# Antenna system for AN/UPD-501 receiver S-band, vertical polarization

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# ANTENNA SYSTEM FOR AN/UPD-501 RECEIVER S-BAND, VERTICAL POLARIZATION

F. V. CAIRNS, J. H. CRAVEN, W. L. HANEY

A. STANIFORTH, K. A. STEELE



OTTAWA

AUGUST 1961 

## ABSTRACT

This report describes the AN/UPD-501 antenna system for S-band, vertical polarization. Mechanical features and electrical performance are given. The design of this antenna was completed in 1957.

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

# CONTENTS



## FIGURES



## PLATES

# ANTENNA SYSTEM FOR AN/UPD-501 RECEIVER
# S-BAND, VERTICAL POLARIZATION

F.V. Cairns, J.H. Craven,
W.L. Haney, A. Staniforth, K.A. Steele

## INTRODUCTION

The AN/UPD-501 is an instantaneous direction finder for reception of pulsed transmissions at microwave frequencies. Bearing indication is 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 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 S-band antenna system for frequency coverage from 2.35 kmc/s to 5.5 kmc/s for vertical 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 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.

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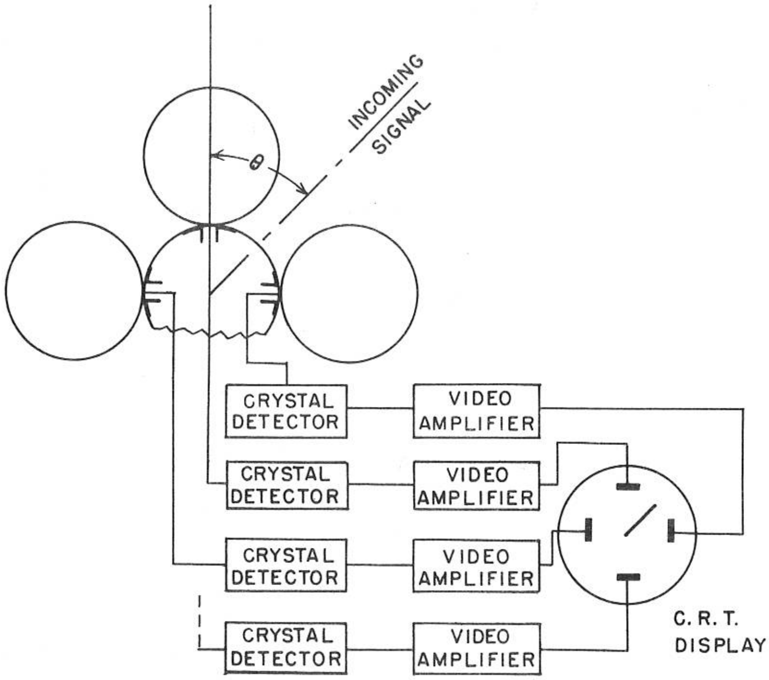


FIG. 1(a) 4-CHANNEL INSTANTANEOUS DIRECTION FINDER

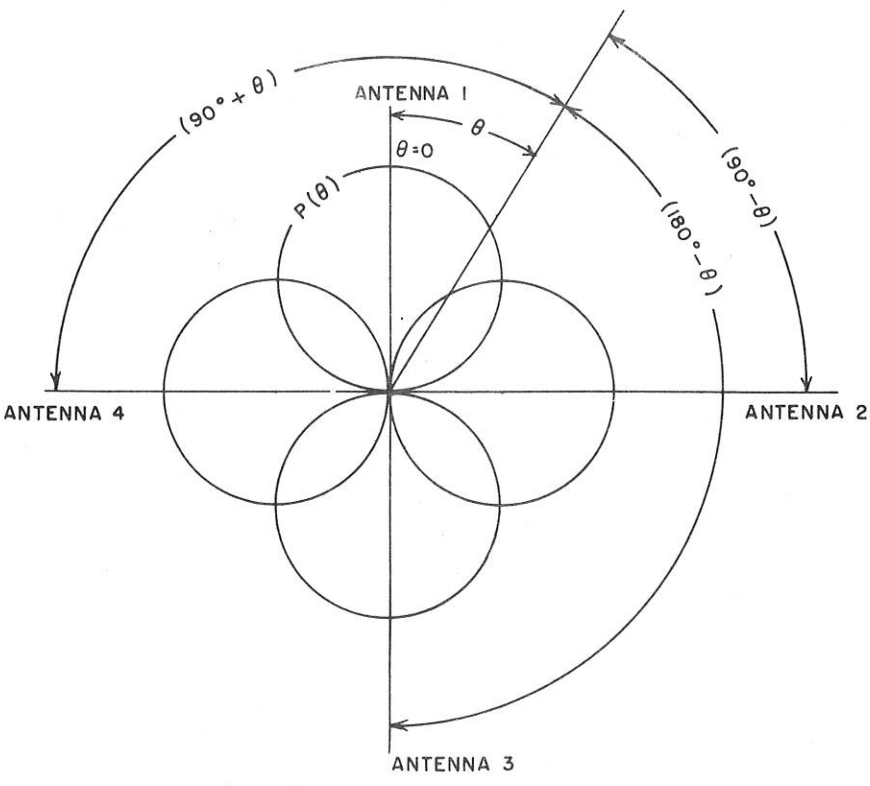


FIG. 1(b) ANGULAR RELATIONSHIPS IN 4-CHANNEL DIRECTION FINDER

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 parallel, 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 result theoretically 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 S-band, vertically polarized antenna cylinder, with two antenna sub-assemblies mounted within, is shown in Plates I and II. The unit shown 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 due 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 system, 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 S-band antenna assembly may be 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 for ships, such as that shown in Plate I, 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 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.

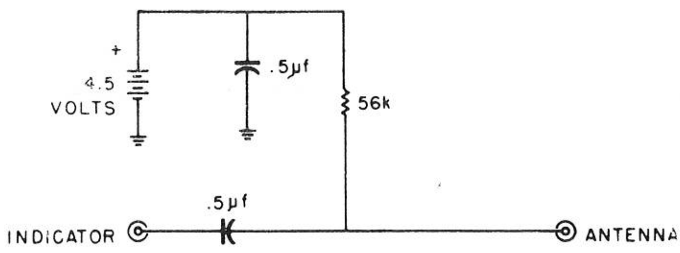


FIG. 2 BIAS SUPPLY FOR VIDEO DETECTOR

## MECHANICAL FEATURES

It is very necessary that considerable care be taken in maintaining dimensions within tolerance, especially those which have to do with the electrical performance of the antenna. While the VSWR or mismatch losses may not be great in the individual components of a system if dimensions are somewhat outside tolerance, the over-all effect on an assembly may be considerable. The combination of several transmission line components of slightly different lengths and VSWR's may result in assemblies with widely varying insertion losses over a broad frequency band. It is very important that the individual antennas of a system track with frequency so that they maintain parallel signal sensitivities across the frequency band.

The physical dimensions of an S-band, vertically polarized antenna subassembly are shown in Fig. 3. The electrical performance is most sensitive to the dimensions of the beam-shaping devices fitted about the aperture of the horn and the dimensions of the coaxial-to-waveguide transition. The transmission path lengths in each microwave component should also be held within close limits, since the net mismatch loss in the system is dependent on the relative phases of the various mismatches in the system as well as on their magnitudes.

The horn and transition are aluminum precision castings manufactured by the lost wax process. The internal waveguide dimensions of the horn are not machined, as sufficiently close tolerances (± .004 inch per inch) are held in casting. Production units of the transition are broached. The transition dimensions are essentially identical to those of a "toll ticket" waveguide transition described by Cohn [3]. Care must be taken that the cone of the beryllium copper pin makes good electrical contact with the top of the ridge inside the waveguide.

The Transco Products switch is used for protection of the detector diode against burnout from nearby high power radars, and is operated from a 28-volt d-c source. The crystal mount is disconnected from the antenna when the power to the switch is turned off.

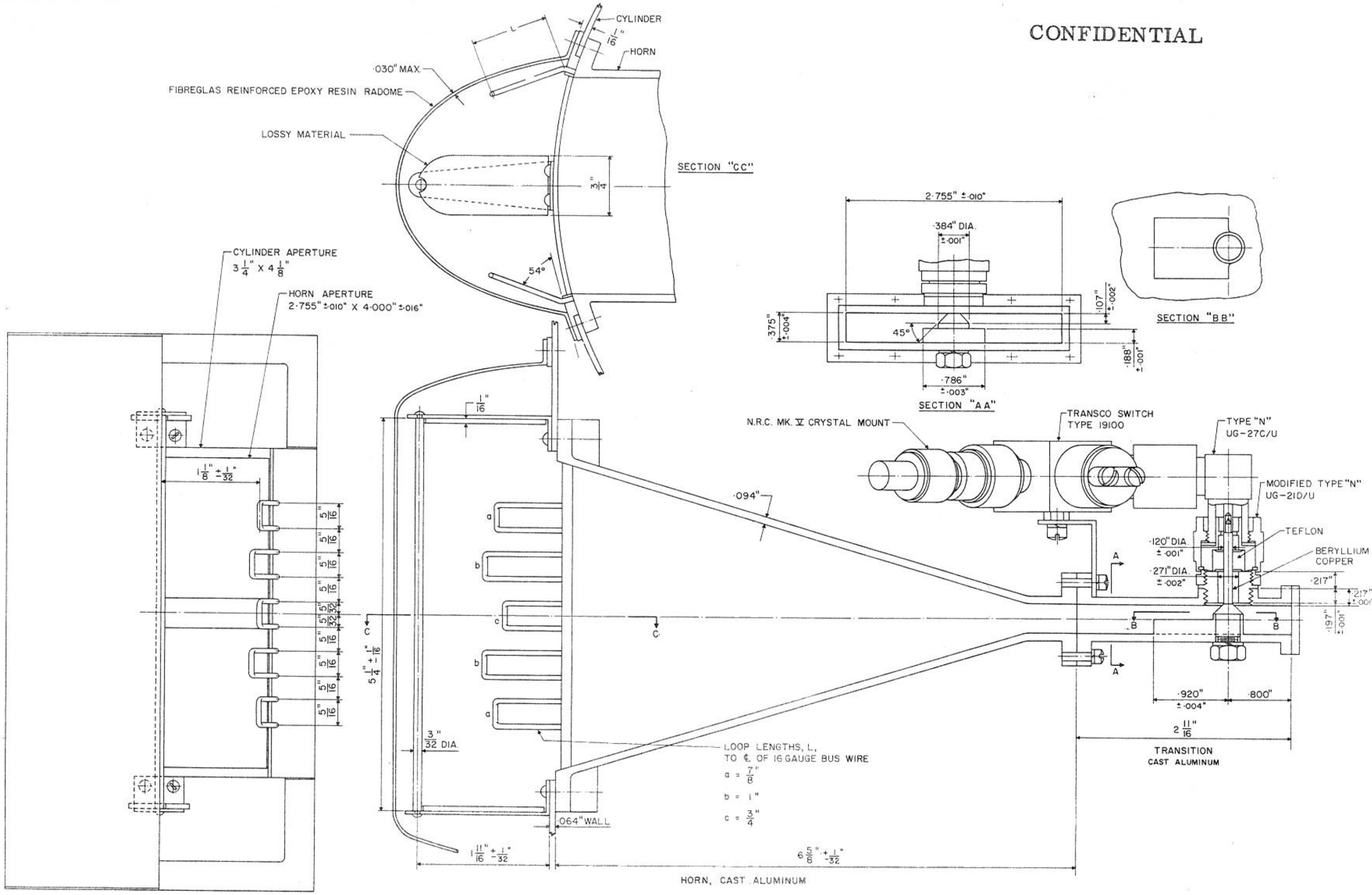


FIG. 3 S-BAND ANTENNA, VERTICAL POLARIZATION — ASSEMBLY

The NRC Mk. V crystal mount [4] is designed for use with crystal diodes of the type-1N23 series, and particularly the type-1N23B series. A drawing of the mount is shown in Fig. 4. The main body of the mount is constructed from a UG21D/U type-N connector. Foam plastic, instead of a solid dielectric, is used inside the mount to hold the center conductor pin. This increases the impedance and provides a better match to the detector crystal. An insulated sleeve at the cap end of the crystal provides a low impedance output termination. This bypass capacitance is approximately 35 $\mu\mu$f. The video output crystal cap contains a block of radio-frequency absorbing material [5] which absorbs microwave energy coupled past the detector crystal. Such microwave energy might otherwise cause resonance effects and result in widely differing detection characteristics for different crystal mounts. The crystal cap is a common part used on all antenna assemblies. The absorber in the cap is useful mainly at X-band and higher frequencies.

Two types of beam-shaping devices are fitted to the antenna horn aperture. A $\frac{3}{8}$-inch-diameter brass post is mounted in front of the horn parallel to the E-plane, and also a series of wire loops are placed so as to extend in front of the horn on the sides of the aperture parallel to the post. The relative spacing of these loops and the position of the post must be maintained for proper electrical performance. Mechanical protection for these devices and waterproofing is provided by a molded Fiberglas-reinforced epoxy resin cover.

Good electrical contact is essential between the flange of the horn and the inner surface of the 10-inch-diameter aluminum antenna cylinder. The two surfaces are held together by a row of machine screws. A gap between the horn and the cylinder would very likely cause serious distortion of the antenna radiation pattern or a reduction of signal sensitivity, or both.

The aluminum cylinder, horn, and transition are treated with Iridite No. 14-2* for protection against corrosion. This treatment results in a surface which also has good electrical conductivity.

## ELECTRICAL PERFORMANCE

A considerable amount of experimental work was done on the S-band antenna for vertical polarization. This was mainly directed towards obtaining antenna radiation patterns broad enough ( $\approx 130°$ at half-power points) for a four-channel system. The waveguide size and frequency band previously chosen for S-band, horizontal polarization, imposed a limit on how narrow the horizontal aperture could be. With this aperture the beamwidth was much too narrow. Antenna radiation patterns at six frequencies throughout the band are shown in Fig. 5 for the horn alone, without beam-shaping devices.

* Allied Research Products Inc., Baltimore, Md.

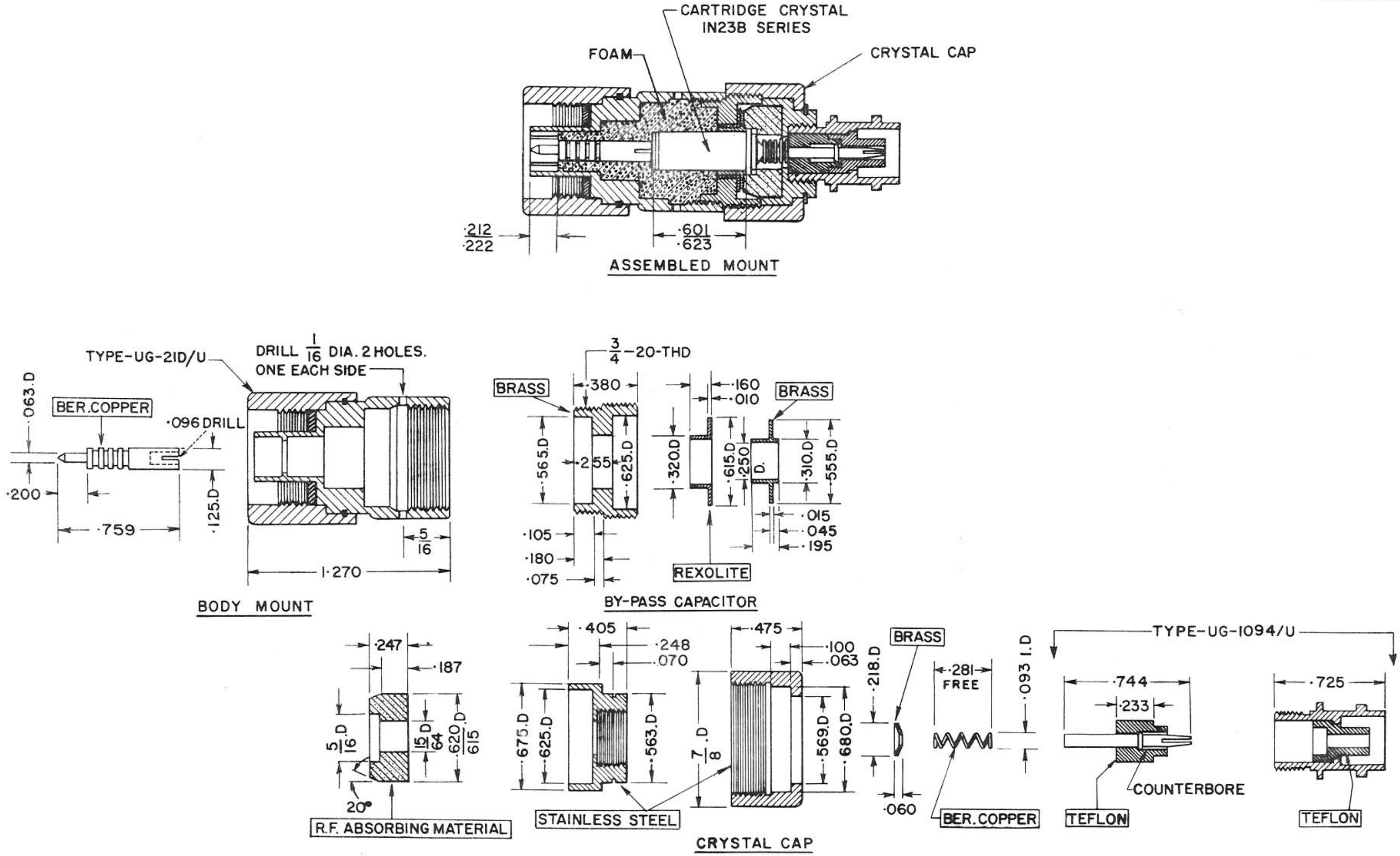


FIG. 4 ASSEMBLY OF NRC MK.V CRYSTAL MOUNT

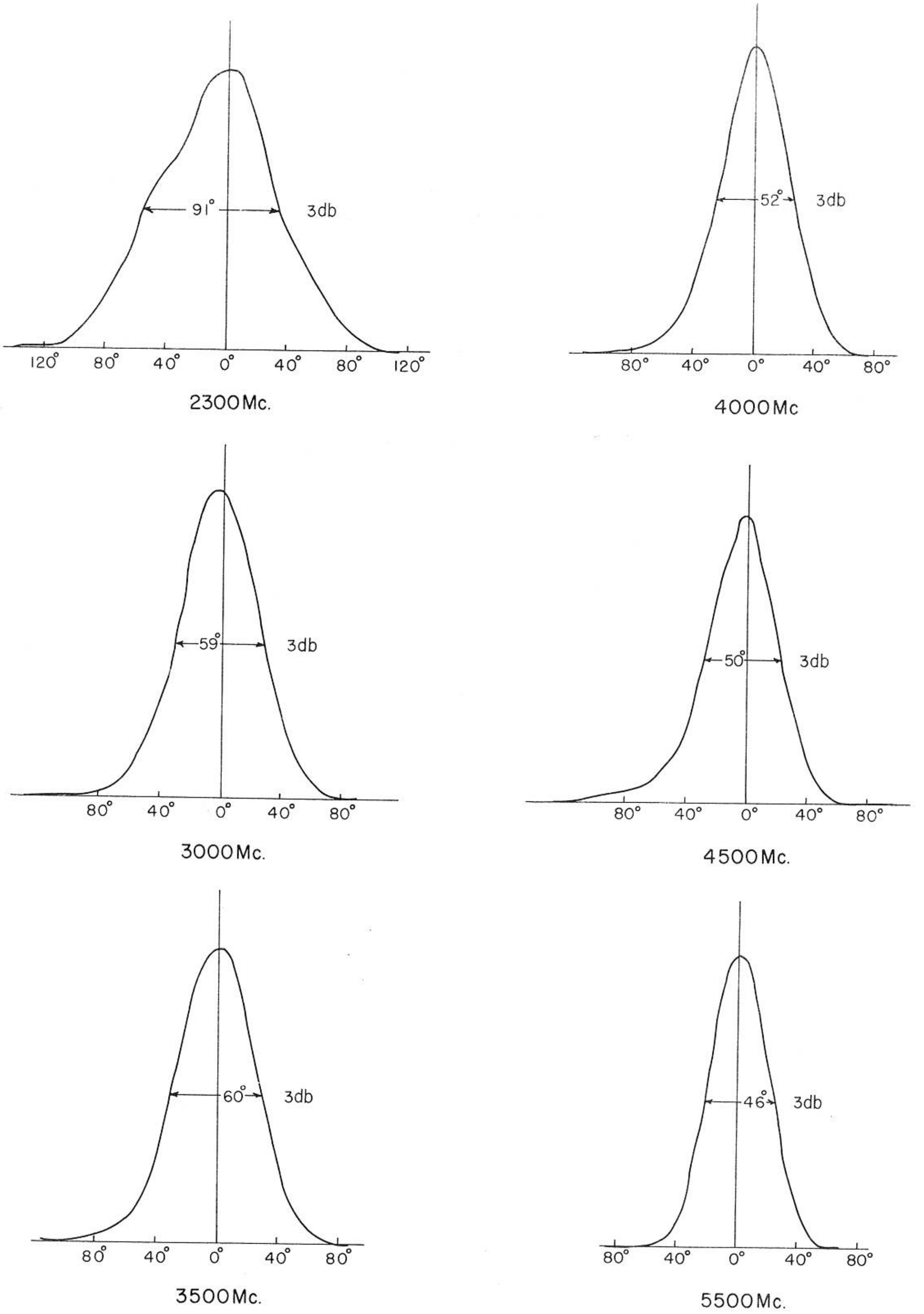


FIGURE 5
ANTENNA POWER RADIATION PATTERNS
S-BAND VERTICAL POLARIZATION
WITHOUT BEAM-SHAPING DEVICES

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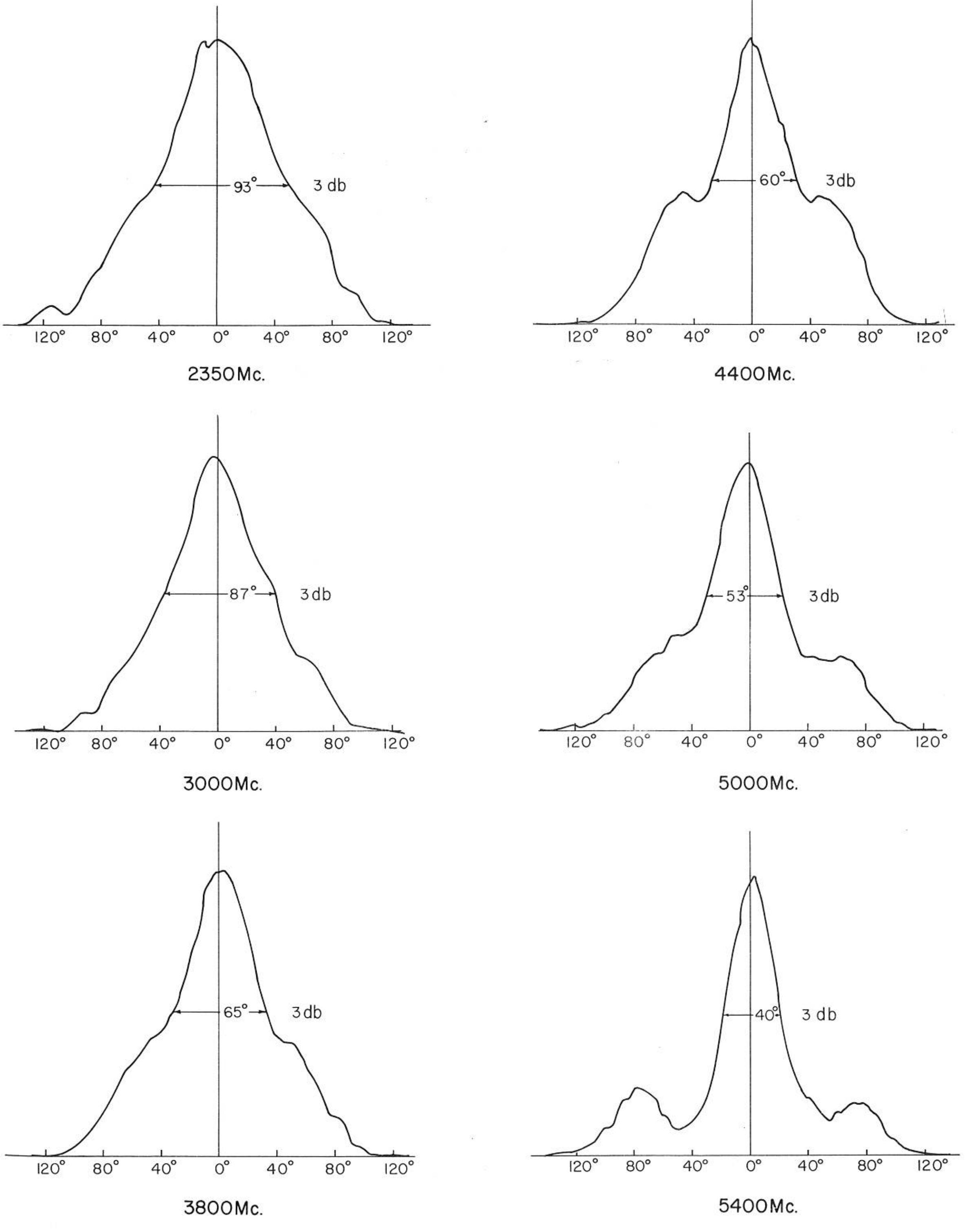


FIGURE 6
ANTENNA POWER RADIATION PATTERNS
S-BAND VERTICAL POLARIZATION
COMPLETE WITH BEAM-SHAPING DEVICES

A combination of two types of beam-shaping devices is used on the horn to broaden the radiation pattern. Two were required, since neither alone is sufficiently broadband to cover the intended frequency range. A vertical post mounted in front of the horn acts to broaden the antenna pattern mainly from 2300 mc/s to 3800 mc/s. The wire loops, parallel to the post and mounted on each side of the horn aperture, are effective mainly from 3800 to 5500 mc/s. The basic ideas for beam-shaping with loops were obtained from Reference 6. A particular difficulty in the design was to avoid coupling between post and loops, accompanied by resonance effects which cause distortion of the antenna radiation patterns. Coupling between the beam-shaping devices of the two antennas mounted on the same cylinder was also a problem. The flat plates of epoxy resin - powdered iron absorbing material mounted on the post support brackets are used to damp out resonances due to coupling to the brackets.

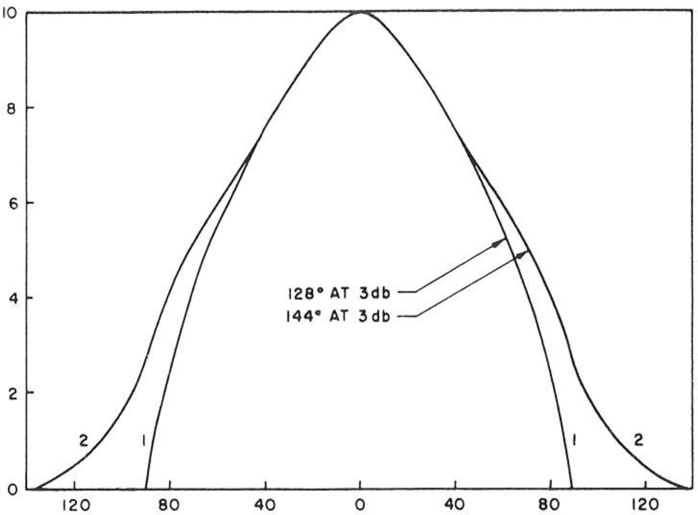

FIG. 7 IDEAL POWER RADIATION PATTERNS

Power radiation patterns of an antenna complete with beam-shaping devices for six frequencies throughout the band are shown in Fig. 6. These may be compared with the ideal radiation patterns shown in Fig. 7. Curve 1 - 1 in Fig. 7 is a radiation pattern which results in zero bearing error and maximum constant sensitivity when used in a four-channel system. Curve 2 - 2 is also a zero bearing error pattern for a four-channel system, but does not result in constant sensitivity with azimuth. Allowance was made in calculating these patterns for the nonlinearity of the video amplifiers in the indicator unit.

The VSWR of a horn with beam-shaping post and loops is shown in Fig. 8. This figure also shows the effect of the Fiberglas - epoxy resin radome. This radome provides mechanical protection for the beam-shaping devices and also

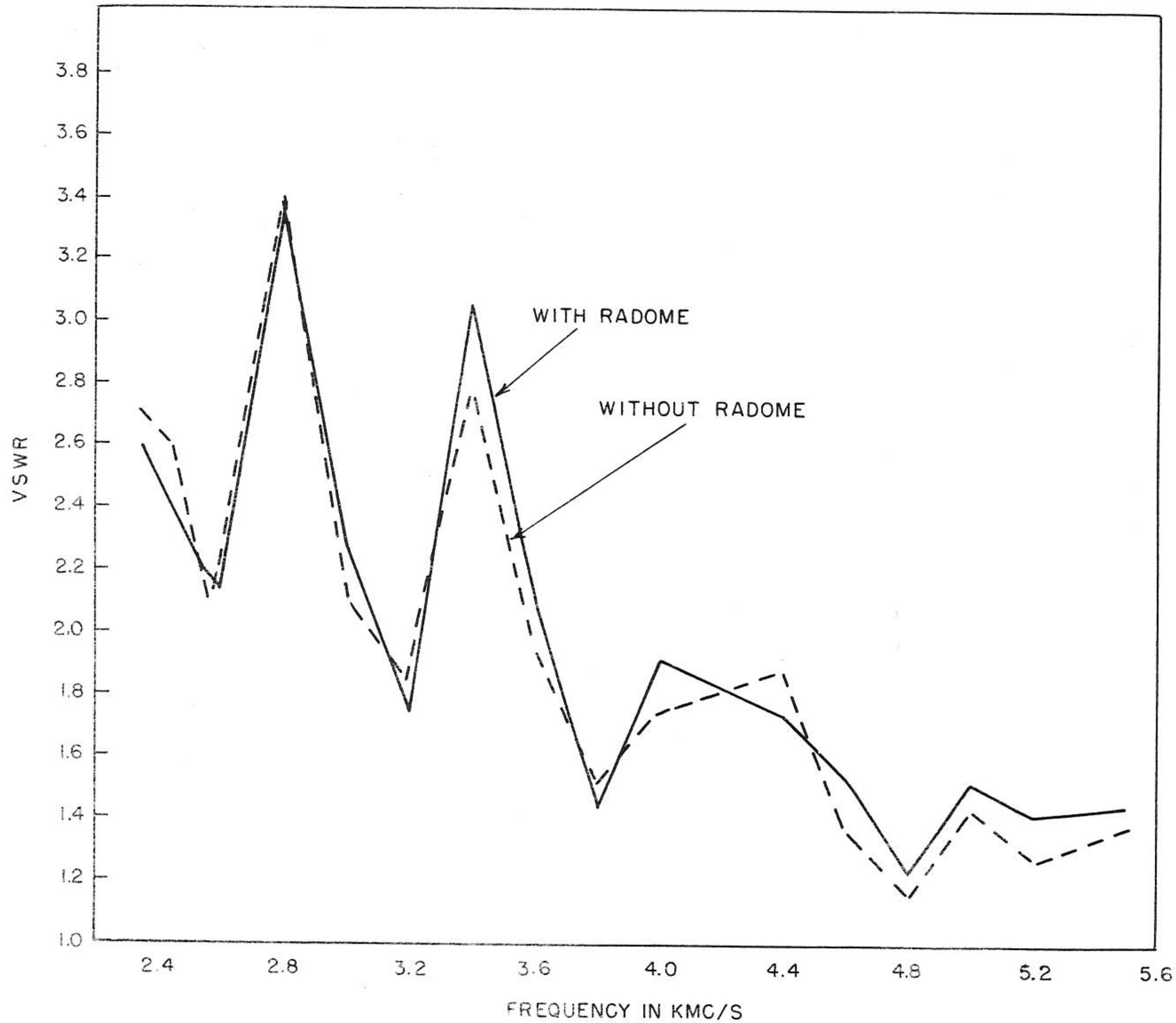


FIG. 8 VSWR OF HORN WITH BEAM-SHAPING POST AND LOOPS

acts as a moisture barrier. It has very little effect on the antenna radiation patterns, and hence on the system bearing error. The transmission loss is also very small.

A Transco Products Inc., 19,000 series, coaxial "on-off" switch is used for crystal detector protection. Manufacturers' data indicate a maximum VSWR of 1.3 throughout S-band, with typical values less than 1.2. Tests in an S-band antenna assembly indicate that in the "off" position this switch provides minimum isolation of 40 db. The insertion loss in an assembly does not exceed $\frac{1}{2}$ db.

VSWR and tangential sensitivity of the coaxial crystal mount (NRC Mk. V) are given in Fig. 9. These measurements were made relative to a 50-ohm line. The VSWR data was obtained with signal levels not exceeding -25 dbm at the crystal mount. The sensitivity of a complete antenna channel is given in Fig. 10. The performance data, which includes the crystal mount, was all taken with a type-1N23B crystal of average sensitivity in the coaxial mount. Such a crystal is chosen on the basis of comparative sensitivity measurements on at least 20 crystals.

The necessity that bearing errors be within acceptable limits is of primary importance, in addition to adequate sensitivity. Thus, maximum errors must not exceed ±15° when measured under laboratory conditions. Small bearing error cannot be achieved without properly shaped antenna radiation patterns and equal signal sensitivities in all four channels. Signal sensitivities may be made equal at any one frequency by adjustment of the video amplifier gain controls. The amplitude distribution curve of bearing errors shown in Fig. 11 was taken with one setting of the amplifier gain controls for measurements at all frequencies, so that it includes error due to non-tracking (error due to non-parallel sensitivity characteristics among the channels as the frequency is altered). The data for Fig. 11 was obtained from a number of measurements across the frequency band and at 20-degree intervals in azimuth. The root mean square error obtained from this data is also indicated.

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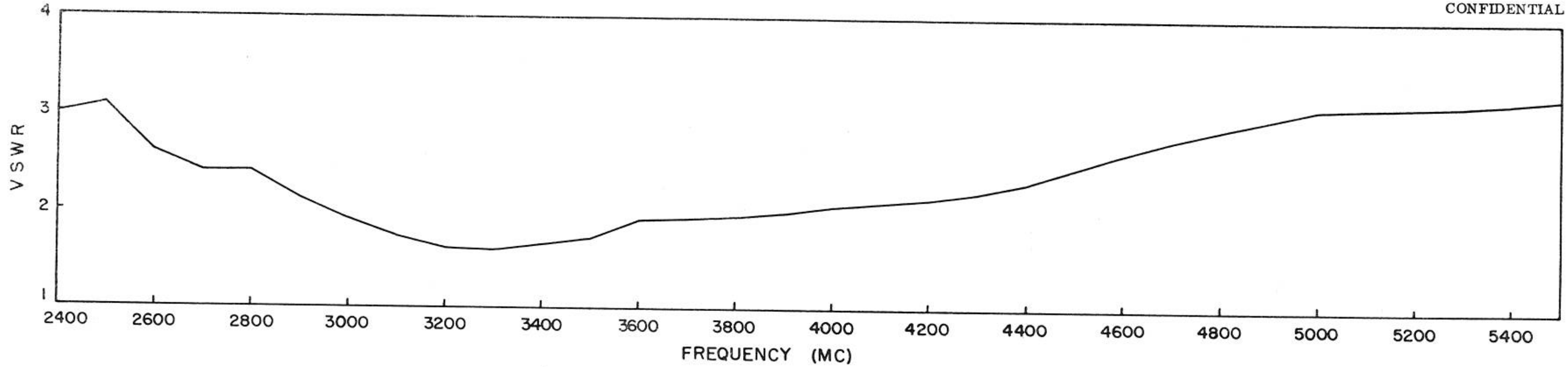


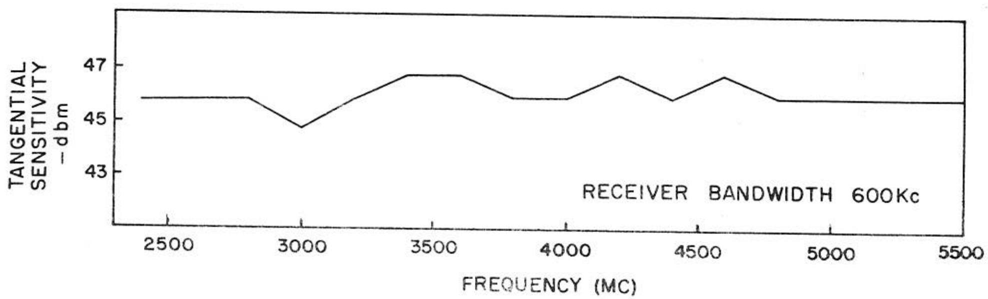


FIG. 9 VSWR AND TANGENTIAL SENSITIVITY OF NRC MK.V CRYSTAL MOUNT

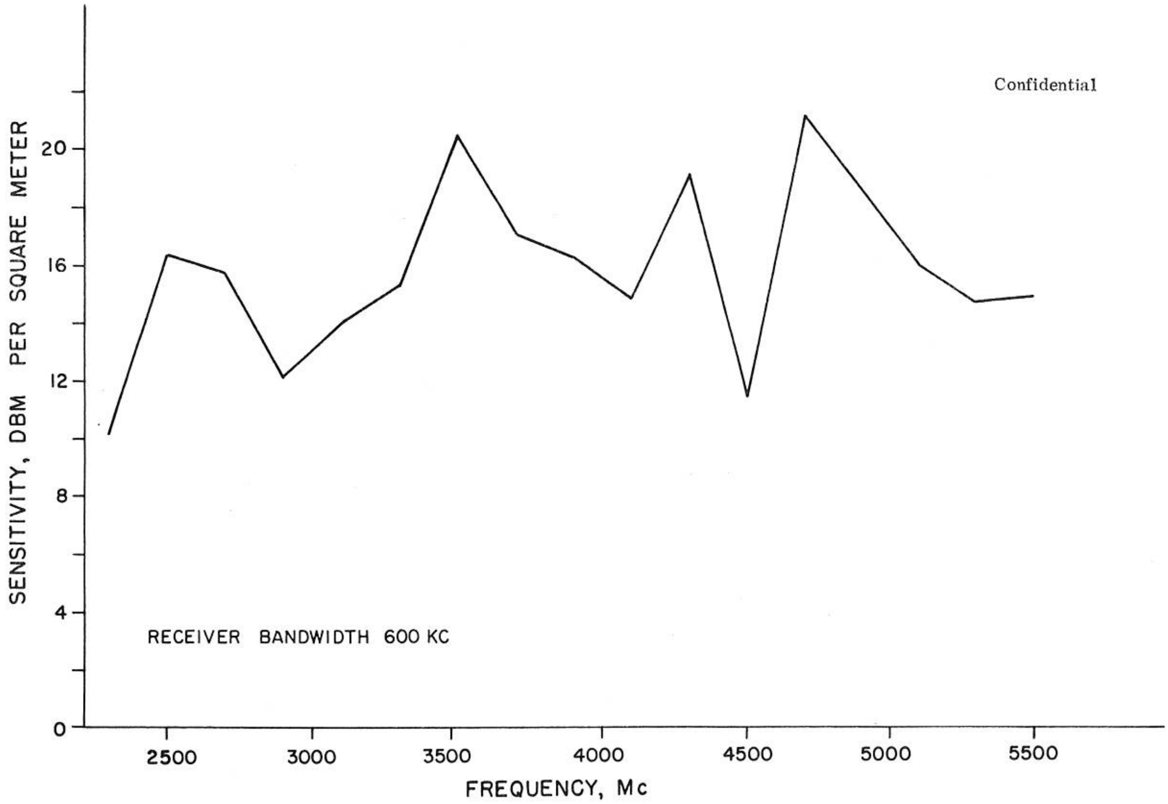


FIG. 10 TANGENTIAL SENSITIVITY OF A COMPLETE ANTENNA CHANNEL

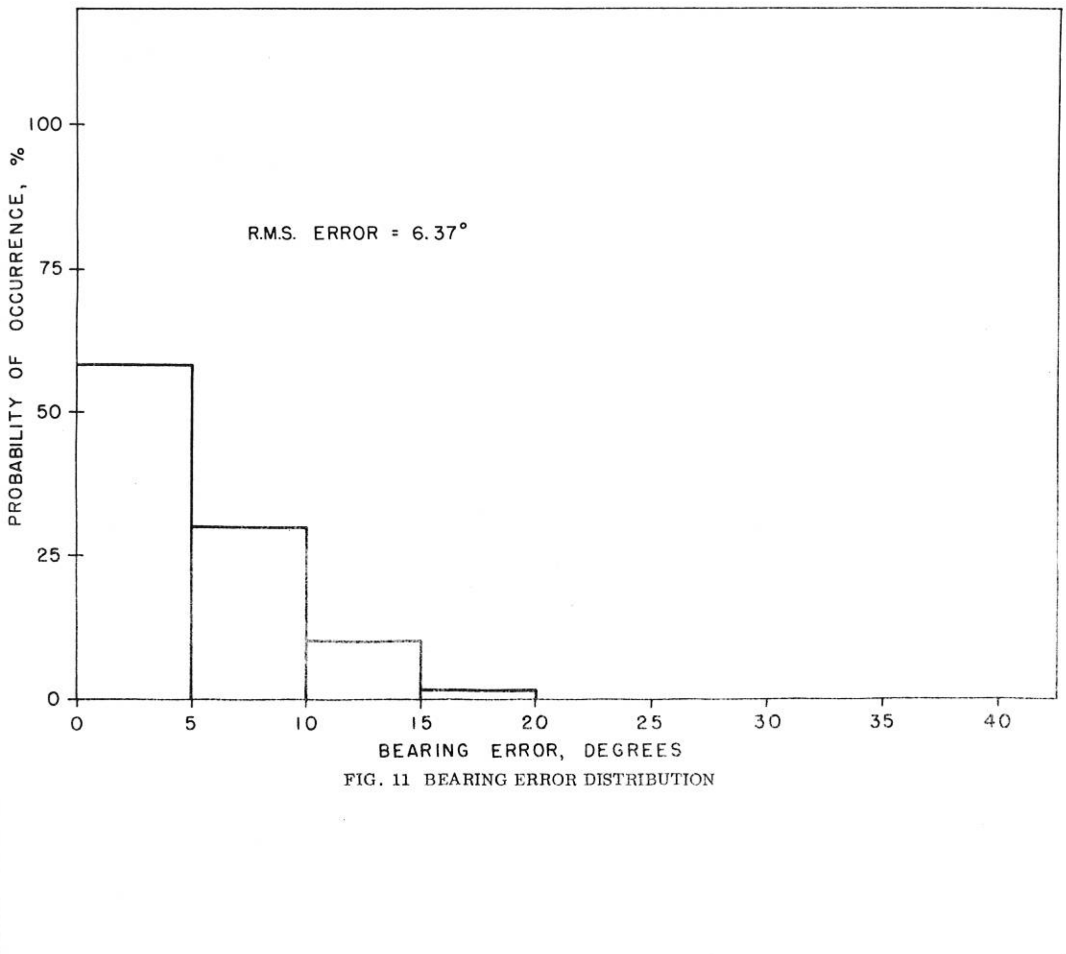


FIG. 11 BEARING ERROR DISTRIBUTION

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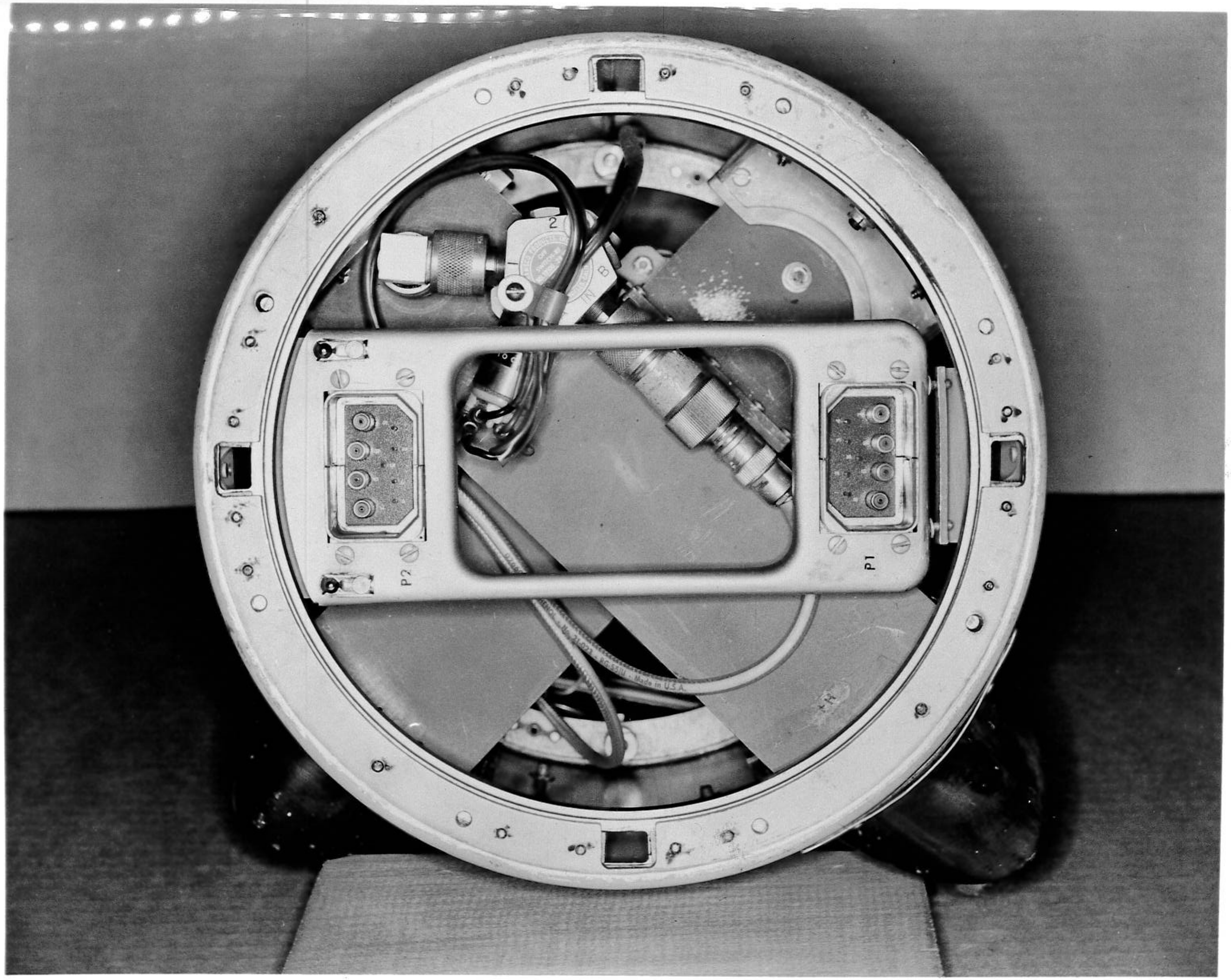


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PLATE I — S-BAND ANTENNA CYLINDER, VERTICAL POLARIZATION — END VIEW
(RCN Photo)

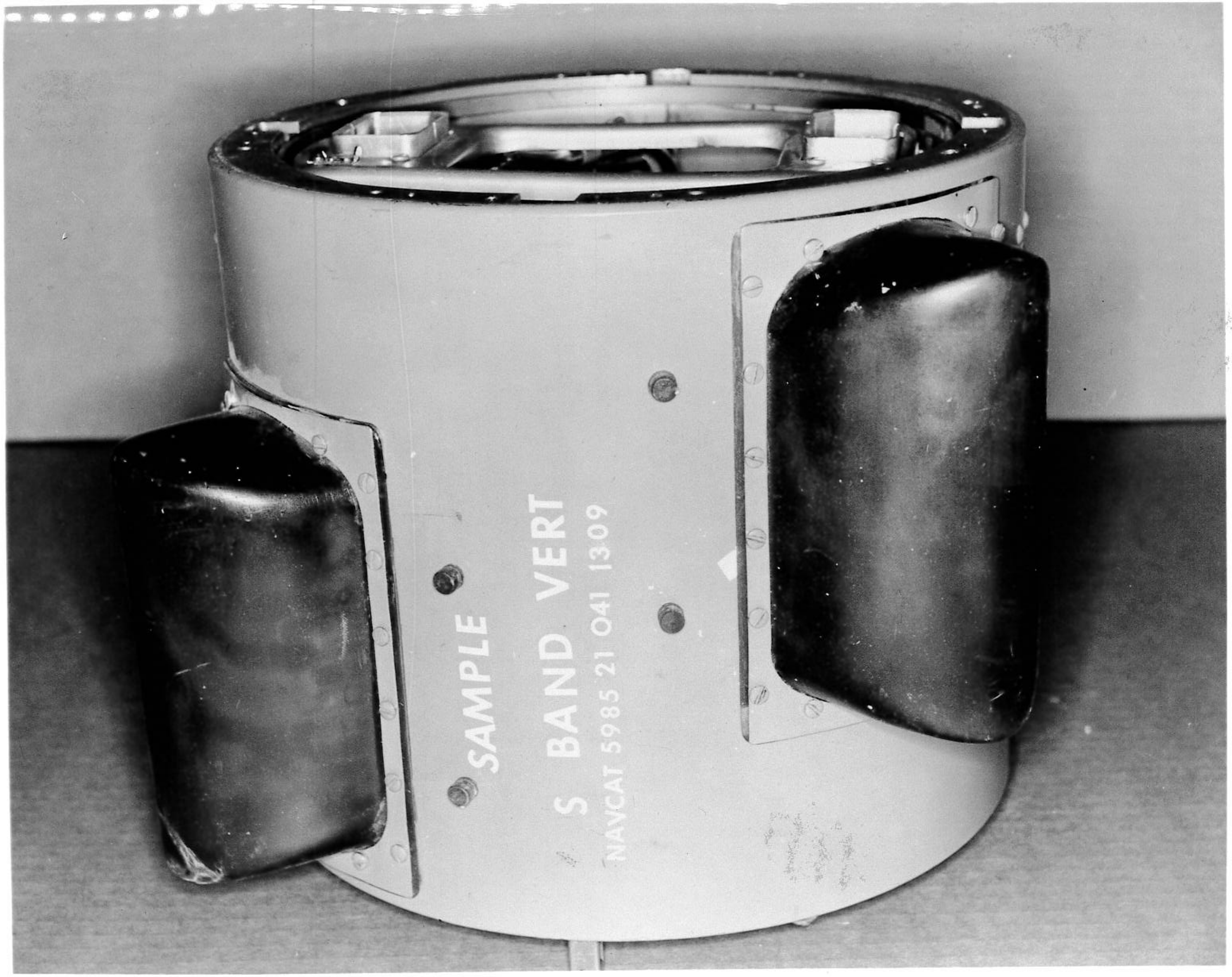


PLATE II — S-BAND ANTENNA CYLINDER, VERTICAL POLARIZATION — SIDE VIEW
(RCN Photo)

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