NRC·CNRC

NRC Publications Archive
Archives des publications du CNRC

A variable-polarization antenna

Allan, L. E.; Markell, R. C.; McCormick, G. C.; National Research Council Canada. Radio and Electrical Engineering Division

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40001832
Technical Report (National Research Council Canada. Radio and Electrical Engineering Division); no. ERB 768, 1967-06-01

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=151bc2f8-6ce5-4c46-a847-d60278ec89de
https://publications-cnrc.canada.ca/fra/voir/objet/?id=151bc2f8-6ce5-4c46-a847-d60278ec89de

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada Conseil national de recherches Canada

Canada

ERB-768

UNCLASSIFIED

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

A VARIABLE-POLARIZATION ANTENNA

L. E. ALLAN, R. C. MARKELL AND G. C. McCORMICK

OTTAWA

JUNE 1967

NRC # 22156

ABSTRACT

An antenna having variable polarization capability, using a parabolic reflector 22 feet in diameter, has been developed for the S-band radar operated by the Alberta Hail Studies Research Project. Transmission on an arbitrarily assigned polarization, and reception on the transmitted polarization and the orthogonal polarization simultaneously is possible. Flexible operation results from the possibility of choosing any axial ratio and then causing the polarization ellipse to rotate at a fixed rate. Polarization purity is obtained by use of a dual-mode feed horn, resulting in an integrated cancellation ratio on circular polarization of 34 db. Other antenna characteristics are: beamwidth, 1.15°; gain, 43.2 db; azimuth sidelobes, -23 db; elevation sidelobes, -30 db.

CONTENTS

PLATES

FIGURES

A VARIABLE-POLARIZATION ANTENNA

- L.E. Allan, R.C. Markell, and G.C. McCormick -

INTRODUCTION

This report deals with the 22-foot paraboloidal reflector antenna used with the S-band radar of the Alberta Hail Studies research project, in particular, those aspects pertaining to its variable-polarization capability. The reason for providing polarization diversity in hail observation is that, in the generation of hail, certain particle asymmetries may develop which can be detected or measured if accurate polarization data can be added to the usual radar backscatter information.

In addition to its primary function for hail observation, it was felt that the radar could be used for the general observation of the polarization properties of precipitation, about which insufficient information is available in the literature.

The design objective was to provide an antenna such that the transmitted radiation should have an axial ratio which could be arbitrarily assigned by the operator and an orientation of the polarization ellipse which could also be arbitrarily assigned. While complete flexibility in this regard is available with this antenna, polarizations at or near circular and at or near linear are evidently of the greatest interest. Two simultaneous receptions are available, viz. the backscattered power in the transmitted polarization, and the backscattered power in the orthogonal polarization.

This design objective is an ideal which can not be exactly realized. The first requirement in its realization is to transmit a unique polarization. However, the "target" in precipitation studies is generally distributed over the entire main beam of the antenna and over all of the sidelobes. Hence a feed horn is required which radiates a beam having a high degree of polarization purity. The design of such a horn has been previously described [1]. On account of the importance of low-angle observation it was decided that sidelobes under the beam should be as low as practicable. This requirement was given some precedence over that for low-azimuth sidelobes although the latter is desirable in the interests of good resolution.

Feed legs, waveguides, and other structures which intercept radiation from the reflector set the limits in the attainment of polarization purity and low sidelobes. An unusual configuration of two vertical feed legs and two horizontal Fiberglas rods to serve as guys was used. This was intended to produce the most favourable elevation sidelobes. A photograph of the assembled antenna is shown in Plate I.

The reflector itself, a solid surface consisting of panels of aluminum, has a stated surface accuracy of ± $\frac{1}{8}$ inch. Some necessary reinforcement of the hub led to a distortion of the surface contour, which was eventually corrected. The corrected surface was checked mechanically with a 24-foot template, and the symmetry and other characteristics of the radiation patterns confirm the belief that the reflector surface is accurate and does not in itself lead to any degradation of performance. Further information regarding the antenna, scan requirements, pedestal, and system characteristics is available elsewhere [2].

The turnstiles and other microwave devices used in this antenna have a narrow frequency band. The optimum polarization performance exists only within the range 2.880 GHz ±0.001 GHz, and for polarization observations the radar will be maintained within this limit by the adjustment of a tunable magnetron. For ordinary hail observations the radar may be operated within the band 2.880 GHz ±0.050 GHz.

ANTENNA AND FEED-HORN DESIGN

A diagram of the basic geometry of the antenna is shown in Fig. 1. The result of putting the major supporting structures in a vertical plane is that elevation

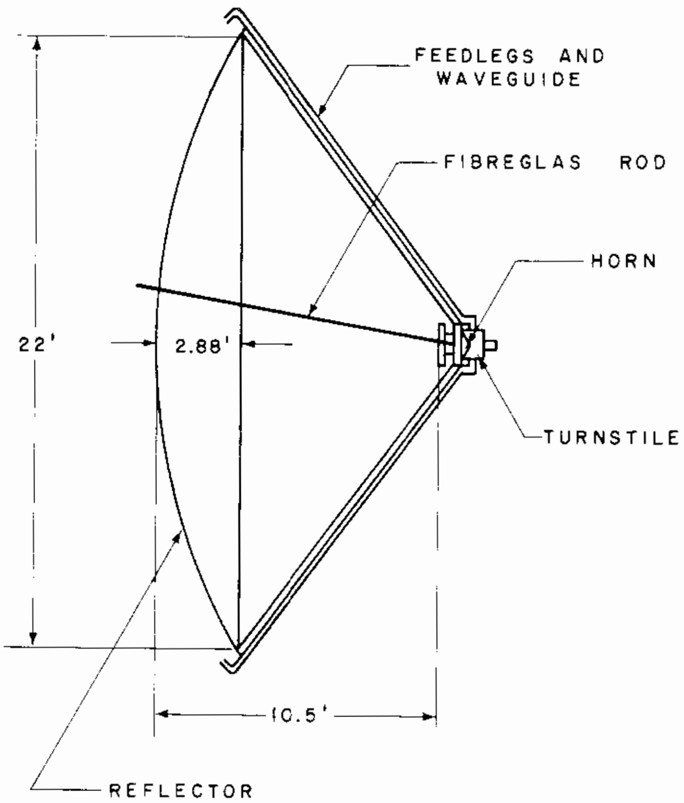


Fig. 1 Diagram of parabolic reflector, feed, and feed supports

sidelobes are substantially unaffected by radiation scattered by the feed legs. However, with this arrangement of the feed legs, azimuth sidelobes may be greater than they could be with a 3-leg or 4-leg structure. The actual geometrical shadowing as a percentage of antenna area is as follows: vertical feed legs, 1.7%; Fiberglas rods, 0.4%; ground plane, 0.3%. The equivalent widths of feed legs and rods will be substantially in excess of their physical dimensions, probably by a factor of at least two for parallel polarization.

The dual-mode feed horn was scaled exactly from the Ku-band horn previously reported [1]. A diagram is shown in Fig. 2 and Plate II is a photograph of the turnstile and feed horn. The rectangular patterns of this horn, shown in Fig. 3,

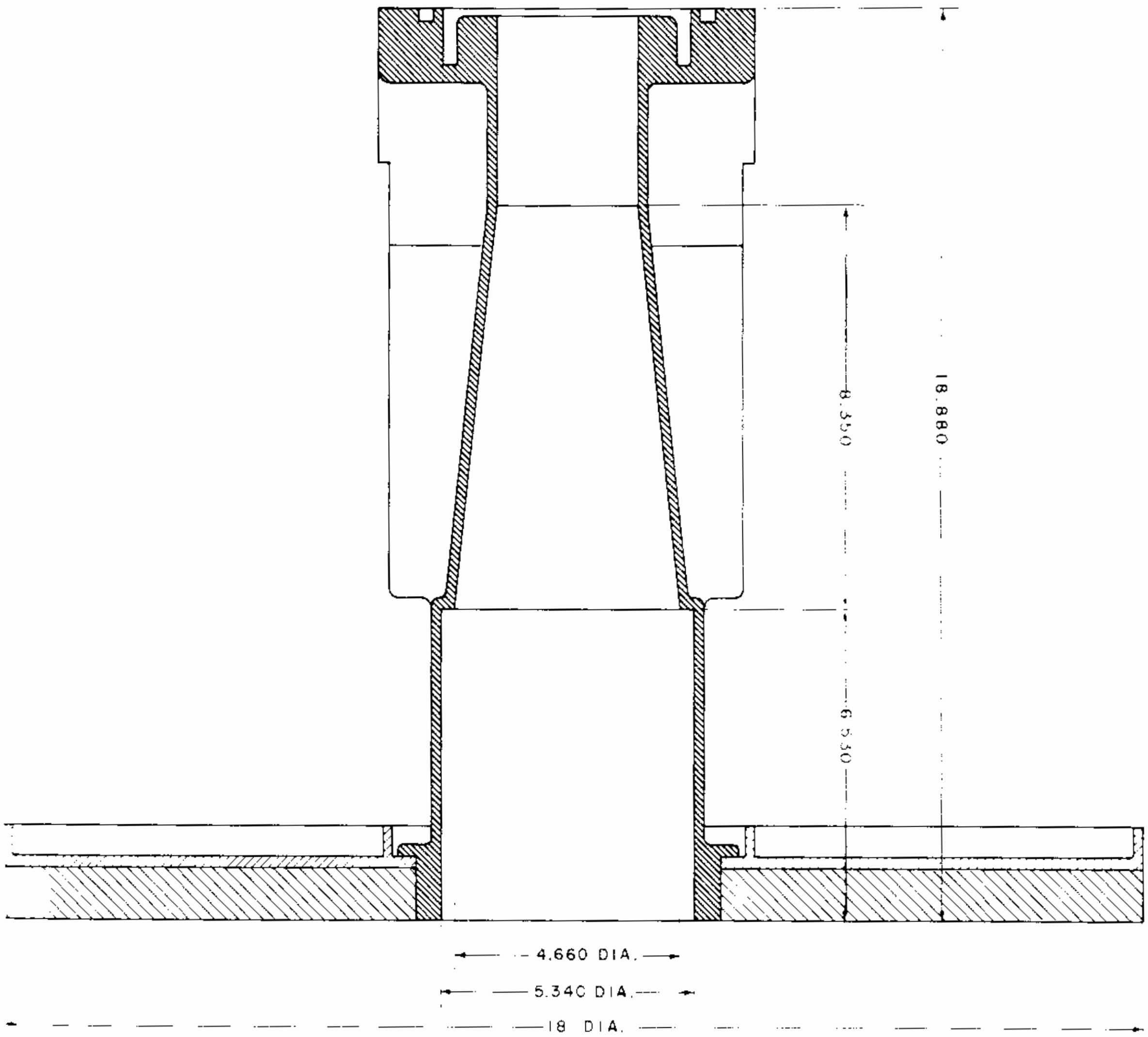


Fig. 2 The feed horn

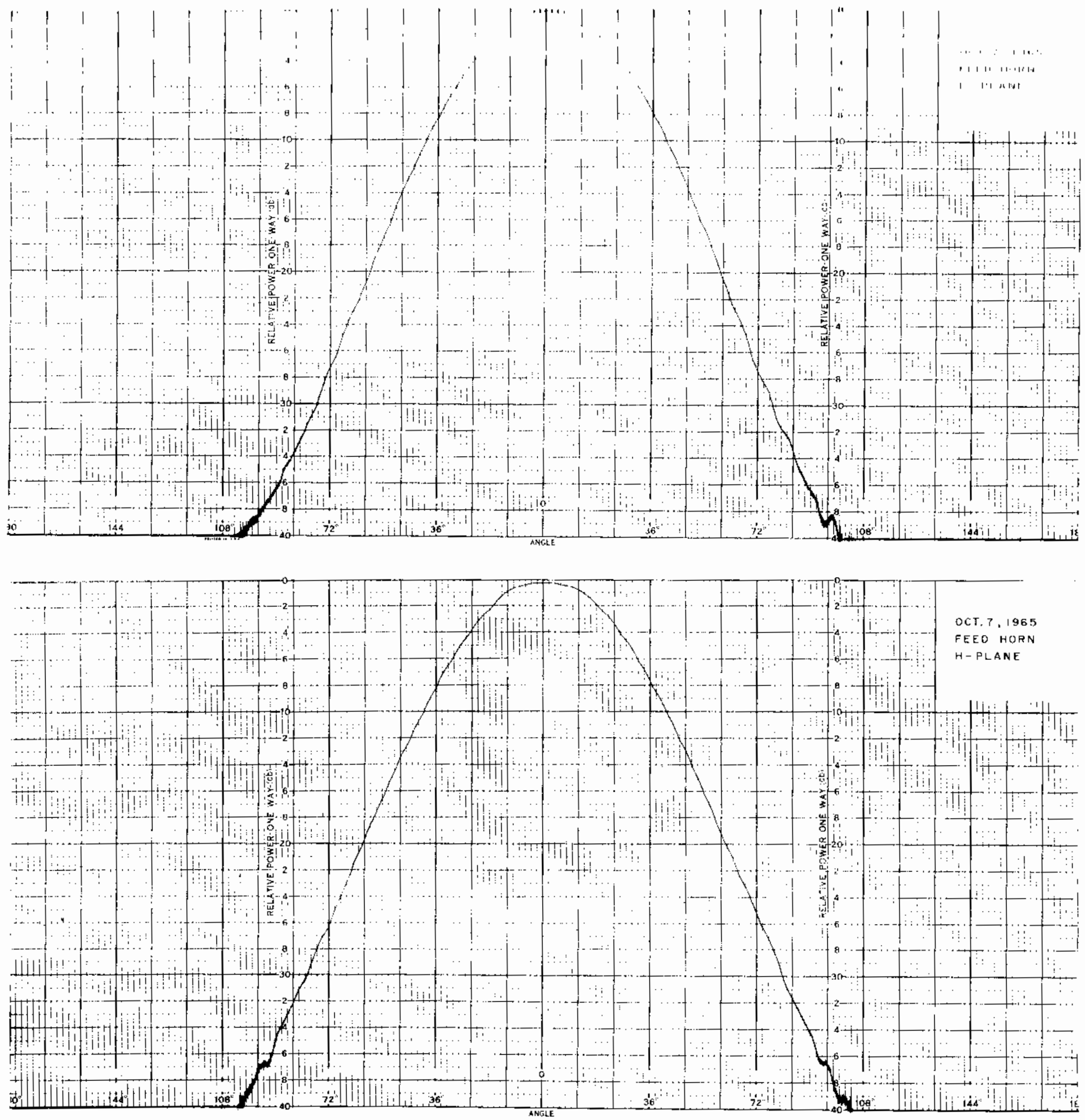


Fig. 3 E-plane and H-plane patterns of feed horn. (Note distortion of beamwidth - see text)

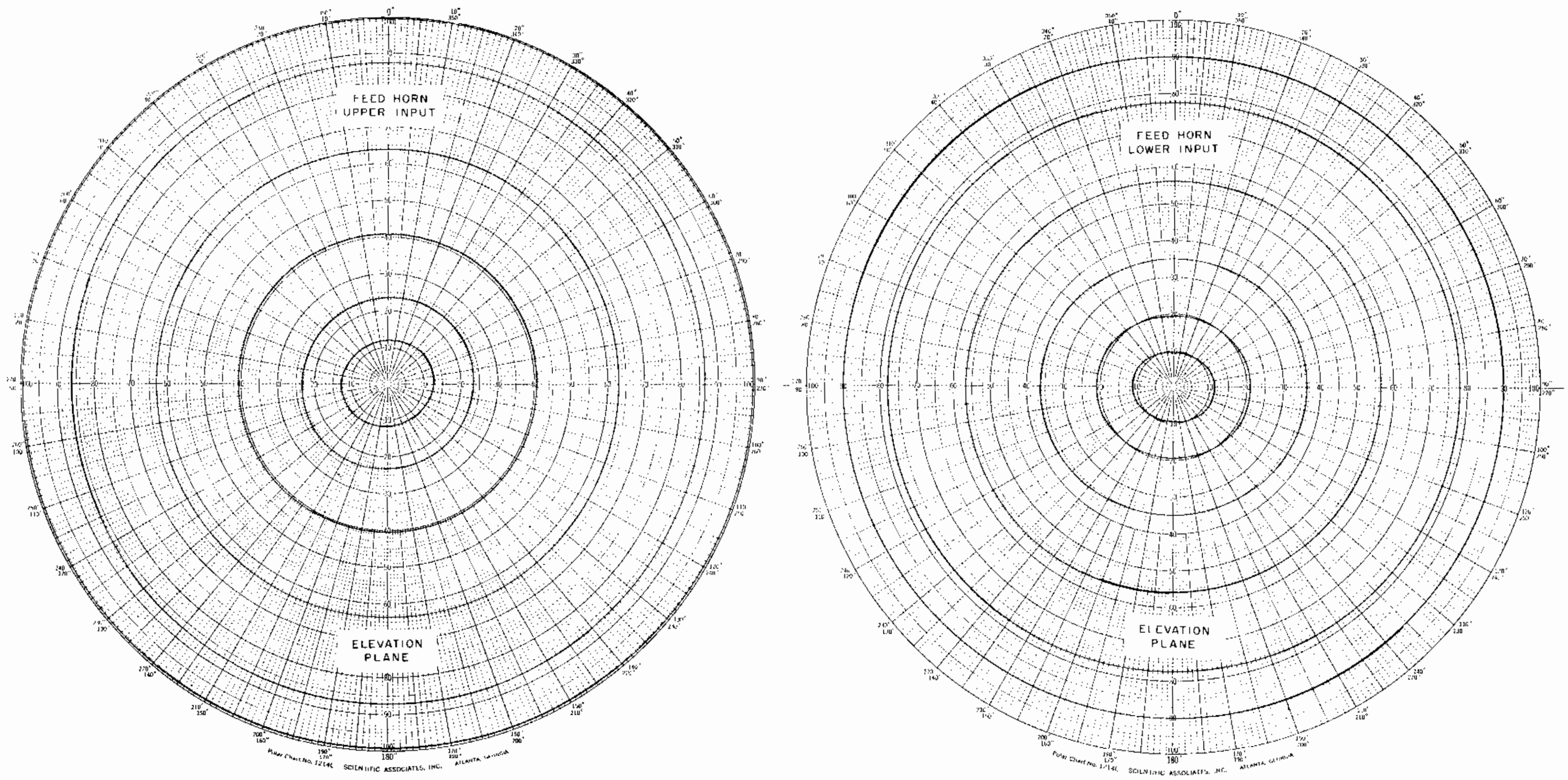


Fig. 4 Polarization patterns through main beam in elevation plane, outer pattern taken on peak of beam, inner patterns at successive 12° angles from peak

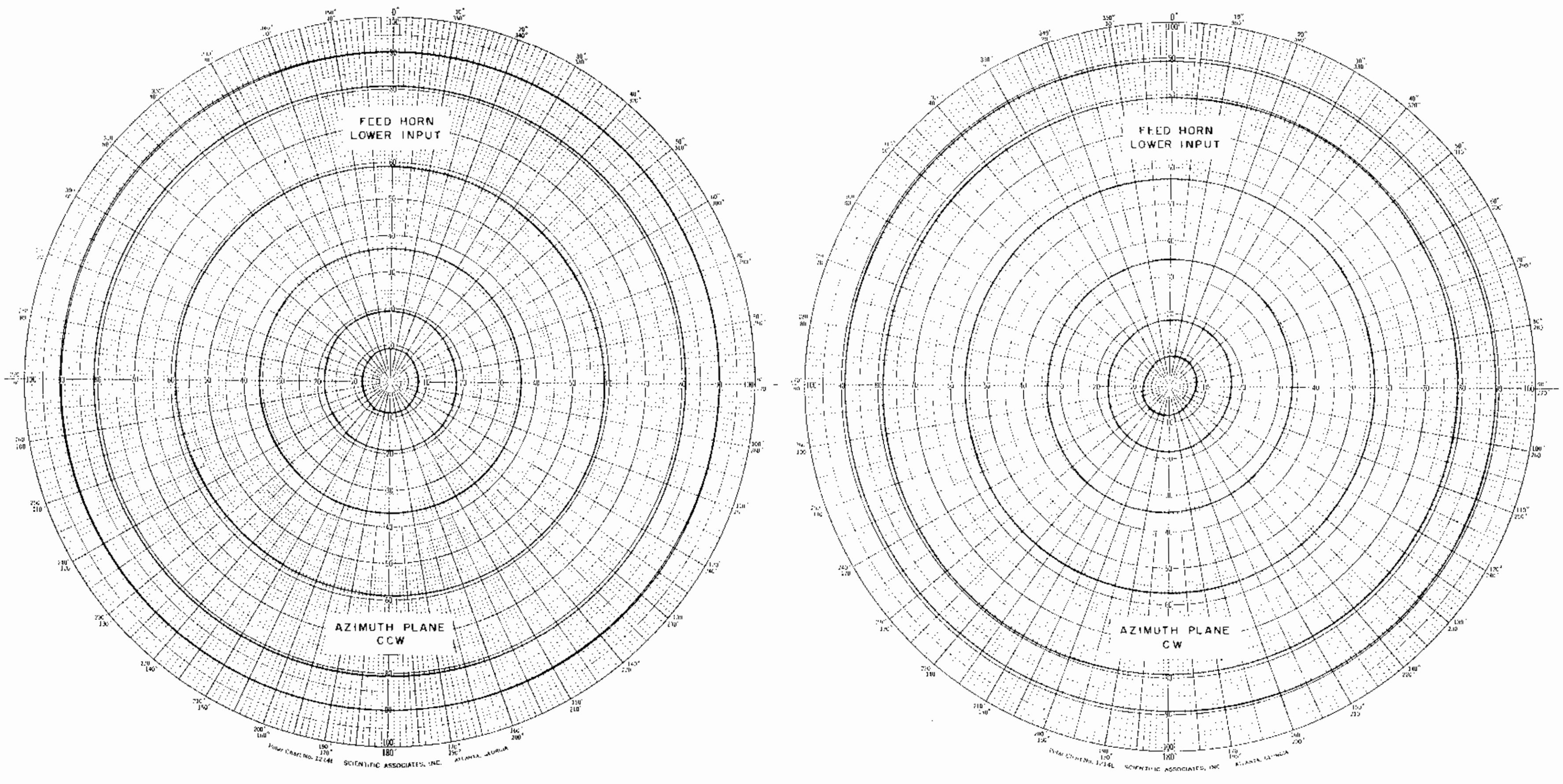


Fig. 5 Polarization patterns through main beam in azimuth plane, outer pattern taken on peak of beam, inner patterns at successive 12° angles from peak

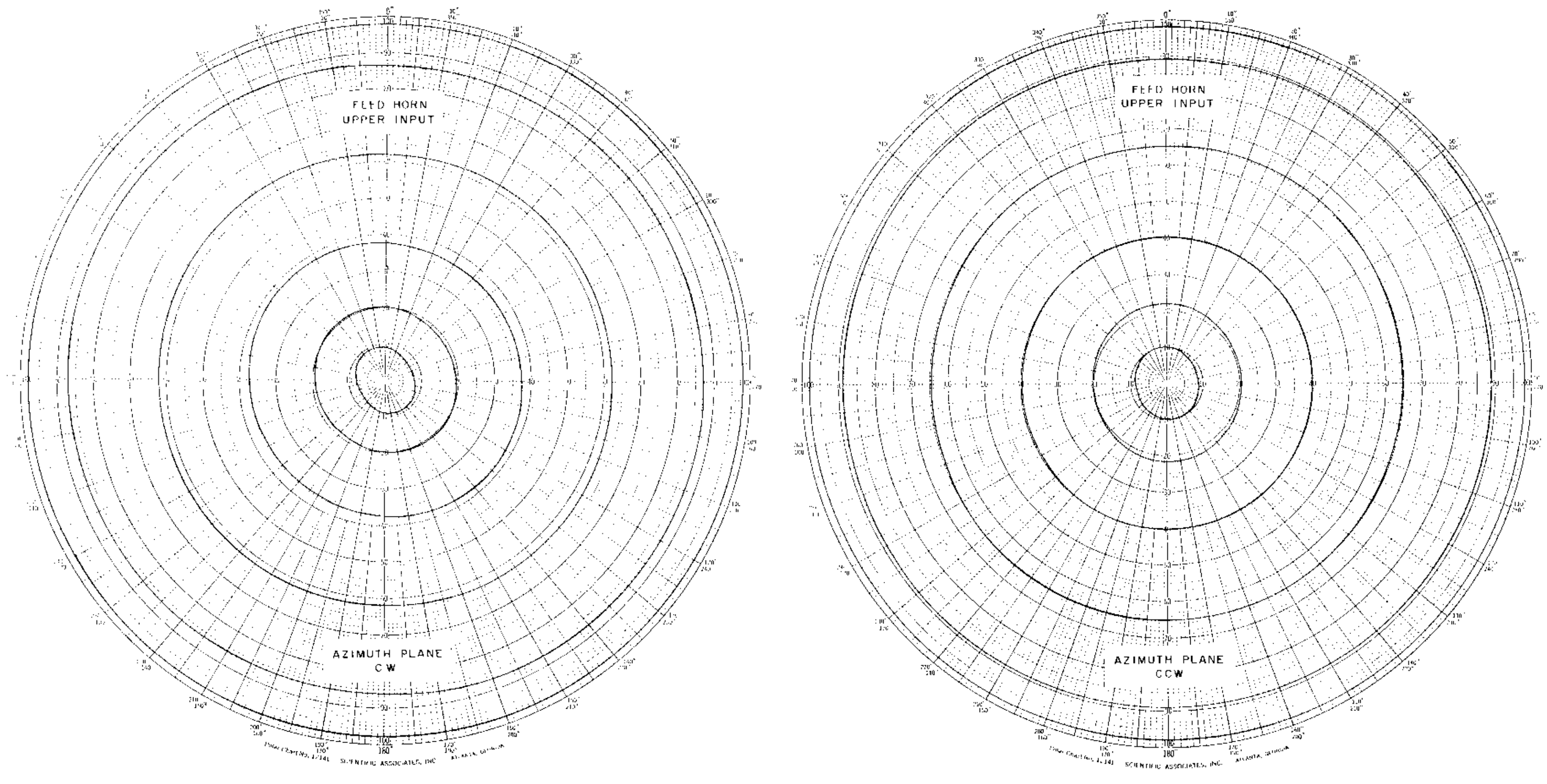


Fig. 6 Polarization patterns through main beam in azimuth plane, outer pattern taken on peak of beam, inner patterns at successive 12° angles from peak

indicate the absence of sidelobes and backlobes, but are inaccurate in respect to beamwidth because of the necessity for offsetting the feed from the axis of rotation during pattern measurements. Polarization patterns in two planes over the relevant part of the beam are shown in Figs. 4, 5, and 6. These patterns are taken by feeding the horn through the turnstile with the turnstile tuned for circular polarization; thus power fed through one turnstile port results in right-hand circular polarization, and through the other port, left-hand circular polarization. A diagram of the turnstile is shown in Fig. 7.

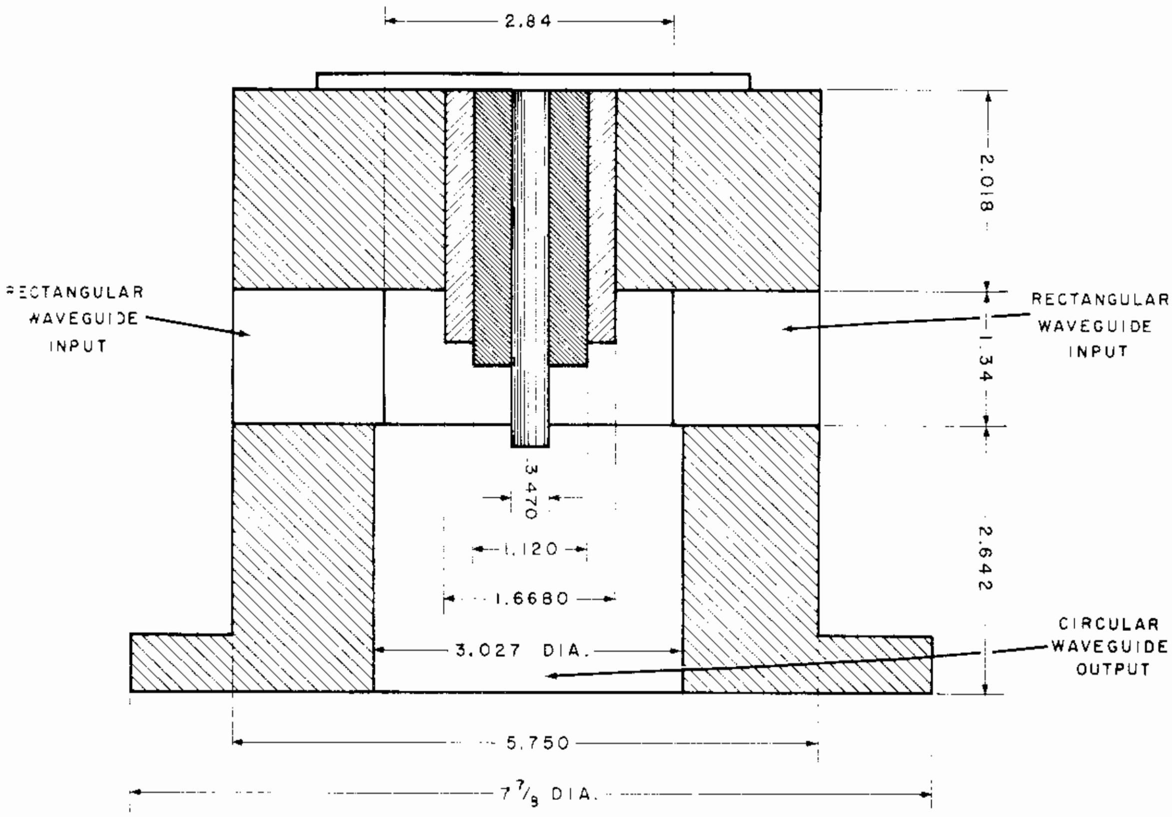


Fig. 7 Diagram of turnstile junction showing concentric tuning plungers

THE MICROWAVE CIRCUIT

It is evident that, ideally, radiation can be transmitted with a polarization having any desired axial ratio at any orientation. The axial ratio is proportional to the amplitude ratio of the signals fed to the two turnstile ports while the orientation angle of the polarization ellipse in space equals one-half of the phase difference at the two inputs. The microwave circuit of Fig. 8 is used to obtain the necessary power division and phase relationship.

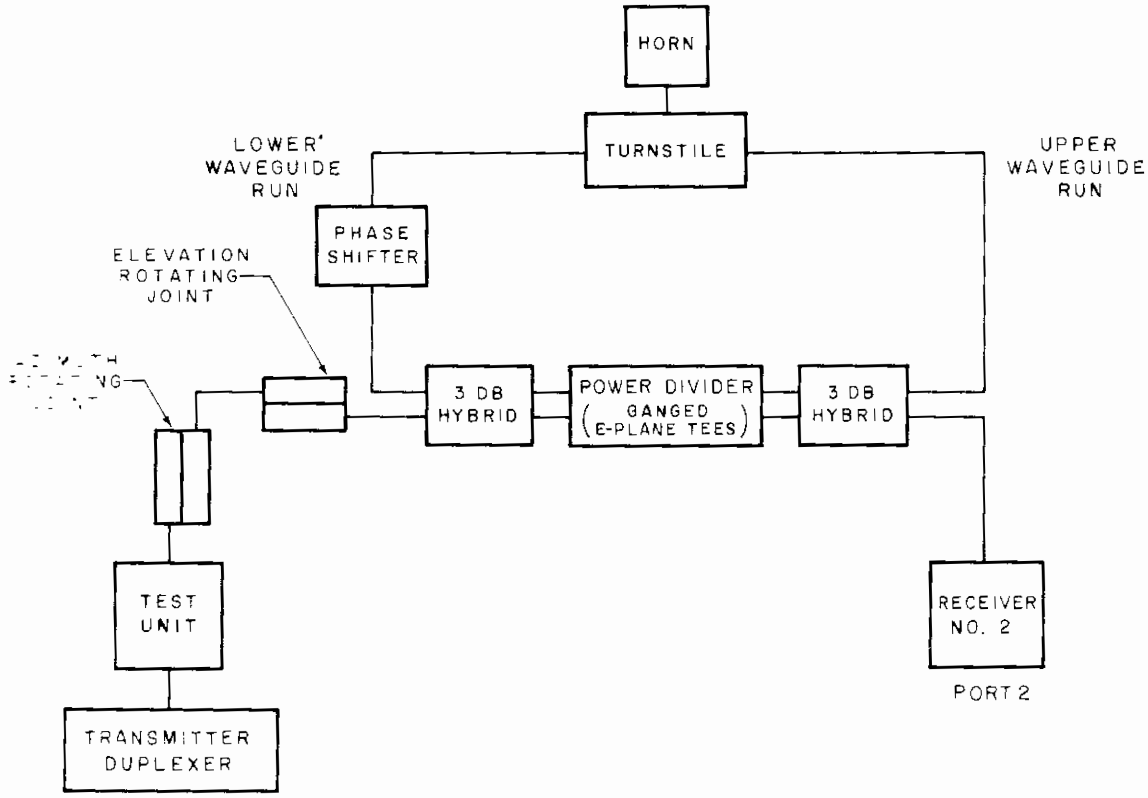


Fig. 8 The microwave circuit

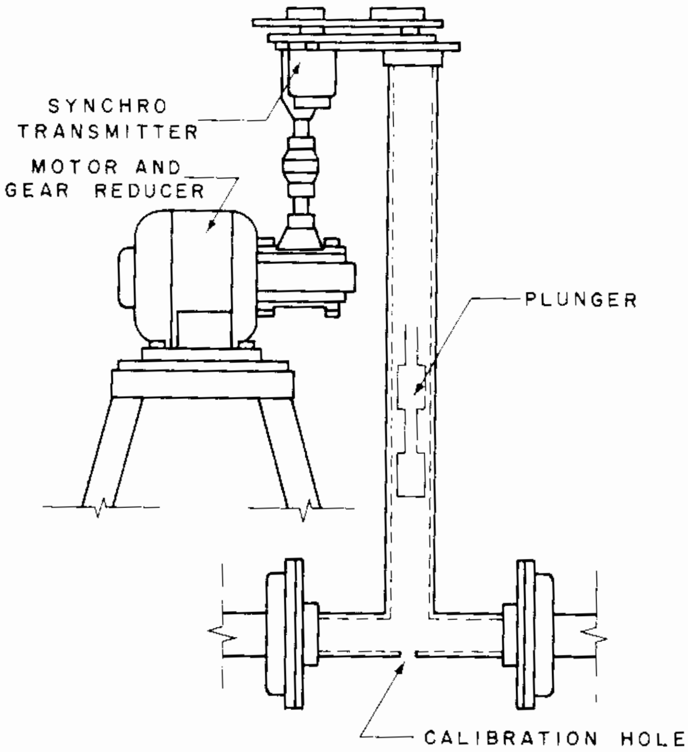


Fig. 9 The power divider

The power divider, details of which are shown in Fig. 9, consists of ganged plungers in E-plane tees in the two waveguide lines between the two hybrids. The equal reactances thereby introduced into the lines can be varied continuously so that ideally the reflected power can be varied from 0% to 100%. The waves transmitted past the tees have equal amplitude and such phase that on passing through the hybrid there is perfect isolation from receiver No. 2, and all the power is carried in the upper waveguide run to the turnstile and feed horn. Similarly all the reflected power on passing through the hybrid will go into the lower waveguide run through the phase shifter to the turnstile.

The phase shifter comprises two turnstile junctions with their circular waveguide sections colinear, the top one being capable of rotation with respect to the bottom one. The output of the top turnstile then passes through a rotary joint to the lower waveguide run. A diagram of the phase shifter is shown in Fig. 10 and a photograph in Plate III. Necessary characteristics of the phase shifter are that

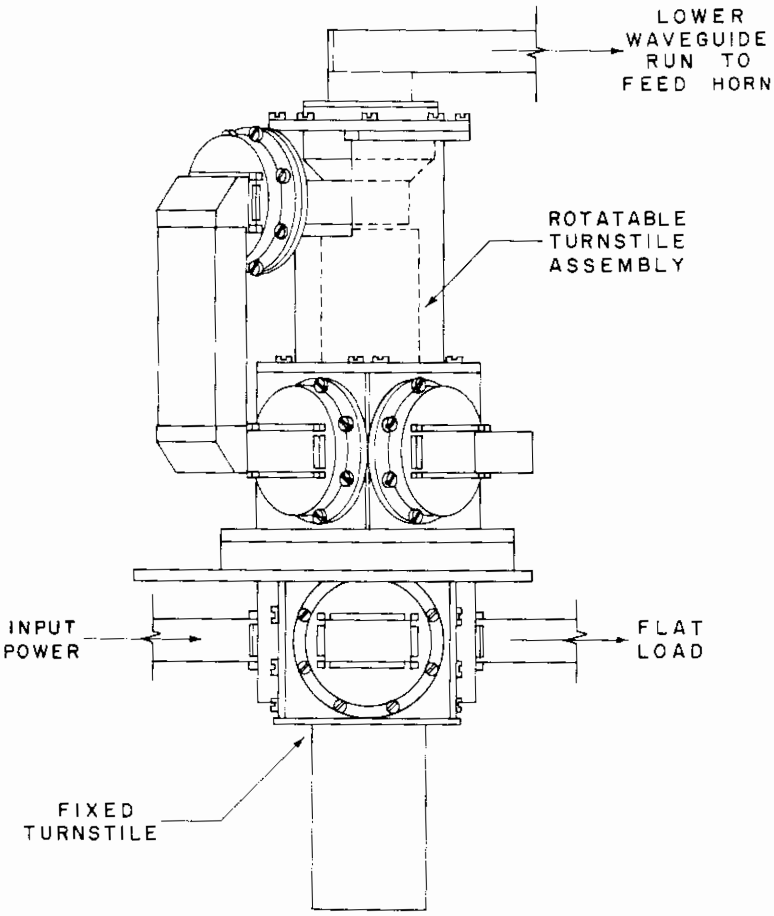
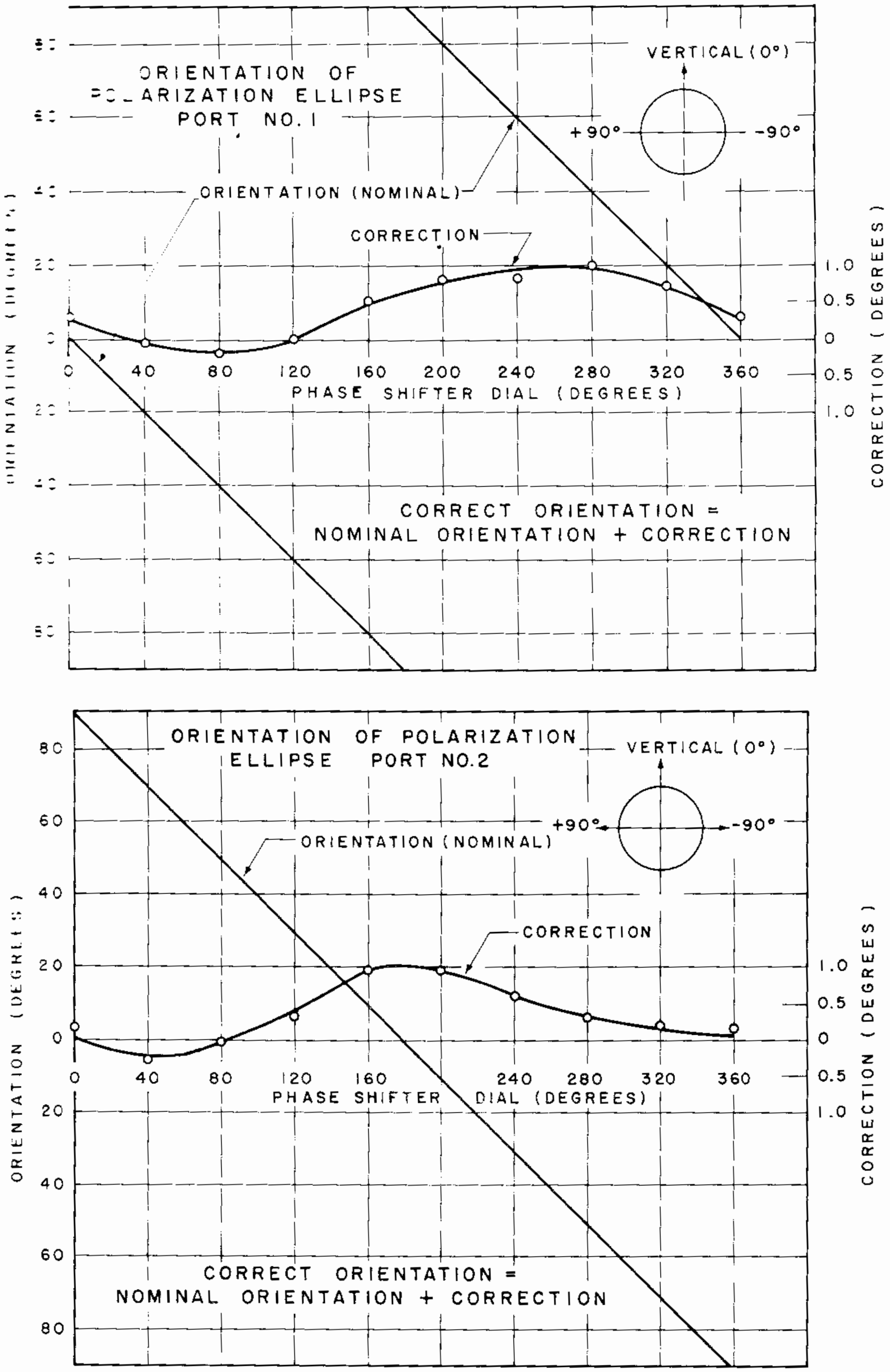


Fig. 10 The phase shifter



Figs. 11 and 12 Orientation of polarization ellipse as function of phase shifter dial setting. Fig. 11, Port 1; Fig. 12, Port 2 be capable of handling high power, that it have low VSWR and an insertion loss independent of phase shift. In the present instance VSWR varied from 1.04 to [illegible], and the insertion loss varied by 0.02 db. It is also desirable that the phase shifter provide continuous rotary phase shift, linear with rotation. The correction from linearity as it affects the orientation of the polarization ellipse is shown in Figs. 11 and 12. These corrections are based on the null positions of polarization patterns taken at a linear polarization setting and are referred to the synchro-controlled phase shifter dial. These orientation curves apply ideally for all axial ratios, but a significant error can be expected for k > 0.95 where k is the axial ratio.

The absolute orientation of the polarization ellipse is affected by any path length difference in the two lines while the correction curves of Figs. 11 and 12 are related solely to the phase shifter. These other effects include differences in line length due to temperature differences between the two waveguide lines, and uncertainty due to changes in mechanical strains when the waveguide lines are dismantled and reassembled. It is estimated that the electrical path length of either line changes by 0.6 electrical degrees for a change in temperature of 1°F.

The polarization performance of the antenna is limited by the extent to which the individual components depart from ideal. In the case of the short slot hybrids, commercial units were tuned for optimum coupling and isolation. The plunger mechanism was tested to determine that it tracked properly over its full length

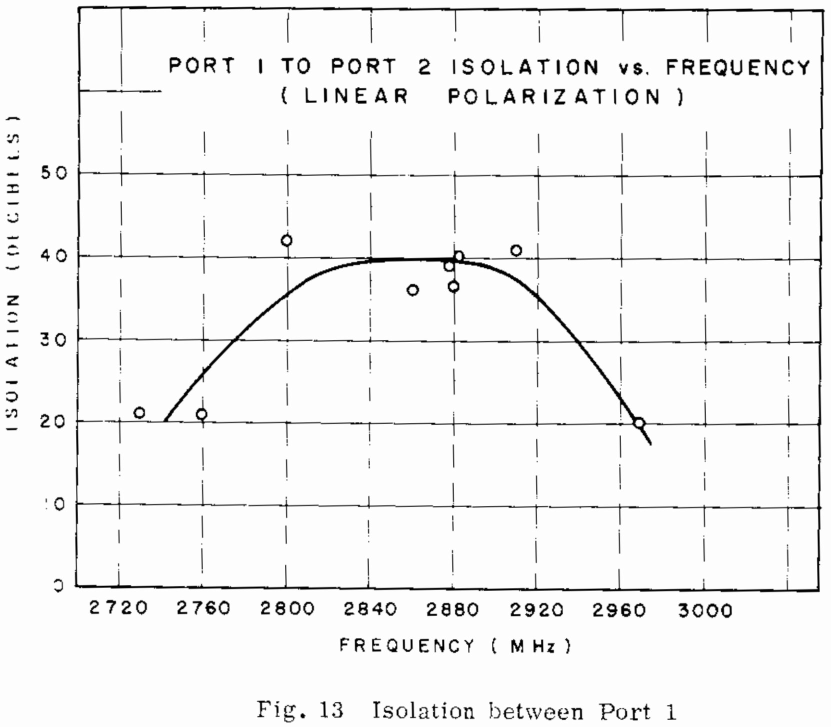


Fig. 13 Isolation between Port 1 and Port 2 as function of frequency

of travel. Special mounting in the plunger arms was provided to remove thermal expansion effects, and backlash was largely eliminated. Path lengths between the hybrids were carefully equalized. The isolation between Port 1 and Port 2 for the hybrid assembly only (i.e., before connection to the phase shifter and turnstile) was 46 db. The isolation between adjacent ports (e.g., Port 1 and the waveguide leading to the phase shifter) was also 46 db. The isolation between Ports 1 and 2 for the complete antenna is shown as a function of frequency in Fig. 13 for vertical linear polarization. The isolation for circular polarization is generally somewhat better. The highest VSWR at linear polarization which was observed while the phase shifter rotated is shown in Fig. 14.

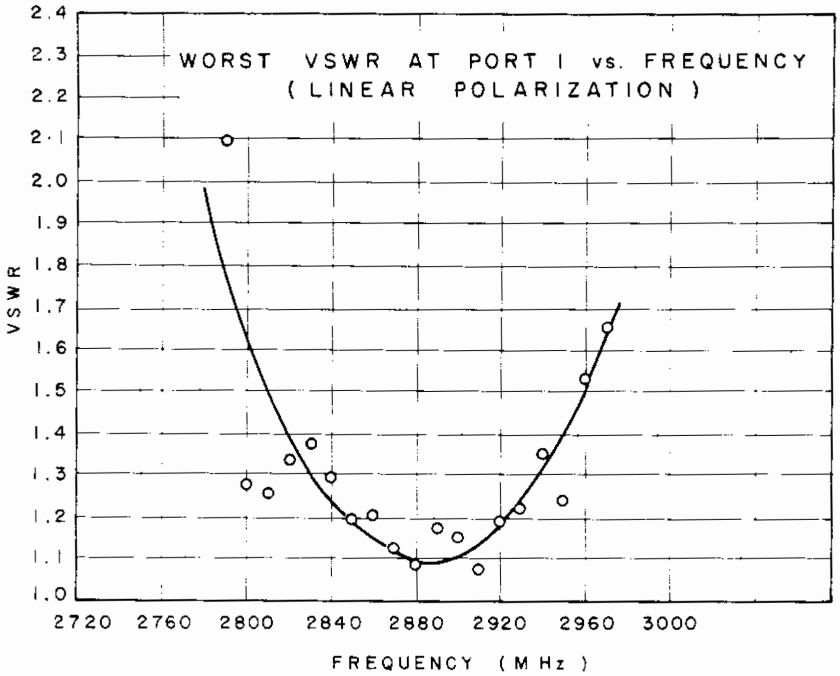


Fig. 14 Highest VSWR at Port 1 as function of frequency. Antenna set for linear polarization

The observed axial ratio, as a function of the plunger counter reading on the control panel, is shown in Fig. 15. Counter readings for linear polarization (axial ratio = 0) and for circular polarization (axial ratio = 1) are indicated. The detail for near-circular polarization is shown in Fig. 16 and Fig. 17.

There is provision for a mechanical check of plunger position by means of a depth gauge measurement through holes in the bottom walls of the tee sections. With the panel counter at 58529 the plunger counters should read 58529 and [illegible]. Then the respective depth gauge readings, through the holes to the bottom of the plungers, should be 2.3245 inches and 2.3220 inches.

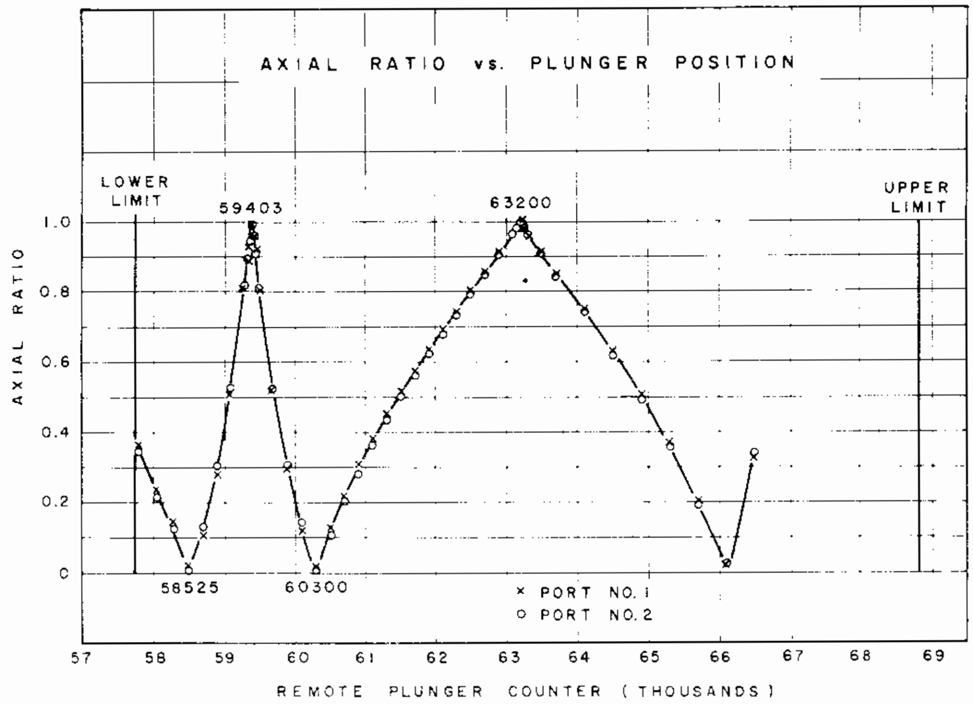


Fig. 15 Axial ratio of polarization ellipse as a function of remote counter reading. Linear polarization corresponds to axial ratio = 0; circular polarization corresponds to axial ratio = 1

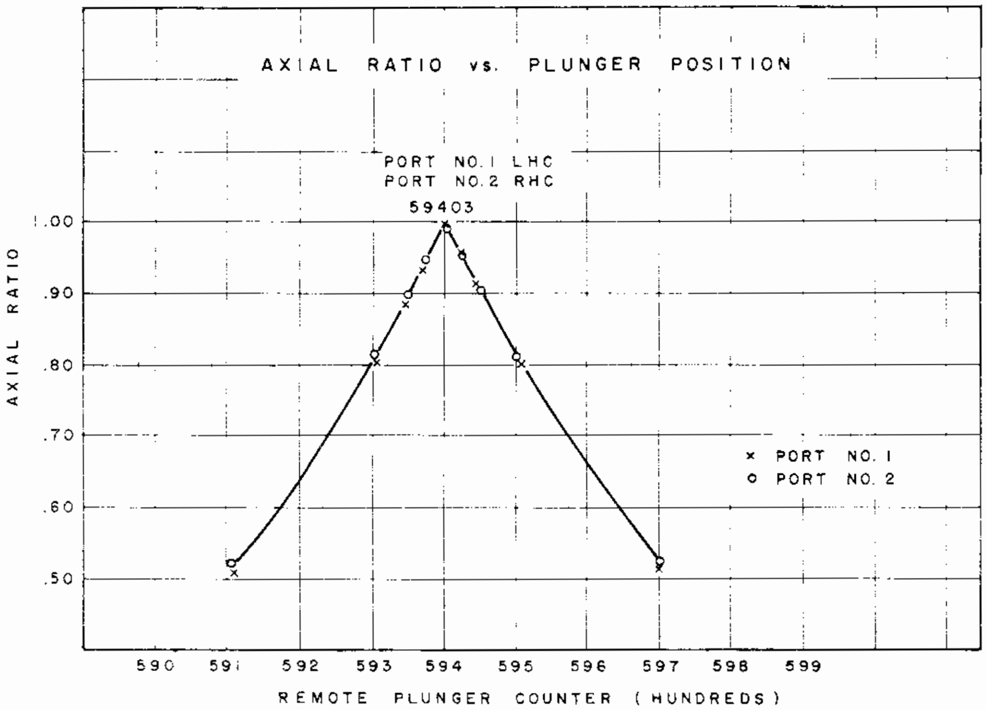


Fig. 16 Detail of axial ratio curve in vicinity of total reflection setting

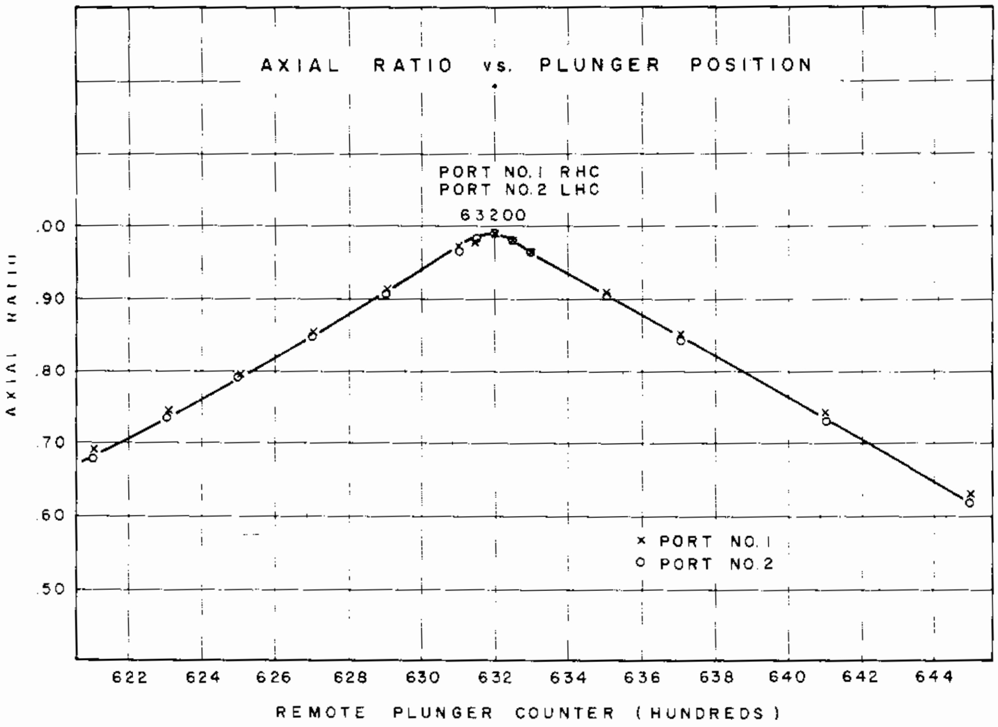


Fig. 17 Detail of axial ratio curve in vicinity of total transmission setting

RECTANGULAR PATTERNS

Rectangular patterns for various polarization settings are shown in Figs. 18 to [illegible]. The synchro system of the antenna pedestal was used to operate the pattern recorder and this led to an unusual elevation expansion scale (5 divisions = 1°). It is to be noted that the right half of the elevation pattern corresponds to the antenna being tilted forward; beyond 1° from the peak of the beam it is erroneous owing to ground reflection.

The beamwidth is 1.15° in both E-plane and H-plane at the 3-db level. Maximum sidelobes are -23 db in azimuth and -30 db in elevation.

POLARIZATION CHARACTERISTICS

The foregoing discussion of the effect of the microwave circuit on the polarization characteristics of the antenna (see Section 3) was based on the ideal hypothesis that power incident to the feed through Port 1 produces exactly left-hand circular polarization over all significant parts of the beam, and that power incident

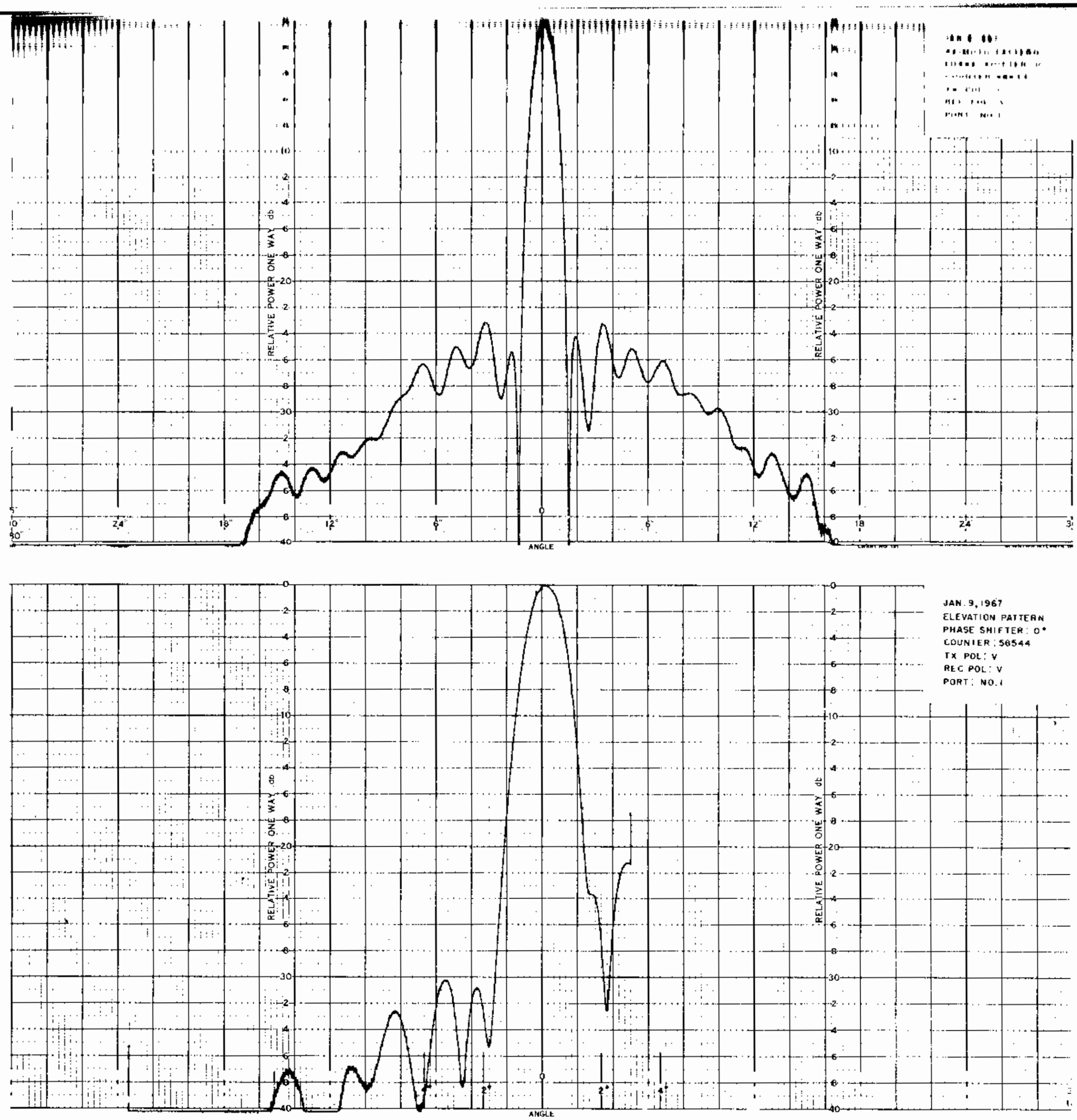


Fig. 18 Azimuth and elevation patterns for typical polarization setting. Port No. 1

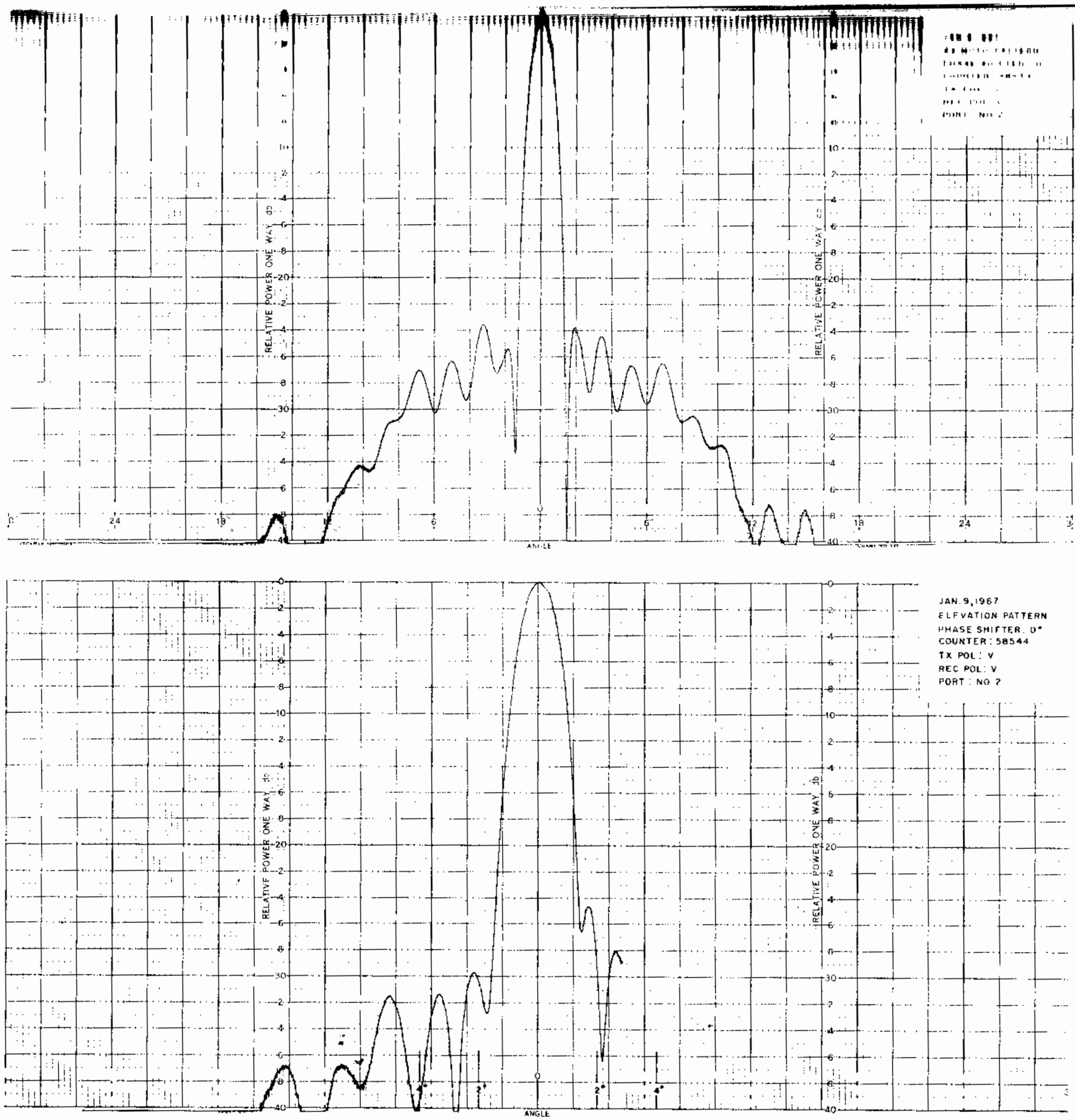


Fig. 19 Azimuth and elevation patterns for typical polarization setting. Port No. 2

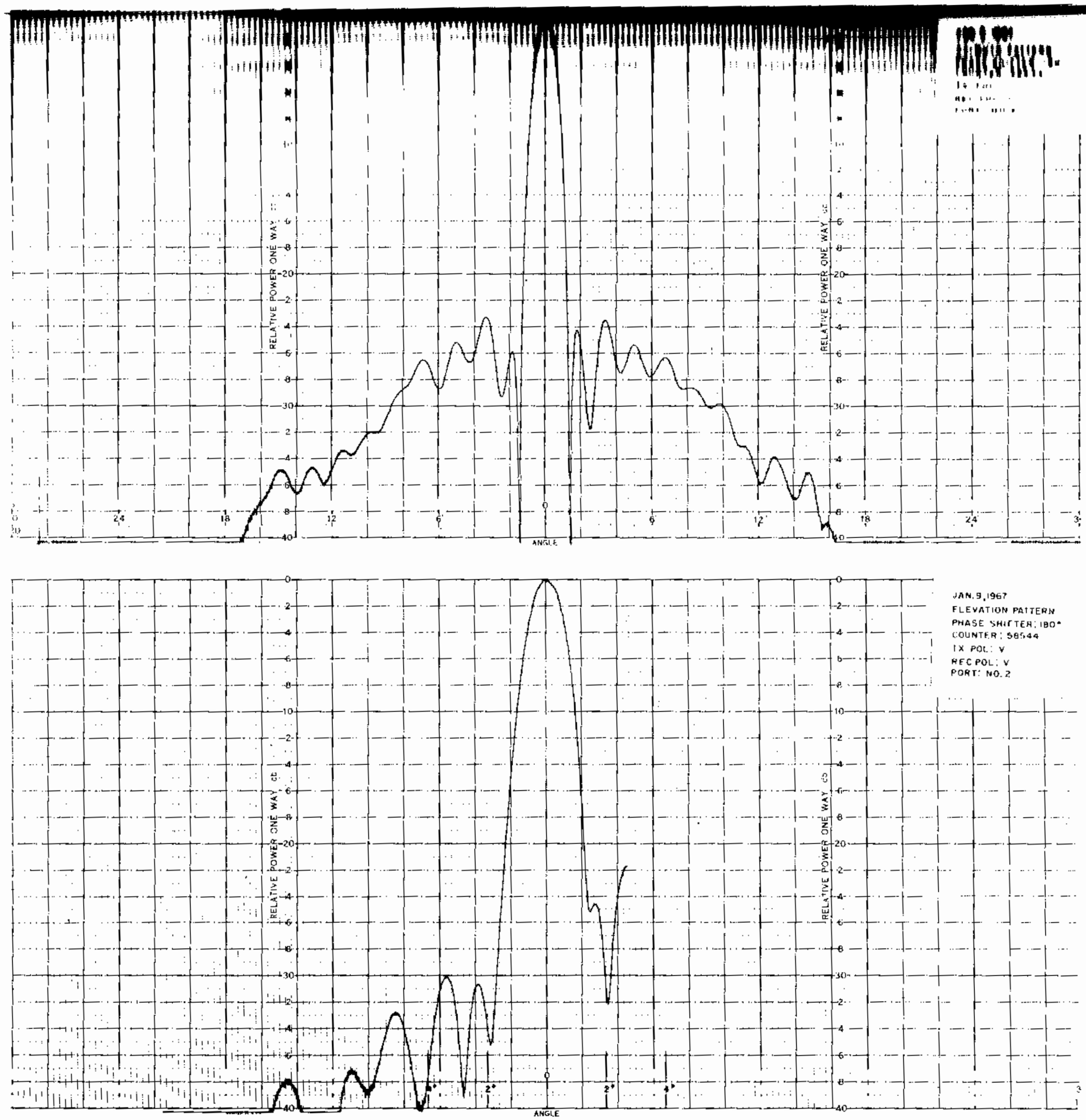


Fig. 20 Azimuth and elevation patterns for typical polarization setting. Port No. 2

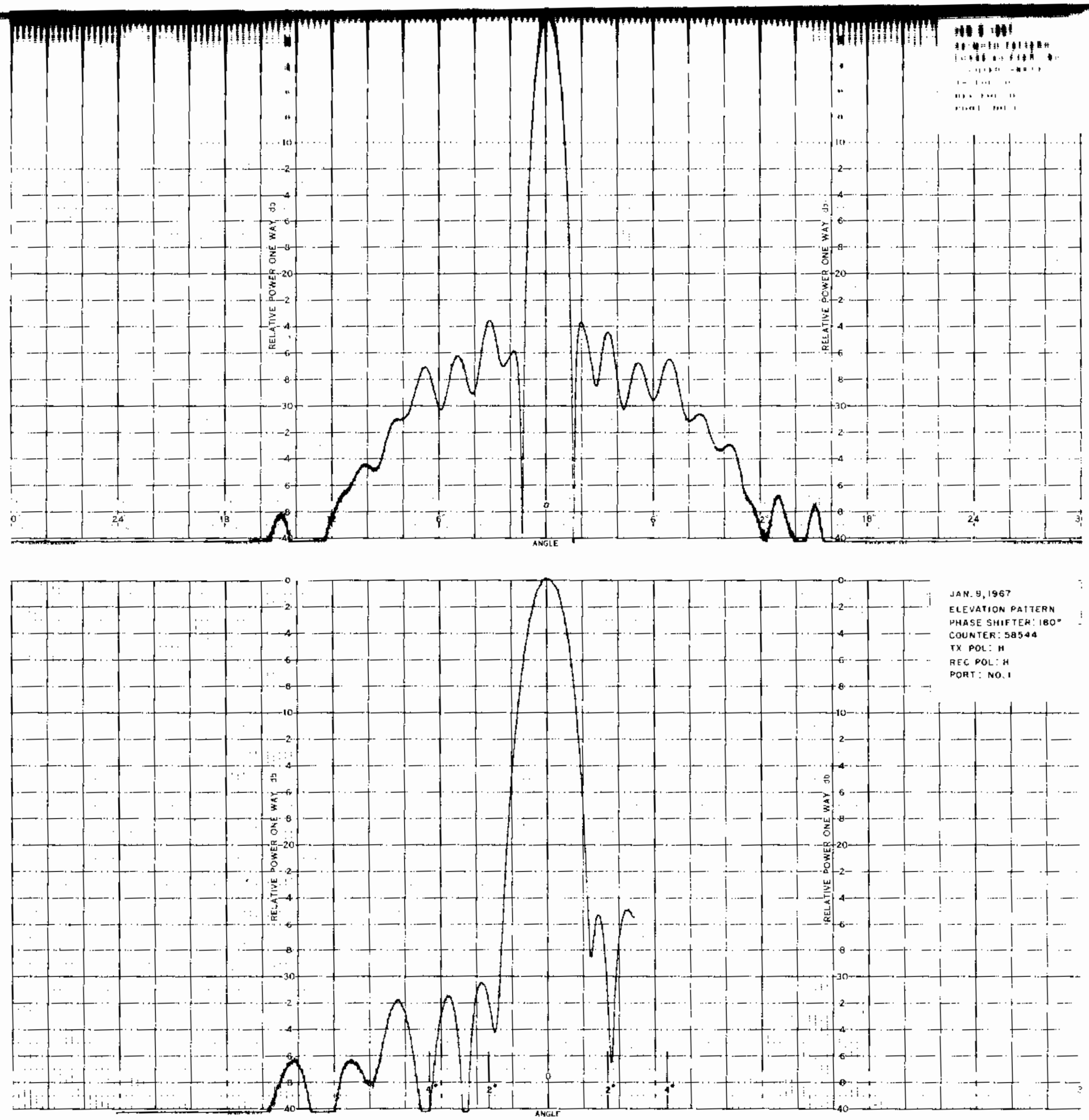


Fig. 21 Azimuth and elevation patterns for typical polarization setting. Port No. 1

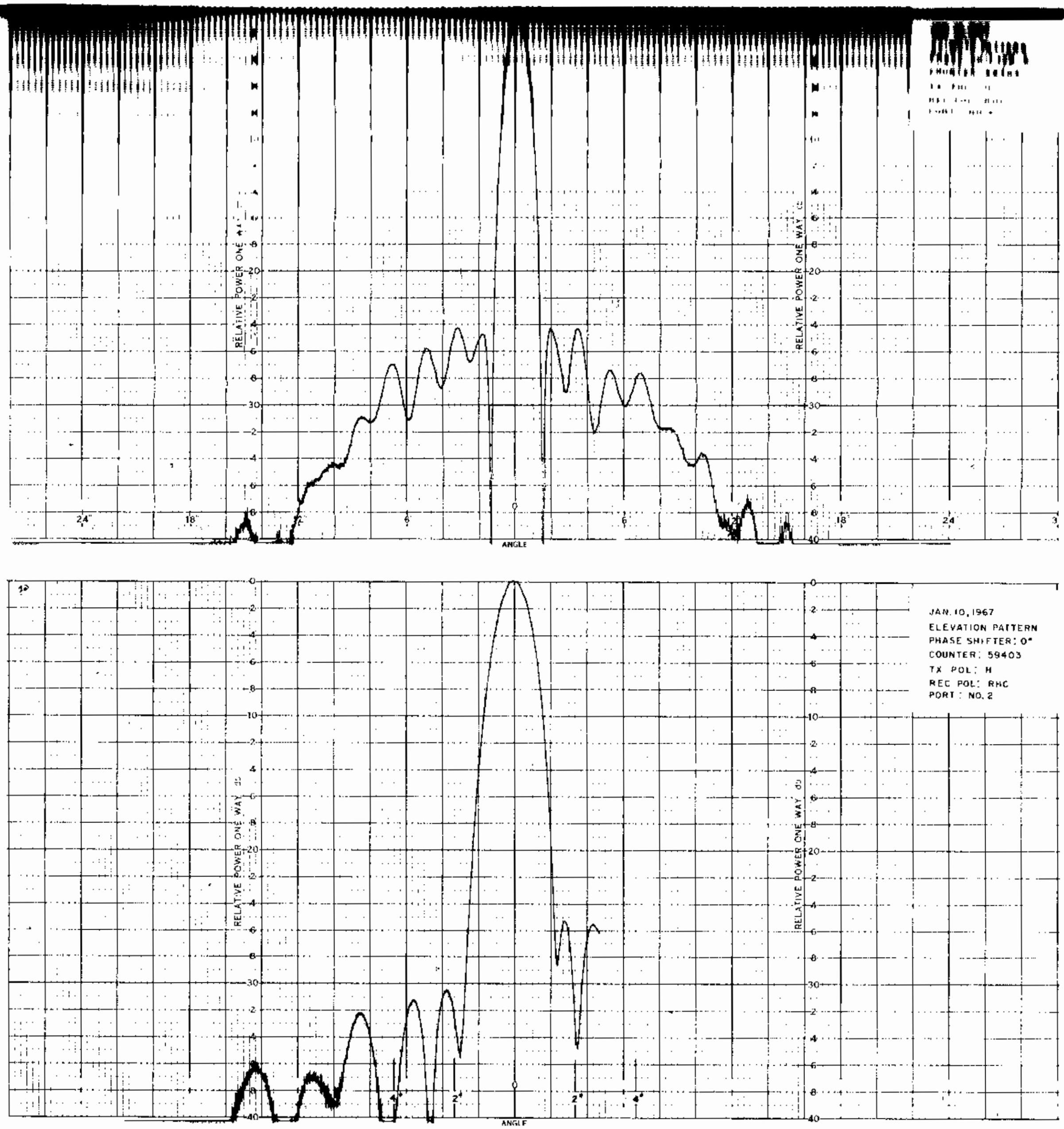


Fig. 22 Azimuth and elevation patterns for typical polarization setting. Port No. 2

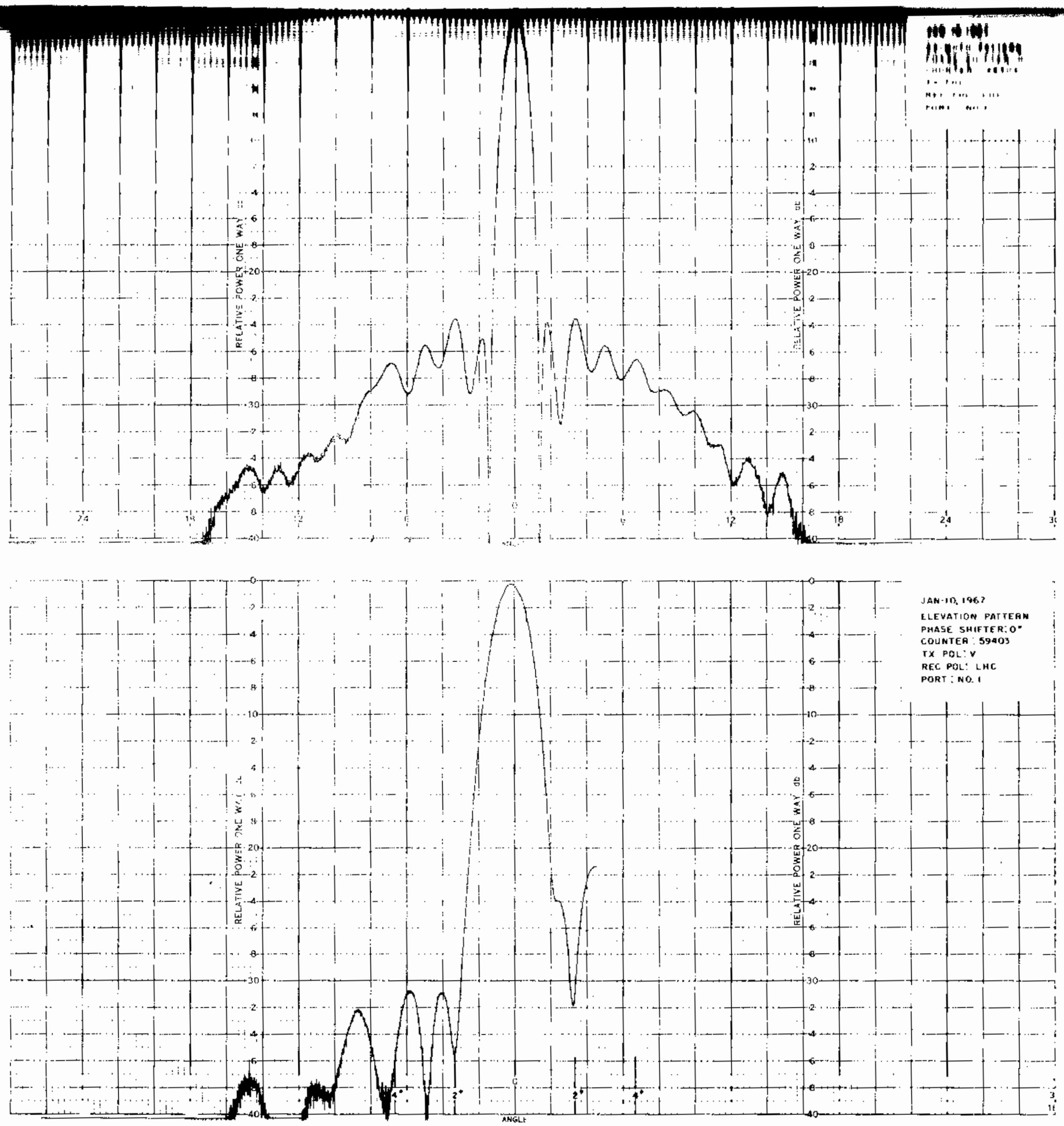


Fig. 23 Azimuth and elevation patterns for typical polarization setting. Port No. 1

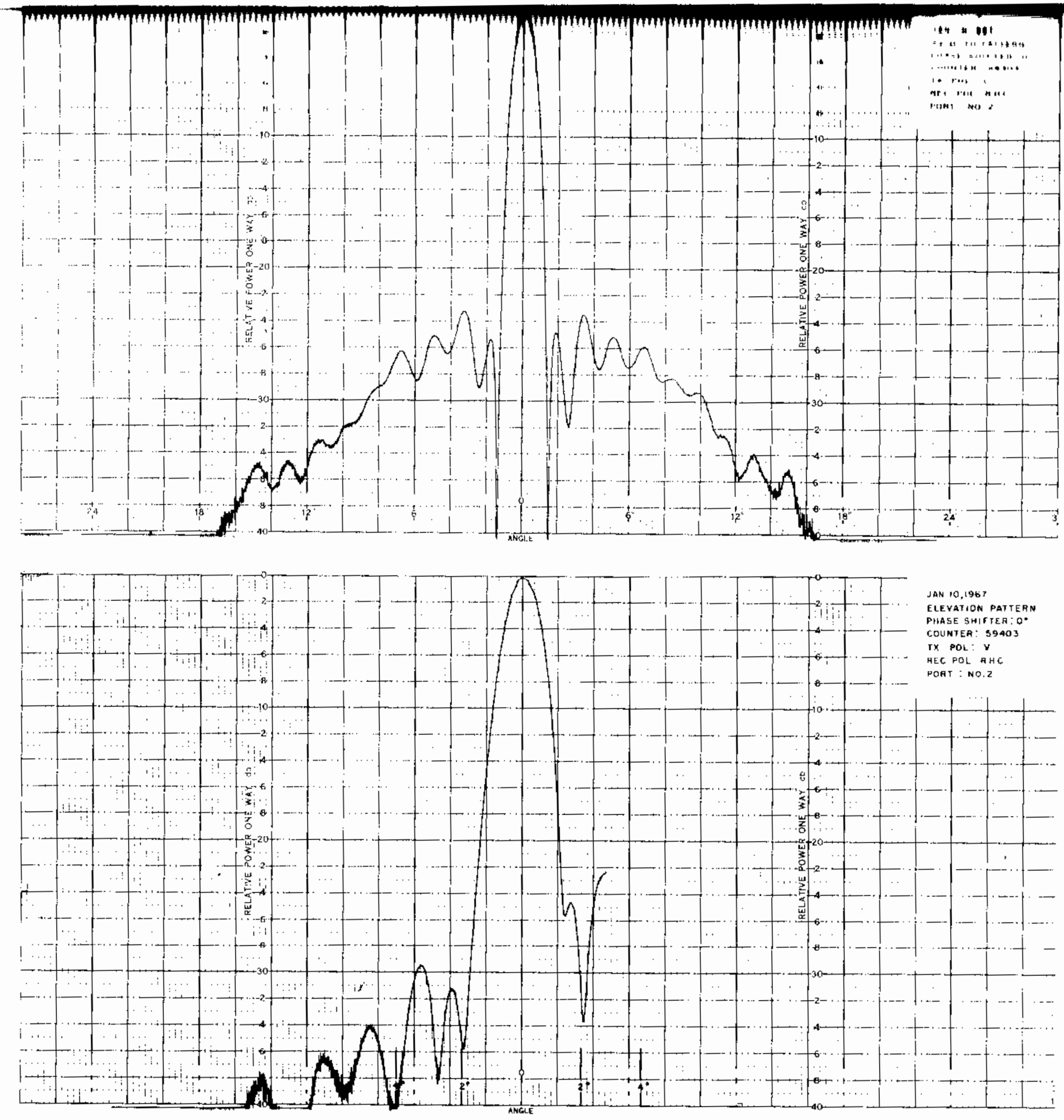


Fig. 24 Azimuth and elevation patterns for typical polarization setting. Port No. 2

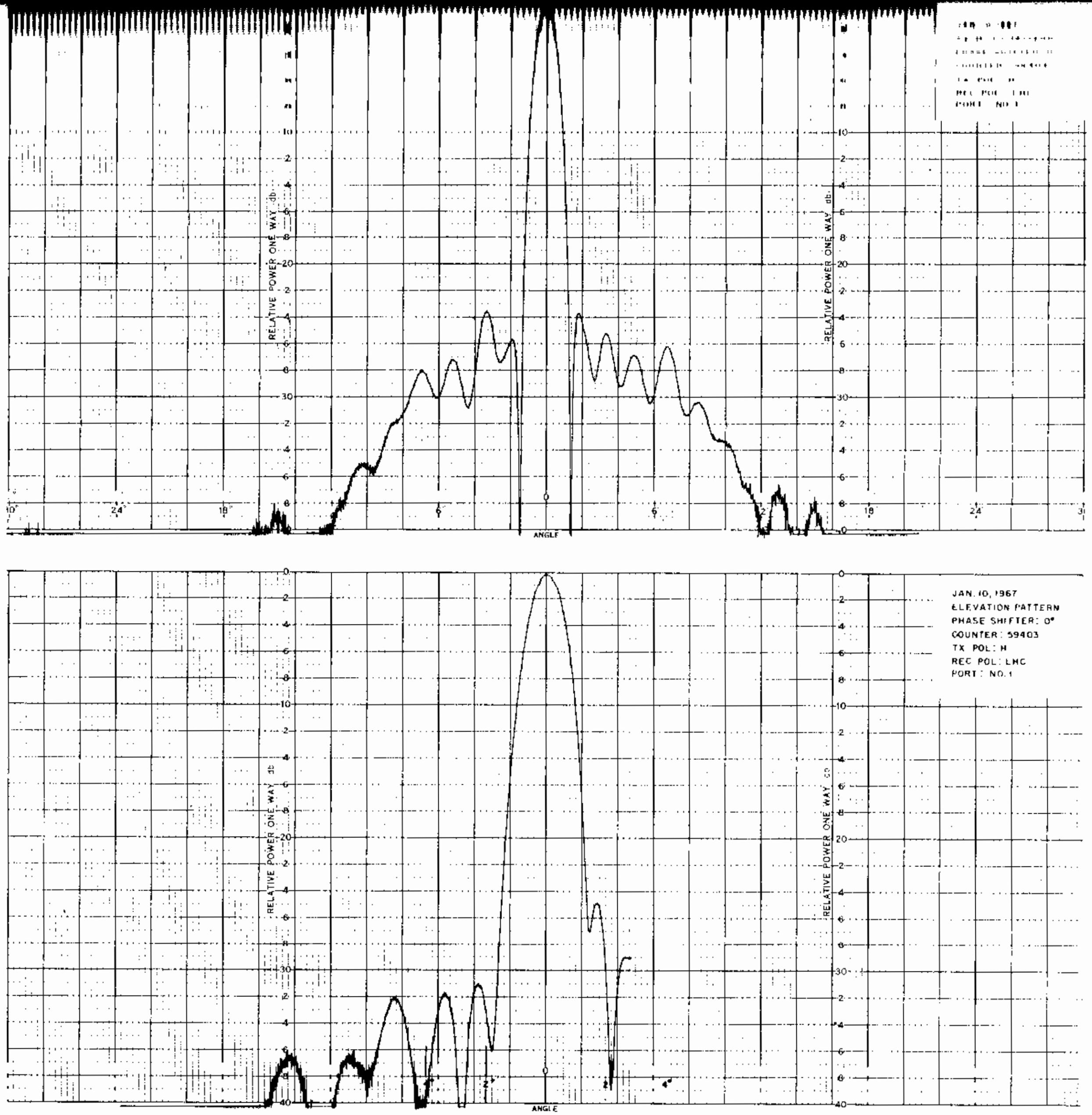


Fig. 25 Azimuth and elevation patterns for typical polarization setting. Port No. 1

through Port 2 produces exactly right-hand circular polarization. The dual-mode feed horn referred to in the discussion produces polarization patterns which approximate those desired. Representative patterns taken over that part of the primary radiation which strikes the reflector have been shown above in Figs. 4, 5, and 6. Of the concentric patterns the outer one is taken on the peak of the beam and the inner ones at 12° intervals off the peak of the beam. The half angle subtended by the reflector is 55°18'.

A serious change in axial ratio occurred when the horn and turnstile, as adjusted for the previous patterns, were installed in the antenna. This change resulted from scattering of both primary and secondary radiation by supporting structures, particularly the steel A-frame supporting the feed and the two waveguide runs. Minor changes in feed position may cause an appreciable change in the effect of primary scattering. Hence, the positioning of the feed was determined by optimizing the polarization patterns while staying within the region where no deterioration in rectangular patterns occurred. It was then found that an adjustment of the turnstile shorts could be made such that the pattern associated with either port was nearly circular. In doing so, isolation and hence orthogonality were preserved.

The small amount of noncircularity which still remained in the polarization patterns on the peak of the beam (about 1.5%) could be removed by introducing a small amount of loss in the turnstile shorts. The polarization patterns of Figs. 26 and 27 were obtained with this arrangement. The production of near-ideal patterns on the peak of the beam permitted an investigation of patterns produced by various settings of the power divider and phase shifter. It was confirmed that the patterns did indeed appear as predicted on the basis of assigned settings for the phase shifter and plungers.

It became apparent, however, that the perfection of on-axis patterns was obtained at the expense of some deterioration off-axis. It was concluded that the advantage of the 'lossy' shorts, if any, was insufficient to justify the increased complexity and uncertainty in their use, and they were replaced by shorting plates with an adjustable screw.

Polarization patterns taken with the 'lossless' shorts formed the basis for a calculation of the integrated cancellation ratio. An antenna which produces radiation having an axial ratio k will receive from a symmetrical scatterer a signal proportional to $G^2 C^2$ where G is the antenna gain and C the cancellation ratio, $\frac{1 - k^2}{1 + k^2}$. Hence the integrated cancellation ratio is given by

$$C_I^2 = \frac{\int C^2 G^2 \, d\Omega}{\int G^2 \, d\Omega}$$

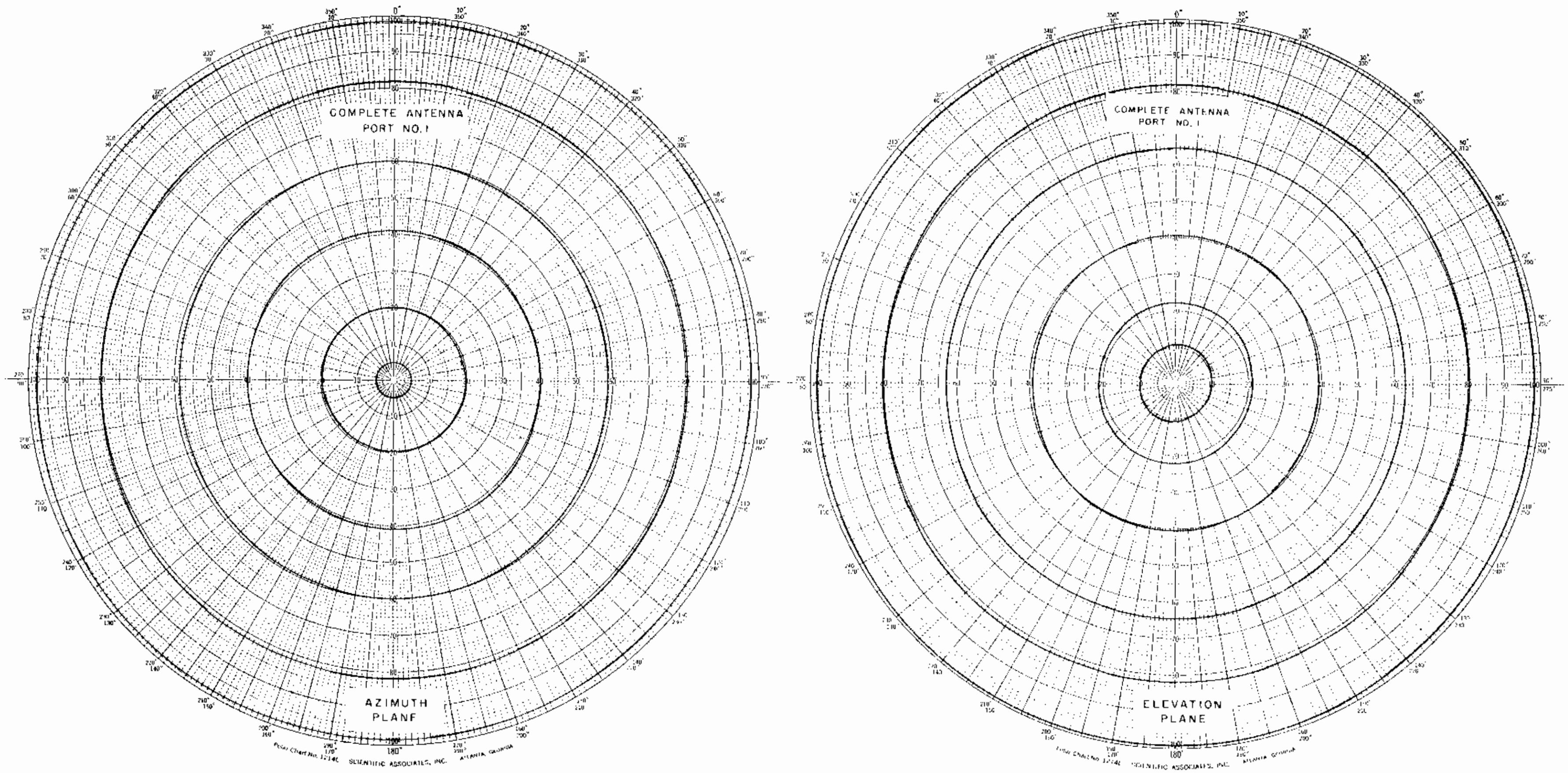


Fig. 26 Polarization patterns, Port No. 1, obtained with complete antenna set for circular polarization. Outer pattern was taken on peak of beam, inner patterns at successive angles off peak in azimuth and elevation planes. All patterns indicate square root of received power

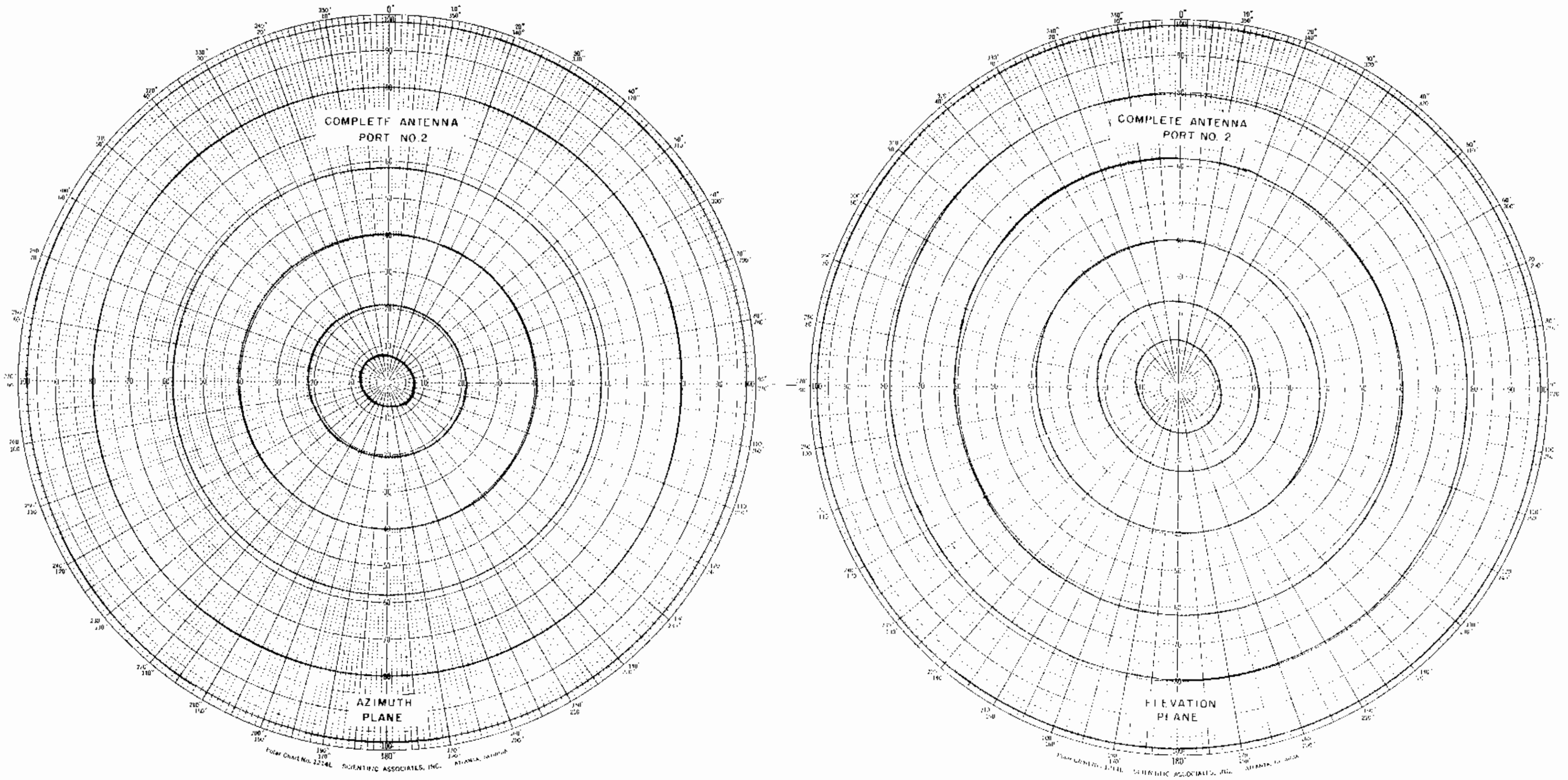


Fig. 27 Polarization patterns, Port No. 2, obtained with complete antenna set for circular polarization. Outer pattern was taken on peak of beam, inner patterns at successive angles off peak in azimuth and elevation planes. All patterns indicate square root of received power

where integrations are over solid angles which include all significant parts of the main radiation beam and sidelobes. It was found that $C_I^2 = 0.402 \times 10^{-3}$ corresponding to -34 db. This corresponds to an equivalent axial ratio, $k_I = 0.9802$.

The plunger settings for linear polarization, 58525 and 60300, are shown in Fig. 15. At these settings the cross polarization is -40 db on the peak of the beam for both ports. Optimum settings based on cross polarization observed on the peak of the beam are 58544 and 58500 for ports 1 and 2, respectively, at which the cross polarization power varied from -43 db to -47 db depending on the orientation. The cross polarization at the other port for these optimum settings is approximately -33 db. Cross polarization off the peak of the beam can be expected to exceed these values.

GAIN

The gain was measured by transmitting a known power through a standard-gain horn. A measurement of the received power permitted the calculation of the antenna gain by the formula,

$$\frac{P_R}{P_T} = \frac{G_R\, G_T}{16\pi^2} \left(\frac{\lambda}{R}\right)^2$$

With $G_T = 17.8$ db, $\lambda = 4.10$ inches, $R = 2200$ feet, it was found that $\frac{P_R}{P_T} = -37.1$ db as measured at Port 1 with a linear polarization adjustment of the microwave circuit. This corresponds to,

$$G_R = 43.25 \text{ db.}$$

The measured value of insertion loss between Port 1 and the input to the turnstile was 0.46 db. Hence the antenna has a directive gain of 43.7 db corresponding to a gain factor of 0.57. A comparison was made of the two power meters, and the rotary wave attenuator used at the transmitting site was checked. It is believed that the error in the gain measurement does not exceed 0.2 db.

FREQUENCY CHARACTERISTICS

Components of the antenna which are particularly frequency sensitive are the turnstile and the power divider. The frequency sensitivity of the latter increases with stub length. Where there is a choice, it should, therefore, be used at the lowest counter setting. Polarization patterns on the peak of the beam as a function of frequency are shown in Figs. 28 and 29. Narrow-bandwidth preamplifiers are being used to prevent deterioration due to any extension of the frequency spectrum beyond the acceptable range of 2880 ± 1 MHz.

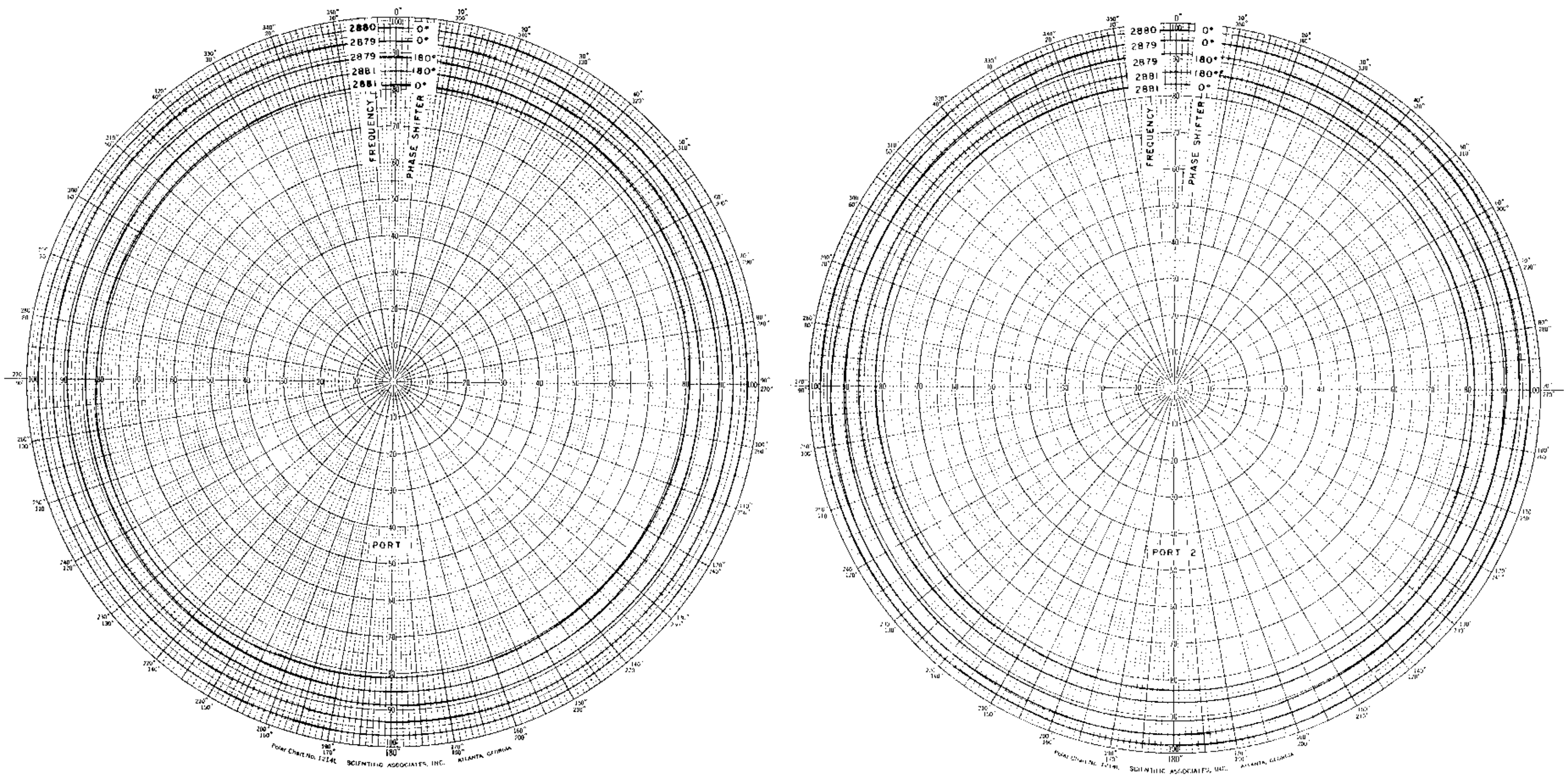


Fig. 28 Polarization patterns taken at 2880 MHz, 2879 MHz, and 2881 MHz

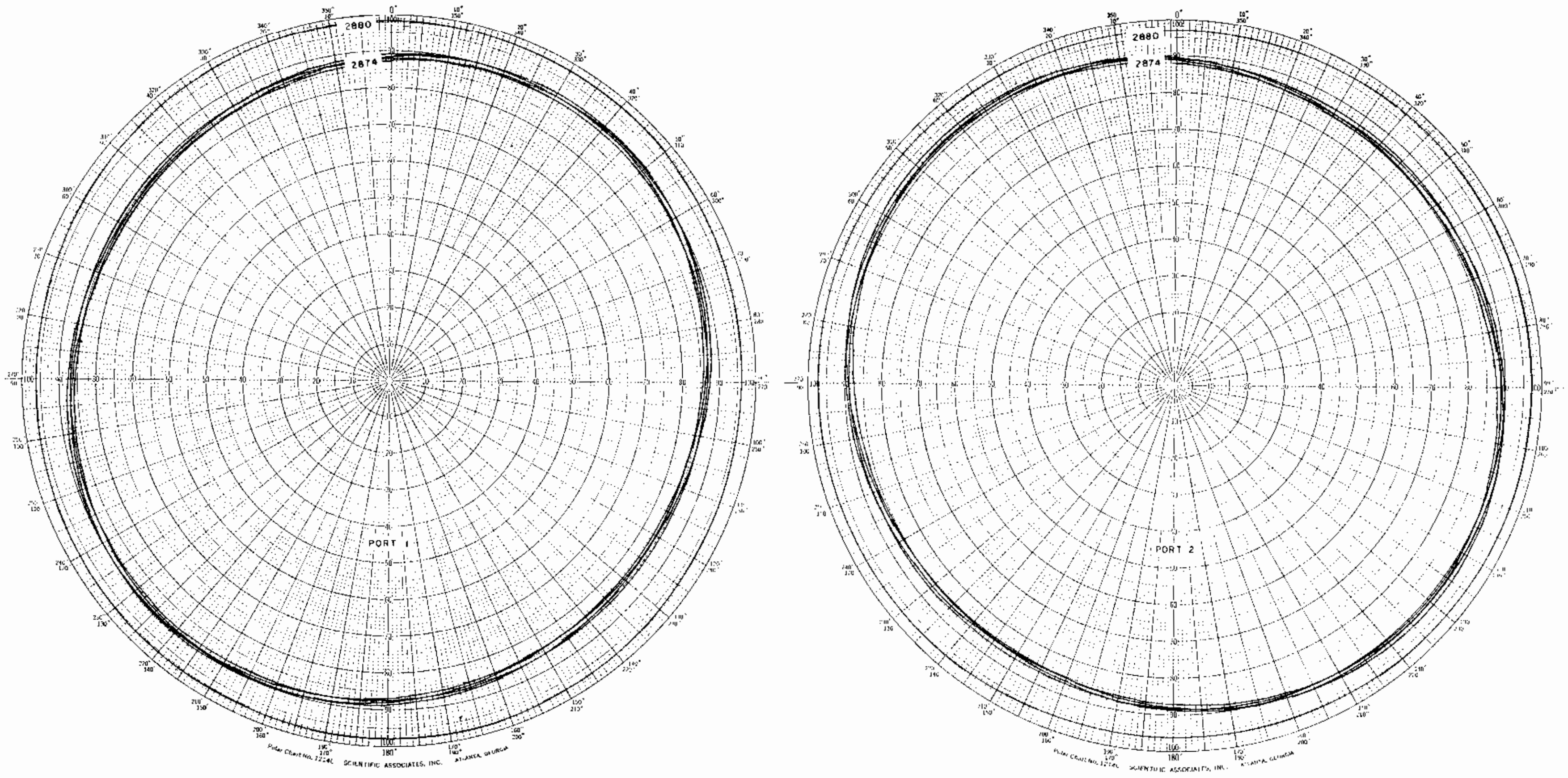


Fig. 29 Polarization patterns taken at 2880 MHz and 2874 MHz. Counter setting was for circular polarization. Patterns at four phase shifter settings shown at 2874 MHz

There is no deterioration in the normal monitoring function of the radar within the frequency band 2880 ± 50 MHz. Isolation and VSWR are indicated in Figs. 13 and 14. Plunger-counter and phase-shifter settings for maintaining vertical linear polarization are shown in Fig. 30. There is no deterioration in rectangular patterns over the frequency range 2880 ± 50 MHz.

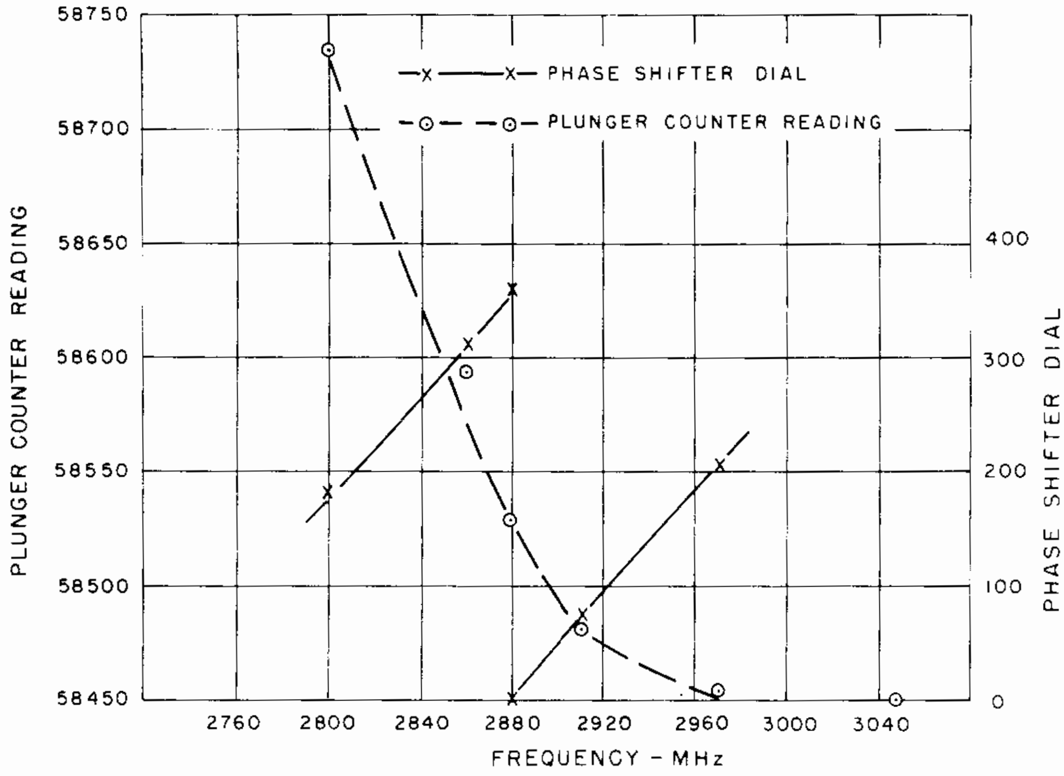


Fig. 30 Settings vs frequency for transmission of linear vertical polarization

STABILITY OF POLARIZATION PERFORMANCE

The performance characteristics reported herein are based on an optimum adjustment of the antenna. It is reasonable to expect that the total process of dismantling, transportation to Alberta, and reassembly will result in some degradation of performance. This degradation should occur only in the polarization characteristics. Gross mishandling would be necessary to affect the ordinary performance of the antenna.

It was necessary, for mechanical reasons, to dismantle the antenna shortly before shipment and then to reassemble it for a final mechanical test. Advantage was taken of this opportunity to check the stability of electrical performance. It was found that the rectangular patterns were still excellent. The turnstile isolation was found to have changed from -50 db to -28 db. Investigation showed that this was due mainly to a shift in the feed position of approximately $\frac{1}{4}$ inch with respect to the reflector surface. The horn was rematched and it is believed that on the basis of reference measurements, this difficulty will be avoided in the future.

After rematching, the axial ratio of the reference polarization patterns were found to be 0.980 (RH-circular) and 0.988 (LH-circular). Adjustment could have been made to produce an axial ratio in each of approximately 0.990, but it was not thought to be worthwhile to do this in view of the uncertainties of dismantling and reassembly. However, the information available indicates that the performance of the antenna when reassembled will differ only slightly from the optimum. It would be reasonable to expect an effective axial ratio of 0.970 instead of 0.980; but a deterioration to a value less than 0.960 would appear to be improbable. It will be necessary to have a final check on the site to obtain the optimum adjustment.

REFERENCES

1. G.C. McCormick. An antenna designed for the investigation of precipitation phenomena. REED Bulletin, NRC, 14(4): 15; 1964

2. A.D. Hood and G.C. McCormick. REED Bulletin, NRC, 17(1): 13; 1967

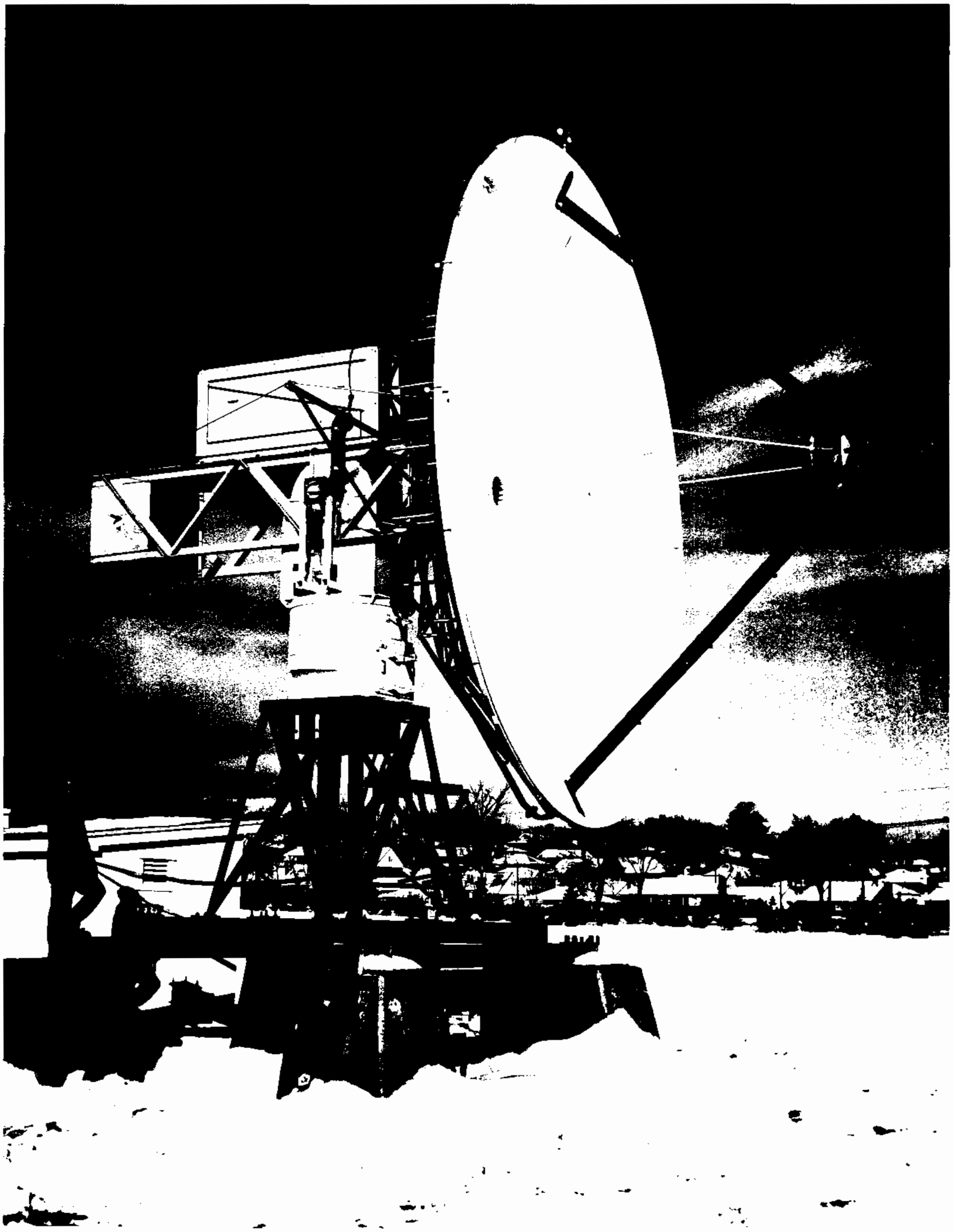


Plate I   Antenna and pedestal assembled

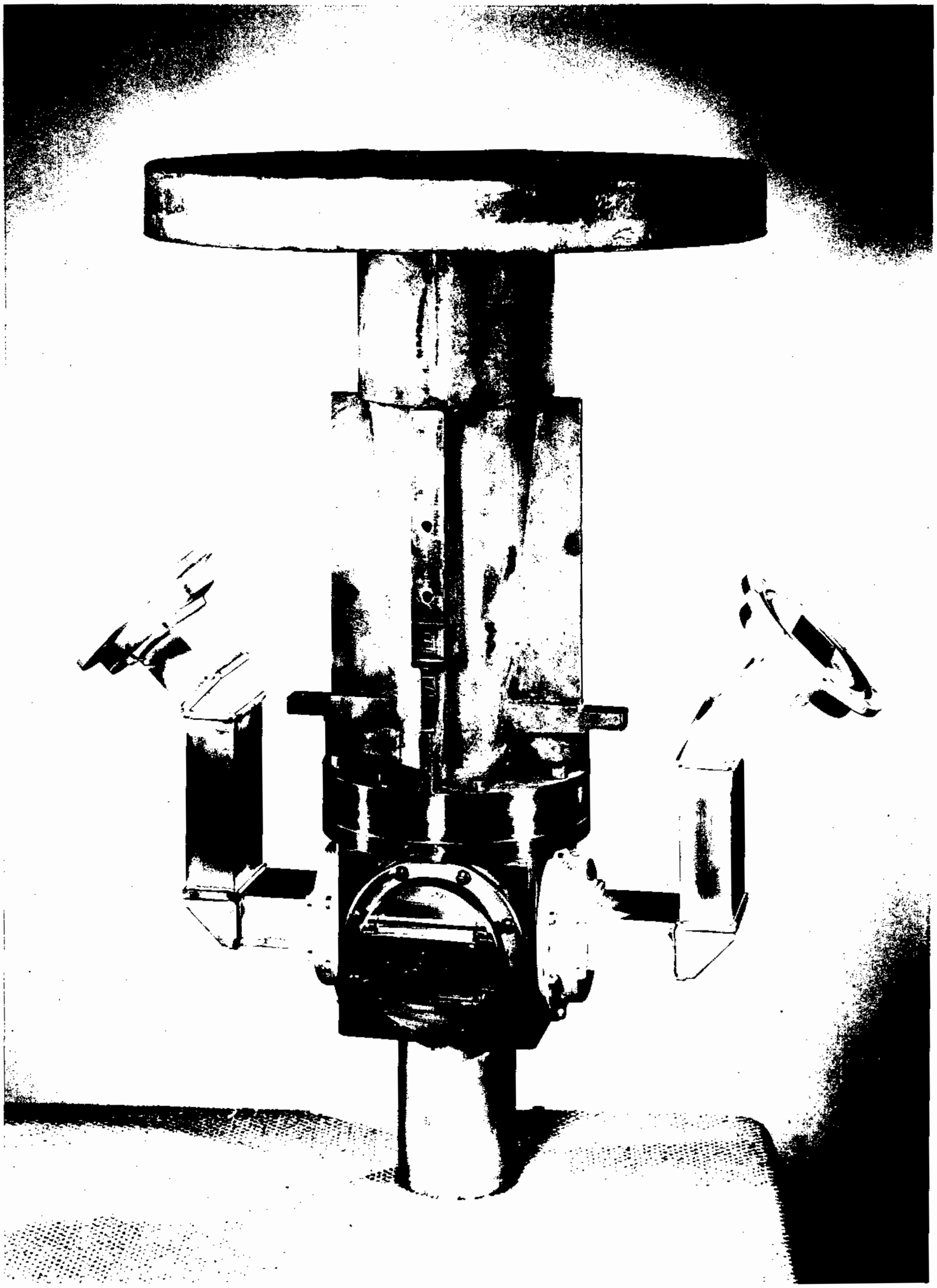


Plate II Feed horn and turnstile junction

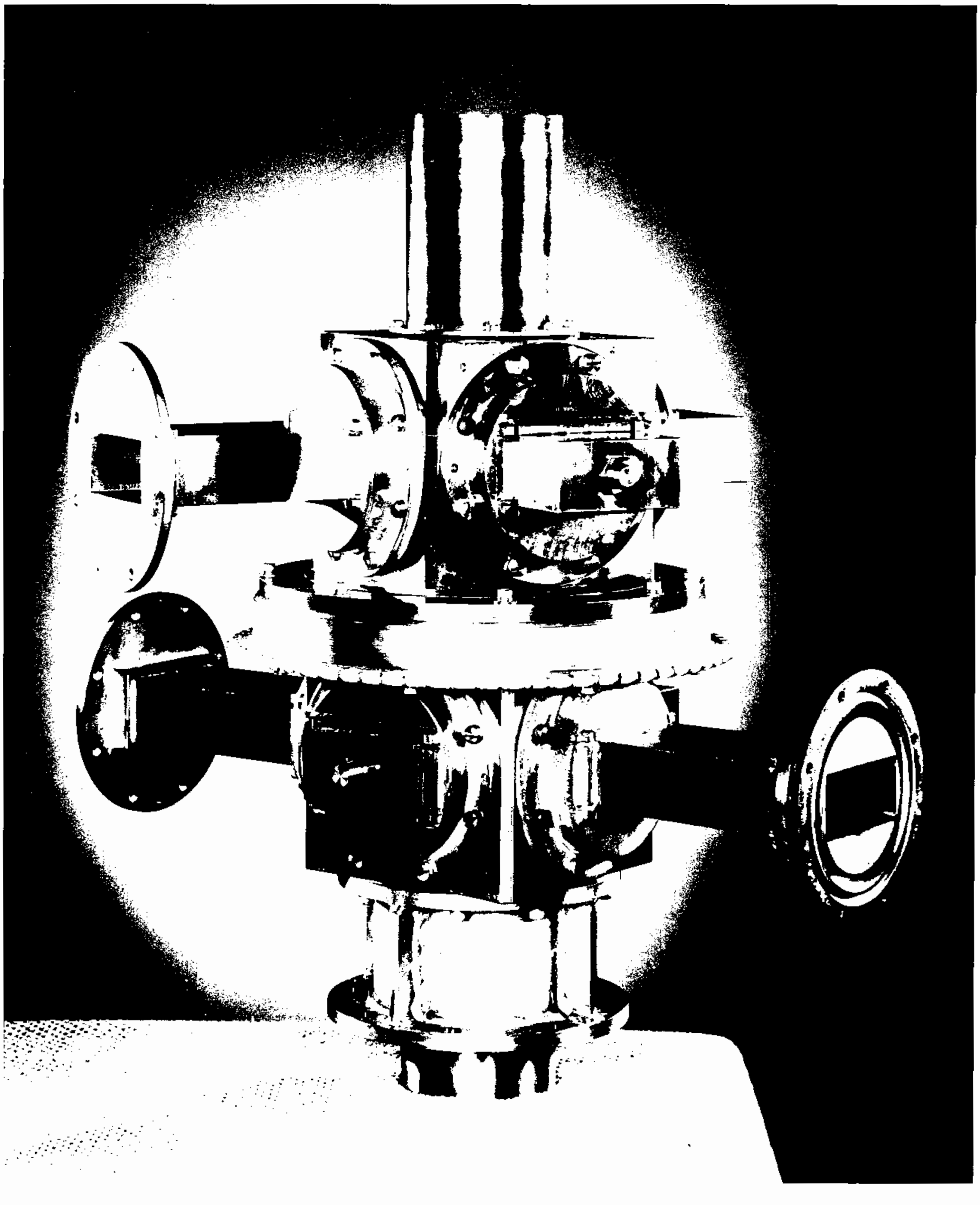


Plate III   Phase shifter