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AN ARBITRARILY POLARIZED ANTENNA FOR USE AT X-BAND

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ABSTRACT

An antenna has been designed to transmit r-f energy of any desired polarization and then to receive separately and simultaneously the transmitted polarization and its cross-polarized analogue. This special property is accomplished in the r-f line feeding the antenna rather than in the antenna proper. The procedure is to divide the power equally by means of a hybrid junction, to introduce a controllable phase shift into one component, and then to combine the two components in space quadrature in the antenna feed line. It is possible to adjust the system so that any arbitrarily chosen polarization, including linear and circular as special cases, can be transmitted or received.

PROBLEM STATUS

This is an interim report; work is continuing.

AUTHORIZATION

NRL Problem No. R11-10R

AN ARBITRARILY POLARIZED ANTENNA FOR USE AT X-BAND

INTRODUCTION

A greater knowledge of the polarization characteristics of radar reflections from the sea, from clouds, and from man-made objects might have important effects on the design and performance of future radar and communication systems. Conditions can be visualized in which such reflections may want either to be emphasized or minimized for increased contrast in received signals. The Antenna Research Section is cooperating with the Wave Propagation Research Section on NRL Problem R11-10R, the object of which is to measure the characteristics of radar reflections from the sea and from certain targets on the surface of the sea. The responsibility of the Antenna Research Section is the design and construction of the antennas required for the aircraft and ground equipment used in this study. Measurements are to be made at X-, S-, and L-band. The unusual requirement common to these several antennas is that they transmit circular polarization in either sense or linear polarization in any component, and that they receive both the transmitted polarization and its cross-polarized analogue separately and simultaneously. If two orthogonal components of the reference field have an amplitude ratio R and a phase difference ϕ, then, by definition, the same components of the cross-polarized analogue have an amplitude ratio 1/R and a phase difference $\phi + \pi$.

This report discusses the general principles and techniques upon which the design of all these antennas can be based and describes in detail the design of the X-band airborne antenna.

The antenna must be adapted to an existing mount inside a radome approximately 30 inches in diameter. Maximum antenna gain and minimum beam width consistent with these space limitations are desired. The magnetron used for transmitting has an operating frequency of 9375 megacycles and a power output of 30 kilowatts. The PSWR should be less than 1.5 over a 1 percent band.

GENERAL PRINCIPLES

Desirability of Using One Antenna

It would be possible to meet the needs of the propagation experiment by means of a number of antennas at each frequency, each one so designed as to transmit or to receive one of the several polarizations required. A solution which uses fewer antennas is more practicable, and one which uses a single antenna for all polarizations both transmitting and receiving would simplify the experimental work considerably. Furthermore, it is desirable that this performance be achieved by means not too dependent upon a particular antenna design, in order that the design technique can be applied to various installations at different frequencies. The scheme described below contains these general features.

Determination of Polarization Characteristics

The polarization characteristics are determined, not by the antenna design itself, but by the design of an r-f circuit which couples both the transmitter and the receiver to the antenna. The transmitted power is divided into two equal parts in a hybrid junction (in this case a magic tee), the phase of one part is adjusted relative to the other, and the two parts are combined in space quadrature in the antenna or in the feed line immediately adjacent. Circular polarization requires a $\pm\ \pi/2$-radian phase difference between components; linear polarization requires a zero or π-radian phase difference; elliptical polarization requires other phase differences. The antenna feed line and feed must deliver these components in the proper time and space relationship, but beyond this there is considerable freedom in the antenna design. On reception, the hybrid junction permits both the transmitted polarization and its cross-polarized analogue to be received on two receivers simultaneously, as indicated in the block diagram of a typical system (Figure 1).

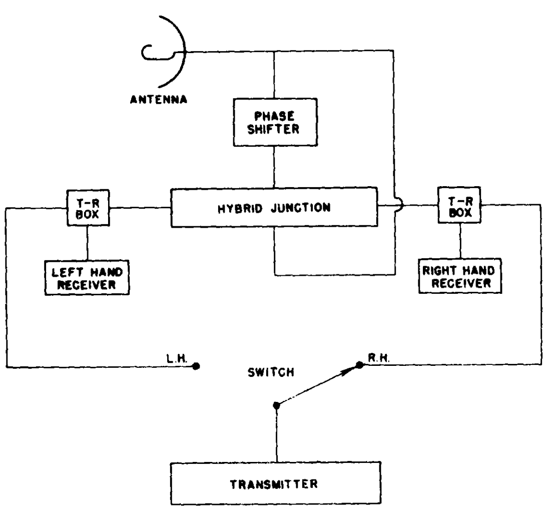

Fig. 1 - Block Diagram of Typical System

The ability of this system to transmit circular polarization of one sense and then to receive both senses of circular polarization separately and simultaneously is shown in Figure 2. A generator, furnishing a voltage $V\underline{/0^{\circ}}$, is placed at the right hand terminal. For purposes of explanation, another generator furnishing no voltage is assumed at the left hand terminal. Therefore, equal voltages of $.7V\underline{/0^{\circ}}$, in time phase with each other, will appear at equal path distances in the E- and H-plane terminals of the magic tee. By adding 90° of phase change to the E-plane path, two voltages equal in magnitude and in time and space quadrature will appear at the antenna terminals. The space quadrature is obtained by the relative orientation of the two inputs with respect to the square waveguide. The signal that is radiated will therefore be right-hand circularly polarized. A left-hand circularly polarized signal can be radiated merely by interchanging the two generators.

Upon reception, the following occurs. If the voltage induced at the vertical terminal of the horn is equal in magnitude to, and leads in phase by 90°, the voltage induced at the horizontal terminal, the field is right-hand circularly polarized. Due to the phase shifter, the two voltages arrived at the E- and H-plane arms in phase and are therefore detected at the right-hand terminal of the magic tee as indicated in Figure 3. If, on the other hand, the signal is left-hand circularly polarized, it will be received at the left-hand terminal.

To use this same antenna to transmit and receive linear polarization, it is necessary that a 180° phase shift be introduced between components. Also, if horizontal and vertical polarization are desired, the antenna must be so oriented that the input terminals

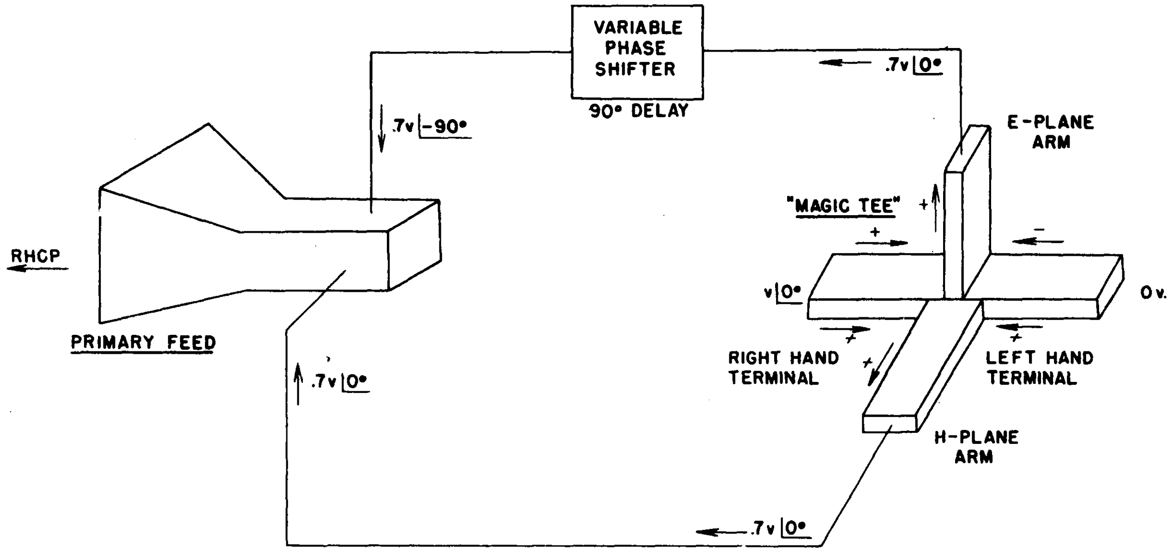

Fig. 2 - Transmission of Right-Hand Circular Polarization

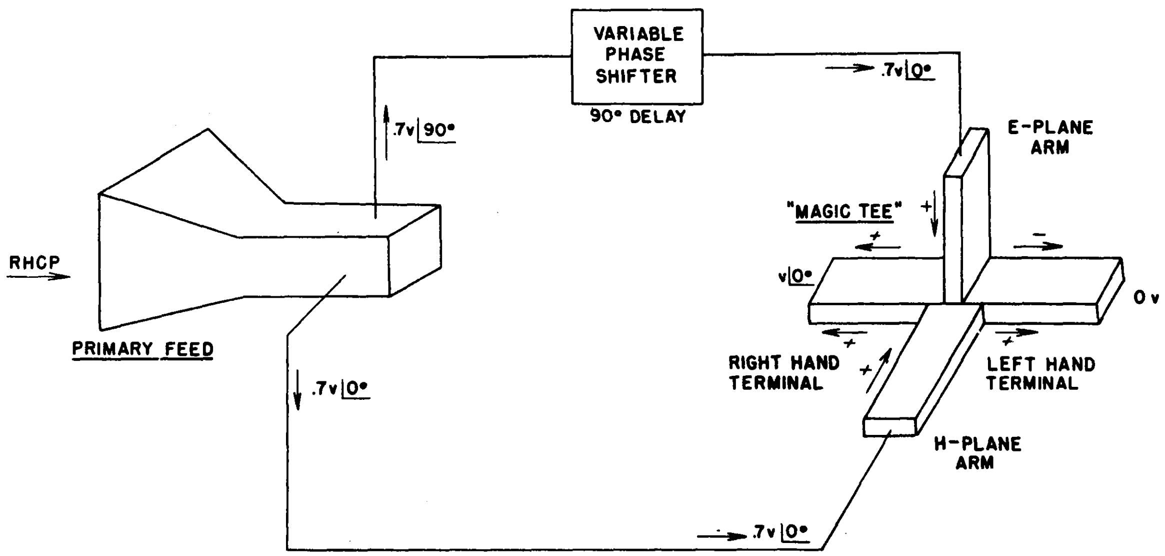

Fig. 3 - Reception of Right-Hand Circular Polarization

make angles of 45° and 135° with the ground as shown in Figure 4. Figure 5 indicates the operation of the antenna in transmitting vertical polarization under these conditions.

It is interesting to note that in the case of the transmission of linear polarization both the transmitter and receiver for a given polarization are located at the same terminal of the hybrid junction, whereas in the case of circular polarization the transmitter and receiver for a given polarization are located at opposite terminals.

It is obvious that any arbitrarily chosen elliptical polarization can be transmitted and received by adjusting the phase shift and the ratio of the amplitudes of the two components.

DESIGN OF THE X-BAND AIRBORNE ANTENNA

Design of the Waveguide

Due to certain electrical and mechanical limitations, square rather than circular waveguide was used in this application. The square waveguide was designed so that two TE_{10} waves at right angles to each other are propagated but all higher modes are rapidly attenuated. Since the TE_{11} mode is the first mode to cause trouble, the inner dimension "a" of the square waveguide should satisfy the condition

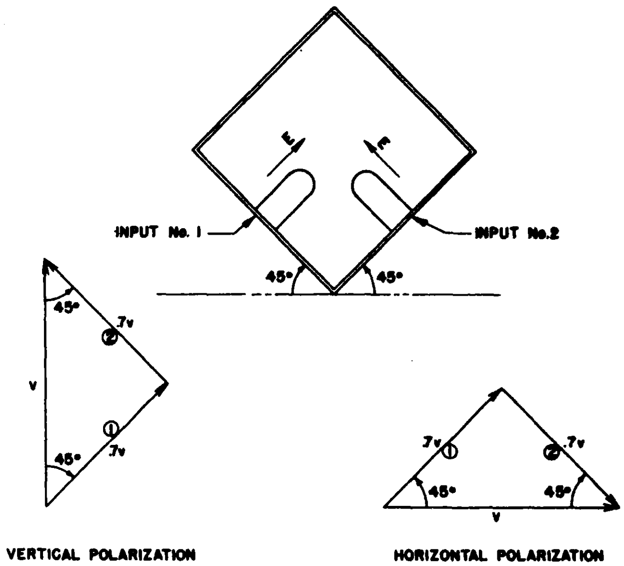

Fig. 4 - Operation of Antenna When Used to Transmit and Receive Linear Polarization

$$\lambda/\sqrt{2} > a > \lambda/2$$

where λ is the wavelength.

The Coupling Problem

In order to facilitate the mechanical construction in coupling from standard 1" x 0.5" x 0.050" X-band waveguide into the square guide, the dimensions of the square guide were

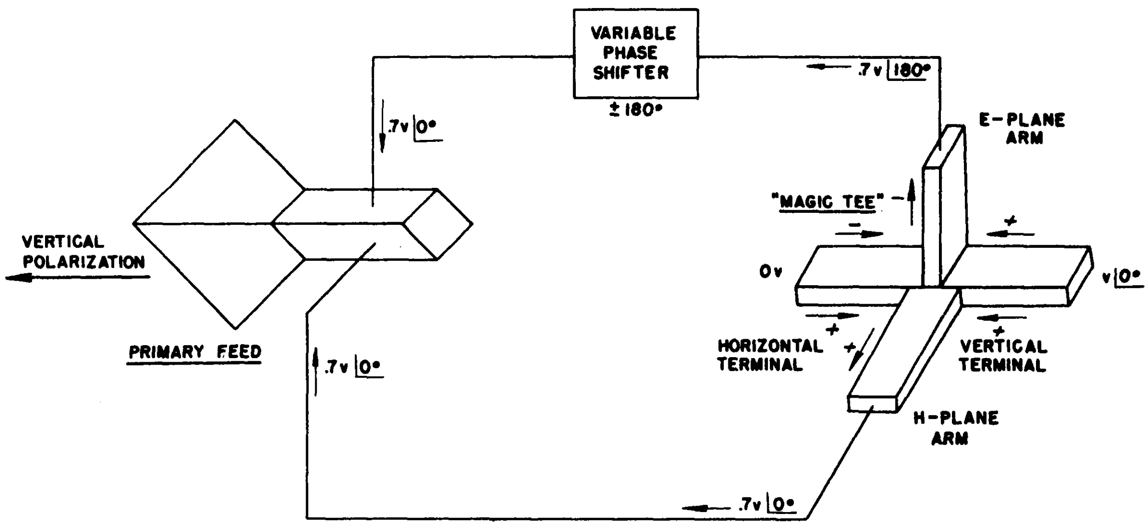

Fig. 5 - Transmission of Vertical Polarization

chosen to be 1″ x 1″ x 0.050″. This makes "a" equal to 0.900″, slightly larger than the cut-off dimension but still sufficiently small to attenuate the TE_{11} mode appreciably if it is generated.

Various coupling methods can be employed to establish the desired field configuration within the square waveguide. Most methods produced large mismatches which, when corrected, caused the junction to be very frequency-sensitive.

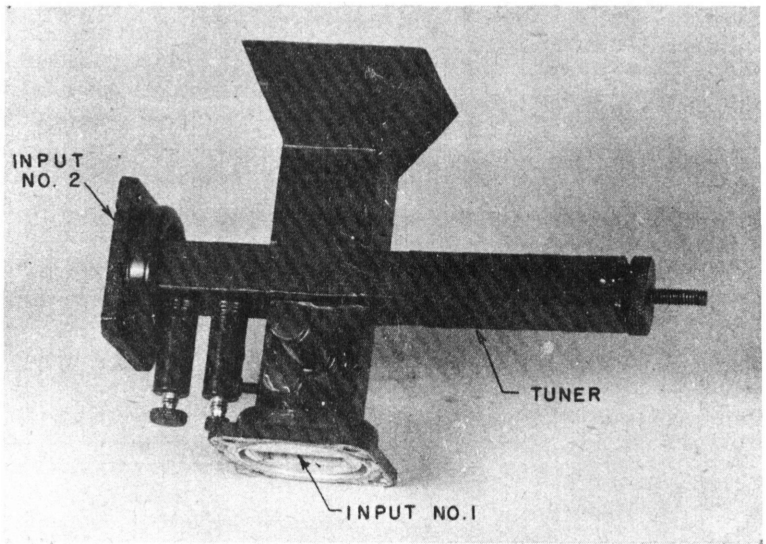

Fig. 6 - Method Employed in Coupling From Rectangular to Square Waveguide

Of several methods investigated, the method shown in Figure 6 produced the best results. The PSWR looking into input (1) was reduced to 2 by coupling directly into the rear of the square waveguide. This mismatch is due to the abrupt transition from waveguide of one dimension to waveguide of larger dimension. It was much more difficult to find a solution for input (2). By placing an adjustable shorted section of waveguide opposite the input guide, the original PSWR of 10 was reduced to 2 when the short was placed at the optimum match position. Two tuning screws $\lambda_g/4$ apart were then placed in each input to provide a means of matching each input down to a PSWR less than 1.2 over the range from $\lambda = 3.17$ cm to $\lambda = 3.23$ cm.

In this manner, it is possible to couple two TE_{10} waves of equal amplitude into the square waveguide, providing the initial amplitudes are equal. Inputs (1) and (2) are decoupled from each other since each guide is physically so oriented that its propagation mode is not excited by the field in the other guide.

The Phasing Problem

There are many methods available to produce the desired phase variation. In this application, the phase shifter must be small in size, continuously variable, and capable of calibration.

The simplest phase shifter meeting these requirements is a dielectric slab which can be moved across the waveguide while remaining parallel to the E-vector. The phase shifter used consists of a piece of Lucite about 5 inches long and a quarter inch thick. It is tapered at both ends to reduce any mismatch that it may produce. Moving from a position adjacent to the guide wall to the center of the guide produces a phase change of about 340° at 9375 megacycles. It can be calibrated readily at a fixed frequency and will retain its calibration. A photograph of the phase shifter as it is used in the system is shown in Figure 7.

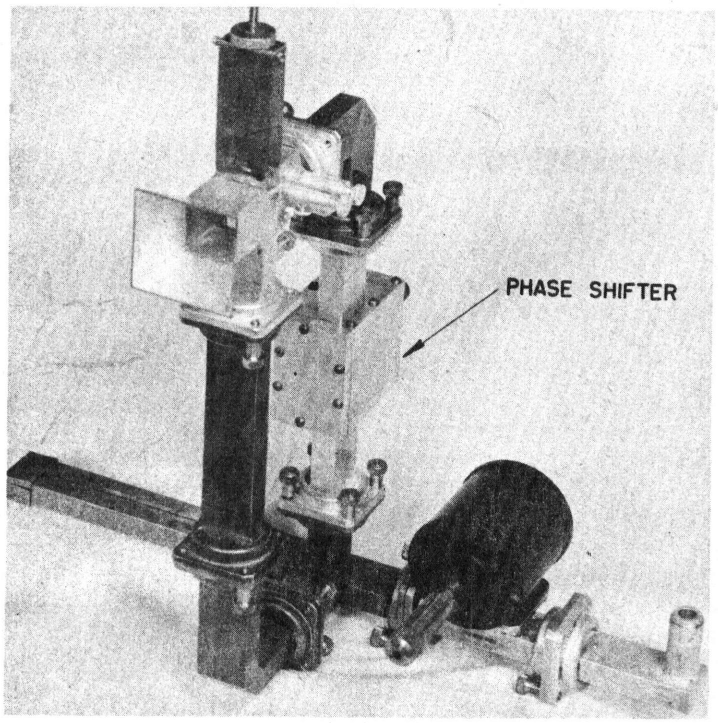

Fig. 7 - R-F Circuitry as Used in the X-Band Airborne Antenna

Choice of an Aperture

It was feared that, if the antenna design consisted of a symmetrical paraboloid illuminated by a horn feed, the polarization of the radiated field would be disturbed by two effects, namely, the interaction between the feed and the reflector and the blocking of the paraboloidal aperture by the feed and feed line. For this reason, the use of an asymmetrically cut paraboloid to remove the feed and the feed line from the most intense part of the reflected field, or the use of a larger flare-horn antenna without reflector were considered. Both of these designs would have resulted in a loss of antenna gain and an increase in over-all weight and so were discarded. It was found upon experimental investigation that a symmetrical paraboloid could be used in this particular application, because it is possible to control the phase and amplitude of each component separately in the feed line and thus to compensate for the effects of the interaction between the feed and the reflector. Another contributing factor to the success of this method is the fact that the primary patterns of each component do not necessarily have to be identical; only the integrals of these patterns over the angle subtended by the reflector need to be equal to insure circularity over the important portion of the main beam.

It is thus possible in this application to use a 29″ x f = 10.6″ paraboloid with a horn feed as shown in Figure 8. It was not necessary to flare the open end of the square waveguide, since its dimensions were such as to give optimum electrical performance.

PERFORMANCE OF THE X-BAND AIRBORNE ANTENNA

The radiation pattern, gain, circularity, and cross-coupling of this antenna were measured at $\lambda = 3.20$ cm, and the results agree closely with theoretical predictions.

The far-field power pattern was measured in the following manner. The antenna under test was used as the receiving antenna. A linearly polarized antenna approximately 500 feet away was used as the transmitter. After the test antenna had been adjusted so that the on-axis circularity was unity, various cuts through the axis of the main lobe were taken. Each cut was measured three times, with the polarization of the transmitting antenna kept horizontal, vertical, or 45° for each pattern measurement. The patterns for the three were found to be practically identical over the major portion of the main lobe. Figure 9 shows the patterns of three typical cuts. The measured half-power width is 3.1°, whereas the theoretical value is 3.04°.

The measured 10-db widths of the primary patterns of the horn feed 0.900" x 0.900" were 120° in the E-plane and 140° in the H-plane, compared to calculated values of 126° in the E-plane and 143° in the H-plane. The measured primary patterns are shown in Figure 10.

The power gain of this antenna relative to an isotropic radiator was measured as 40.4 db compared to the theoretical value of 41 db.

The on-axis circularity can be made as close to unity as the measuring equipment will allow. In this case the accuracy of the measurement was ± 0.25 decibel.

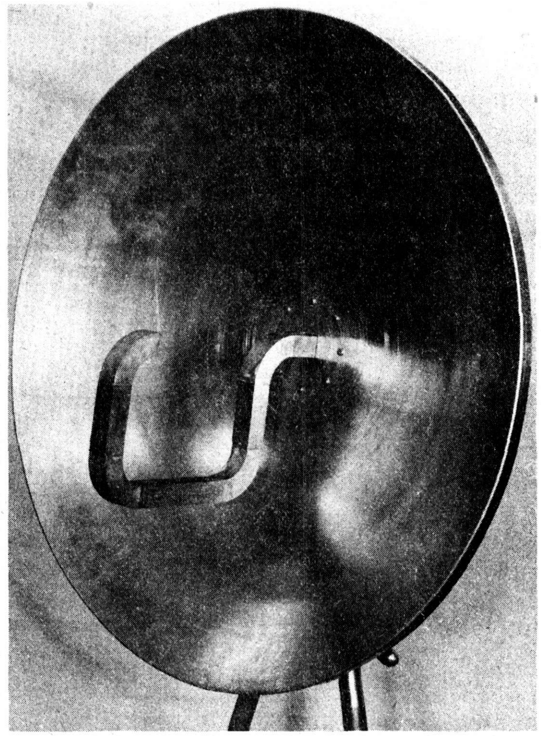

Fig. 8 - Paraboloid Fed by the Square Waveguide

The measured cross-coupling between the antenna terminals is at least 40 db down. It was measured by placing at terminal (1) (Figure 6) a signal generator whose power could be measured accurately and then measuring the power received at terminal (2). The feed was used with the reflector in this measurement. This cross-coupling would be troublesome only for c-w operation.

POSSIBLE APPLICATIONS

Up to the present time it has not been possible to design a circularly polarized search radar system with a single antenna for transmission and reception, since the sense of polarization is reversed upon reflection and thus the returned signal will be rejected by the antenna. This antenna design removes such a limitation and so can be used in a search system using circular polarization.

Another possible application is to the measurement of the scattering cross-section of targets as a function of polarization. Such a study may indicate the applicability of an antenna of this type to insure continuous communication between the transmitter and the target being tracked merely by the addition of another receiver.

This antenna design may also be adapted for jamming and anti-jamming purposes.

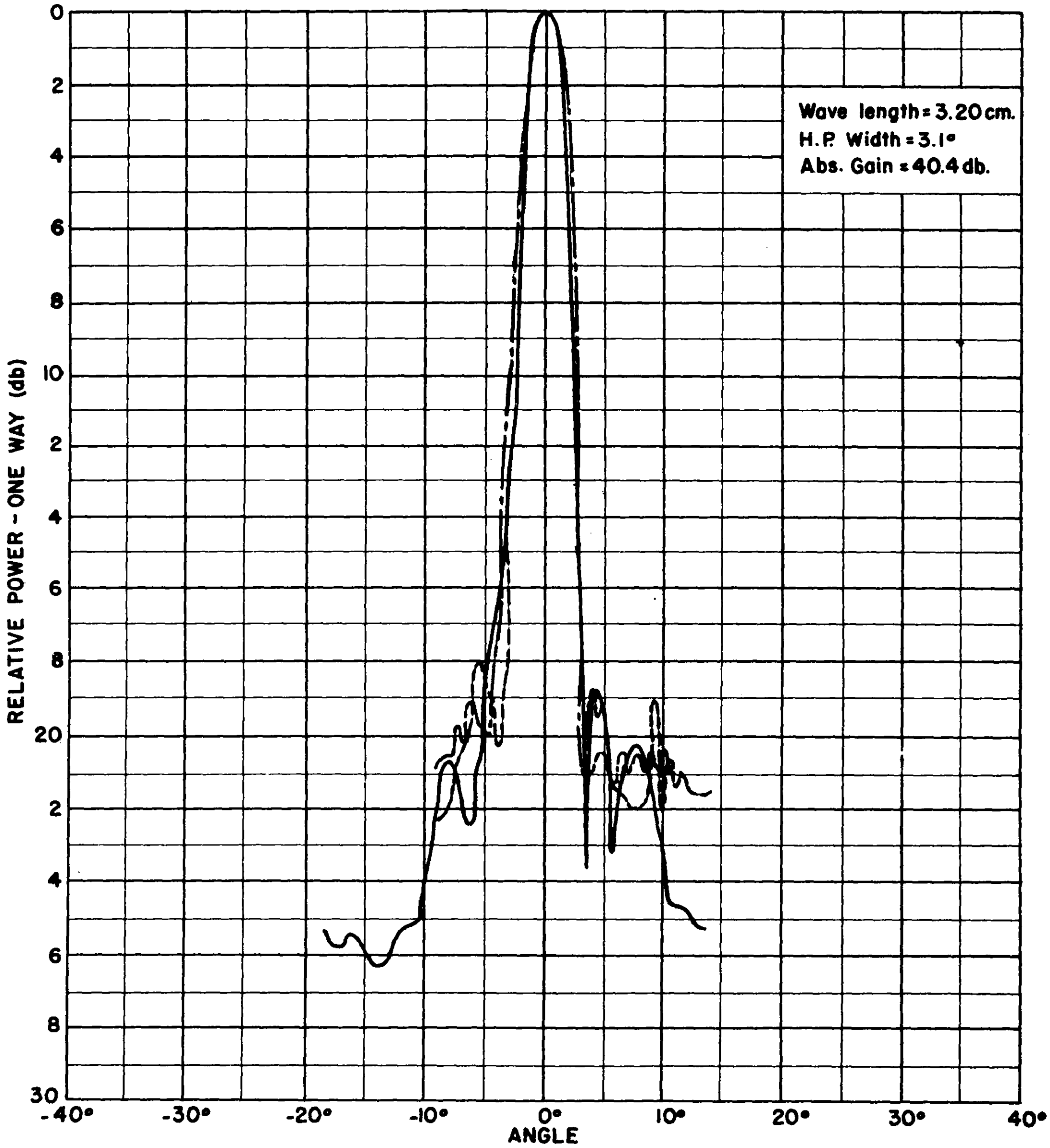

Fig. 9 - Power Patterns of Circularly Polarized Antennas

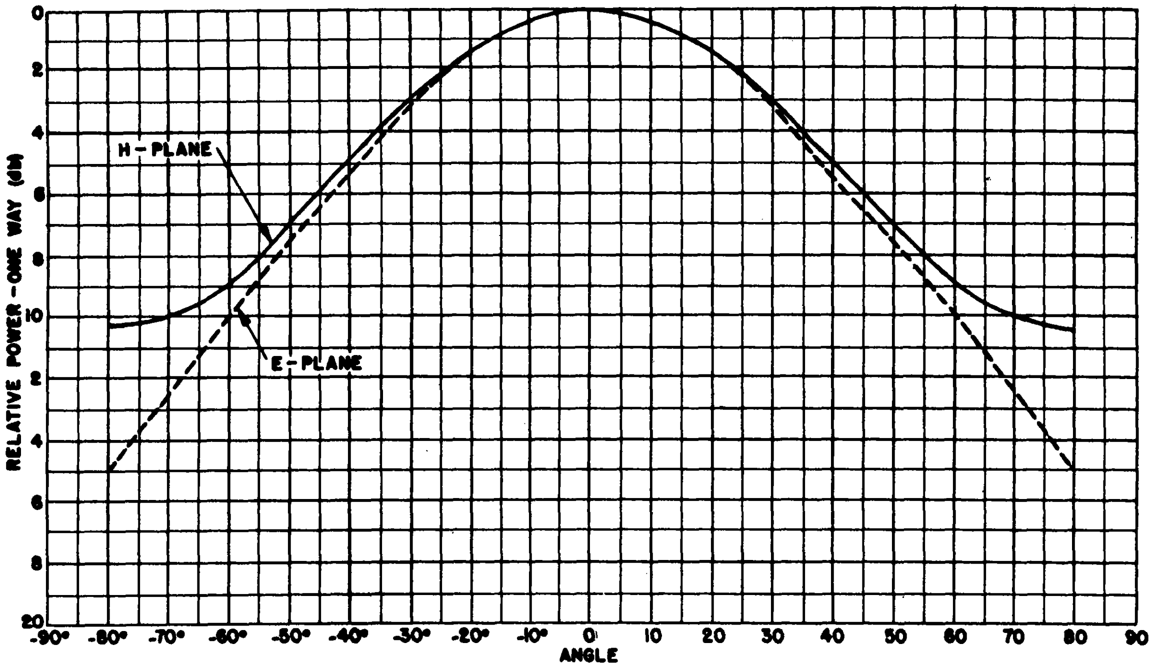

Fig. 10 - Primary Patterns of .9 x .9 Inch Horn
(λ = 3.20 cm)

Another use is for the measurement of the axial ratios of other elliptically polarized antennas. The accuracy obtained could be very great since no mechanical motions are required.

High power duplexers can be designed embodying the principles mentioned in this report. The advantage gained would be the utilization of low-power T-R and anti-T-R tubes to protect the receiver instead of the high power components that would ordinarily be required.

MTI systems utilize two antennas, one for transmission, the other for reception. If circular polarization can be used, only one antenna will be required.

The use of circular polarization for beacon transmitters will permit the differentiation between the beacon signal and the beacon echo.

ACKNOWLEDGMENT

Gratitude is expressed to Dr. L. J. Chu for his numerous suggestions concerning the design of the r-f circuitry.

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