NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA ELECTRONICS MEMORANDUM NO. 206

VLA 327 MHz PROTOTYPE FEED SYSTEM

P. NAPIER

Introduction

Since the VLA subreflector is only 2.6 wavelengths in diameter at 327 MHz and because a 327 MHz Cassegrain feed would need to be approximately 6.3m in diameter, it is obviously not feasible to place the 327 MHz receiver at the secondary focus. The rms deviation of the VLA main reflector from the best fit parabola is 1.0 cm which will cause negligible loss of gain for a prime focus 327 MHz feed. Clearly, then, the 327 MHz receiver system should be placed at the prime focus. The design goals for the feed system design were as follows (more or less in descending order of importance).

(1) The complete receiver/feed system must be inexpensive enough so that 28 systems could be constructed from available OOE funds. $5K to $10K per system is a reasonable goal. This clearly rules out an automatic mechanism to move the subreflector in and out of position.

(2) It must not be necessary to manually remove the subreflector to use the 327 MHz system. Estimates by the VLA Antenna Division show that, with available manpower, at most 4 antennas a day could have their subreflectors removed and 327 MHz Systems installed. Thus, 7 working days would be needed to convert the array to 327 MHz

operation, and another 7 days would be needed to convert back again. This is considered unacceptable, especially since it would have to be done at least for the A and D arrays to allow for high resolution and wide field observing (the antenna half power beamwidth at 327 MHz is approximately 2.6°). The astronomical output of the VLA is enhanced considerably by being able to switch to any observing band in 30 seconds. Thus it would also be desirable if the 327 MHz feed were permanently in place.

(3) The primary pattern at 327 MHz must be as circularly symmetric as possible. A study (Spangler, 1982) has shown that confusing sources in the outer parts of the primary beam combined with pointing errors and a rotating (az-el mount) assymetric beam will be the limiting factor for dynamic range at 327 MHz. A primary beam circular to 5% at the -4.3dB power point is a desirable goal, with circularity to 10% an upper allowable limit.

(4) Provide a usable aperture efficiency (greater than 30%) and reasonable spillover temperature (less than 20°K).

(5) Dual circular polarization should be provided and the feed should be usable over the range 300-350 MHz.

Designs Considered

The 327 MHz feed system design is made very complicated by the need to keep the subreflector in place. Figure 2 shows the location of the VLA assymetric shaped subreflector with respect to the primary focus. Several possible feed systems were considered.

Dipoles mounted in front of the Subreflector

A pair of dipoles for each linear polarization could be mounted on the face of the subreflector as shown in figure 1. Circular polarization could be formed using a hybrid. The subreflector would then act as a curved, assymetric, ground plane for the dipoles.

The nominal position of the subreflector is shown in Figure 2. The subreflector mount allows ± 6 inches of travel about this nominal position, but approx 2 inches of this is used up in correcting for differences between antennas. Thus, the phase center of such a dipole feed (Jasik, 1961; Christiansen and Hogbom, 1969) which would be close to the subreflector surface, could be placed approximately 16.6 inches (0.5λ) from the prime focus. The loss of gain as a function of defocussing for the VLA 25m reflector, calculated from formulas given in Ruze (1969), is shown in Figure 3. The predicted gain loss is -1.7 dB (efficiency reduced by a factor of 0.68). This gain loss would possibly be bearable, but other factors make this feed unattractive. The effect of the assymetric curved subreflector on the radiation pattern of the dipoles is almost impossible to predict accurately. A large antenna range would be needed to measure the patterns experimentally. The effect of the dipoles on the performance of the Cassegrain feeds is also difficult to determine. Finally, a receiver mounted on the back side of the subreflector would be extremely inconvenient to install and maintain because this region is blocked by the subreflector support structure.

Flat Dipoles mounted on the Subreflector

B. Clark has suggested that flat dipoles could be made right at the subreflector surface by making cuts in the thin aluminum conductive coating of the fiberglass subreflector. In this case the dipoles would be within 0.5λ of the prime focus and the defocussing loss of -1.7dB might be bearable. This feed suffers from the same disadvantages as the dipole feed. If the current design proves inadequate, however, Clark's idea and the dipole feed should be investigated further.

Large Dipole Array In Front of Subreflector

One could conceive of a large, two dimensional array of dipoles in front of the subreflector, with the complex excitation of the elements chosen to give the correct amplitude pattern and an apparent phase center at the prime focus. This idea was not pursued because of its complexity and because such a feed would have to be moved in and out of position.

The concept finally chosen was a compact feed placed off axis at the edge of the subreflector.

The Prototype Prime Focus Geometry

The feed element chosen is a "crossed-dipoles-in-a-cavity" feed (Wong and King, 1973; Ruze, 1976.) This type of feed is commonly used at Greenbank as a prime focus feed. It has adequate spillover efficiency and beam circularity and is inexpensive. The scalar feed has better performance but is more expensive and, because it is larger, would have to be located further off axis. Figure 4 shows the location of the feed with respect to the subreflector in its fully retracted position. The feed must be located far enough off axis to clear the largest radius of the subreflector. In this position the feed is 67.7 in (1.87 λ) off axis.

The feed element described below has a pattern taper of approx -11.9dB at the edge of the main reflector at 327 MHz. This, together with a space factor loss at the dish edge of -3.4dB gives an aperture distribution with a total edge taper of -15.3dB. Comparison of the measured feed patterns with the families of circular aperture distributions presented by Hansen (1964, Page 65) shows that the expected aperture distribution at 327 MHz is closely approximated by a distribution of the form $f(r) = 0.25 + (1-r^2)^3$, where r is normalized radius.

The primary beam properties of this distribution, in the absence of blockage or aberration are as follows.

3dB Beamwidth = $1.25\ \lambda/D = 2.63^\circ$ at 327 MHz.
Aperture Taper Efficiency = 0.79
First Sidelobe Level = -32dB
First Null = $1.97\lambda/D = 4.14^\circ$ at 327 MHz.

The antenna performance with the feed 1.87 λ off axis can now be estimated using the curves presented by Ruze (1965). These curves are reproduced as Figure 5, with the approximate operating points for the VLA 327 MHz feed marked. A feed lateral displacement of ΔX will cause a beam scan of $(\Delta X/F)$ BDF, where F is the focal length (9.0m) and BDF is the Beam Deviation Factor. From Fig. 5, BDF = 0.80 giving a predicted beam scan (pointing offset) of 8.8° (3.3 beamwidths). The 327 MHz feed will be located directly over the LBand Cassegrain Feed. The pointing offset is in the plane containing the 327 MHz feed and the axis of the main reflector and is in the direction opposite to the direction of the lateral offset (see inset in Figure 6). The quantity X in the curves in Figure 5 is 22 for 3.3 beamwidths scan and F/D = 0.36. These curves predict the following: in the plane of the scan the 3dB beamwidth will broaden by 7% and the 10dB beamwidth will broaden by 14%. The coma lobe, on the axis side of the offset beam, will increase to approx 12dB. The loss of gain is approx -1.0dB.

The beam assymetries predicted above are just within Spangler's (1982) limits, although it should be noted that Spangler assumed an elliptical gaussian beam for his analysis. The data in Ruze (1965) shows that this is not an appropriate model beyond the 3dB beamwidth. Figure 4 shows that, even with the subreflector in its fully retracted position, the subreflector comes close to blocking a part of the main reflector. This, together with the assymetric location of the feed with respect to the feed legs, could give rise to significant assymetry in the aperture illumination. If tests show that the primary beam is unacceptably assymetric, a holographic measurement of the aperture distribution (Napier, 1982) should reveal the cause.

Figure 6 shows the overall assymetry of the geometry and shows the optimum tilt of the feed to get best symmetry of illumination in the dish aperture.

Note that Ruze (1965) and Rusch (1976) predict that the focal point in the off axis location will be $\Delta X^2/2F$ (0.18λ) further away from the main reflector vertex than the nominal prime focal point. Figure 3 predicts a -0.3dB gain loss due to this defocussing, some of which can be recovered by moving the feed as far back as subreflector blockage will allow.

Finally, the off-axis feed will cause the circularly polarized beams to point in slightly different directions. The curves in Chu and Turrin, (1973) predict that the right and left polarized beams will be separated by 0.05 beamwidths in the sky.

The Prototype Feed Element

The prototype feed design was scaled from a Greenbank design provided by R. Fisher and J. Coe. Examination of Greenbank measured feed patterns showed that an edge taper of approximately -12dB would give a taper efficiency slightly below optimum, but the increased taper would reduce the effect of the lateral feed displacement and give a reduced spillover temperature contribution.

The feed design chosen to provide this illumination is shown in Figure 7. Figure 8 shows the measured feed patterns for 300, 325 and 350 MHz. These patterns were measured on a simple antenna range constructed at the VLA. Table 1 shows the measured reflector edge taper.

f (Mhz	E	H
300	-10.0dB	-10.7dB
325	-11.4	-12.3
350	-11.7	-13.0

Table 1. Feed pattern taper at ±70°.

The patterns were integrated (Leonard - Napier, 1973) to give predictions of efficiency and spillover temperature. This data is tabulated in Table 2, in which E and H plane data have been averaged together. The spillover temperature calculations are uncertain by 20%. The spillover temperatures are higher than desired but probably bearable considering that sky temperature will vary between 34°K in directions near the Galactic pole and 450°K towards the Galactic Center. Figure 9 shows Kraus' (1966) data for sky temperature. Note that the feed taper efficiency of 0.83 is in reasonable agreement with the efficiency of the model aperture distribution of 0.79.

f (MHz)	Taper Efficiency η_t %	Spillover Efficiency η_s %	Feed Efficiency $\eta_t x \eta_s$ %	Ground Spillover Temperature (°k)
300	85	84	71	24
325	83	87	72	20
350	83	88	72	21

Table 2. Efficiency and Spillover Calculations

The predicted aperture efficiency for the feed system can now be obtained as the product of the feed efficiency (0.72), blockage efficiency (0.85), coma loss (0.79), defocussing loss (0.93), insertion loss (0.93) to give a total of 0.42. Experience would predict that this estimate is only accurate to 10%, especially given the uncertain effects of subreflector and feed leg blockage.

Figure 10 shows the measured return loss of the feed which was optimized by experimentally adjusting the dipole length and the size of the matching plates in front of and behind the dipoles. Circular polarization will be provided using a 90° hybrid located after the preamplifiers if the amplifiers can be well enough matched in amplitude and phase, or, otherwise, in front of the amplifiers. The cost of the feed and its mounting structure is less than $500.

Future Work. After the prototype feed is rebuilt in permanent form and mounted on antenna 12, careful tests will be needed on focus adjustment, aperture efficiency, spillover temperature, beam symmetry, and polarization purity. These latter two measurements will probably need to wait until a two element interferometer is available in late 1982. If this feed proves acceptable, a useful continuing development project would be to study the addition of a choke ring around the outside of the cavity aperture to further improve spillover and circularity.

Acknowledgements. The prototype feed design was scaled from the Greenbank design by T. Cwik, who also prepared Figure 3. M. Jenkins built the prototype feed and made the pattern measurements with Z. Nosal, who also optimized the VSWR. Thank to S. Spangler, R. Ekers and B. Clark for useful discussions concerning the astronomical requirements of the system.

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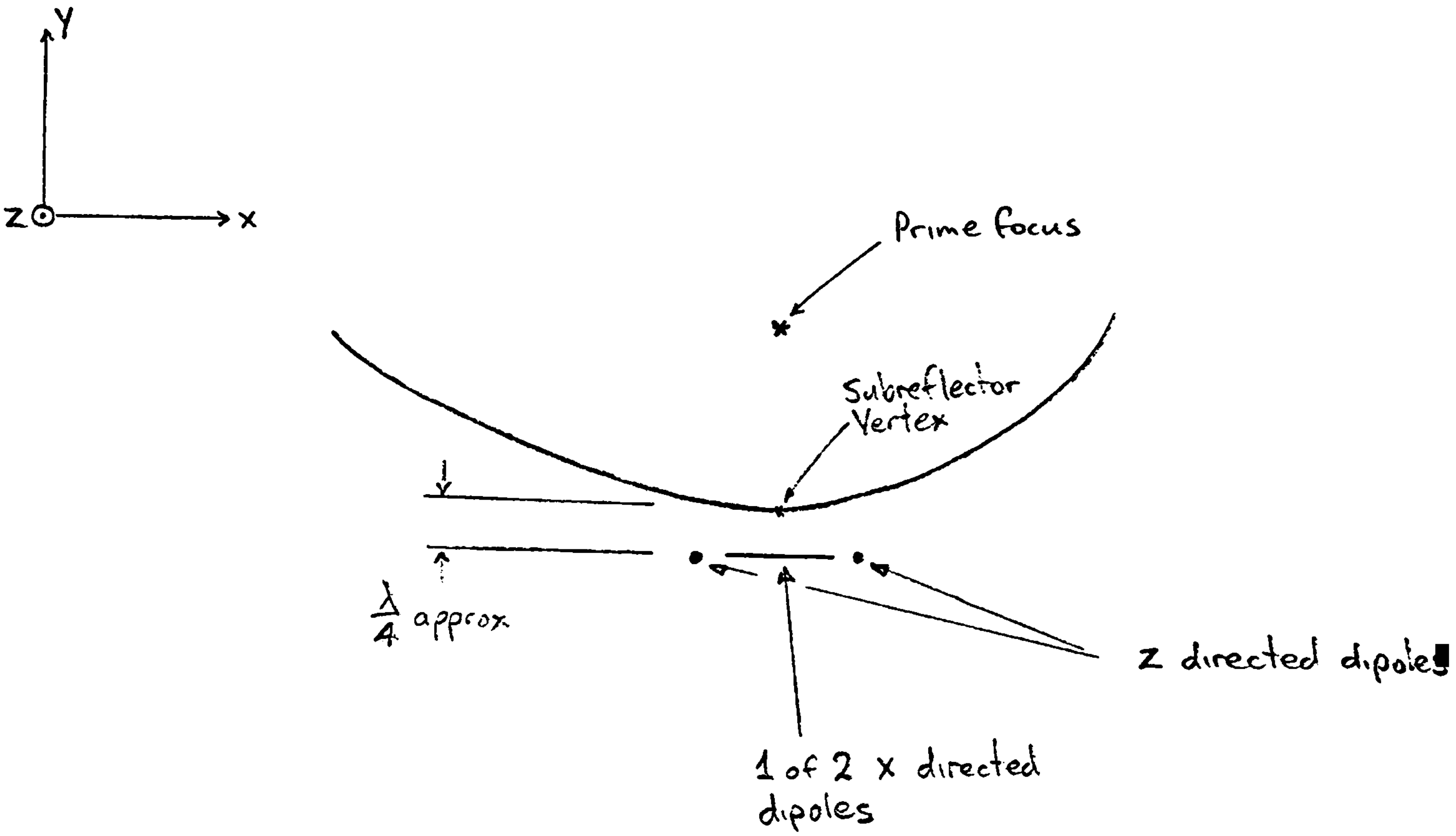


Figure 1 Dipoles on the Subreflector

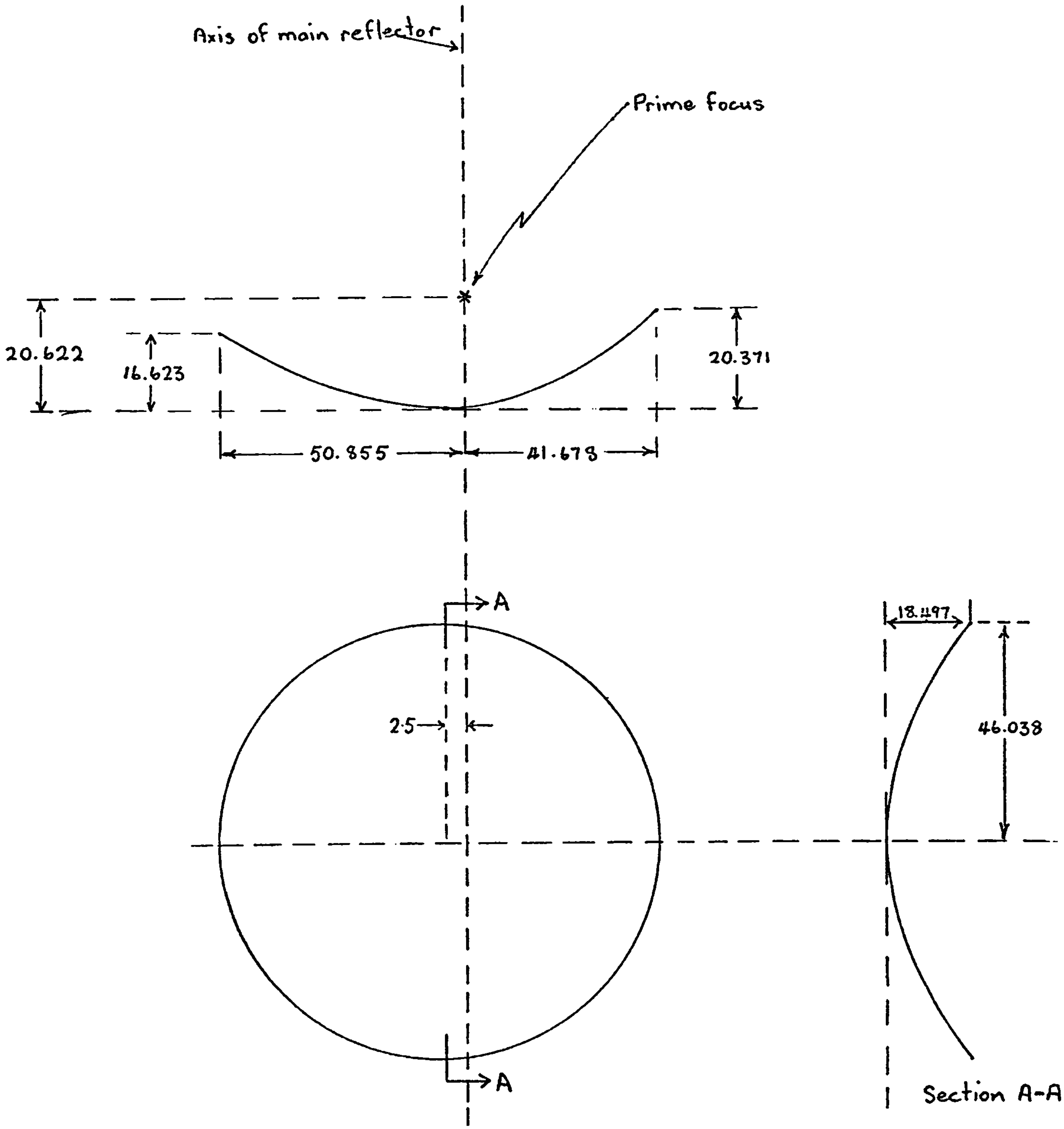


Figure 2 VLA Subreflector Dimensions and Location.

All dimensions in inches

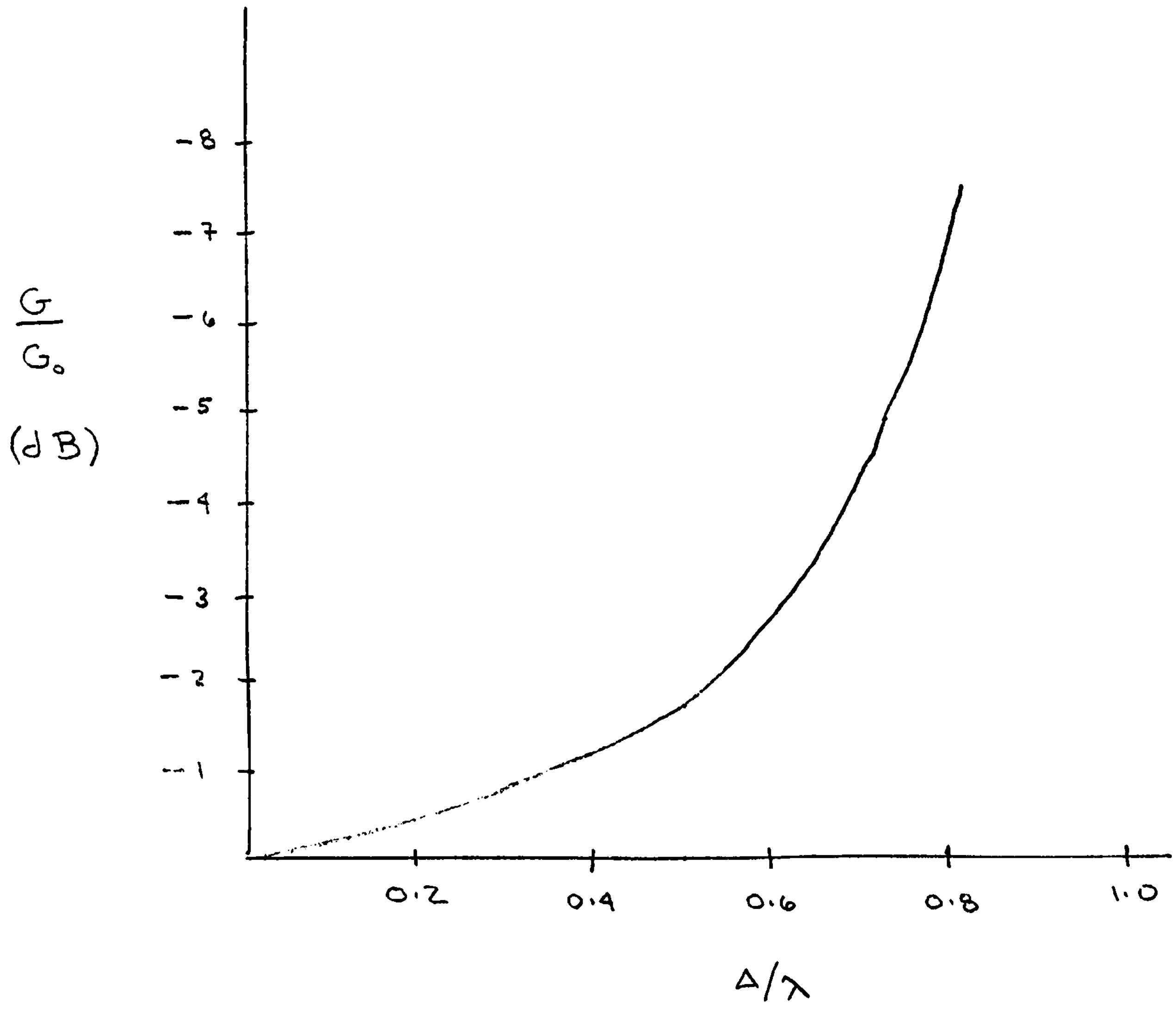
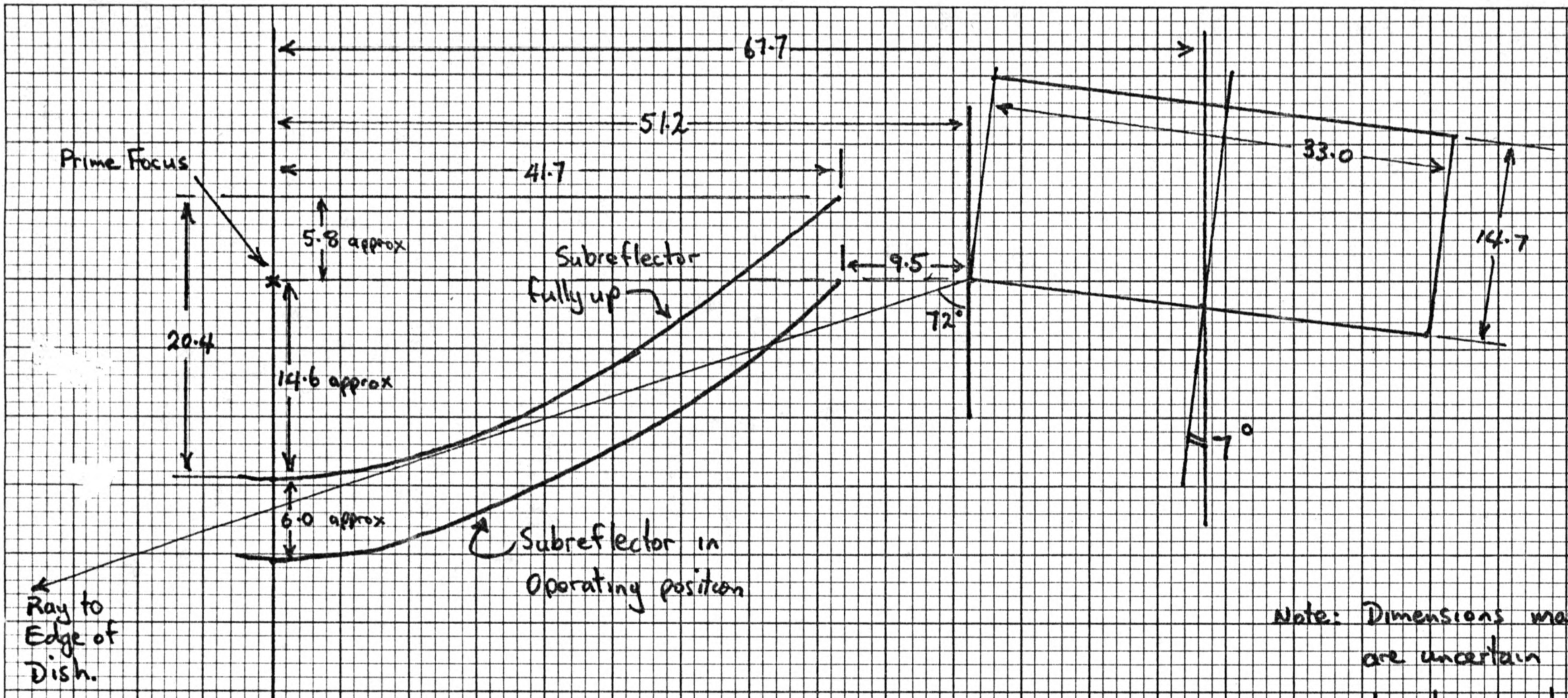


Figure 3. Loss of Gain versus Axial Displacement. 11 dB edge taper.



Note: Dimensions marked "approx" are uncertain by ≈ ± 1 in due to variations in the Stirling Mount Locations.

Locating Procedure for 327 Mhz Feed.

(1) Move Subreflector to normal L Band Position.

(2) Place edge of feed 9.5 inches from the edge of the subreflector, directly above the L Band feed. Edge of feed is at same height as edge of subreflector.

(3) Tilt feed 7° ± 1 in plane of symmetry of the subreflector.

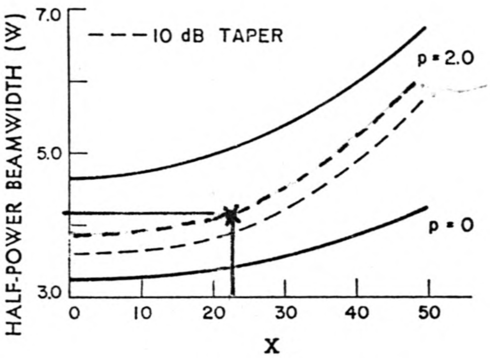
(4) Check for sufficient clearance when subreflector is rotated 180°.

Scale |—10 in.—|

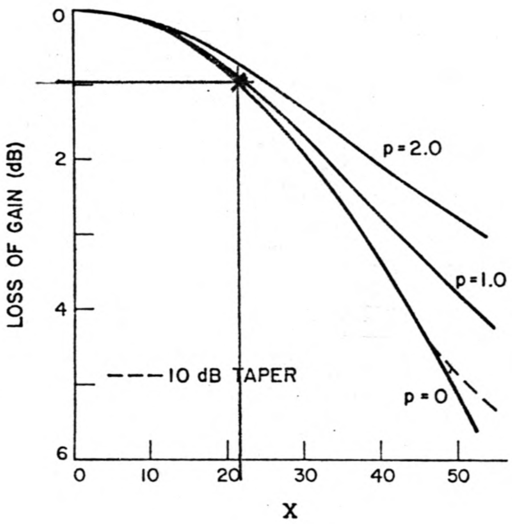
All dimensions in inches.

VLA 327 Mhz Feed
Location
PJN 820515

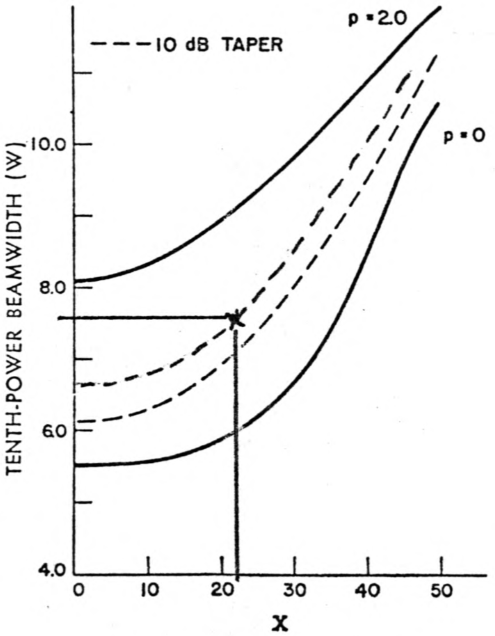
Figure 4



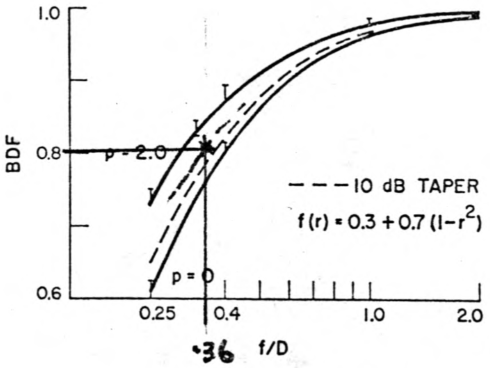
Half-power beamwidth.



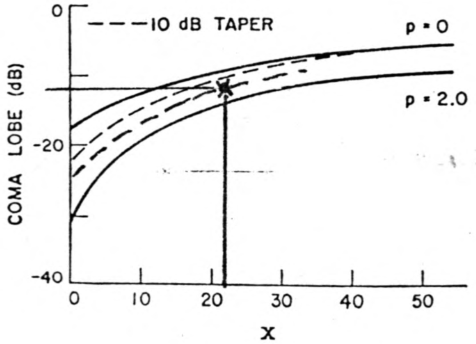
Loss of gain.



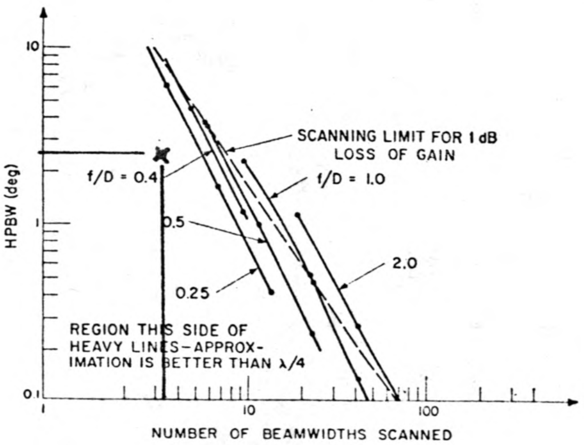
Tenth-power beamwidth.



Beam deviation factor.



Coma lobe.



Region of validity.

Figure 5. Curves from Ruze (1969).
VLA 327 Mhz approximate operating point is marked ✗

Difference in Spherical Wave attenuation $= \left(\frac{467}{588}\right)^2 = -2.0\,\mathrm{dB}$.

From measured pattern, feed must be tilted 4.3° to correct for this

$\therefore$ Total feed tilt $= 4.3° + \frac{72-67}{2} = 6.8°$. Use 7°

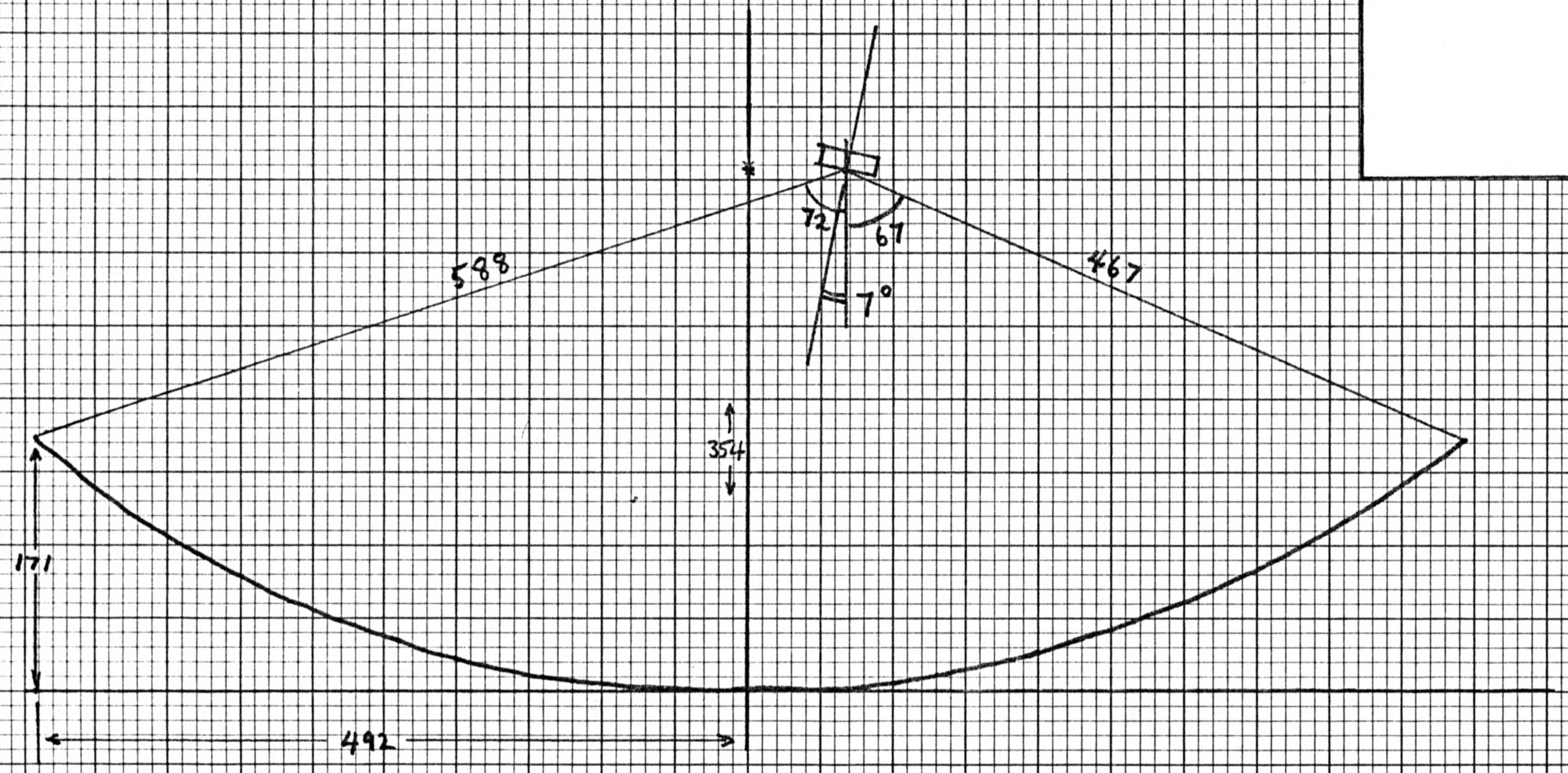
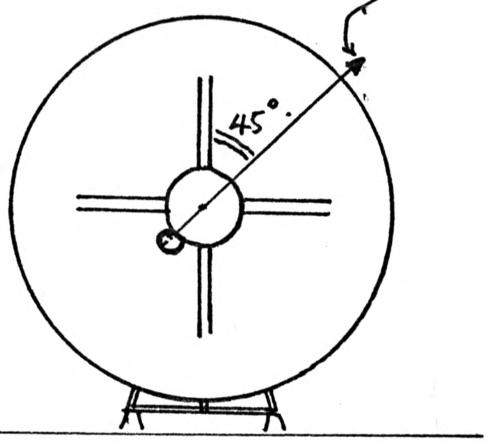


Figure 6. Overall asymmetry and feed tilt.

[redacted]ctio[redacted]f [redacted]Mhz [redacted]m [redacted]



View looking into dish with dish tipped to the horizon.

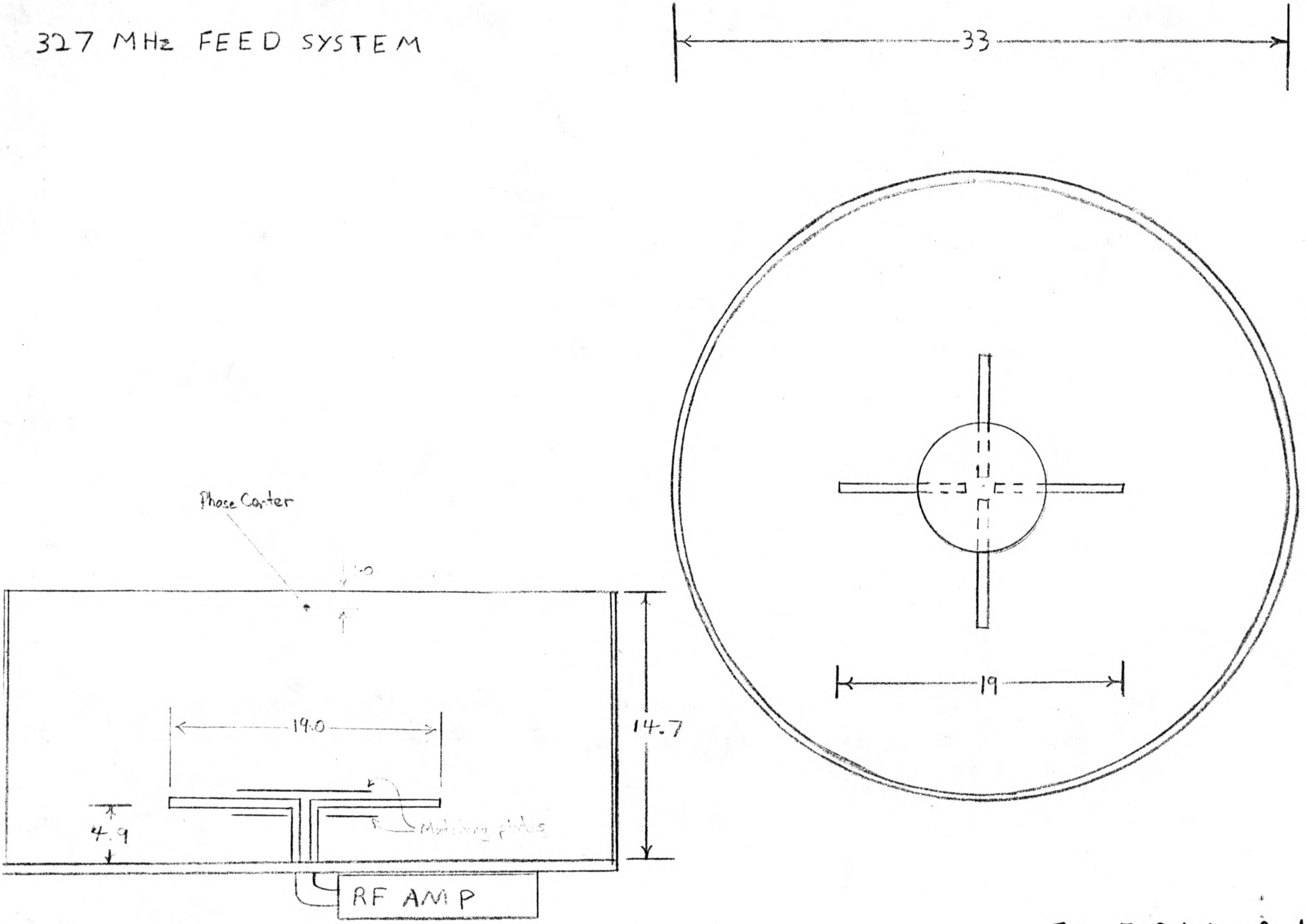


Figure 7. Prototype feed.

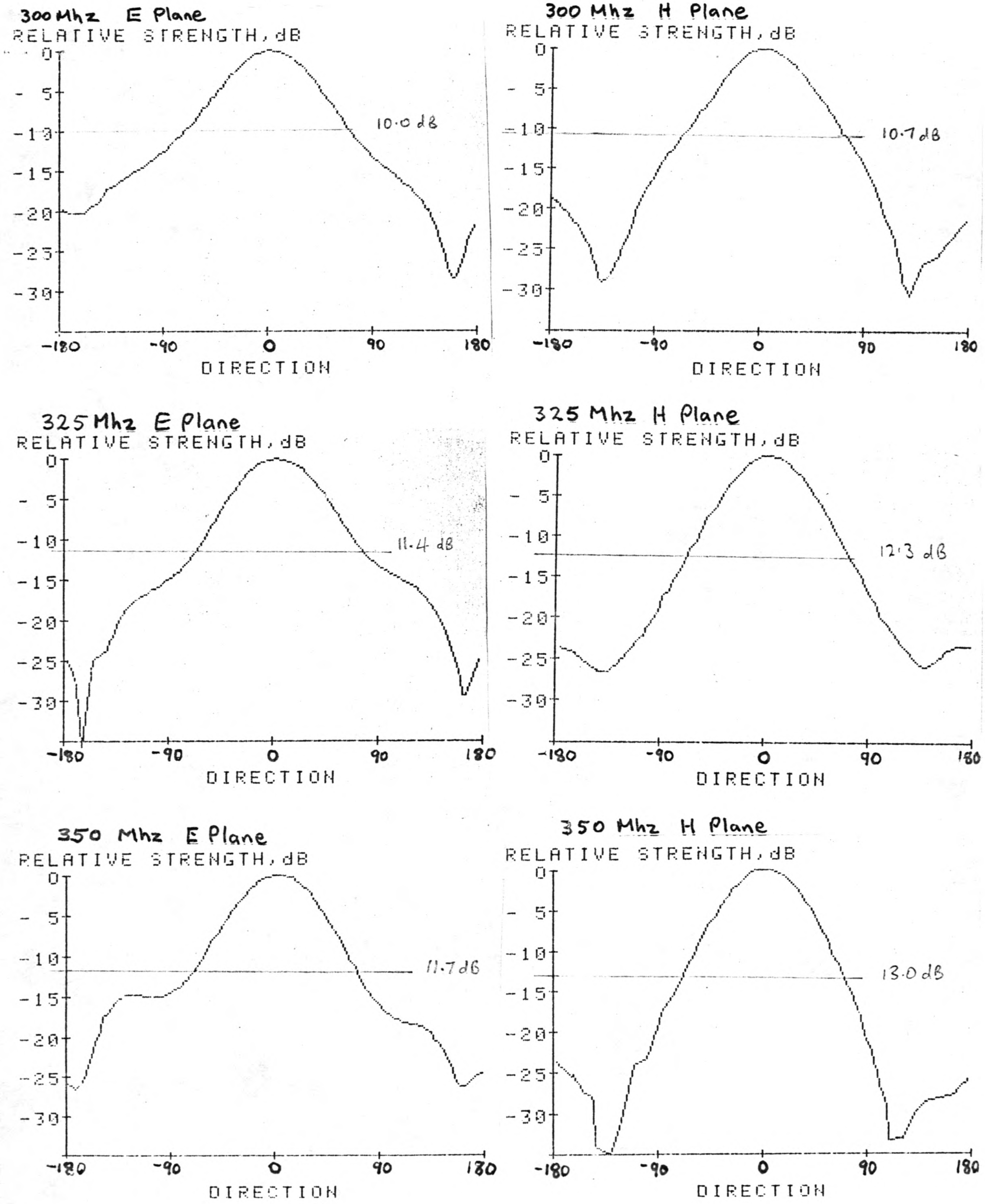
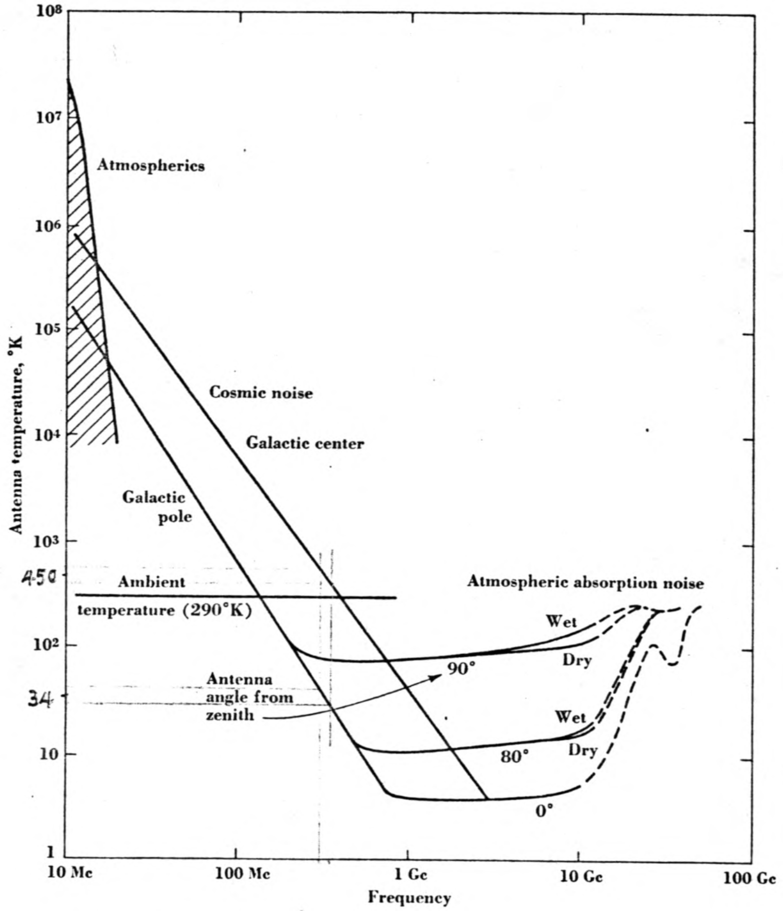


Figure 8. Prototype 327 Mhz Feed Measured Feed Patterns.



Antenna sky noise temperature as a function of frequency and antenna angle. A beam angle (HPBW) of less than a few degrees and 100 percent beam efficiency are assumed. (*After Kraus and Ko*, 1957, *cosmic noise below* 1 Gc; *Penzias and Wilson*, 1965, *and Dicke et al.*, 1965, *cosmic noise above* 1 Gc; *Croom*, 1964, *atmospheric noise; and CCIR*, 1964, *atmospherics*).

Figure 9. From Kraus (1966)

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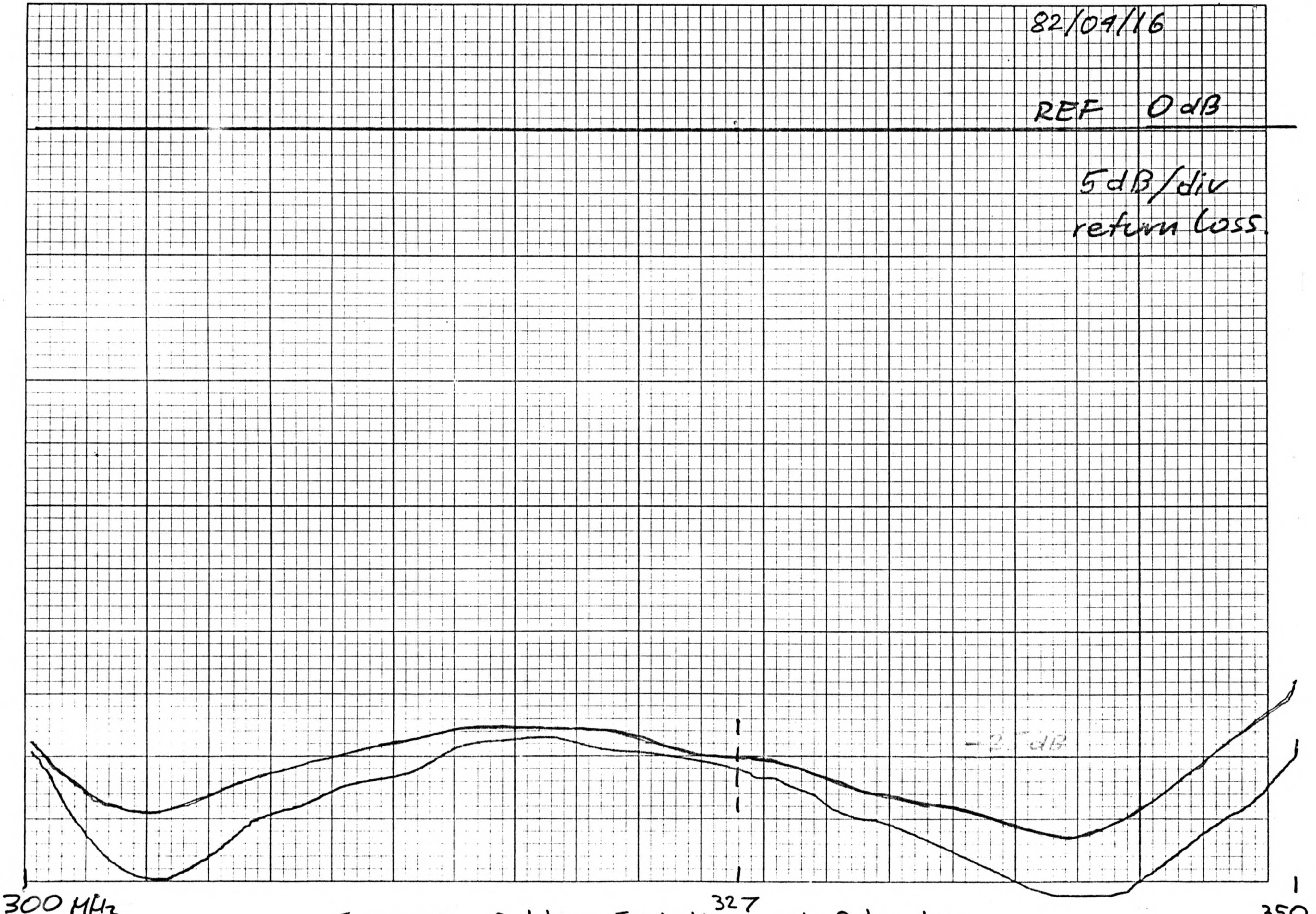

Figure 10 Prototype Feed Measured Return Loss