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A VERY BROAD BAND LOW SILHOUETTE ANTENNA

by

John L. Kerr

January 1969

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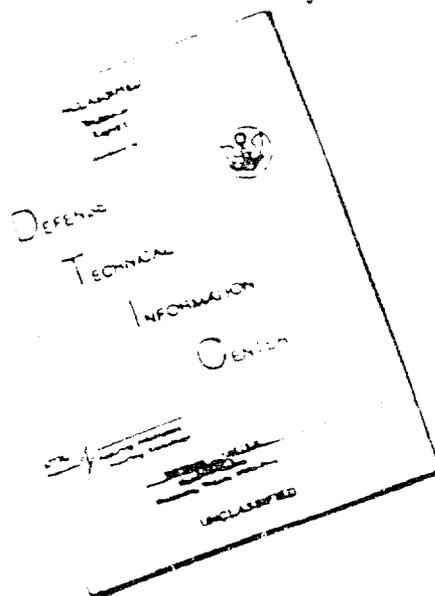
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TECHNICAL REPORT ECOM - 3087

A VERY BROAD BAND  
LOW SILHOUETTE ANTENNA

by

John L. Kerr

Radar Technical Area  
Combat Surveillance and Target Acquisition Laboratory

January 1969

Subtask Nr. 1Z6-62704-A-188-05-04

UNITED STATES ARMY ELECTRONICS COMMAND, FORT MONMOUTH, NEW JERSEY

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#### ABSTRACT

This report describes the development of a very broad band, light-weight, linearly polarized, low silhouette antenna which operates over a bandwidth in excess of 12:1.

The antenna consists of a very short section of a double-ridged waveguide, with a coaxial input, which is used to launch a wave on logarithmically curved extensions of the ridges. Radiation pattern, gain and VSWR data for an experimental model, which operates over the 1 - 12 GHz frequency range, are presented.

A technique for reducing back and side radiation, as well as improving the VSWR performance at the lower end of the frequency range, is discussed and experimental results are included. These data show that a backward travelling wave, reflected from the tips of the radiators, leads to high back and side lobes and introduces violent oscillatory excursions into the VSWR curve at the lower end of the frequency range.

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## A VEE BROAD BAND LOW SILHOUETTE ANTENNA

### INTRODUCTION

Over the past several years, various double-ridged pyramidal horn antennas have been developed by personnel of this Laboratory. The very early work, for countermeasures applications, began more than a decade ago and resulted in the development of several feed horns which exhibited bandwidths of slightly more than three to one. During that effort, the possibility of achieving greatly increased bandwidth was recognized but little additional work was done for a period of some six years. Increased bandwidth requirements, for radio frequency interference measurements, revived the program and resulted in a design for a feed horn having a six to one bandwidth, covering the frequency range from 1.8 to 10.8 GHz. More recent work, also for RFI applications, has resulted in achieving bandwidths in excess of twelve to one for a feed horn as well as for a larger aperture horn with a nominal gain of 15 dB. It is from the latter horn that the antenna to be described in this report is directly derived.

During the course of the broad-band horn development program, it was noted that the pattern data could not be correlated with that for an ordinary pyramidal horn of the same dimensions, leading to the thought that the ridges, although primarily for broad-band impedance matching purposes, have a major effect on the radiation patterns. It was also noted that the VSWR was not greatly affected when the horn sides were removed. Based on those observations, an experimental program was initiated to determine the characteristics of such a structure which is, simply, a gradually diverging two conductor balanced transmission line.

Although it has long been recognized<sup>1, 2</sup> that such a line would serve as a broadband radiator, it does not appear that the technique has been exploited to the extent which would seem to be indicated by the very broad bandwidth, exceptionally low silhouette, and lightweight characteristics which are inherent in this configuration.

### DESCRIPTION

The antenna (Figure 1) consists of a short section (about 1.5 inches) of double-ridged waveguide, with a 50-ohm coaxial input, which is used to launch a wave on the logarithmically curved extensions of the ridges. In the experimental model, the ridge extensions are .375 inches wide, have an axial length of eighteen inches and diverge so that the separation between the elements increased from .050 inches at the aperture of the launcher to twelve inches at the extremities of the radiators. Figure 2 is a photograph of the

experimental model. Figures 3 and 4 are comparison views of the broad-band antenna and the double-ridged pyramidal horn from which it was derived. These show the very low silhouette feature of the antenna. Taking the front comparison view (Figure 3) as an example, the horn has a projected area of 180 square inches as compared with 13.9 square inches for the broad-band antenna. An even greater reduction in projected area is possible in the side view of Figure 4. Since the field is highly concentrated between the ridge surfaces which face each other, the radiating elements can be reduced essentially to thin strips as long as they can be made to conform to the desired curvature. In the model investigated, no attempt was made to minimize either the weight or the profile of the antenna. On the contrary, the main objectives were to make the structure entirely self-supporting and to insure that the required curvature of the radiating elements would be maintained during the development and evaluation program.

The rectangular cavity at the feed point is 1.4 inches wide by .872 inches high. That cross section is maintained for a distance of .325 inches back to a shorting plate (to the left in Figure 1) to form a high impedance cavity shunted across the input. It is interesting to note that both the cross section and length of the back cavity are extremely small, with the length being about an order of magnitude shorter than normal for operation at the low end of the frequency range. The size of the cavity increases from 1.4 inches by .872 inches at the feed point to 3.4 inches by 2.616 inches at the aperture of the launcher, which is one inch away from the feed point in the forward direction (to the right in Figure 1).

The launcher may be considered as a special version of a broad-band microwave balun,<sup>3</sup> which was also developed by personnel of this Laboratory as another component directly attributable to the continuing broad-band antenna program.

Figure 5 is the graph from which the radiating element curvature was determined. The X-coordinates are axial distances measured along the center line of the antenna, beginning at the aperture plane of the launcher. The Y-coordinates are perpendicular distances from the center line of the antenna to the radiating element surface. As indicated on the graph, an additional linear taper is superimposed on the logarithmic curve. The amount of this additional linear taper was determined during the double-ridged horn development program. The amount of additional linear taper has ranged from .008X inches to .020X inches for various horn configurations in which this parameter has been varied. In the horn model from which this antenna was derived, the added taper amounted to .011X inches and that value was carried over directly into this program without further investigation. The additional linear taper serves to provide a significant improvement in the VSWR over the first octave of the bandwidth and has little effect elsewhere in the range of interest.

#### MEASURED CHARACTERISTICS

The performance characteristics of the antenna were determined experimentally by measuring radiation patterns, gain, and VSWR over the 1 to 12 GHz frequency range. Typical E- and H-plane radiation patterns, plotted on a relative voltage scale, are shown in Figures 6 through 32. Examination of the patterns reveals that significant back radiation occurs in the lower portion

of the band. During the early part of the experimental program, it was thought that the high back radiation was due to spillover at the aperture of the launcher since the largest dimension of the waveguide is little more than one-quarter wavelength at 1.0 GHz. In an attempt to reduce the back radiation, a one-foot-square ground plane was fitted around the aperture of the launcher and radiation pattern measurements were repeated. No significant improvement was noted and the ground plane was abandoned. Although this was in the nature of a negative result, it was accepted with some relief since the use of such a ground plane would have greatly detracted from the utility of the device, especially as regards the very low silhouette feature.

It was then assumed that the antenna was not radiating efficiently in the lower portion of the frequency range and that a backward travelling wave, generated by reflection of a significant amount of energy at the tips of the radiators, was the major contributor in the formation of the large back lobes. Based on that assumption, tapered polyiron loads were fabricated from available material and attached to the tips of the radiating elements. The material used was Crowley material,<sup>4</sup> MP-2312(D-1), which was tapered from a knife edge at the tip of the element to approximately three-quarters of an inch at the outer end (see Figure 32). The maximum length of the available polyiron was approximately four inches, which was considered to be much too short to serve as a matched termination at frequencies in the lower portion of the band of interest. Since there was no way to assess the quality of these terminations in a quantitative way with respect to the intended application, they were attached to the antenna and radiation patterns were again recorded (see Figures 33 through 46).

Although it was assumed that the terminations were too short at the lower frequencies, it can be seen that a significant reduction in back lobe level has been achieved in that region and that the effect of the termination decreases with increasing frequency, indicating that the antenna becomes a more efficient radiator in the upper portion of the band. It may also be noted that there is an accompanying reduction in the H-plane side lobe level. The major effect in the E-plane forward lobes at some of the lower frequencies is a significant broadening of the beam up to about 3 GHz. A prime example of this effect is the difference in the E-plane patterns at 2 GHz with and without terminations (Figures 11 and 38). Again, it appears that the patterns at the lower frequencies are the result of interference between the forward travelling wave and a large reflected wave when the terminations are not present. In the same vein, it is interesting to note the similarity between the E-plane pattern at 2 GHz with terminations present and that of the unterminated E-plane pattern at 4 GHz, where the reflected wave is apparently at much lower level and the terminations have very little effect (Figures 15 and 38).

Although use of the terminations does result in a marked improvement in the pattern characteristics, it also results in an undesirable loss of gain at some of the lower frequencies. Initial gain measurements indicate losses on the order of 2 to 3 dB at some of the lower frequencies when the elements are terminated, as compared with the unterminated condition. This is shown in Figure 47. However, the reduction in gain can not be entirely attributed to absorption by the loads, since at those frequencies there is a substantial reduction in directivity due to the broadening of the E-plane patterns as discussed earlier.

The measured VSWR of the antenna with and without terminations is presented in the curves of Figure 48. The reduction in the reflected wave is again very apparent, as evidenced by the reduction in the violent excursions of the VSWR at the lower frequencies when the polyiron terminations are attached. Insofar as the VSWR is concerned, the terminations appear to be very effective down to about 2 GHz or slightly lower, beyond which point they become increasingly less effective due to the short length of polyiron which was used. The question may well arise as to whether or not the aluminum extensions (see Figure 32) which hold the polyiron wedges contribute to the improved VSWR. Before the polyiron was applied, the aluminum brackets were attached to the antenna and VSWR measurements were made. No improvement was noted and the only change observed was a slight shift in frequency of the maxima and minima of the VSWR curve at the low end of the frequency range. That particular experiment was not made in connection with radiation patterns. However, other ridge configurations which closely approximate that situation have been tried with no apparent improvement noted in the radiation characteristics.

#### CONCLUSIONS AND RECOMMENDATIONS

A very broad band, linearly polarized antenna has been developed which has the very desirable characteristics of being light weight and having a low silhouette. In its simplest form, the antenna should find wide applications in such areas as communications, wide band frequency monitoring, RFI measurements, and in the design of light weight, low profile antennas for forward area use.

From the results of this experimental program, some additional effort appears to be desirable. This would include such programs as: investigation of other techniques directed toward improving pattern and VSWR performance at the lower frequencies; extending the bandwidth to include, possibly, the 12 to 18 GHz frequency range; and detailed investigation of the near-field phase and amplitude distribution aimed at explaining the radiation mechanism of the antenna and perhaps suggesting methods for improving some of the performance characteristics.

A program to investigate the properties of an image plane version of the antenna has recently been initiated. This type structure appears to be ideally suited to vehicular applications with particular emphasis on aircraft, where the underside of a wing or fuselage may serve as the ground plane. Preliminary results on an initial model indicate satisfactory performance over a 10:1 band.

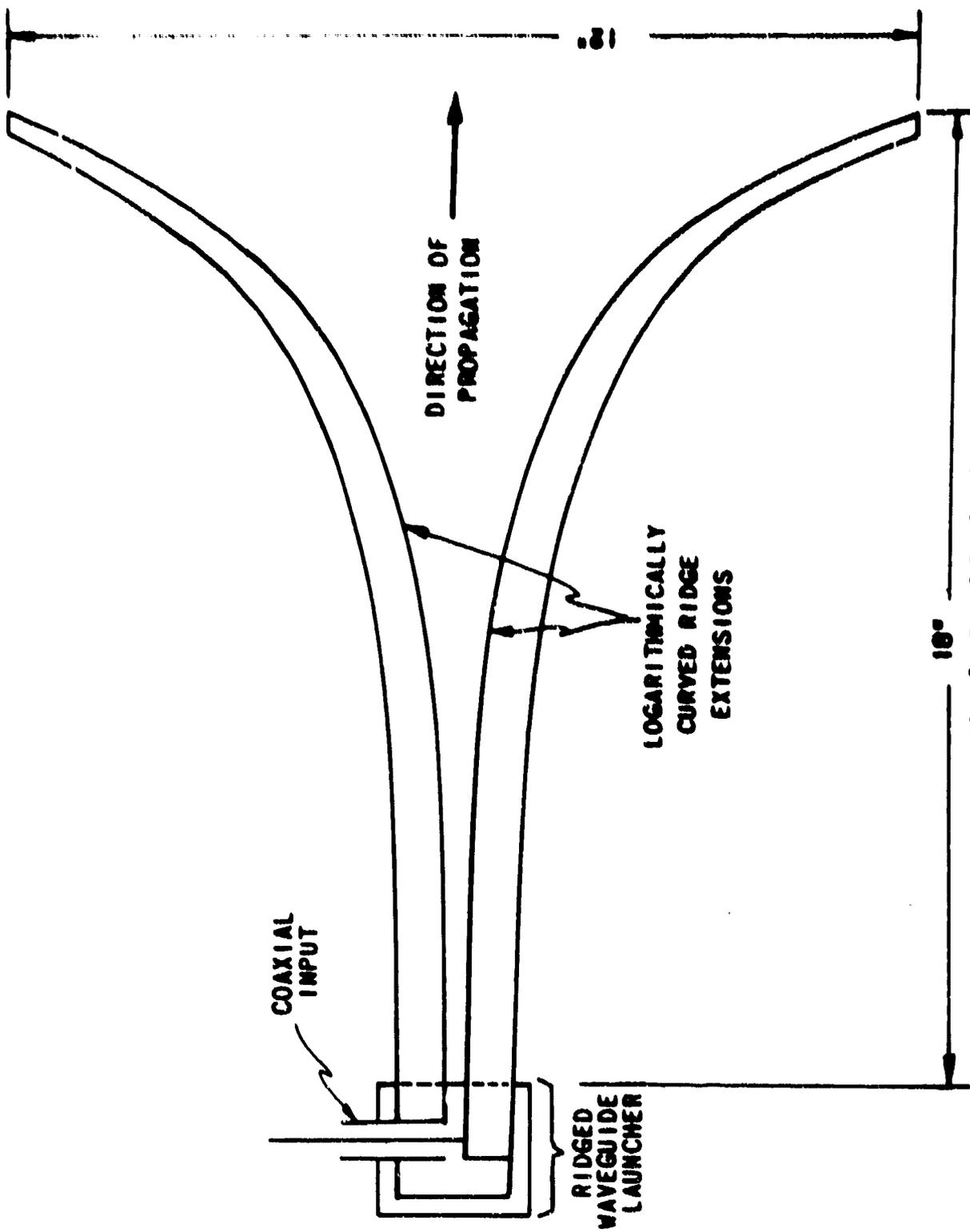
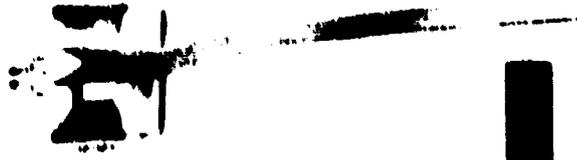
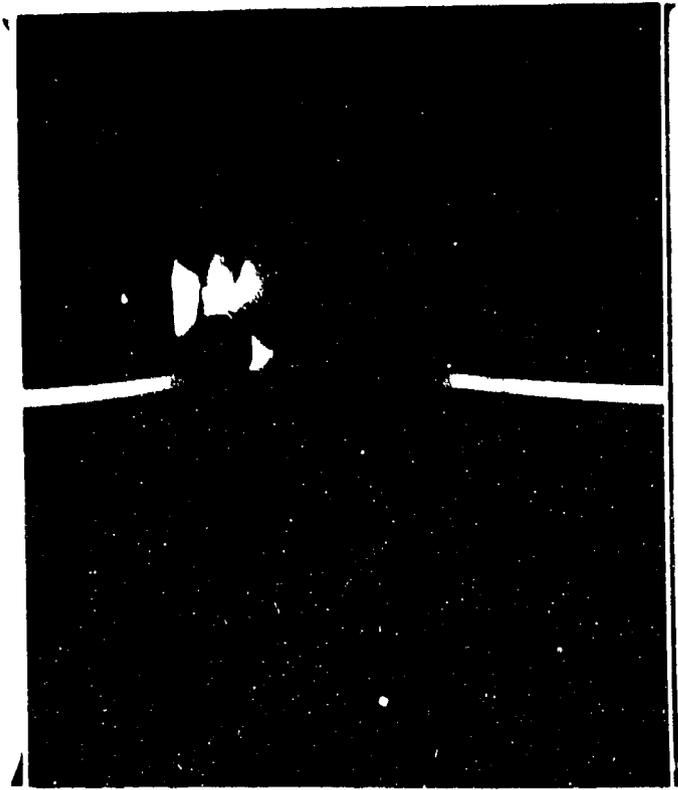


Fig. 1 Broad Band Antenna



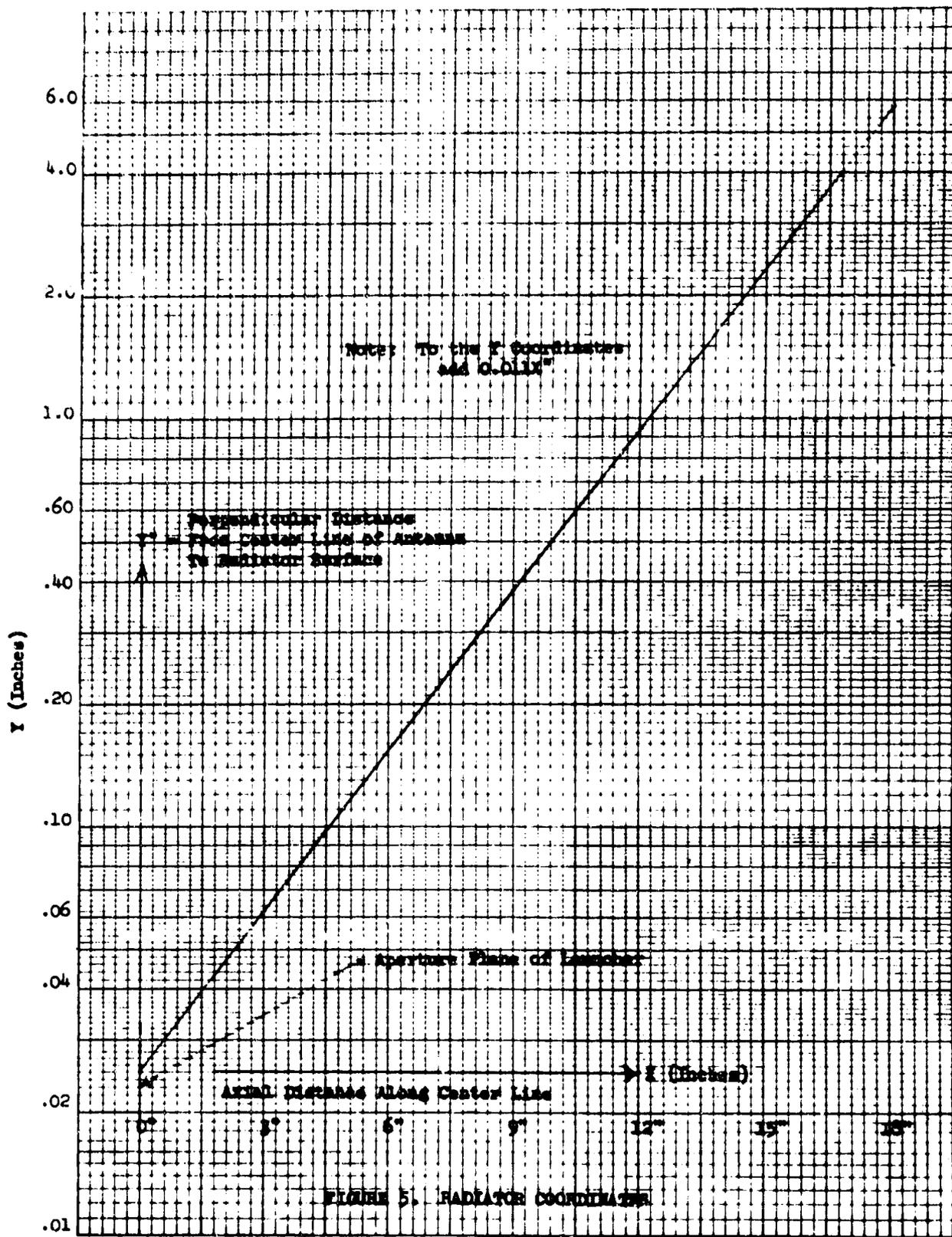
Fig. 2 Broad-Band Antenna - Experimental Model



**Fig. 3 Double-Ridged Horn and Broad-Band Antenna  
Aperture Comparison View**



Fig. 4 Double-Ridged Horn and Broad-Band Antenna  
Side Comparison View



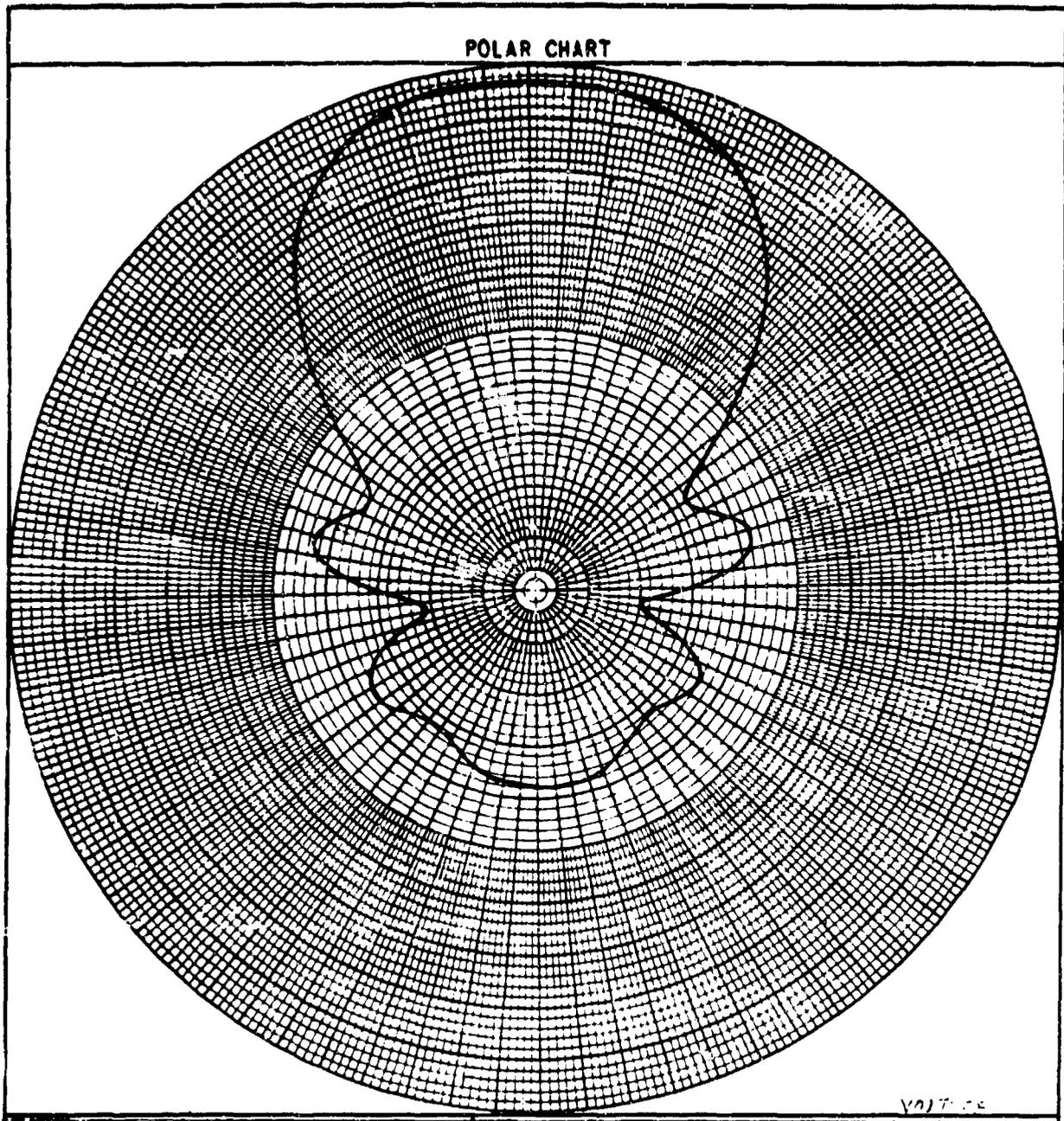


FIGURE 6. 1.0 GHz H-PLANE

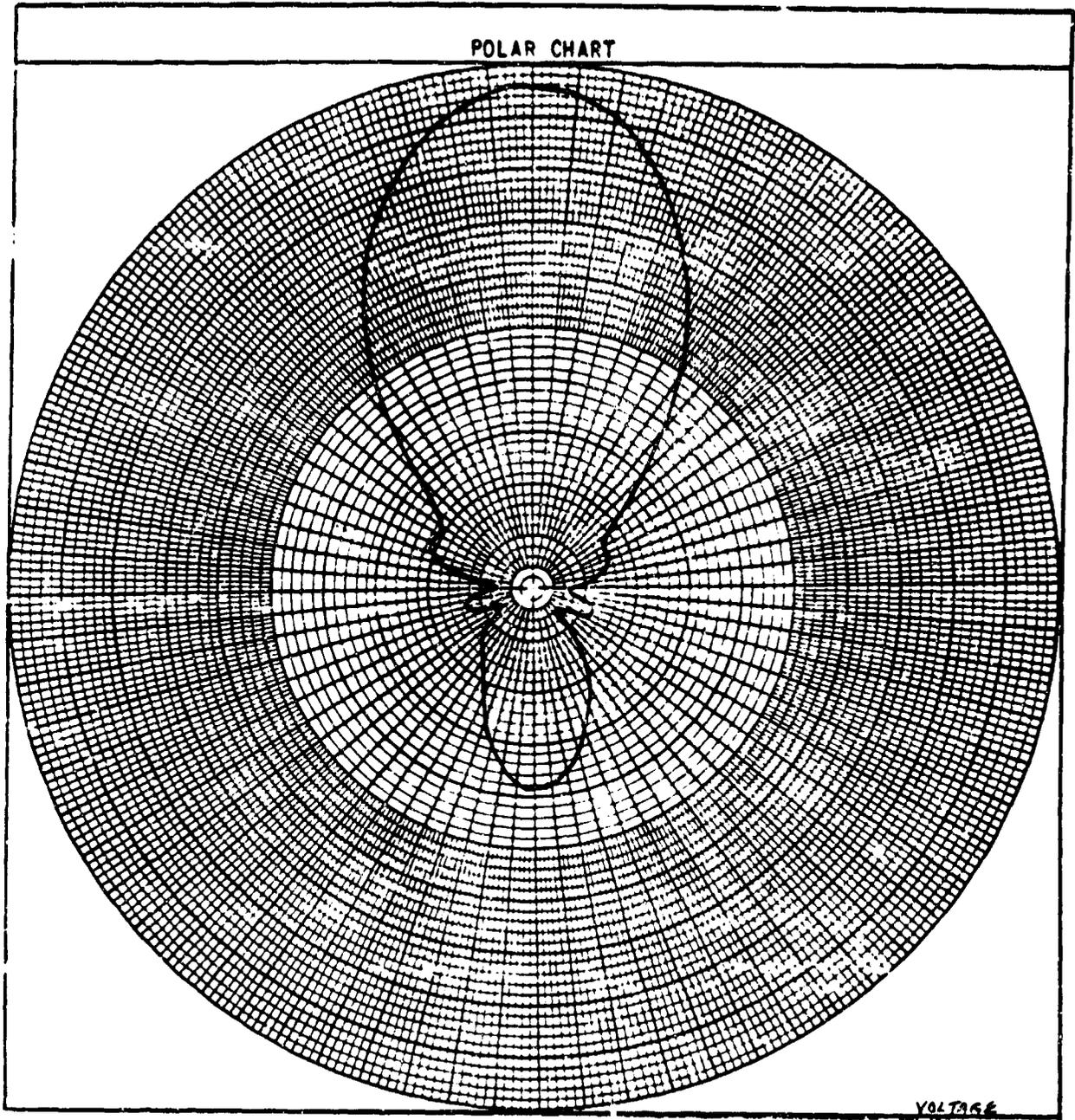
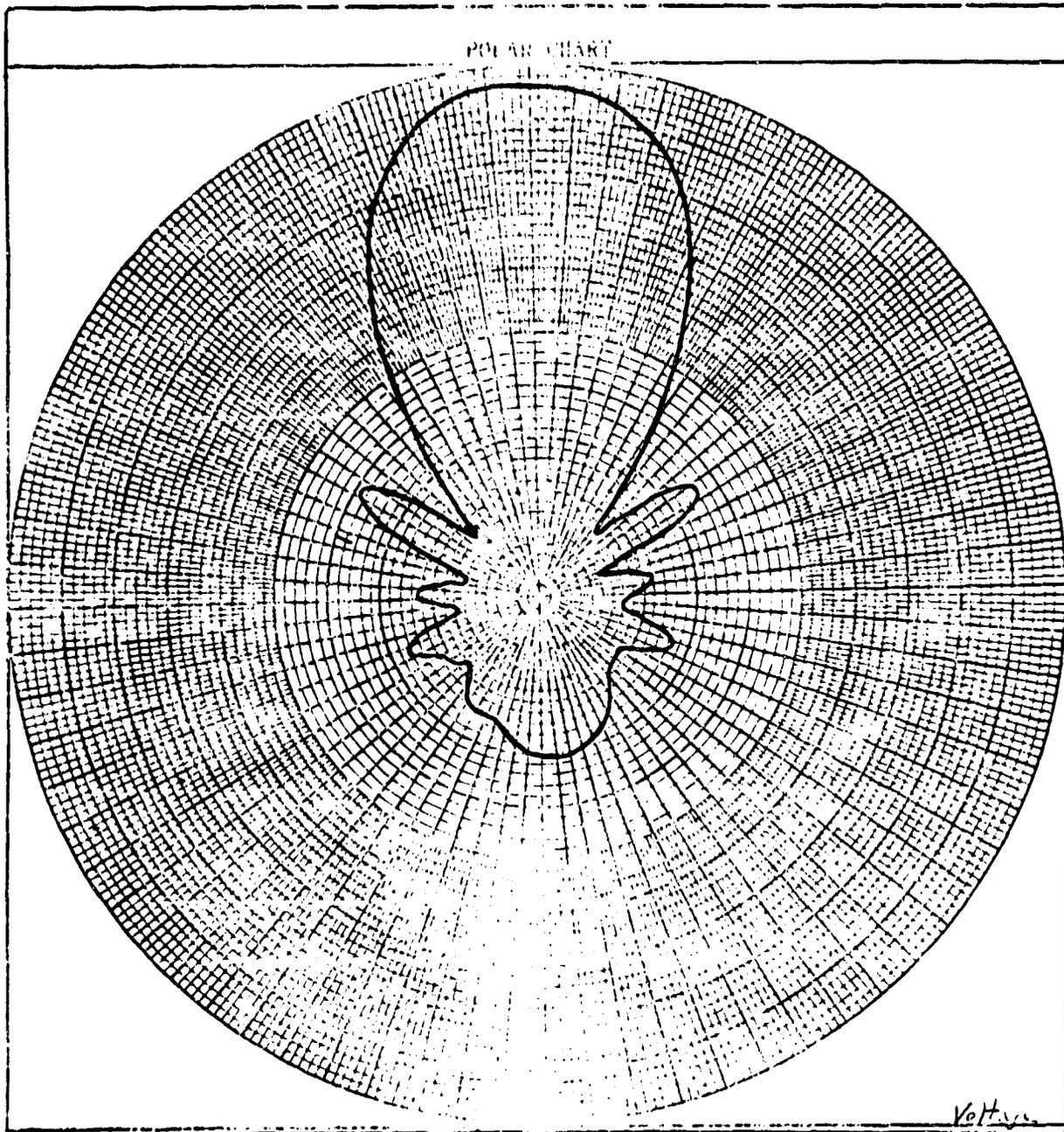


FIGURE 7. 1.0 GHz E-PLANE



**FIGURE 8. 1.5 GHz H-PLANE**

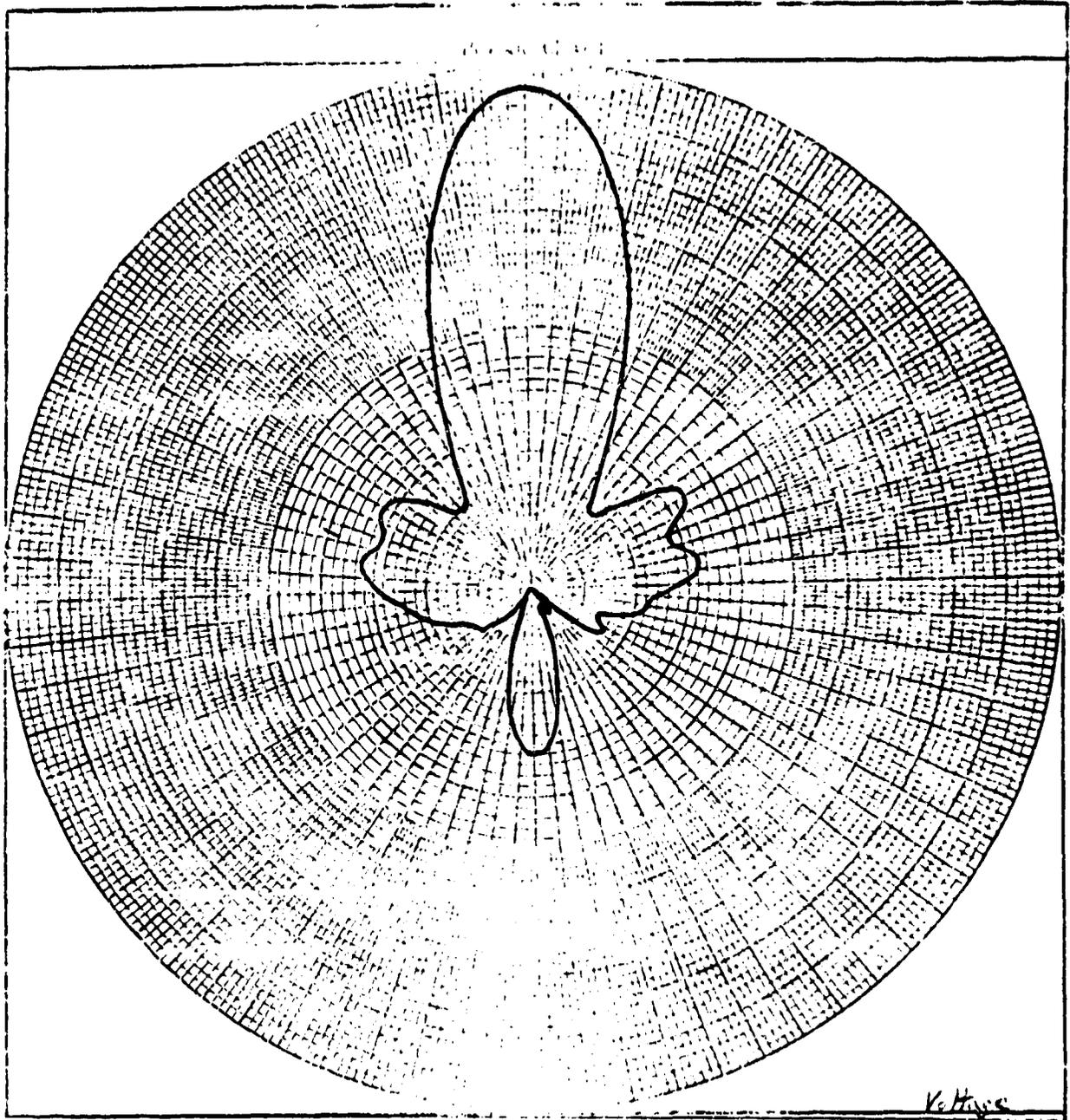
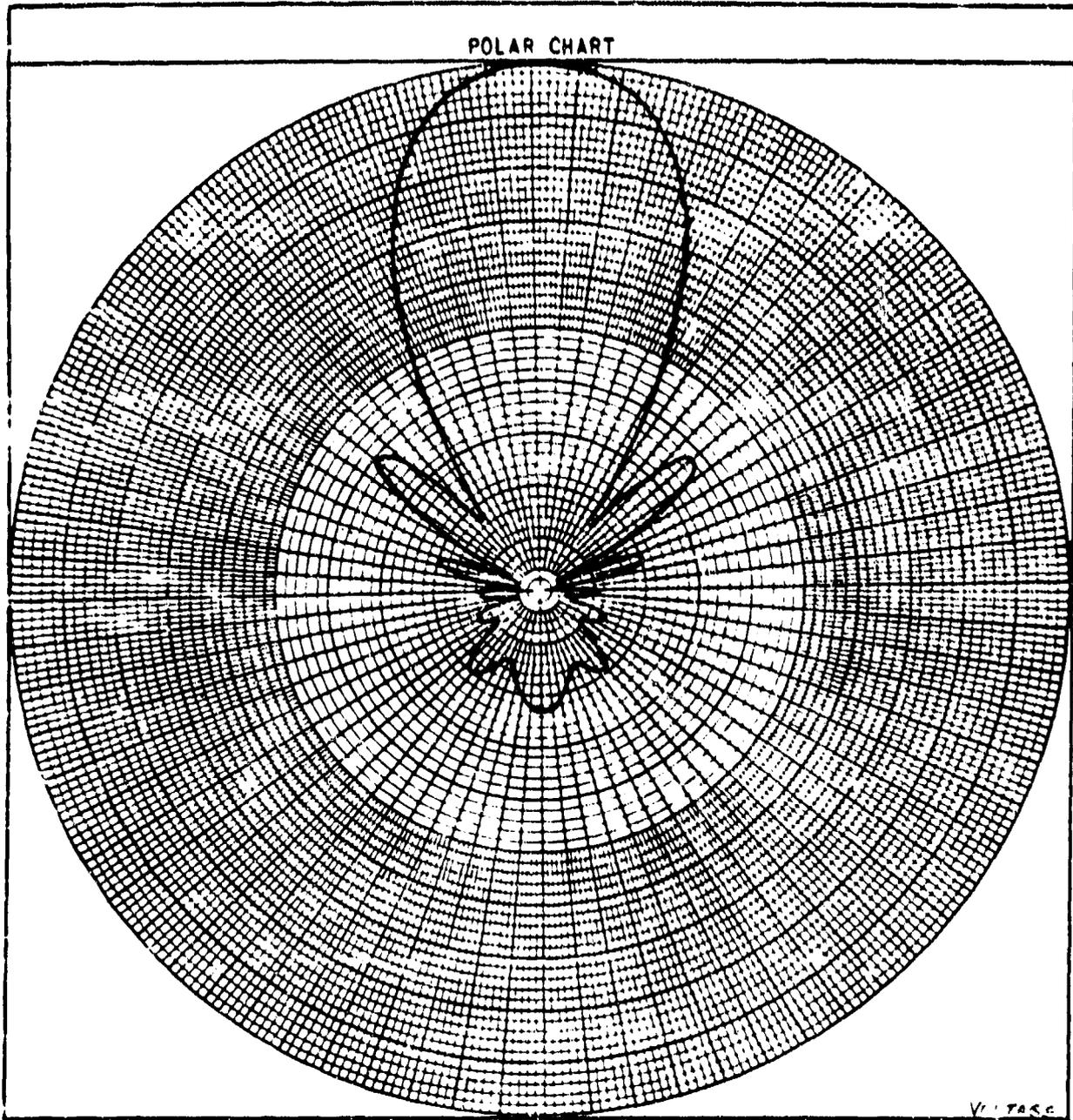


FIGURE 9. 1.5 GHz E-PLANE



**FIGURE 10. 2.0 GHz E-PLANE**

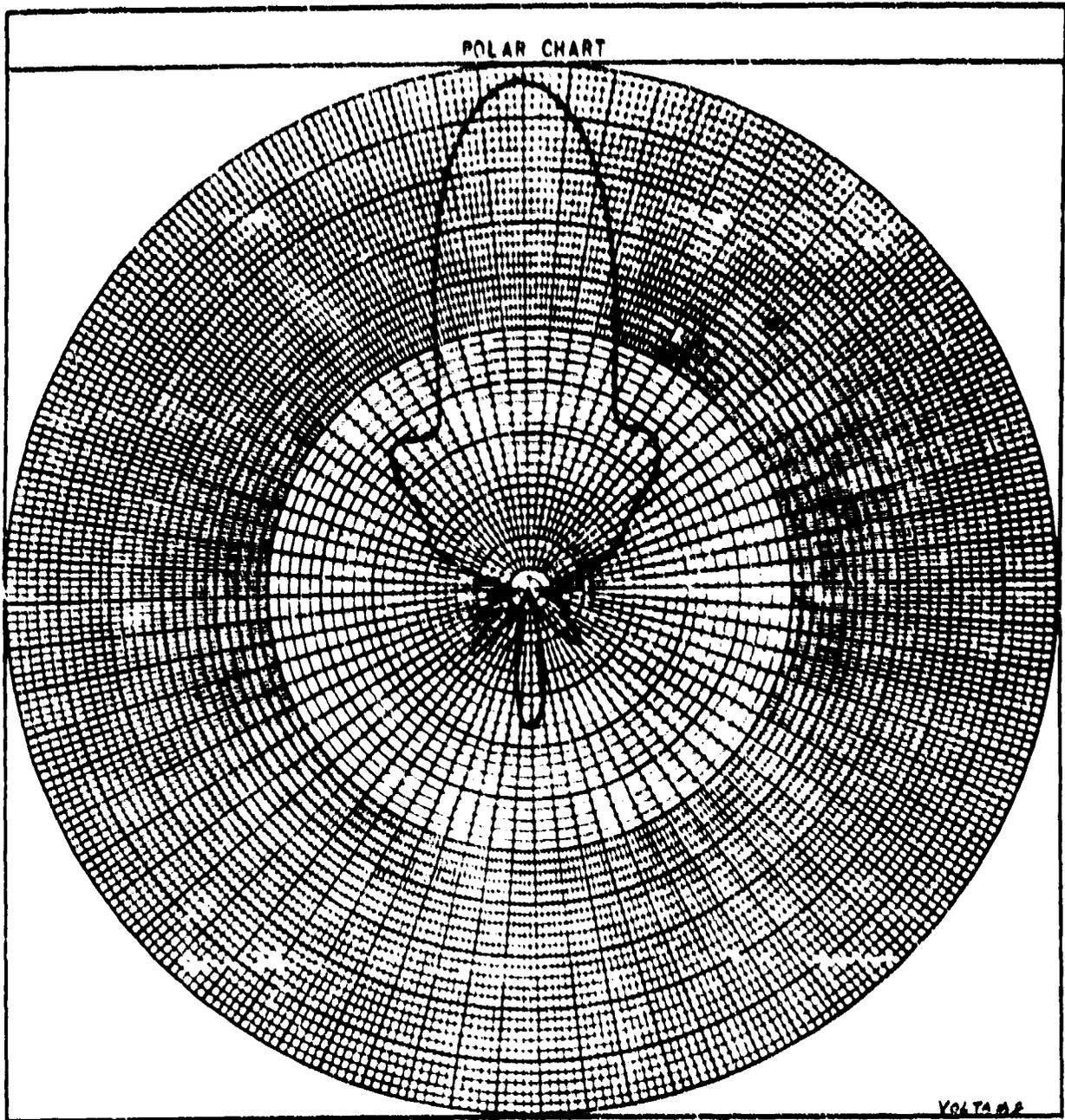


FIGURE 11. 2.0 GHz E-PLANE

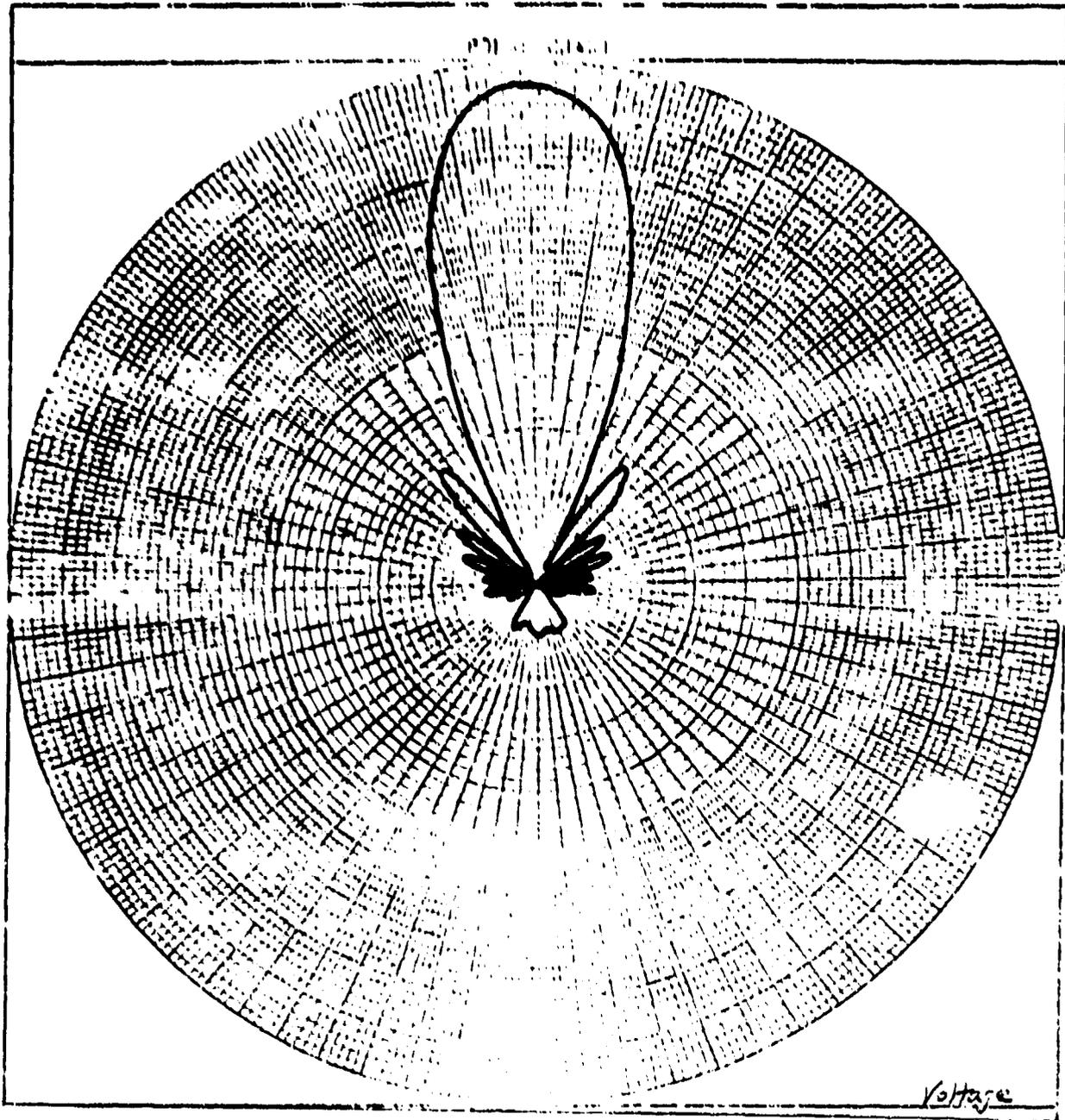


FIGURE 12. 3.0 GHz H-PLANE

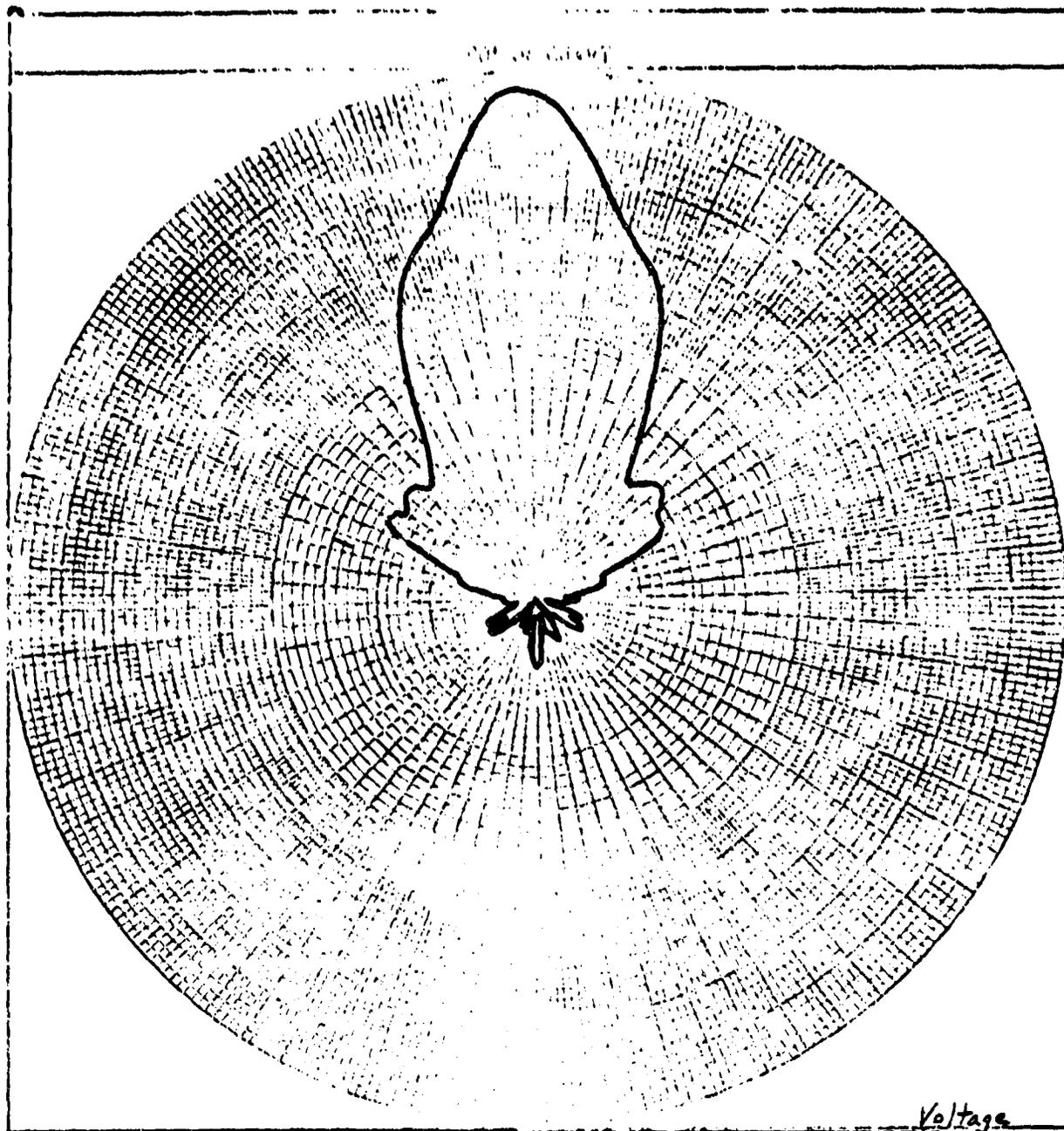
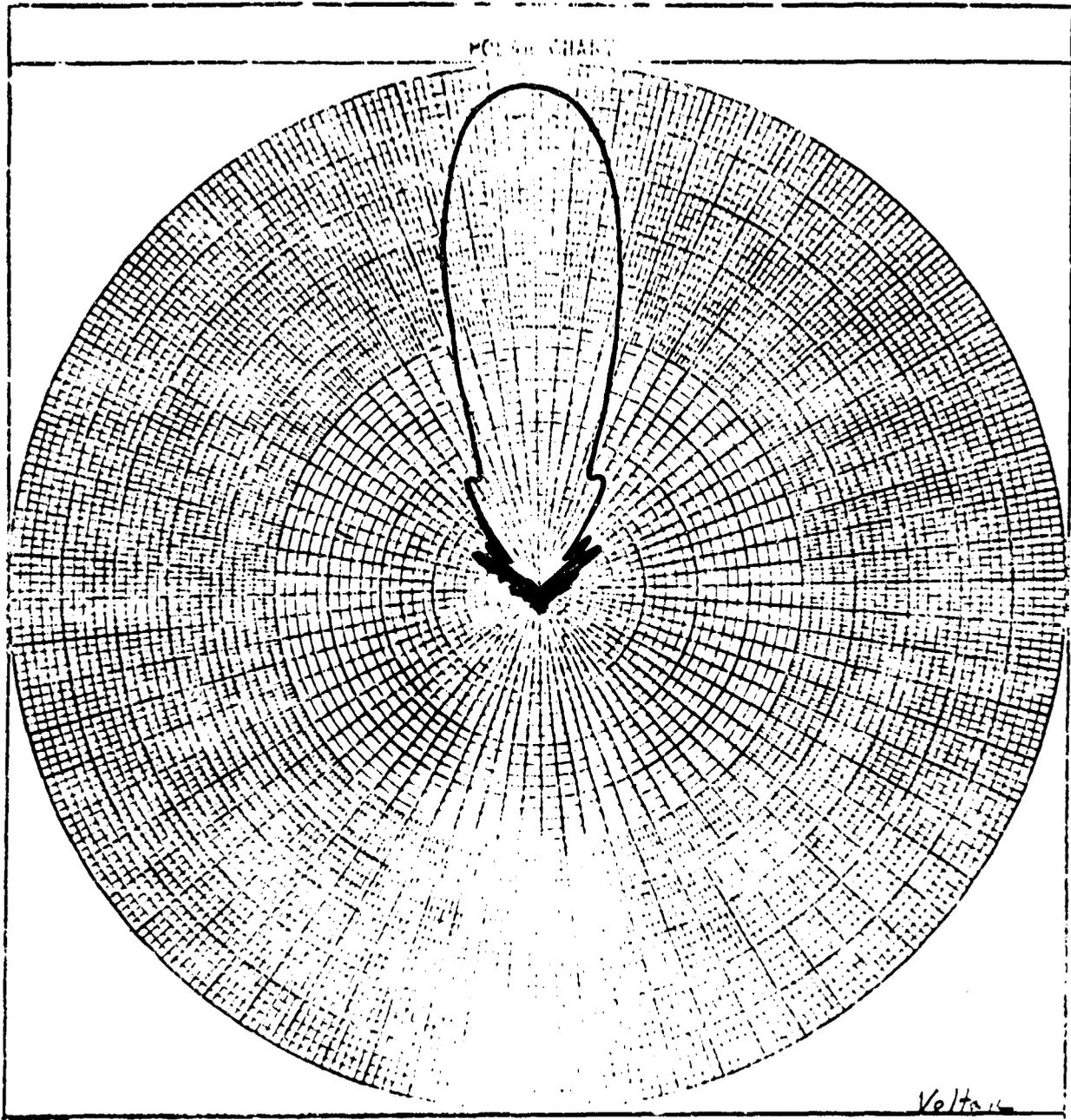


FIGURE 13. 3.0 GHz E-PLANE



**FIGURE 14. 4.0 GHz E-PLANE**

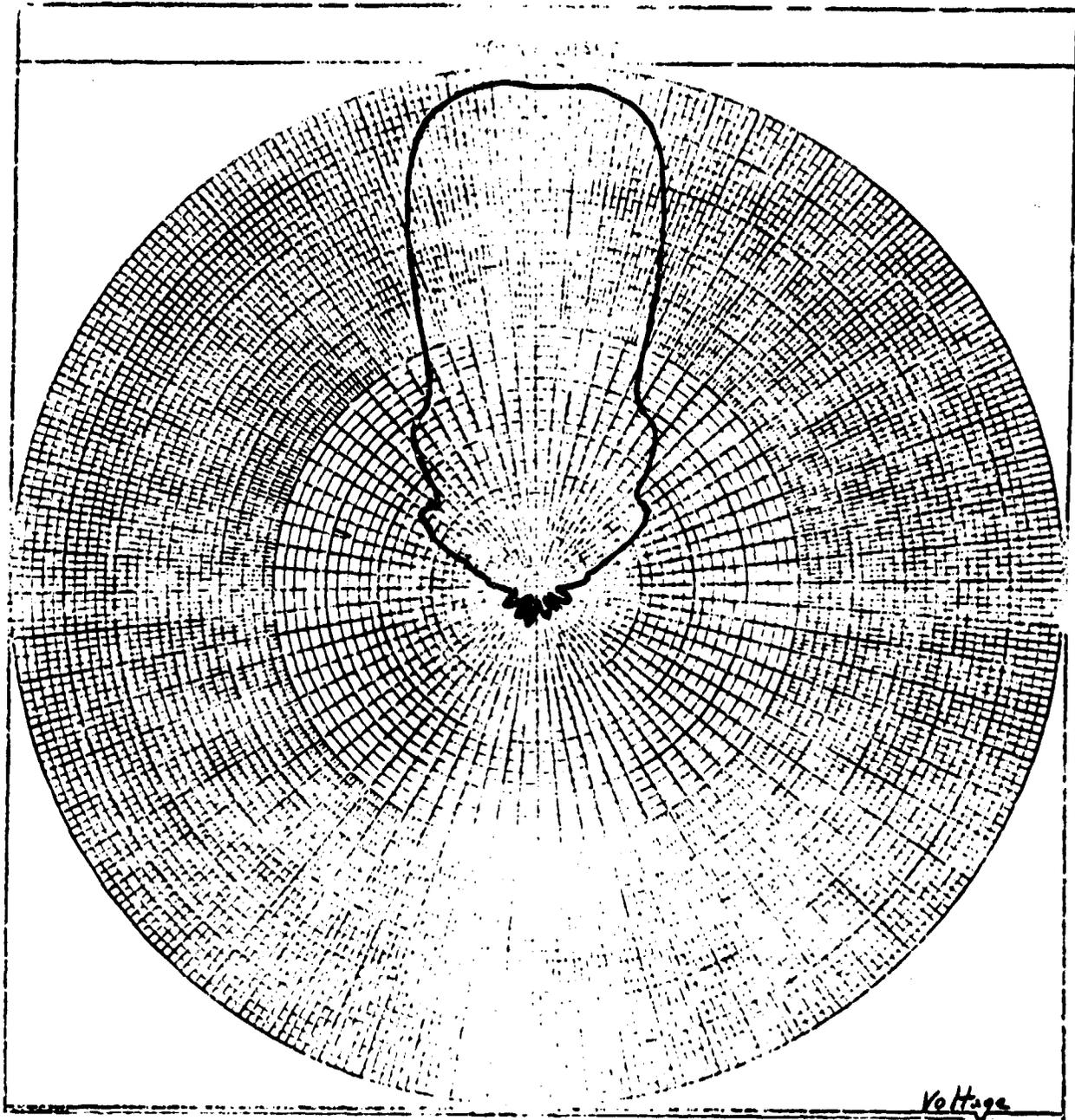


FIGURE 15. 4.0 GHz E-PLANE

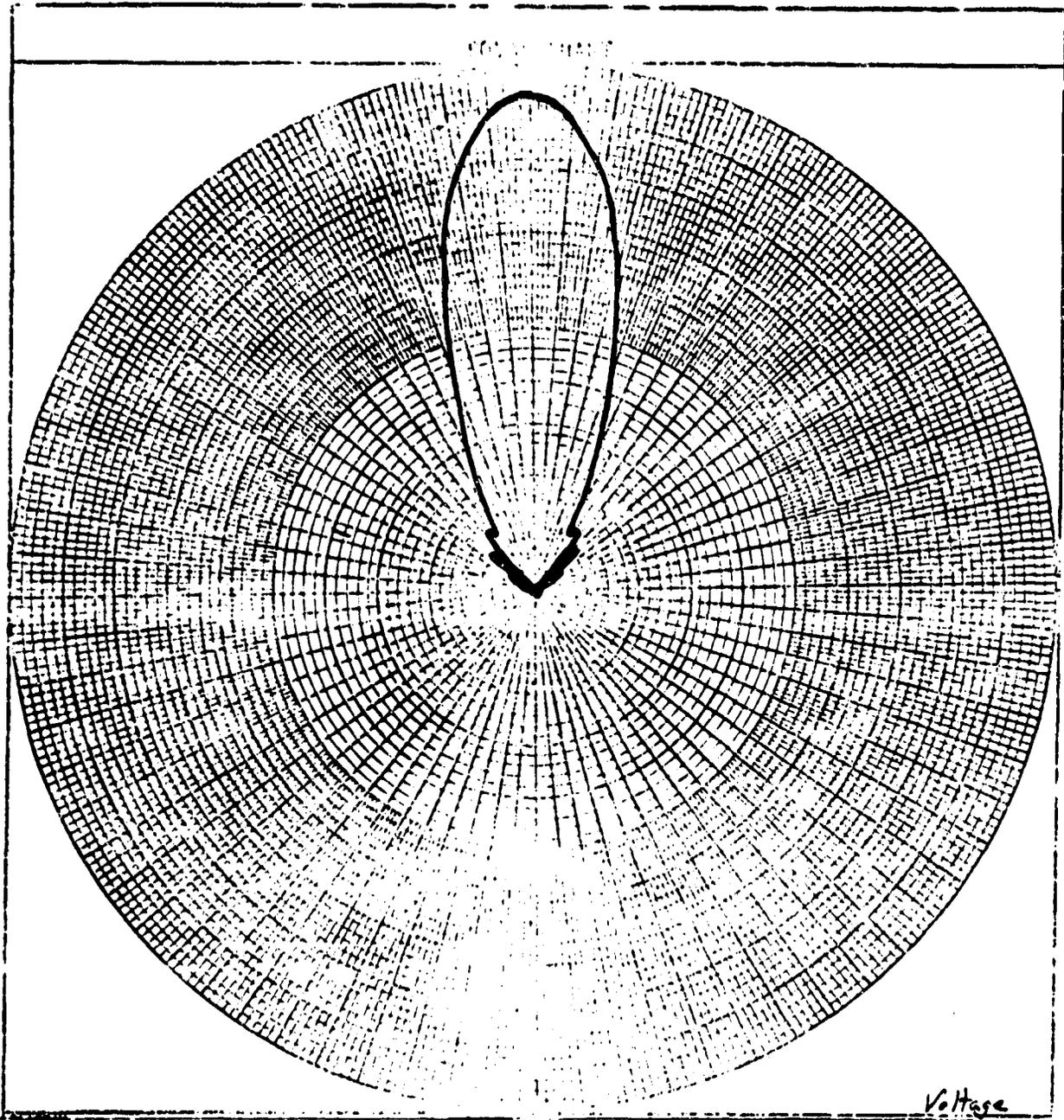


FIGURE 16. 5.0 GHz E-PLANE

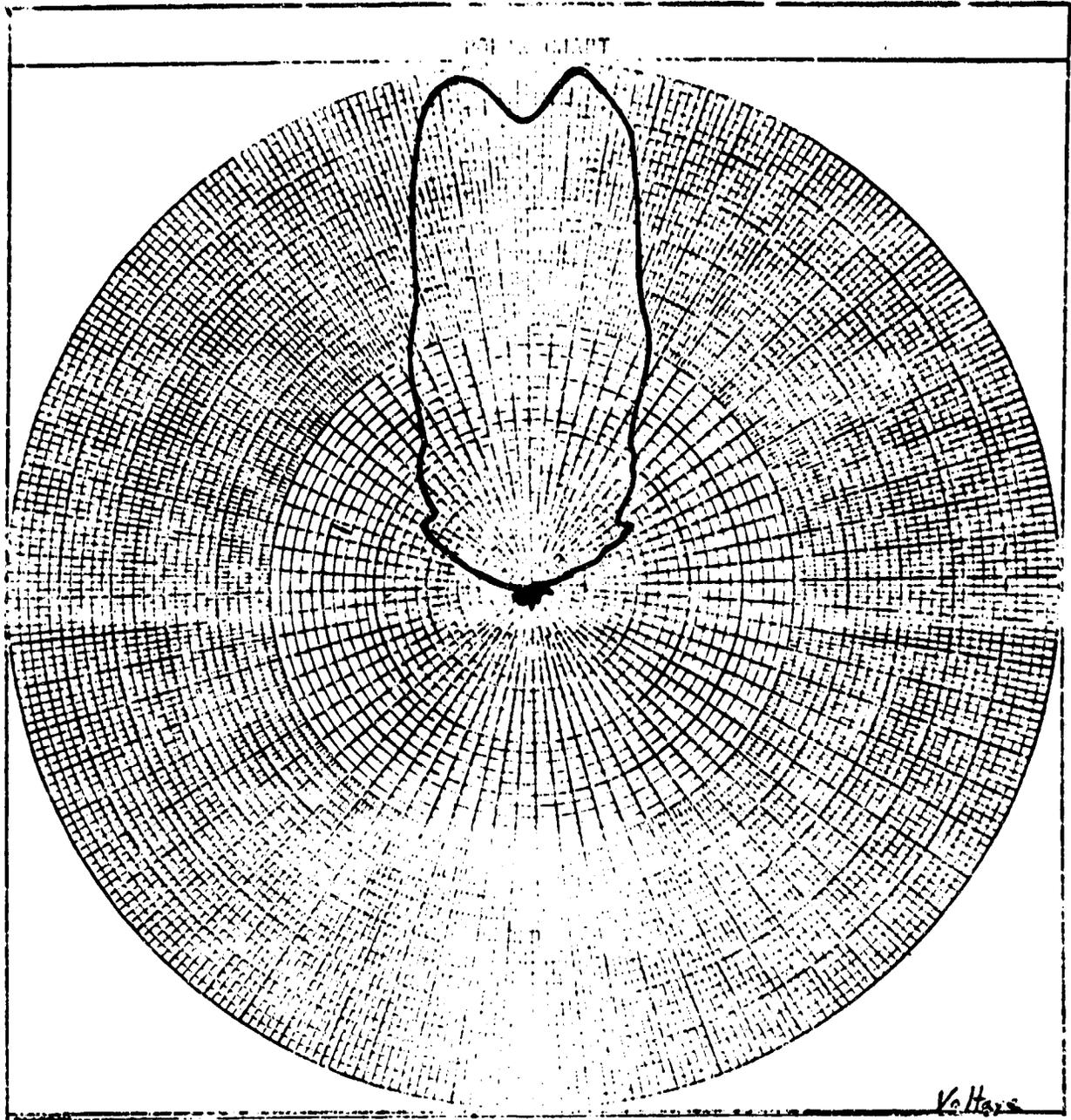


FIGURE 17. 5.0 GHz E-PLANE

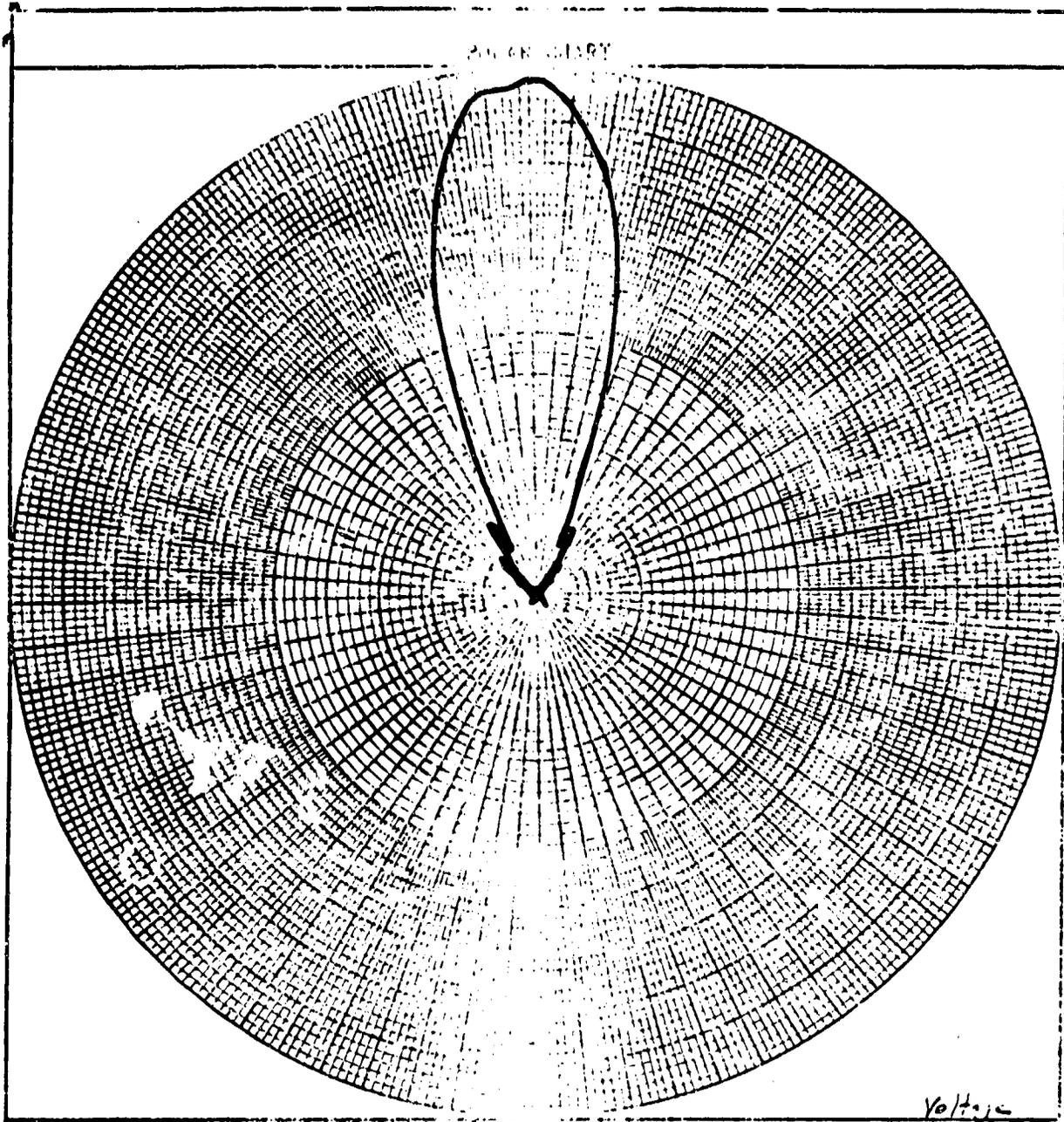


FIGURE 18. 6.0 GHz H-PLANE

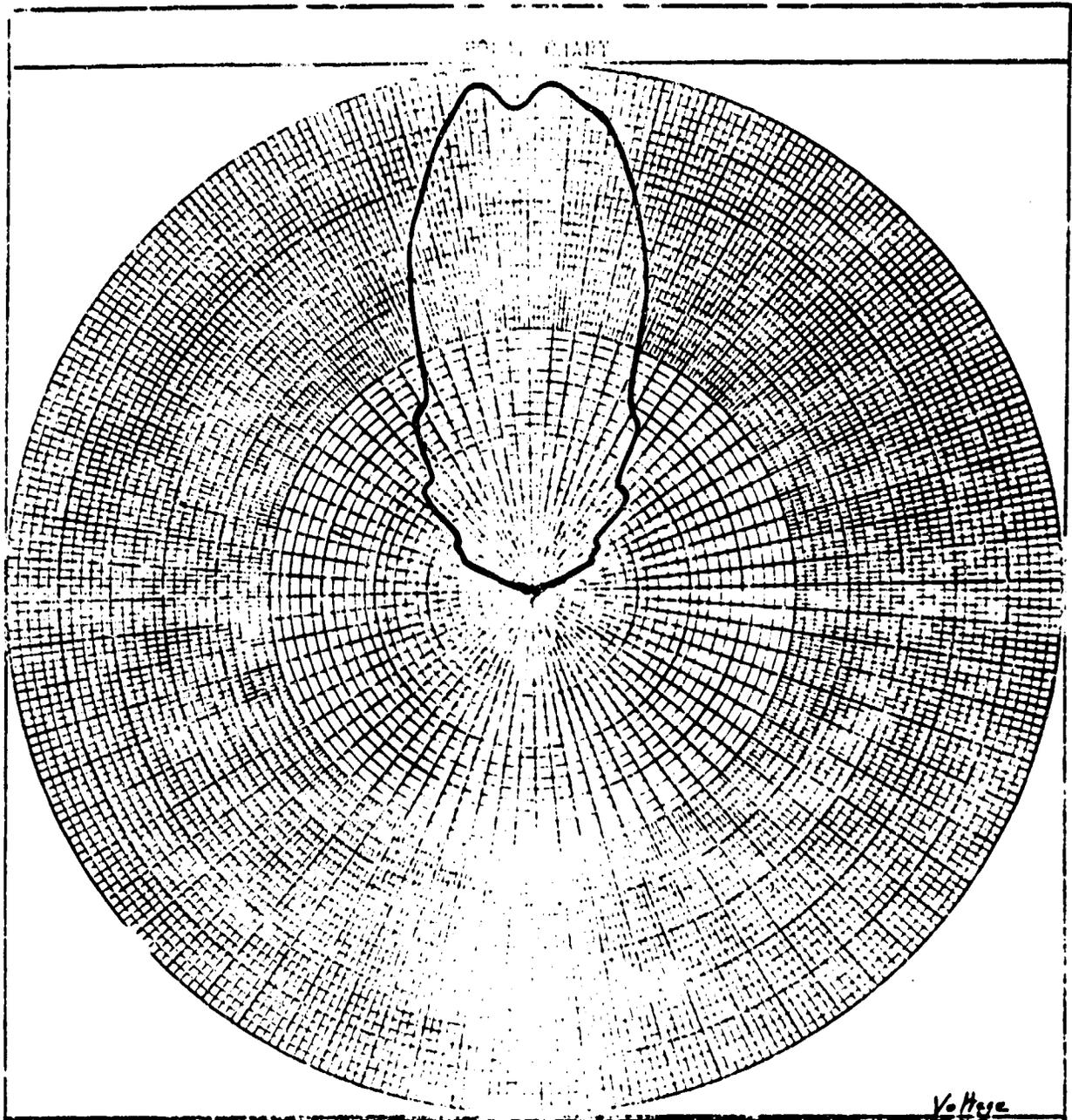


FIGURE 19. 6.0 GHz E-PLANE

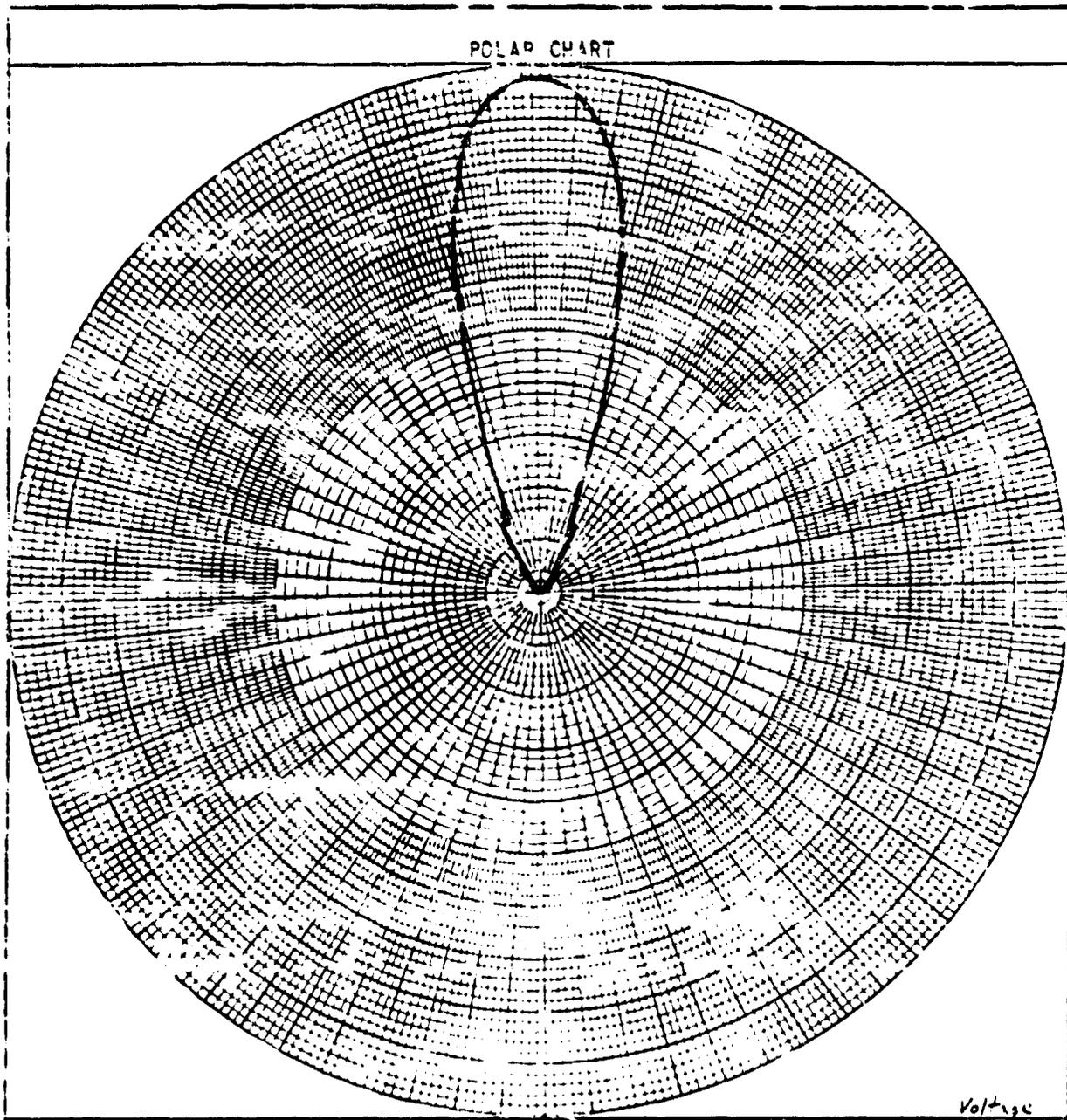


FIGURE 20. 7.0 GHz H-PLANE

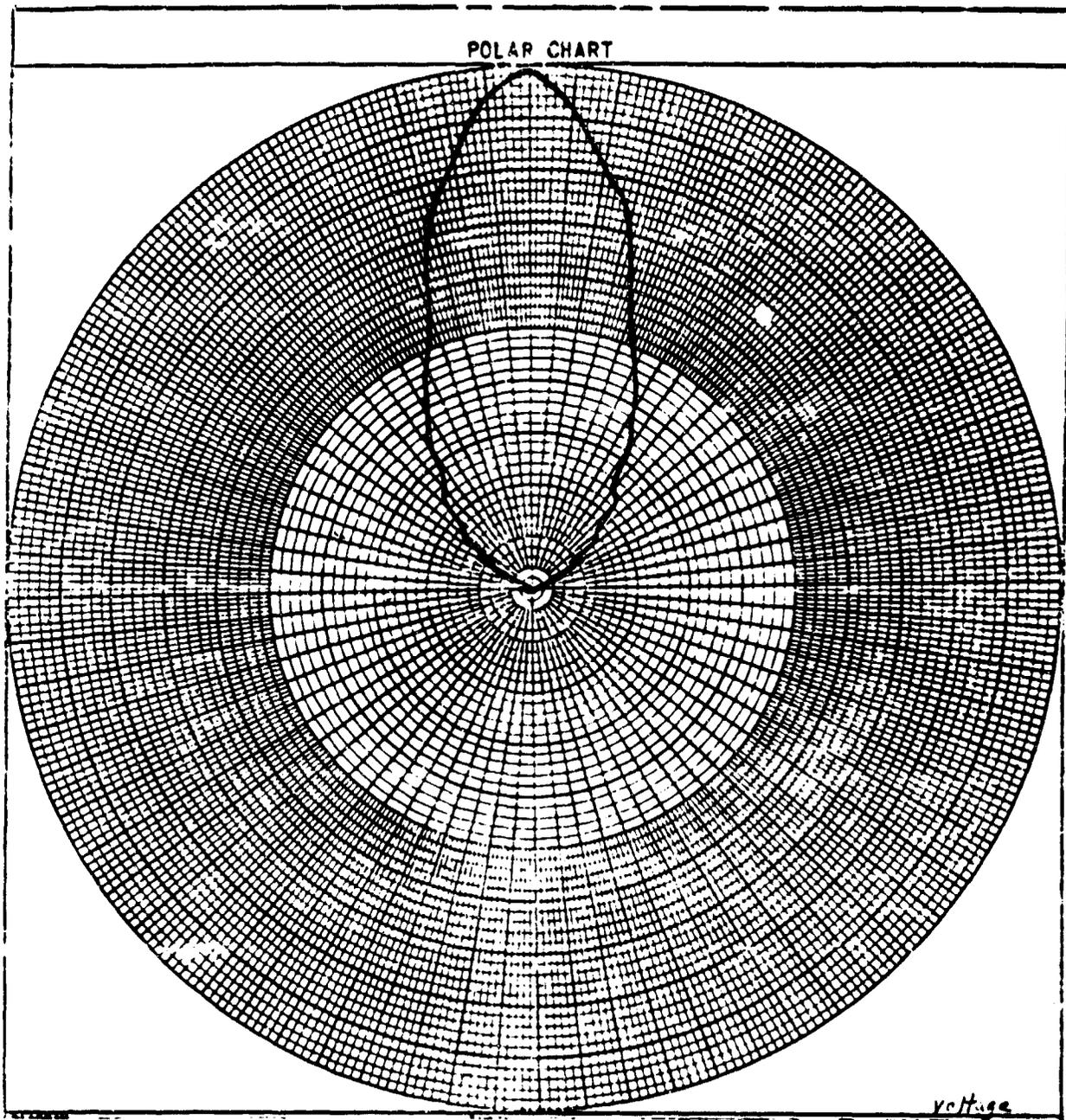


FIGURE 2. 7.0 GHz E-PLANE

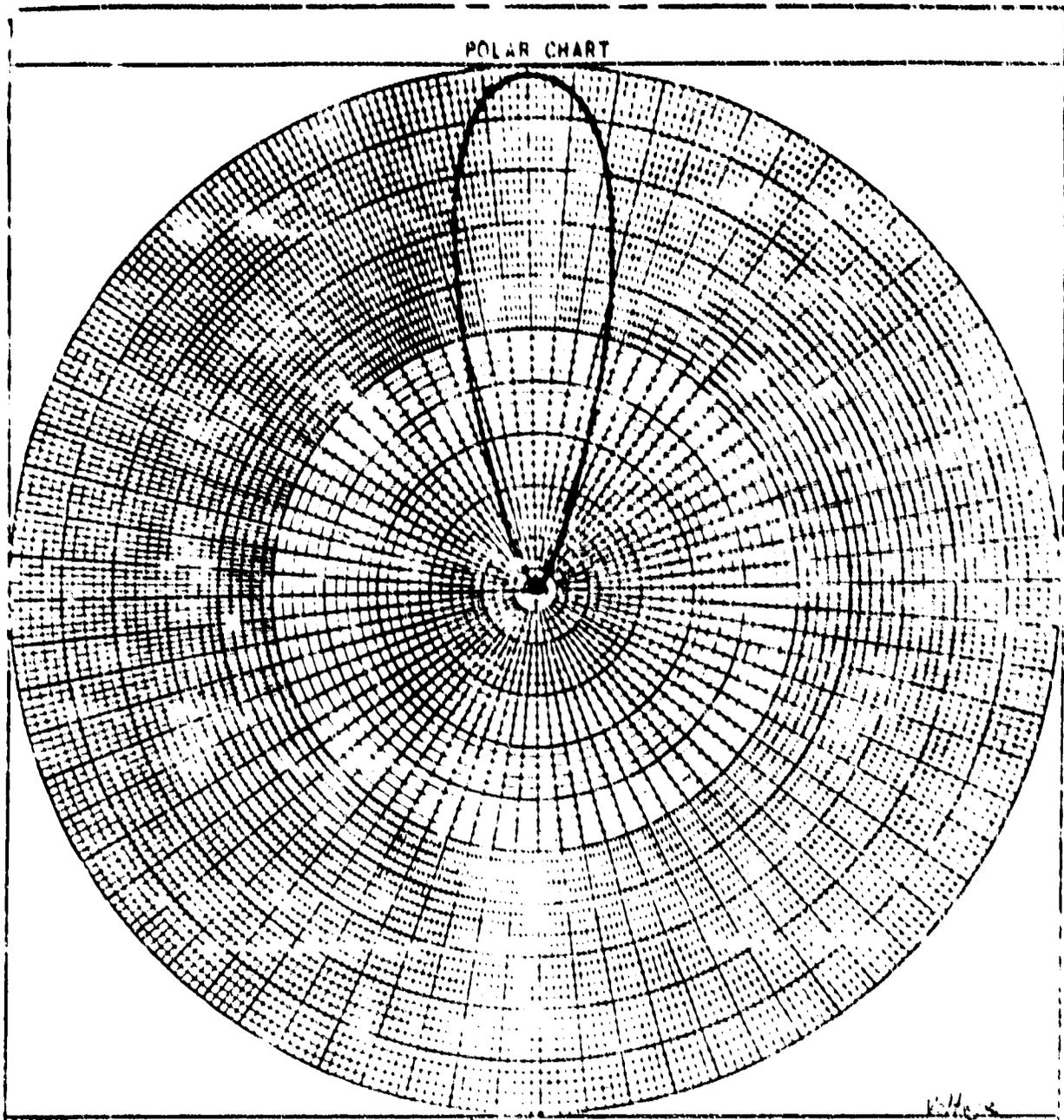


FIGURE 22. 8.0 GHz H-PLANE

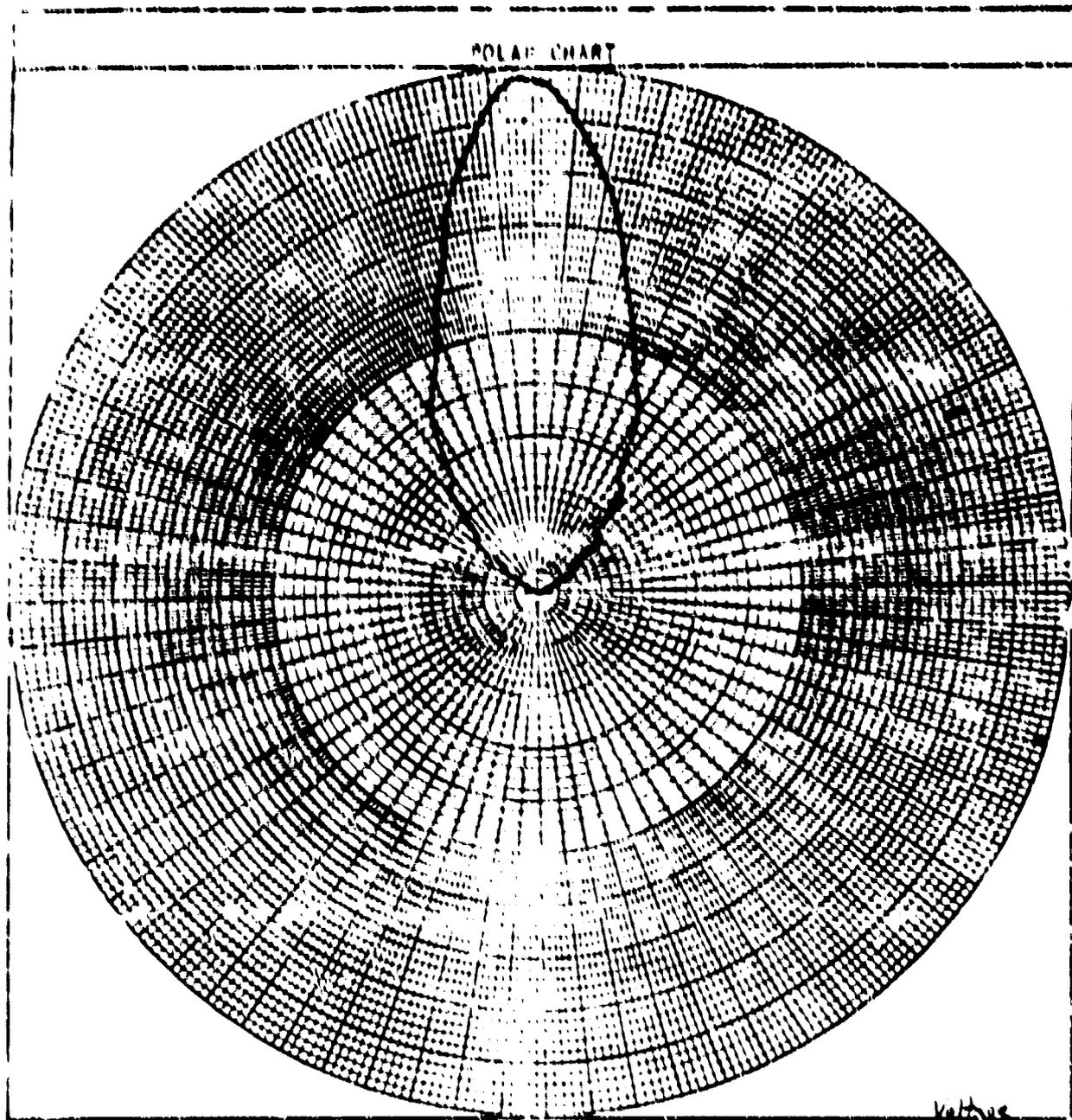


FIGURE 23. 8.0 GHz E-PLANE

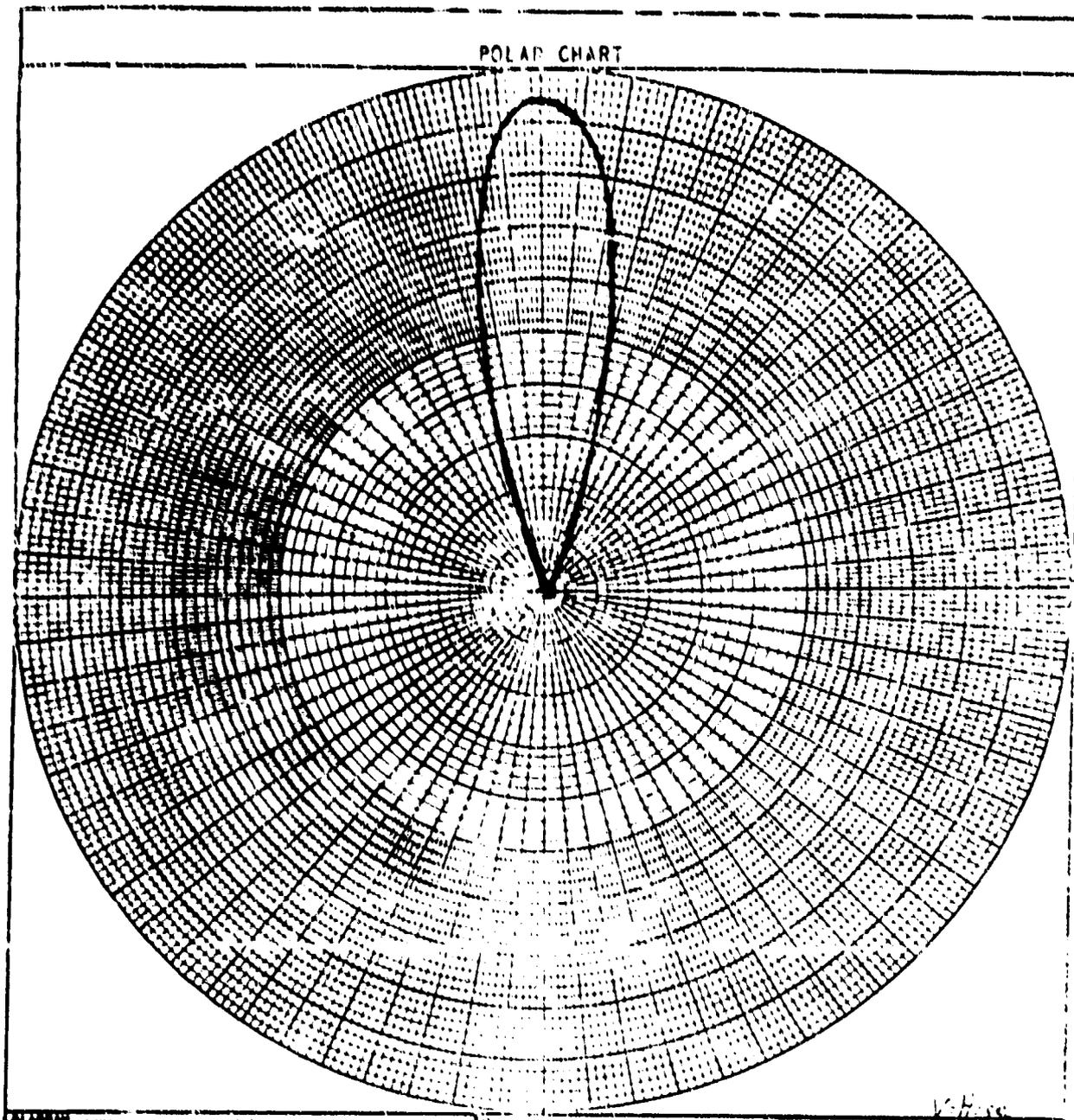


FIGURE 24. 9.0 GHz H-PLANE

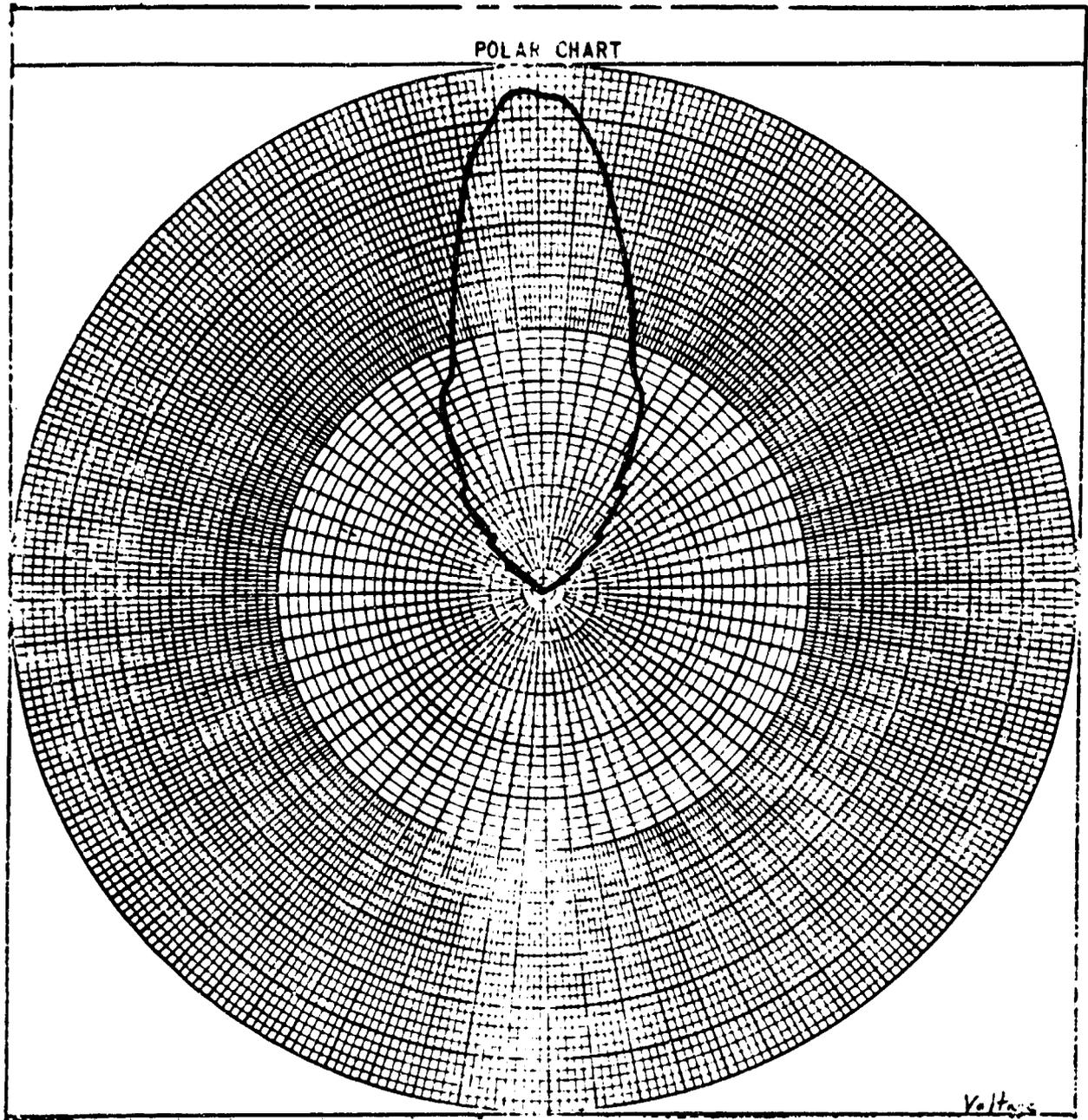


FIGURE 25. 9.0 GHz E-PLANE

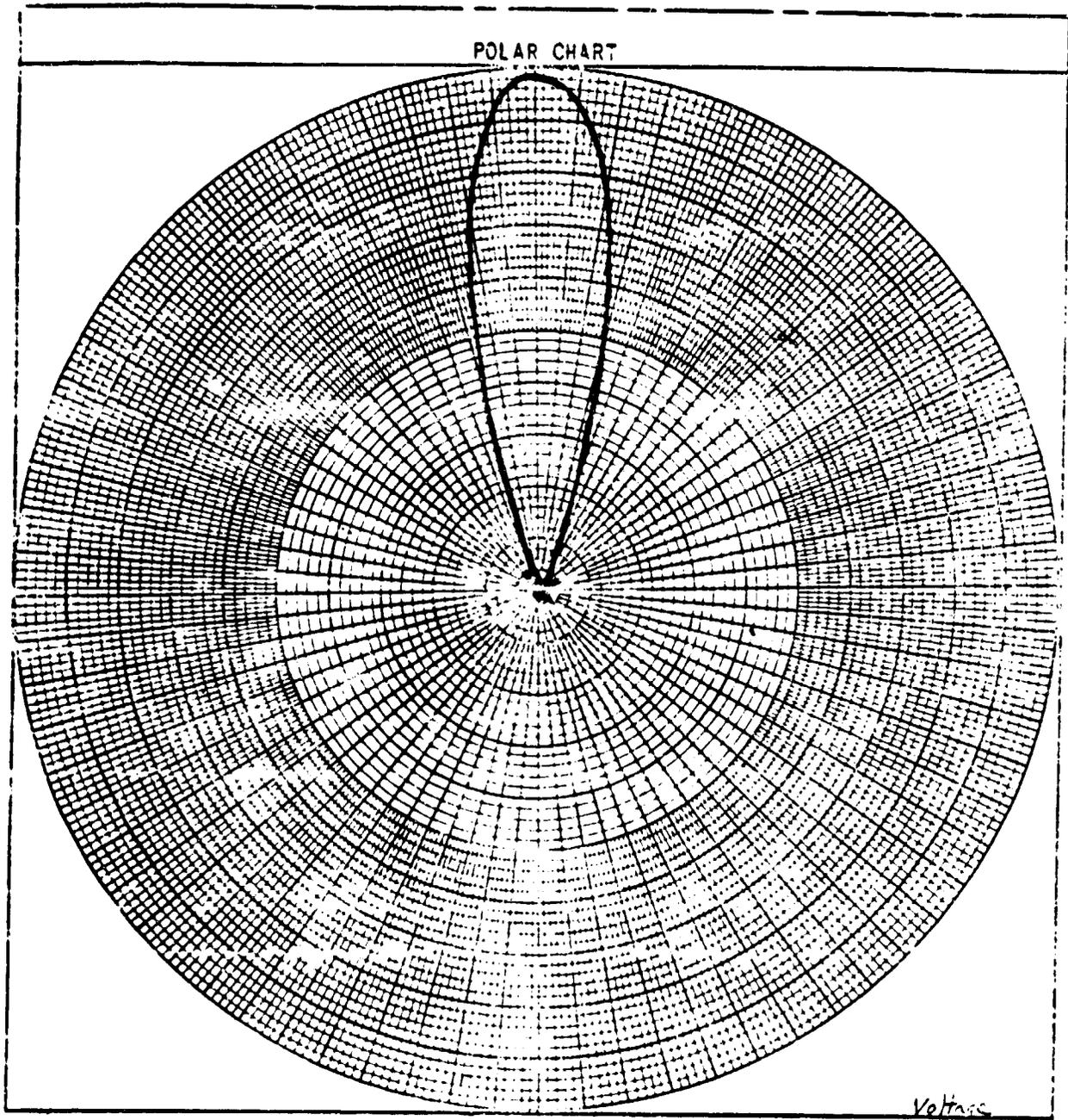


FIGURE 26 10.0 GHz H-PLANE

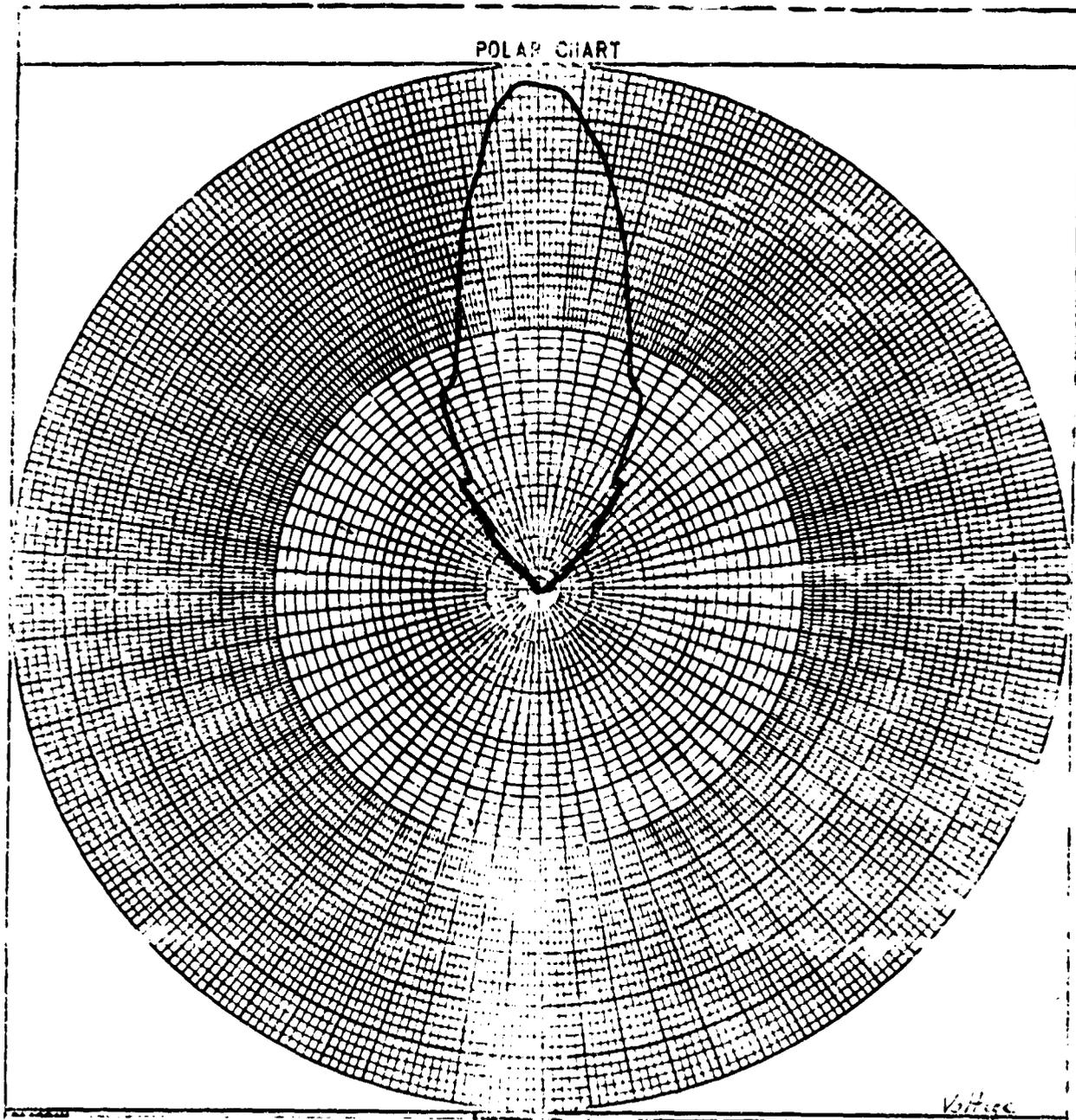


FIGURE 27. 10.0 GHz E-PLANE

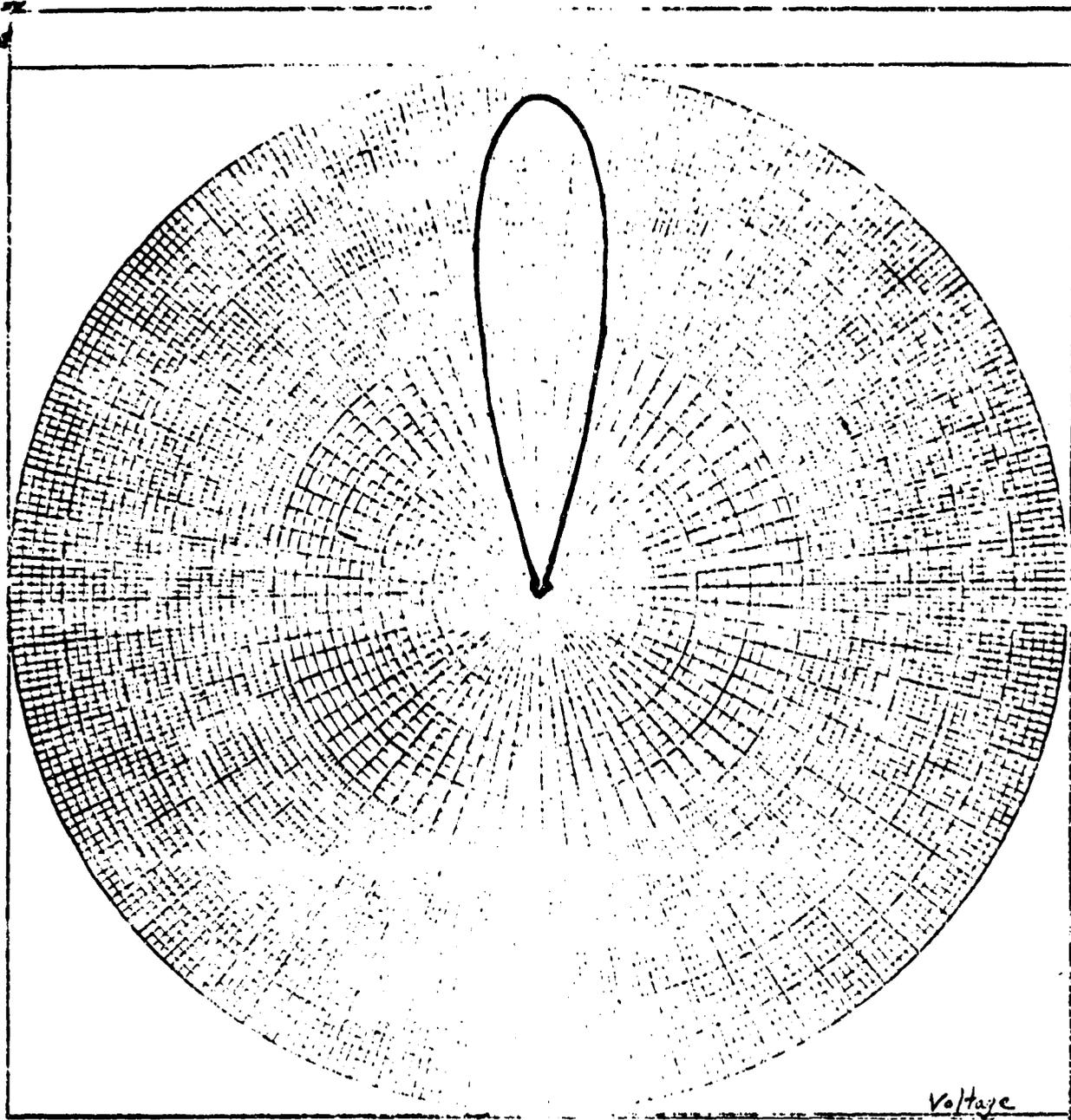
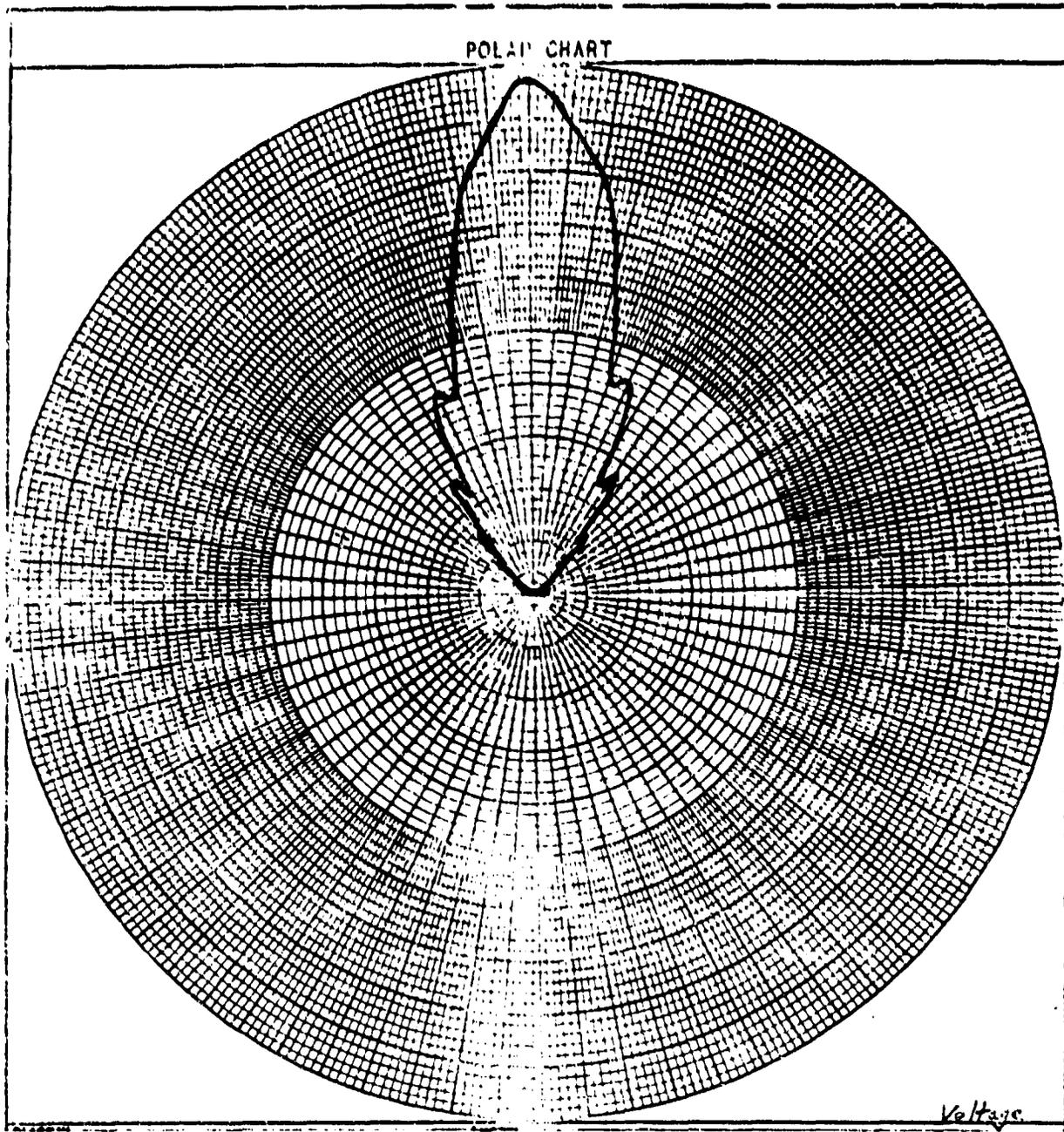


FIGURE 26. 11.0 GHz E-PLANE



**FIGURE 29. 11.0 GHz E-PLANE**

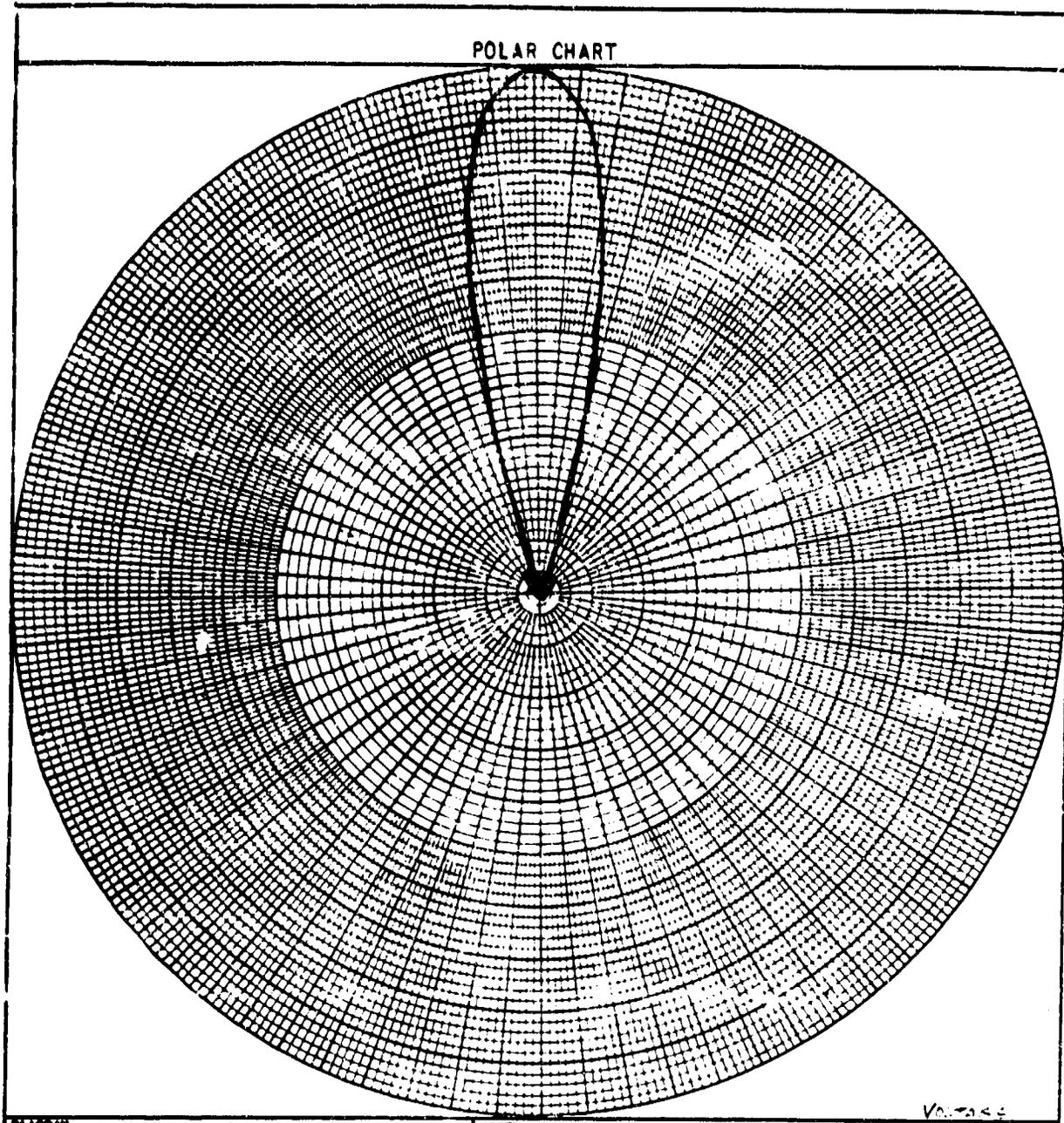


FIGURE 30. 12.0 GHz H-PLANE

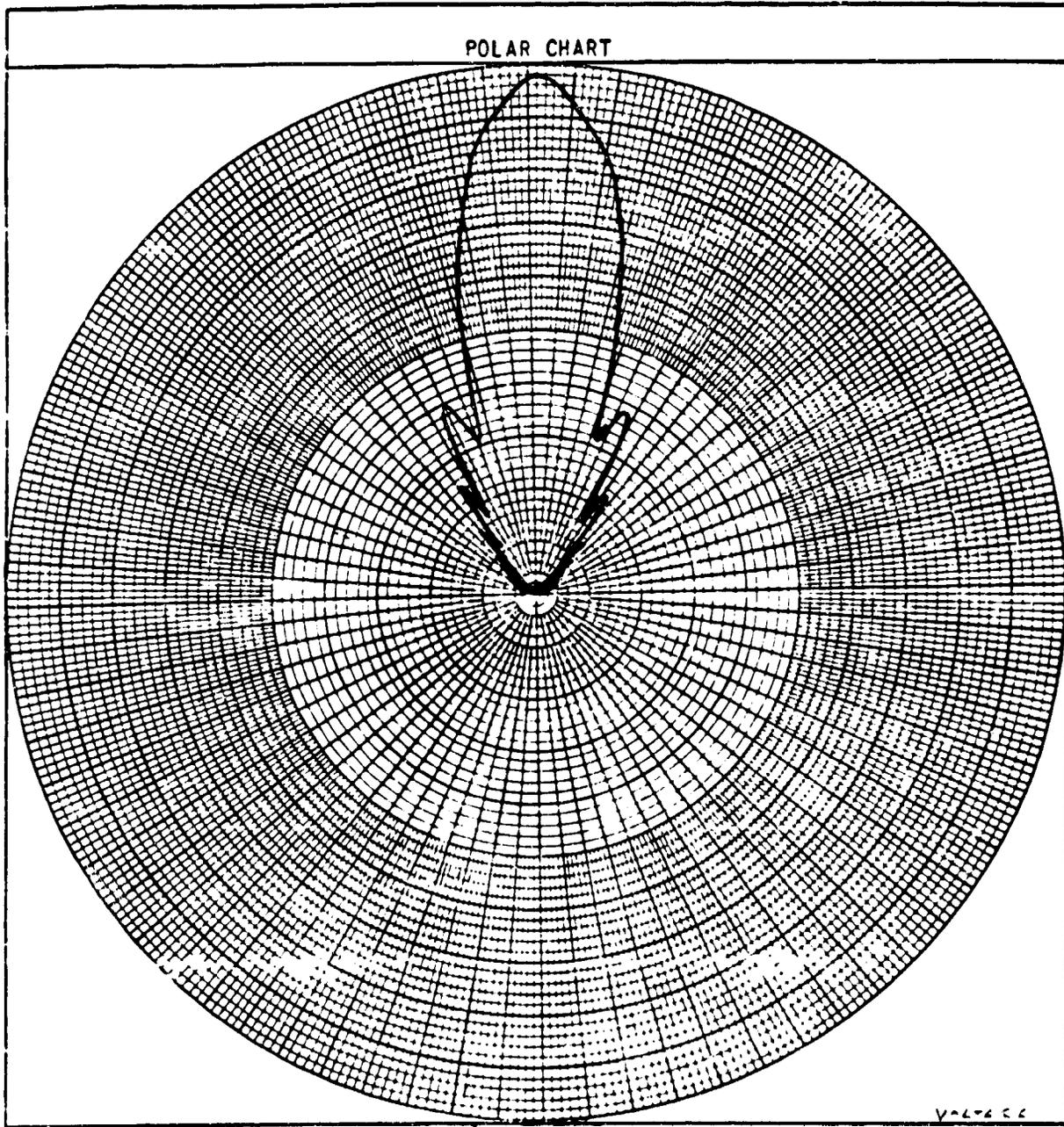


FIGURE 31. 12.0 GHz E-PLANE

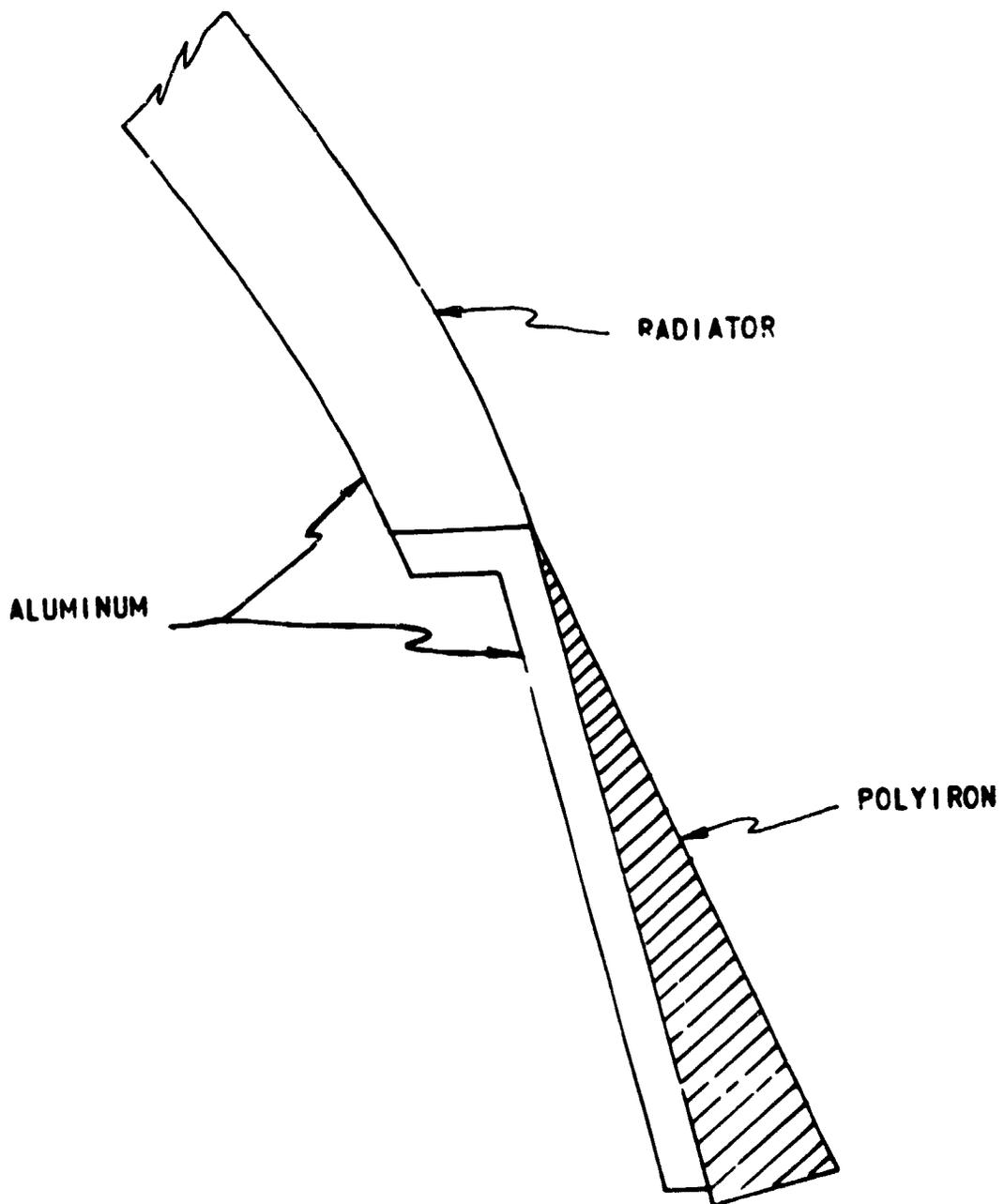


Fig. 32 Termination

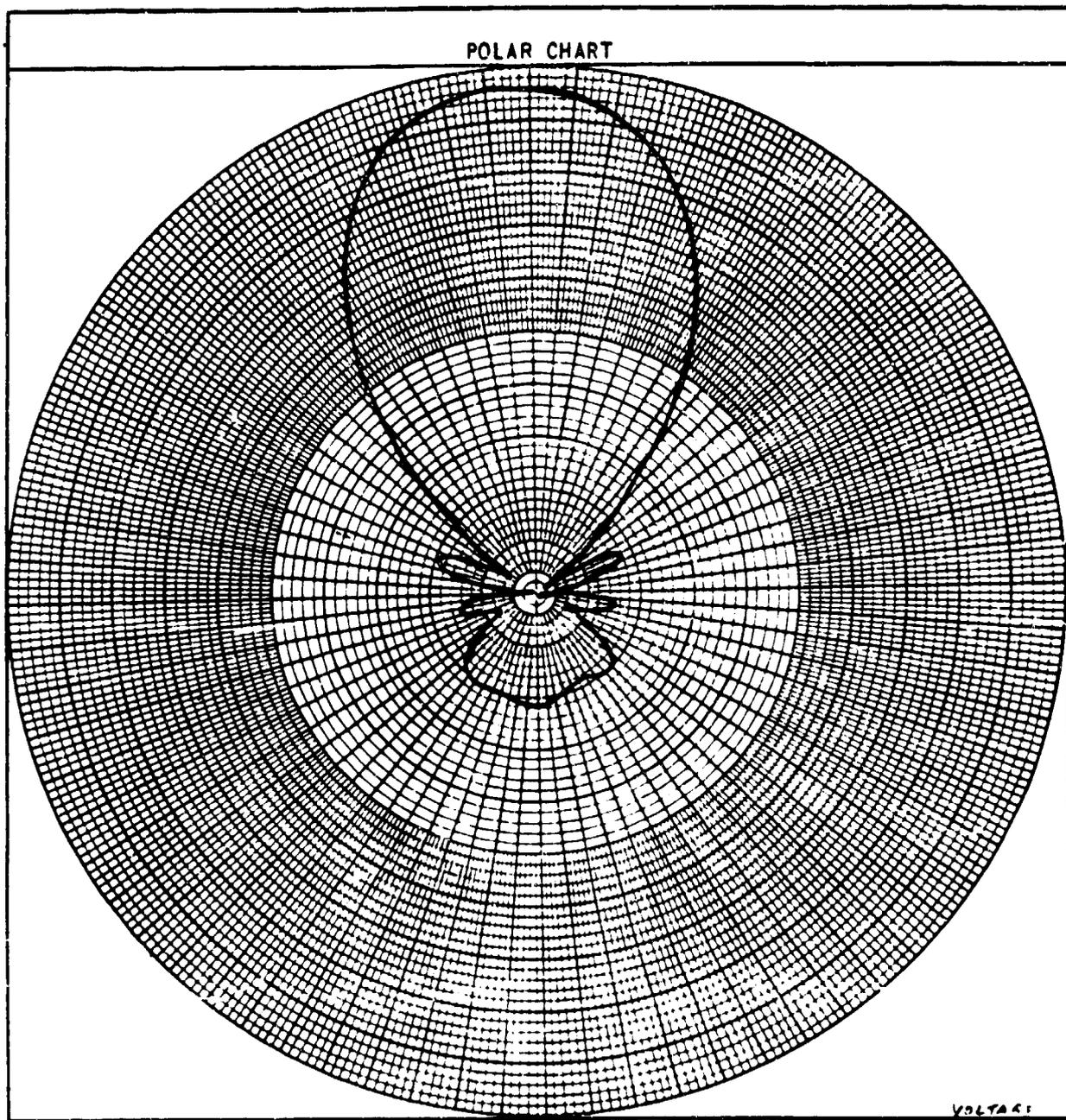


FIGURE 33. 1.0 GHz H-PLANE  
WITH TERMINATIONS

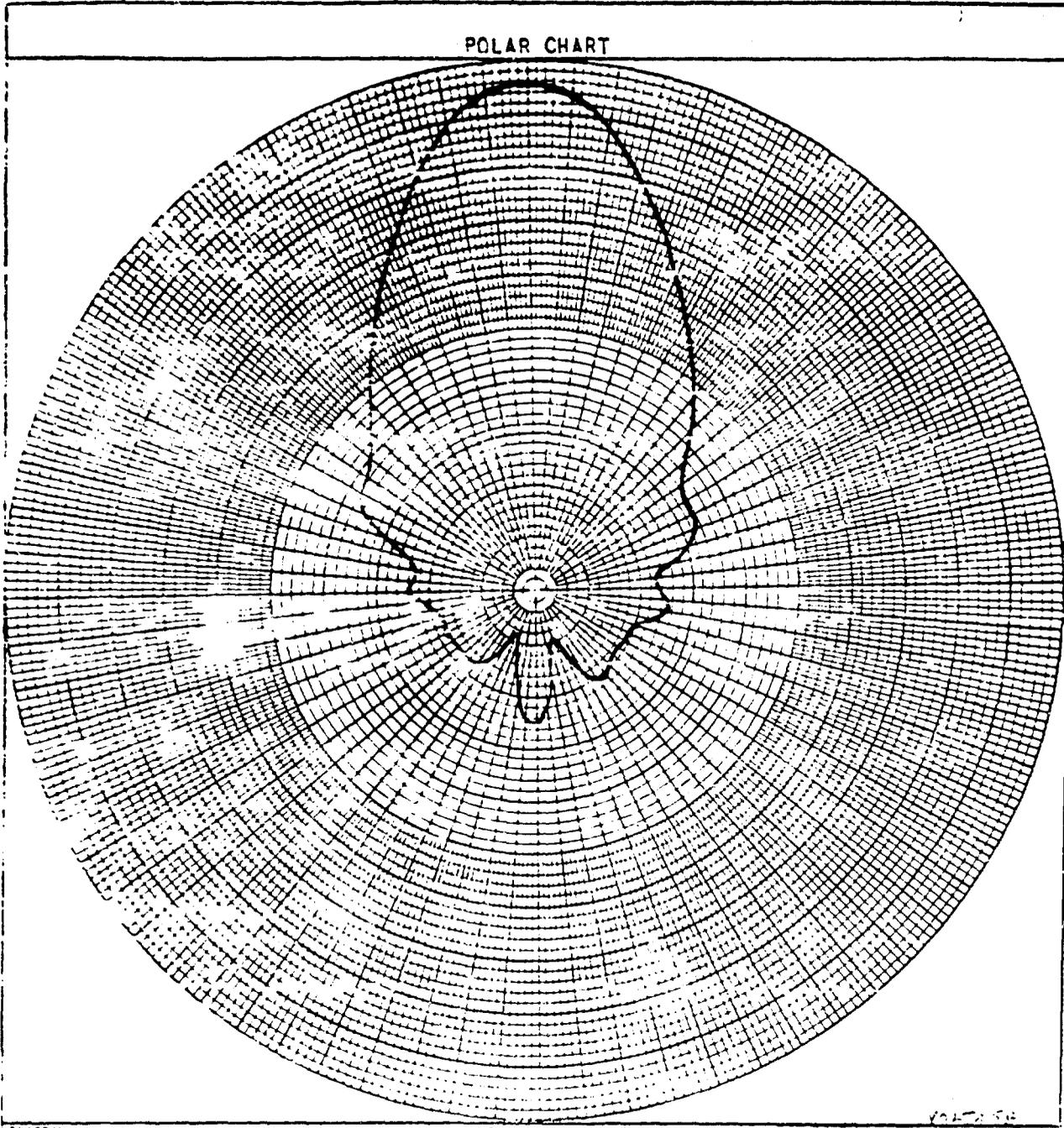


FIGURE 34. 1.0 GHz R-PLANE  
WITH TERMINATIONS

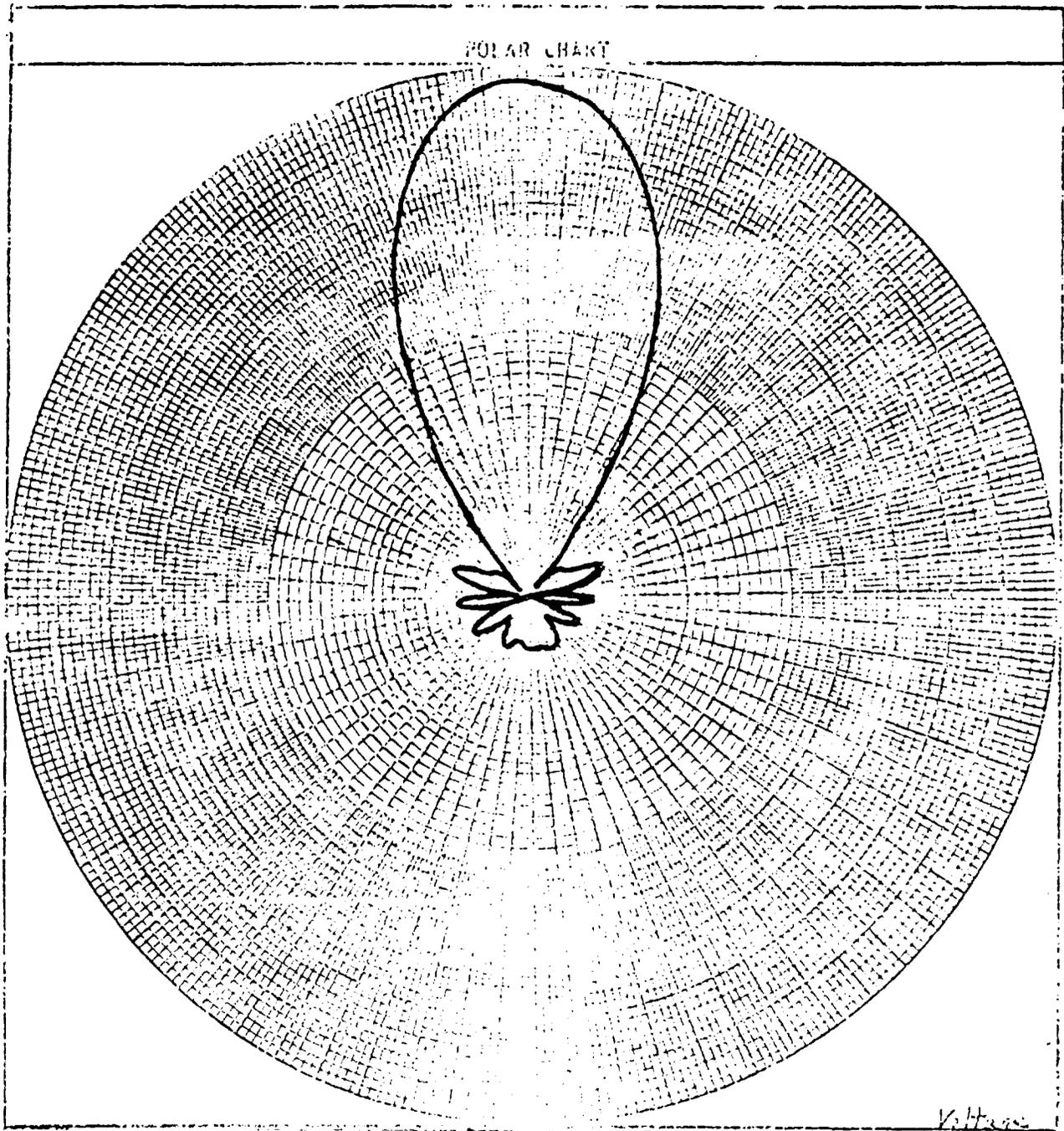


FIGURE 35. 1.5 GHz H-PLANE  
WITH TERMINATIONS

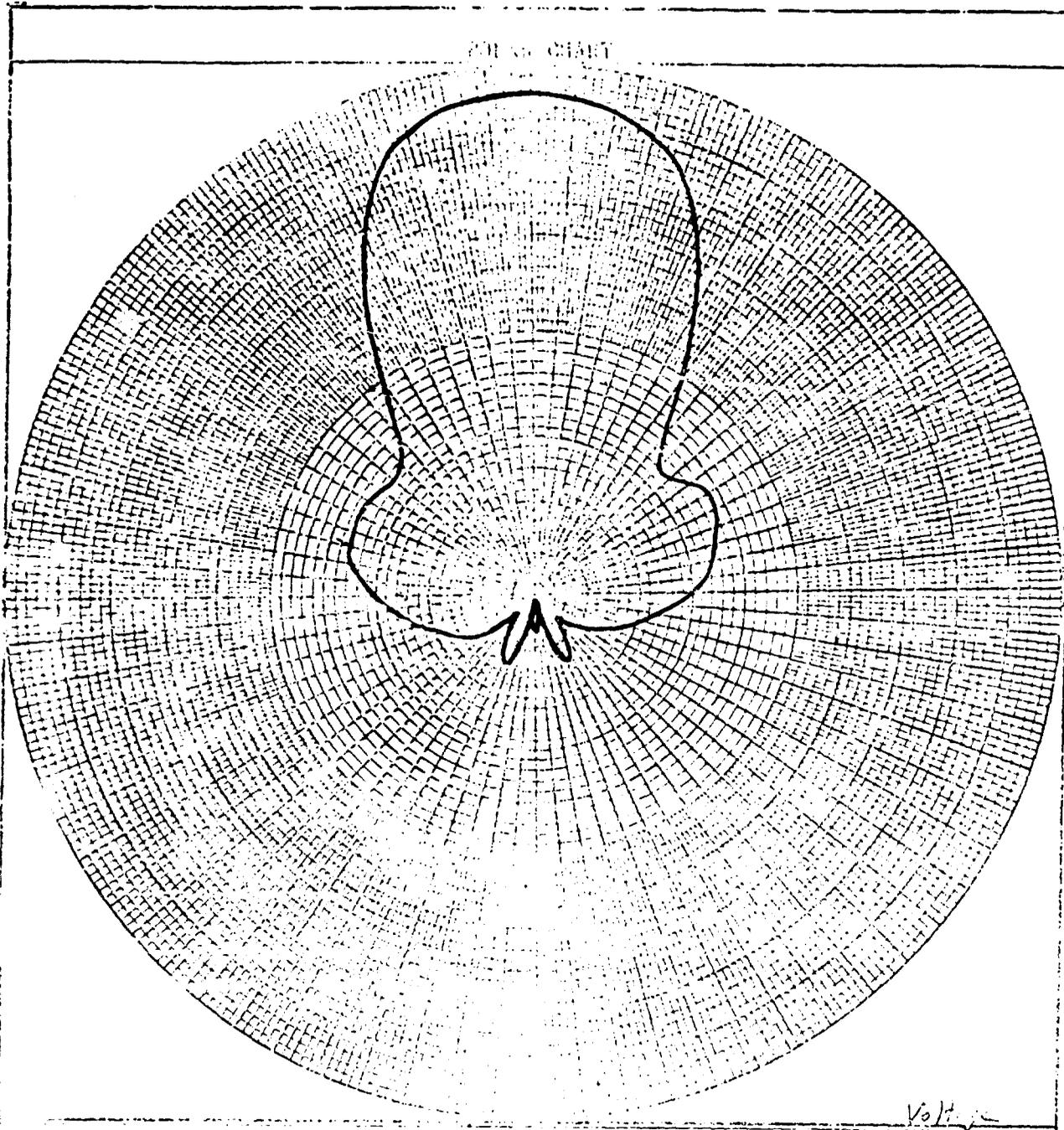


FIGURE 36. 1.5 GHz E-PLANE  
WITH TERMINATIONS

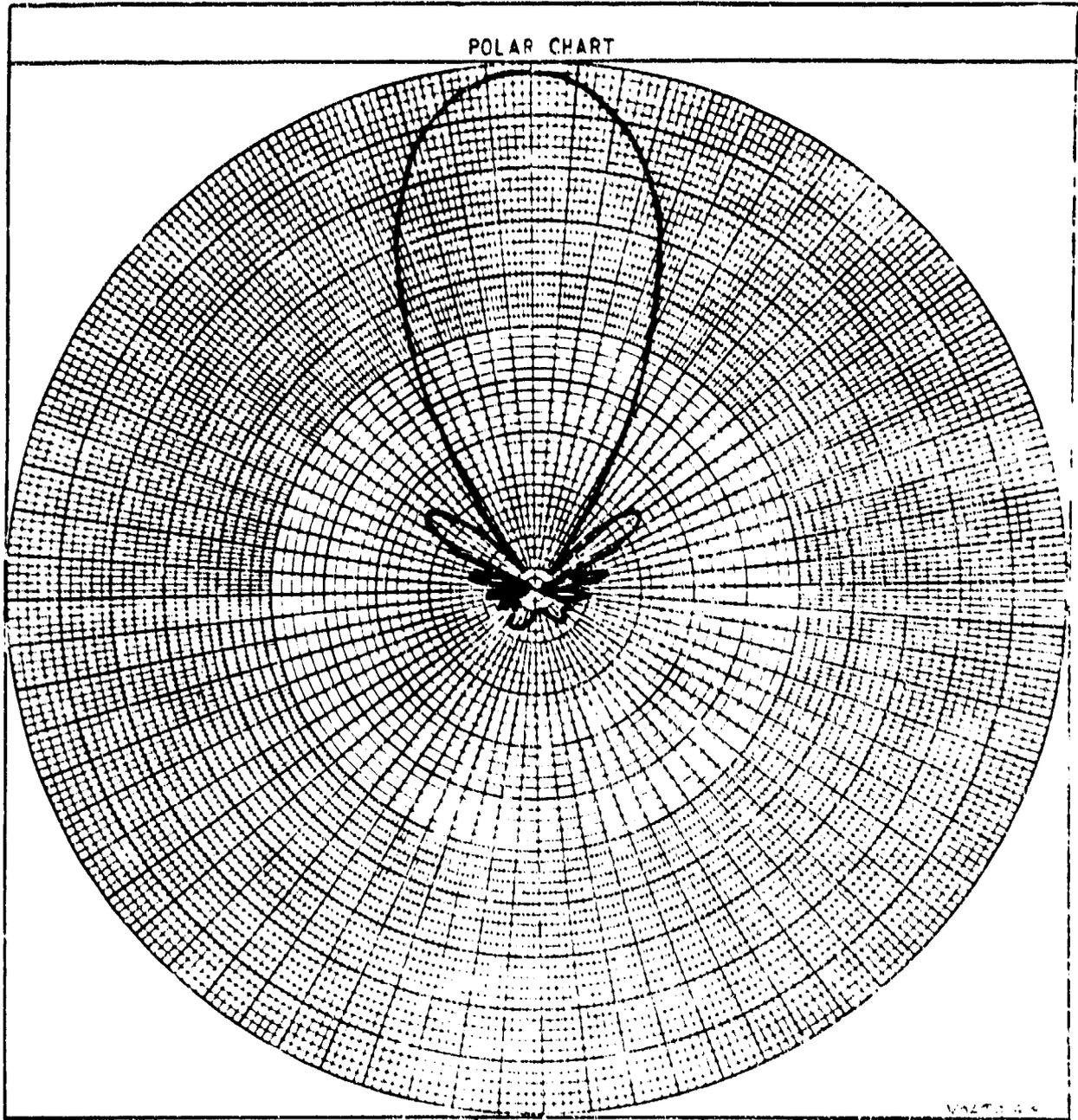


FIGURE 37. 2.0 GHz H-PLANE

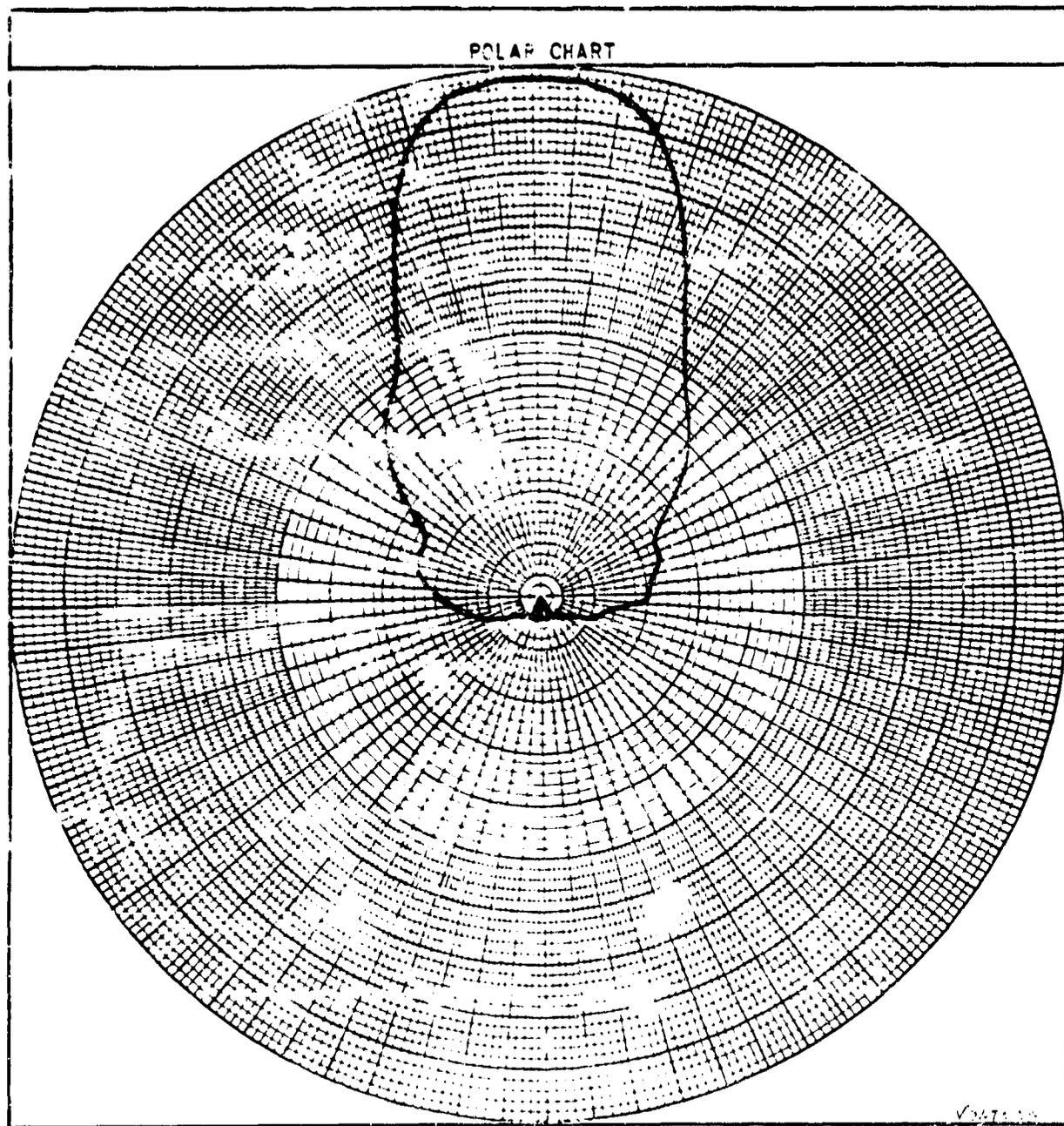


FIGURE 38. 2.0 GHz E-PLANE  
WITH TERMINATIONS

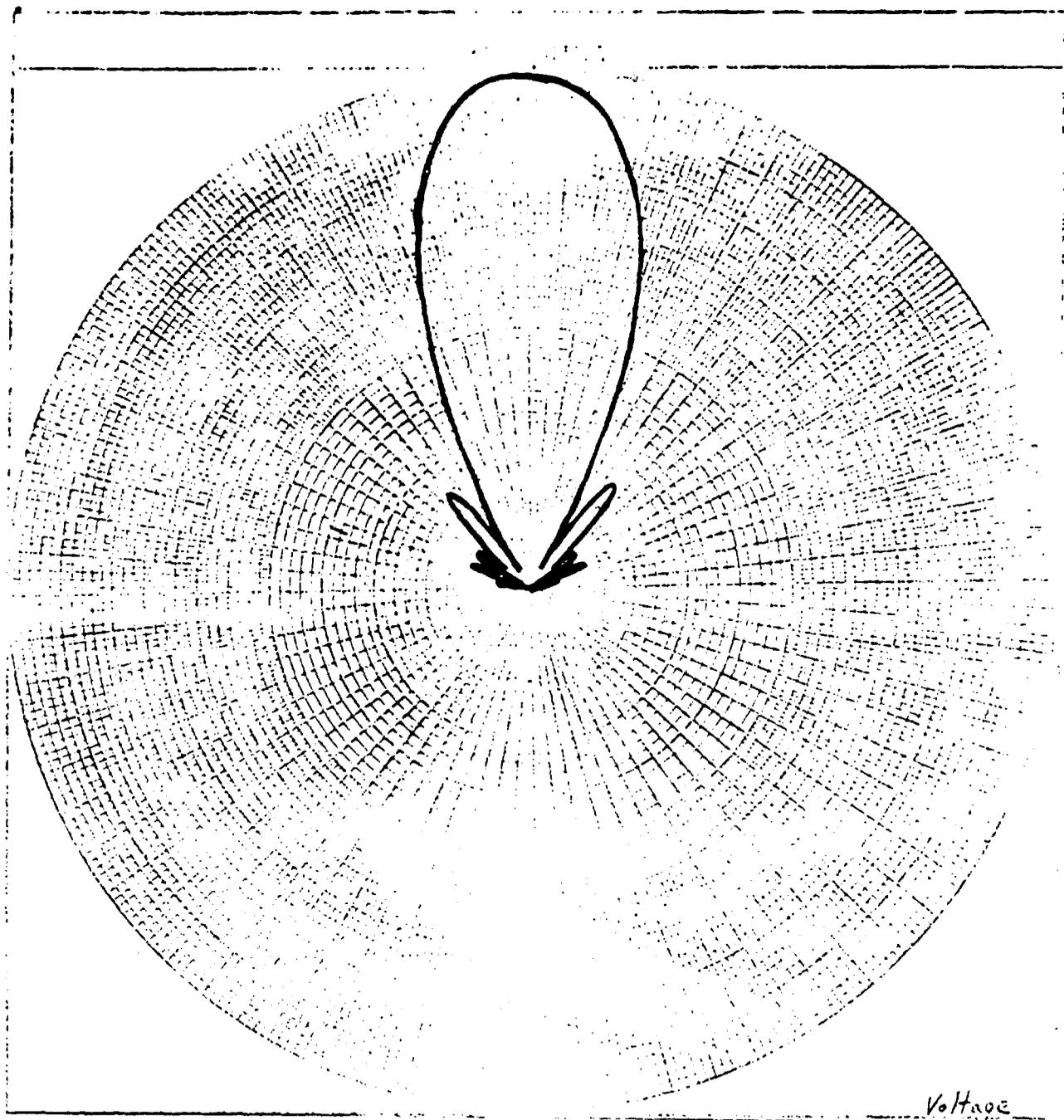


FIGURE 39. 3.0 GHz H-PLANE  
WITH TERMINATIONS

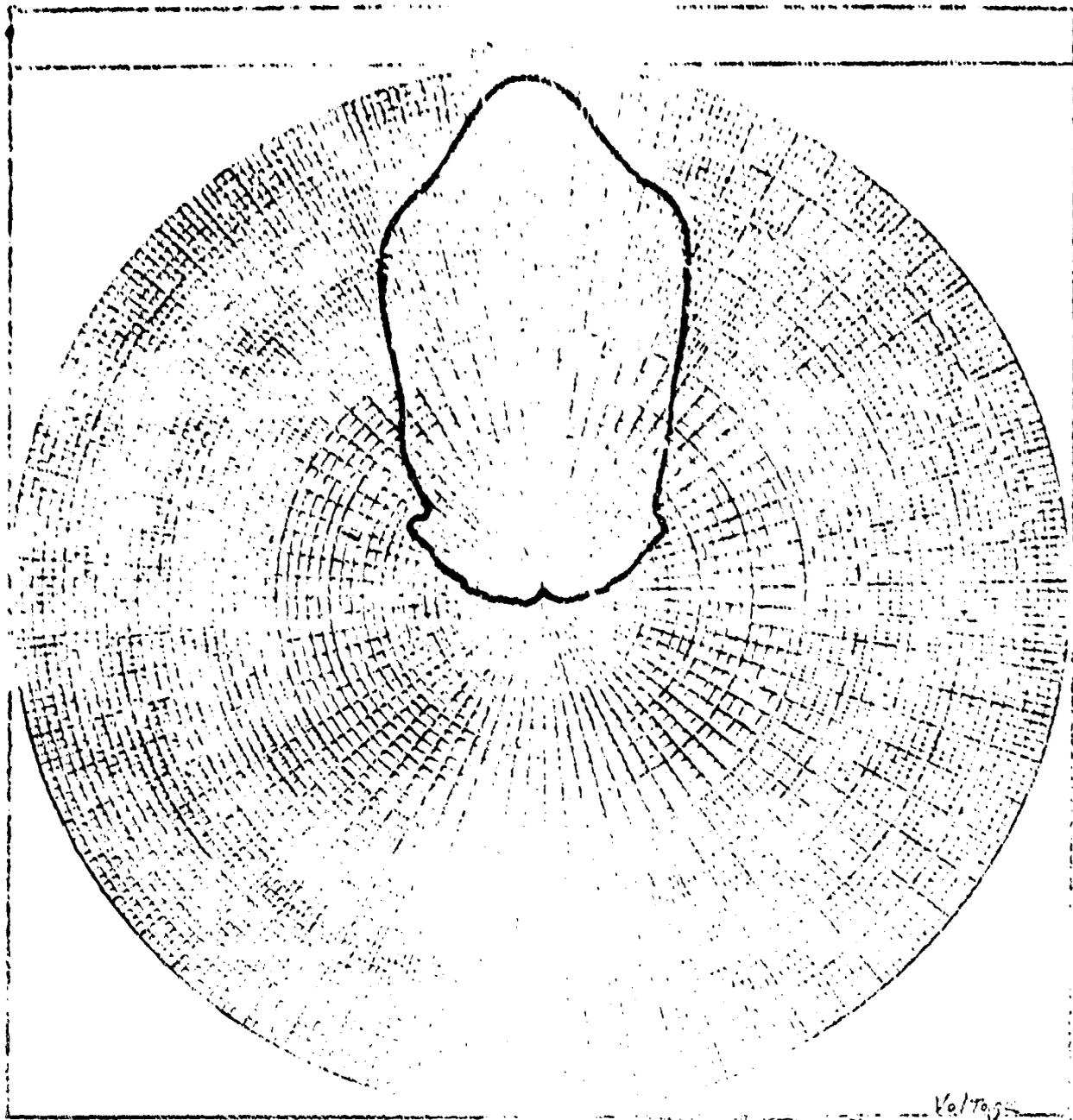


FIGURE 40. 3.0 GHz E-PLANE

WITH ENCLOSURE

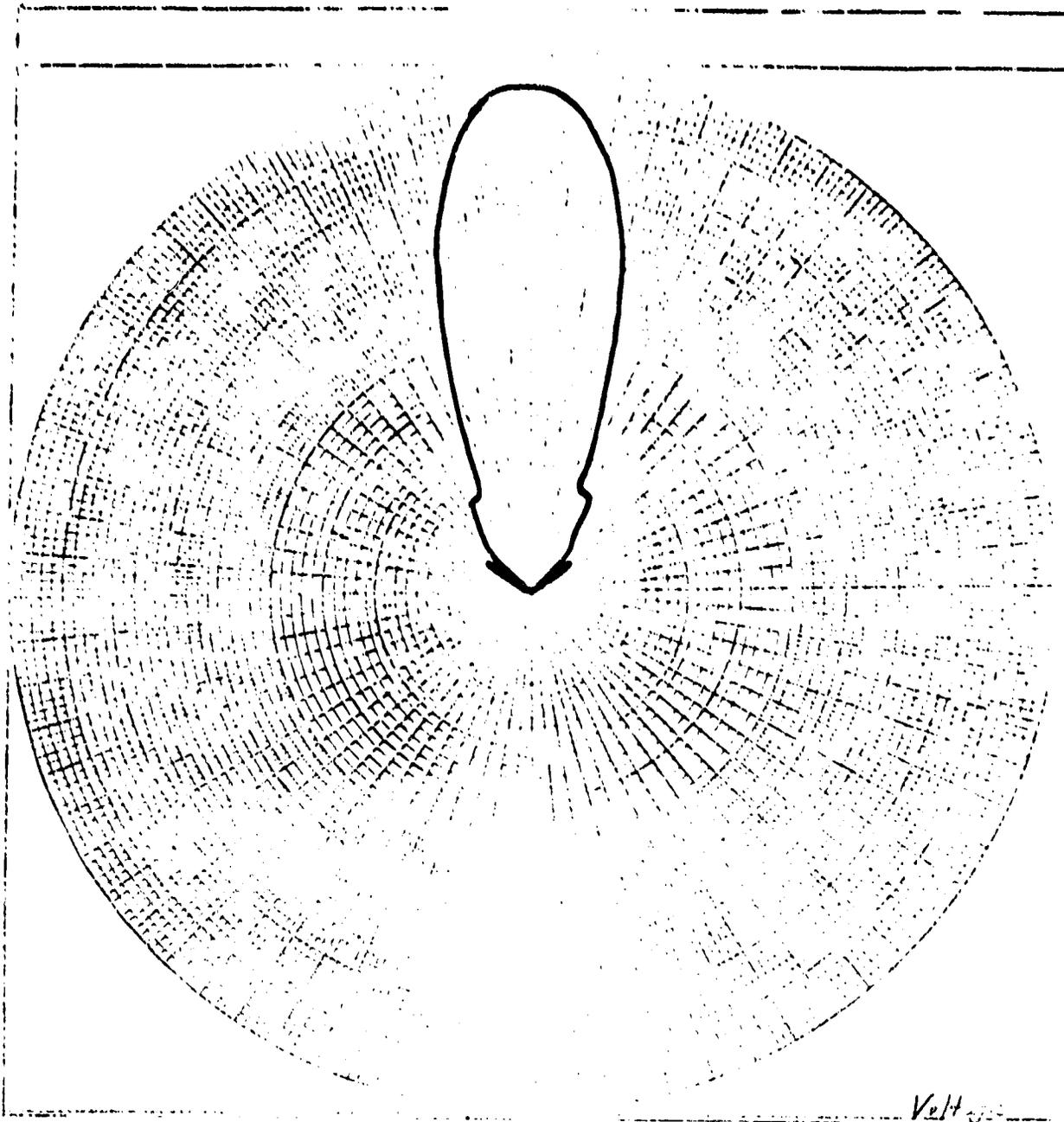


FIGURE A1. 4.0 GHz H-PLANE  
WITH TERMINATIONS

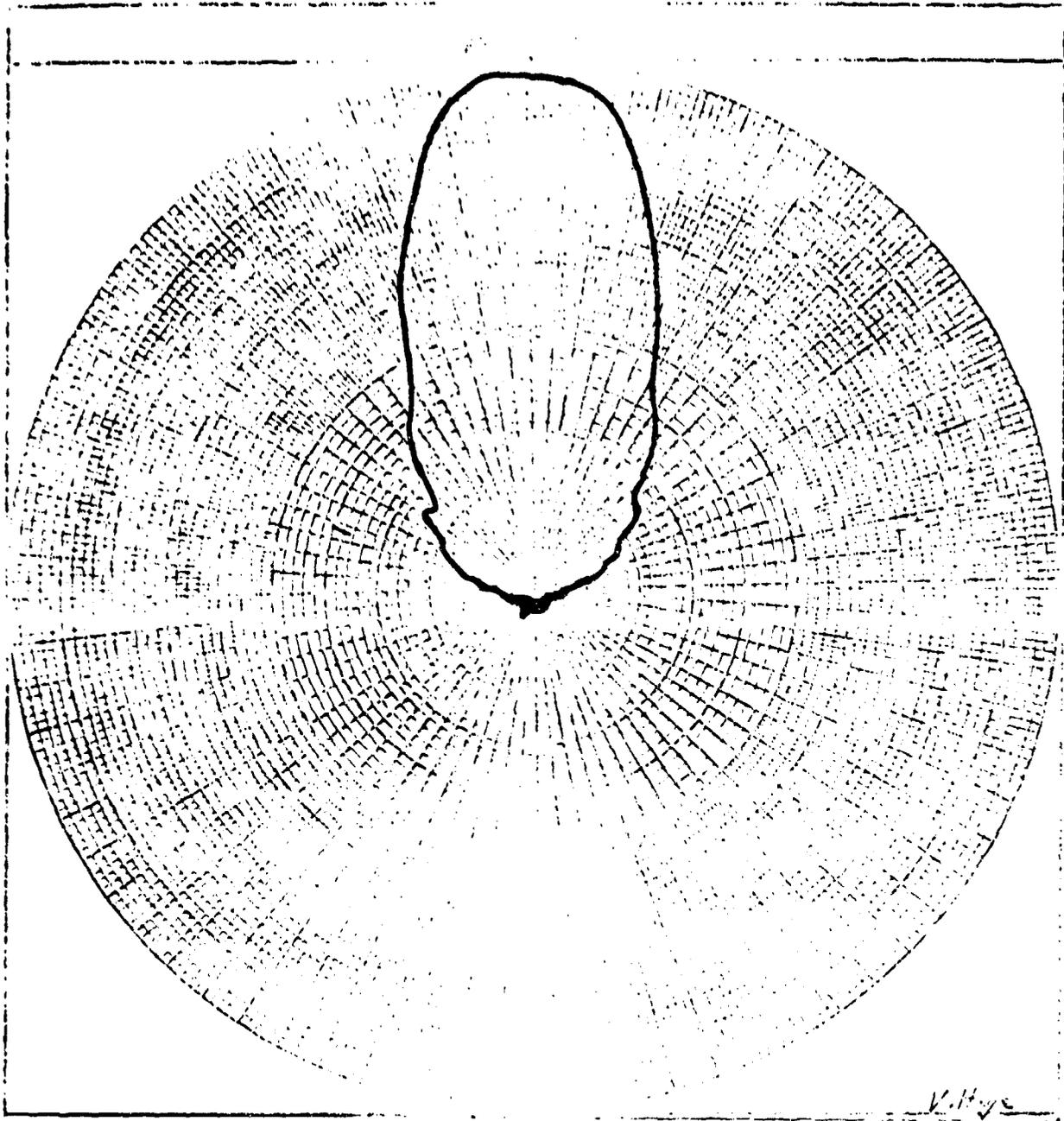


FIGURE 42. 4.0 GHz E-PLANE  
WITH TERMINATIONS

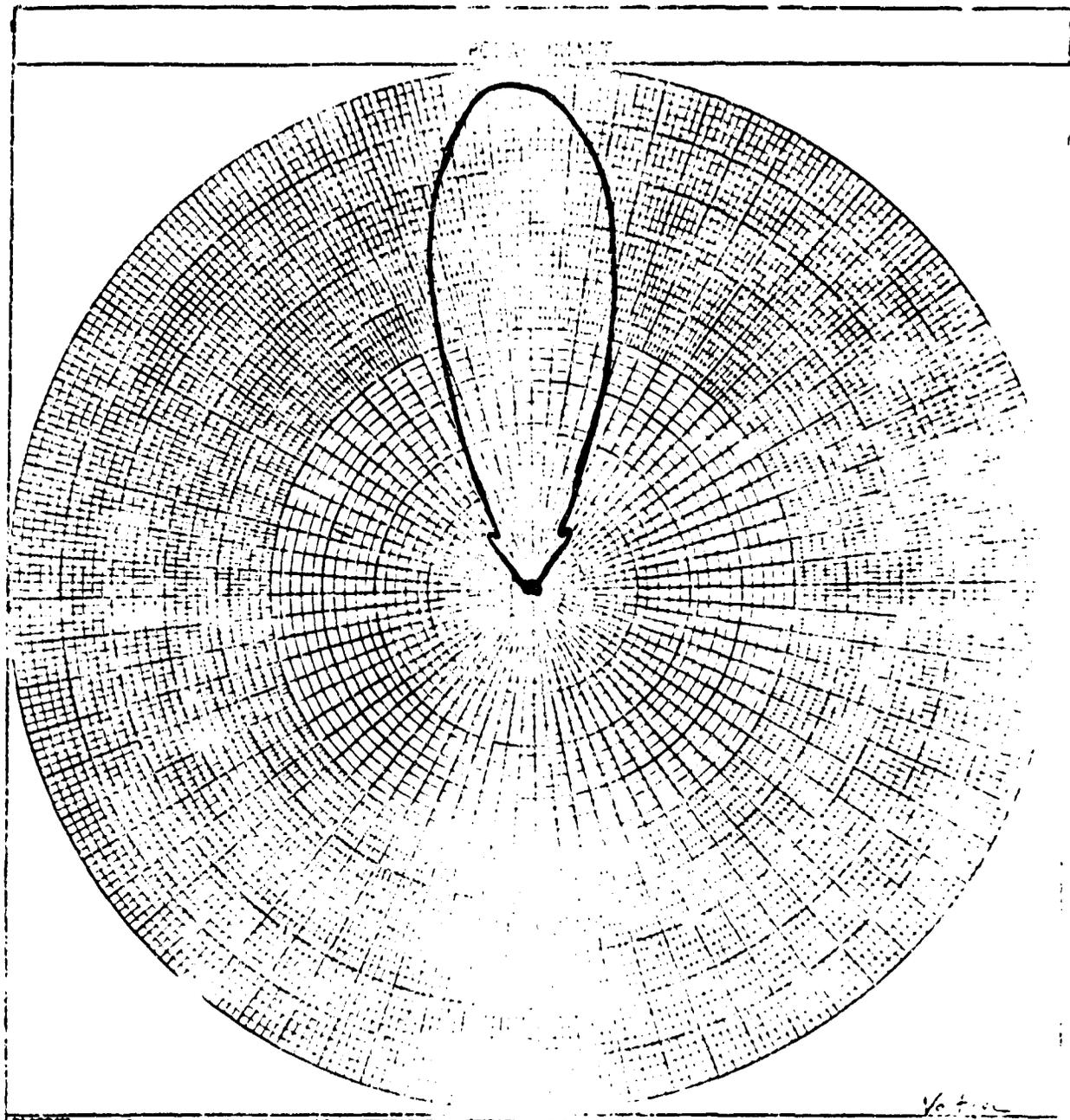


FIGURE 43. 5.0 GHz E-PLANE  
WITH TERMINATIONS

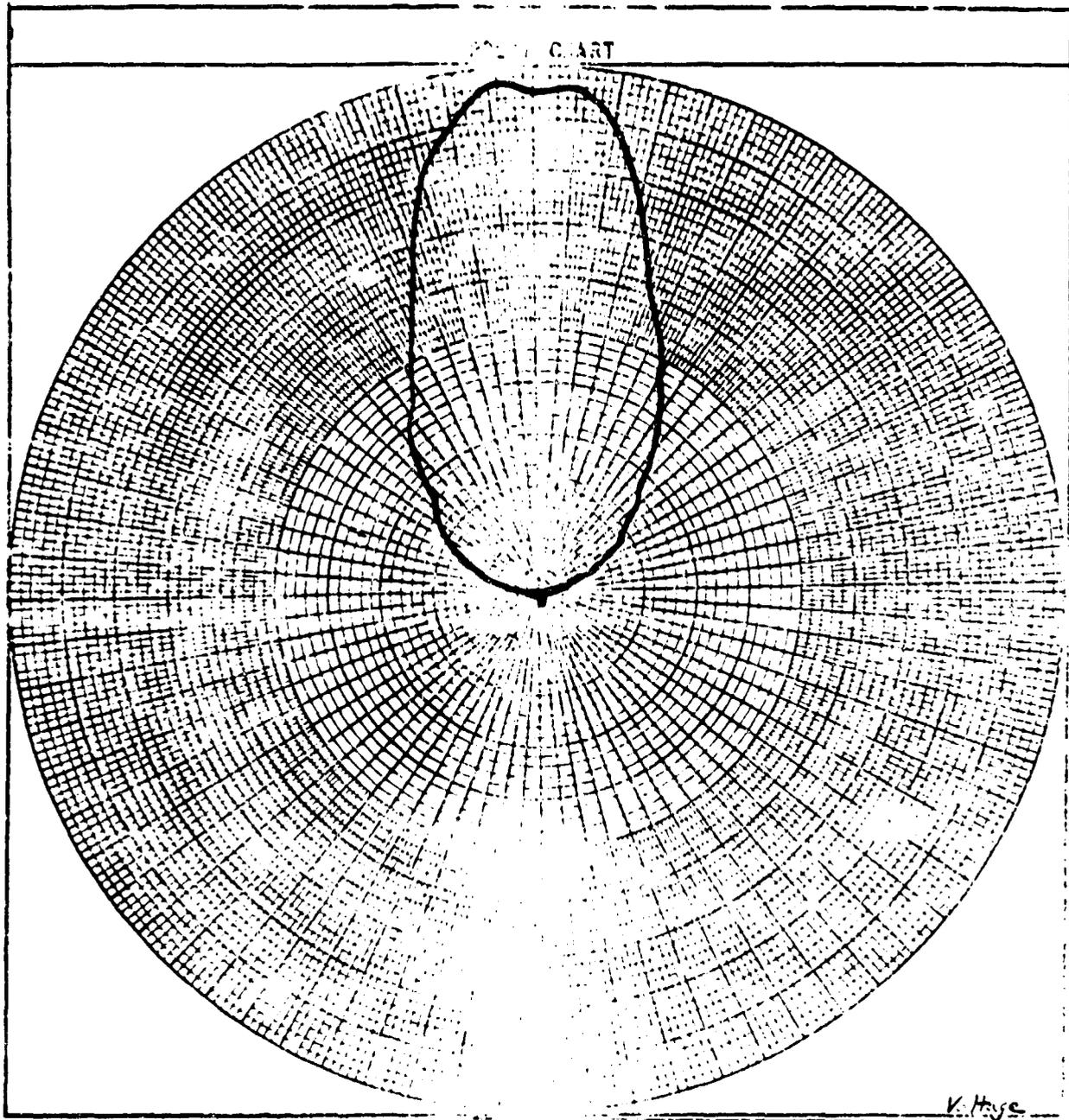


FIGURE 44. 5.0 GHz B-PLANE  
WITH TERMINATIONS

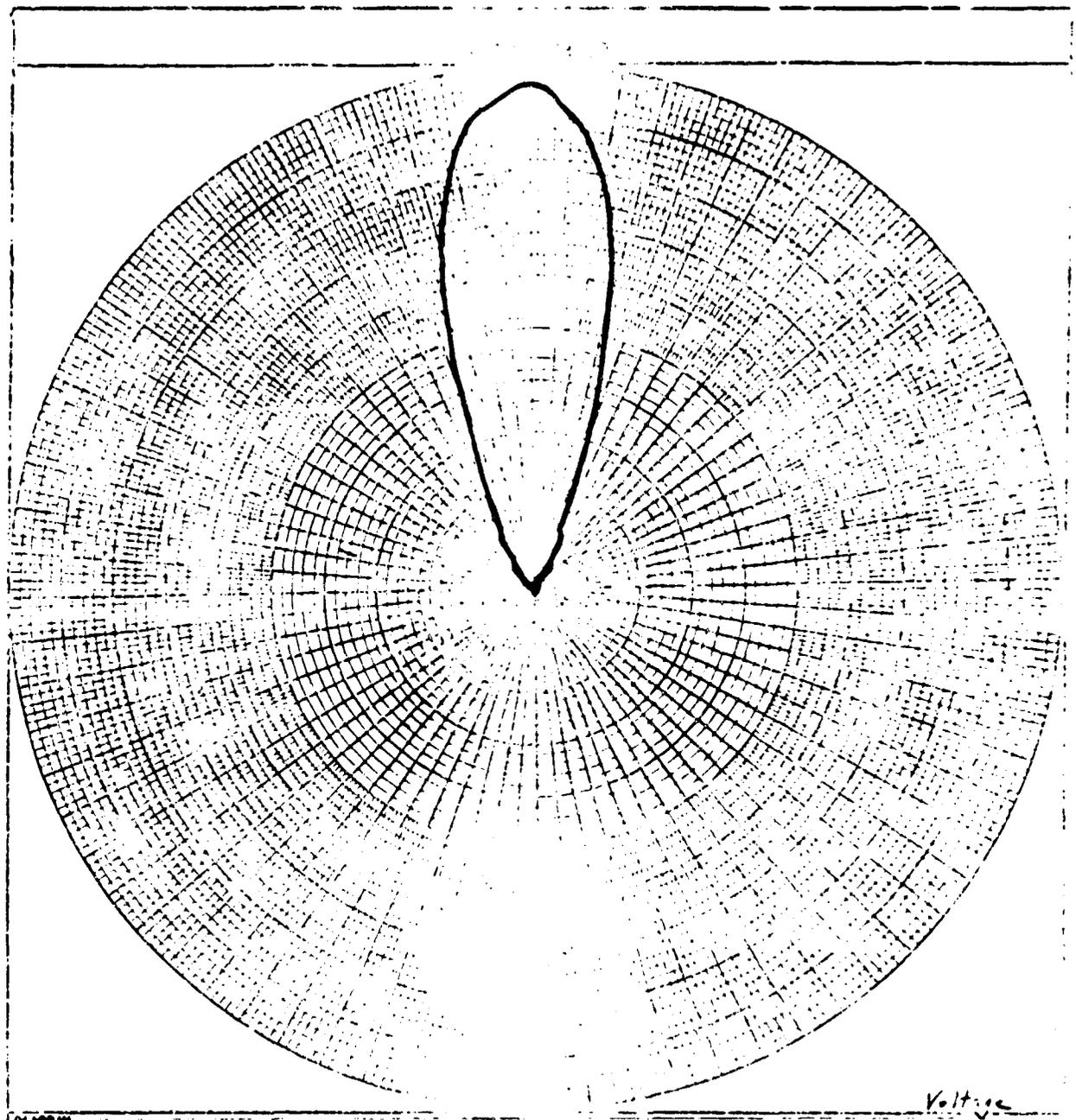


FIGURE 45. 6.0 GHz I-PLANE  
WITH TERMINATIONS

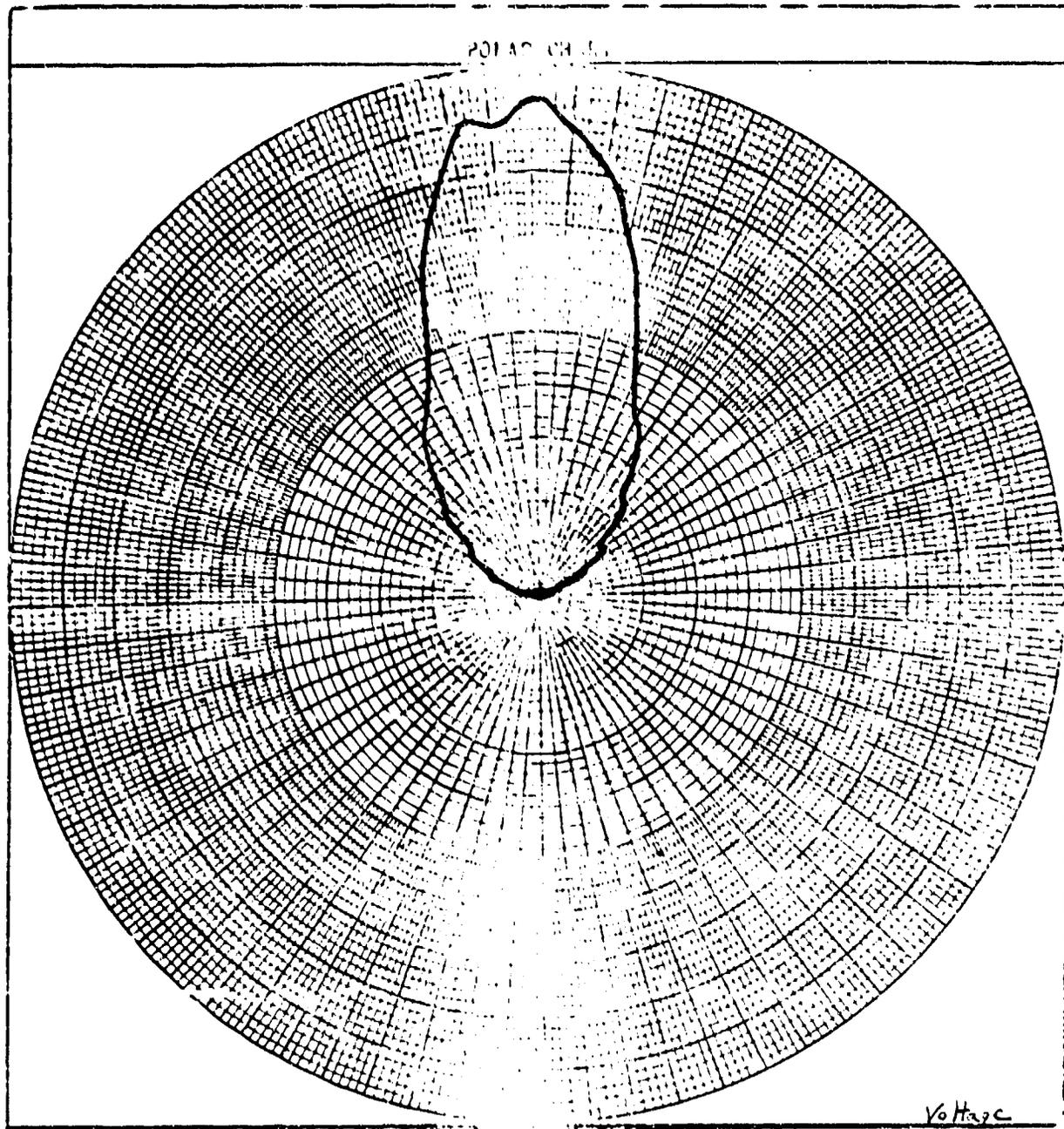


FIGURE 46. 6.0 GHz E-PLANE  
WITH TERMINATIONS

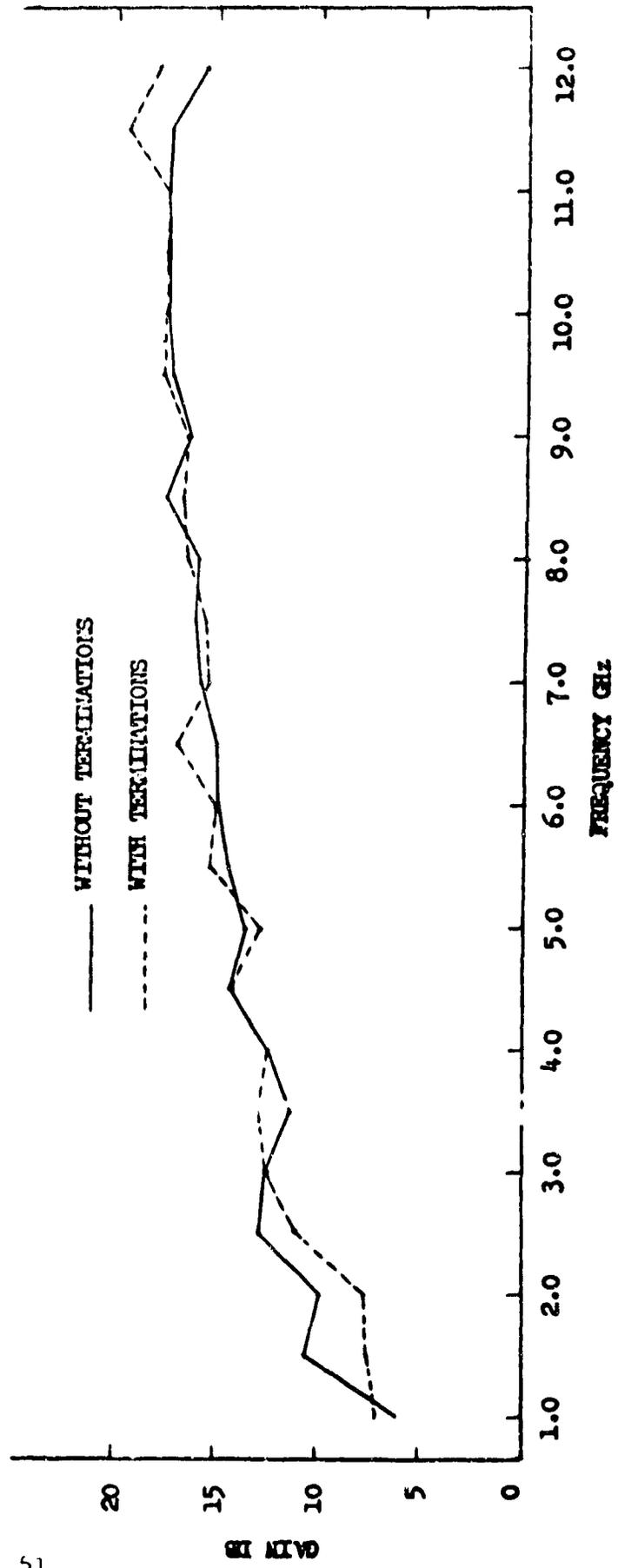


FIGURE 47. MEASURED GAIN

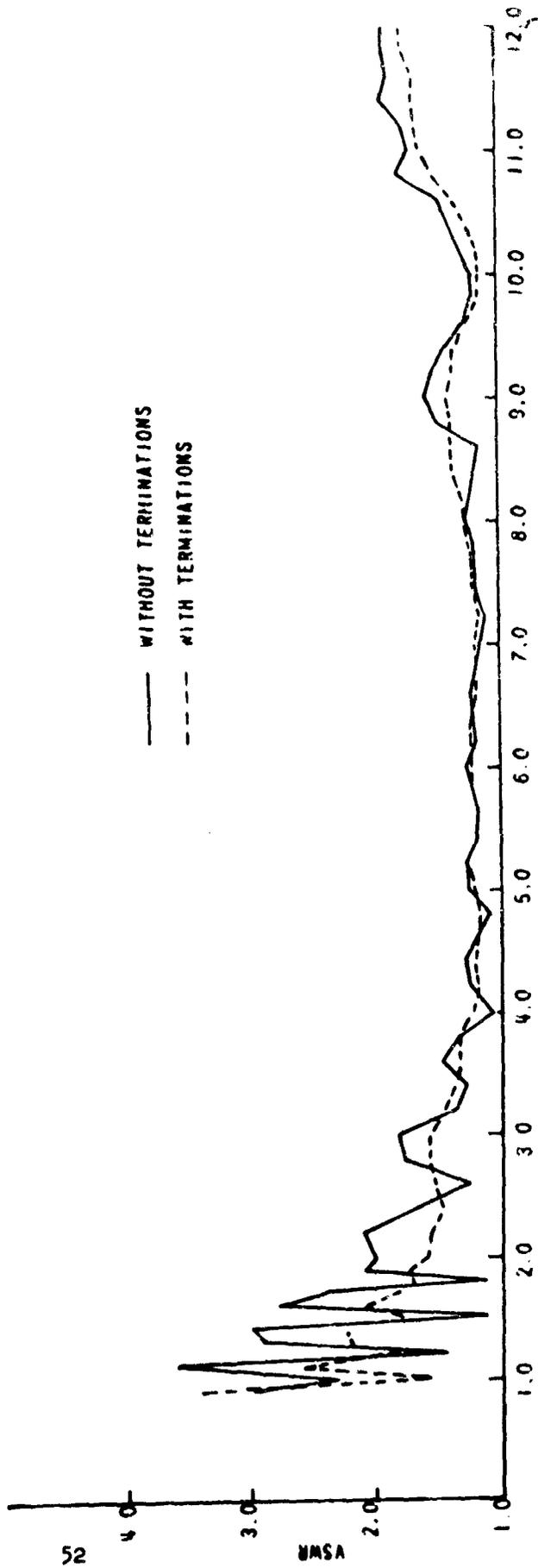


FIGURE 48. VSMR vs FREQUENCY

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13. ABSTRACT This report describes the development of a very broad-band, lightweight, linearly polarized, low silhouette antenna which operates over a bandwidth in excess of 12:1.  The antenna consists of a very short section of a double-ridged waveguide, with a coaxial input, which is used to launch a wave on logarithmically curved extensions of the ridges. Radiation pattern, gain and VSWR data for an experimental model, which operates over the 1 - 12 GHz frequency range, are presented.  A technique for reducing back and side radiation, as well as improving the VSWR performance at the lower end of the frequency range, is discussed and experimental results are included. These data show that a backward travelling wave, reflected from the tips of the radiators, leads to high back and side lobes and introduces violent oscillatory excursions into the VSWR curve at the lower end of the frequency range.		

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Antennas Broad Band Microwaves Low Silhouette						
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