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

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

A. STANIFORTH, AND K. A. STEELE

OTTAWA

AUGUST 1961

ABSTRACT

This report describes the AN/UPD-501 antenna system for L-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:

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

CONTENTS

Page

FIGURES

PLATES

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

F.V. Cairns, J.H. Craven,
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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 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 L-band antenna system for frequency coverage from 1 kmc/s to 2.35 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.

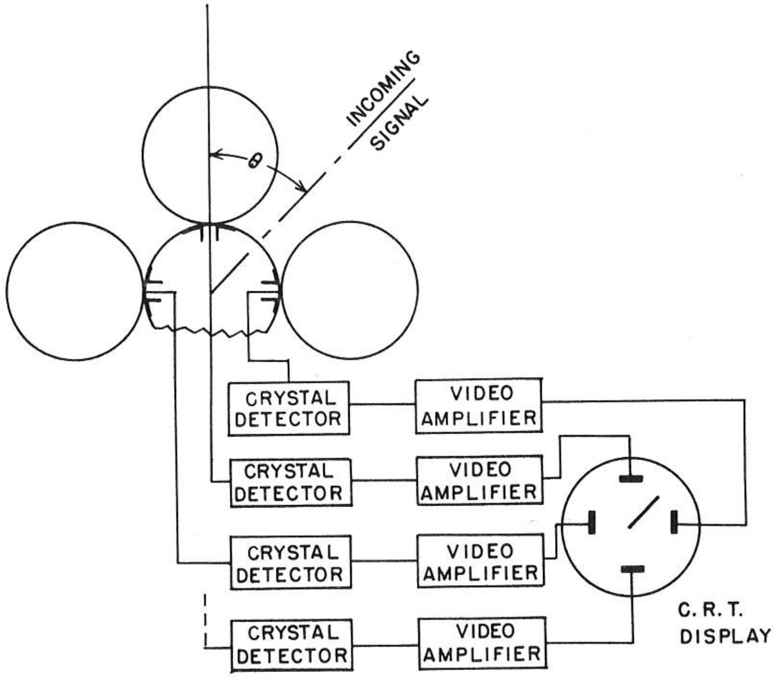

FIG. 1(a) 4-CHANNEL INSTANTANEOUS DIRECTION FINDER

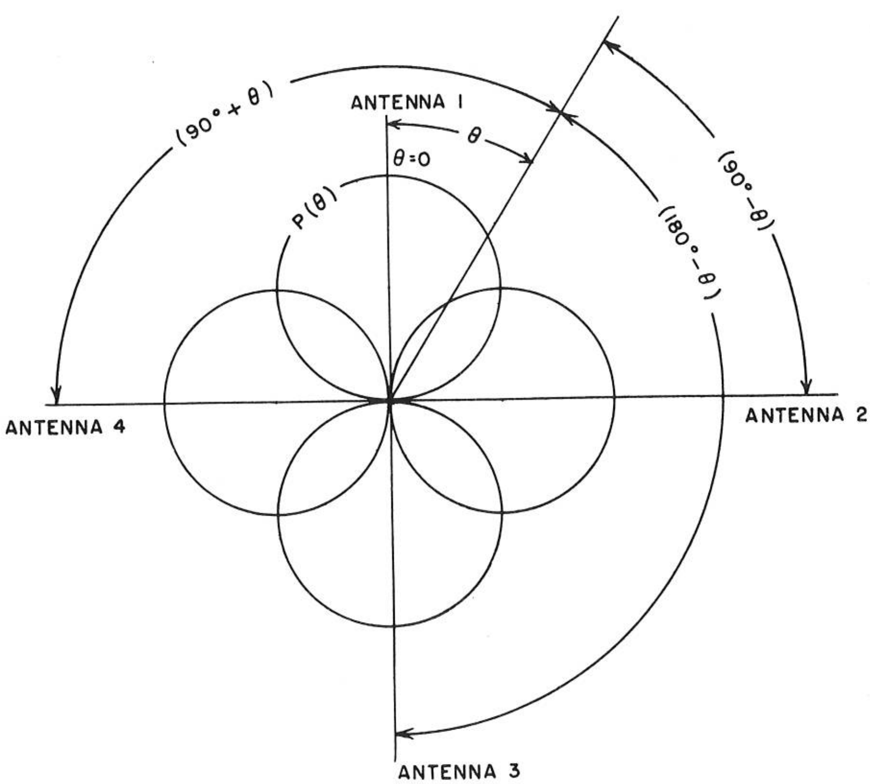

FIG. 1(b) ANGULAR RELATIONSHIPS IN 4-CHANNEL DIRECTION FINDER

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:

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

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 L-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 L-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 for ships 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, such as that shown in Plate I, 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.

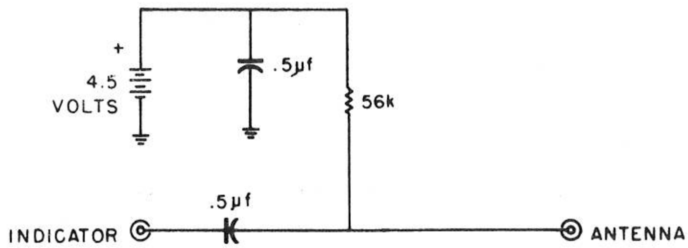

FIG. 2 BIAS SUPPLY FOR VIDEO DETECTOR

MECHANICAL FEATURES

A pictorial assembly of an L-band, vertically polarized antenna channel is shown in Fig. 3. The components are folded to a certain extent inside the 10-inch-diameter antenna cylinder because of space limitations. This folding is done at the type-"N" connectors between units and can be seen, in part, in Plate I. Mechanical details of the individual microwave components of the antenna sub-assembly are shown in Figs. 4, 5, and 6.

The radiator shown on Fig. 4 is a dipole fed from a cylindrical coaxial balun [3]. The impedance of the coaxial line input is 50 ohms. Rexolite covers over the dipole elements provide mechanical protection and a moisture seal. The mounting spacing of the dipole elements to the surface of the cylinder is $1\frac{3}{8}$ inches. Metal parts of the dipole assembly are of brass.

Provision is made to mount the dipole so that the elements can be oriented at 45° to the horizontal, as well as in the usual vertical position. The slots in the antenna cylinder for this purpose are visible in Plate II. Cylinders with dipoles mounted at 45° to the horizontal may be used in an eight-channel antenna system for dual polarization [4]. Such a system uses four 2-element antenna cylinders and offers the advantage of increased bearing accuracy over a 4-element antenna system.

The frequency band of the L-band antenna system is limited at the upper end, 2350 mc/s, by use of the low-pass filter shown in Fig. 5. The filter is a varying impedance type with M-derived matching half-sections at each end, and is constructed in photo-etched strip transmission line [5]. The stripline is made of two sandwiched sheets of $\frac{1}{8}$-inch-thick Rexolite faced with 0.0015-inch copper. All of the copper is etched from the inside face of one sheet, and all but the inner conductor configuration is removed from the inner face of the other sheet. The copper on the outside of both sheets is left intact and forms the ground plane. The dimensions of the stripline filter inner conductor are not shown in Fig. 5, but a reproduction of the negative used in the photo-etching process is shown to the scale indicated. The stripline filter is terminated in type-"N" connectors. The two Rexolite sheets are clamped together with a single row of machine screws around the outer edge, and the unit is completely coated with plastic to exclude moisture and to provide some mechanical strength and stiffening. The electrical

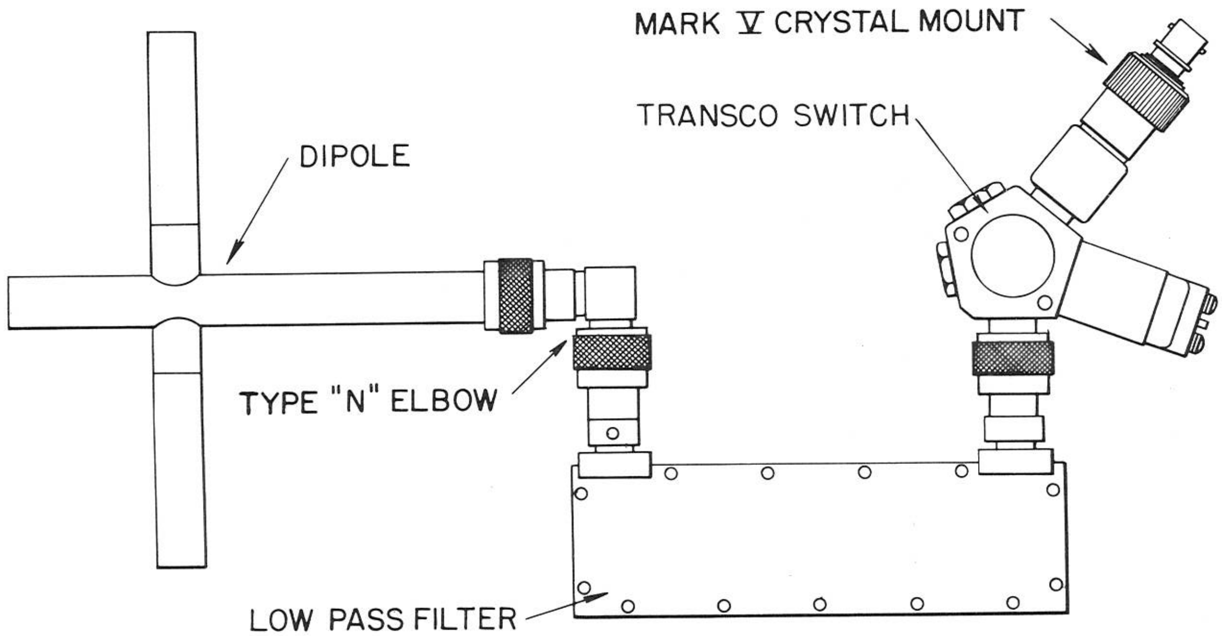

FIGURE 3

L-BAND VERTICAL POLARIZATION
ANTENNA ASSEMBLY

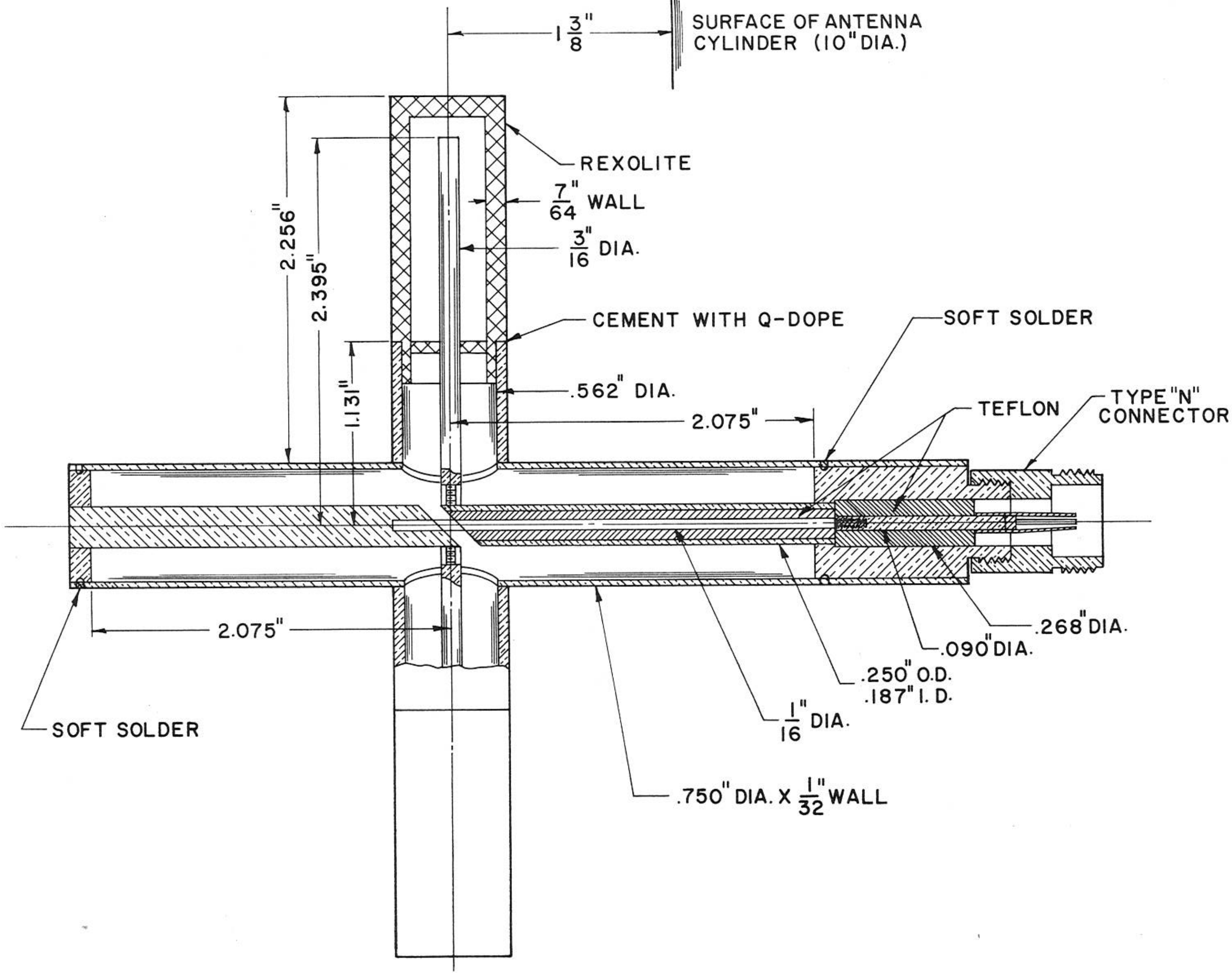

FIG. 4 L-BAND DIPOLE ANTENNA ASSEMBLY

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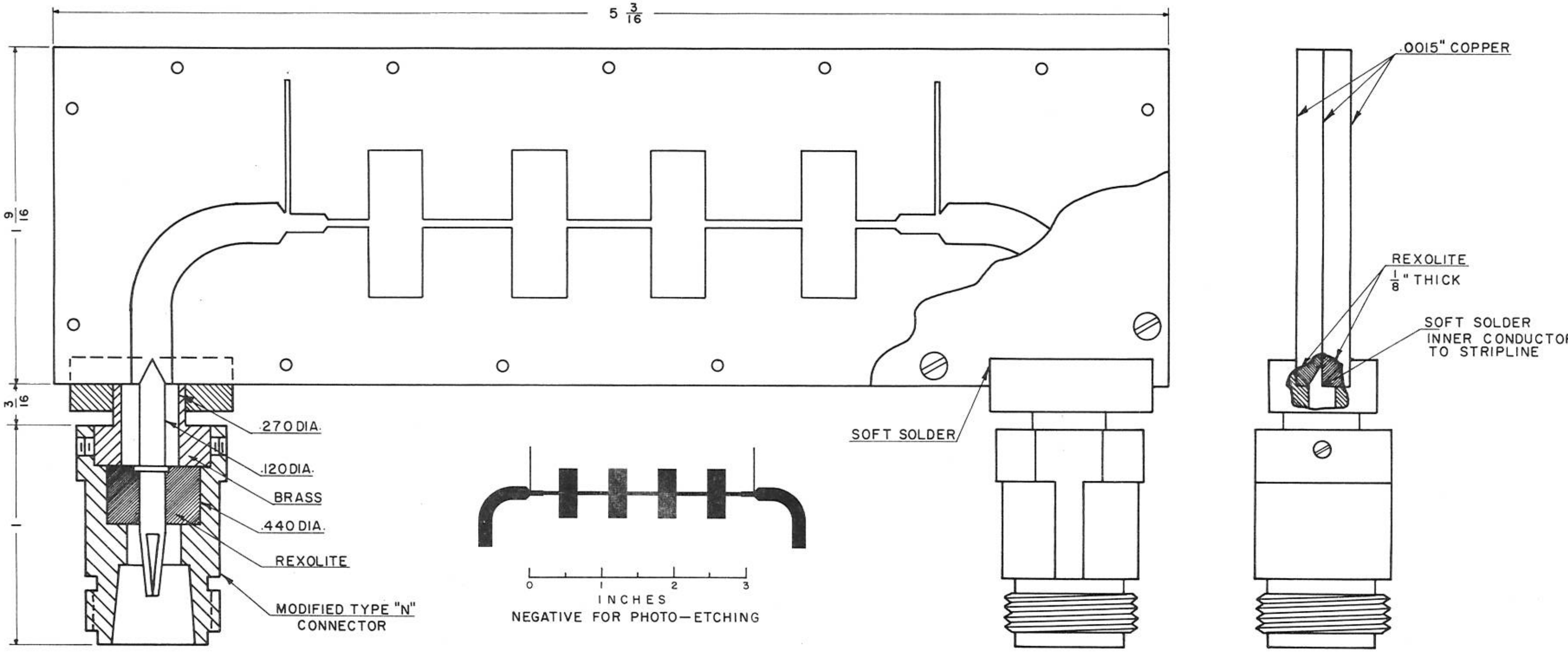


FIG. 5 FILTER FOR L-BAND ANTENNA

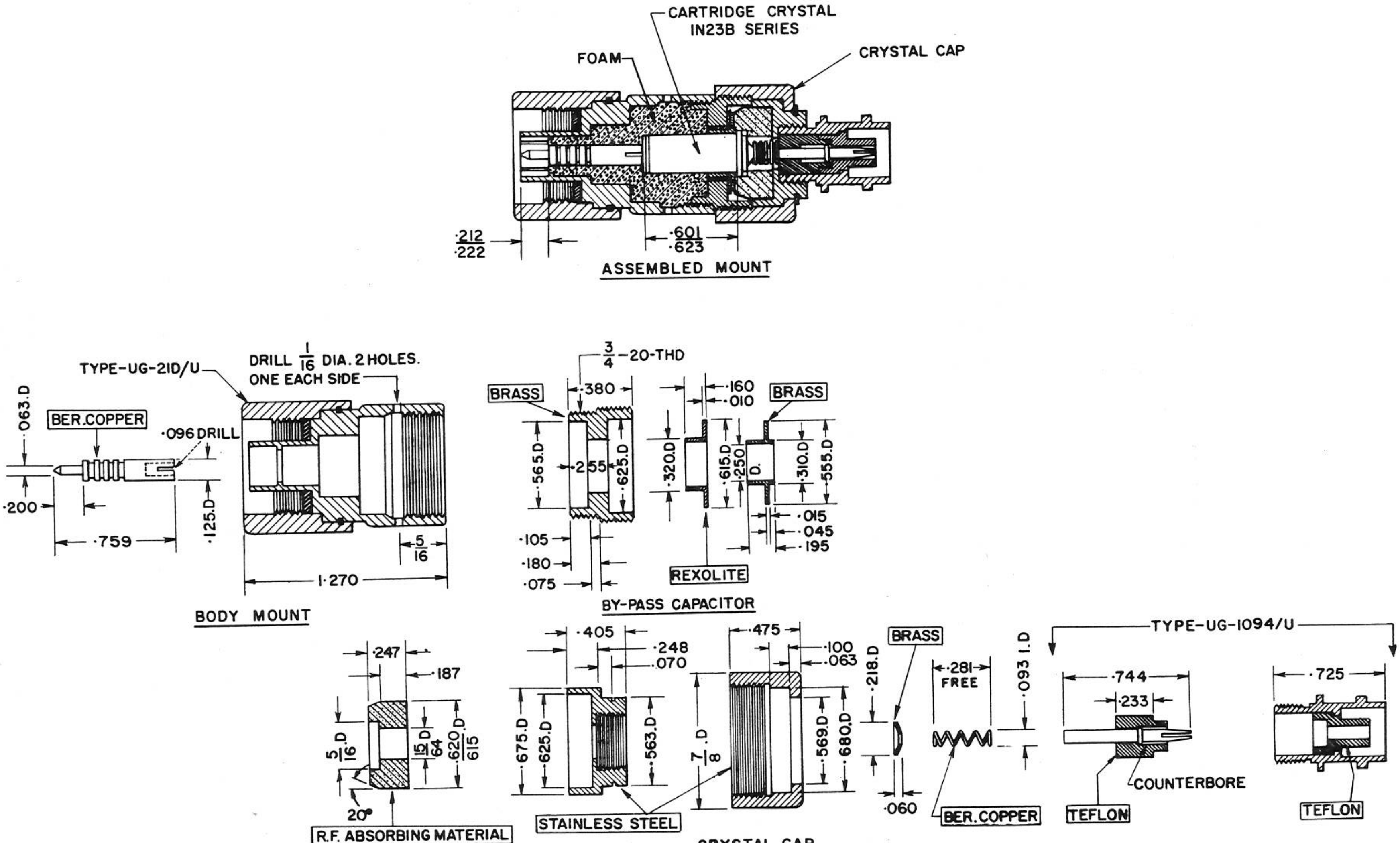


FIG. 6 NRC MK.V CRYSTAL MOUNT — ASSEMBLY

characteristics, such as cutoff frequency and rate of attenuation, are quite sensitive to warping or twisting of the strip transmission line. A high degree of electrical similarity between units may be obtained by careful assembly. This objective is facilitated by use of only one negative for making the inner conductor configurations, all of which are then identical.

The Transco Products Inc. coaxial switch indicated in Fig. 3 is used for protection of the detector diode against possible burnout by nearby high power radars. Power for the switch is obtained from a 28-volt d-c source. The switch disconnects the crystal mount from the antenna when the power is off.

The NRC Mk. V crystal mount [6] is a broadband coaxial mount designed for use with crystal diodes of the type-1N23 series, and in particular for the type-1N23B. A drawing of the mount is shown in Fig. 6. The main body of the mount is constructed from a UG-21 D/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 [7] which helps to eliminate resonance effects due to microwave energy being coupled past the detector crystal. The absorber is mainly useful at X-band and higher frequencies, but is used in L-band antennas since the crystal cap is a common part used on all UPD-501 antenna assemblies.

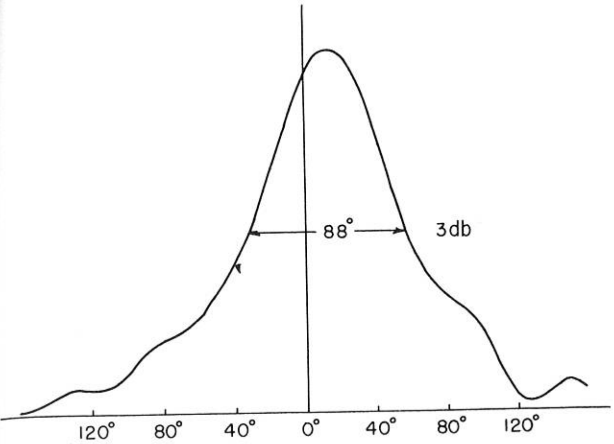
All aluminum parts of the antenna cylinder and assembly are treated with Iridite No. 14* for protection against corrosion. This treatment produces a surface of good electrical conductivity.

ELECTRICAL PERFORMANCE

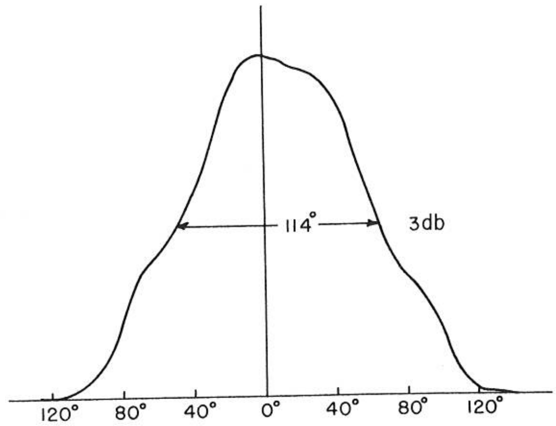
Electrical tests were performed on experimental models and on a pre-production prototype. None of the results are based on tests on production antennas.

Antenna power radiation patterns for six frequencies throughout the band are shown in Fig. 7. These may be compared with the ideal radiation patterns shown in Fig. 8. Curve 1 - 1 of Fig. 8 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 radiation pattern, but does not result in constant sensitivity in azimuth. In calculating these patterns, allowance was made for the nonlinearity of the video amplifiers of the indicator unit. Antenna radiation patterns similar to curve 1 - 1 are most desirable.

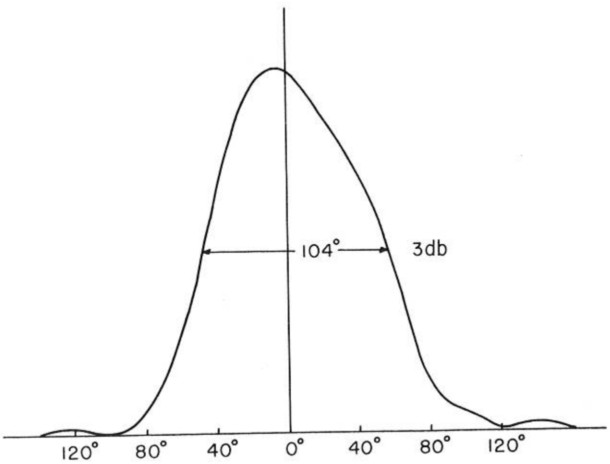
* Allied Research Products Inc., Baltimore, Md.



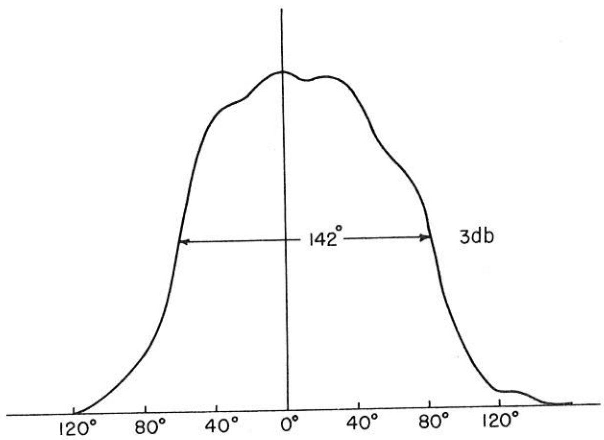
1000 Mc.



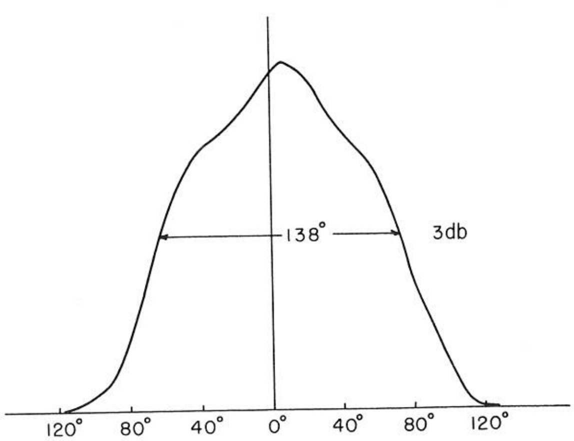
1600 Mc.



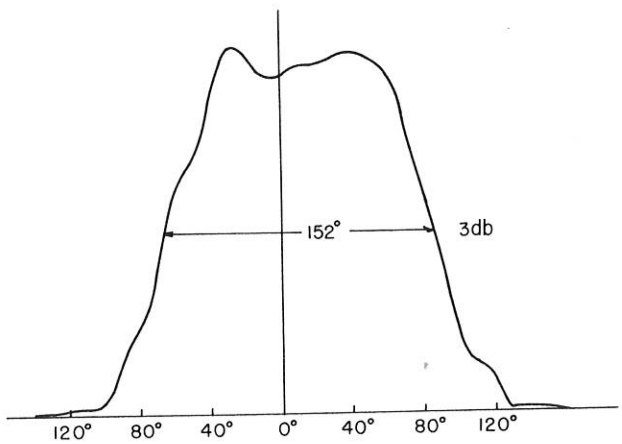
1200 Mc.



2000 Mc.



1400 Mc.



2300 Mc.

FIGURE 7
ANTENNA POWER RADIATION PATTERNS
L - BAND, VERTICAL POLARIZATION

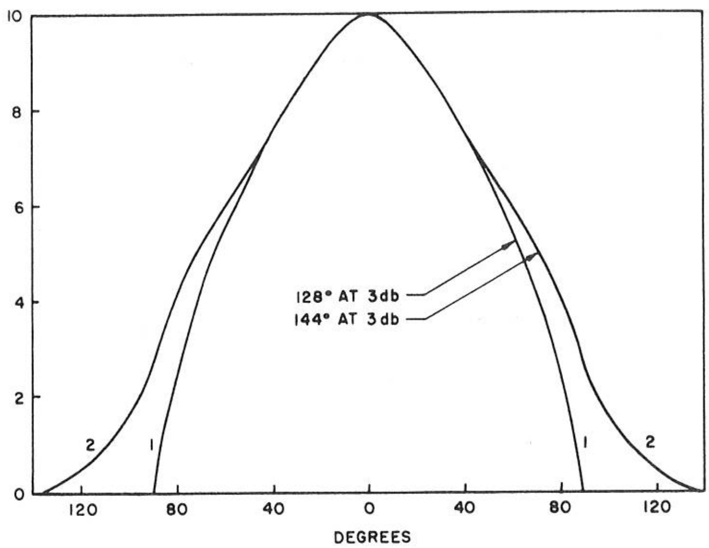


FIG. 8 IDEAL POWER RADIATION PATTERNS

The VSWR of an L-band dipole antenna is shown in Fig. 9. It is less than 3 to 1 for greater than an octave bandwidth.

The insertion loss characteristic of the low pass filter is shown in Fig. 10. This data was taken with a typical unit terminated in a matched source and load. The insertion loss characteristic, when connected in an L-band antenna assembly may be expected to be somewhat different.

Manufacturer's data on the Transco switch for crystal detector protection indicate a maximum VSWR of 1.3 throughout L-band, with typical values less than 1.2 compared with a 50-ohm line. The switch provides a minimum isolation of 40 db when in the "off" position.

The tangential signal sensitivity of a complete antenna channel is shown in Fig. 11. This performance 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.

The necessity that bearing errors be within acceptable limits is of primary importance. These limits have been taken to be a maximum error not to exceed 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. If bearing errors are to be small, properly shaped antenna radiation patterns and equal signal sensitivities in

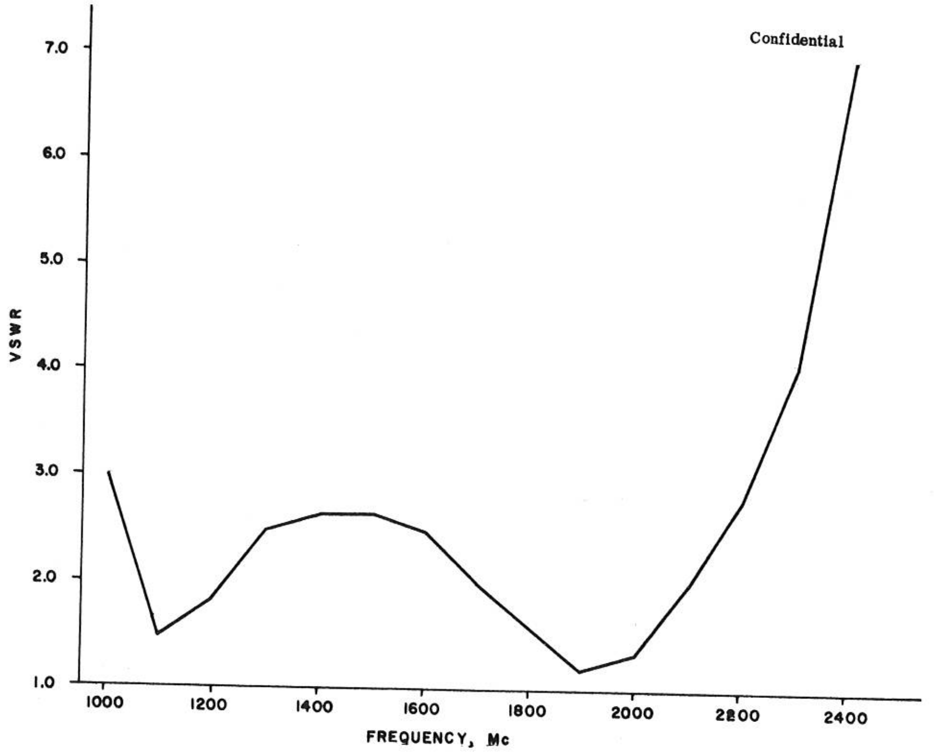


FIG. 9 VSWR OF L-BAND DIPOLE ANTENNA

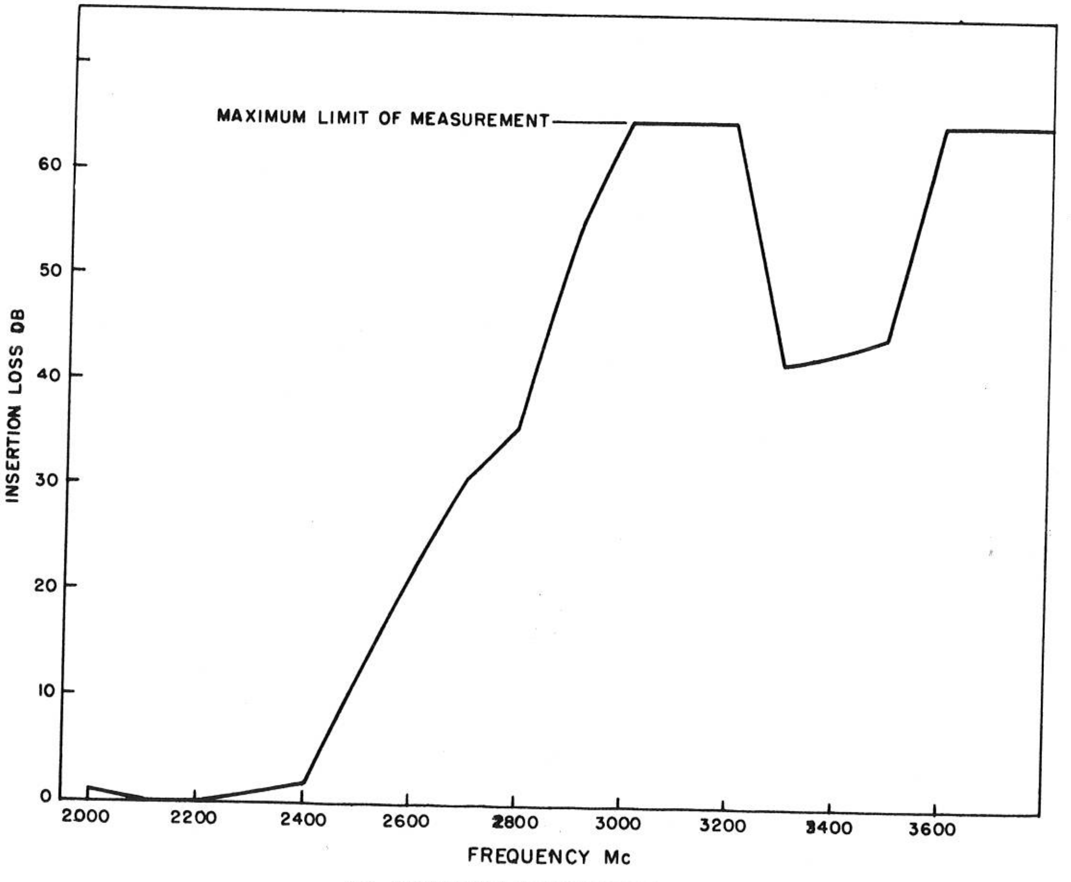


FIG. 10 INSERTION LOSS OF LOW-PASS FILTER

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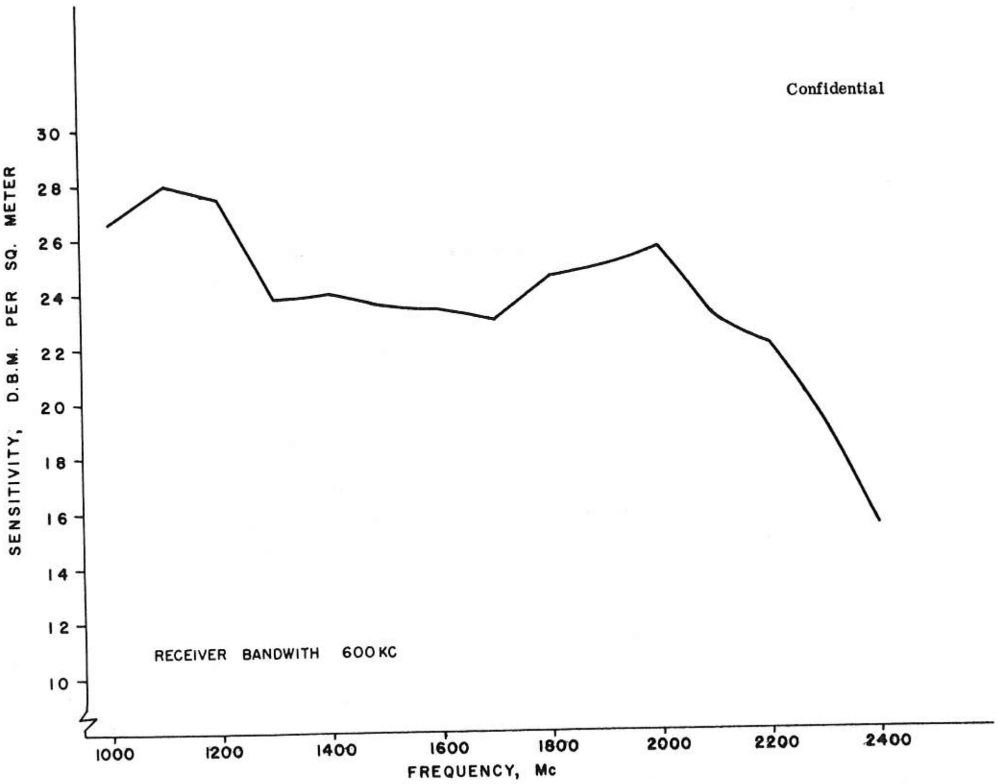

FIG. 11 TANGENTIAL SENSITIVITY OF A COMPLETE ANTENNA CHANNEL

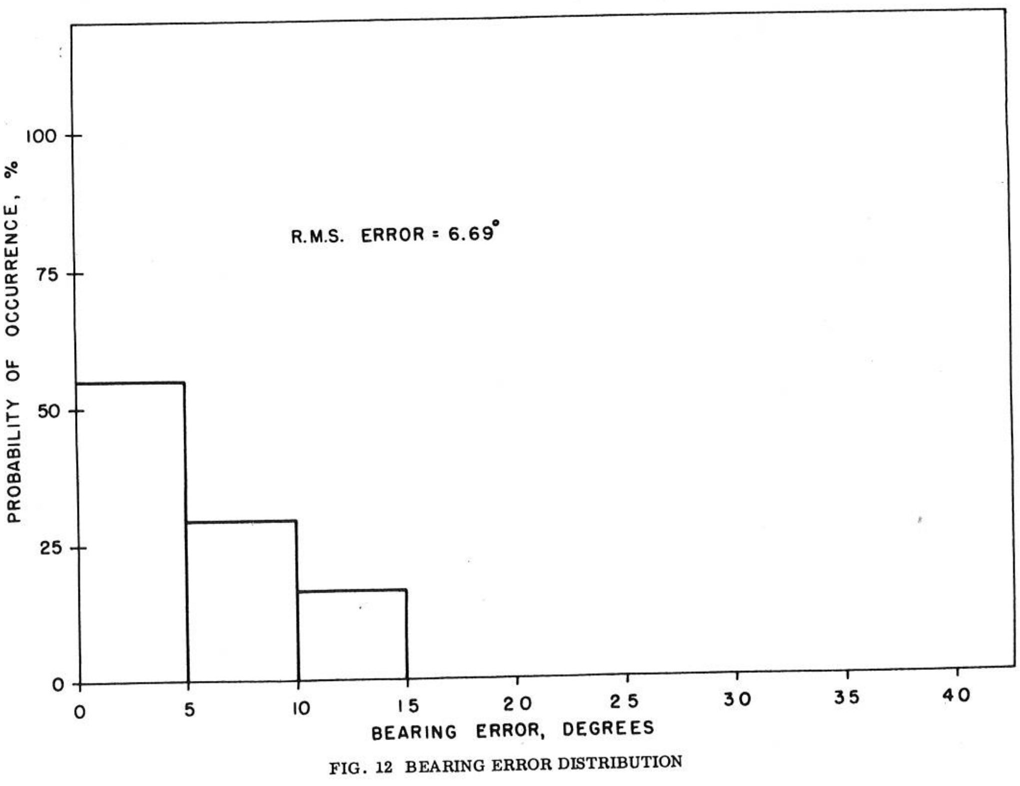

FIG. 12 BEARING ERROR DISTRIBUTION

all four channels are required. Signal sensitivities may be made equal at any one frequency by adjustment of the video amplifier gain controls. The data for the above error distribution diagram was taken with one setting of the amplifier gain controls, so that it includes error due to non-tracking (i.e., error due to non-parallel sensitivity characteristics among the channels as the frequency is altered).

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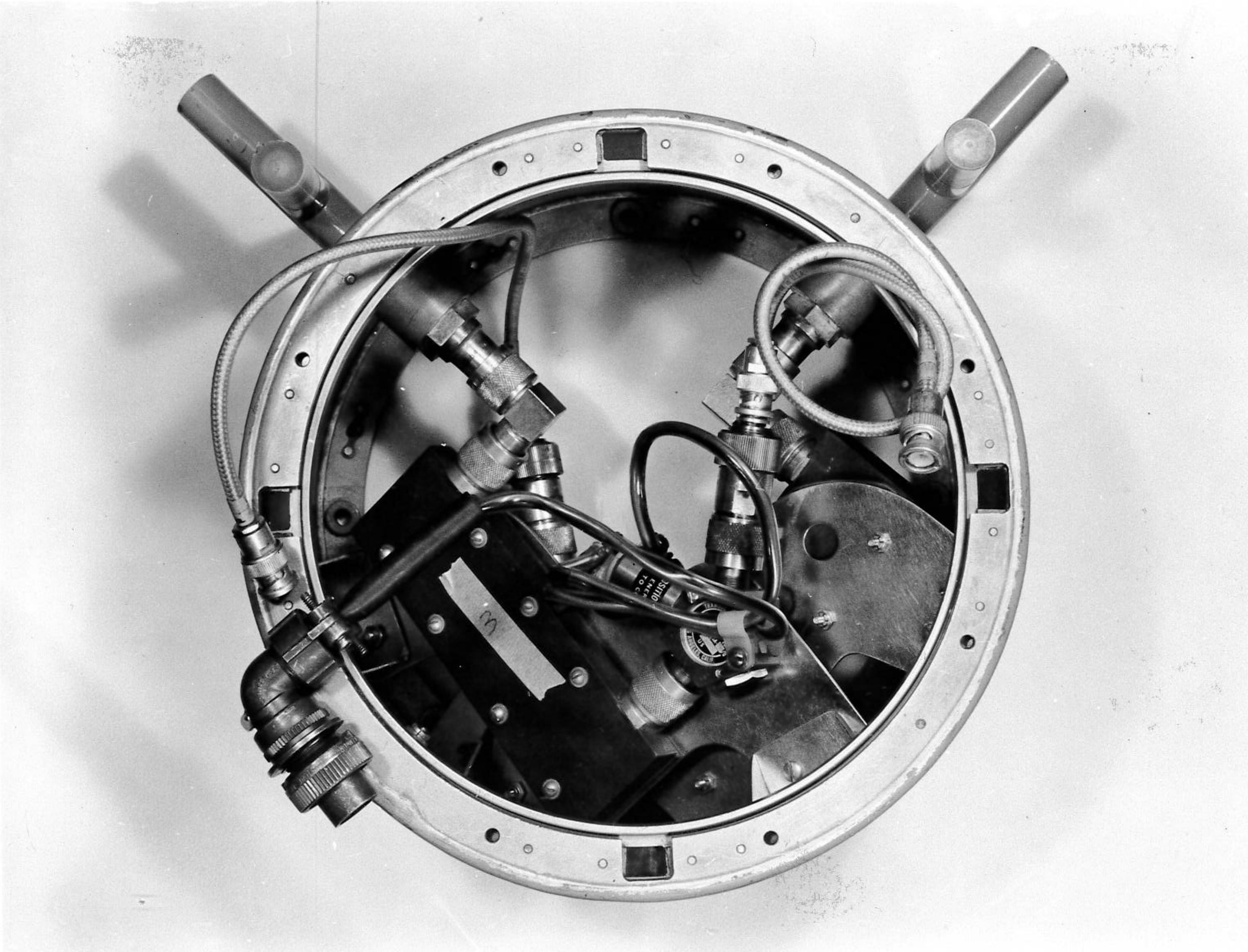

PLATE I — L-BAND ANTENNA CYLINDER, VERTICAL POLARIZATION — END VIEW

(RCN Photo)

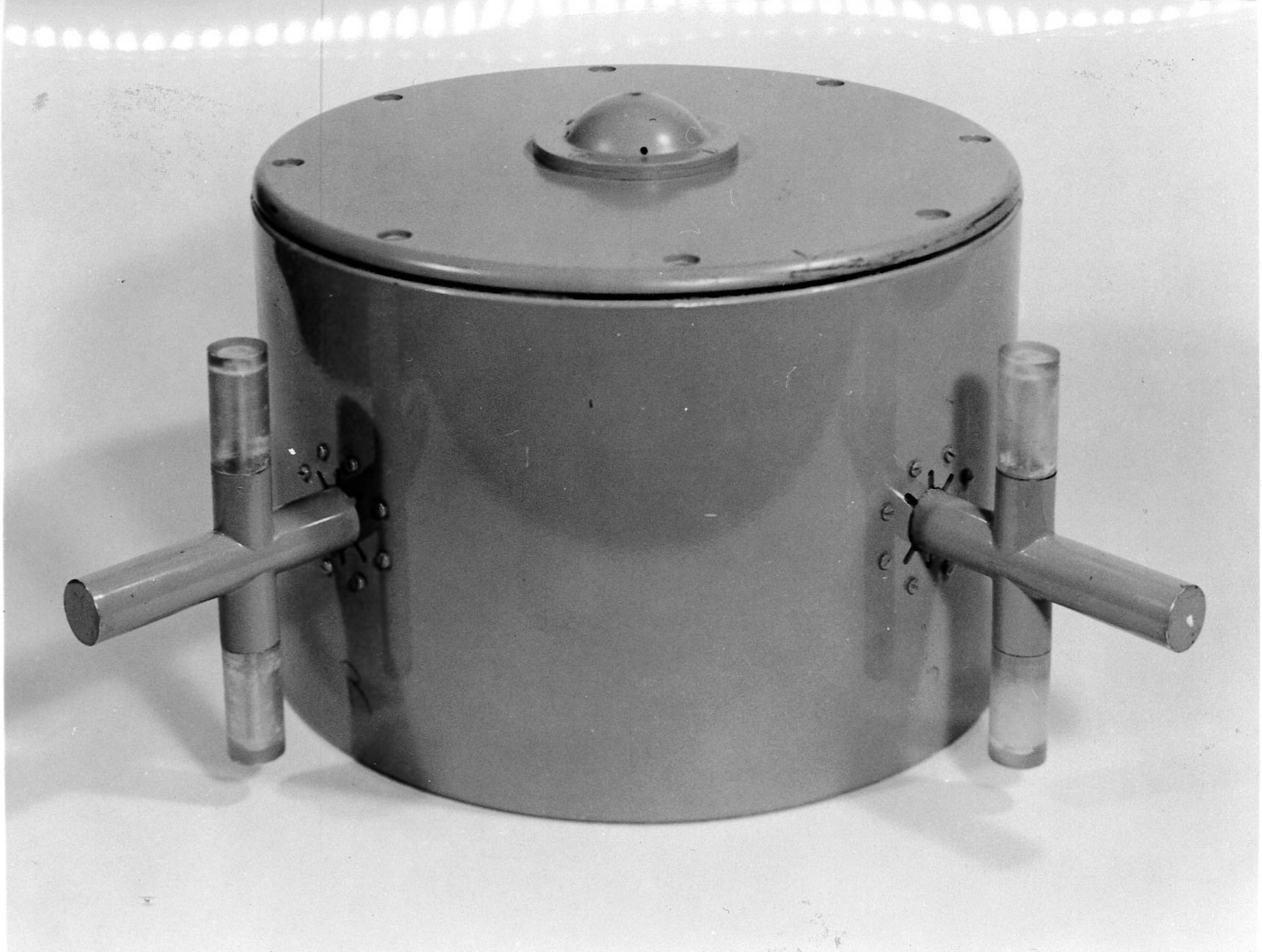

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PLATE II — L-BAND ANTENNA CYLINDER, VERTICAL POLARIZATION — SIDE VIEW

(RCN Photo)