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ANTENNA SYSTEM FOR AN/UPD-501 RECEIVER X-BAND, HORIZONTAL POLARIZATION

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OTTAWA
AUGUST 1960 NRC#35631

ABSTRACT

This report describes the AN/UPD-501 antenna system for X-band, horizontal polarization. Mechanical features and electrical performance are given. The design of this antenna was completed in 1955.

INTRODUCTORY NOTE

This report is one of a series describing antenna systems for use with the AN/UPD-501 receiver. Each of these systems is designed for a particular frequency band and polarization. The following reports are included in the series:

Report	Description	Frequency range
ERB-556	L-band, horizontal polarization RCN (ships) AS5025 RCN (air) AS5020	1 to 2.35 kmc/s
ERB-557	L-band, vertical polarization RCN (ships) AS5026 RCN (air) AS5019	
ERB-558	S-band, horizontal polarization RCN (ships) AT5006 RCN (air) AT5023	2.35 to 5.5 kmc/s
ERB-559	S-band, vertical polarization RCN (ships) AT5009	
ERB-560	X-band, horizontal polarization RCN (ships) AT5007 RCN (air) AT5022	5.5 to 10.5 kmc/s
ERB-561	X-band, vertical polarization RCN (ships) AT5010	
ERB-562	K_u-band, dual polarization RCN (ships) AS5027	10.5 to 20 kmc/s

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ANTENNA SYSTEM FOR AN/UPD-501 RECEIVER
X-BAND, HORIZONTAL POLARIZATION

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INTRODUCTION

The AN/UPD-501 is an instantaneous direction finder for reception of pulsed transmissions at microwave frequencies. Bearing indication is obtained by amplitude comparison of the amplified outputs of four antennas on the four deflection plates of a cathode-ray tube. Wide frequency coverage is obtained by using crystal video detectors and video amplifiers. A block diagram of the system is shown in Fig. 1(a).

The antenna system described in this report includes the microwave portions of the equipment such as the receiving antennas, video detector mounts, and crystal protection switches. The switches are used to isolate the detector mounts from the antennas so as to protect the crystal detectors from burnout due to energy from a nearby radar. The indicator unit which includes the video amplifiers and cathode-ray tube display, is not described [1]. The indicator may be considered as a common part for use with all antenna systems.

DESIGN CONSIDERATIONS

In the design of the antenna systems it has been the objective to provide frequency coverage from 1 kmc/s to 20 kmc/s for both horizontal and vertical polarizations with a minimum number of antenna systems. This has been accomplished with six systems from 1 kmc/s to 10.5 kmc/s, three for each polarization, and one system for both polarizations for coverage from 10.5 kmc/s to 20 kmc/s. This report describes the X-band antenna system for frequency coverage from 5.5 kmc/s to 10.5 kmc/s, with horizontal polarization.

The main criterion in the development has been to obtain systems whose maximum bearing error, measured under laboratory conditions, does not exceed ±15° due to all causes, and to a lesser but still important degree, to obtain a high system tangential sensitivity over the intended bandwidth. This bearing accuracy has been obtained over an octave of bandwidth, or a little more, for one polarization with each antenna system.

The main limitations on useful bandwidth of an antenna system are as follows.

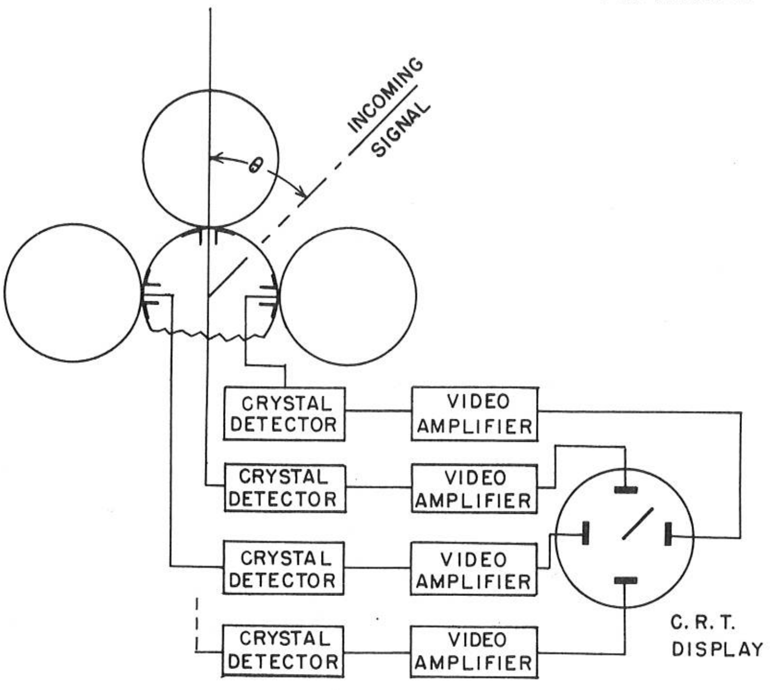

FIG. 1(a) 4-CHANNEL INSTANTANEOUS DIRECTION FINDER

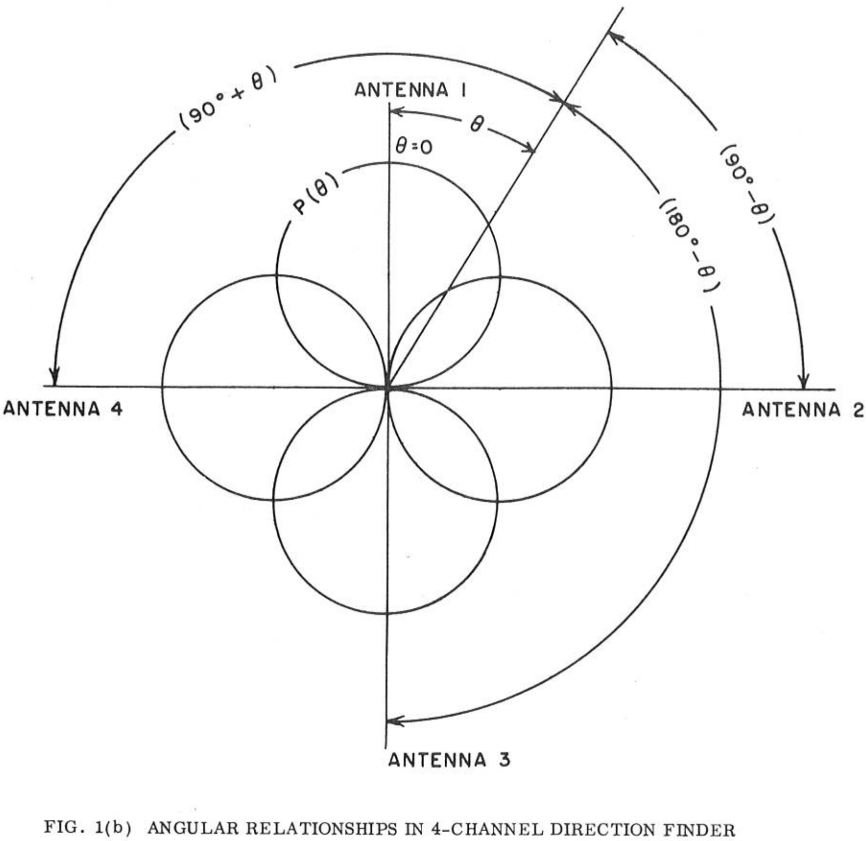

FIG. 1(b) ANGULAR RELATIONSHIPS IN 4-CHANNEL DIRECTION FINDER

1) Antenna radiation patterns change with frequency and cannot be ideal at all frequencies. For accurate bearings, a system with square law detectors and linear amplifiers must have four antennas whose power radiation patterns, $P(\theta)$, obey the condition:

$$\frac{P(\theta) - P(180° - \theta)}{P(90° - \theta) - P(90° + \theta)} = \cot \theta .$$

This condition may be derived from consideration of Figs. 1(a) and 1(b).

2) Detector sensitivities do not track with frequency. It is desirable that the crystal detectors have equal sensitivities or at least parallel characteristics across the frequency band. Unequal, but constant, detection sensitivities, within 2 or 3 db, can usually be compensated for by adjustment of video amplifier gains.

3) Mismatch losses are not equal in each antenna channel. It has been found that even when the mismatches in systems are less than about 3 or 4 to 1, which would theoretically result in relatively low losses, differences between systems may be excessive. This is due to the relatively long transmission lines between the larger system mismatches. Small differences in mechanical dimensions may cause large changes in mismatch losses. One of the most important considerations in the manufacture of an antenna system is the adherence to close tolerances on dimensions; close mechanical similarity of individual channels results in a high degree of electrical similarity. Satisfactory performance as a direction finder is obtained only with a system whose channels are equivalent electrically.

The antenna systems have been designed so that any one, or all, may be used in one installation provided space and weight are allowed for. Each antenna system of four antenna channels is mounted in a pair of 10-inch-diameter aluminum cylinders; two antennas per cylinder. An X-band, horizontally polarized antenna cylinder, with two antenna sub-assemblies mounted within, is shown in Plates I and II. The unit was made by EMI-Cossor Electronics Ltd. of Halifax, N.S. This division of a system into two halves is made so that the antennas may be mounted at the extremities of an aircraft (nose and tail or on each wing tip) or on either side of a ship's mast. Otherwise, considerable difficulty would arise in locating antennas to avoid reflections and shadowing at certain bearings owing to the proximity of reflecting surfaces, such as aircraft wings and ship superstructure [2].

Each antenna cylinder has mounting devices at each end so that any cylinder may be connected to the aircraft or ship mounting ring. Also, by this method, any number of antennas may be connected end to end, to provide a particular frequency coverage. Some detail of the cylinder-to-cylinder or cylinder-to-mounting ring connecting mechanism is shown in Plate I. The connecting devices between cylinders consist of a set of four inclined plane wedges at one end of a cylinder which engage with four forks on the opposite end of another cylinder. A single Allen wrench operates a rack and pinion drive on all four wedges at once, to engage the forks of the other cylinder or mounting ring and draw the two units snugly together and at the same time compress a waterproof neoprene gasket between them. This type of antenna mounting makes replacement of a unit quite simple if it is faulty or if a change to another frequency band or polarization is desired.

Two different models of the X-band antenna assembly have been made, one for use on RCN ships and the other for RCN aircraft. These units differ in two main respects: the type of electrical connectors and the absence of cylinder-to-cylinder connecting devices on one end of aircraft cylinders. The unit shown in Plate I is for ships and uses a pair of Cannon type DPX connectors fitted on brackets at each end of the antenna cylinder. Each DPX connector provides four coaxial connections, as well as pins for the 28-volt circuits to the crystal protection switches. The DPX connectors engage automatically when cylinders are connected. This is necessary with ship antennas, since it may be desired to stack several antennas end to end, and it would be extremely difficult to make electrical connections after the cylinders were connected mechanically. Aircraft antenna assemblies are fitted with a small AN-type connector for 28-volt power, and individual video cables are connected directly to the detector mounts. It is considered that no more than two four-channel systems would be used at a time on an aircraft and, therefore, the smaller AN-type connector is adequate, as well as being lighter. Since cylinders are mounted above and below the installation mounting ring, there is no requirement for cylinder-to-cylinder connecting mechanisms at both ends of aircraft antenna cylinders. A light flat cover is bolted to the end of aircraft cylinders opposite the mounting ring. Covers on ship antennas are connected in the same way as another cylinder would be connected (i.e., with a wedge and fork mechanism).

Switches may be used to connect one or more antennas to one indicator unit. However, when paralleling more than one antenna system to one indicator, special provisions must be made for d-c bias to the detector crystals of the antenna channels. When one antenna system is connected to the indicator unit the cables which carry the detected video signals to the indicator unit also are used to supply a forward bias current of 75 microamperes to each of the detector crystals. The source of this bias is the indicator unit power supply. A typical bias supply circuit is shown in Fig. 2. The principal improvement in performance of the low-level video detectors due to the bias is that their "detection efficiency-versus-frequency" characteristics become more similar; i.e., tracking is improved. When antennas are to be paralleled, a separate bias supply is used so that each crystal mount receives bias independently; otherwise, there would usually be an unequal division of bias current among crystals of different d-c resistances. The antennas are then connected in parallel at the input to the indicator unit.

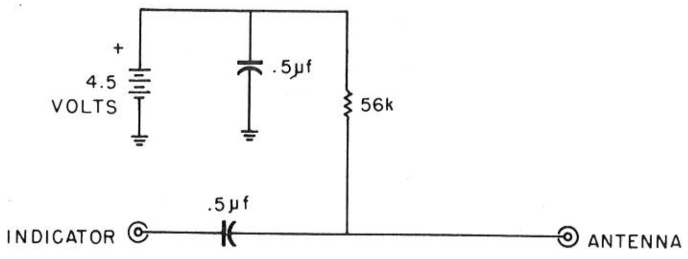

FIG. 2 BIAS SUPPLY FOR VIDEO DETECTOR

MECHANICAL FEATURES

The principal dimensions which affect electrical performance of the X-band antenna sub-assembly are shown in Fig. 3. The waveguide size, 0.187" by 1.375" inside, was chosen for broad-band performance from 5.5 kmc/s to 10.5 kmc/s. The main body of each of the three sub-units, horn, switch, and crystal mount, are aluminum precision castings made by the lost wax process. The inside waveguide dimensions of these components are not machined, as sufficiently close tolerances can be held in casting. Only the mating faces of the waveguide flanges are machined.

The flange of the horn aperture is held against the inner surface of the antenna cylinder with a large number of machine screws. It is quite important that good electrical contact be made between the horn casting and the cylinder, as otherwise serious distortions of the antenna radiation pattern may occur and thus cause an increase in bearing error or a reduction of signal sensitivity.

Although not shown on Fig. 3, the aperture of the horn is covered by a Fiberglas-reinforced epoxy resin window for weatherproofing. It is 0.015 inches thick and is cemented to the horn flange (not to the surface of the cylinder) with Bondmaster M688 adhesive.*

The rotary waveguide switch contains a section of waveguide pivoted in Teflon bearings so that it can be rotated out of alignment with the input and output waveguides. Microwave lossy material is cast on the rotor to reduce leakage between the rotor and the barrel of the switch when in the "off" position. Alignment of rotor waveguide with input and output waveguides is to within ± .005 inch. Adjustable stops are provided so that final adjustment of the limits on the rotary motion may be made after the switch is assembled. A description of manufacture of the lossy material is given in Reference 3. The switch is operated by a 28-volt d-c

* Rubber and Asbestos Corp., Bloomfield, N.J.

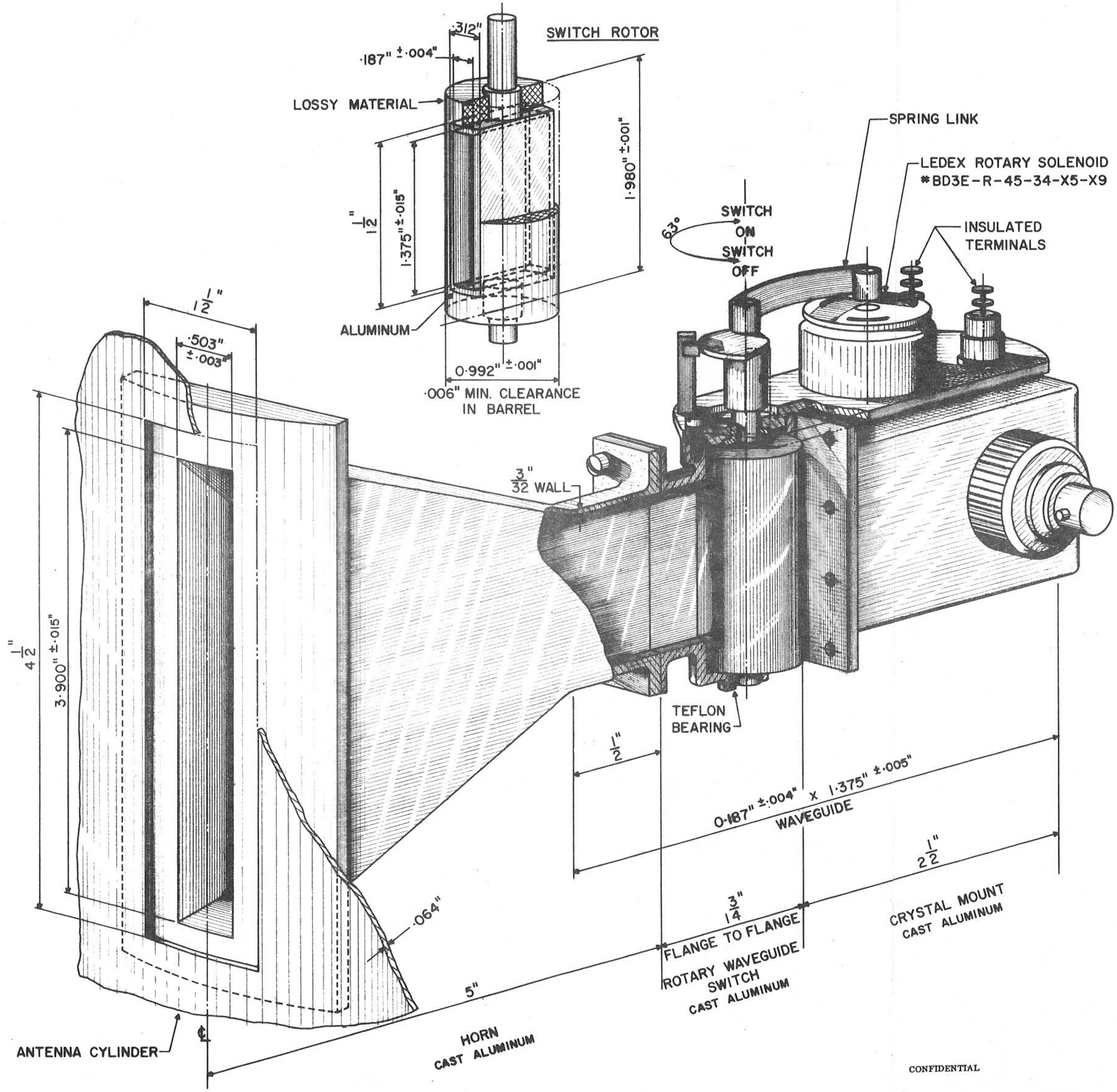

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FIG. 3 X-BAND ANTENNA, HORIZONTAL POLARIZATION — ASSEMBLY

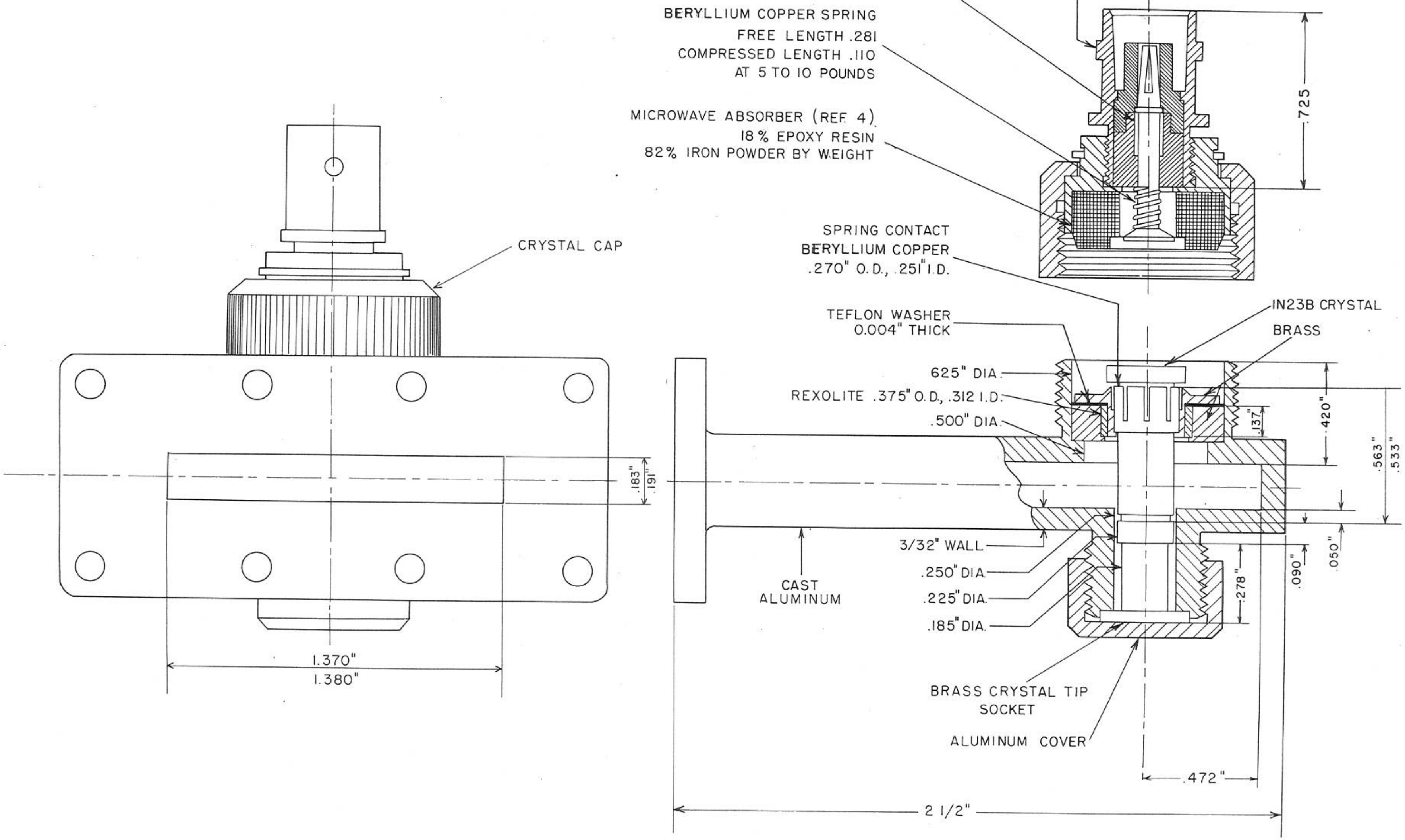

FIG. 4 X-BAND CRYSTAL MOUNT — ASSEMBLY

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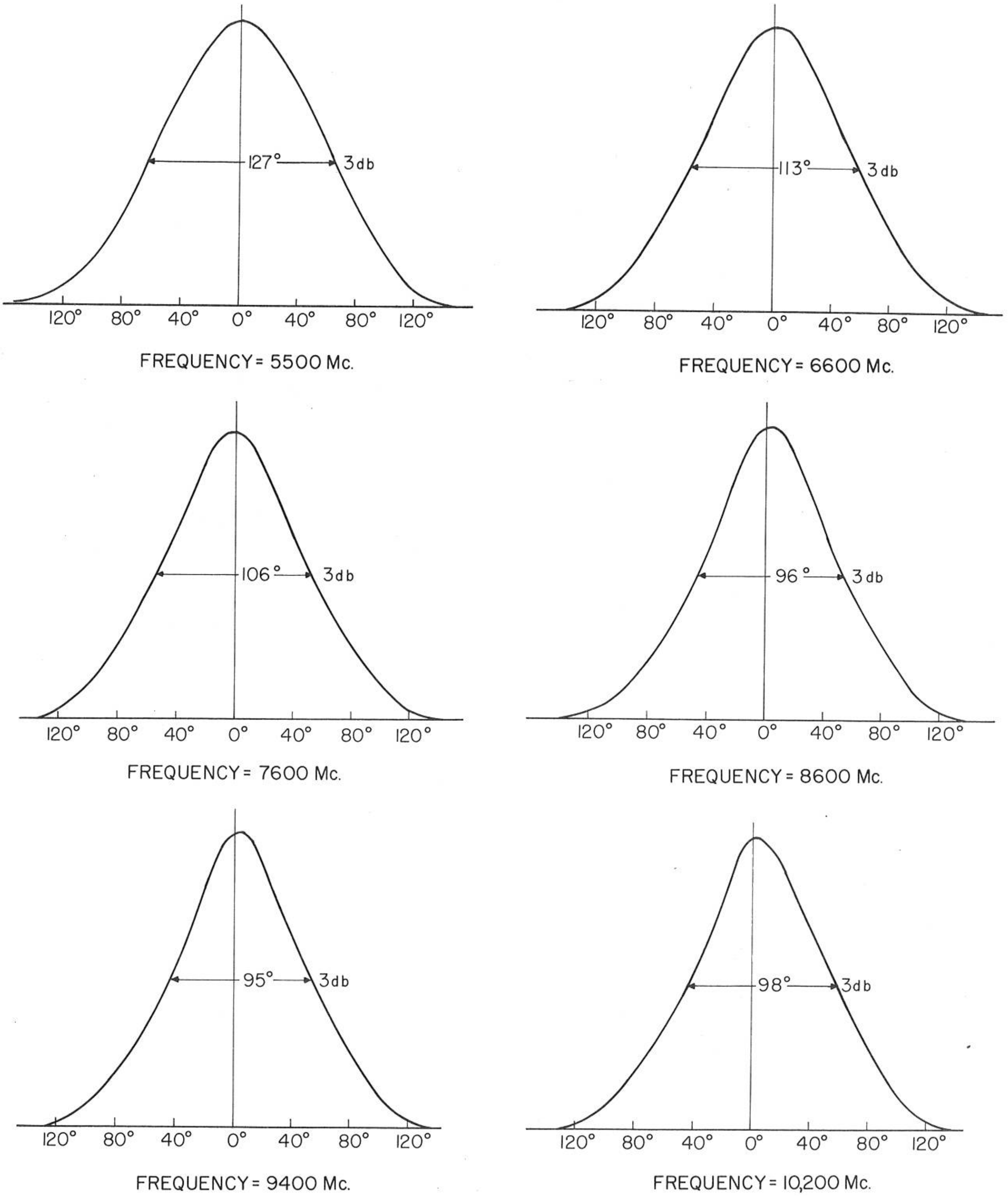

FIGURE 5

ANTENNA POWER RADIATION PATTERNS

X - BAND, HORIZONTAL POLARIZATION

rotary solenoid, being normally "off" when the power is off.

The crystal mount shown in Fig. 4 is a modified model of an NRL design. It is intended for use with a type-1N23B crystal which is mounted directly across the narrow dimension of the waveguide on the center line. Low capacitance is obtained between the body of the crystal and the mount by use of a Teflon washer and Rexolite sleeve which form a capacitance of approximately 35 $\mu\mu$f. The video output crystal cap contains a block of radio-frequency absorbing material which absorbs any microwave energy coupled from the waveguide past the detector crystal and bypass capacitance. Such microwave energy might otherwise cause resonance effects and result in widely differing detection characteristics in different crystal mounts of the same type.

A wide variety of structures was investigated experimentally for the grounded crystal tip connection. The method shown proved to be most suitable for tracking and sensitivity across the frequency band. No spring contact is used at the crystal tip. The crystal bottoms in the brass socket against the shoulder on the tip. The cap-end of the crystal is held by beryllium copper spring contacts.

All aluminum parts of the antenna are treated with Iridite No. 14* for protection against corrosion. This treatment results in a surface which also has good electrical conductivity.

ELECTRICAL PERFORMANCE

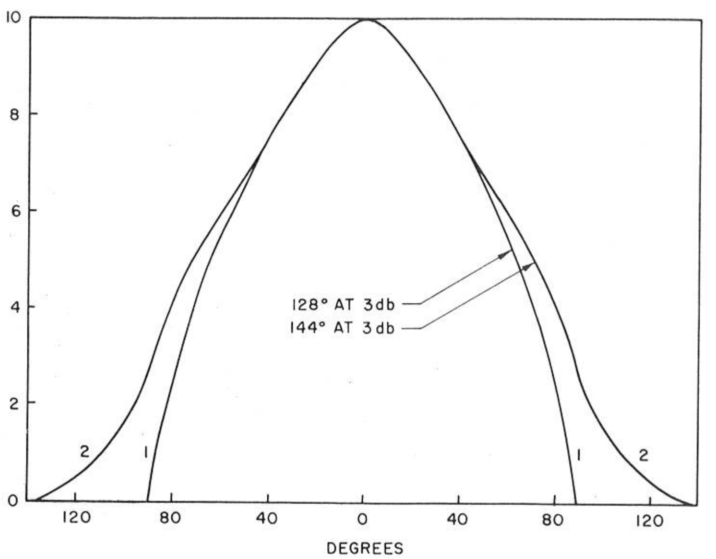

FIG. 6 IDEAL POWER RADIATION PATTERNS

* Allied Research Products Inc., Baltimore, Md.

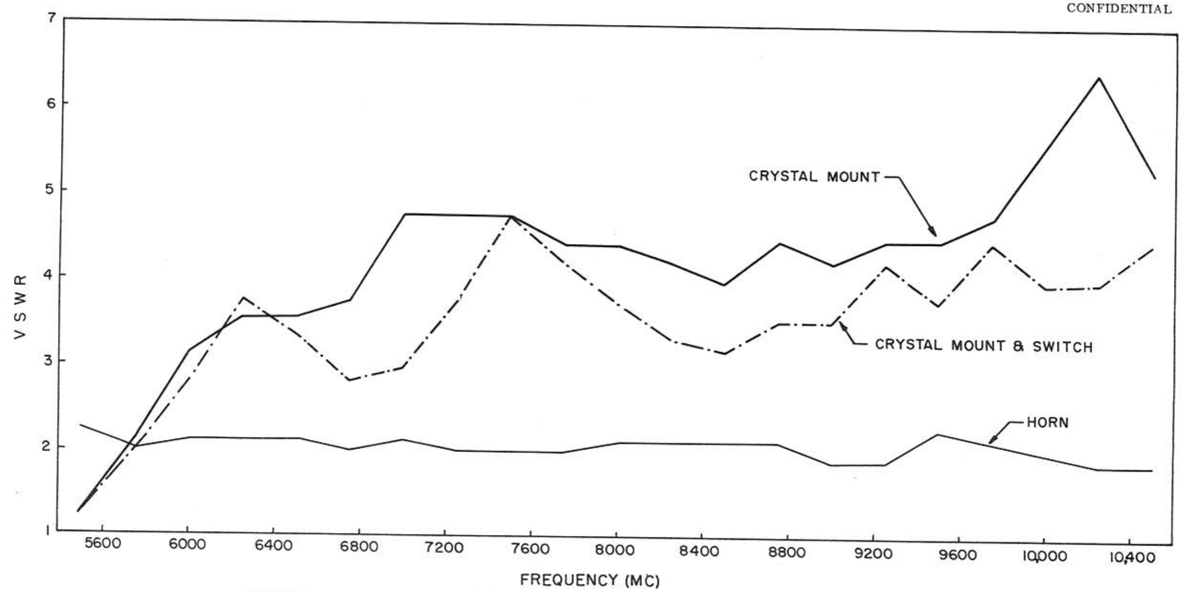

FIG. 7 VSWR OF CRYSTAL MOUNT, CRYSTAL MOUNT AND WAVEGUIDE SWITCH, HORN ANTENNA

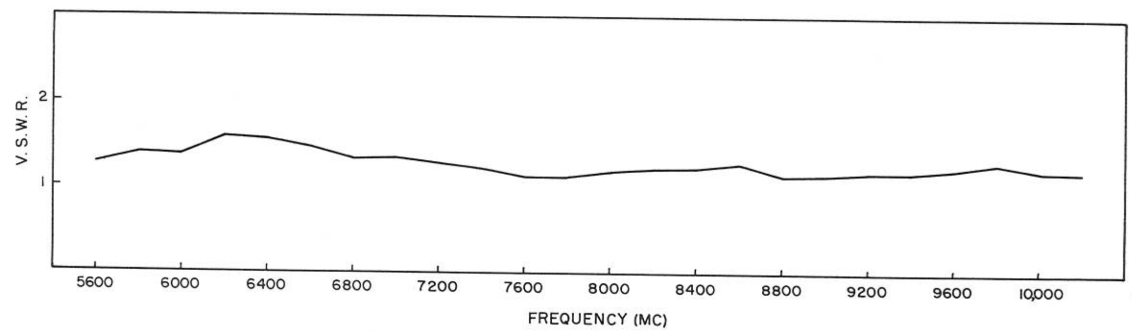

FIG. 8 VSWR OF WAVEGUIDE SWITCH

Electrical tests were performed on experimental models and a pre-production prototype, but not on a production antenna system.

Antenna power radiation patterns for six frequencies throughout the band are shown in Fig. 5. These may be compared with the ideal radiation patterns shown in Fig. 6. Curve 1-1 is a radiation pattern which results in zero bearing error and maximum constant sensitivity when used in a 4-channel system. Curve 2-2 is also a zero bearing error pattern but does not result in constant sensitivity in azimuth (considering the antenna system as a unit). Allowance was made in calculating these patterns for the nonlinearity of the video amplifiers in the indicator unit.

The VSWR of a typical crystal mount, a crystal mount and waveguide switch combination, and a horn antenna alone are shown in Fig. 7. VSWR measurements which include the crystal mount were made with a peak power level at the crystal detector not exceeding -25 dbm, and the crystal was supplied with 75 μamp of positive bias current. At higher incident power levels, the VSWR of the crystal mount with detector crystal increases.

The VSWR of the waveguide switch alone in the "on" (non-attenuating) position is shown in Fig. 8. This is not very much different from the VSWR of the flat load used to terminate the switch. When in the "off" position the switch provides minimum isolation of 40 db from 5.5 kmc/s to 10.5 kmc/s. Over the same frequency range the insertion loss of the switch connected to a crystal mount does not exceed 2 db, and the average loss is less than $\frac{1}{4}$ db. A net gain occurs due to the presence of the switch over certain bands of frequency. This results from periodic cancellation of mismatch conditions.

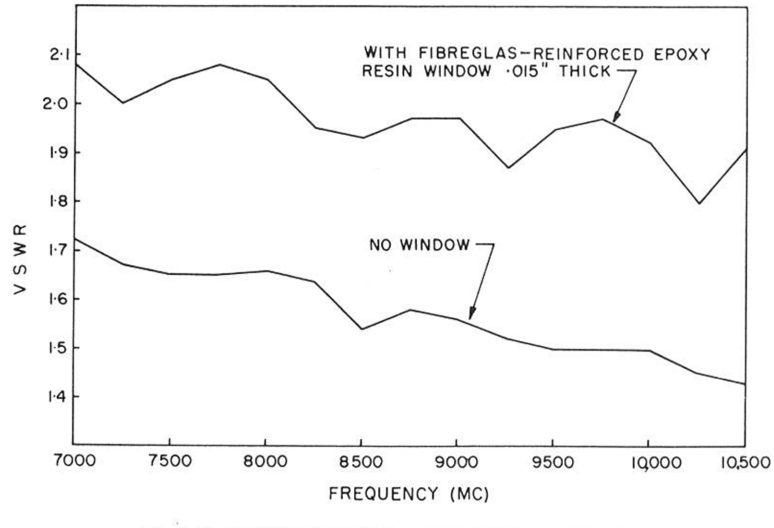

FIG. 9 VSWR OF HORN ANTENNA — EFFECT OF APERTURE COVER

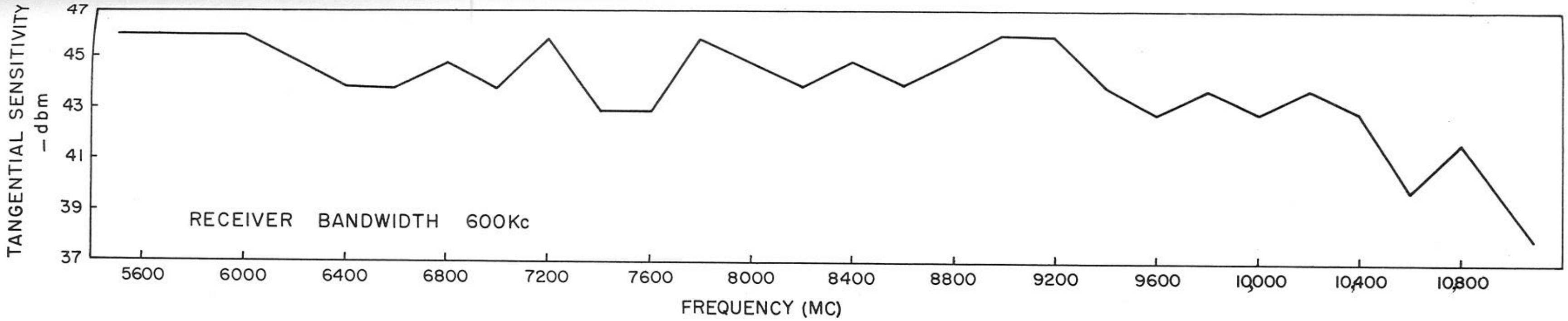

FIG. 10 TANGENTIAL SENSITIVITY OF CRYSTAL MOUNT

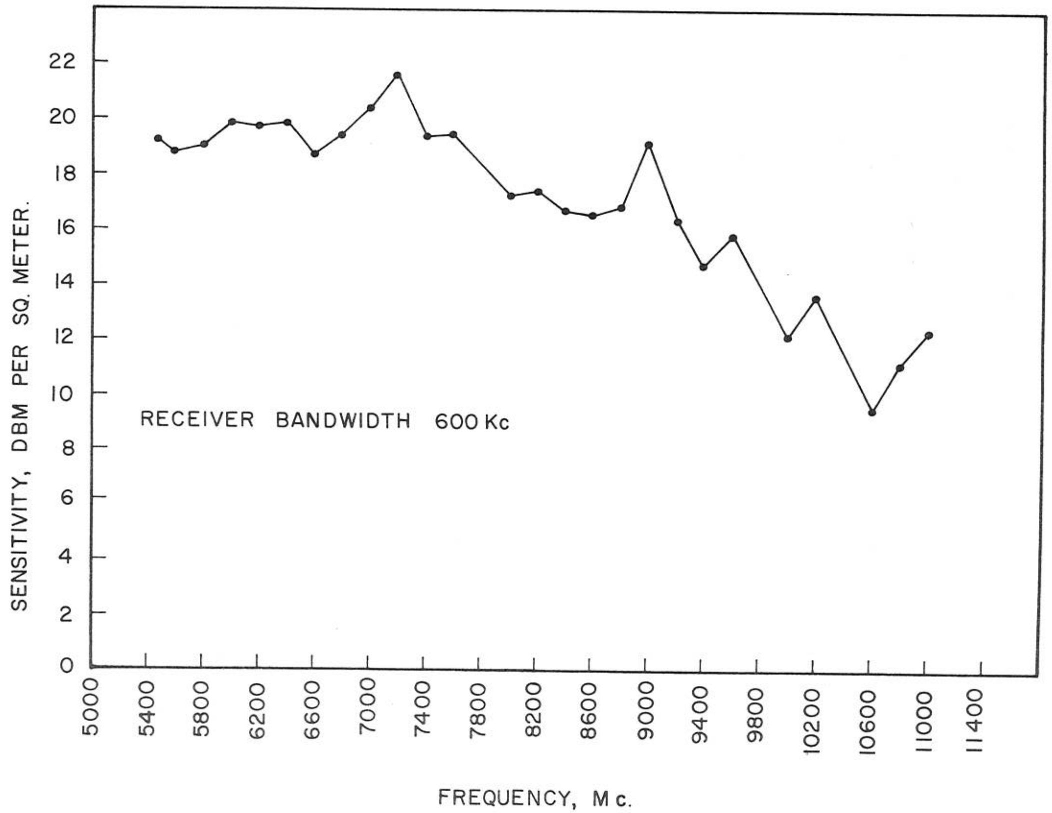

FIG. 11 TANGENTIAL SENSITIVITY OF ANTENNA CHANNEL

The VSWR of a horn with, and without a Fiberglas-reinforced epoxy resin window over its aperture is shown in Fig. 9. A thinner window would have less effect, but would not be sufficiently strong mechanically.

The tangential sensitivity of the crystal mount is shown in Fig. 10. These measurements were made relative to a matched source. The sensitivity of a complete antenna channel is given in Fig. 11. This data was taken with a type-1N23B crystal of average sensitivity in the crystal mount. Such a crystal is chosen on the basis of comparative sensitivity measurements on at least 20 crystals.

Of primary importance, in addition to adequate sensitivity, is the necessity that bearing error be within acceptable limits. These limits have been taken to be a maximum error not exceeding ±15° when measured under laboratory conditions. Fig. 12 illustrates an amplitude distribution curve of bearing errors taken from a number of measurements across the frequency band of the antenna and at 20° intervals in azimuth. The root mean square error obtained from this data is also indicated. In order to obtain low values of bearing error, properly shaped antenna radiation patterns and equal signal sensitivities in all four channels are required. Signal sensitivities may be made equal at any one frequency by adjustment of the video amplifier gain controls. The above error distribution curve was obtained with a fixed setting of the amplifier gain controls, so that it includes error due to non-tracking (error due to non-parallel sensitivity characteristics among the channels as the frequency is altered).

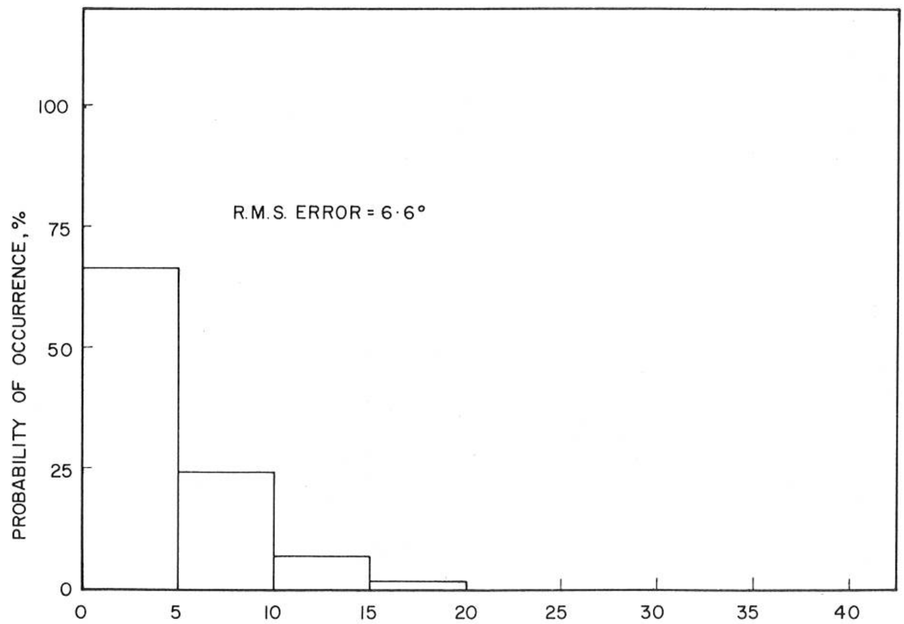

FIG. 12 BEARING ERROR DISTRIBUTION

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PLATE I — X-BAND ANTENNA CYLINDER, HORIZONTAL POLARIZATION — END VIEW

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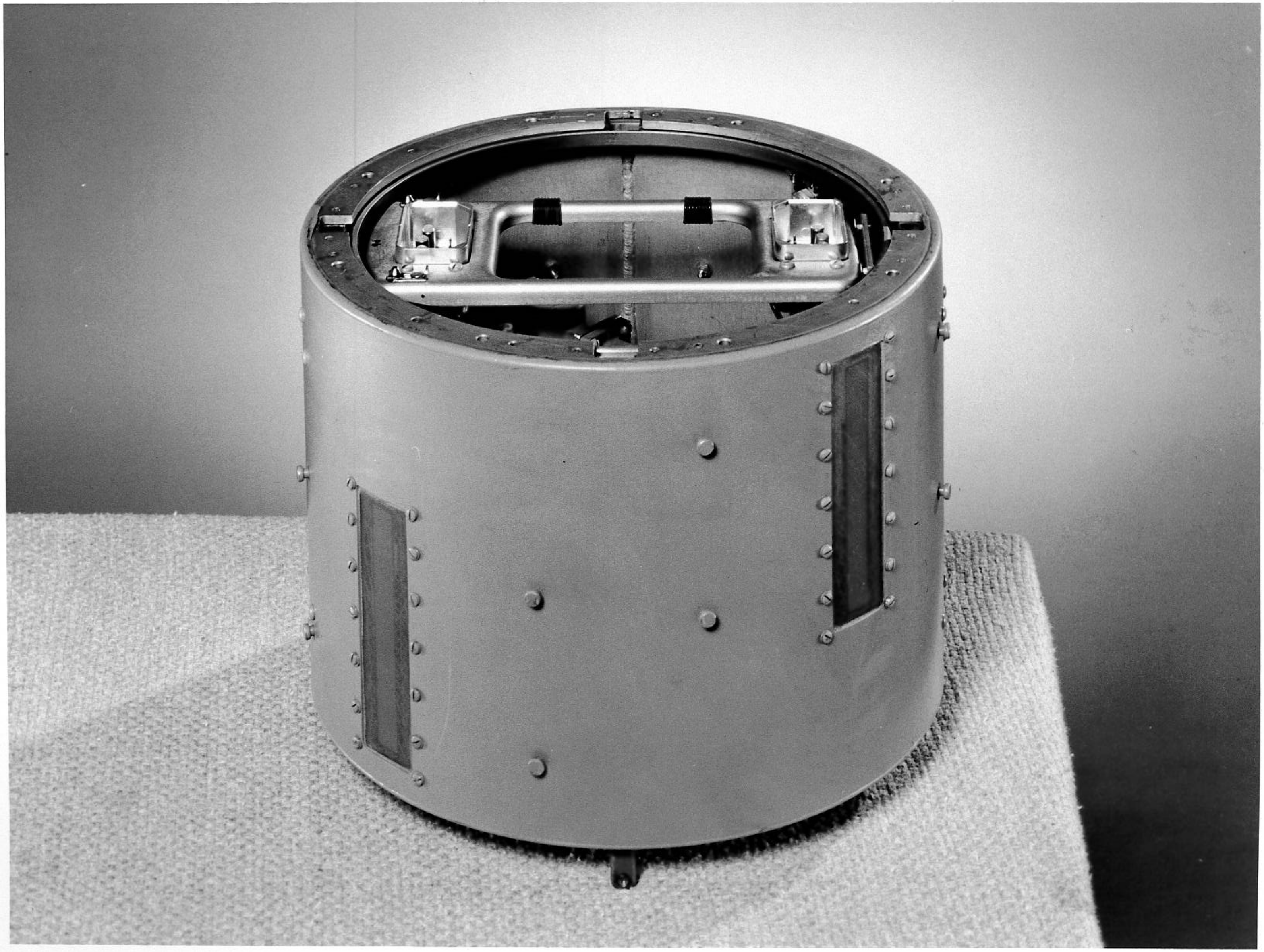

PLATE II — X-BAND ANTENNA CYLINDER, HORIZONTAL POLARIZATION — SIDE VIEW

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