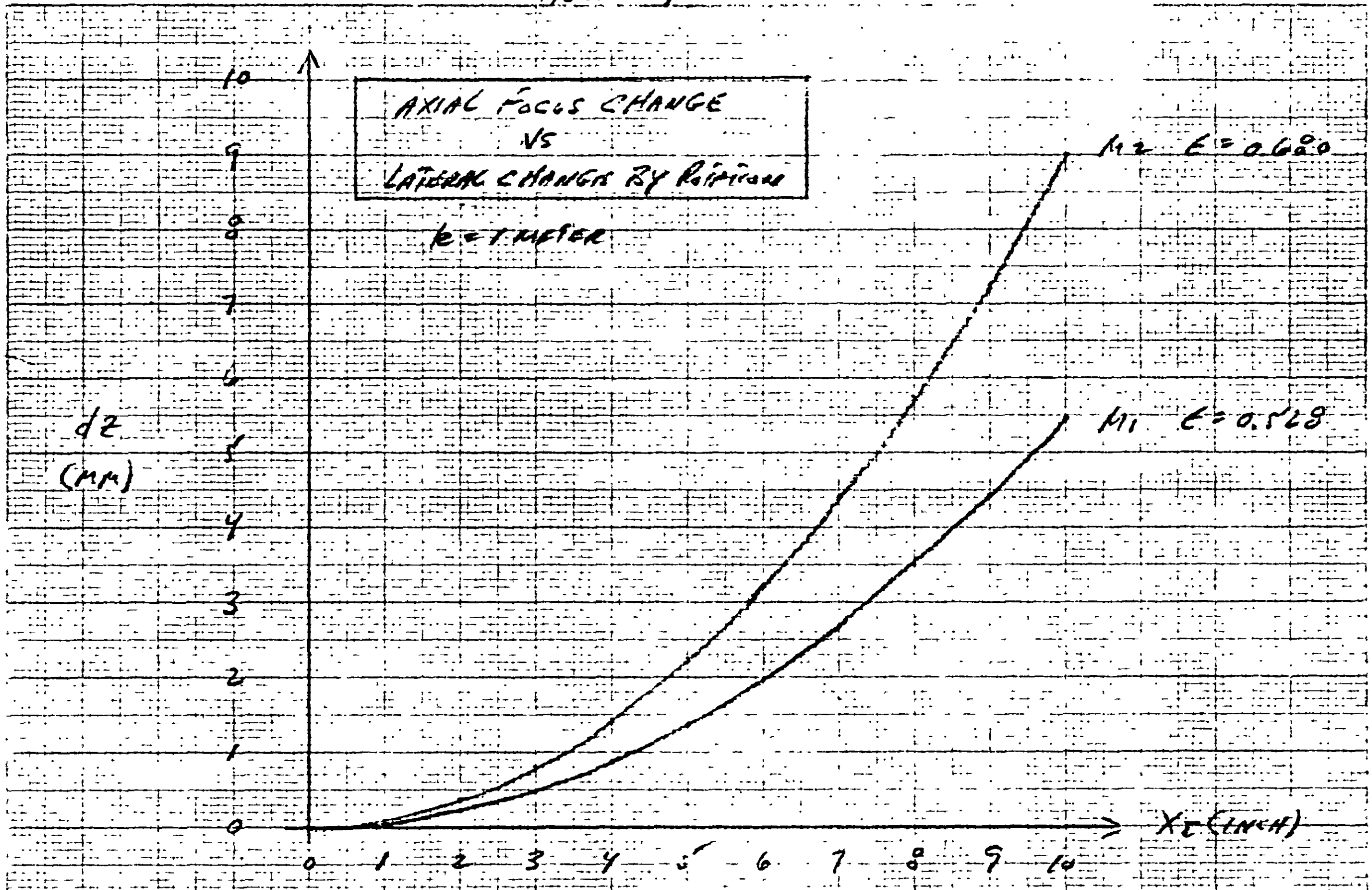


FIGURE 3

FIGURE 4



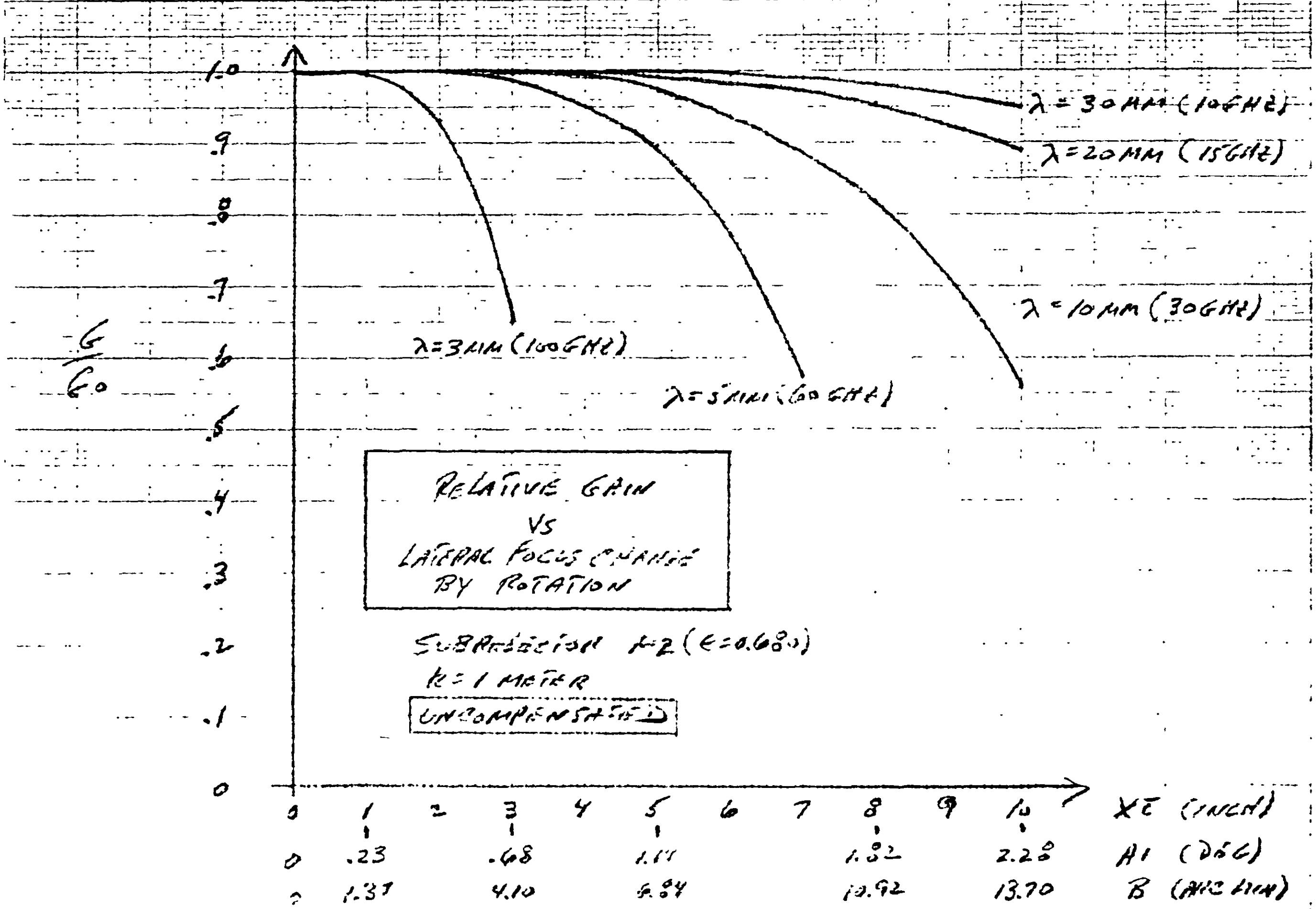


FIGURE 5