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Broadband Antenna Techniques Study

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ABSTRACT

Work on the design, fabrication and testing of three broadband antennas is described. The antenna types are, 1) high-gain constant beamwidth, 2) omnidirectional and 3) loaded conical helix.

During this reporting period an experimental study has been conducted to determine methods by which the patterns of the ridged horn may be optimized. The results of this study have suggested that it would be desirable to lengthen the horn to minimize phase errors at the aperture. A fiberglass parabolic contour has been obtained from the plaster mold discussed in the second interim report. This surface has been metallized with silver paint and antenna patterns obtained. A typical set of H-plane pattern data for the asymmetrical parabolic reflector is presented in this report. These patterns demonstrate that a constant beamwidth can be achieved for a 7:1 frequency band.

An experimental study has also been conducted investigating several conical ground plane configurations. Both VSWR and pattern data have been obtained and are reported. An additional antenna type (the "cage antenna") has been considered during this interim. VSWR data for this antenna exhibits excellent characteristics over a 10:1 frequency band. The study of the manipole antenna has also been continued during this reporting period. An experimental study to investigate the mutual coupling effects between elements of the manipole has been initiated.

Many background experiments have been performed in the design of a circularly polarized antenna covering the frequencies 50 MHz to 1.1 GHz. A preliminary design of the prototype loaded log 'conical' helix has been made. This is a square pyramidal structure which is equivalent in operation to the log conical helix. The most critical aspect of the design has been the weight problem. Intensive effort is being placed upon weight reduction.

FOREWORD

This report was prepared by the University of Michigan Radiation Laboratory of the Department of Electrical Engineering under United States Army Electronics Command Contract No. DA 28-043 AMC-01263(E). The contract was initiated under United States Army Project No. 5A0-21101-A902-01-08, "Broadband Antenna Techniques Study". The work was administered under the direction of the Electronics Warfare Laboratory, Advanced Developments Technical Area at Fort Monmouth, New Jersey. Mr. Anthony DiGiacomo is the Project Manager and Mr. George Haber is the Contract Monitor.

The material reported herein represents the results of the preliminary investigation into techniques applicable to the design and development of broadband antennas.

The authors wish to acknowledge the contributions of Professor C. T. Tai and E. Andrade for their work on the omnidirectional antenna, and to K. Jagdmann, T. Lewis, A. Loudon and P. R. Wu for their contributions in obtaining much of the data presented in this report.

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I

INTRODUCTION

This contract is divided into three tasks; 1) broadband constant beamwidth high-gain antenna, 2) omnidirectional broadband antenna and 3) broadband loaded conical helix.

Under Task 1, a high-gain antenna is to be developed that covers the frequency range 1 - 10 GHz. The beamwidth is to vary less than 2:1 such that a relatively constant gain of 20 db above an isotropic source is achieved with a VSWR less than 3:1 with respect to a 50 ohm load. The investigation is to include a theoretical and experimental study of broadband, constant beamwidth, high-gain antennas. Electronic switching, electromechanical or mechanical motion to effect the constant beamwidth characteristics of the antenna are not to be considered. As a result, the constant beamwidth characteristics must be achieved employing antenna beam shaping techniques.

Under Task 2, a broadband omnidirectional antenna of the monopole or dipole configuration is to be developed which will be operational over the frequency range of 100 MHz to 1 GHz having a VSWR of less than 3:1 with respect to a 50 ohm load. It is desired that the configuration be as thin as possible and its overall length comparable to that of a half-wave dipole at the low end of the frequency band (100 MHz). The maximum diameter of the configuration is to be less than 20".

The objective of Task 3 is to design a circularly polarized antenna covering the frequencies of 50 MHz to 1.1 GHz, with a 2:1 reduction in size, and a maximum weight of 20 lbs. The antenna is to be a loaded conical helix. Various loading techniques are to be investigated including ferrites and dielectrics. The conical sections of the antenna may be truncated with the possibility that one may be set within the other. Cross-over networks which cause different sections to operate at different frequencies may be required.

Preliminary work on these tasks was reported in the first two quarterly reports, (Ferris et al, 1965a, Ferris et al, 1965b).

II

BROADBAND CONSTANT BEAMWIDTH HIGH-GAIN ANTENNA

A broadband high-gain antenna is being developed to satisfy the following requirements: 1) the gain of the antenna is to be approximately 20 db above an isotropic source and is to be constant over a frequency range of 1:10 GHz, 2) the beamwidth variation is to be less than 2:1 within the frequency band, 3) the VSWR is to be less than 3:1 with respect to 50 ohms, and 4) the antenna is to be capable of receiving any component of linear polarization.

During the period covered by this report, an experimental study of the pattern characteristics of the ridged horn was performed and tests were made to determine the optimum orientation of the ridged horn when feeding the parabolic reflector.

2.1 Ridged Horn Pattern Study

Details of the design and construction of the ridged horn are discussed in the First Quarterly Report (Ferris, et al 1965a), and will not be considered further here. The VSWR characteristics of the ridged horn over a frequency range of 1:10 GHz were also presented in the first quarterly report; they are also presented in this report for completeness (Fig. 1).

During this reporting period a more extensive study of the pattern characteristics of the horn have been made. The coordinate system established is shown in Fig. 2. Both E and H-plane pattern data has been recorded at several frequencies within the operating band of 1:10 GHz. Figure 3 illustrates the E and H-plane 10 db beamwidth variations for the horn. From Fig. 3 one can see that at the high end of the band (9 - 10 GHz) the 10 db beamwidths (as a function of frequency) tend to broaden with increasing frequency. This is caused because the horn is electrically short, therefore, causing a phase distortion at the aperture of the horn.

Although this horn is physically of the same length of a commerical waveguide gain standard X-band horn (of NRL design), it does not exhibit the same electrical characteristics because of the ridges in horn region. The widening of the pattern results from the electric field being confined between the ridges well into the throat of the horn. Since the electric field is confined to the ridged region of the horn it generates a circular wavefront because of the curvature of the ridges. Therefore, to obtain a uniform phase front at the aperture of the ridged horn, one must either employ a longer horn or some form of lens as noted by Walton and Sundberg, (1964). Another area to note in the curves of Fig. 3 is the variation in the 10 db beamwidth of the E-plane patterns at approximately 5 GHz. The beamwidth is decreasing from

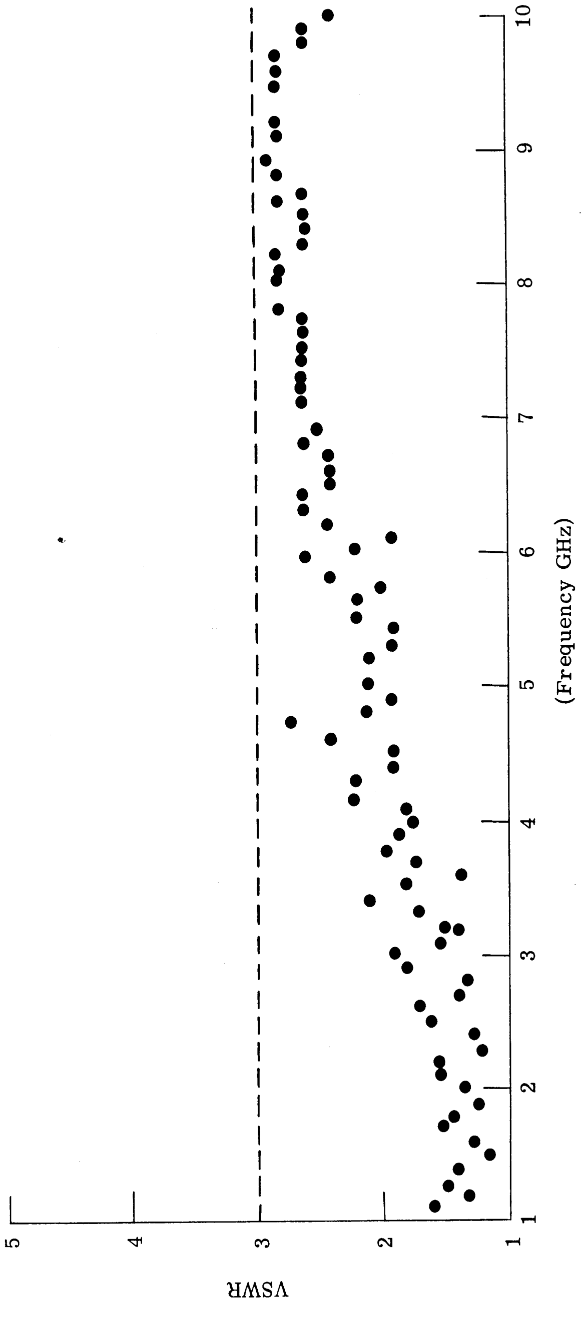


FIG. 1: 10:1 RIDGED HORN VSWR VS FREQUENCY

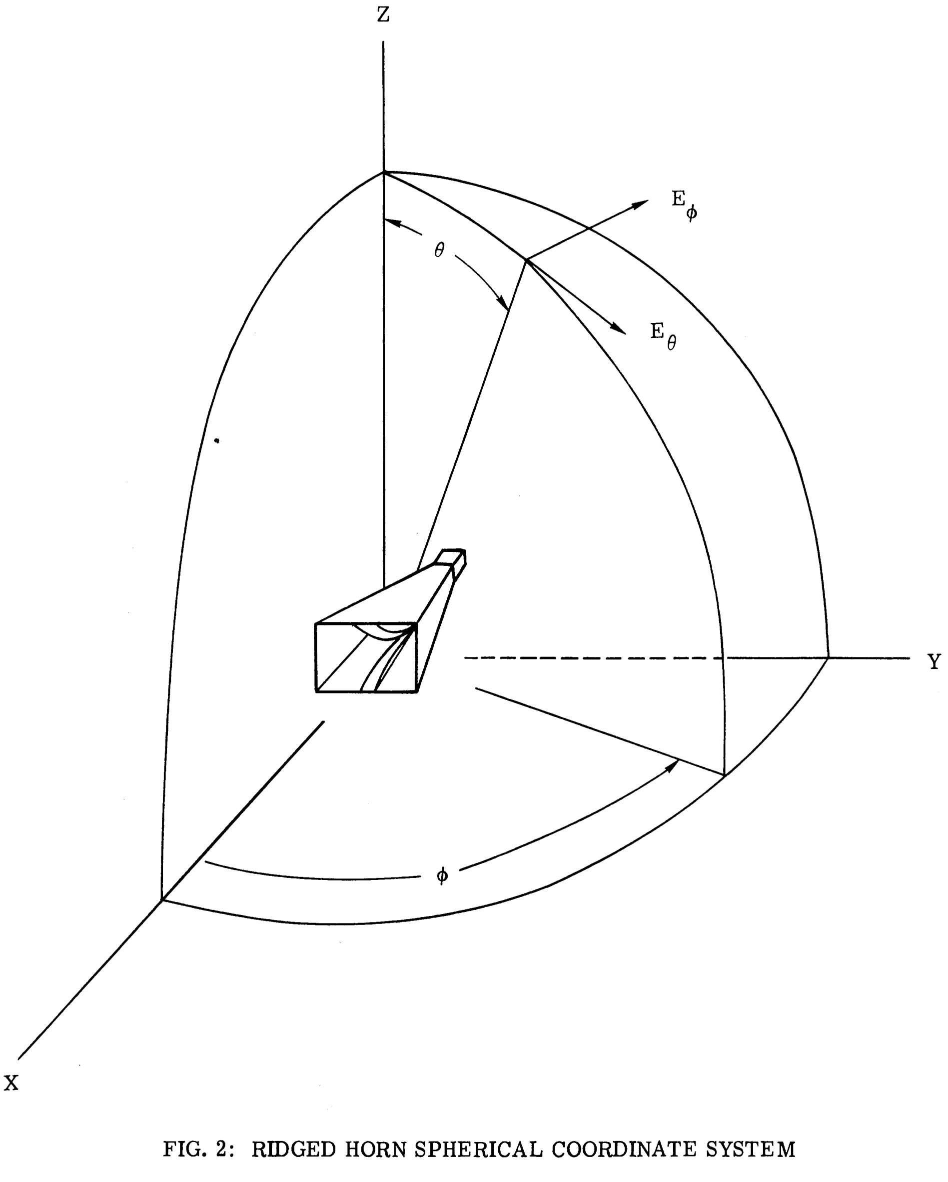


FIG. 2: RIDGED HORN SPHERICAL COORDINATE SYSTEM

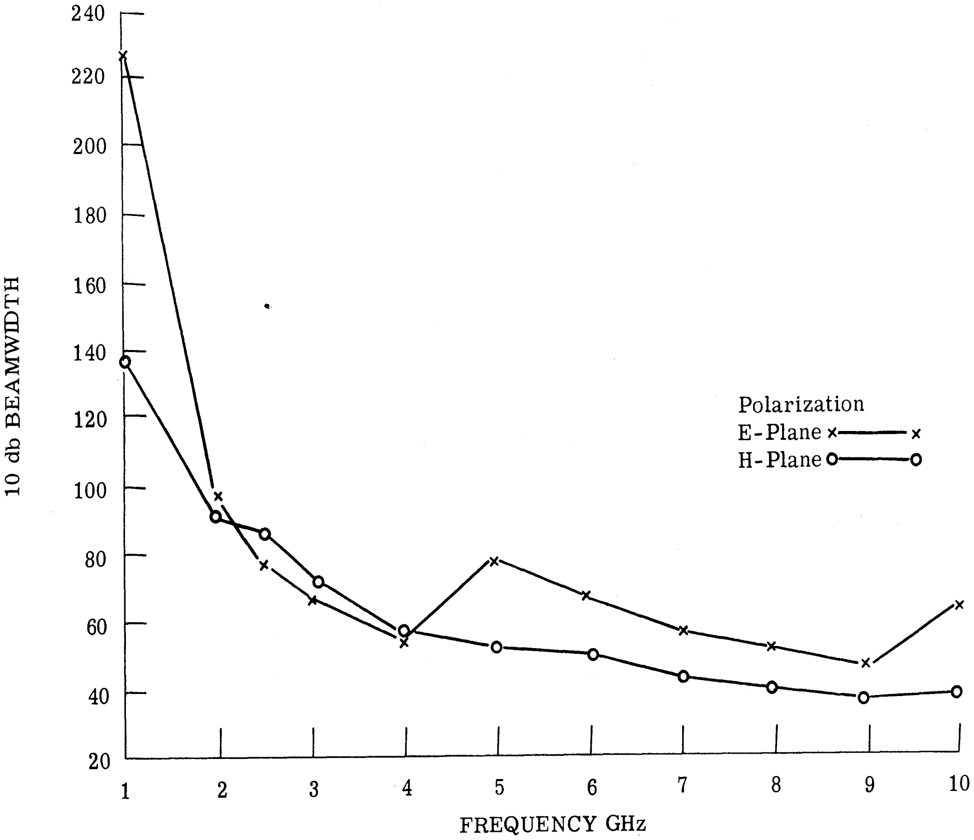


FIG. 3: 10 db BEAMWIDTH VS. FREQUENCY
(1 - 10 GHz Ridged Horn)

1 - 4 GHz, however, at 5 GHz the pattern suddenly broadens. This broadening in the E-plane patterns is caused by the high side-lobe levels associated with this polarization; see Figs. 4 - 14. The cause for the high side-lobe levels in the E-plane is the uniform amplitude distribution associated with the TE_{10} waveguide field distribution in the E-plane. The side-lobes associated with the E-plane of the ridged horn are higher than those of conventional horns (-13 db) because of phase distortions noted above.

Improved pattern characteristics are observed for the H-plane (Figs. 15 - 25). The H-plane patterns of the ridged horn are of a higher quality than the E-plane patterns because of cosine amplitude distributions associated with the TE_{10} waveguide field distribution in the H-plane. However, in general the pattern characteristics of the ridged horn are of a poorer quality than those of conventional horns because of the phase distortions noted above.

The effects of placing flanges or an extension on the ridged horn to improve its pattern characteristics was considered during this reporting period. Both the two and one inch flanges shown in Fig. 26 and the two inch extension shown in Fig. 27 were used. Figure 28 is a plot of the 10 db beamwidth versus frequency with the two inch flange at the aperture of the ridged horn. In general the pattern characteristics were very similar to those noted for the ridged horn without the flange. The broad 10 db beamwidth noted for the E-plane at 3 GHz is caused because of high side-lobe levels at this frequency. The effects of the one inch flange and two inch extension are illustrated in Fig. 29 and 30 respectively. Generally the data for these two conditions did not significantly differ from that of the horn alone. The data of Fig. 30 does show that if the physical length of the ridged horn is extended, the broadening of the beamwidth at the higher frequencies (9 - 10 GHz) can be minimized. It was felt that the improvements gained in designing and building a second ridged horn did not warrant the expense and time required; consequently the present horn has been used as the feed for the asymmetrical parabolic reflector.

2.2 Asymmetrically Fed Parabolic Reflector

The coordinate system employed for the asymmetrical parabolic reflector is shown in Fig. 31.

The present asymmetrical reflector consists of a solid metallic reflecting surface with no provisions for incorporating a constant beamwidth reflecting surface. A solid metallic surface is achieved by applying conductive silver paint to the surface of the fiberglass parabolic contour obtained from the mold discussed by Ferris

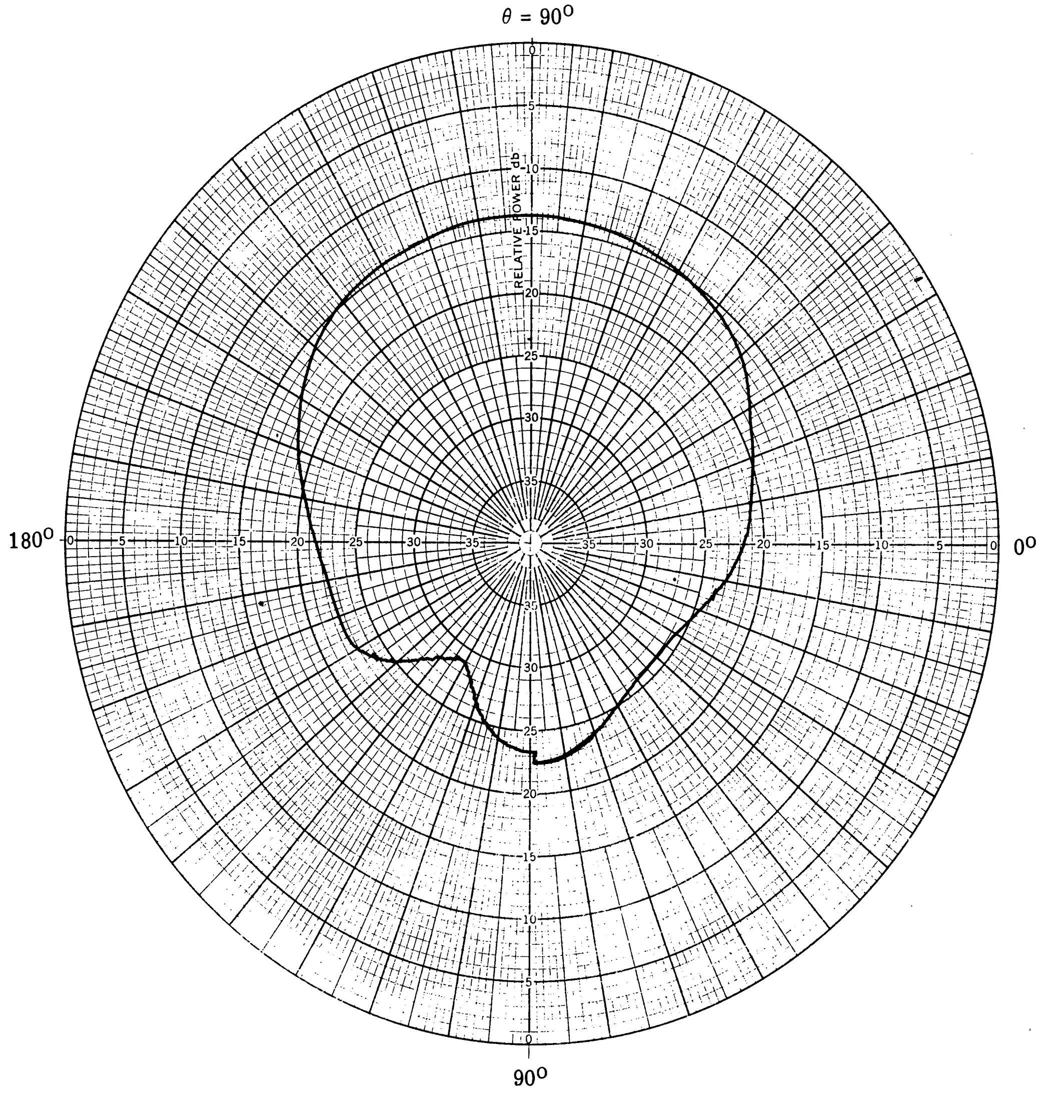


FIG. 4: E-PLANE POLARIZATION OF RIDGED HORN AT 1 GHz

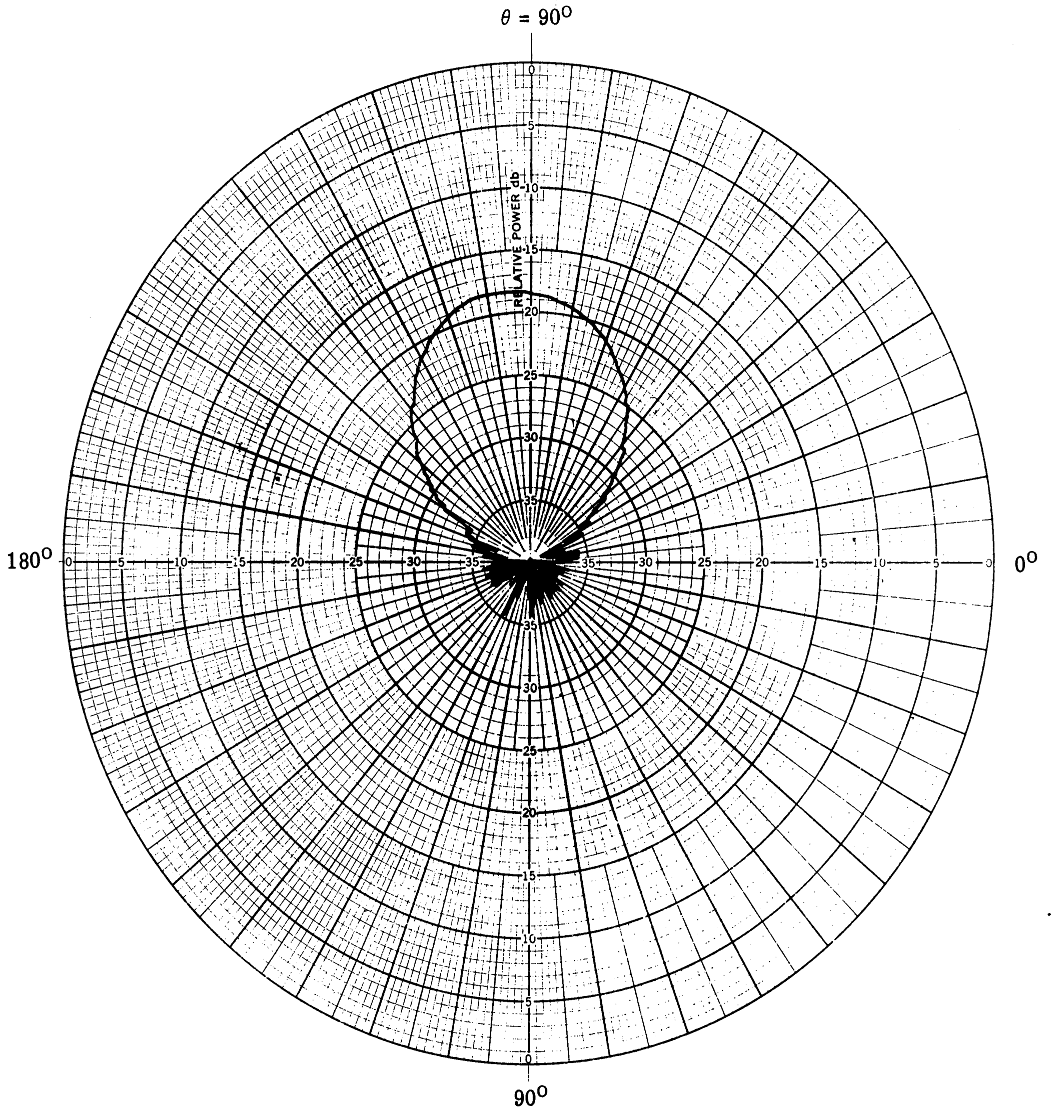


FIG. 5: E-PLANE POLARIZATION OF RIDGED HORN AT 2.1 GHz

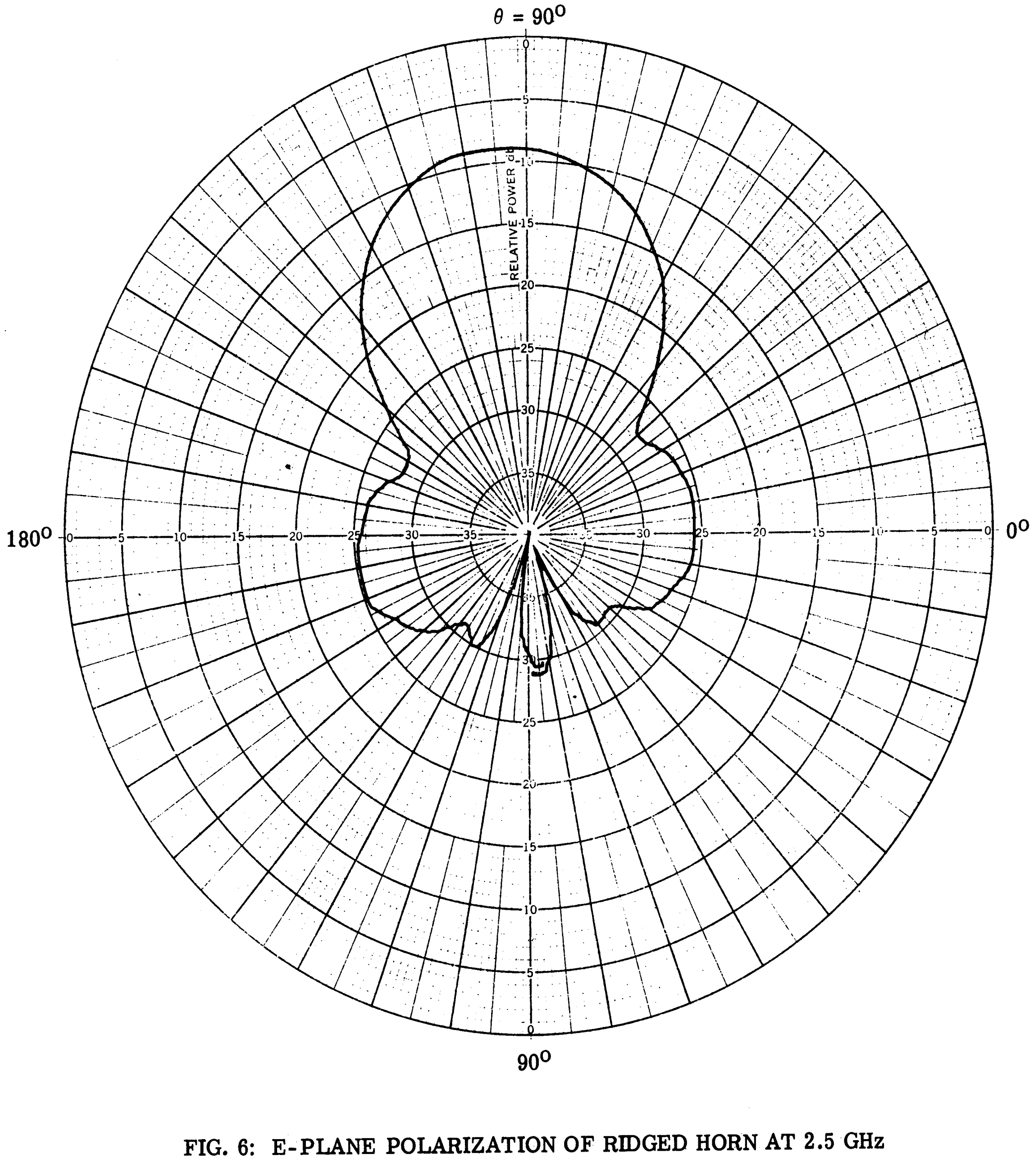


FIG. 6: E-PLANE POLARIZATION OF RIDGED HORN AT 2.5 GHz

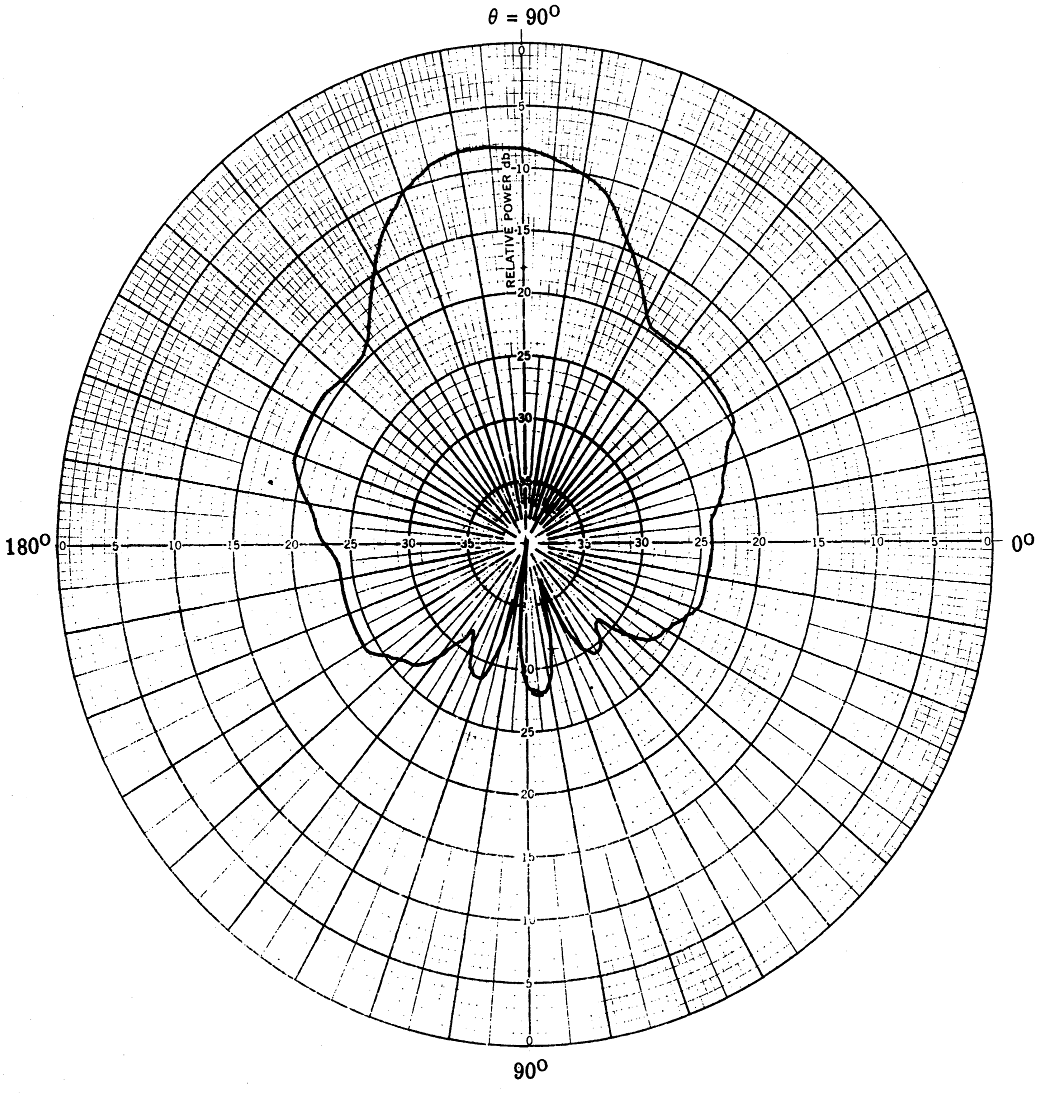


FIG. 7: E-PLANE POLARIZATION OF RIDGED HORN AT 3 GHz

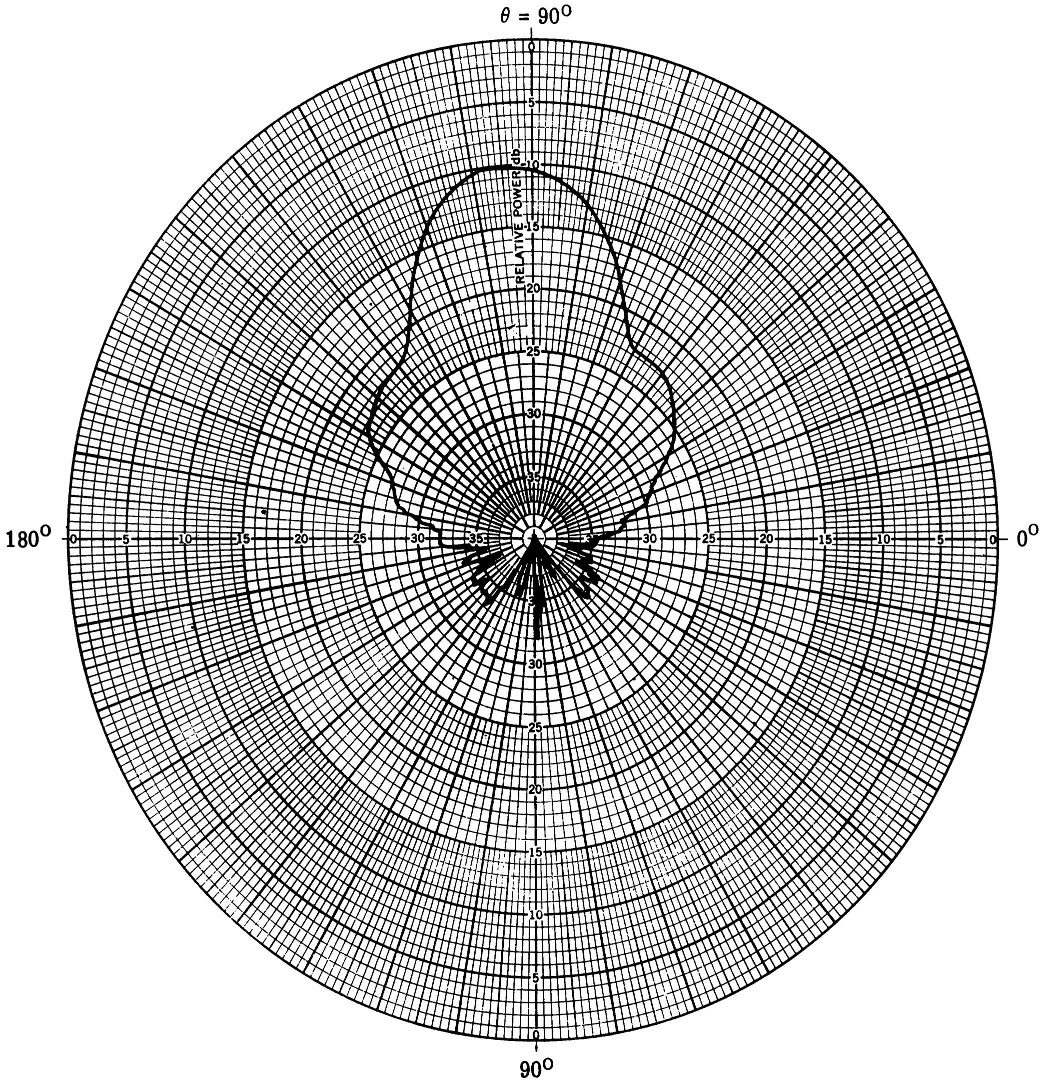


FIG. 8: E-PLANE POLARIZATION OF RIDGED HORN AT 4 GHz

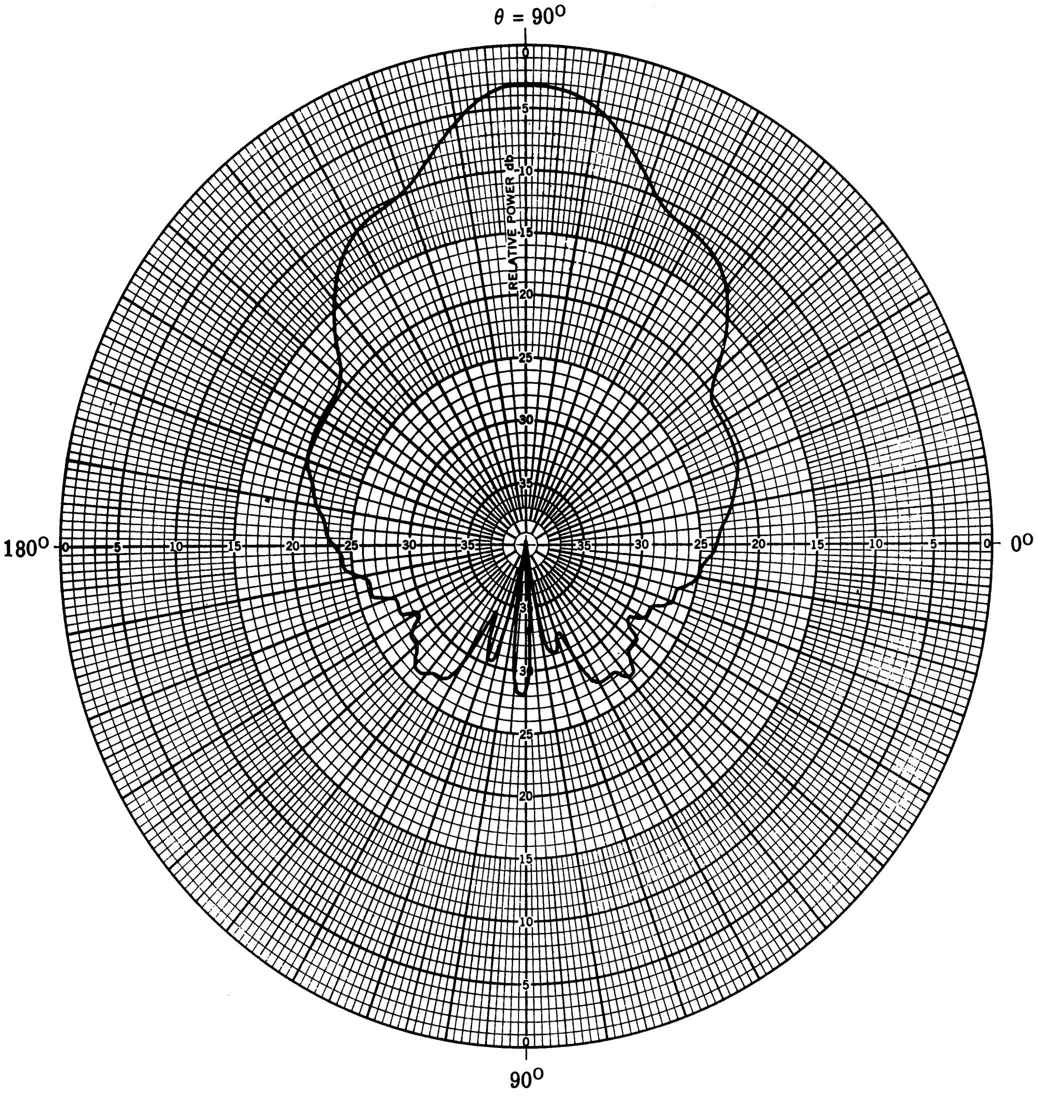


FIG. 9: E-PLANE POLARIZATION OF RIDGED HORN AT 5.3 GHz

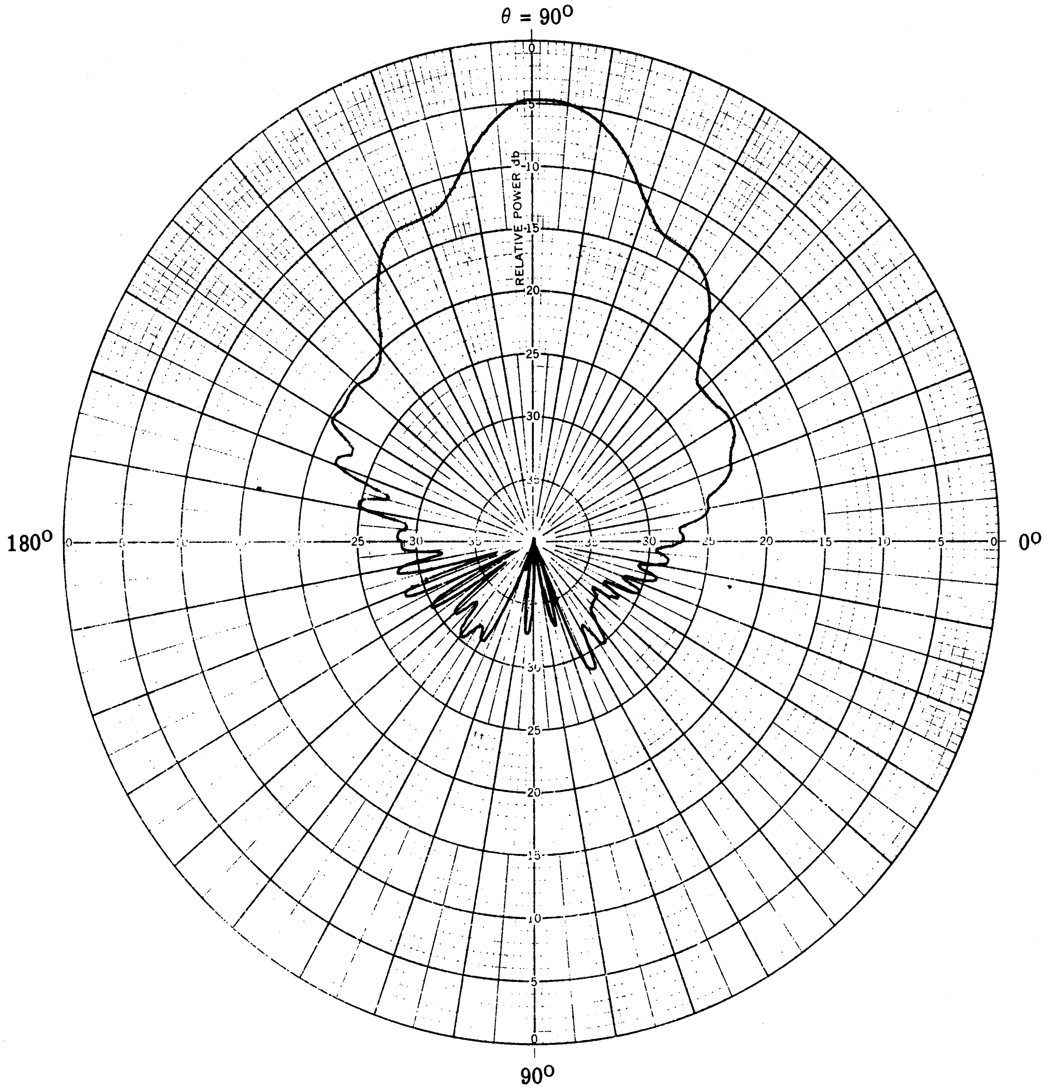


FIG. 10: E-PLANE POLARIZATION OF RIDGED HORN AT 5.93 GHz

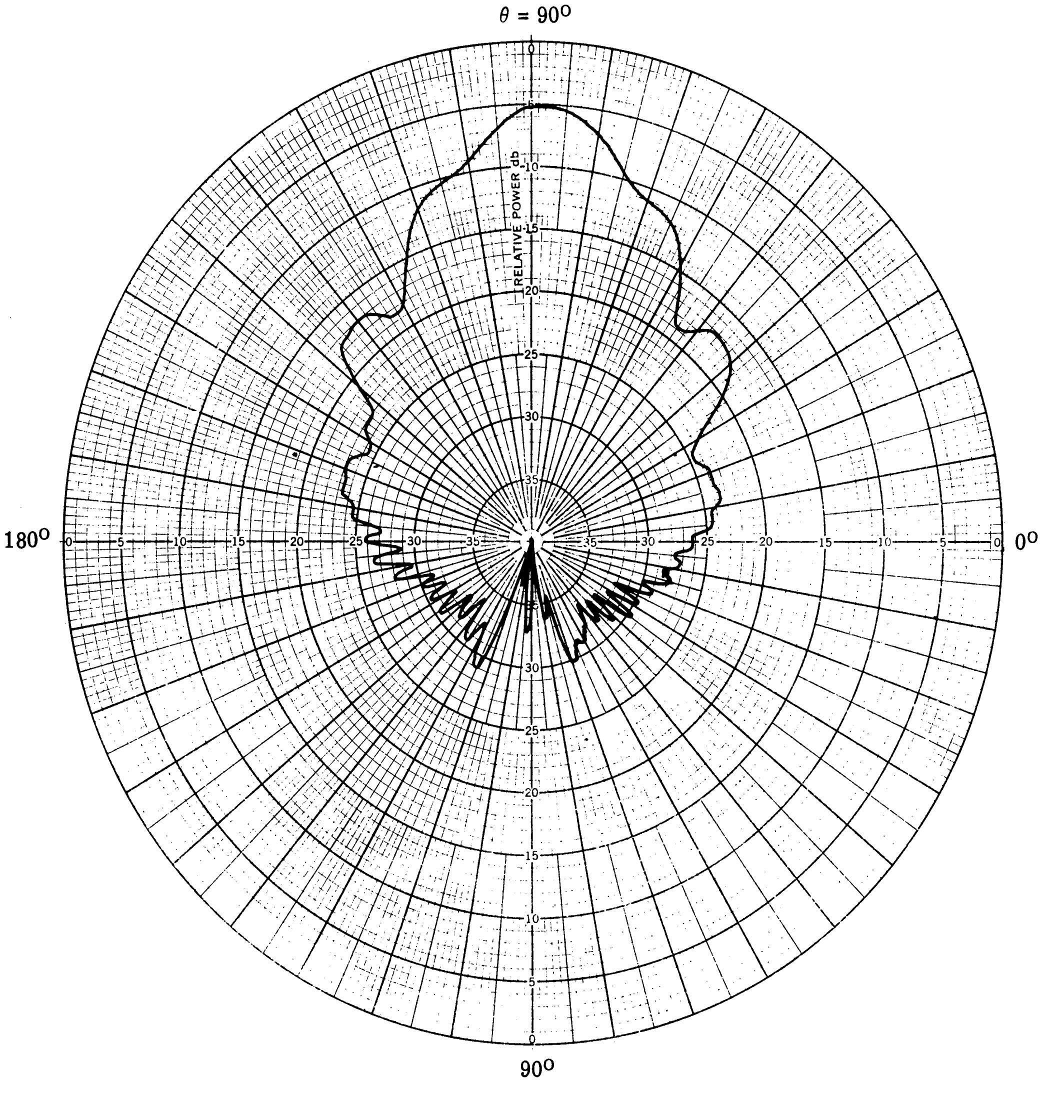


FIG. 11: E-PLANE POLARIZATION OF RIDGED HORN AT 6.95 GHz

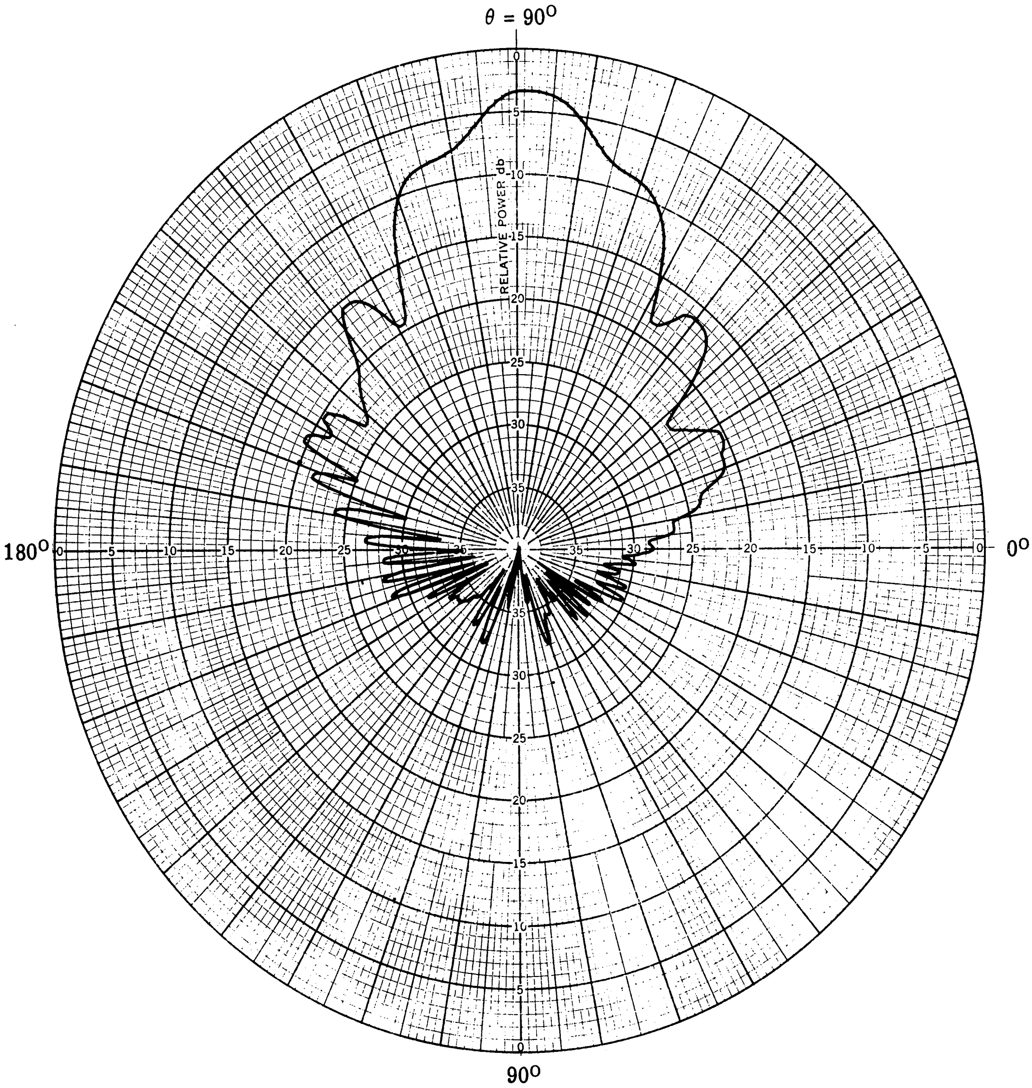


FIG. 12: E-PLANE POLARIZATION OF RIDGED HORN AT 8.2 GHz

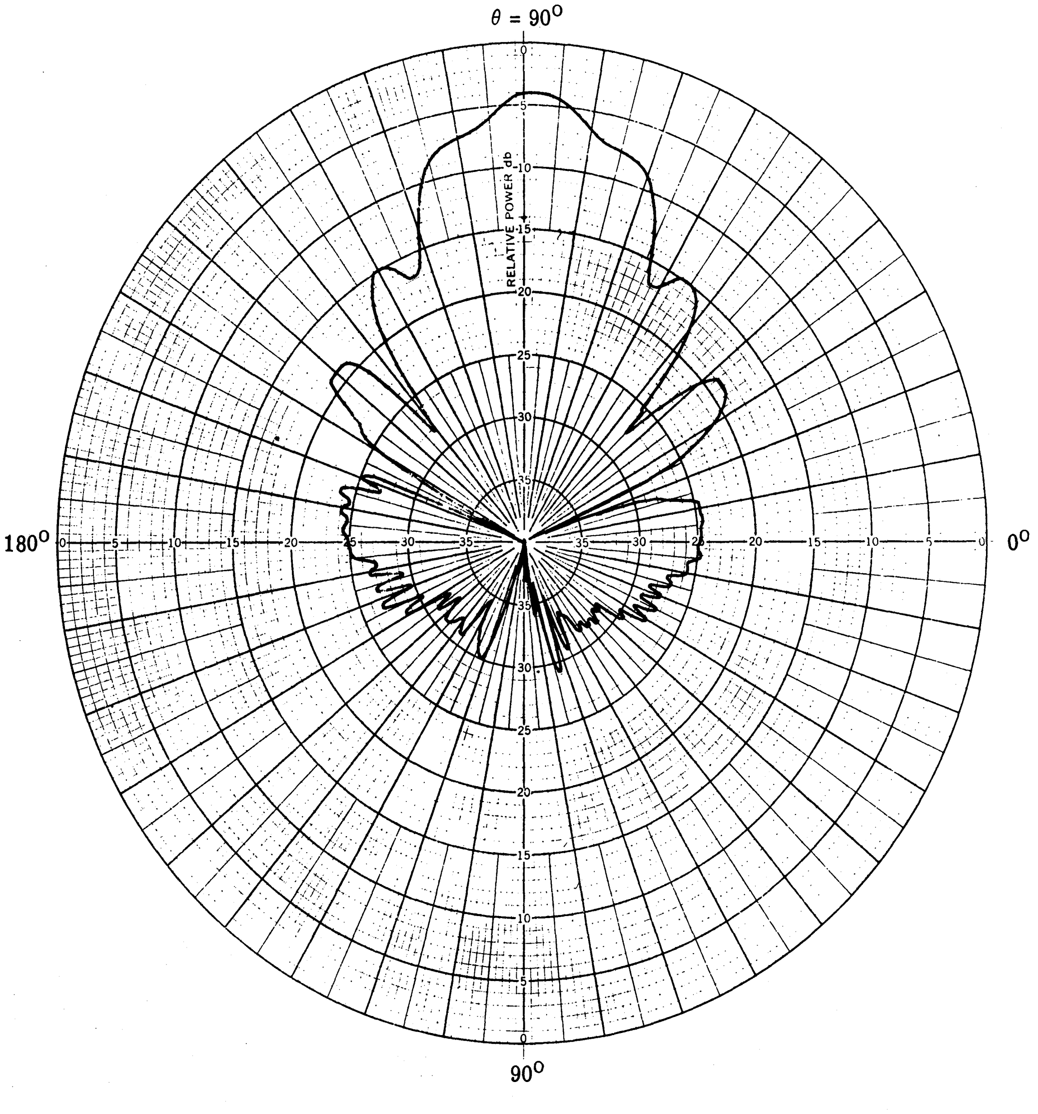


FIG. 13: E-PLANE POLARIZATION OF RIDGED HORN AT 9.12 GHz

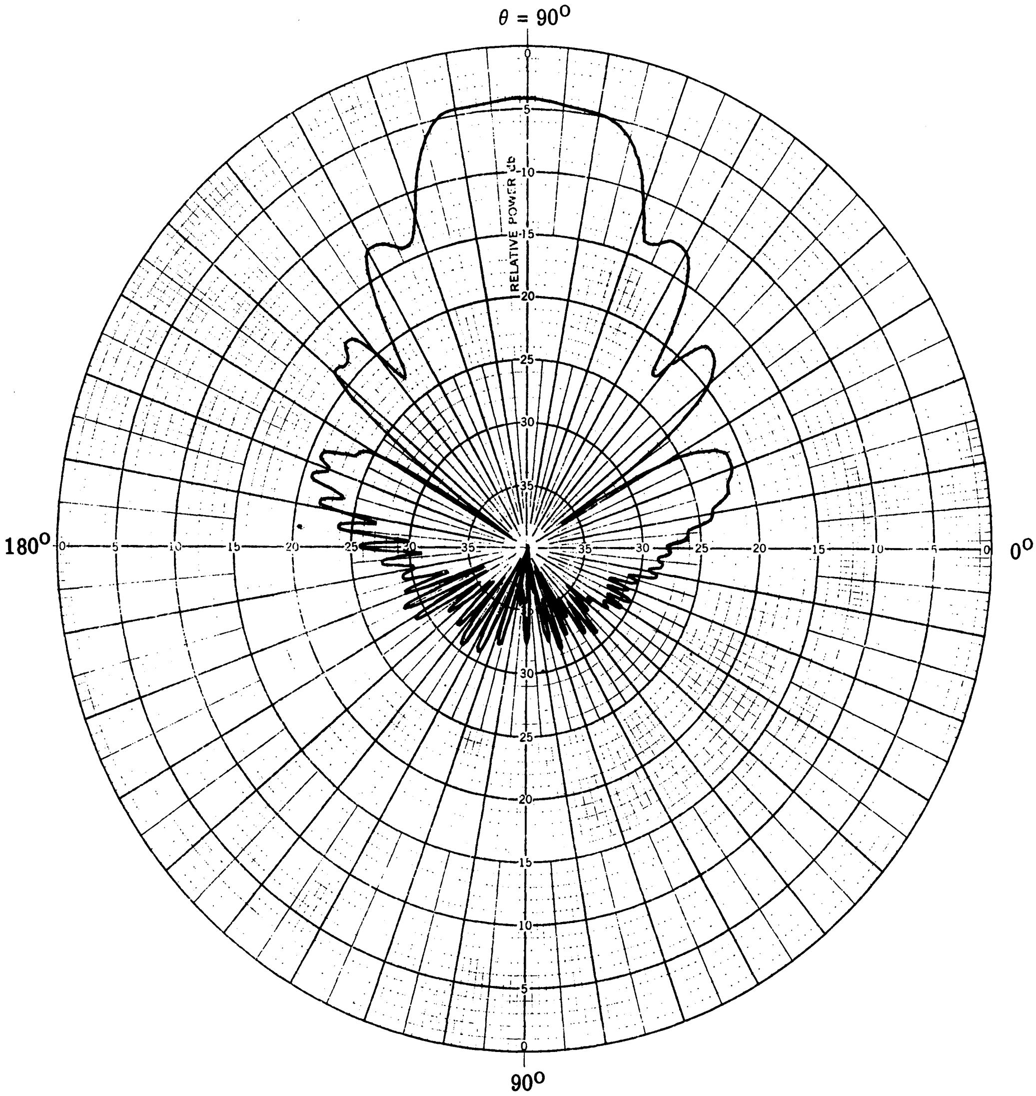


FIG. 14: E-PLANE POLARIZATION OF RIDGED HORN AT 10 GHz

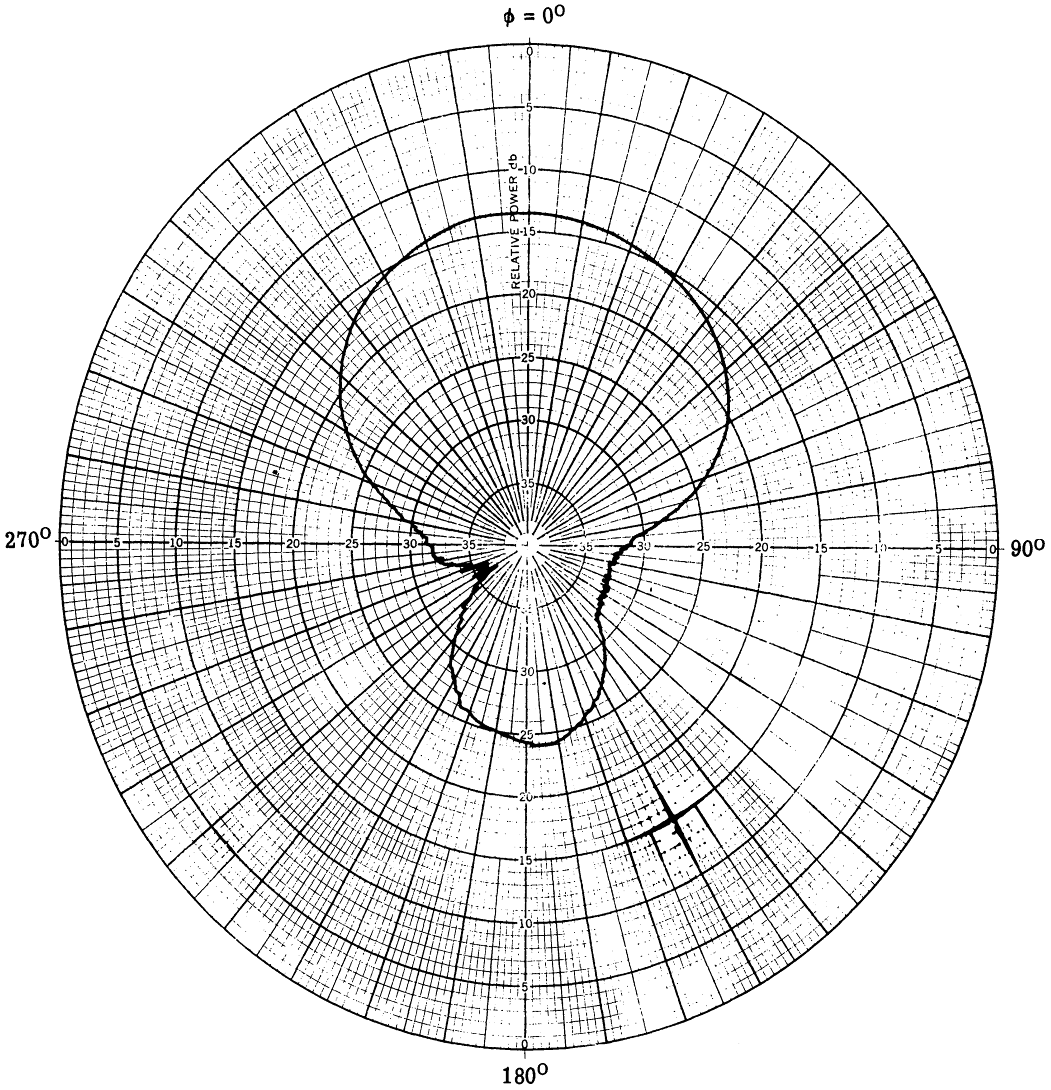


FIG. 15: H-PLANE POLARIZATION OF RIDGED HORN AT 1 GHz

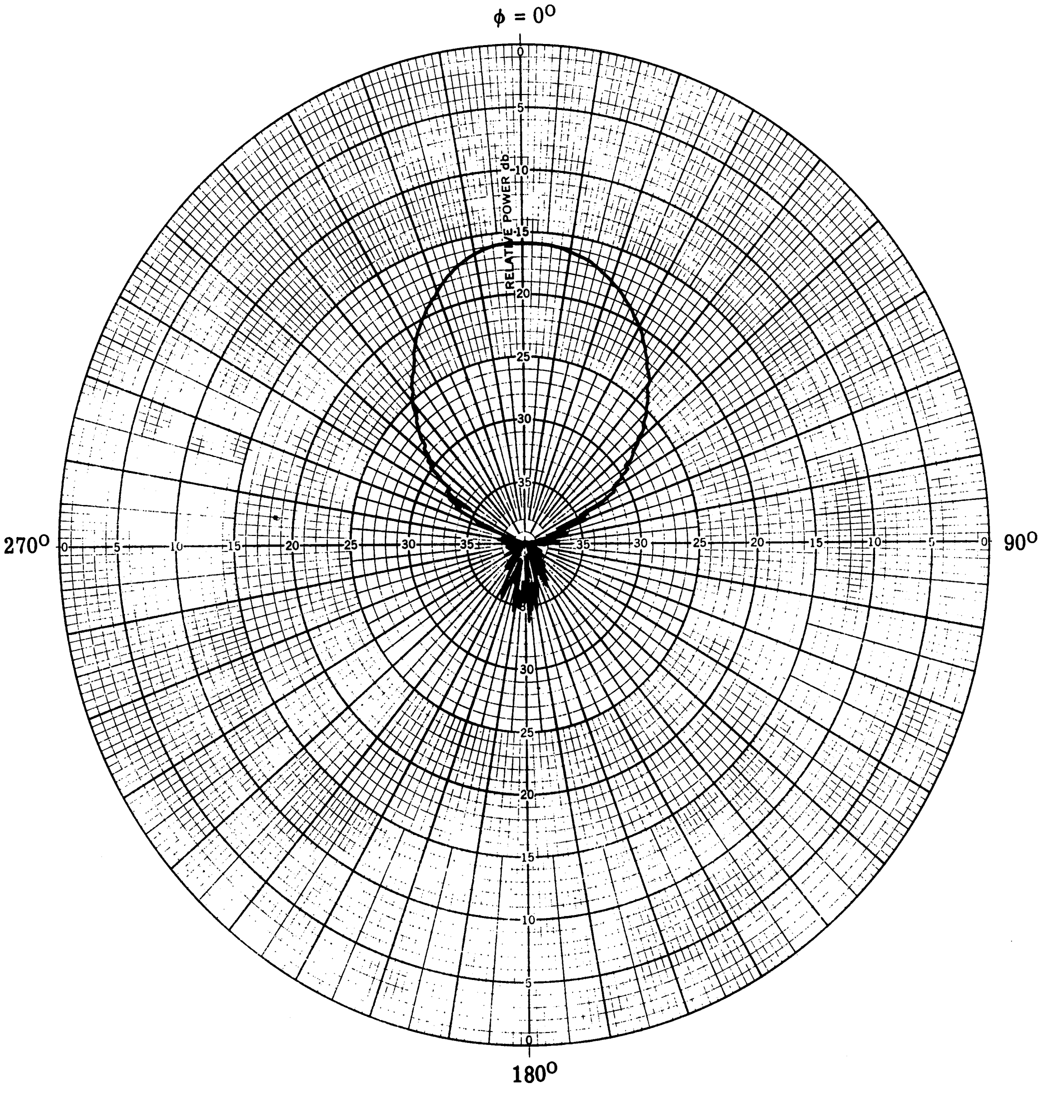


FIG. 16: H-PLANE POLARIZATION OF RIDGED HORN AT 2.1 GHz

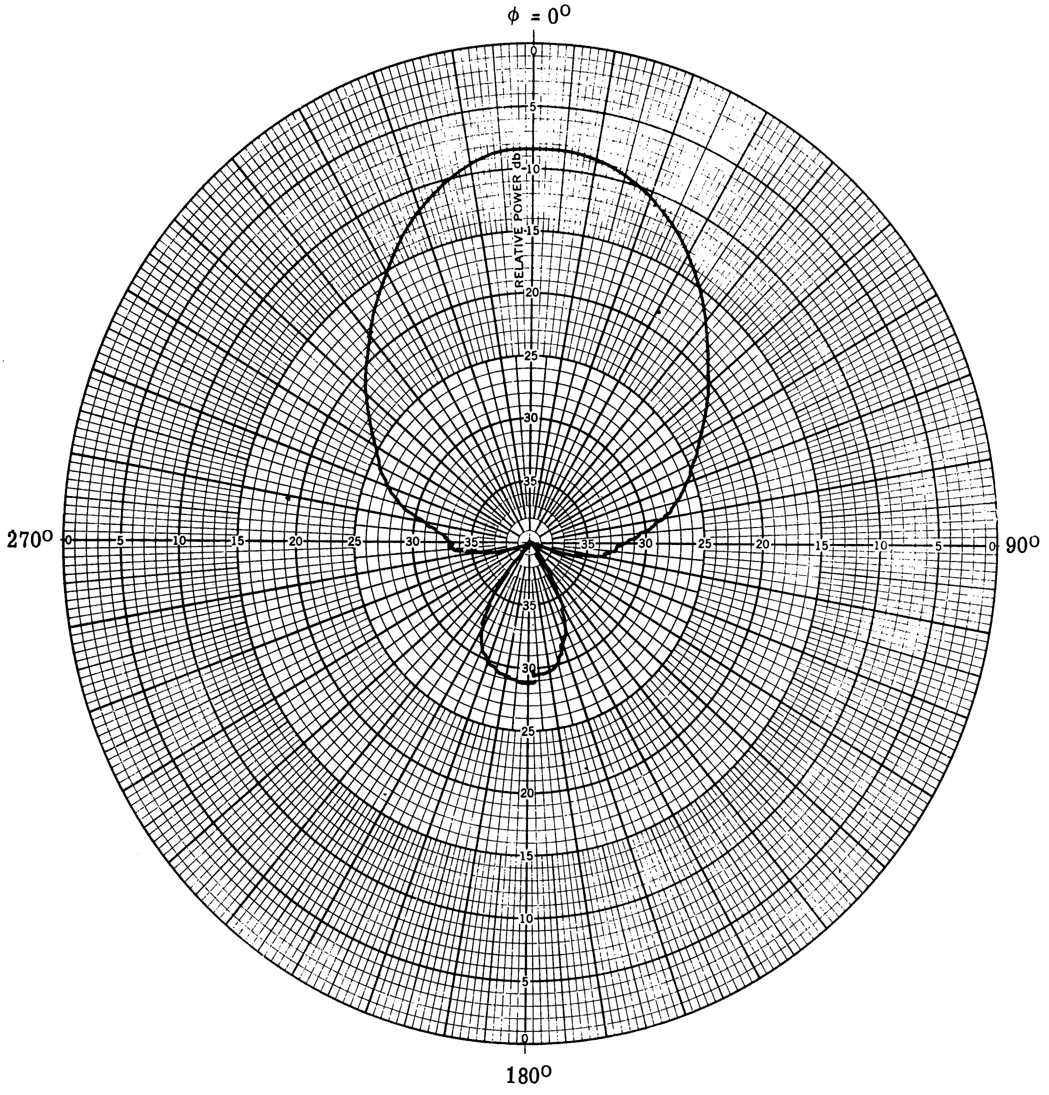


FIG. 17: H-PLANE POLARIZATION OF RIDGED HORN AT 2.5 GHz

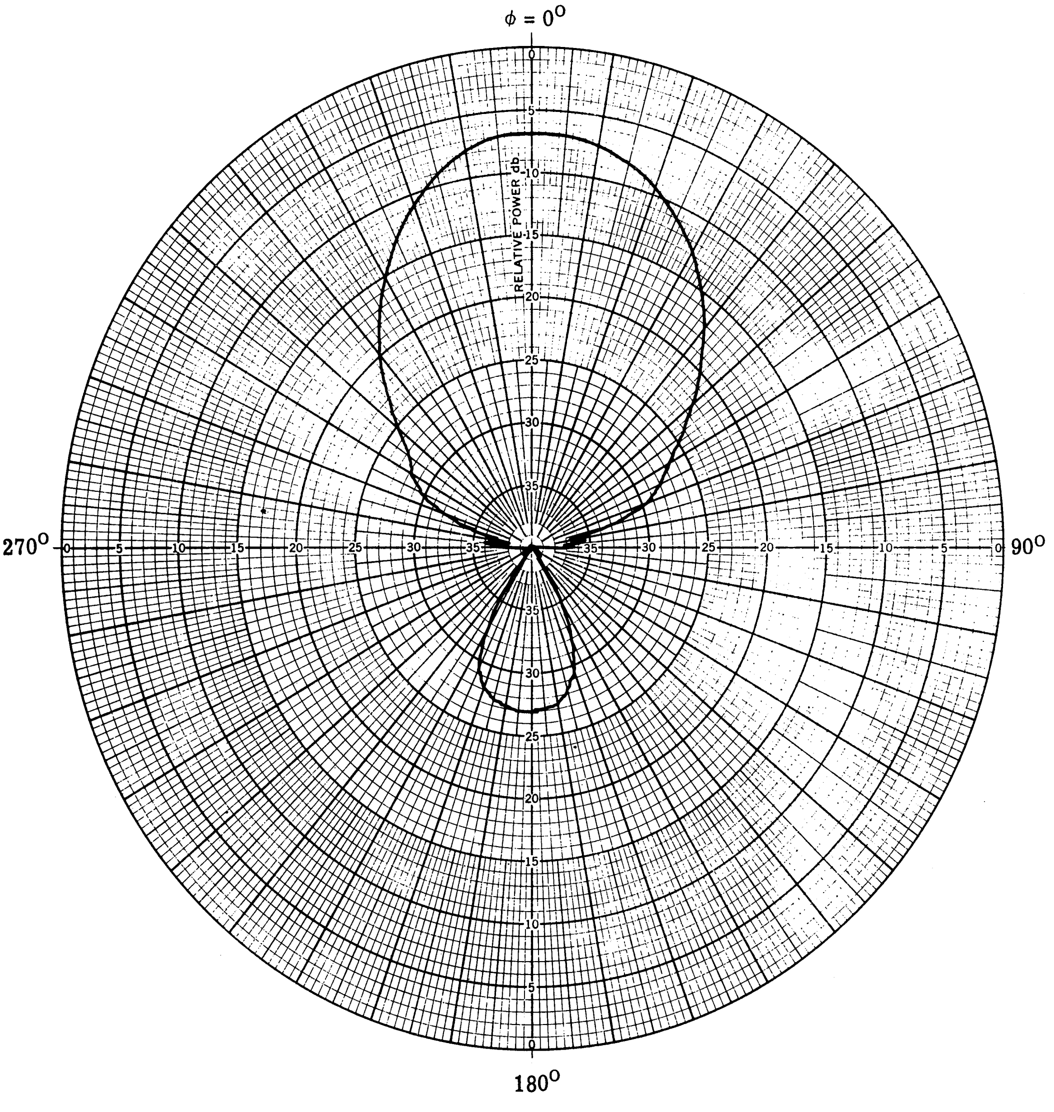


FIG. 18: H-PLANE POLARIZATION OF RIDGED HORN AT 3 GHz

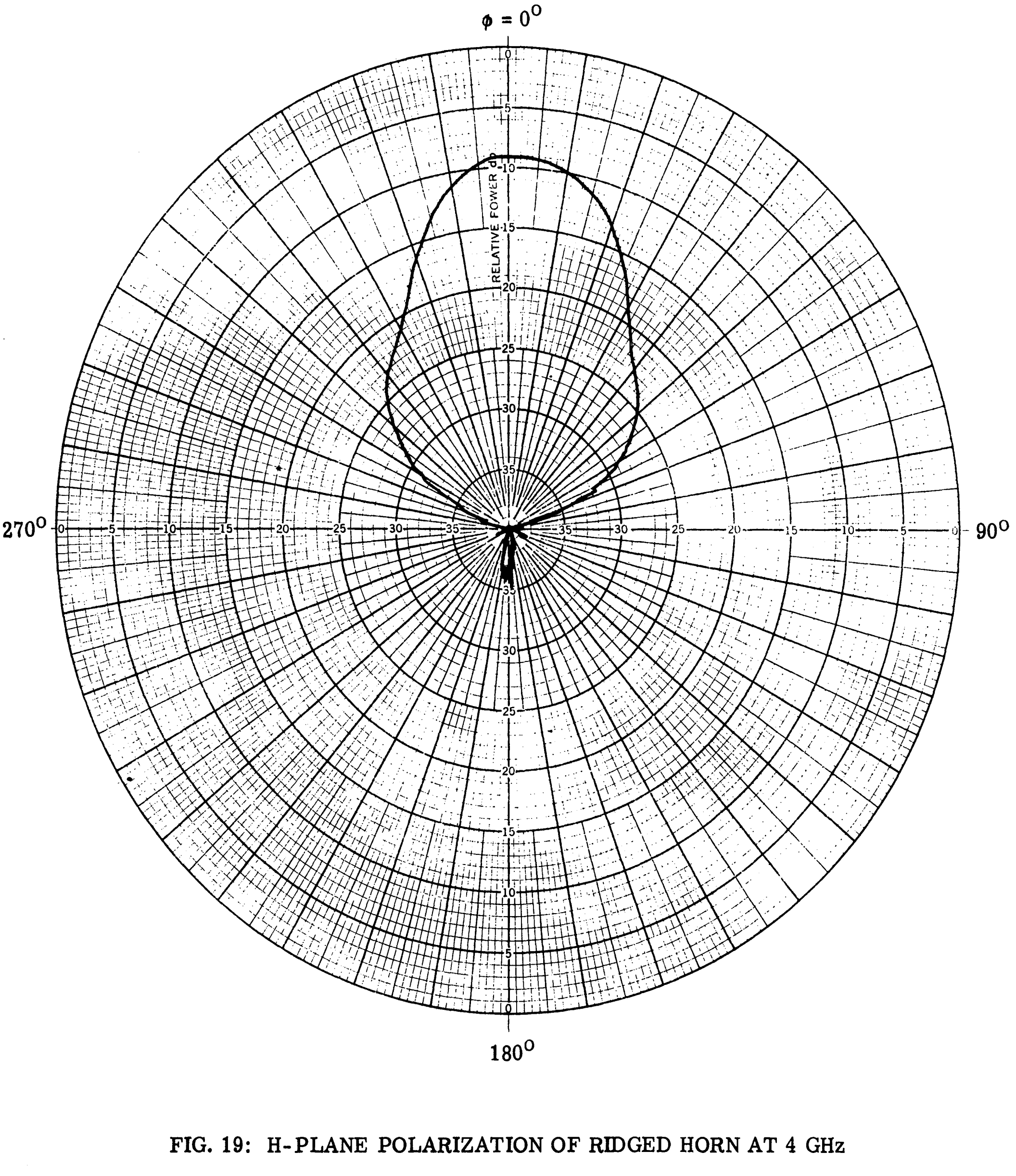


FIG. 19: H-PLANE POLARIZATION OF RIDGED HORN AT 4 GHz

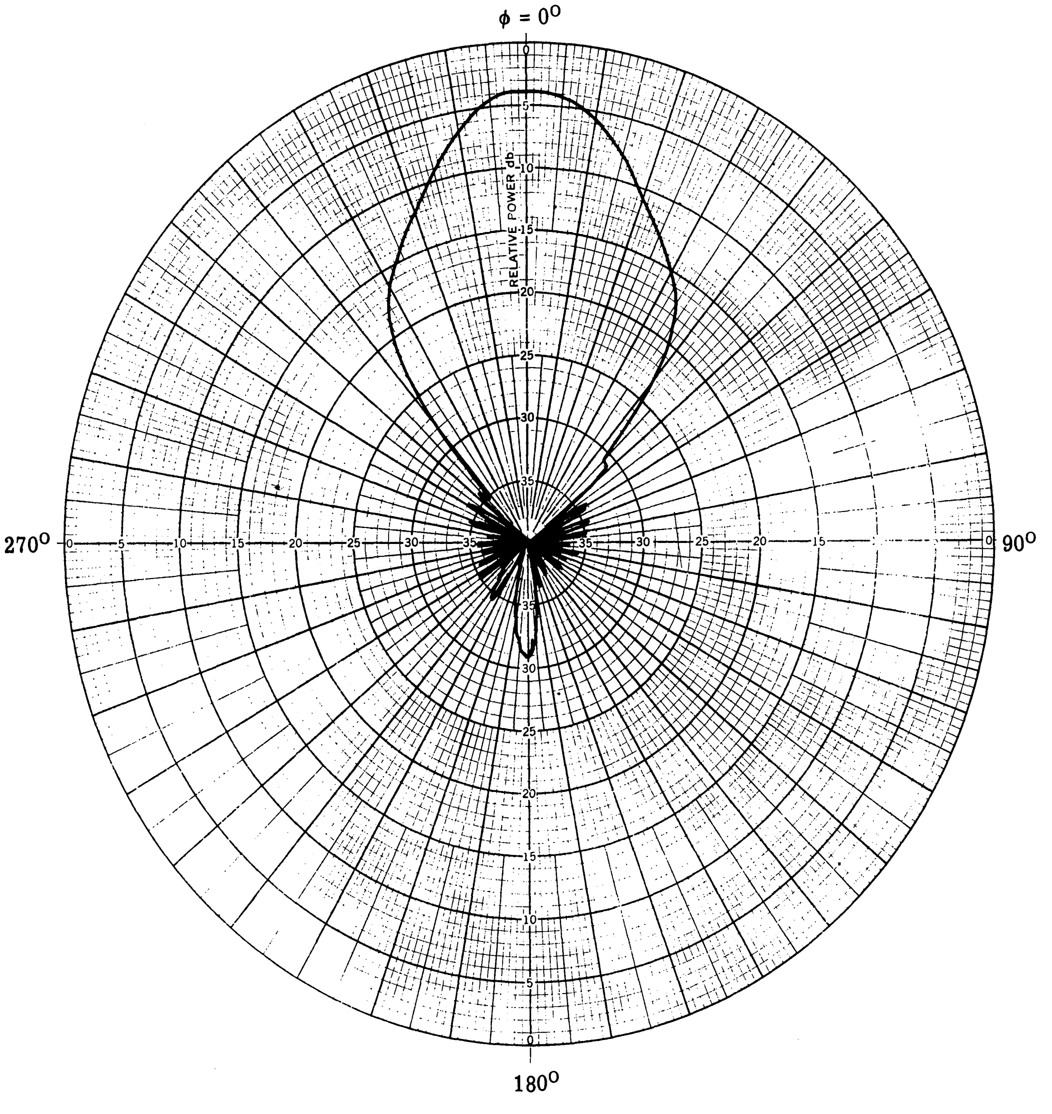


FIG. 20: H-PLANE POLARIZATION OF RIDGED HORN AT 5.3 GHz

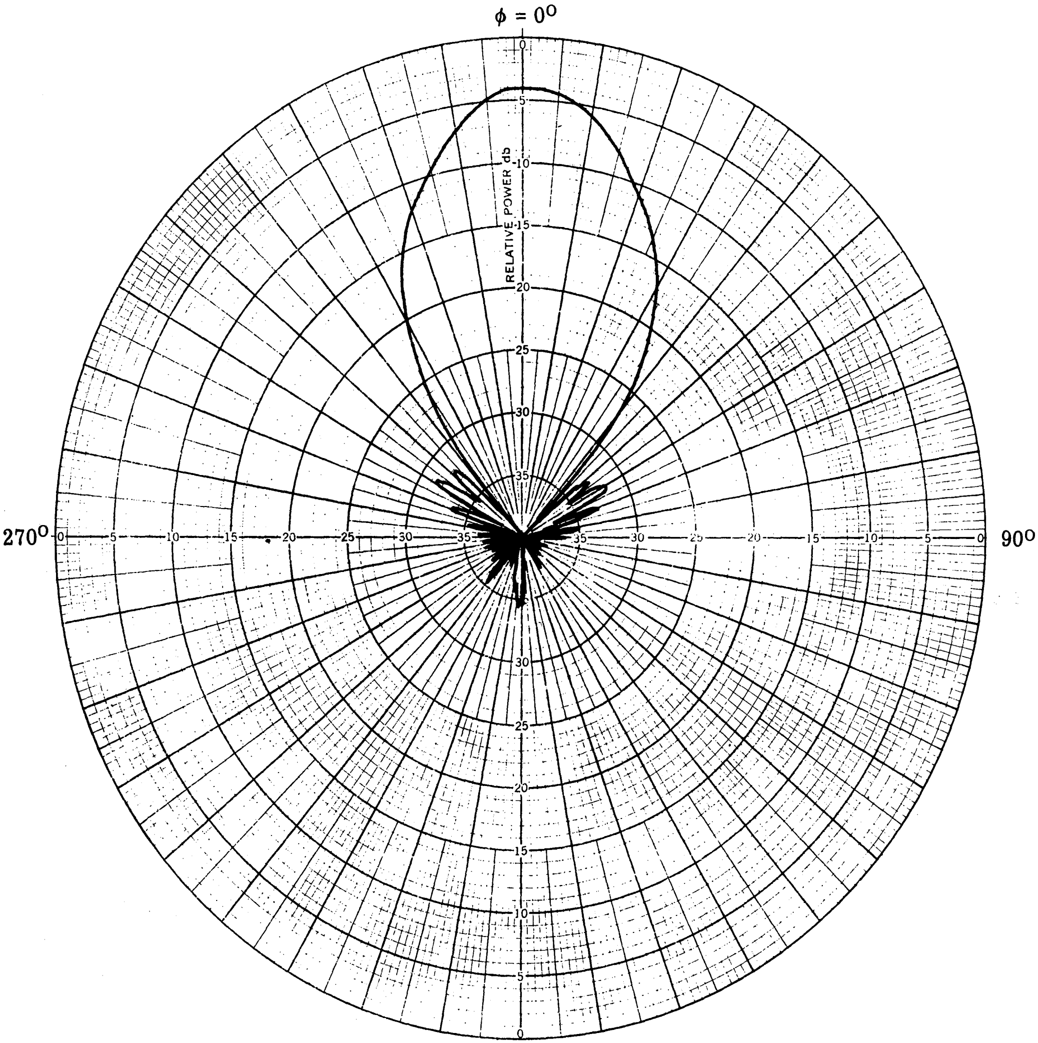


FIG. 21: H-PLANE POLARIZATION OF RIDGED HORN AT 5.93 GHz

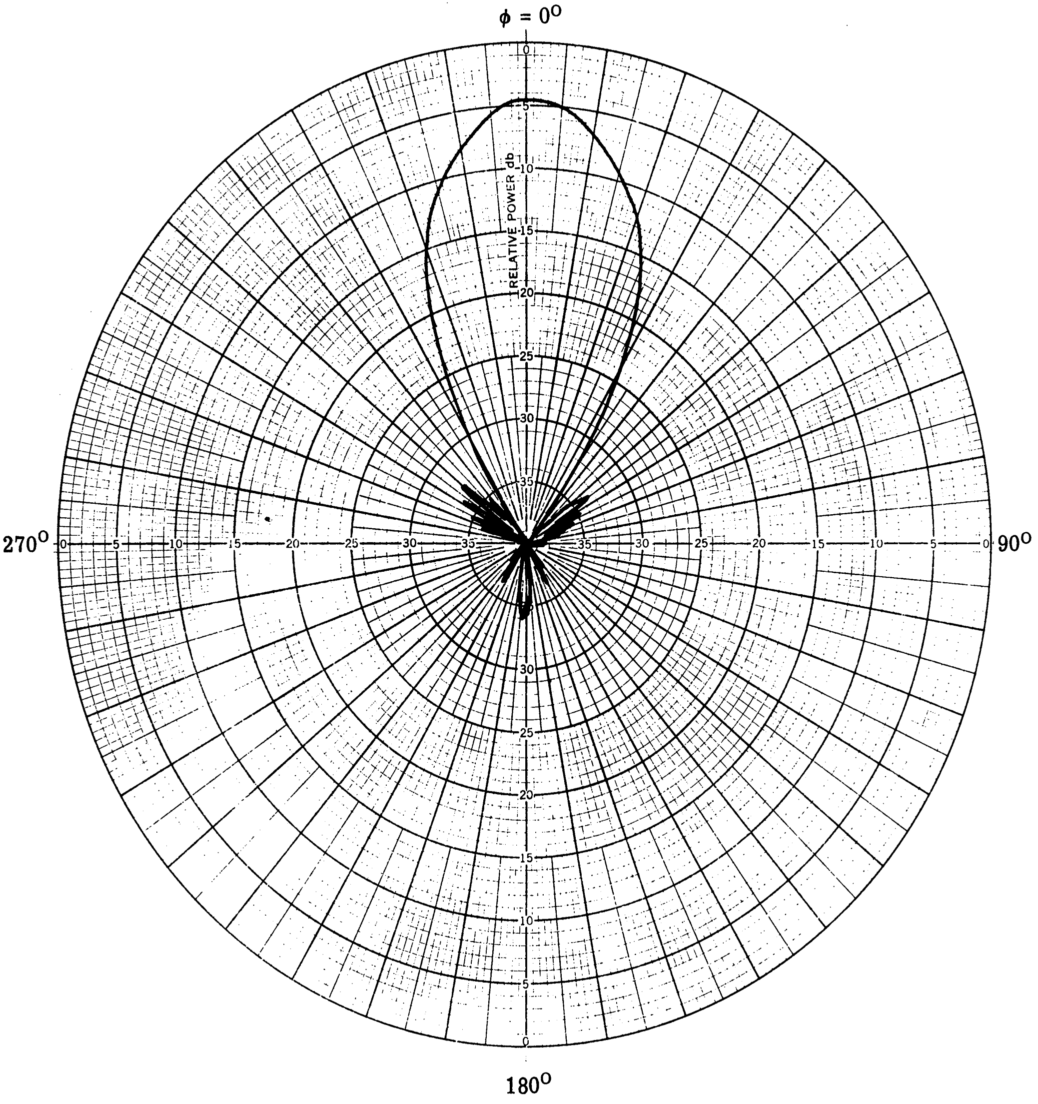


FIG. 22: H-PLANE POLARIZATION OF RIDGED HORN AT 6.95 GHz

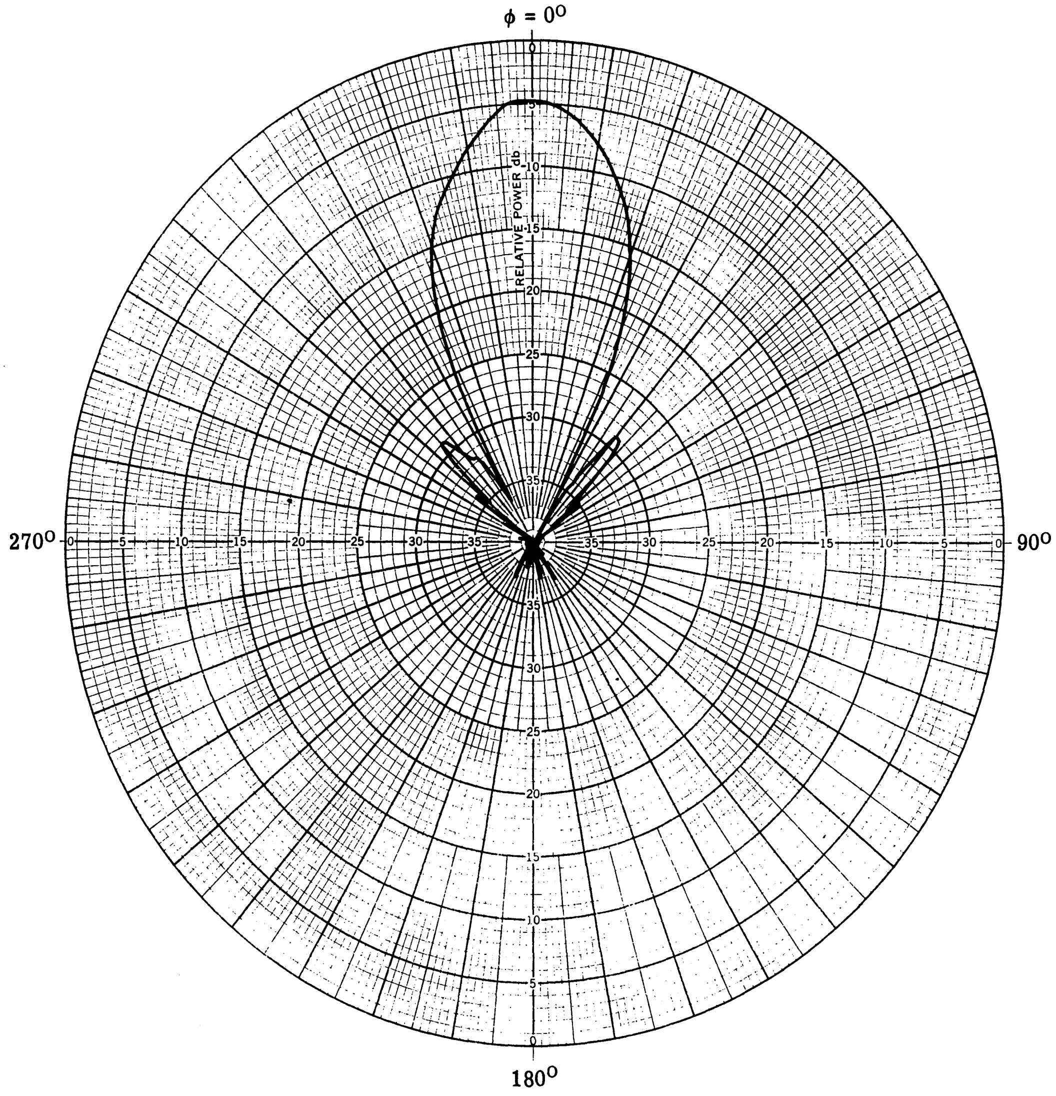


FIG. 23: H-PLANE POLARIZATION OF RIDGED HORN AT 8.2 GHz

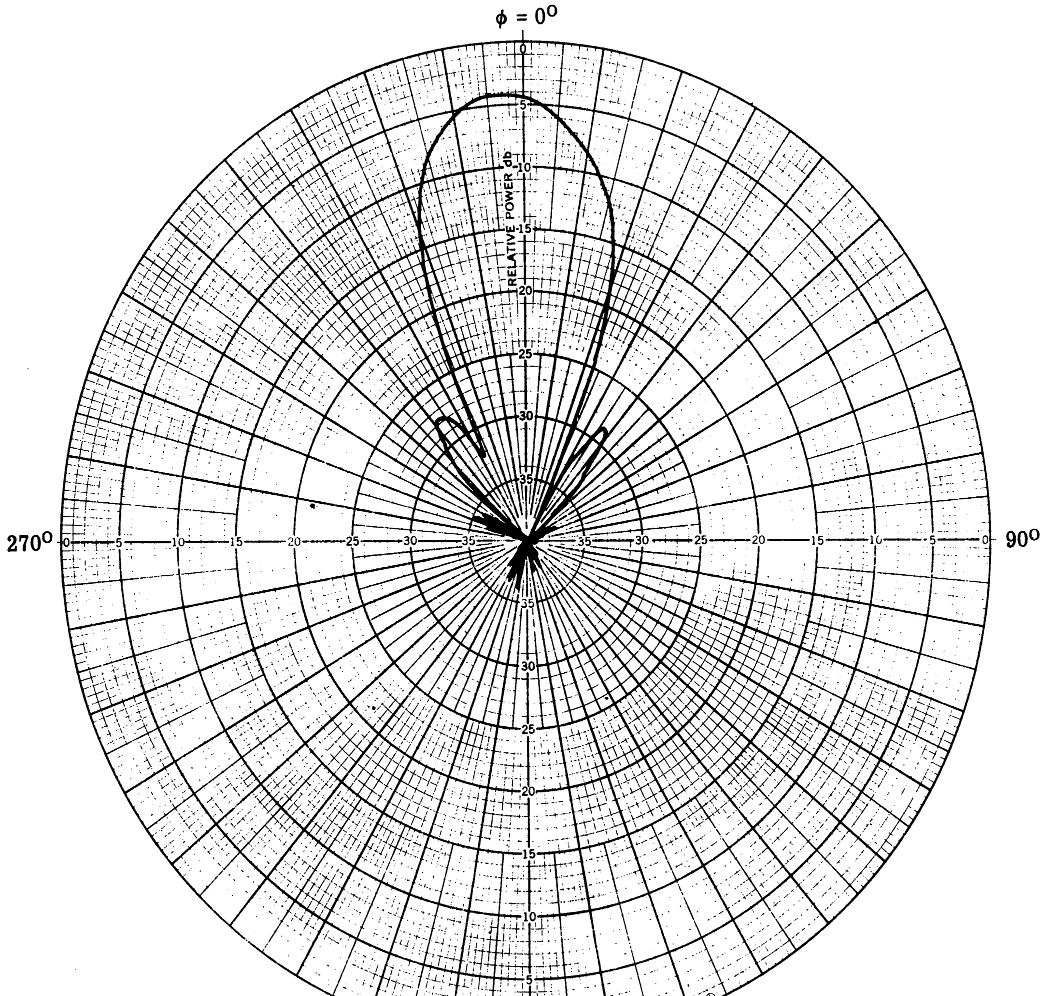


FIG. 24: H-PLANE POLARIZATION OF RIDGED HORN AT 9.12 GHz

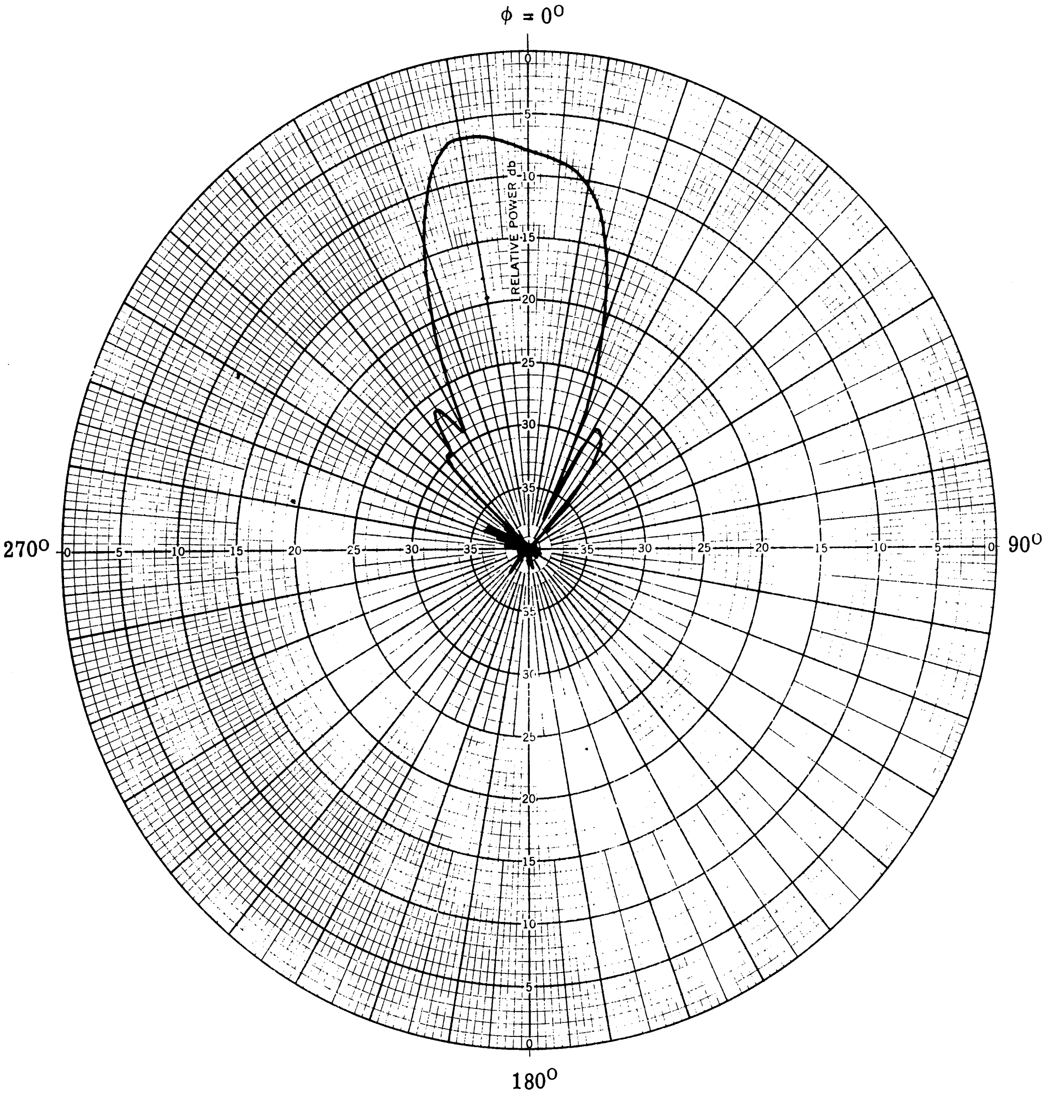


FIG. 25: H-PLANE POLARIZATION OF RIDGED HORN AT 10 GHz

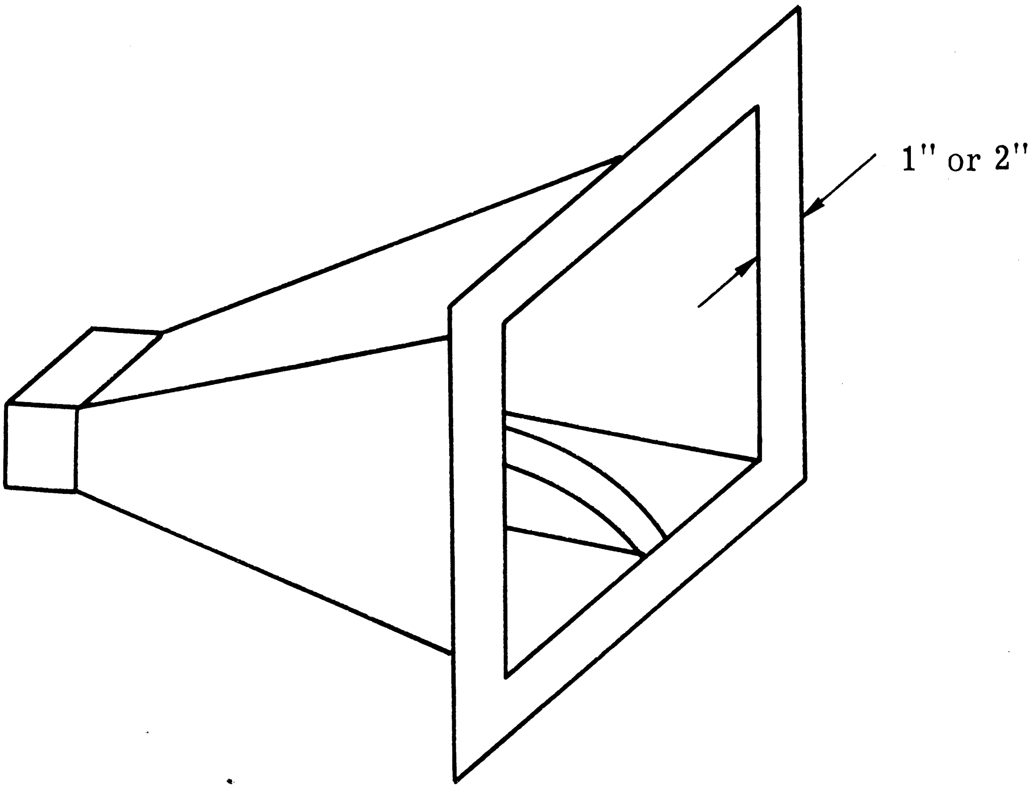


FIG. 26: BROADBAND RIDGED HORN WITH 1" OR 2" FLANGES

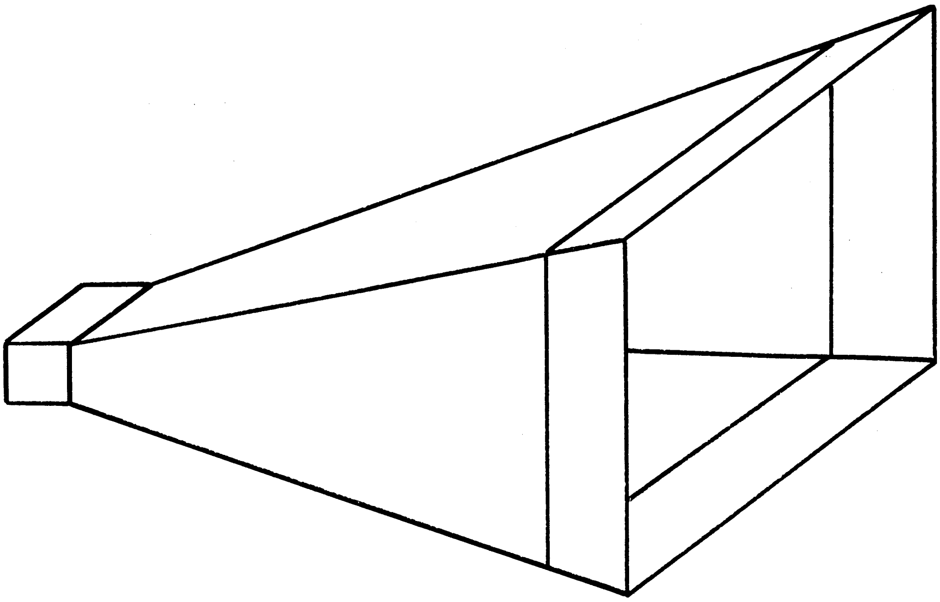


FIG. 27: BROADBAND RIDGED HORN WITH A 2" EXTENSION

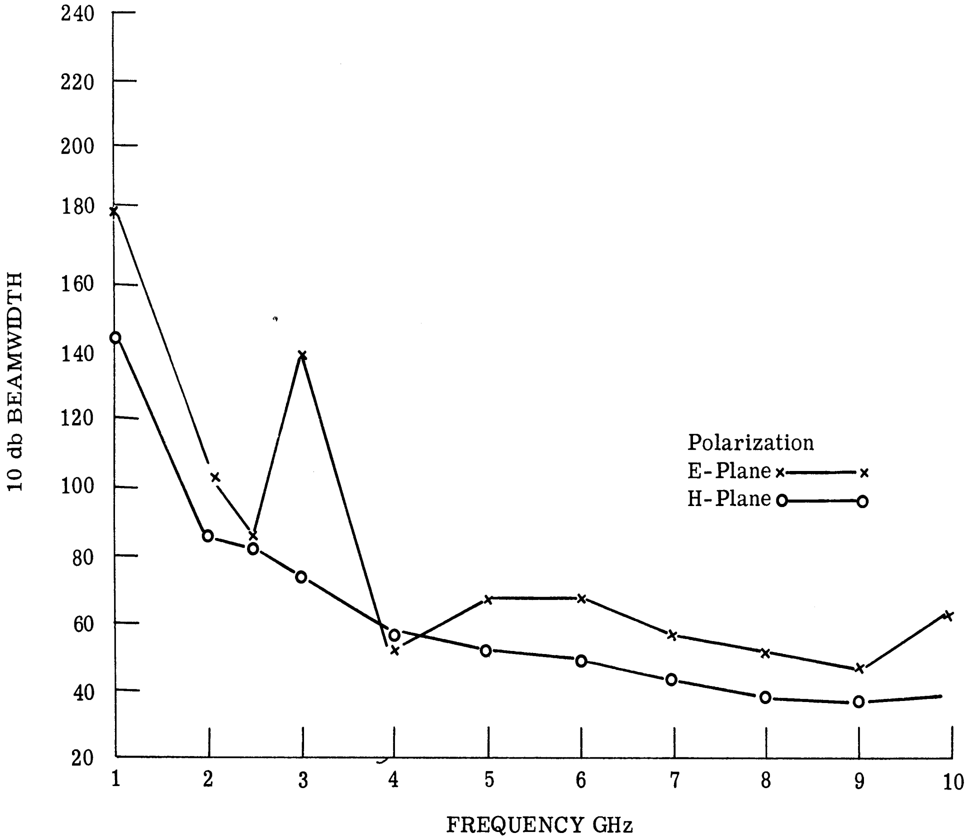


FIG. 28: 10 db BEAMWIDTH VS. FREQUENCY
(1 - 10 GHz Ridged Horn/2 in. Flange)

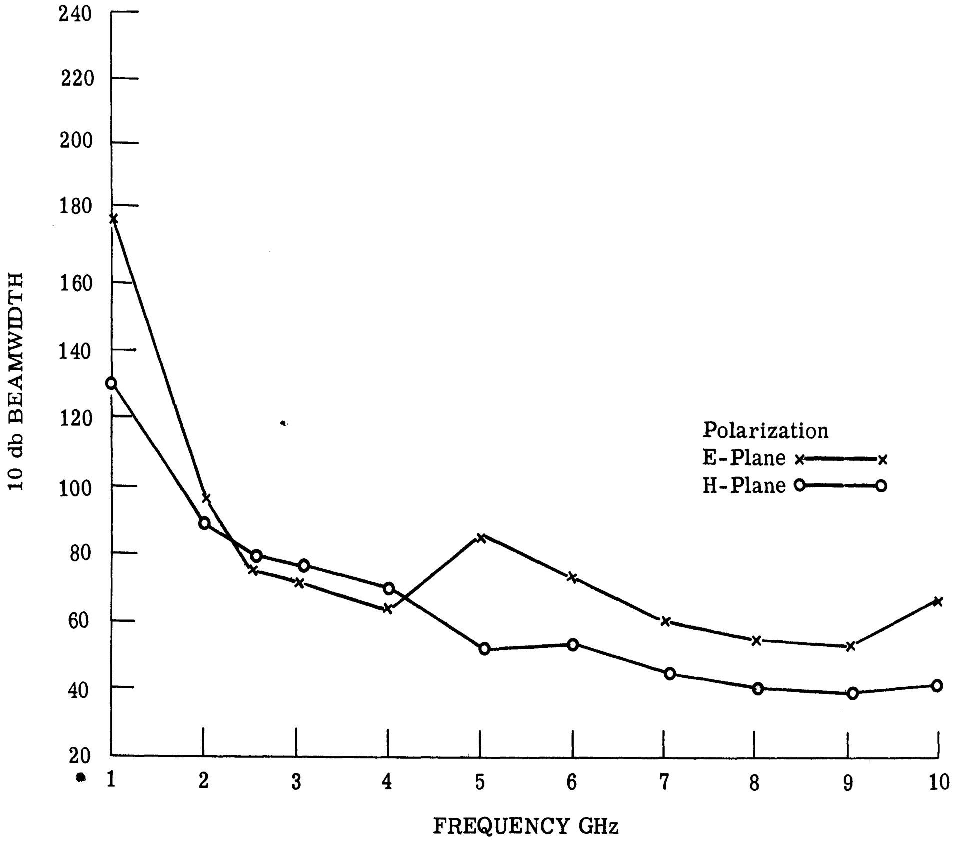


FIG. 29: 10 db BEAMWIDTH VS. FREQUENCY
(1 - 10 GHz Ridged Horn/1 in. Flange)

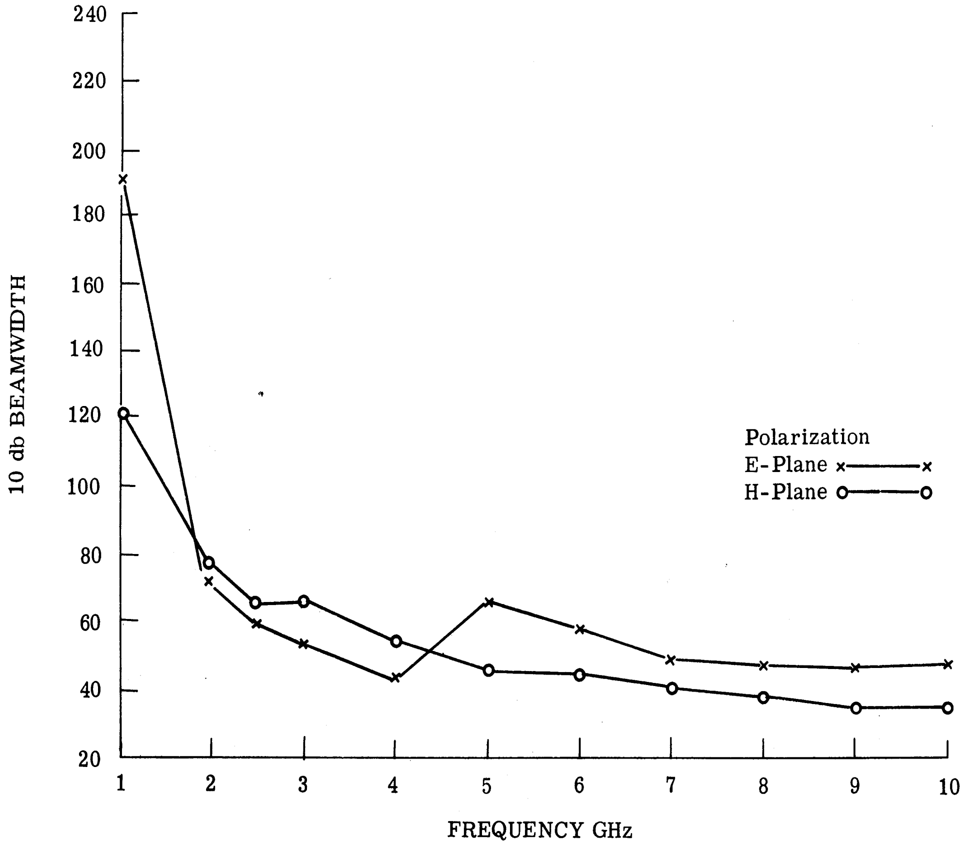


FIG. 30: 10 db BEAMWIDTH VS. FREQUENCY
(1 - 10 GHz Ridged Horn/2 in. Ext.)

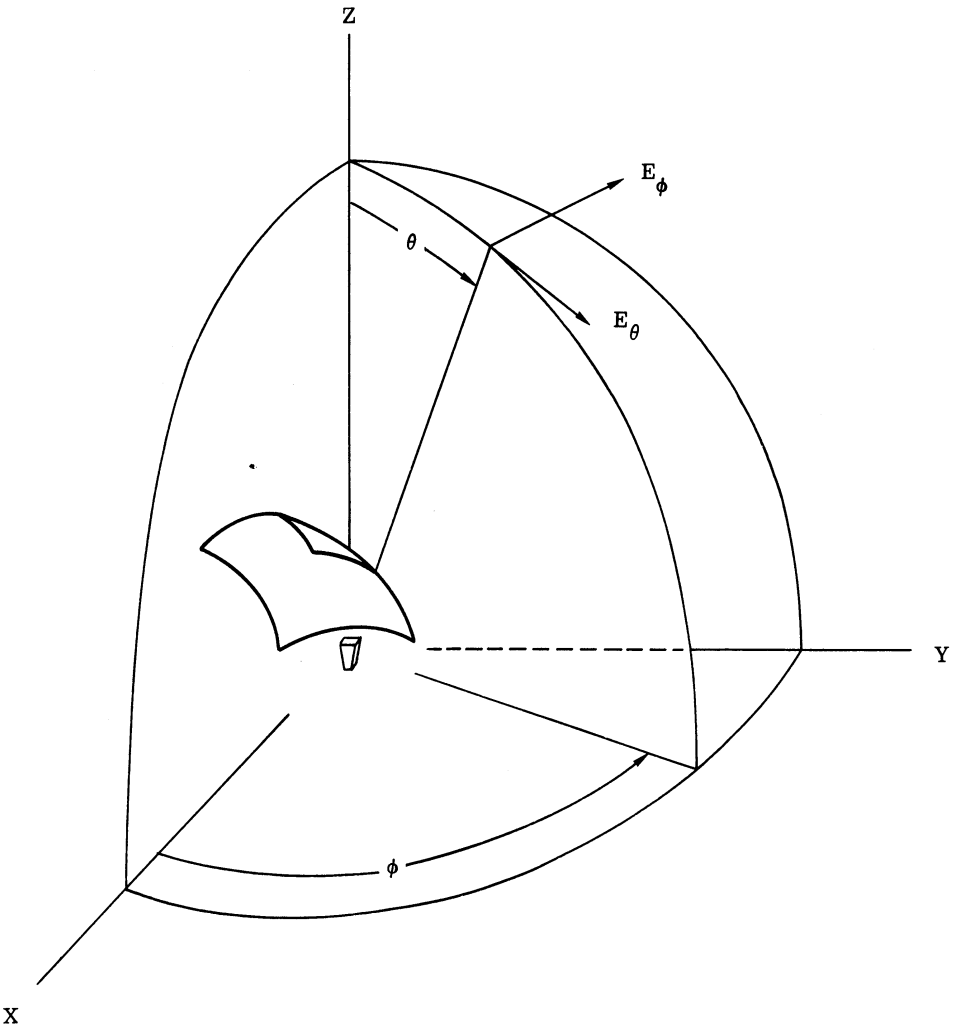


FIG. 31: ASYMMETRICAL PARABOLIC REFLECTOR
SPHERICAL COORDINATE SYSTEM

et al, (1965b). Figure 32 shows the H-plane 3 db beamwidth variation as a function of frequency in the range of 1:10 GHz. These patterns were recorded for $\theta = 90^o$ with ϕ variable (see Fig. 31). The beamwidth variation is less than 2:1 over a frequency range of approximately 7:1. Figure 33 presents the side-lobe level as a function of frequency where it will be observed they are below the 15 db design goal. Figures 34 - 45 are typical of the H-plane patterns obtained from the asymmetrical parabolic reflector. Care was taken to ensure the data was recorded with a high gain antenna rotating in the same direction for each pattern. Therefore, beam steering can readily be determined from the data of Figs. 34 - 45 and is seen to be less than $\pm 1^o$.

The reflector surface has an F/D ratio of 0.27 with focal length $F = 13$ inches and a radiating aperture $D = 48$ inches. To obtain the data of Figs. 34 - 45, the radiating aperture of the ridged horn was centered at the reflector focal point and the horn axis tilted to $\theta = 11.5^o$. Several θ angles were investigated to ensure that $\theta = 11.5^o$ was optimum insofar as pattern gain and construction was concerned. Arrangements are being made to record E-plane patterns; $\phi = 0^o$, θ variable, (Fig. 31).

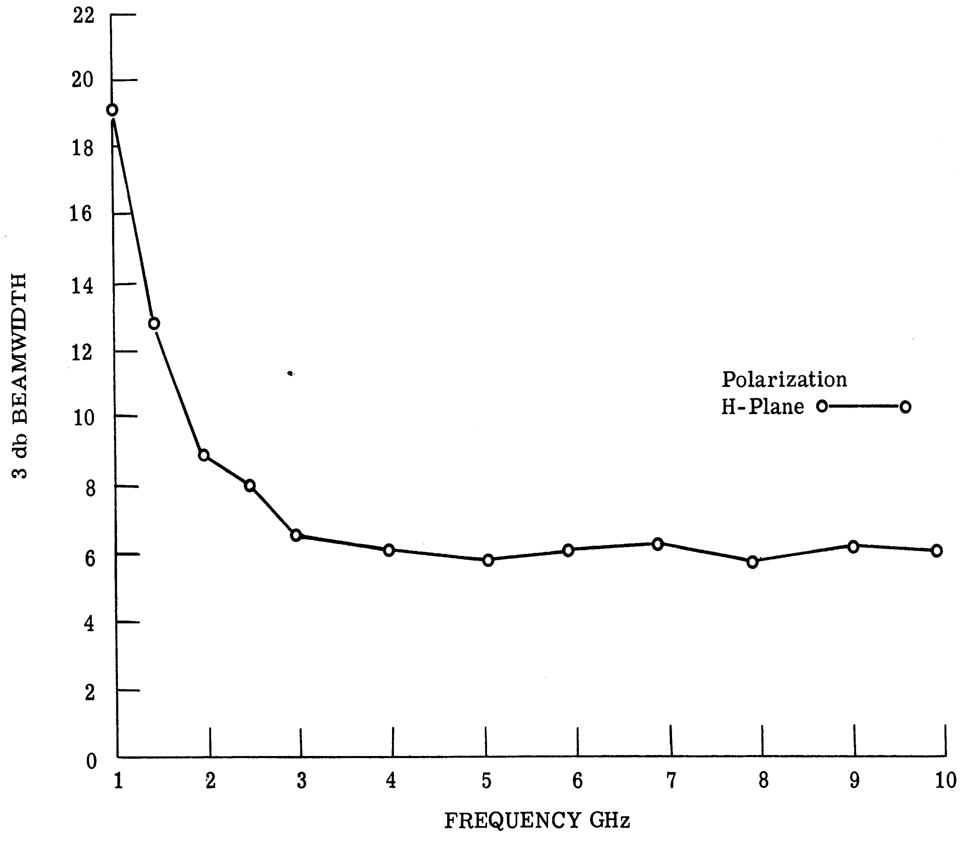


FIG. 32: 3 db BEAMWIDTH VS. FREQUENCY
(1 - 10 GHz Asymmetrically Fed Parabolic Reflector)

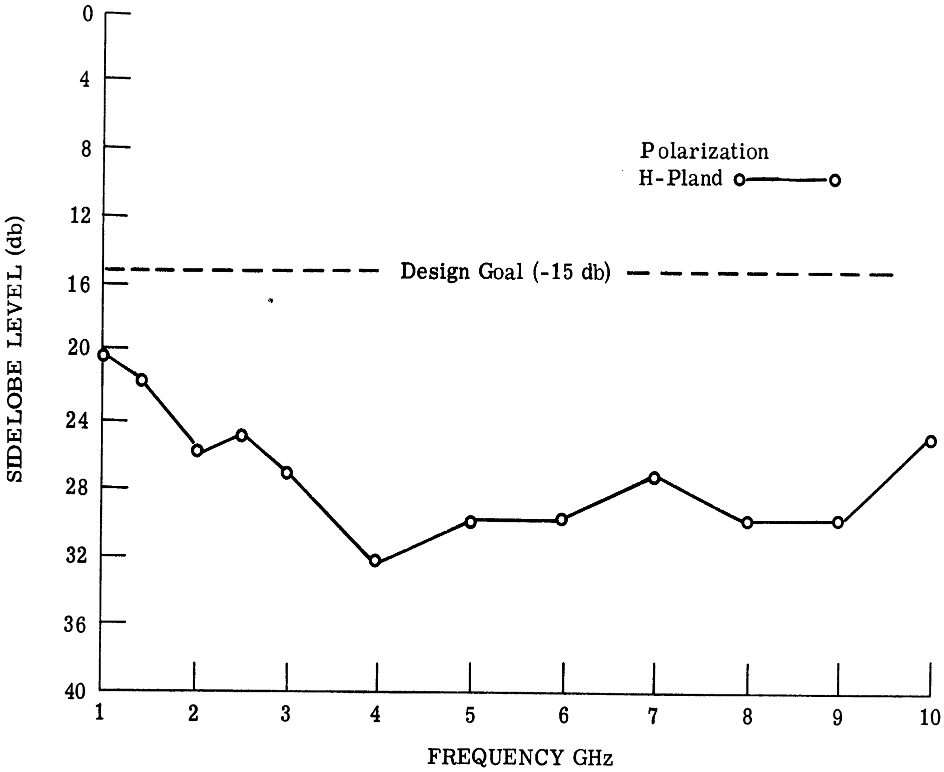


FIG. 33: SIDELOBE LEVEL VS. FREQUENCY
(1-10 GHz Asymmetrically Fed Parabolic Reflector

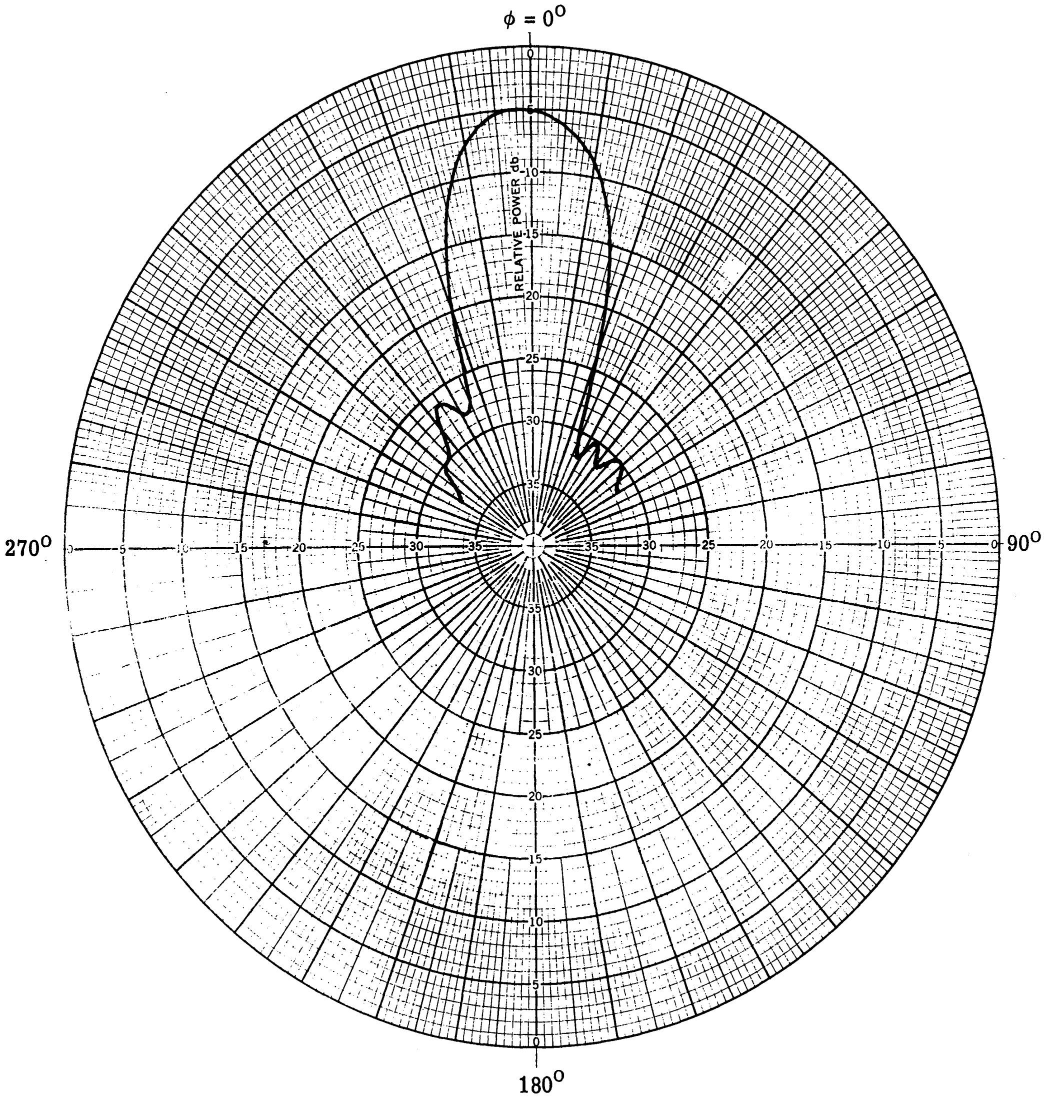


FIG. 34: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR

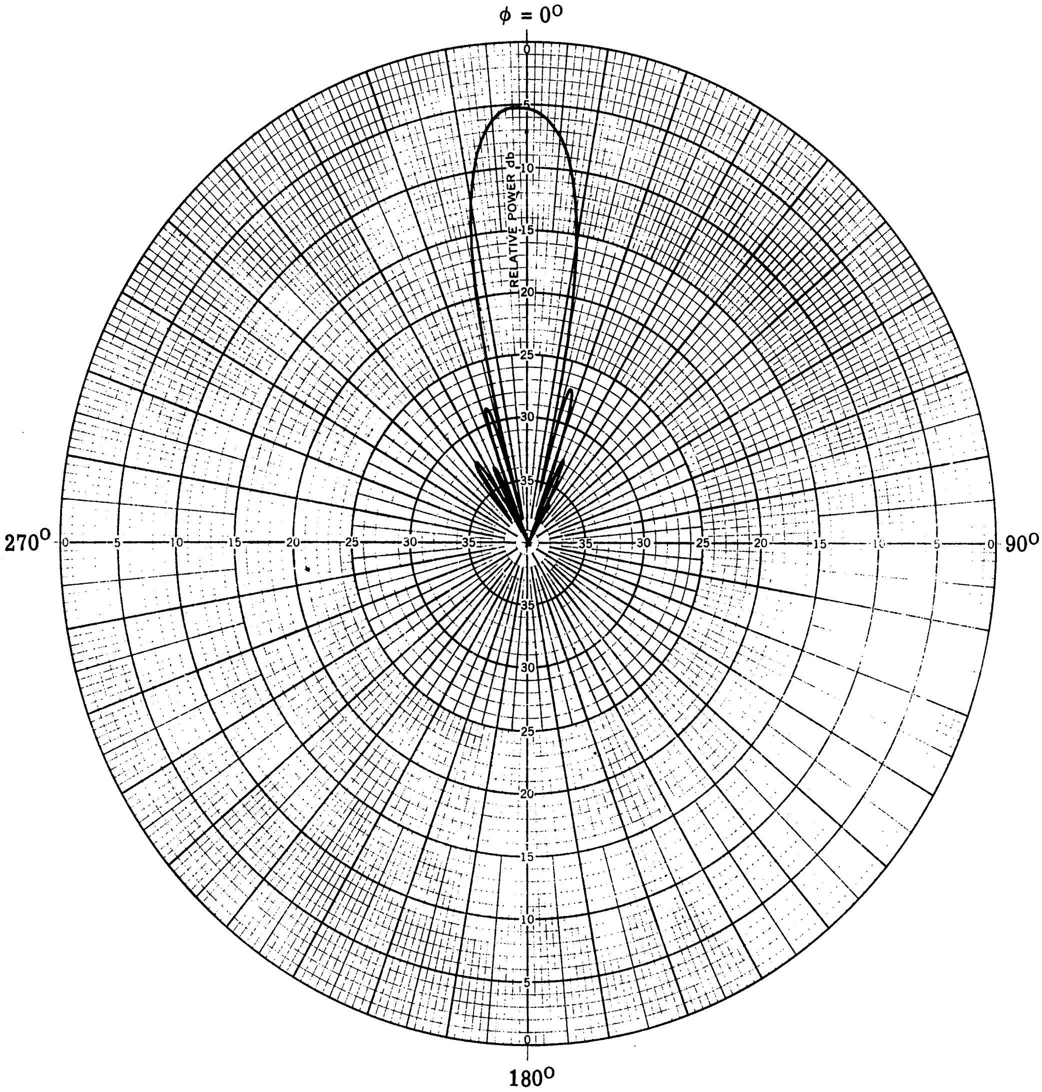


FIG. 35: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 1.5 GHz

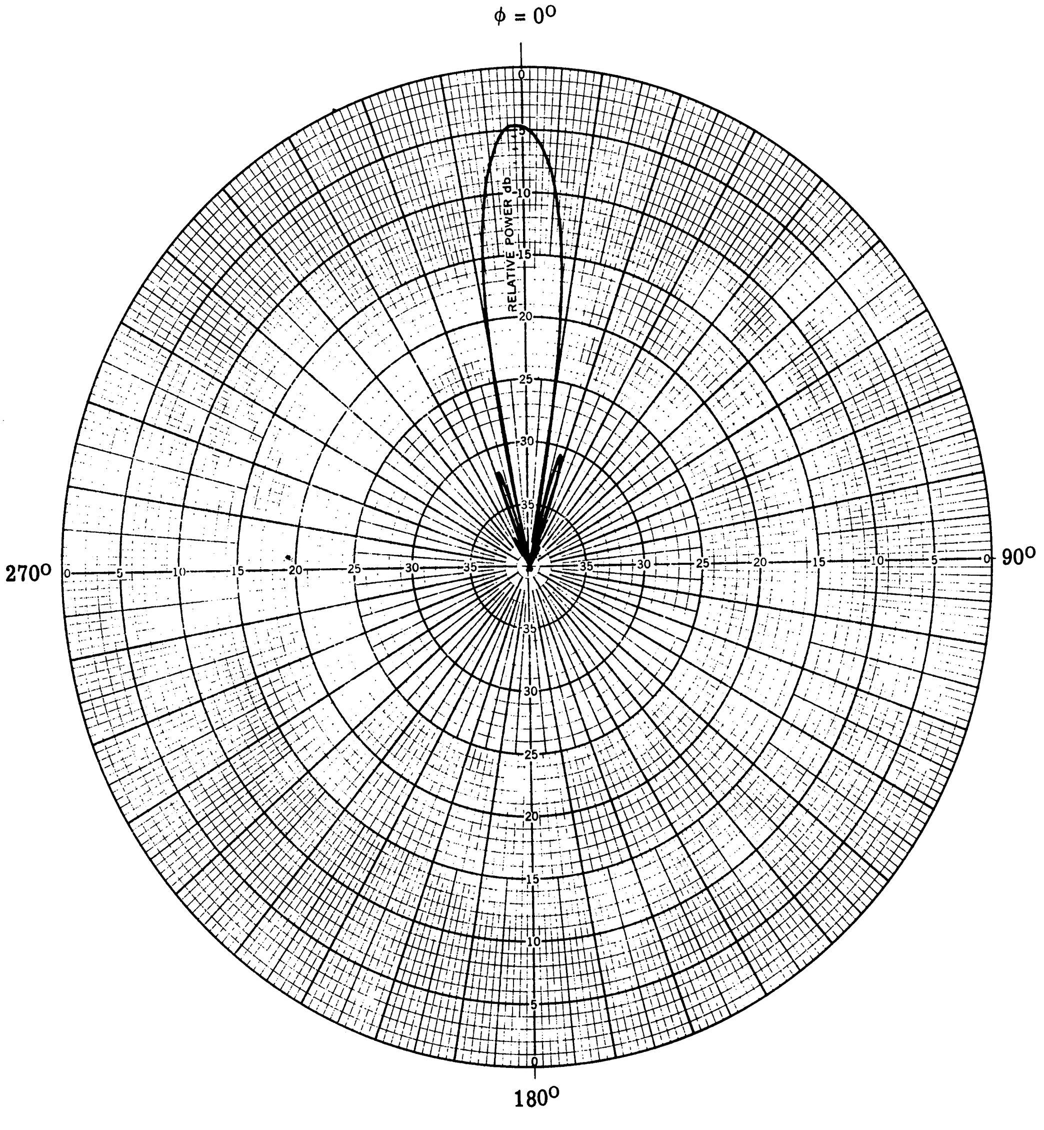


FIG. 36: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 2.1 GHz

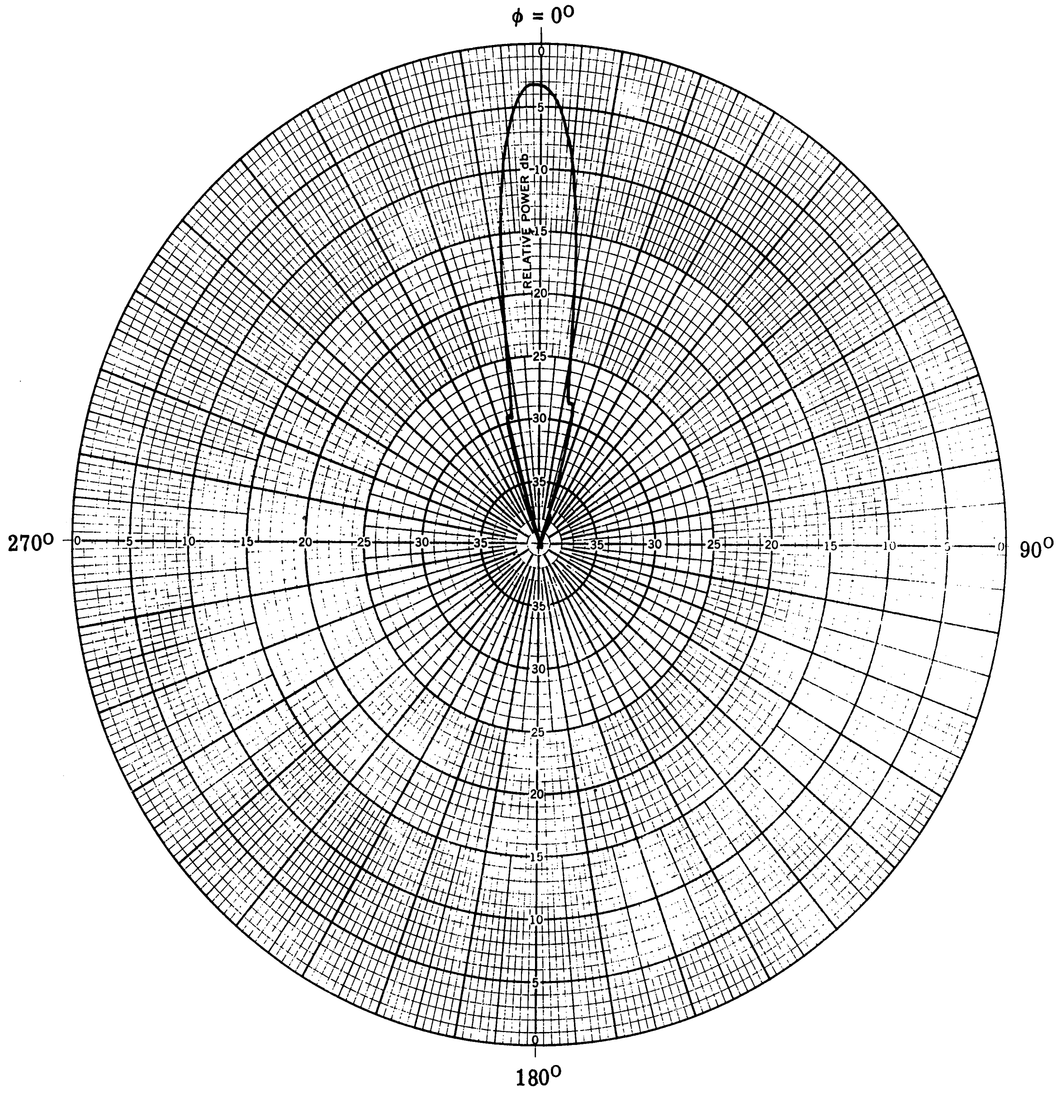


FIG. 37: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 2.5 GHz

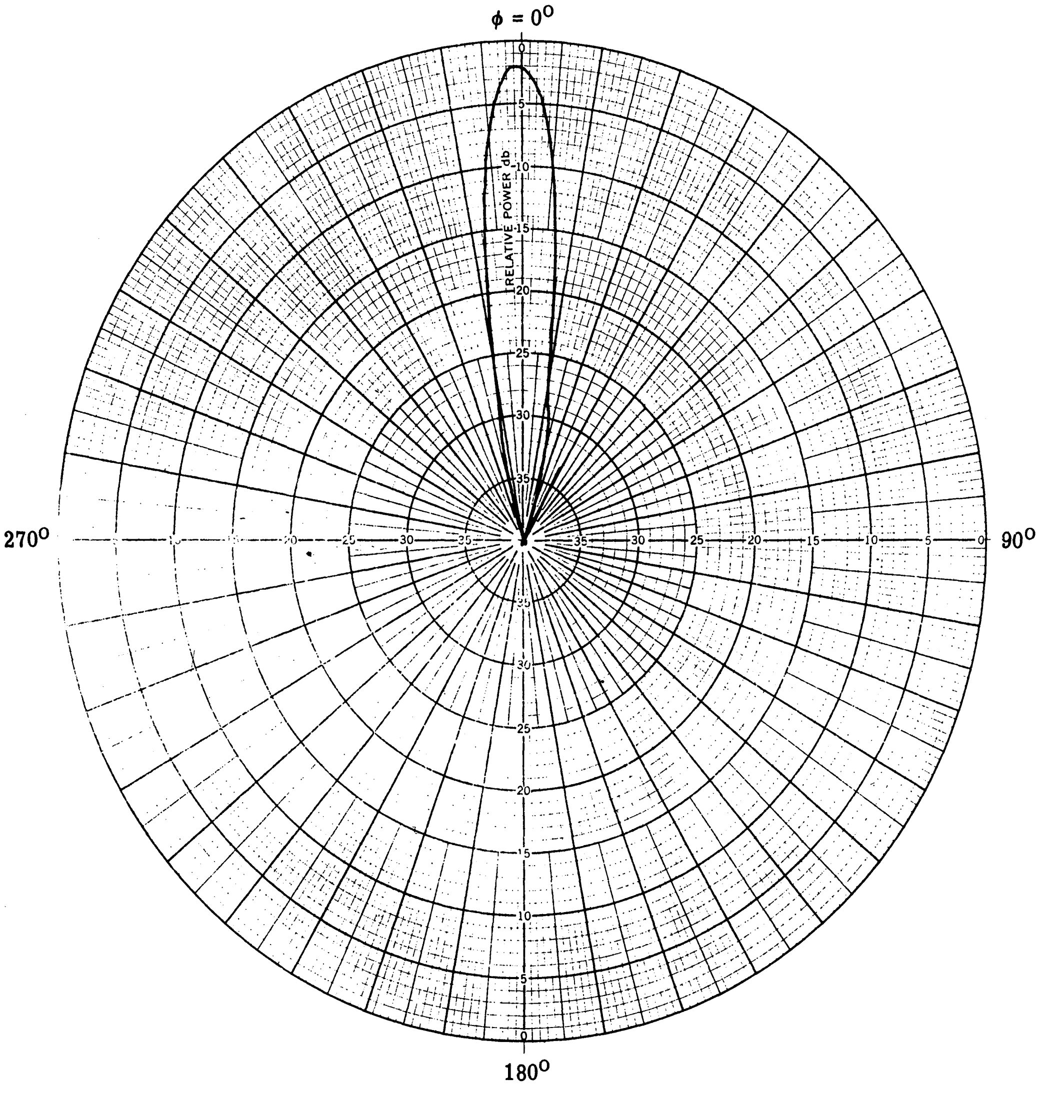


FIG. 38: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 3.0 GHz

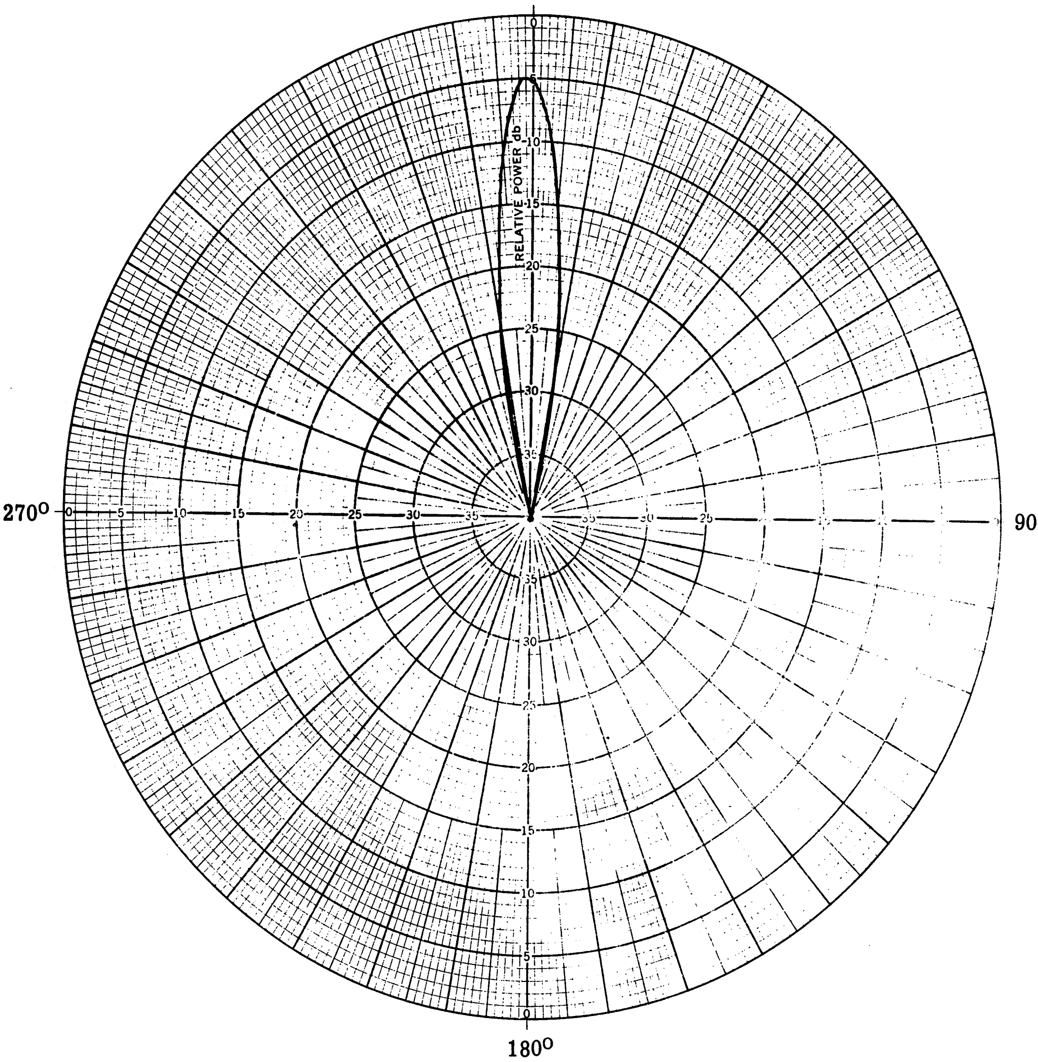


FIG. 39: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 4 GHz

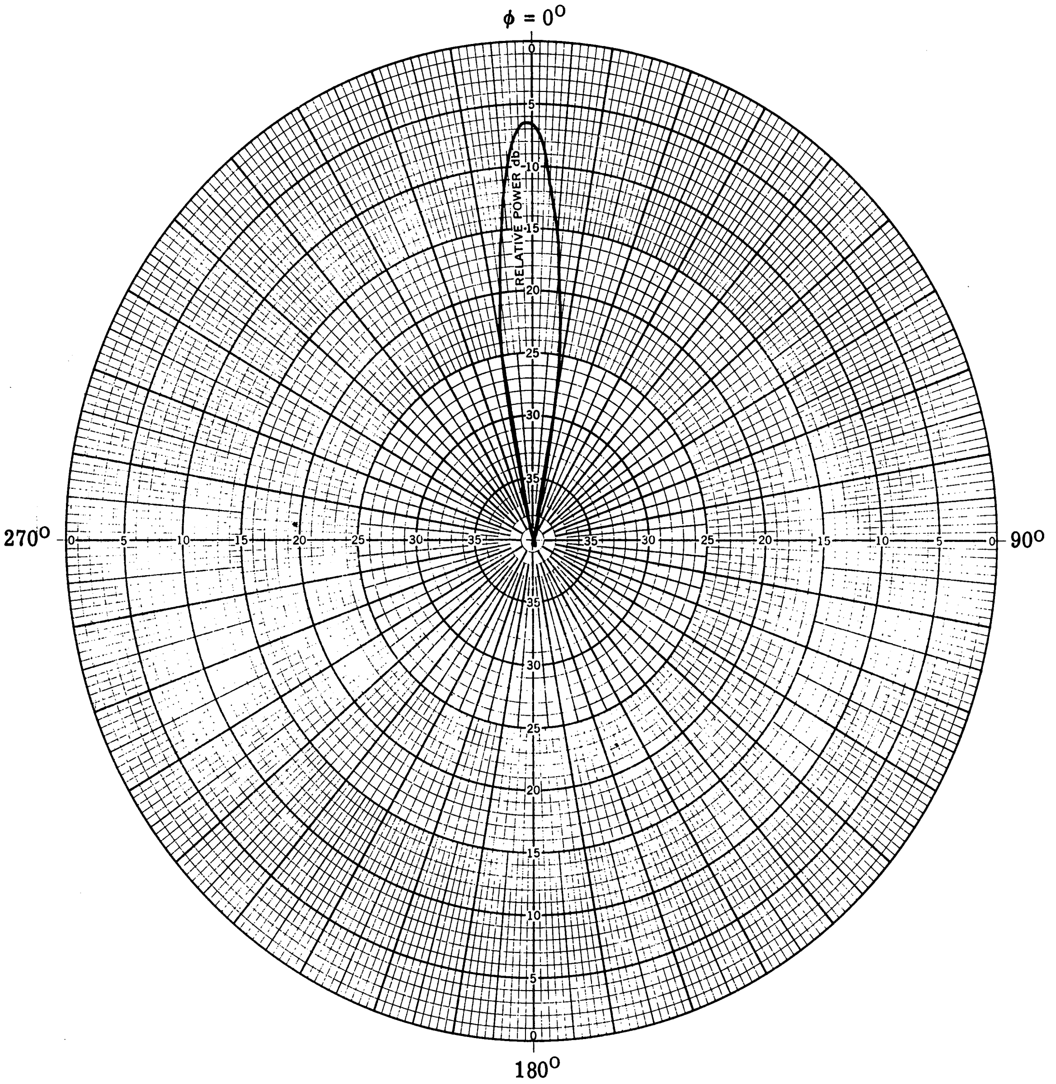


FIG. 40: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 5.3 GHz

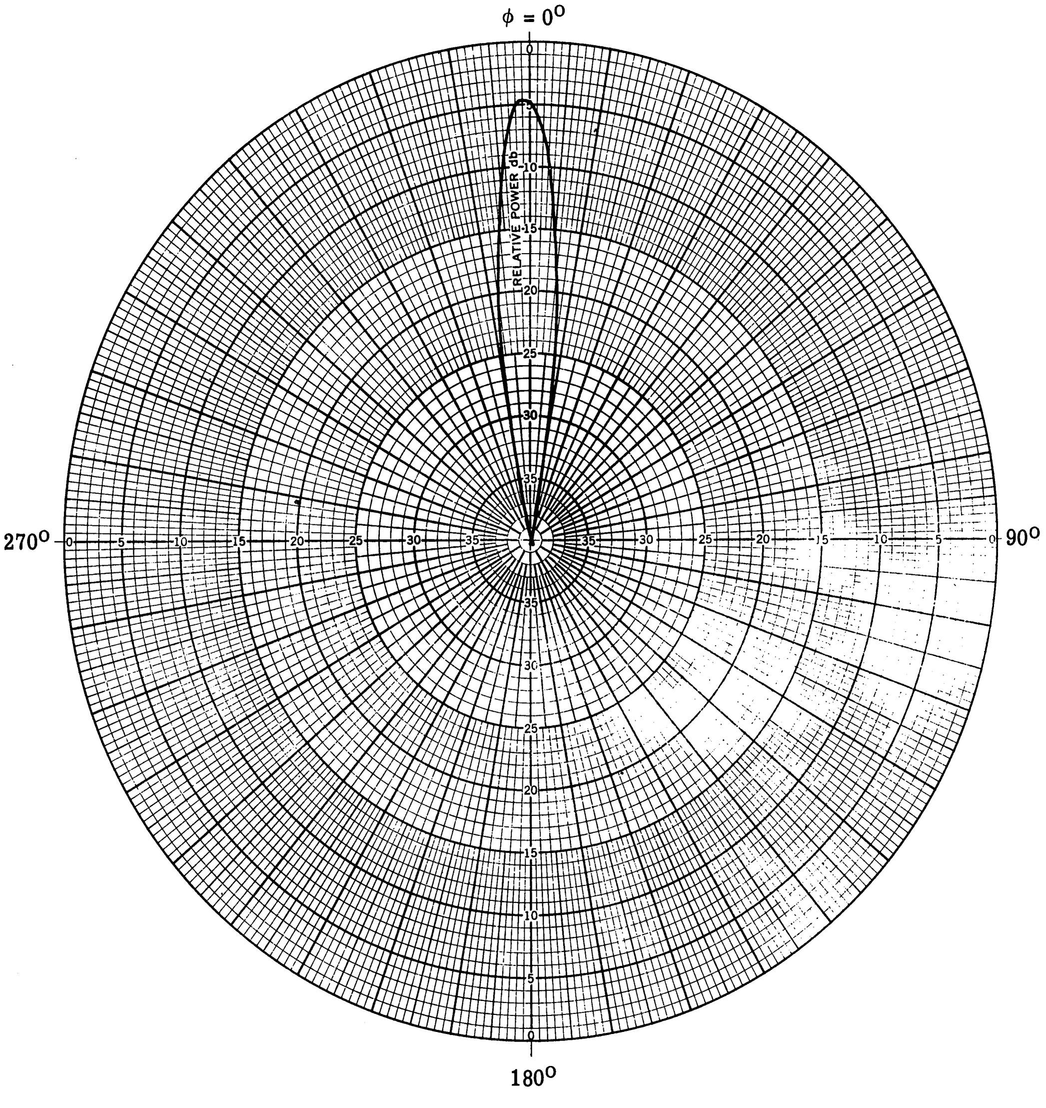


FIG. 41: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 5.93 GHz

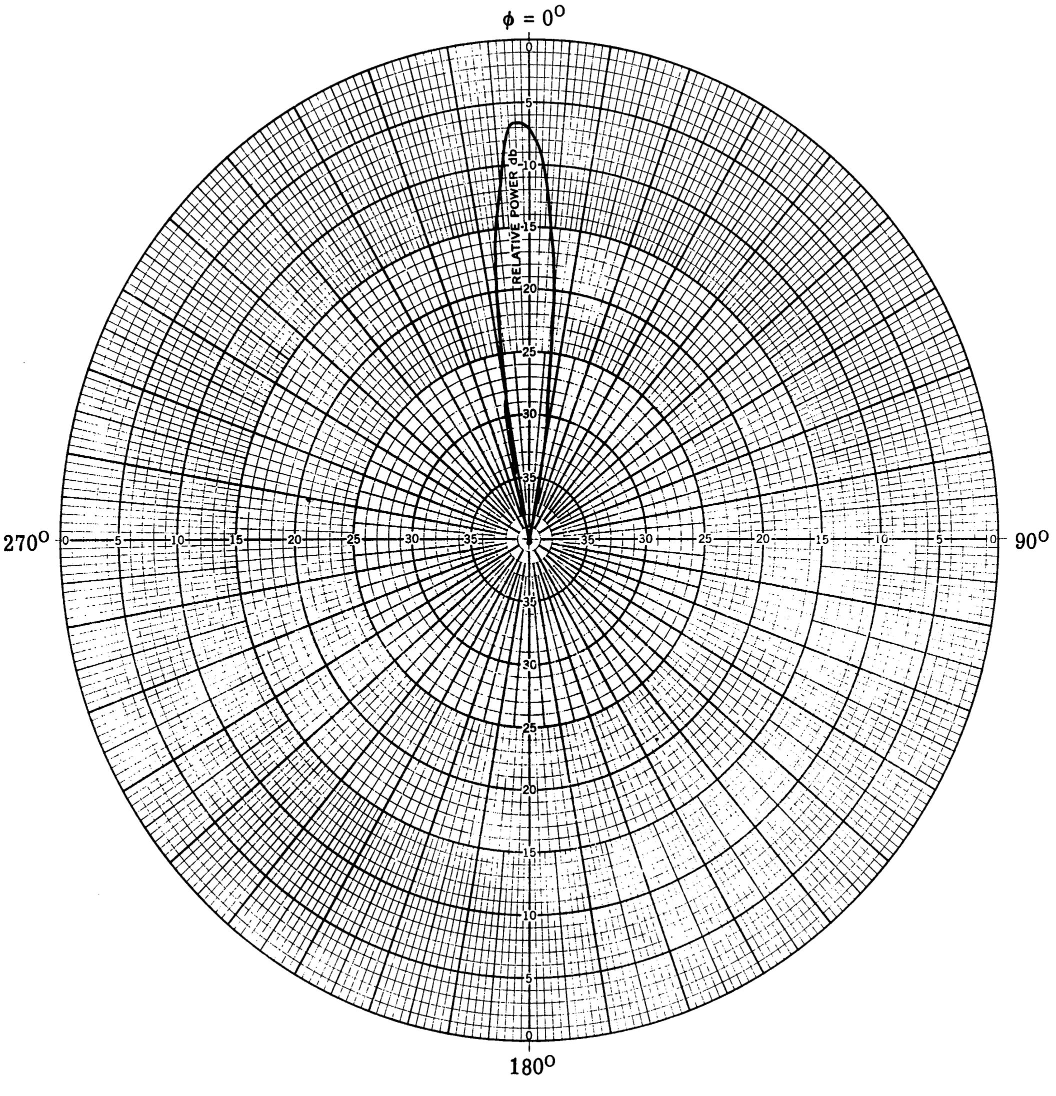


FIG. 42: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 6.95 GHz

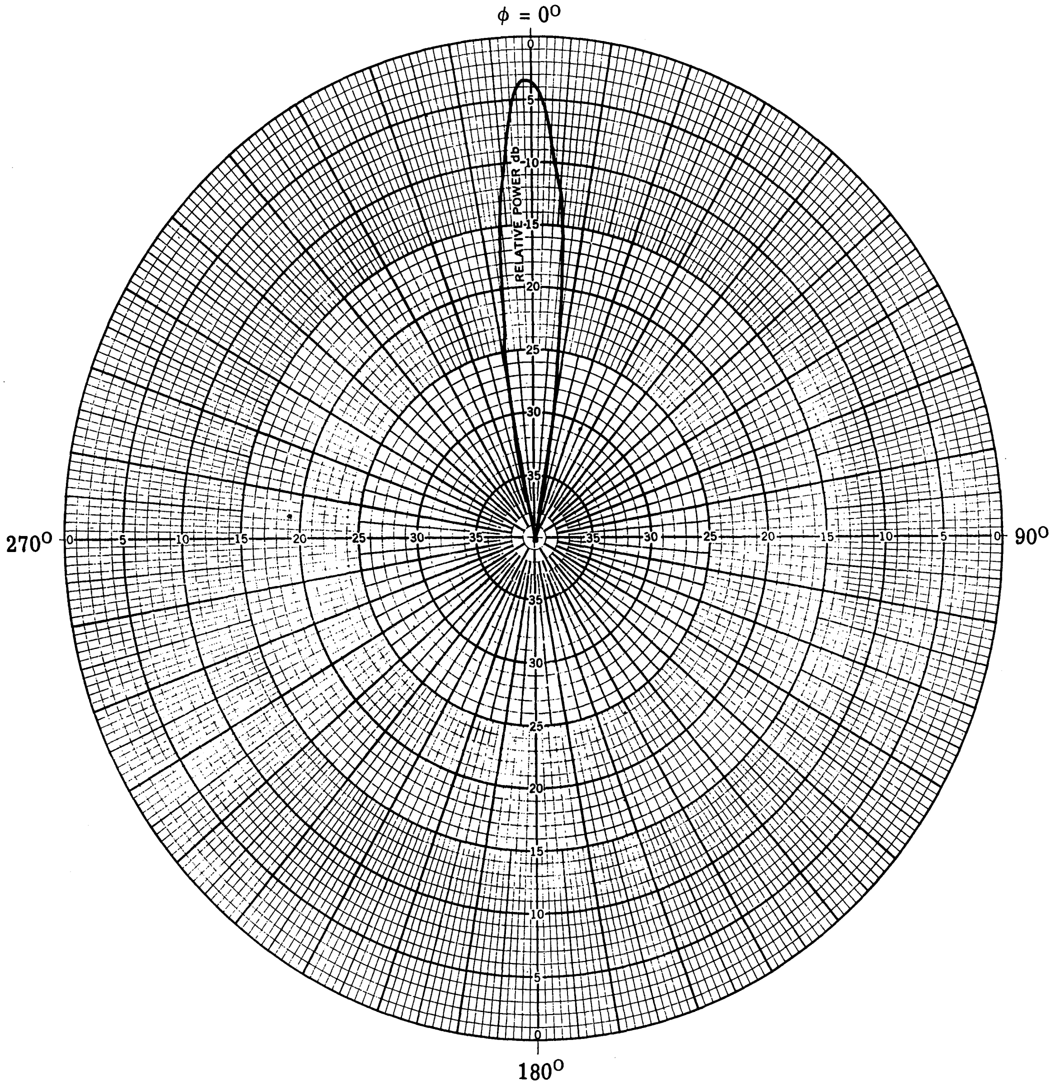


FIG. 43: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 8.2 GHz

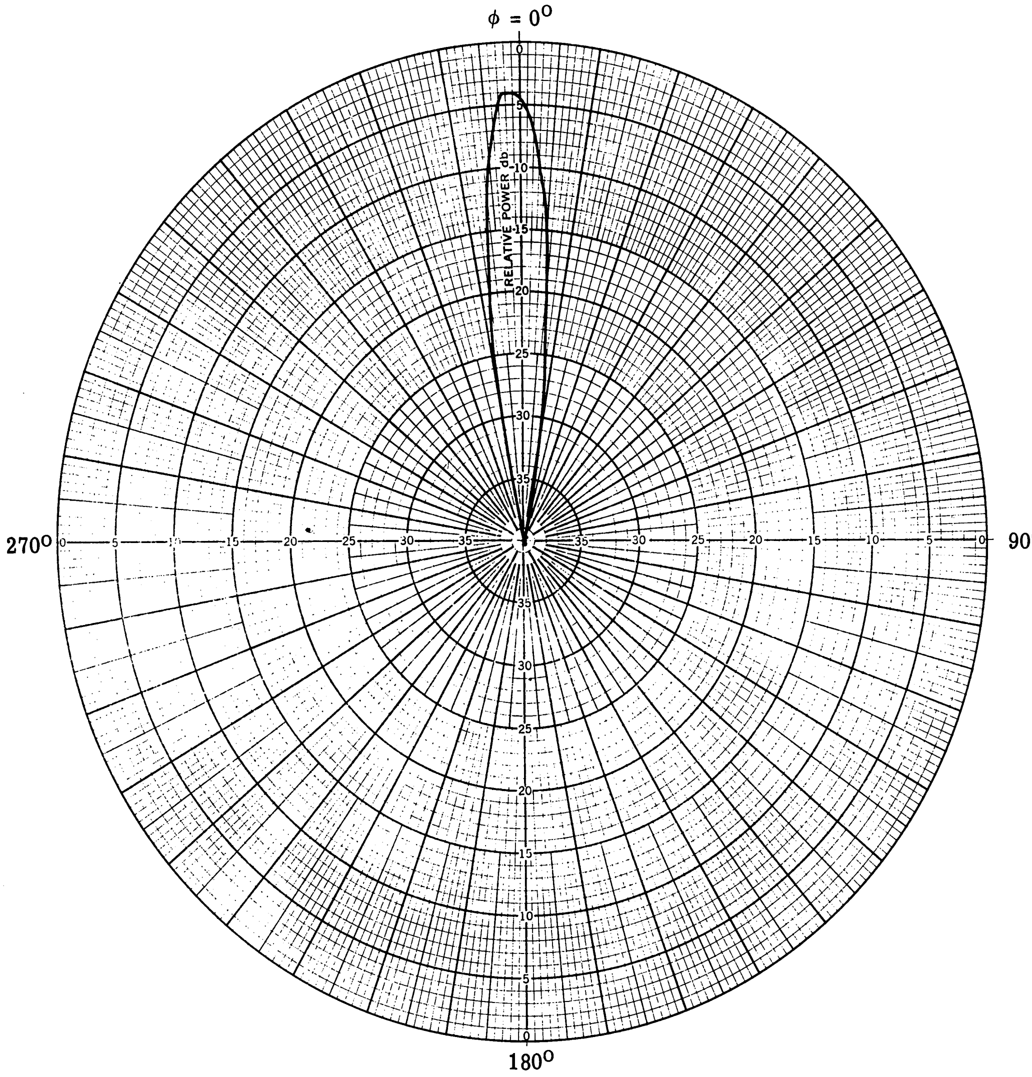


FIG. 44: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 9.12 GHz

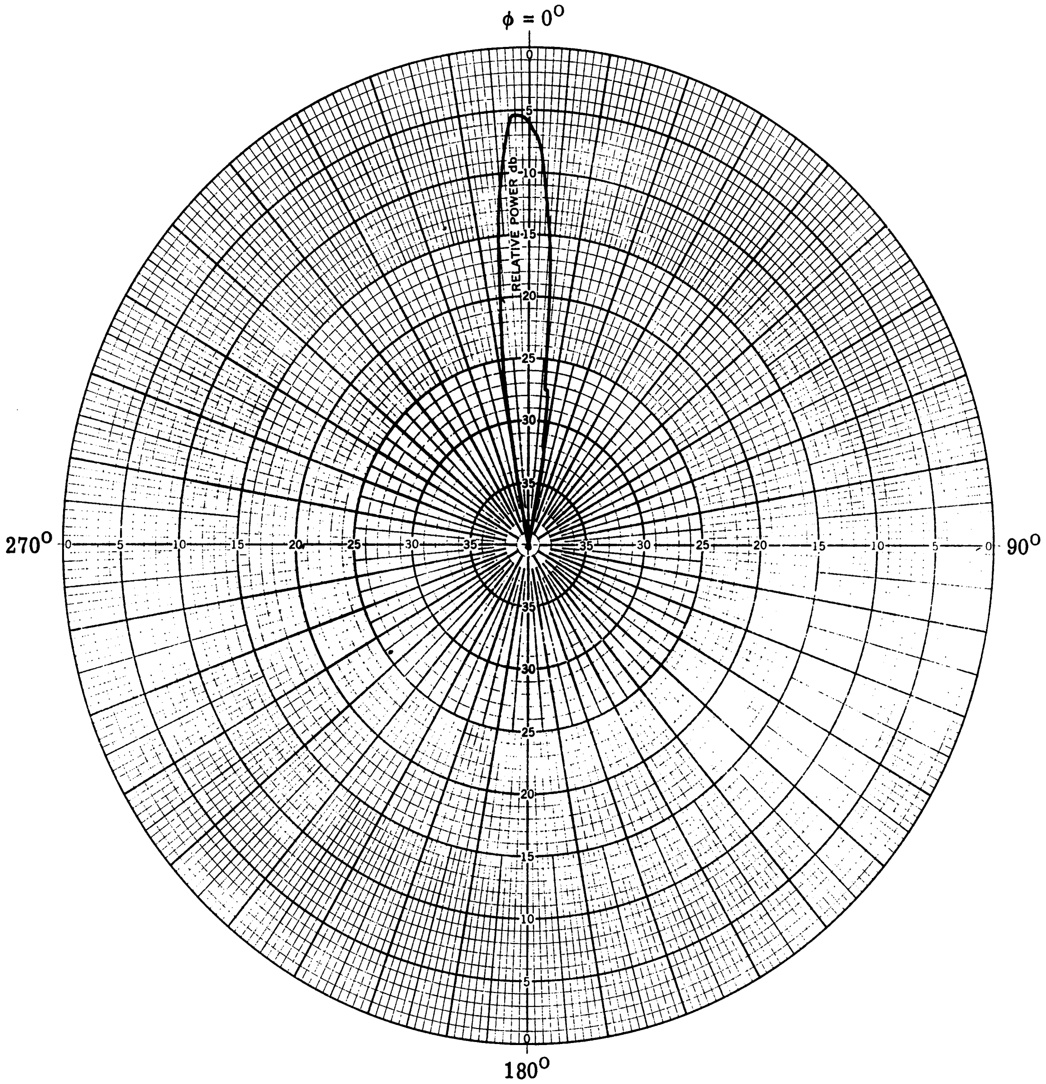


FIG. 45: H-PLANE POLARIZATION OF ASYMMETRICAL PARABOLIC REFLECTOR AT 10 GHz

III

OMNIDIRECTIONAL ANTENNA

The design goals for the omnidirectional antenna are: 1) 10:1 frequency band (0.1 - 1.0 GHz), 2) the gain is to be 1.5 db above an isotropic source over the above frequency range, 3) VSWR is to be less than 3:1 with respect to a 50 ohm load for the above frequency range, and 4) the maximum diameter of the antenna is not to exceed 20 inches. During this reporting period, consideration has been given to techniques for obtaining horizon coverage. In addition another antenna type has been considered and the mutual coupling effects associated with the manipole antenna have been experimentally investigated.

3.1 Conical Ground Plane Study

The VSWR and pattern characteristics for three conical ground plane configurations such as shown in Fig. 46 have been studied. Four sets of VSWR data are shown in Fig. 47; these data are for a crossed plate antenna above a flat ground plane and the three conical ground planes with α values of 30^o, 45^o, and 60^o. The flat ground plane is a four foot diameter disc whose edges have been scalloped to minimize the probability of ground plane resonance. The conical ground planes each have a fixed base diameter of six inches, independent of α. The conical ground plane having an angle $\alpha = 60^o$ exhibited a reasonable VSWR characteristic for the broadest frequency range. The bandwidth was reduced as the angle α decreased such that with $\alpha = 30^o$ the narrowest bandwidth was observed. The principal cause for the decreased bandwidth as α was decreased is the shortening of the ground plane itself; thus causing higher currents at the base of the ground plane. To broadband the VSWR data it was necessary for the ground plane size to be increased to minimize the base currents as is evident from the VSWR data for $\alpha = 60^o$. Additional information on the broadband characteristics of the ground plane was given in the second interim report.

Patterns of the eight plate monopole located above the conical ground plane configurations noted above were recorded in the frequency range of 1.5 to 3.0 GHz. Data first obtained with the antenna over a flat ground plane is shown in Figs. 49 - 52; the coordinate system of Fig. 48 was followed. From these patterns one can readily see that placing the antenna above the flat ground plane causes maximum radiation to occur several degrees above the horizon (with little coverage on the horizon) at the lower frequencies (1.5 GHz). As the frequency is increased coverage on the horizon increases such that several db of improvement is obtained at 3 GHz. Typical patterns for the eight crossed plate antenna above the three different conical ground planes are shown respectively in Figs. 53 - 59, 60 - 63, and 64 - 70. From these patterns it is suggested that optimum horizon coverage can be obtained using a conical ground plane with an α of 30^o. However, before a final recommendation

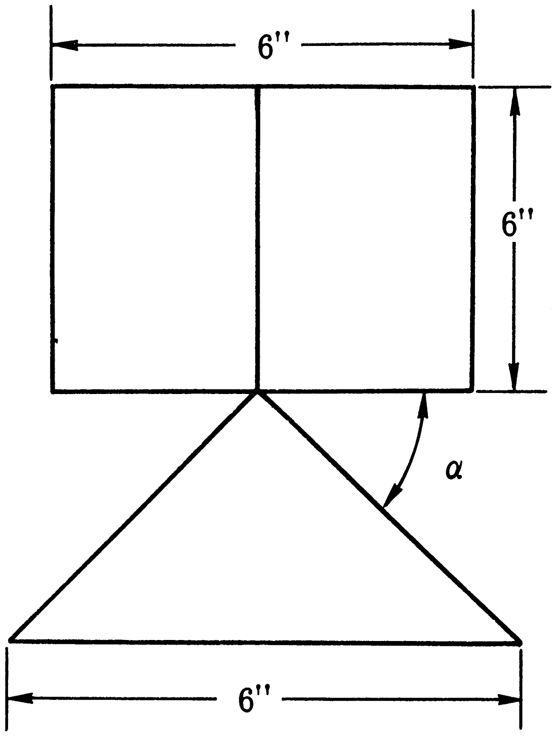


FIG. 46: DESCRIPTION OF CONICAL GROUND PLANE (Freq. Range .3 - 3 GHz)

FIG. 47a: EIGHT CROSSED PLATE/FLAT GROUND PLANE (VSWR)

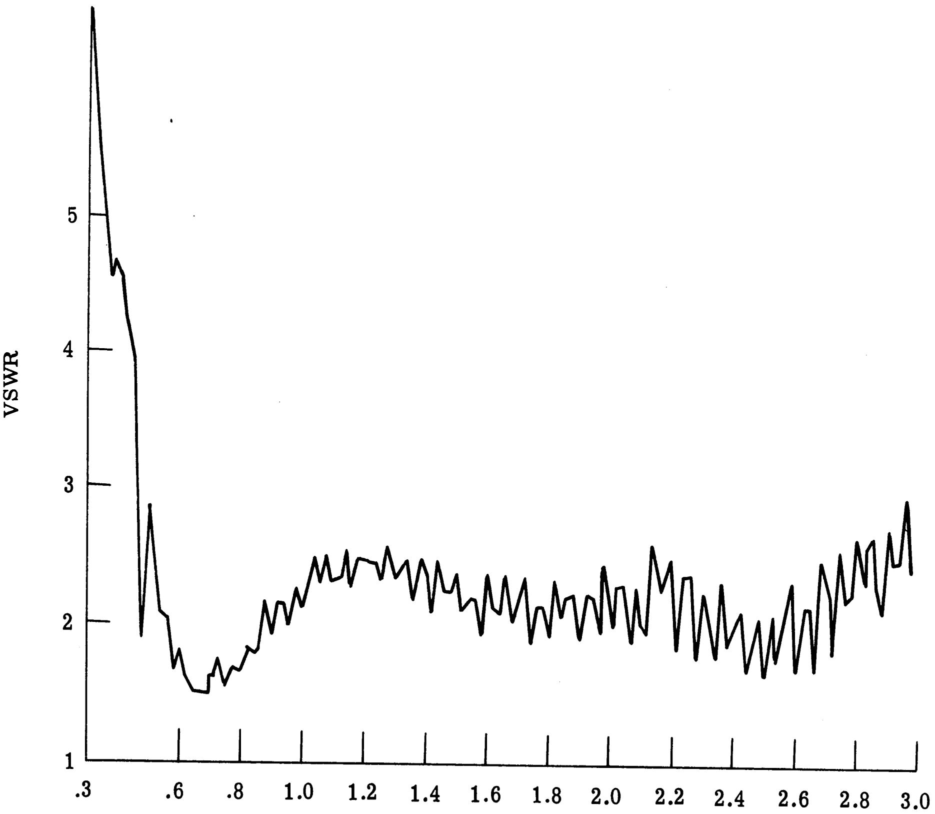


FIG. 47b: EIGHT CROSSED PLATE/30° CONICAL GROUND PLANE (VSWR)

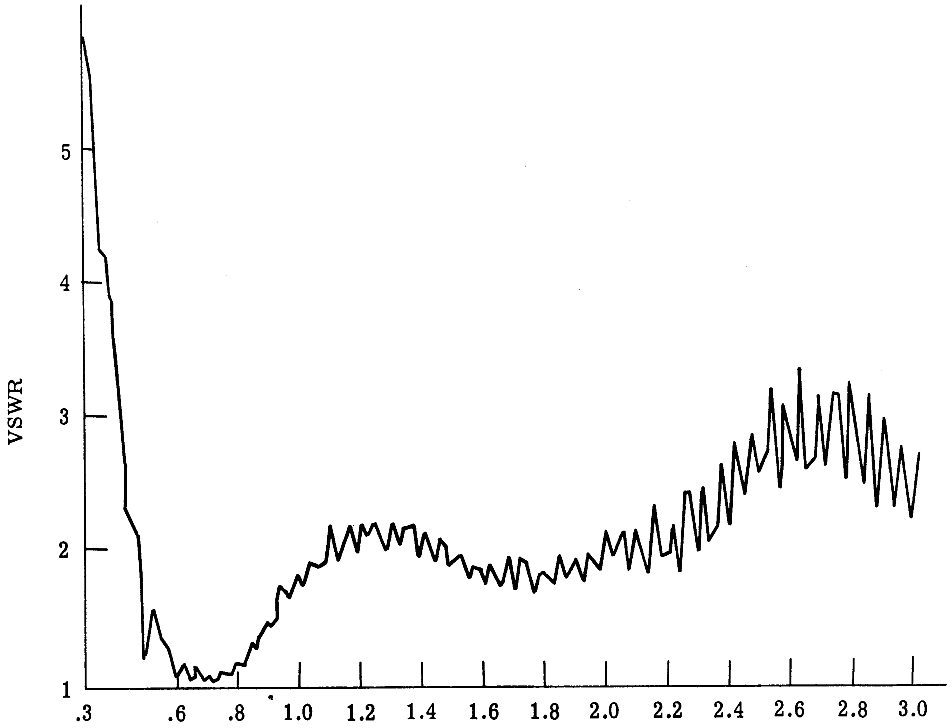


FIG. 47c: EIGHT CROSSED PLATE/45° CONICAL GROUND PLANE (VSWR)

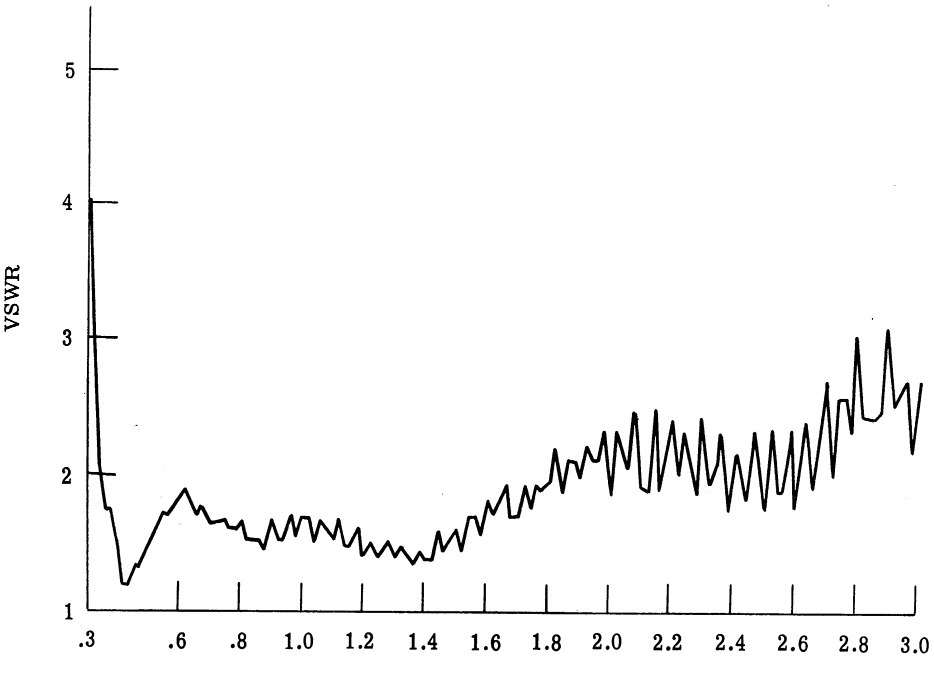


FIG. 47d: EIGHT CROSSED PLATE/60° CONICAL GROUND PLANE (VSWR)

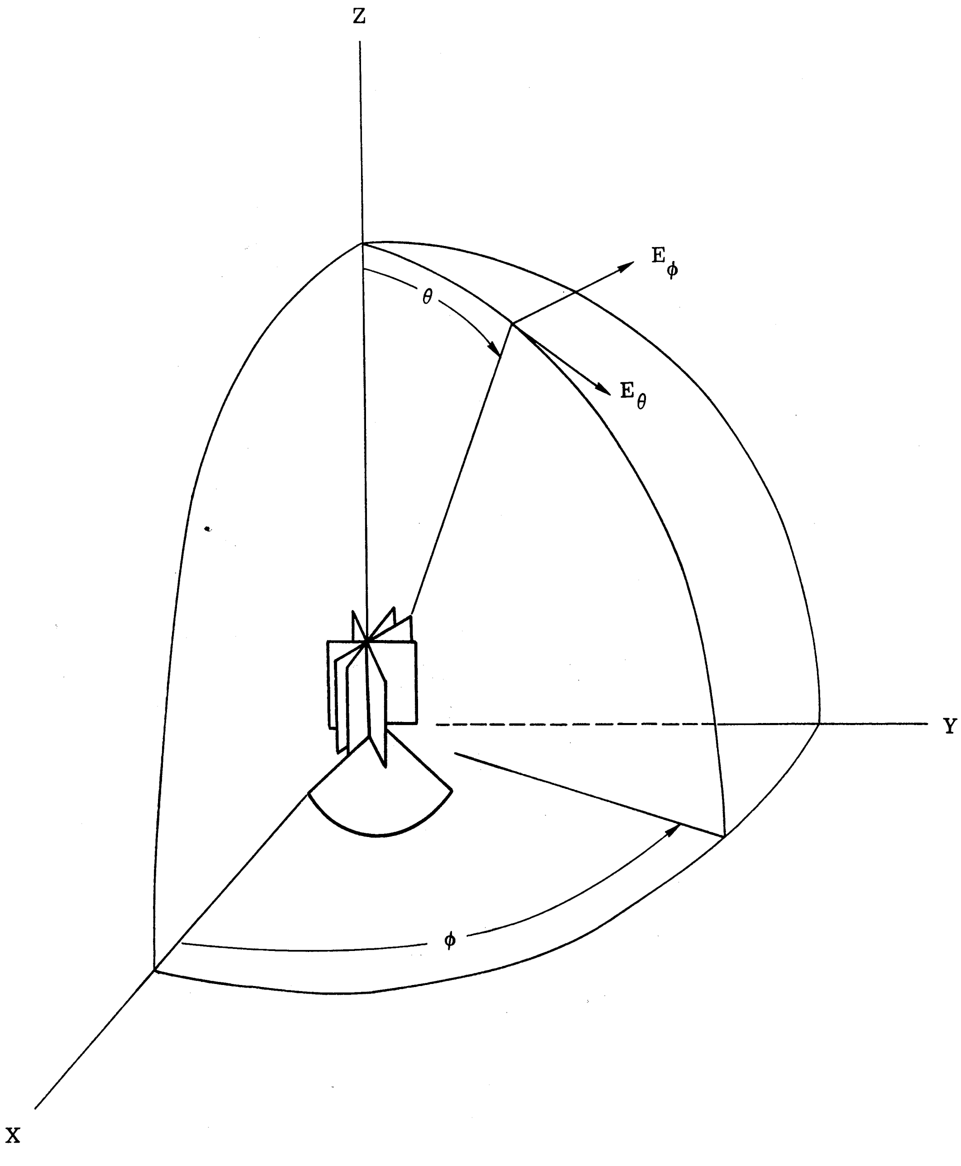


FIG. 48: CONICAL GROUND PLANE SPHERICAL COORDINATE SYSTEM

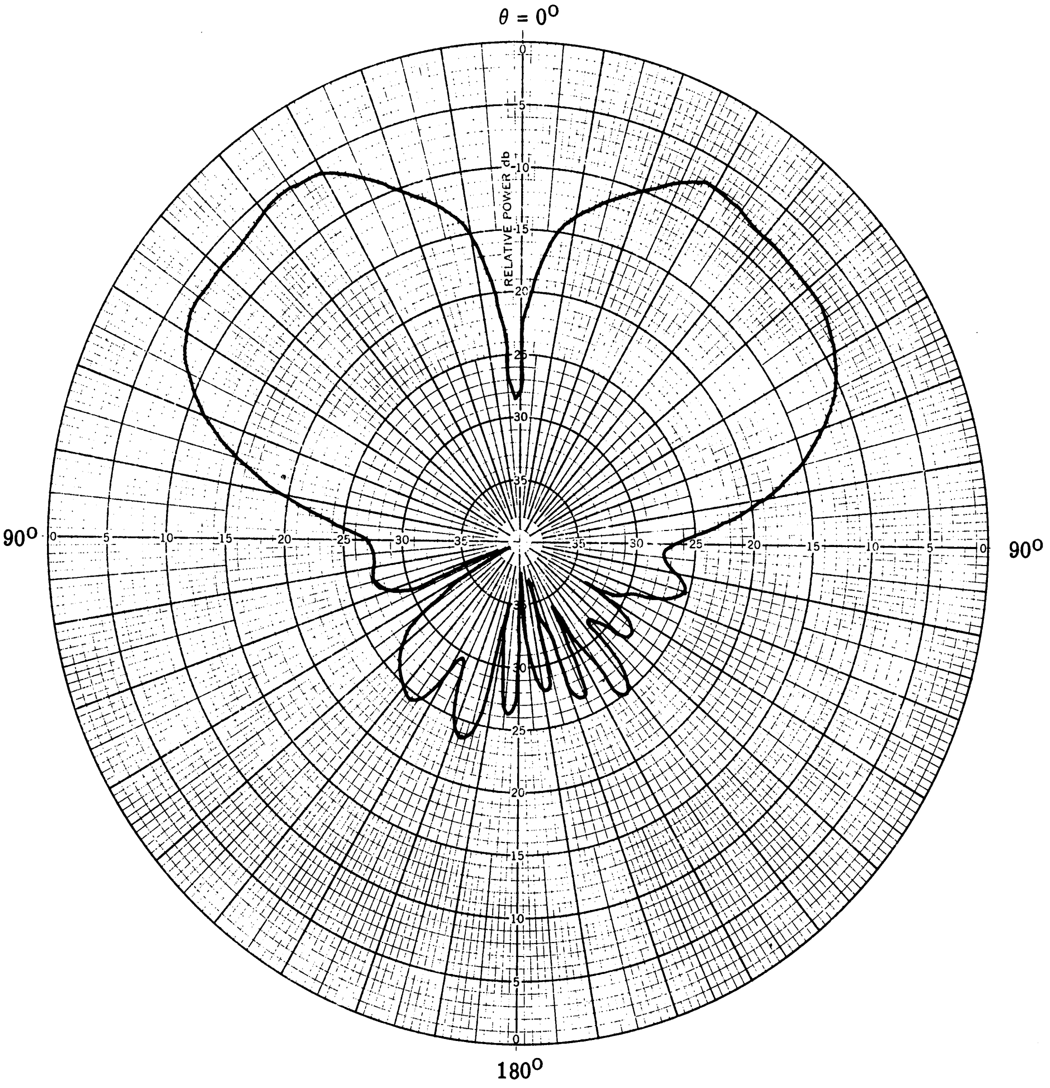


FIG. 49: E-PLANE POLARIZATION OF 8 CROSSED PLATE/FLAT GROUND PLANE AT 1.5 GHz

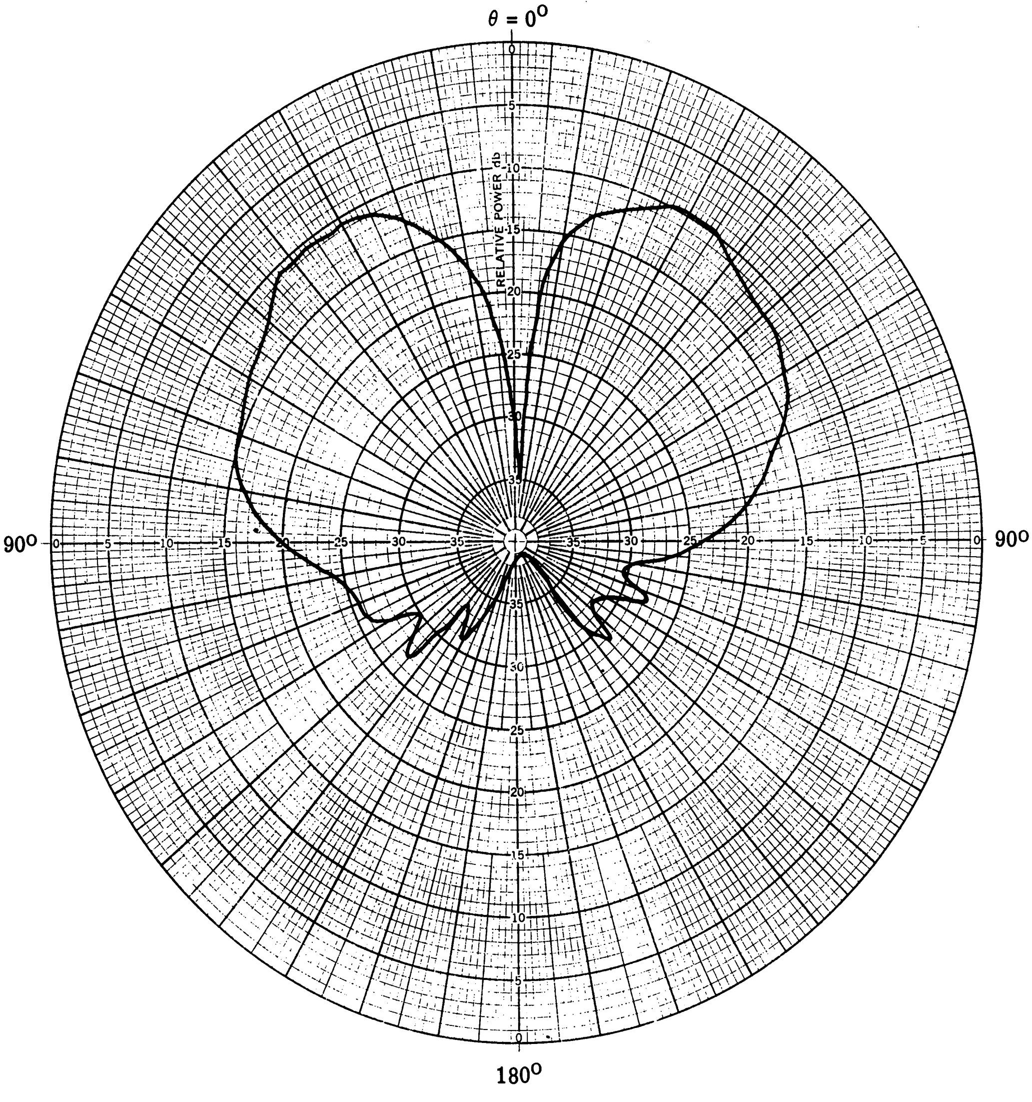


FIG. 50: E-PLANE POLARIZATION OF 8 CROSSED PLATE/FLAT GROUND PLANE AT 2 GHz

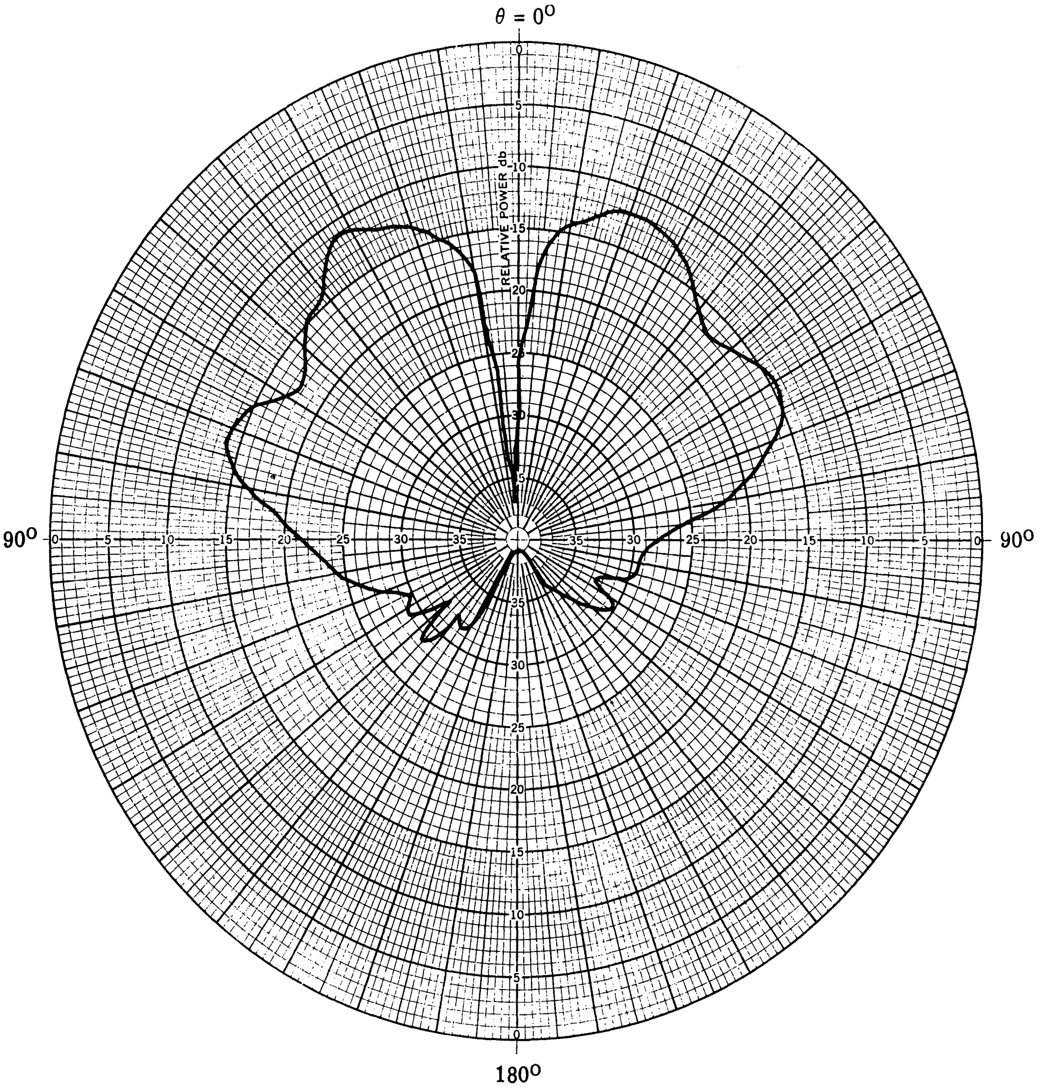


FIG. 51: E-PLANE POLARIZATION OF 8 CROSSED PLATE/FLAT GROUND PLANE AT 2.5 GHz

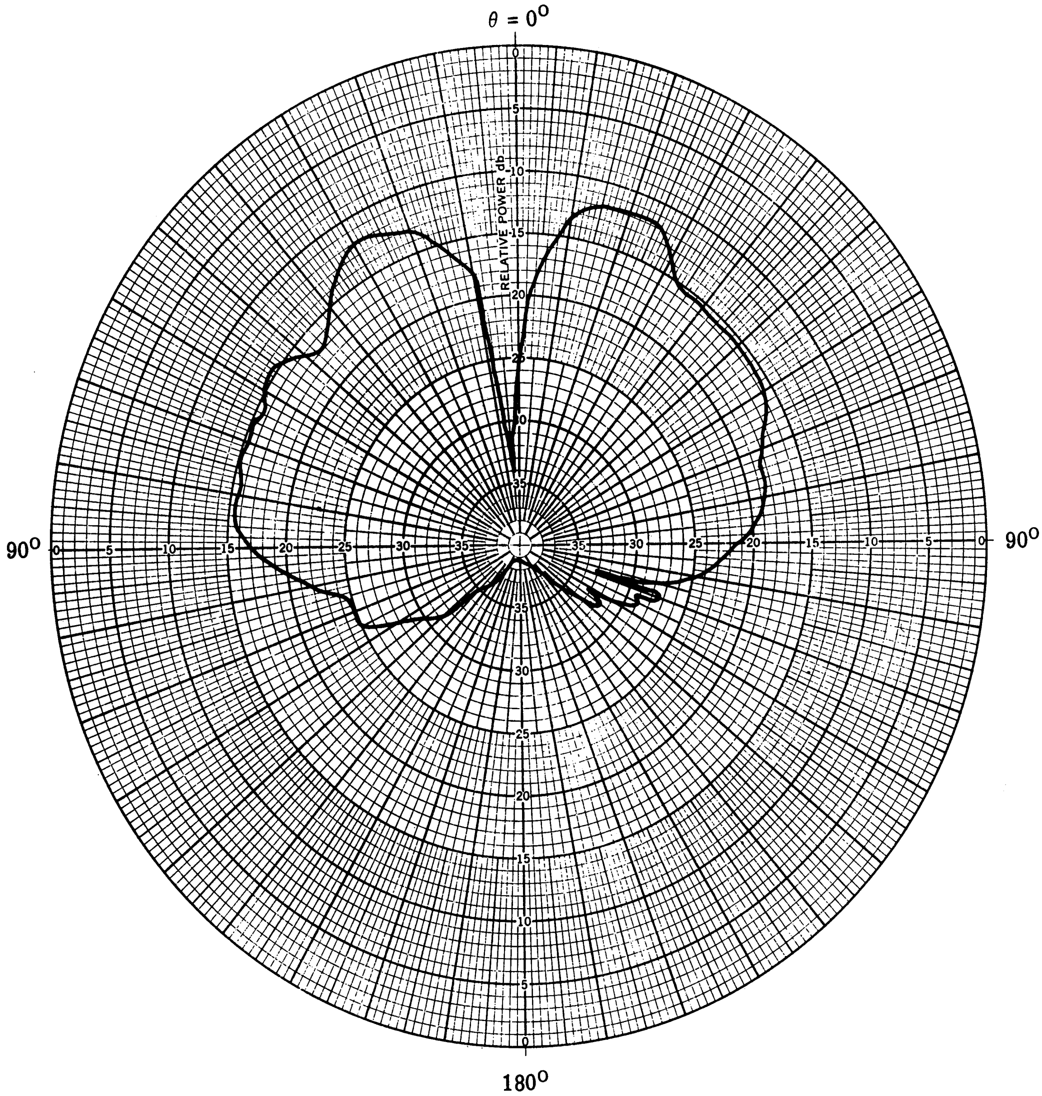


FIG. 52: E-PLANE POLARIZATION OF 8 CROSSED PLATE/FLAT GROUND PLANE AT 3 GHz

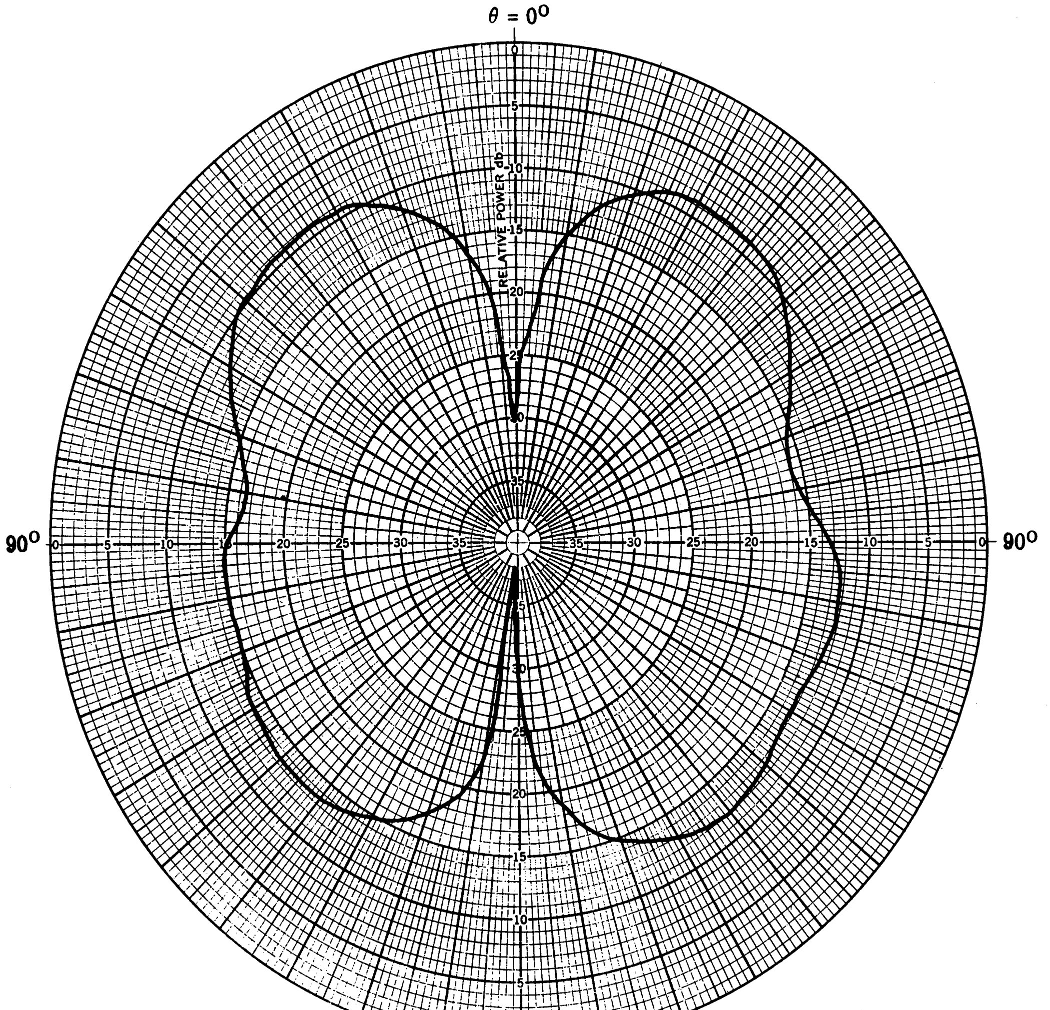


FIG. 53: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 1.6 GHz

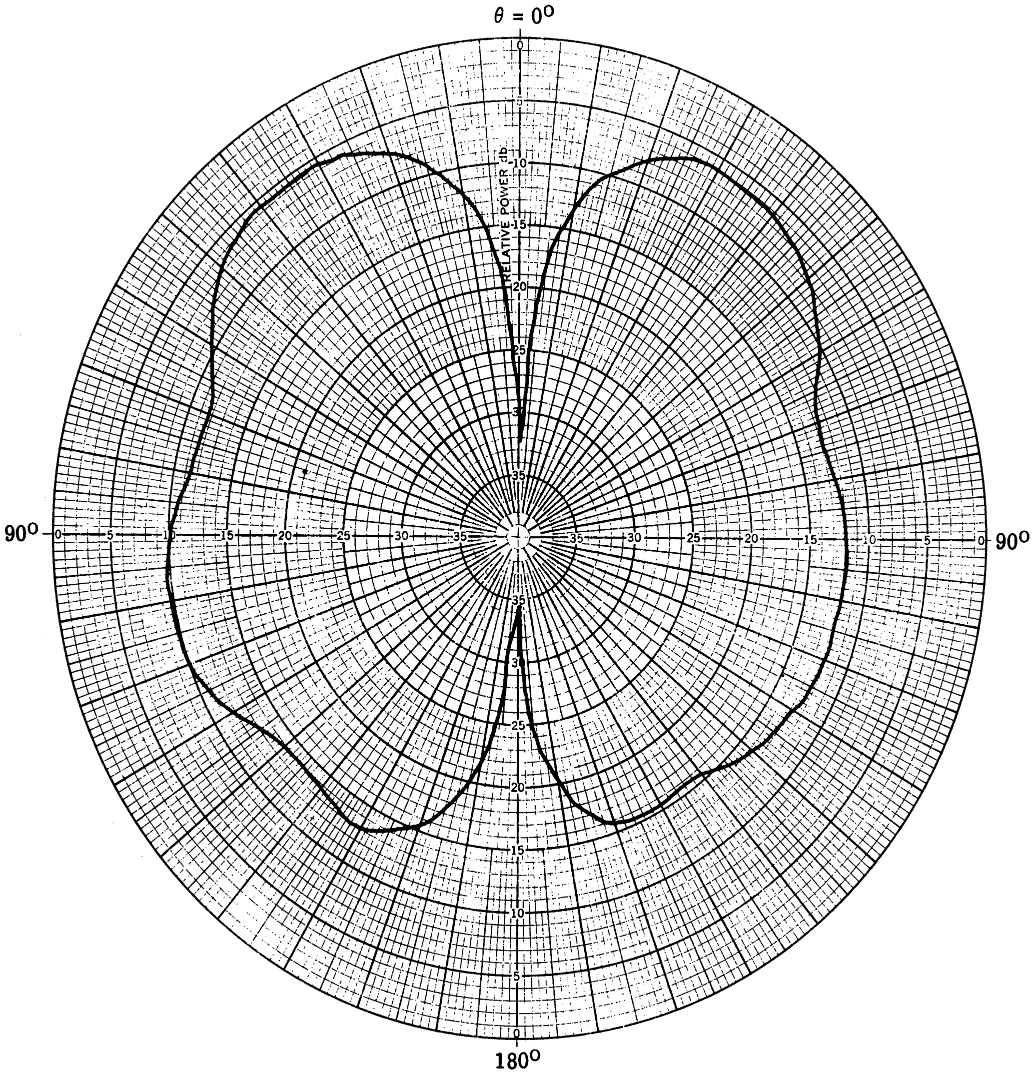


FIG. 54: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 1.8 GHz

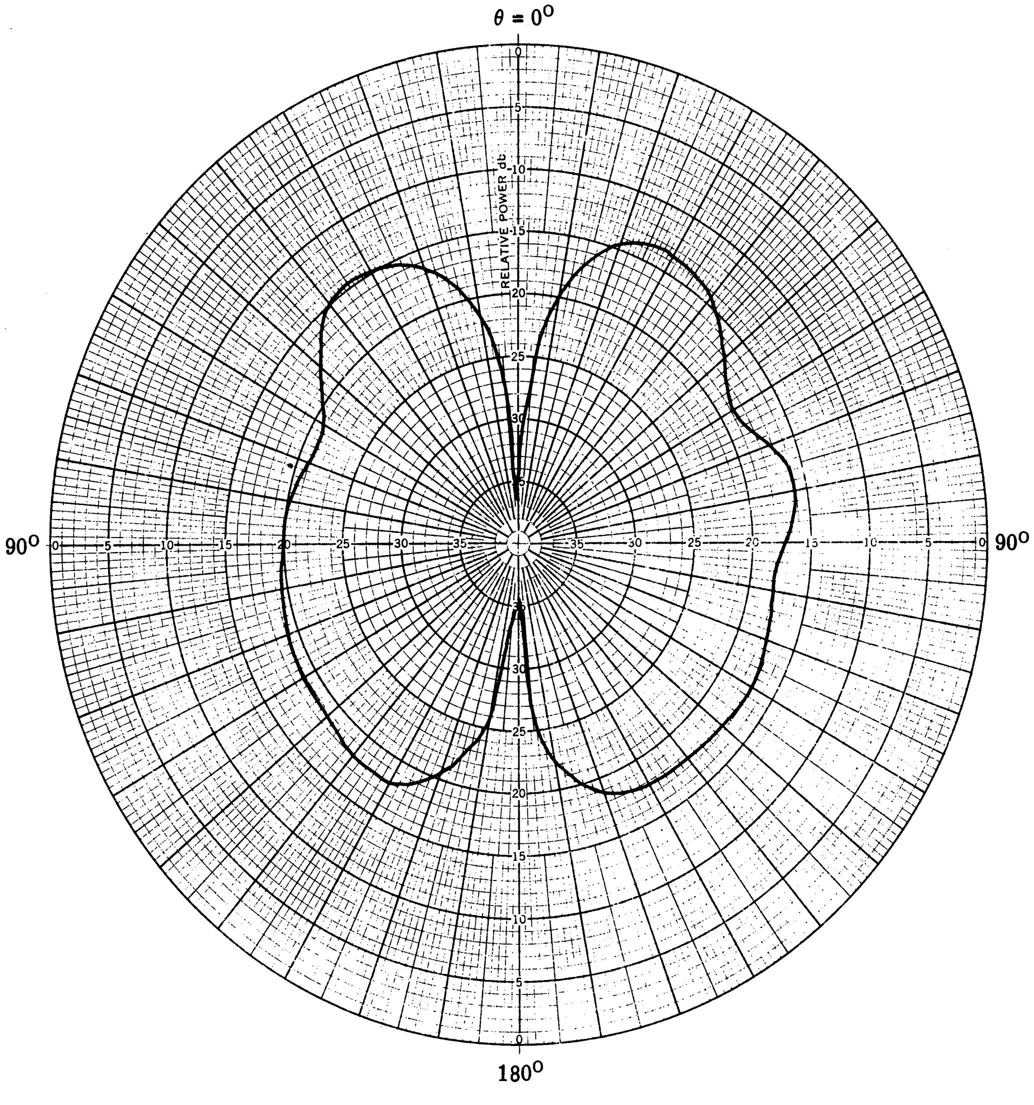


FIG. 55: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 2 GHz

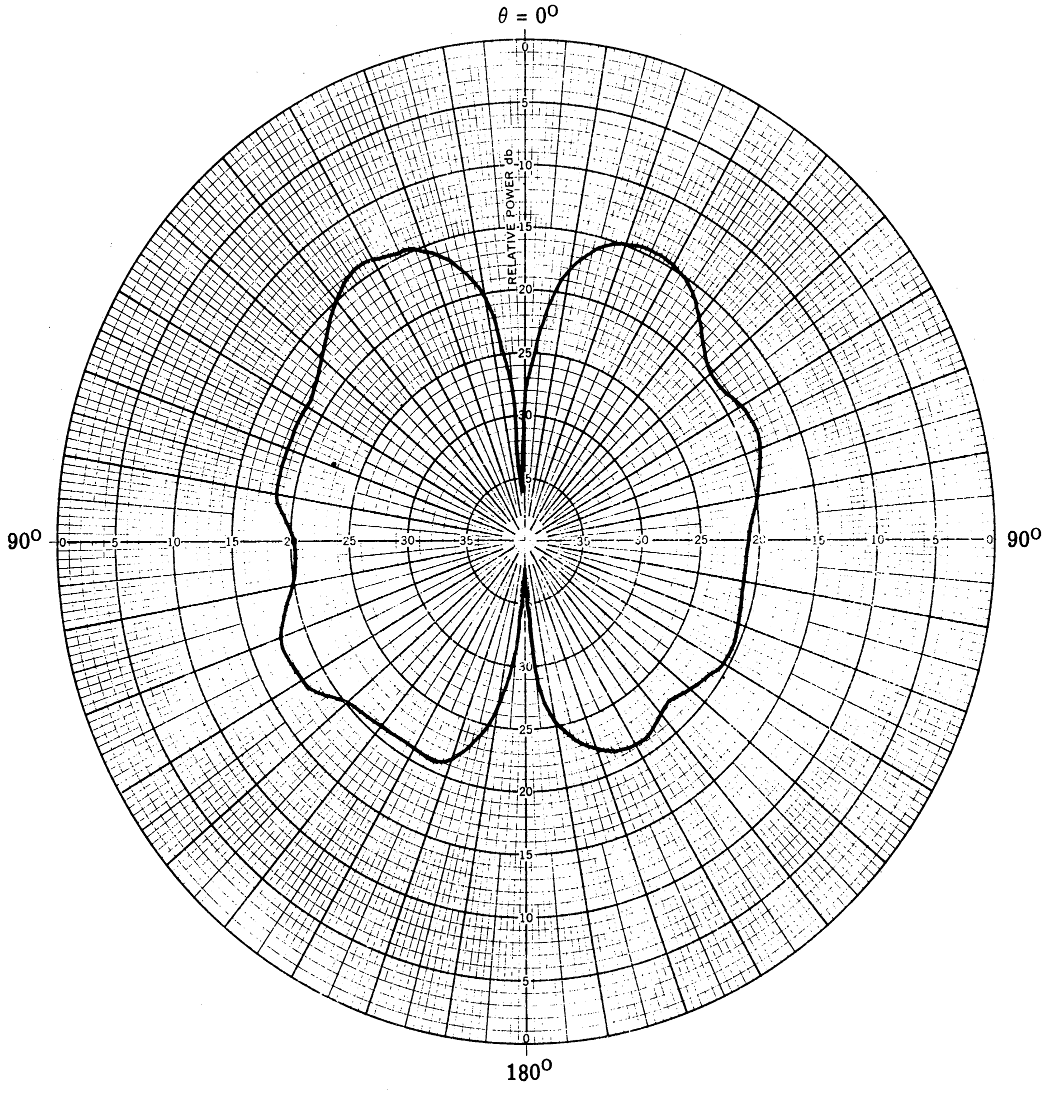


FIG. 56: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 2.3 GHz

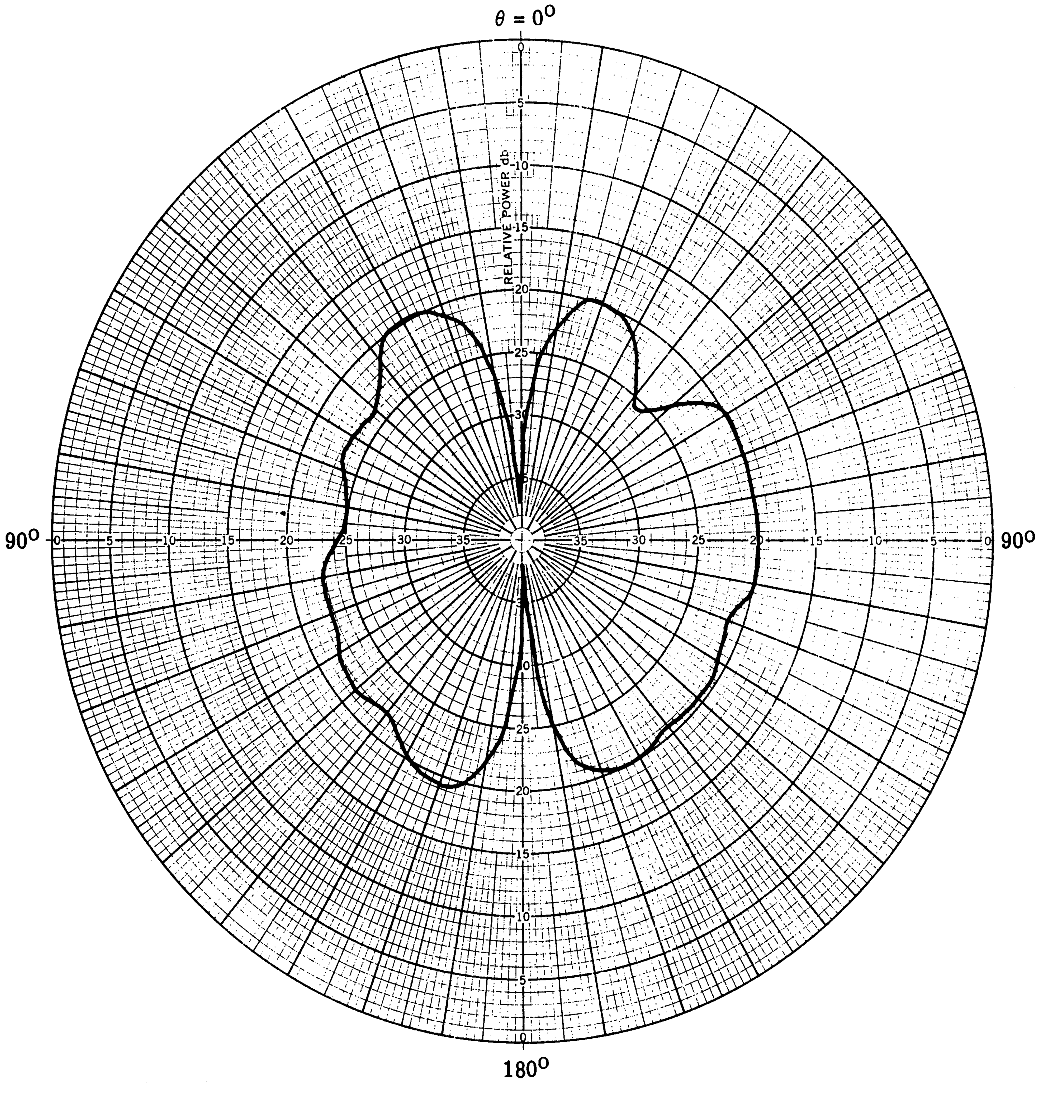


FIG. 57: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 2.6 GHz

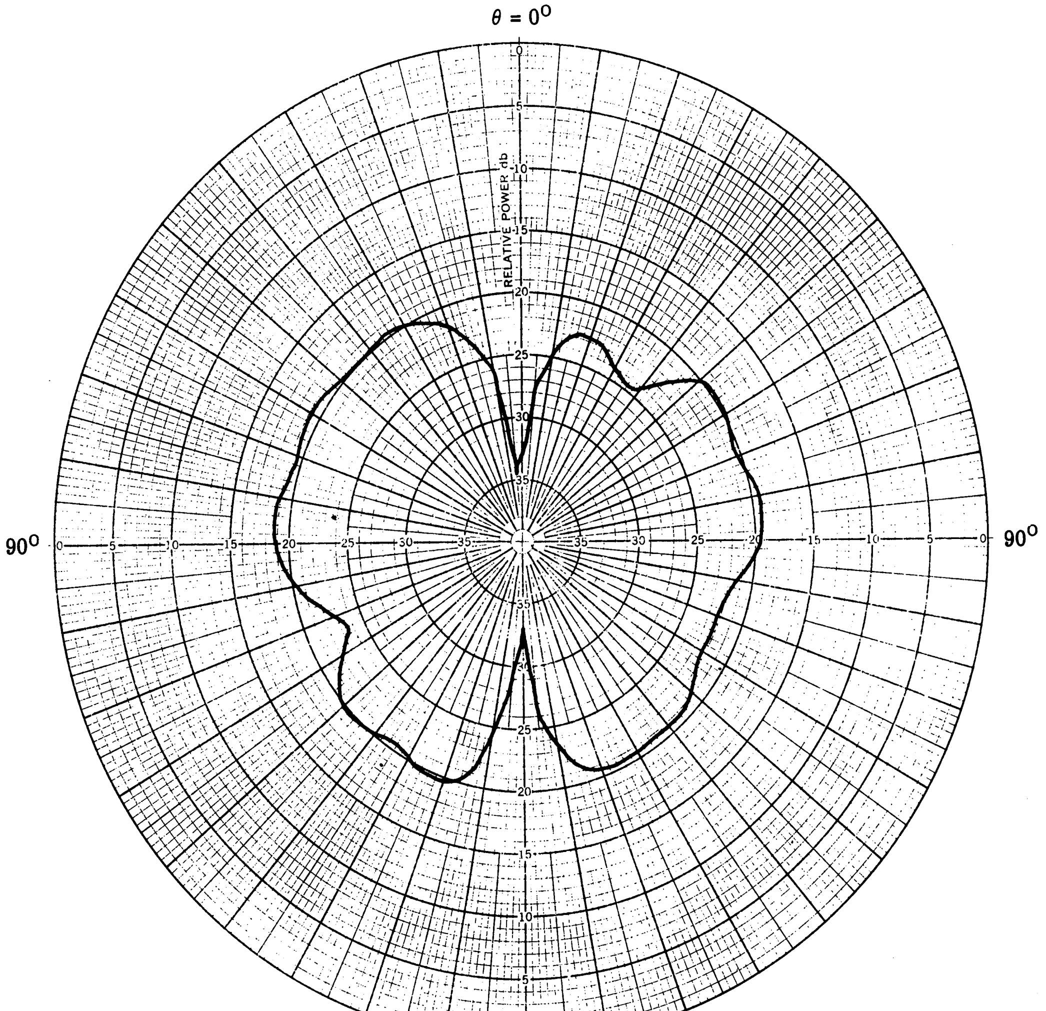


FIG. 58: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 2.9 GHz

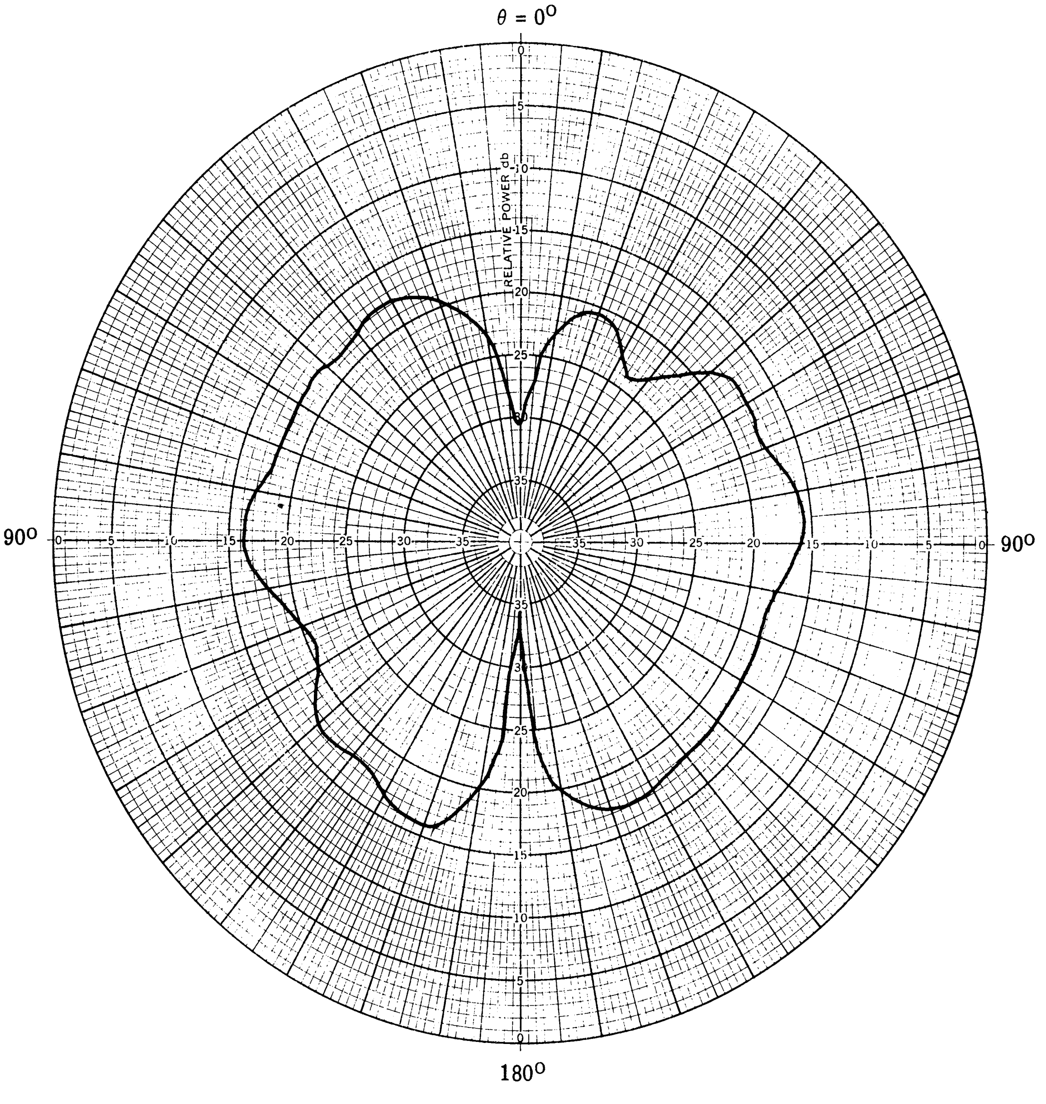


FIG. 59: E-PLANE POLARIZATION OF 8 CROSSED PLATE/30° CONICAL GROUND PLANE AT 3 GHz

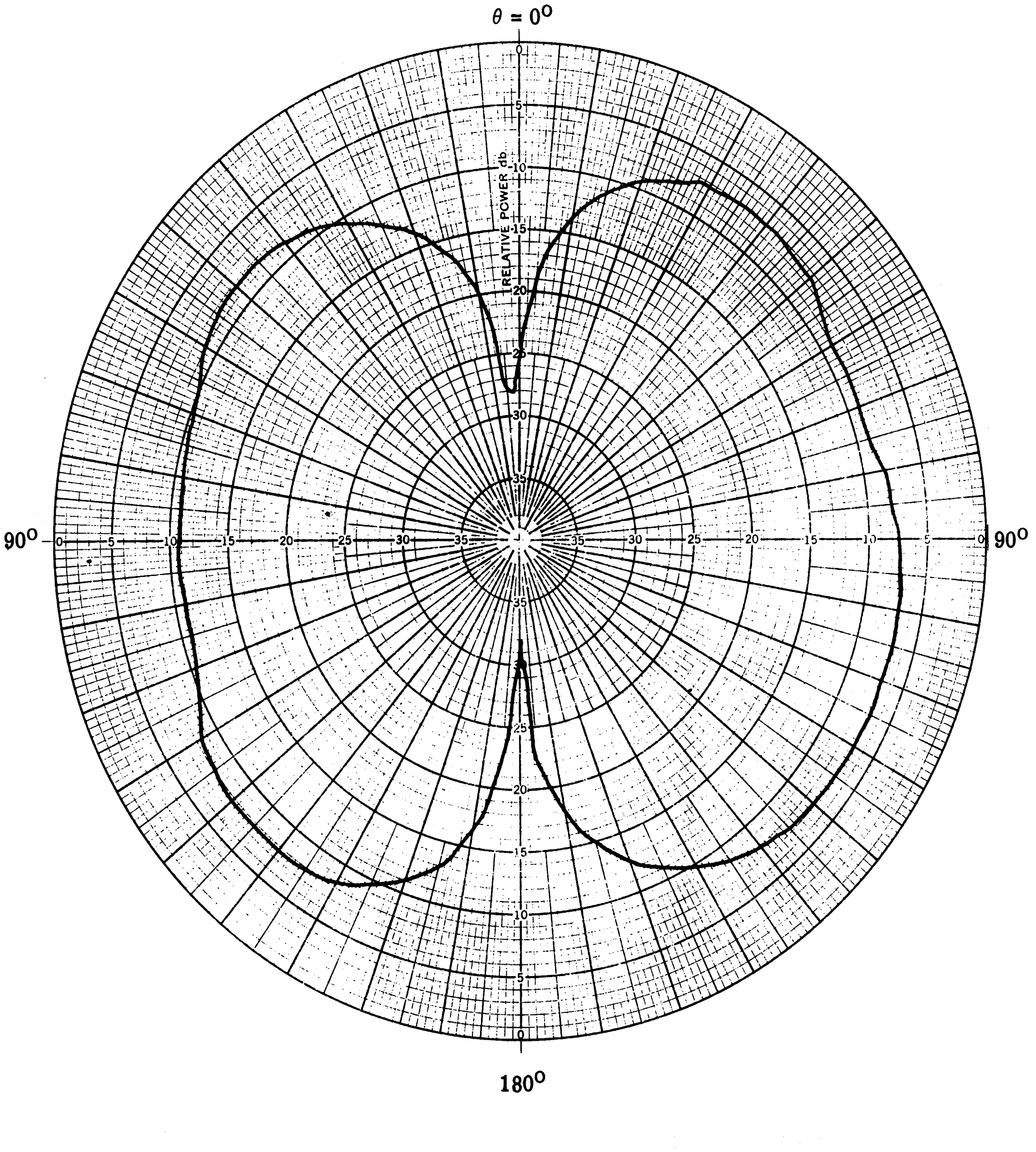


FIG. 60: E-PLANE POLARIZATION OF 8 CROSSED PLATE/45° CONICAL GROUND PLANE AT 1.5 GHz

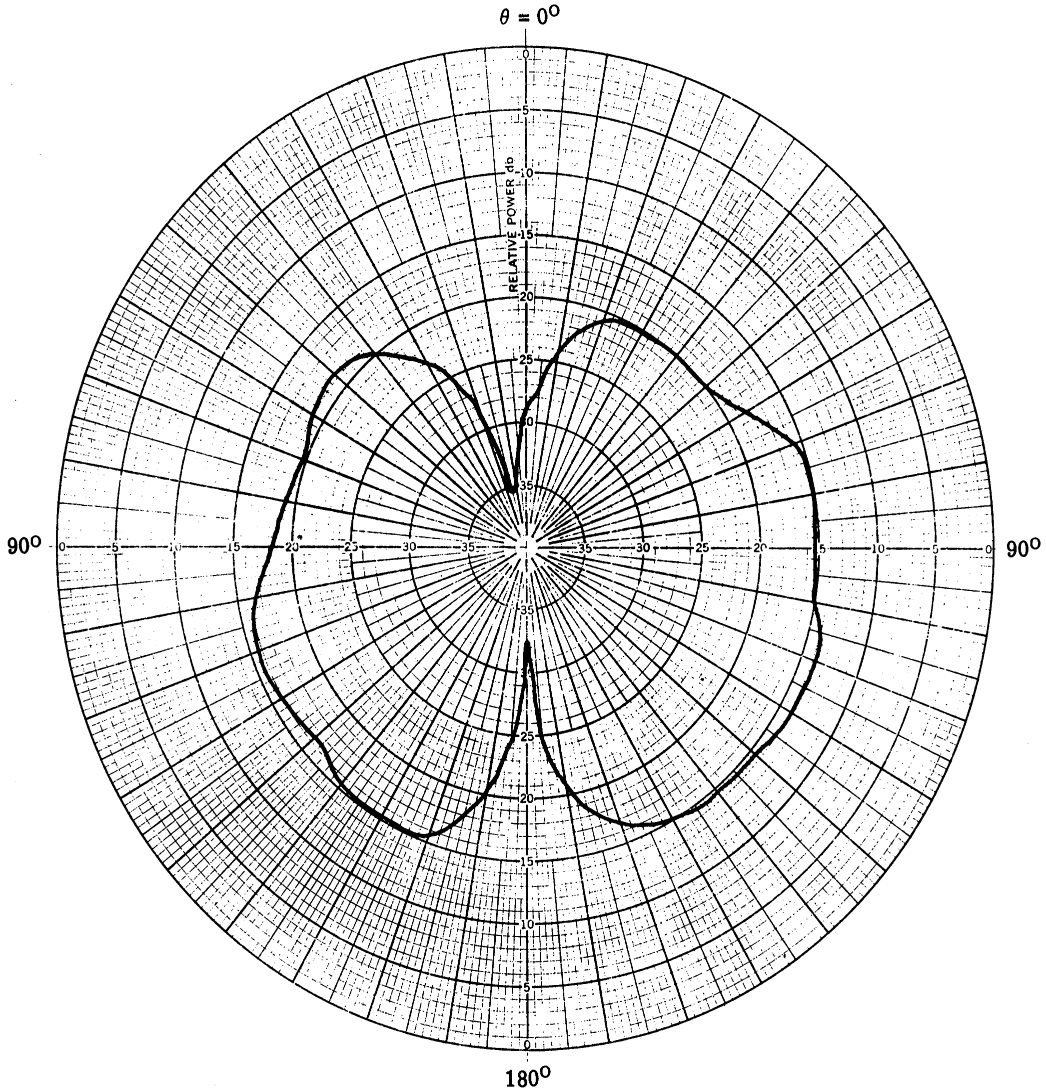


FIG. 61: E-PLANE POLARIZATION OF 8 CROSSED PLATE/45° CONICAL GROUND PLANE AT 2 GHz

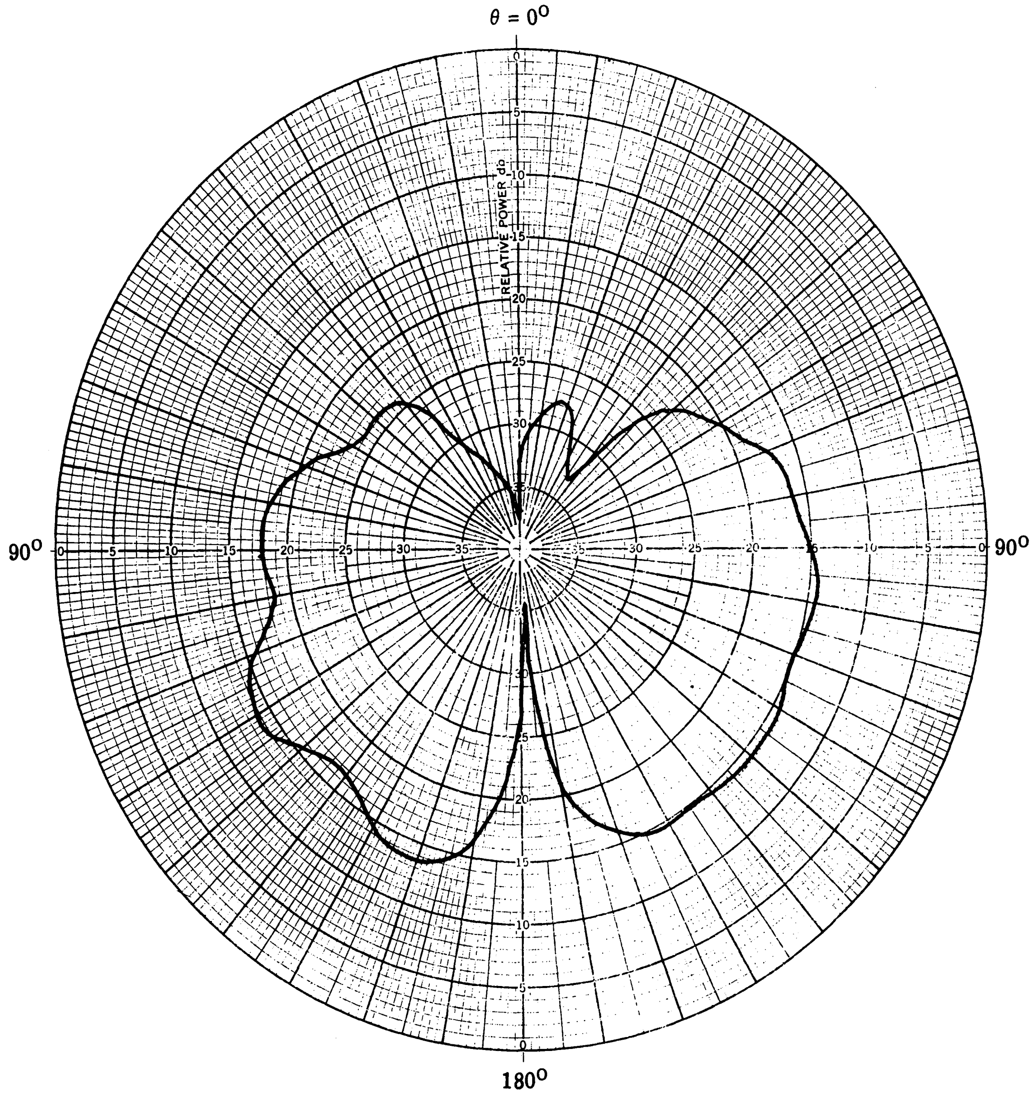


FIG. 62: E-PLANE POLARIZATION OF 8 CROSSED PLATE/45° CONICAL GROUND PLANE AT 2.5 GHz

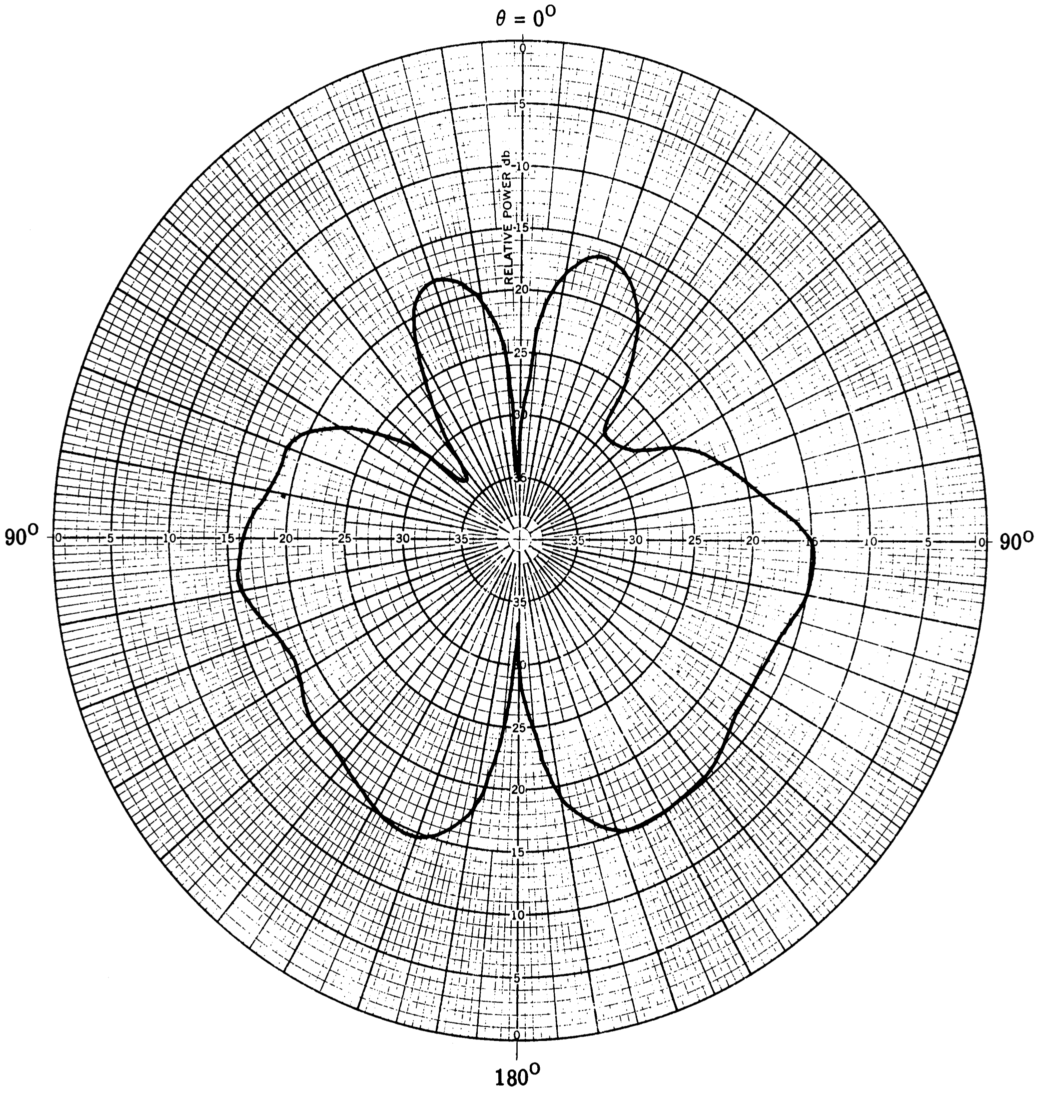


FIG. 63: E-PLANE POLARIZATION OF 8 CROSSED PLATE/45° CONICAL GROUND PLANE AT 3 GHz

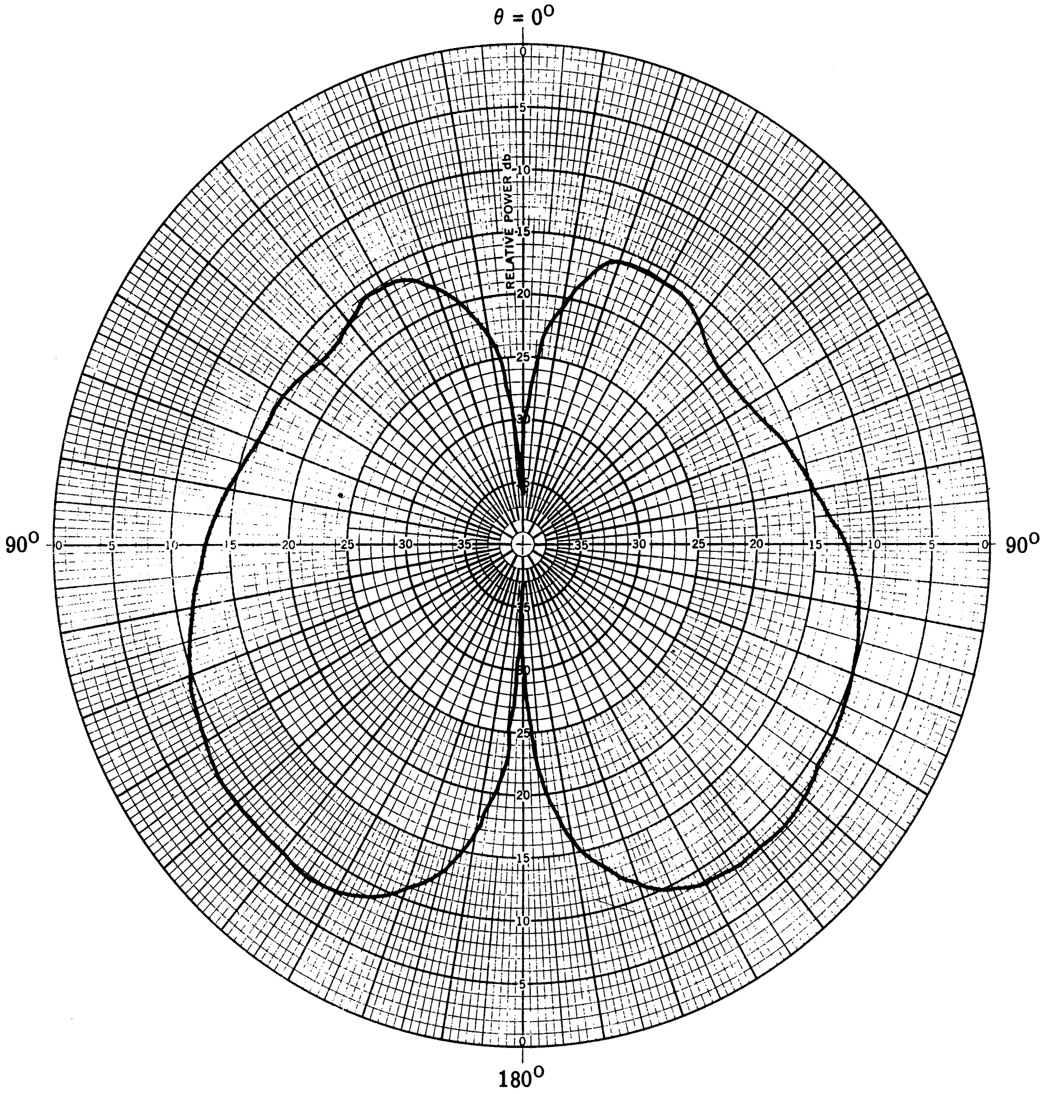


FIG. 64: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 1.6 GHz

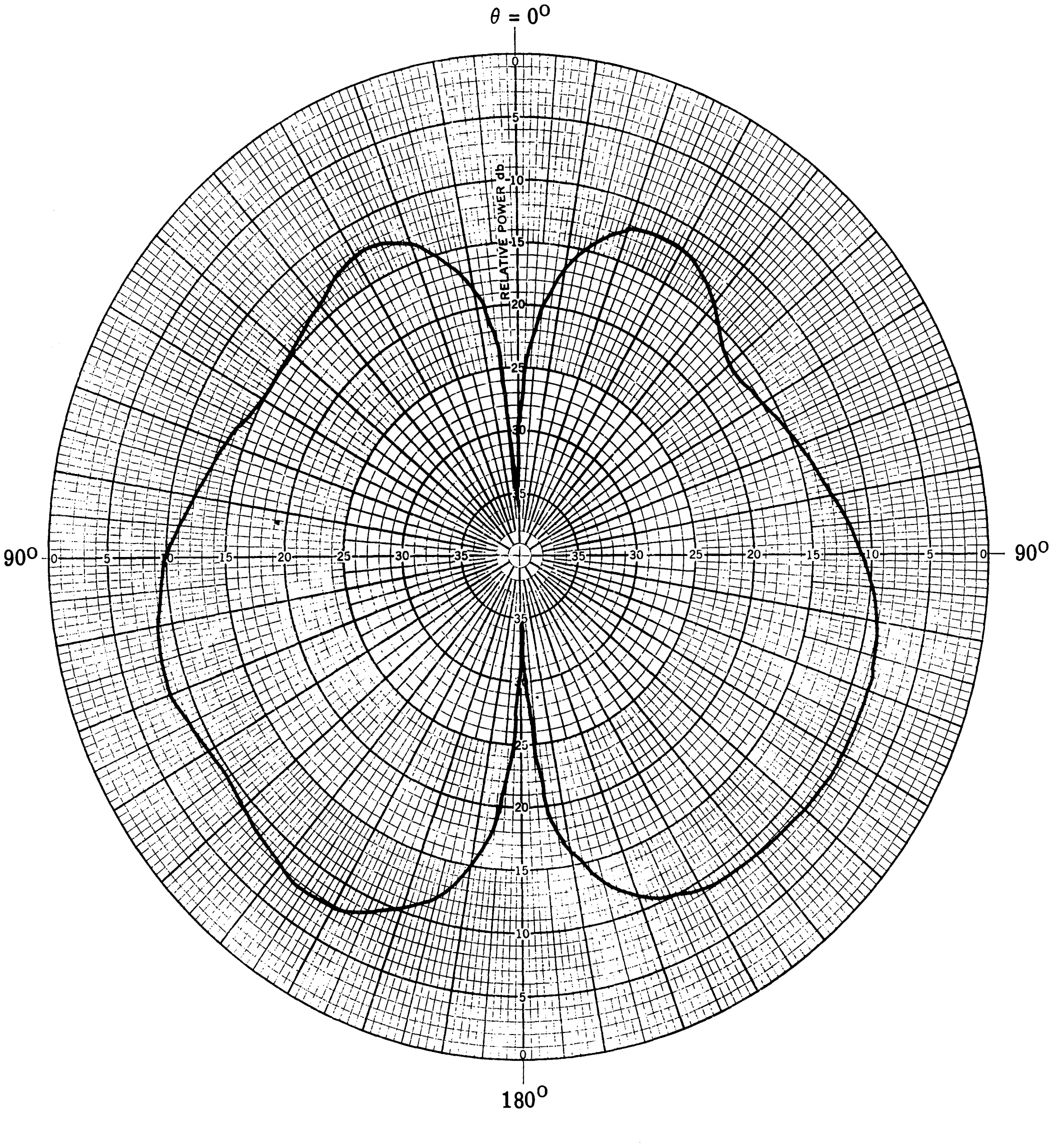


FIG. 65: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 1.8 GHz

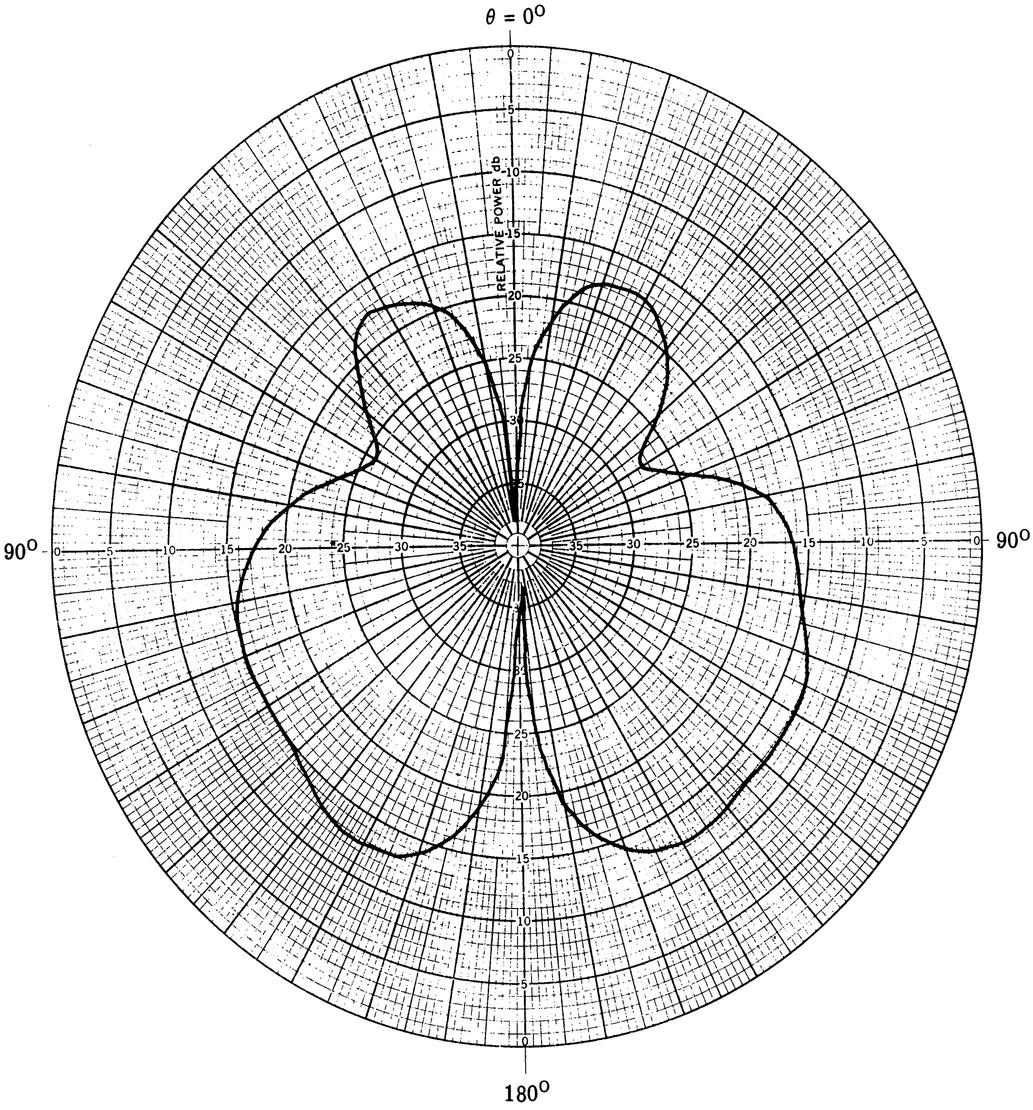


FIG. 66: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 2 GHz

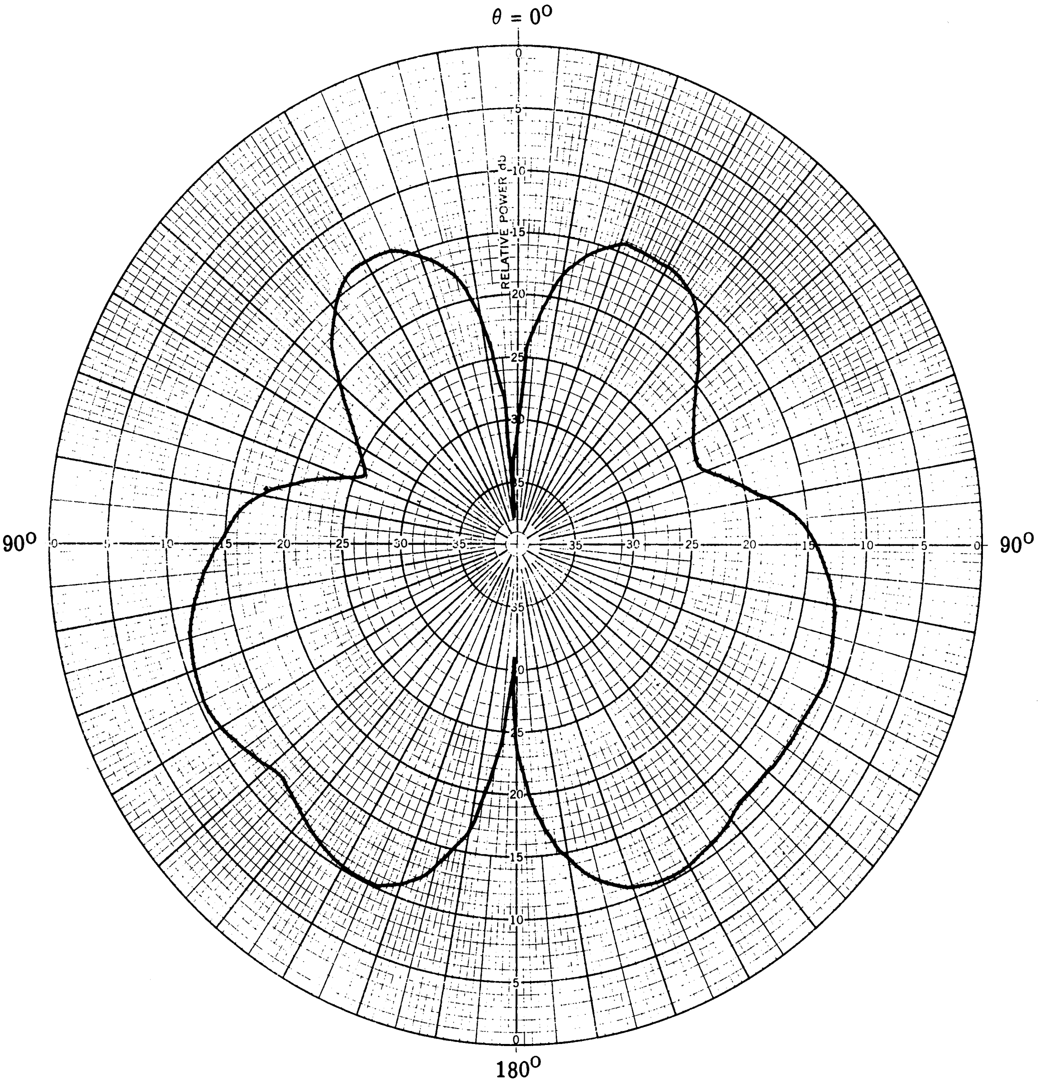


FIG. 67: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 2.3 GHz

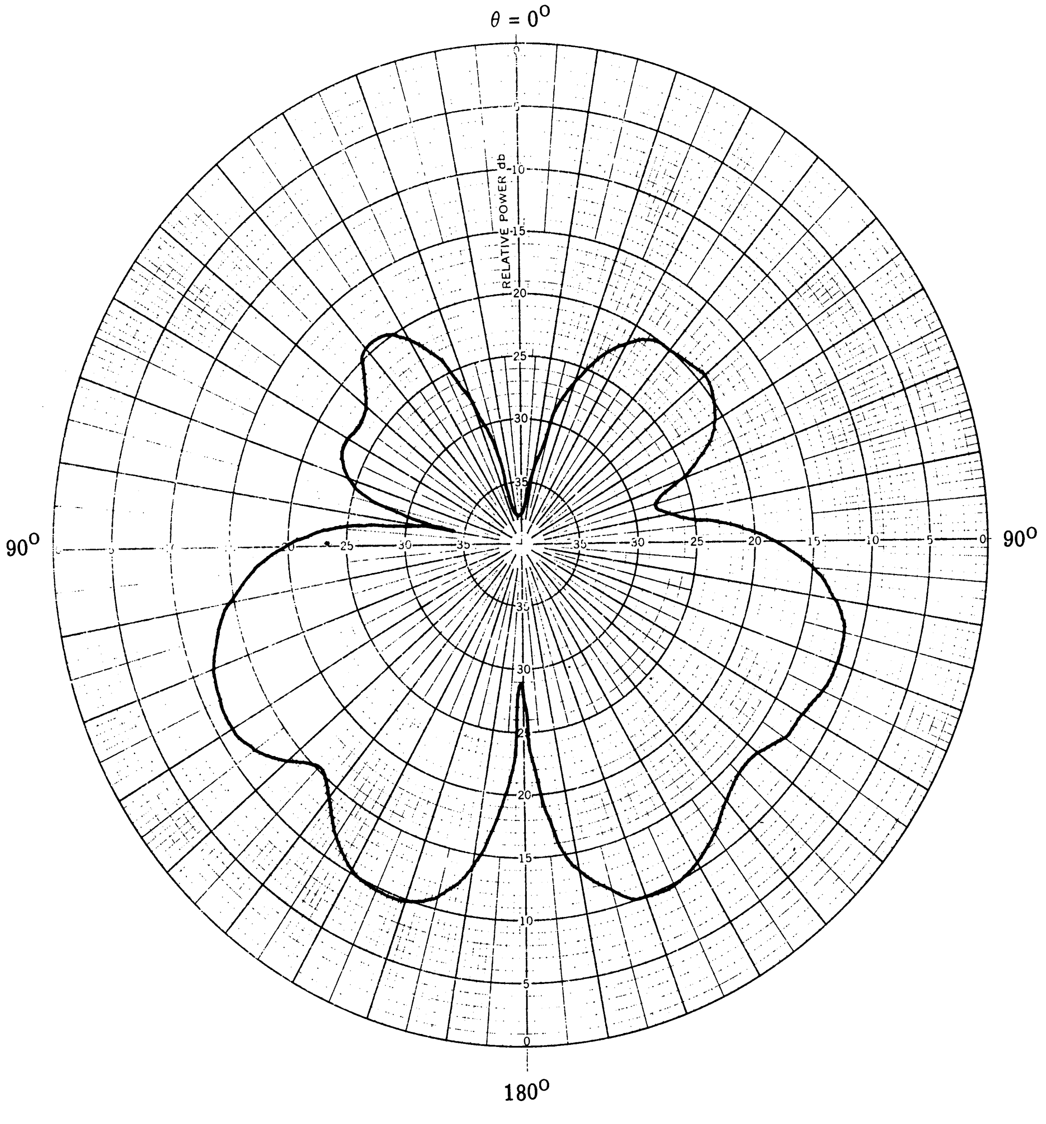


FIG. 68: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 2.6 GHz

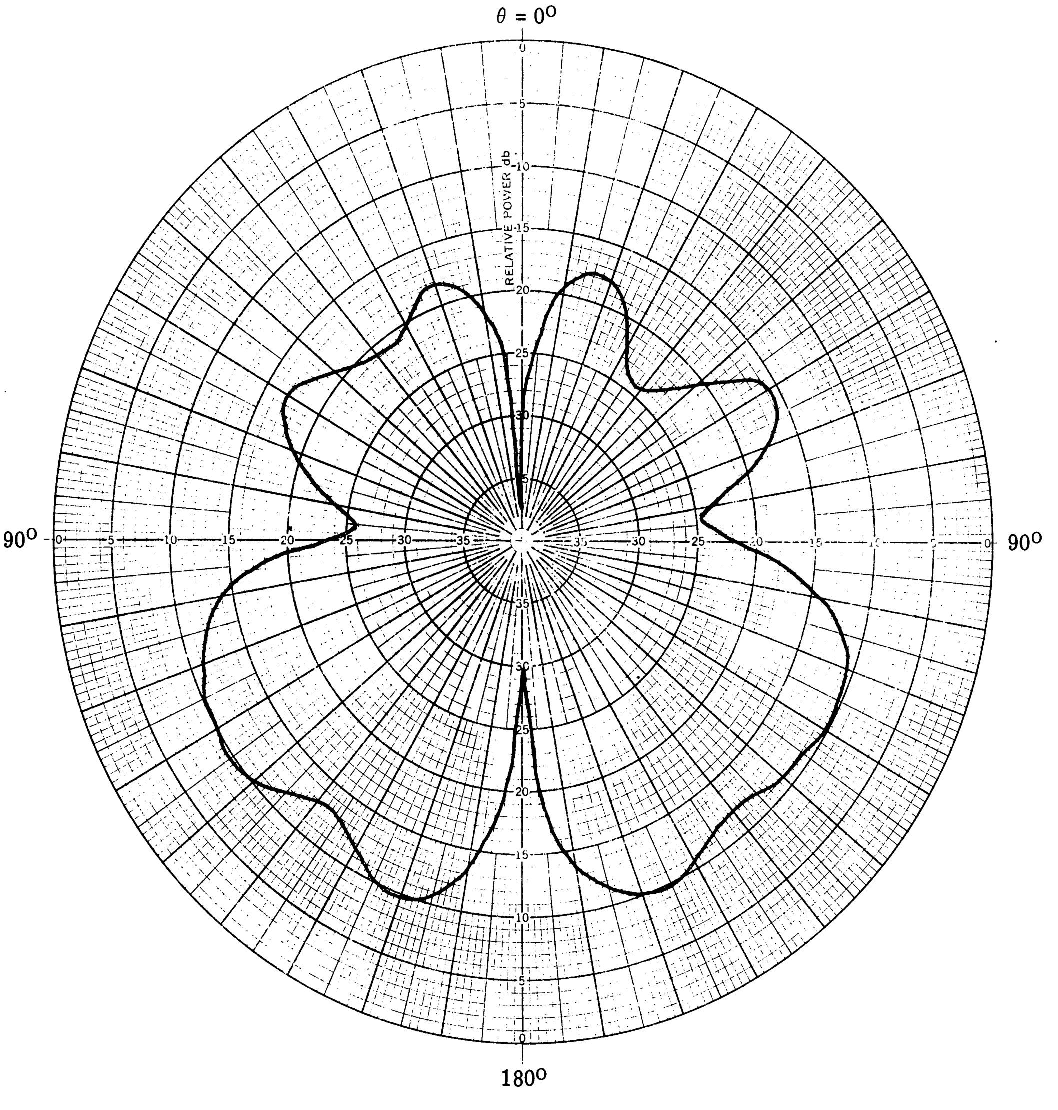


FIG. 69: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 2.9 GHz

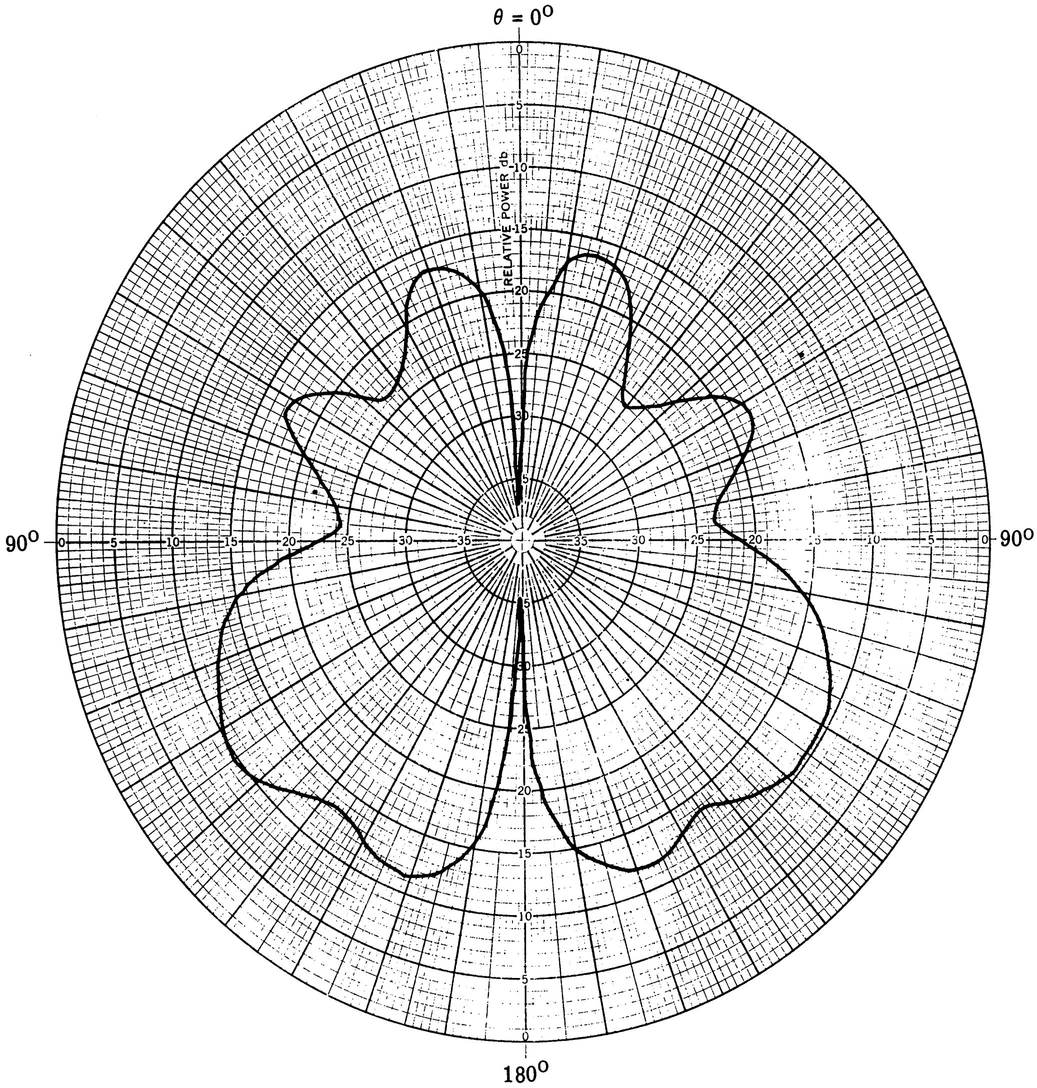


FIG. 70: E-PLANE POLARIZATION OF 8 CROSSED PLATE/60° CONICAL GROUND PLANE AT 3 GHz

can be made, pattern data in the frequency range of 0.3 - 1.5 GHz will be required. It is to be noted that all data presented here was obtained for a free space environment.

3.2 Double Cone Cage Antenna

A new antenna configuration investigated to satisfy the requirements of the broadband omnidirectional antenna during this reporting period is the cage antenna.

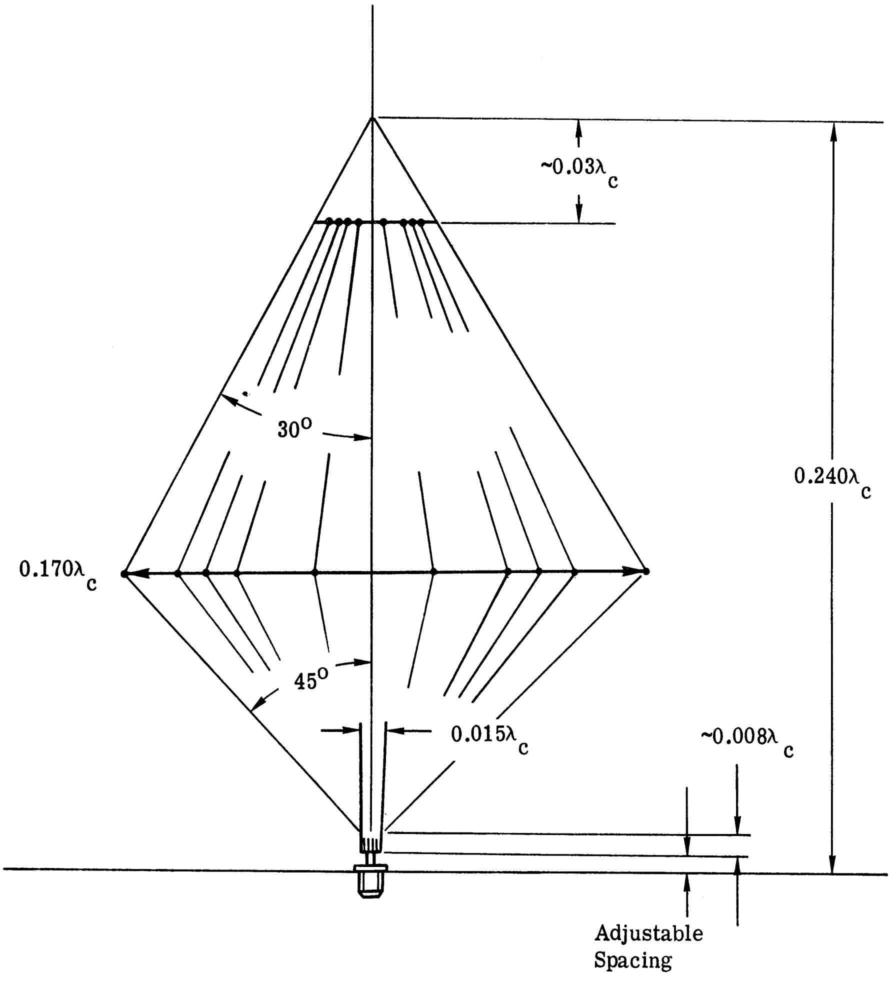
This antenna consists of two cones arranged as illustrated in Fig. 71 whose maximum diameter is $0.170\lambda_c$, where λ_c is proportional to the lowest frequency of operation. A prototype of this antenna was designed and fabricated to operate in the frequency range of 200 MHz to 2000 MHz. It consists of 24 wires spaced at 15^o increments around the circumference of the cones.

Two sets of VSWR data were obtained for two spacings between the ground plane and base of the cage antenna. This data is shown in Fig. 72 where it can be seen that the VSWR for the 10:1 band is less than 3:1. Pattern data has not yet been obtained. It is reasoned that the antenna functions as a monopole antenna in the low frequency range and as the frequency increases the radiation characteristics change such that at the higher frequencies the antenna functions as a disc cone, i.e., it radiates from the cone at the base. In view of past experience with antennas of a similar configuration, it is felt that the patterns will tend to radiate in the upper half plane which is not desirable. To overcome this it may be desirable to employ a conical ground plane with the cage antenna.

3.3 Manipole Coupling Study

A typical set of VSWR data for a 47 element manipole antenna is shown in Fig. 73. The shortest element was 25 mm long and each successive element was 5 mm longer such that the elements were 25, 30, 35, etc until the last element which was 250 mm long following the principal of linear tapering.

The diameter of the base to which the elements are attached is two inches and the diameter of the wire used for each element is 1.6 mm. From the VSWR data, it can be seen that areas of concern exist at 600 MHz and 3000 MHz. An experimental study has been initiated to determine the effects of coupling in these regions. Preliminary results from this study suggest that several longer elements (longer than 250 mm) will be required to minimize the VSWR variation at 600 MHz. To minimize the VSWR variation at the high frequency additional short elements will be required.



λ_c = longest operating wavelength for a minimum VSWR of 3.00
FIG. 71: DOUBLE CONE CAGE ANTENNA

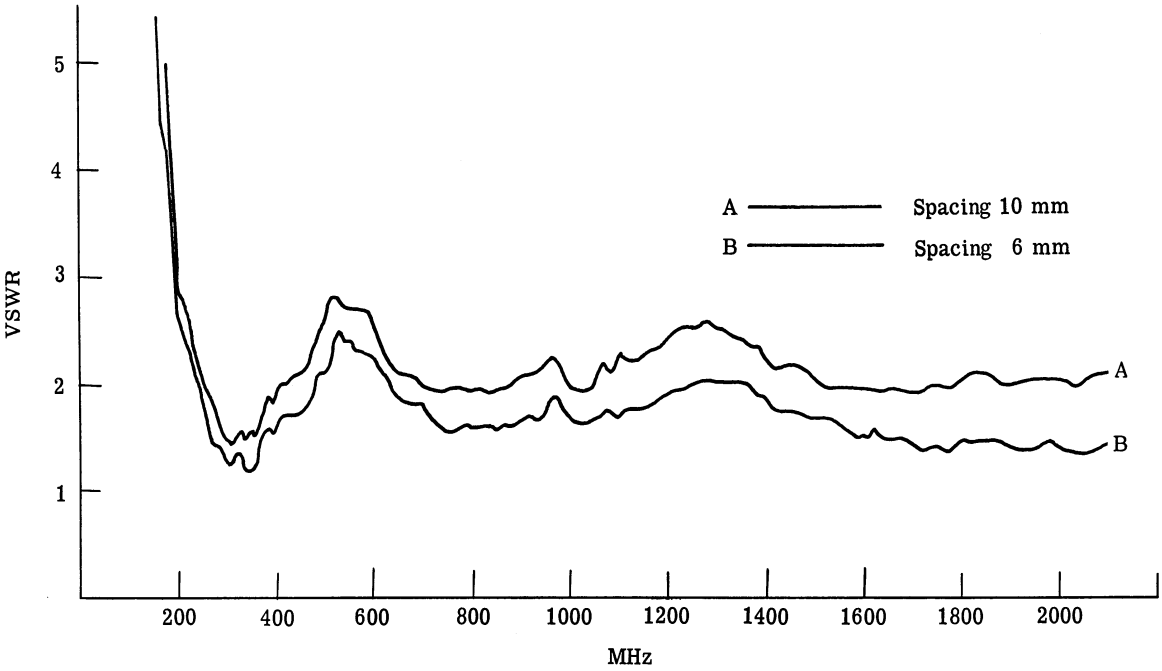


FIG. 72: DOUBLE CONE VSWR CHARACTERISTIC

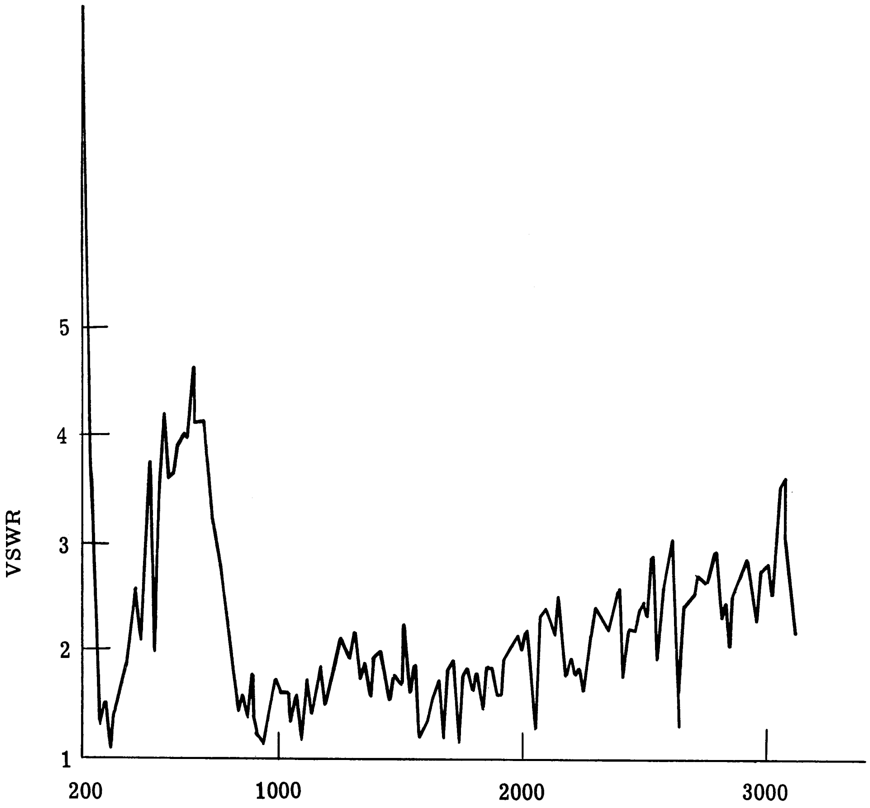


FIG. 73: 47 ELEMENT MANIPOLE VSWR CHARACTERISTICS

However, in general the total number of elements will not have to be increased but rather rearranged. Data obtained to date is inadequate to specify the number of elements required or exact details as to how they should be arranged.

To obtain a better insight into the coupling effects associated with the manipole antenna a special impedance set-up has been established. From this, data is obtained from which the self impedance of an element in the vicinity of a second element may be determined as well as the mutual impedance associated with a second element.

IV

LOADED LOG CONICAL ANTENNA

The goal in this investigation is a design for a log conical antenna having a 2:1 size reduction, a bandwidth from 50 MHz to 1.1 GHz and a maximum weight of 20 pounds.

There are five or so approaches that appear promising for building a broadband log helix antenna with an approximate 2:1 size reduction. These are:

1) loading the antenna with a dielectric or ferrite,
2) designing 2 or 3 log conical helix antennas which may be stacked telescopically each of which cover portions of the band,
3) winding the antenna with a slow wave structure - one way would be by using a log conical spiral with a very small cone angle as a winding; another way would be by winding the structure with wire that has previously been helically coiled, or winding with wire shaped in a zig-zag fashion,
4) the use of special interconnections of quadrafilar or other polyfilar windings,
5) loading the antenna with lumped or distributed reactances such as toroids of ferrite or small capacitors,
6) loading the antenna with metal foil as in a composite artificial dielectric of foil and polyfoam. In some places the polyfoam would be entirely for support. Such a loading could be made anisotropic. The possibilities of the core behaving as a negative uniaxial crystal is intriguing.

To date the first approach has been emphasized. Consequently the prototype design will be based on this principle, although further studies of the other five approaches are scheduled.

Experiments on the loading of helix antennas indicate that the diameter can be reduced by a factor of 0.4 to 0.7 by magneto-dielectric loading. Experiments also indicate that partial loadings with magneto-dielectric materials give almost full antenna reduction (Lyon et al, October 1965). Indeed a loading inside the windings that is one-quarter of a radius thick is sufficient to give almost the same reduction that a full core loading would give. So far the reductions in size obtained can be explained in a qualitative analytical manner. The possibility of forming a better mathematical model is being explored.

4.1 Design of Prototype Structure

There are difficulties in constructing a log conical helix antenna that is collapsible yet rugged. A structure which is inflatable, like a balloon, could be fabricated, but it would not be rugged enough to survive strong winds without structural support. Any light collapsible structure would necessarily have to be segmented. This would force the cross sections of the family of planes perpendicular to the antenna axis to be polygonal. Thus, a log polygonal helix would be the logical result. Tang and McClelland (June 1962) have done work on log polygonal spiral antennas; a family of antennas similar to the log polygonal helix, which are of interest to this prototype. This reference shows a technique of projecting log conical spiral antennas onto inscribed pyramids which produces antennas with characteristics almost identical to the generating antenna.

The best choice of loading material appears to be Emerson and Cuming's Eccofoam Hi-K flexible artificial dielectric which can be produced with a dielectric constant of 6 to 7. The material is relatively light (18 lbs / ft^3) but not as light as the 5 lbs advertised. Tests with styrofoam indicate that thin coats of some epoxy resins improve certain mechanical properties markedly. Notably, the abrasion resistance, impact strength and water imperviability are improved. Weight is not noticeably affected.

The prototype will be bifilar wound with phosphor-bronze wire. The wire material was recommended by the sponsor because of its low work hardening properties. Anzac Electronics is willing to supply a 50 MHz to 3 GHz hybrid capable of handling 100 watts provided the Radiation Laboratory of the University of Michigan tests it and supplies the necessary data to the manufacturer to permit redesign if necessary. Serious consideration has been given to Tschebychev transformers and to a 100:1 bandwidth balun transformer designed by Duncan and Minerva (February 1960). A Tschebychev transformer has been designed for impedance matching and could be used if Anzac cannot produce a suitable hybrid.

The prototype antenna will have a cone angle of 40^o instead of 45^o as originally planned. The results of the far field patterns on the scale models 221 and 223, described later, indicate that the range of half-power beamwidths will be excessive. The switch to a cone angle of 40^o should not affect the average beamwidth, but it should reduce the variation in the beamwidth about the average.

The supporting structure of the prototype antenna was designed on the assumption that a 2:1 reduction in size can be achieved. The prototype, if operated without any loading, can operate from 100 MHz to 1.1 GHz.

Table I gives the electrical dimensions of both the upper and lower levels of the truncated square pyramid structure.

TABLE I: DIMENSIONS OF THE PROTOTYPE ANTENNA

Description	Bottom (in.)	Top (in.)
Radius of circumscribed circle	28.4	0.86
Side of square	40.2	1.21
Distance - base to vertex	78.	2.36
Distance - side to vertex	80.4	2.43
Distance - circle to vertex	83.	2.51

The structure of the antenna is designed so that; 1) no member in compression will buckle, and 2) the tensile stress in any shear plane will not exceed the tensile strength under conditions of severe wind loading. The maximum loading occurs if the antenna offers its maximum cross section to the wind. To simplify the static analysis the resulting force was assumed to be borne solely by the member under consideration. No safety factor was used.

On this basis, the structure designed should break in a 25 mph wind at -60° F if the surface of the structure is entirely covered with a backing plate or dielectric loading material. Catastrophic failure would occur at a higher wind velocity if the temperature were warmer or if the plane of the antenna windings were not supported throughout by loading or backing (Jasik, 1961). Actually, the structure would not fail unless the wind greatly exceeded 25 mph since the assumed force distribution in the structure is quite conservative. It is thought that a wind velocity of 50, or possibly 75 mph would not damage the structure.

It is interesting to note that even at 25 mph, the forces caused by wind loading exceed those caused by the weight of any practical dielectric core by two orders of magnitude. The effect of ice loading on the design was not considered.

All material used in the structure, except for bolts, nuts and cable clamps, will be NEMA grade G-10 phenolite laminated plastic. The corresponding military grade is MIL-P-18177. The material is an epoxy fiberglass cloth laminate. The material has excellent mechanical and electrical properties. Its tensile and elastic properties are about the same as wrought magnesium alloy except it is less ductile. The specific gravity of 1.84 makes it twice as heavy as other phenolite laminates, but its strength to weight ratio is far superior. G-10 has a dielectric constant of about 4.5 and a dissipation factor of approximately 0.01. Its dielectric strength is the same as most common insulators.

The weight of the structure alone should not exceed 14 1/2 lbs. Since standard tube stock is 36", most tubes indicated in the plans will be composed of several standard length tubes connected together by butt and intermediate lap joints. The intermediate piece will be a short section of G-10 pipe which is the next size smaller. The dielectric loading will be held in contact with the windings of the antenna by nylon strapping.

4.2 Scaled Test Models of the Prototype

Both Antennas 221 and 223 are scale models of the proposed prototype antenna. Both antennas have a cone angle (2θ) of 45^o and a wrap angle (α) of 85^o. Both are bifilar wound but 221 is fed with an infinite balun of RG-58 coaxial cable without the outer insulation while 223 is center fed at the tip by a hybrid. Antenna 223 uses No. 16 enameled copper wire as its conductor. Antenna 221 covers the spectrum from 500 - 900 MHz and 223 covers 500 - 3000 MHz. A truncated square pyramid formed of 1/16" thick fiberglass epoxy laminate sheeting supports the windings of 221. Antenna 223, however, is wound on the inside of a square pyramid of 1" styrofoam sheets. This unusual construction gives two advantages; 1) the support of the windings produces almost no loading effect on the antenna, and 2) test loadings of dielectric may be placed next to the windings to produce the maximum reduction of operating frequency.

Antenna 221 was built and tested for two reasons. First, to test the applicability of the design data of Dyson (May 1965) for the square pyramidal helix antennas proposed by Tang and McClelland (June 1962). Secondly, to provide a model for far field test of loadings that showed promise in near field measurements.

The results of the far field patterns on antenna 221 with air loading are very good. In the frequency range for which the antenna was designed, the main lobe beamwidth does not exceed the specified value of 90^o by more than 6 percent. At most measurement points, the beamwidth was less than the maximum specified. At some frequencies, the beam tilt exceeded the maximum specified value by a factor of two. The possible causes of the excessive beam tilt are reflection errors due to the antenna range, inaccuracy in construction, wind flexing of the structure and the infinite balun feed (applies to Antenna 221 only).

The infinite balun feed can produce erratic patterns when the antenna is operated below its lower frequency limit. This occurs when the wave which is traveling down the antenna structure is not radiated but instead travels down the shield of the coax feed causing unbalance and causing the cable to radiate.

The patterns of Antenna 221 in air were circularly polarized as expected with axial ratios of the order of 0 db in several cases. All axial ratios were below the prescribed level of 3 db in the design frequency range of the antenna.

If use is made of an approximate directivity formula (Stegen, July 1964), the directivity of the patterns is 6.2 db or better. Efficiency experiments conducted on a helix antenna at its resonance frequency indicate that the efficiency of 221 was approximately 60 percent. The helix was wound in the same manner as 221 and the cylindrical form of the helix was composed of the same material used in the pyramidal form of antenna 221. Thus, in spite of a loss of 0.5 - 1 db in the feed system, the prototype should still meet the minimum required gain of 3 db. The improvement in efficiency that is expected with the prototype design should make the gain of the prototype about 4 db.

It is gratifying to note also that the VSWR for the prescribed frequency range was less than 2:1 after correcting for cable losses. Table II gives a summary of the beamwidth, beam tilt, VSWR and sidelobe level for Antenna 221 at various frequencies with and without loading.

Table III is a summary of the data for Antenna 221 when it is loaded with Emerson and Cuming's K-10 powdered dielectric in the loading pattern designated as L-2. The loading consisted of an inside layer of dielectric one-quarter of a radius thick at the base with the inside radius remaining constant so that the inner surface of the dielectric intersected the surface of the pyramid.

As would be expected, very little effect of the loading can be observed for frequencies above 600 or 700 MHz. The active region starts to move on to the dielectric loaded area at about 670 MHz. Note that the VSWR does not begin to rise until under 400 MHz and the pattern at 350 MHz meets almost all of the specifications. Also note that all of the patterns are for vertical polarization. The reduction in frequency of operation of Antenna 221 is by a factor of .75; the same antenna with air loading performed satisfactorily for frequencies below 500 MHz.

It is expected that a slightly thicker dielectric layer would give the desired 50 percent frequency reduction. The results obtained were quite close to predicted values based on earlier experiments of partially loaded helices although the reduction was not quite as much as expected.

Patterns on the air loaded antenna 223 were taken to; 1) determine how much size reduction the 1/16" fiberglass epoxy sheet caused in Antenna 221, and 2) to provide a basis of comparison for near field and far field data. The winding and feed on Antenna 223 are similar to the winding and feed that will be used on the prototype.

According to beamwidth information the lower cutoff frequency for Antenna 223 is between 600 - 700 MHz even though the lower dimensions of the antenna are the same as 221. Antenna 221 starts to cut off between 500 - 600 MHz for the same polarization. This is probably due to the infinite balun in Antenna 221. Table IV gives a summary of the pertinent data and patterns for this antenna. Note that the VSWR was measured in the 50 ohm line which feeds the hybrid.

Table V gives a summary of pertinent data taken from the far field patterns of Antenna 223 with a modified loading L-1-2, which consists of an inside layer of K-10 dielectric tapered so that the layer is always a quarter of a radius thick. The amount of dielectric material available was insufficient to fill the lower 4 1/4" of the antenna with dielectric. The patterns above 700 MHz have been useful in interpreting the near field measurements taken on the loaded antenna.

TABLE II: ANTENNA 221, AIR LOADED

Frequency (MHz)	VSWR	Polarization	Beamwidth (degrees)	Beam Tilt (degrees)	Sidelobe Level (-db)
270	-	V	71.	5.5	6
300	-	V	198.	37.	3
360	-	V	110.	2.	21
400	2.5	V	90.	6.	14
400	2.5	H	134.	10.5	8
500	1.92	V	82.	2.5	11
500	1.92	H	94.	10.5	12
600	1.65	V	78.	1.5	15
600	1.65	H	89.	4.	14
700	1.89	V	84.	1.	19
700	1.89	H	91.	2.5	11
800	2.3	V	95.	1.5	14
800	2.3	H	94.	6.	12
900	1.66	V	82.	6.	20
900	1.66	H	93.	3.	13

TABLE III: ANTENNA 221 WITH LOADING L-2 OF K10 DIELECTRIC

Frequency (MHz)	VSWR	Polarization	Beamwidth (degrees)	Beam Tilt (degrees)	Sidelobe Level (-db)
250	3.33	V	116	2.	5
300	3.42	V	108	22.	9
350	3.72	V	92	6.	8
400	1.62	V	90	1.5	14
500	2.08	V	84	3.25	14
600	1.62	V	80.5	4.25	26
700	1.48	V	80	3	13
800	1.28	V	77	0.5	13
900	1.25	V	74	1	21

TABLE IV: ANTENNA 223 IN AIR

Frequency (MHz)	VSWR	Beamwidth (degrees)	Beam Tilt (degrees)	Sidelobe Level (-db)
400	1.545	129	1.5	11
500	1.46	111	1.5	6
600	1.18	106	6	12
700	1.09	83.	13.5	8
800	1.35	91.	22.5	16
900	1.18	94.	12.	14

TABLE V: ANTENNA 223 WITH LOADING OF K10 DIELECTRIC

Frequency (MHz)	Beamwidth (degrees)	Beam Tilt (degrees)	Sidelobe Level (-db)
250	117.	7.5	8
290	96.	9.	6
330	111.	3.5	5
360	148.	4.	6
400	160.	2.	10
500	178.	9.	5
600	360.	-	-
700	115.	4.5	9
800	82.	7.	5
900	102.	9.	7

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13. ABSTRACT

Work on the design, fabrication and testing of 3 broadband antennas is described. The antenna types are 1) high gain constant beamwidth. 2) omnidirectional and 3) loaded conical helix.

During this reporting period an experimental study has been conducted to determine methods by which the patterns of the ridged horn may be optimized. The results of this study has suggested that it would be desirable to lengthen the horn to minimize phase errors at the aperture. A fiberglass parabolic contour has been obtained from the plaster mold discussed in the second quarterly report. This surface has been metallized with silver paint and antenna patterns obtained. A typical set of H-plane pattern data for the asymmetrical parabolic reflector is presented in this report. These patterns demonstrate that a constant beamwidth can be achieved for a 7:1 frequency band.

An experimental study has also been conducted investigating several conical ground plane configurations. Both VSWR and pattern data have been obtained and are reported. An additional antenna type ('cage' antenna) has been considered during this report period. VSWR data for this antenna exhibits excellent characteristics over a 10:1 frequency band. The study of the manipole antenna has been continued. An experimental study to investigate the mutual coupling effects between elements of the manipole has been initiated.

Many background experiments have been performed in the design of a circularly polarized antenna covering the frequency range 50 MHz - 1.1 GHz. A preliminary design of the prototype loaded log 'conical' helix has been made. This is a square pyramidal structure which is equivalent in operation to the log conical helix. The most critical aspect of the design has been the weight problem. Intensive effort is being placed on weight reduction.

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