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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273464
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB); no. ERB-437, 1957-08

ERB-437

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NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

DUAL-MODE HORNS FOR A PARABOLOIDAL REFLECTOR

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OTTAWA

AUGUST 1957

ABSTRACT

Design of a dual-mode 492-mc/s transmitting horn for use with a 28-foot paraboloidal reflector is discussed. Such factors as mouth dimensions and space attenuation are reviewed and the secondary patterns are calculated. Two variations of the horn design are presented: one is an orthogonal transmitting and receiving horn built for 944-mc/s operation with isolating fins between the probes; the other is a center-fed horn of a similar nature. Horns of the latter type are being designed for operation at 488 and 944 mc/s.

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DUAL-MODE HORNS FOR A PARABOLOIDAL REFLECTOR

- E.V. Jull -

Several types of horn feeds have been designed and built for use with large paraboloidal reflectors with $f/_D$ ratios of 0.43. These antennas have been used to obtain moon and auroral echoes at the Radio Physics Laboratory of the Defence Research Board in connection with ionospheric studies.

DUAL-MODE TRANSMITTING HORN

The dimensions of this horn are indicated in Fig. 1. Plate I is a photograph of such a horn built for operation at 492 mc/s. This horn is designed to propagate both the TE_{10} and TE_{01} modes. When mounted at the focus of a 28-foot-diameter paraboloidal reflector, the gain is 33 db, with maximum side lobes of the order of 26 db less than the main beam. The maximum voltage standing-wave ratio is 1.07. Power handling capacity is at least 12 kilowatts, fed through $3\frac{1}{8}$-inch 50-ohm coaxial air-dielectric line.

Horn Mouth Dimensions

The chief difficulty in obtaining a symmetrical beam from a horn-fed paraboloidal reflector is caused by the difference in the E- and H-plane radiation patterns of the feed horn. The field distribution across the mouth of a horn propagating the TE_{10} mode is uniform in the E-plane and cosine-distributed in the H-plane, with the electric field zero at the horn edges in the latter case.

For single-mode horns this problem can usually be overcome with the use of beam-shaping devices in the horn mouth. However, in designing a dual-mode horn such arrangements are difficult to use without disturbing the required symmetry. Hence it is necessary to compromise on the amount of flooding of the edges of the paraboloid in order that unnecessary spillover and large side lobes do not occur in one plane and the gain be needlessly reduced in the other plane.

According to Silver [1], maximum gain will be obtained from a paraboloid with an angular aperture of 120° when it is flooded by a cosine-cubed distribution from the primary horn. Also, for this type of flooding the field strength at the edge of the paraboloid should be down 8.4 db (voltage ratio = 0.380) from the main beam for maximum gain.

The aperture distribution function in the E-plane is

$$F_E(\psi) = \frac{\sin\beta}{\beta} . \qquad (1)$$

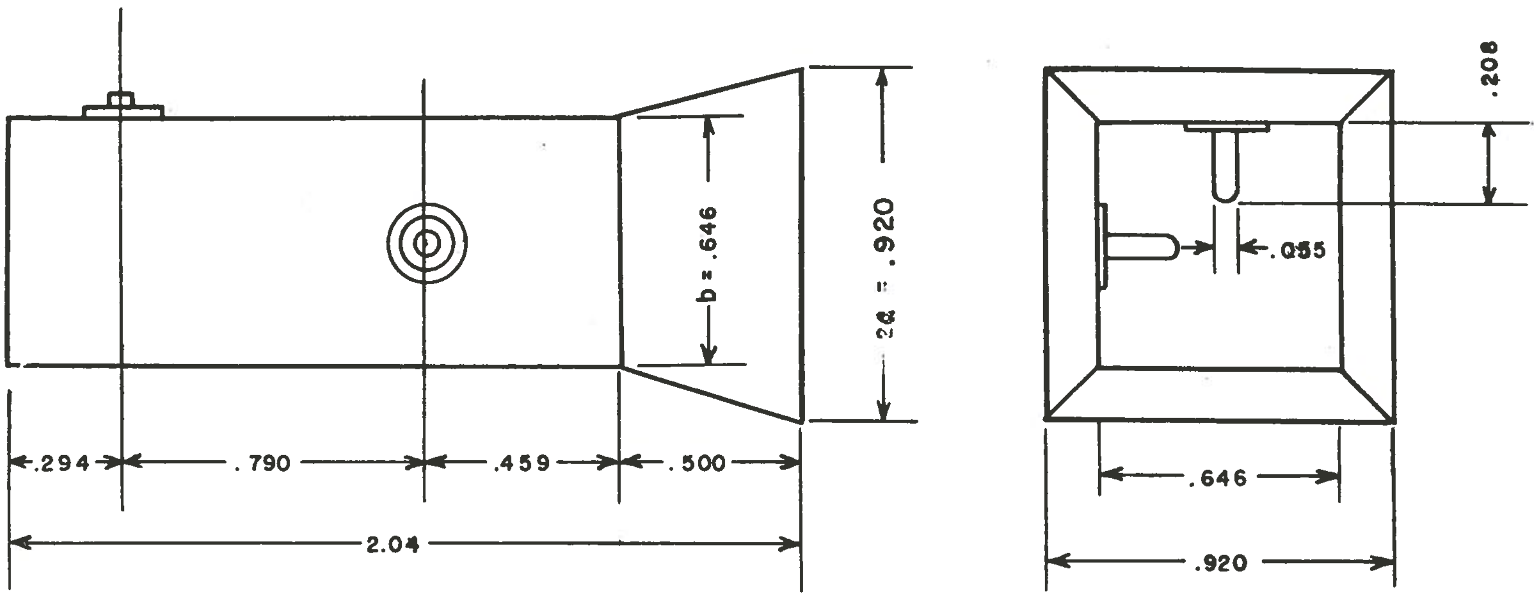

FIG. 1. DUAL-MODE TRANSMITTING HORN (Dimensions in Wavelengths)

The aperture distribution function in the H-plane is given by the expression

$$F_H(\psi) = \frac{2}{\pi} \cdot \frac{\cos\beta}{1-(2\beta/\pi)^2} \, . \qquad (2)$$

Here $\beta = \frac{2\pi a}{\lambda} \sin\psi$, (1a)

λ = wavelength,

ψ = angle off the axis of the paraboloid,

2a = horn mouth dimension.

From a curve of $\frac{\sin\beta}{\beta}$ the value of β for which the field strength is 38% of that of the main beam (down to 8.4 db) is 0.69π. This gives a horn mouth dimension of $2a = 0.8\lambda$ for $\psi = 60°$, the half-angle subtended by the reflector (Eq. 1a). A plot of $F_H(\psi)$, however, shows that this horn dimension results in a drop of only 4.4 db in the H-plane, with resultant excessive spillover. A compromise may be reached by allowing a 6-db drop at the aperture edge in the H-plane. In this case $\beta = 0.8\pi$ and the horn mouth dimension is 0.920λ. From this the primary feed patterns can readily be obtained using Equations (1) and (2).

Space Attenuation

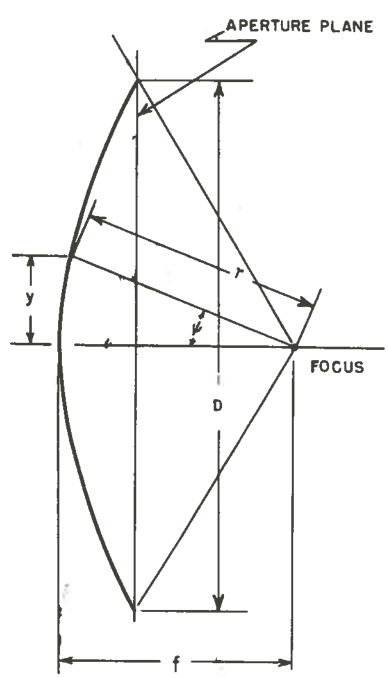

FIG. 2. GEOMETRICAL PARAMETERS OF PARABOLOIDAL REFLECTOR

The field intensity from the horn feed varies inversely as the distance from the feed. It can readily be shown that the space attenuation factor in the aperture plane $F_1(y)$ is given by the relation

$$F_1(y) = \frac{1}{1 + (y/2f)^2}, \tag{3}$$

where f = the focal length of the paraboloid,

and y = distance from the axis of the paraboloid in the aperture plane (see Fig. 2).

Using a normalized coordinate $y_N = y/\frac{D}{2}$, we have:

$$F_1(y_N) = \frac{1}{1 + \left(\frac{y_N}{4f/D}\right)^2}; \tag{4}$$

also $y = r \sin\psi = (f + y^2/4f)\sin\psi$.

$$\psi = \sin^{-1}\frac{y}{f + \frac{y^2}{4f}} = \sin^{-1}\frac{1}{\frac{2(f/D)}{y_N} + \frac{y_N}{8(f/D)}}. \tag{5}$$

Secondary Pattern

Using Equations (5), (1), and (2), the amplitude of the primary field in each plane as a function of y_N can be determined, and the amplitudes in the aperture plane can be determined for various values of y_N by multiplying by $F_1(y_N)$, the space attenuation factor.

These curves closely approximate the equation

$$f(y_N) = \left(1 - \frac{k}{2}\right) + \frac{k}{2}\cos \pi y_N, \tag{6}$$

where k = 0.63 for the H-plane curve,

and k = 0.82 for the E-plane curve.

The secondary patterns can be readily obtained from the expression

$$A(\theta) = \frac{1}{1 - k/2} \cdot \frac{\sin\beta}{\beta}\left[1 - \frac{k}{2} + \frac{k}{2} \cdot \frac{(\beta/\pi)^2}{1 - (\beta/\pi)^2}\right], \tag{7}$$

where $\beta = 2\pi a \sin \theta$,

and θ = angle off the axis.

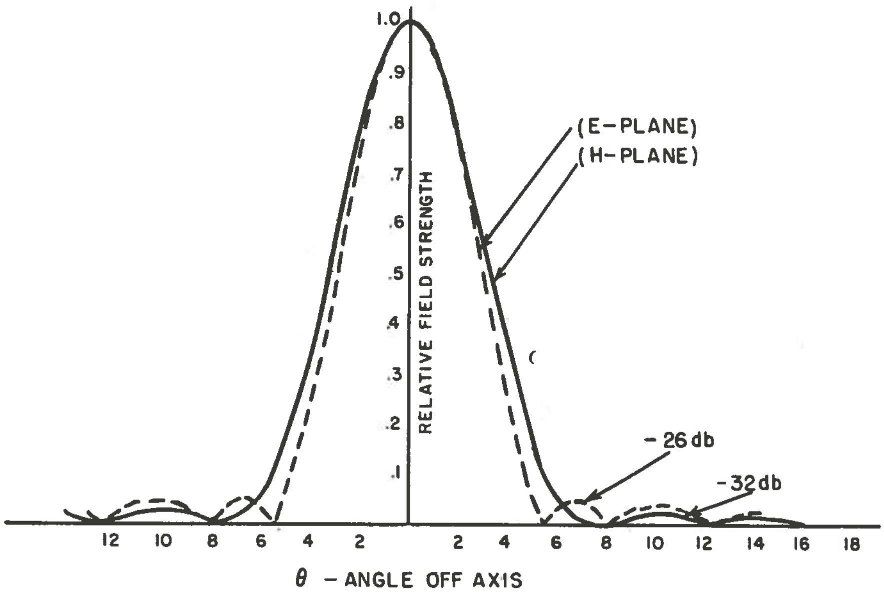

FIG. 3. SECONDARY FIELD STRENGTH PATTERNS OF DUAL-MODE HORN WITH 28-FOOT PARABOLOIDAL REFLECTOR

Fig. 3 shows tha calculated secondary field strength patterns for this horn and paraboloid configuration. Half-power beamwidths are about $4\frac{1}{2}°$ in each plane, indicating a gain of about 33 db.

Flare Angle

The maximum flare angle for a phase difference of less than 45° across the horn mouth is 38°. For convenience an angle of about 16° was chosen.

Waveguide Dimensions

The shape of the waveguide section of the horn is necessarily square, in order that patterns for both modes be identical. In order that the waveguide be above cutoff for the TE_{10} mode ($b > 0.5\lambda$) and below cutoff for the TE_{11} mode ($b < 0.7\lambda$), the guide dimension b was made 0.65λ.

Impedance

The horn was matched experimentally by adjusting the lengths of the feed probes and the position of the rear shorting plate. The two probes were placed half a guide wavelength apart in order that the electrical distance to the rear shorting plate be the same for both. An input voltage standing-wave ratio of less than 1.07 was obtained at 492 mc/s for both probes.

DUAL-MODE TRANSMITTING-RECEIVING HORN

Fig. 4 shows the dimensions of the horn in wavelengths. Plate II is a photograph of such a horn designed for operation at a frequency of 944 mc/s. Since the horn was to be used with the same type of reflector as previously described, the relative guide and aperture dimensions are approximately the same.

This horn has two orthogonal probes. It is capable of transmitting linearly polarized waves in one plane and receiving radiation polarized both in this plane and perpendicular to it. Considerable isolation between the transmitting and receiving probes is ensured by three fins parallel to the transmitting probe, which divide the waveguide into four sections below cutoff.

Impedance

A standing-wave ratio on the transmitting and receiving probes of 1.07 and 1.05, respectively, was obtained experimentally on a 50-ohm line and measured by means of the slotted line technique.

Isolation

The attenuation L, beyond cutoff in a length d of waveguide, is given by the expression

$$L = 54.5 \frac{d}{\lambda_c} \left[1 - \left(\frac{\lambda_c}{\lambda} \right)^2 \right]^{\frac{1}{2}} \text{db.}$$

The theoretical attenuation for the isolation section in this horn should thus be about 76 db. The isolation measured was 61.7 db, the discrepancy being due to imperfect symmetry in the horn and possible leakage errors in the measuring technique. Because of this leakage the actual isolation may be greater than the measured value.

CENTER-FED HORN

A drawing of this type of horn currently under design is shown in Fig. 5. Two such horns will be built, one designed for 944-mc/s operation and one for 488-mc/s operation. They are similar to the second type of horn feed described in this report. However, they will be fed by a rigid coaxial transmission line on the axis of a lightweight 60-foot paraboloidal reflector. The feed antenna will be a slotted-dipole, while the receiving antenna will consist of two identical probes receiving in phase quadrature on opposite sides of the waveguide. The output cable of the

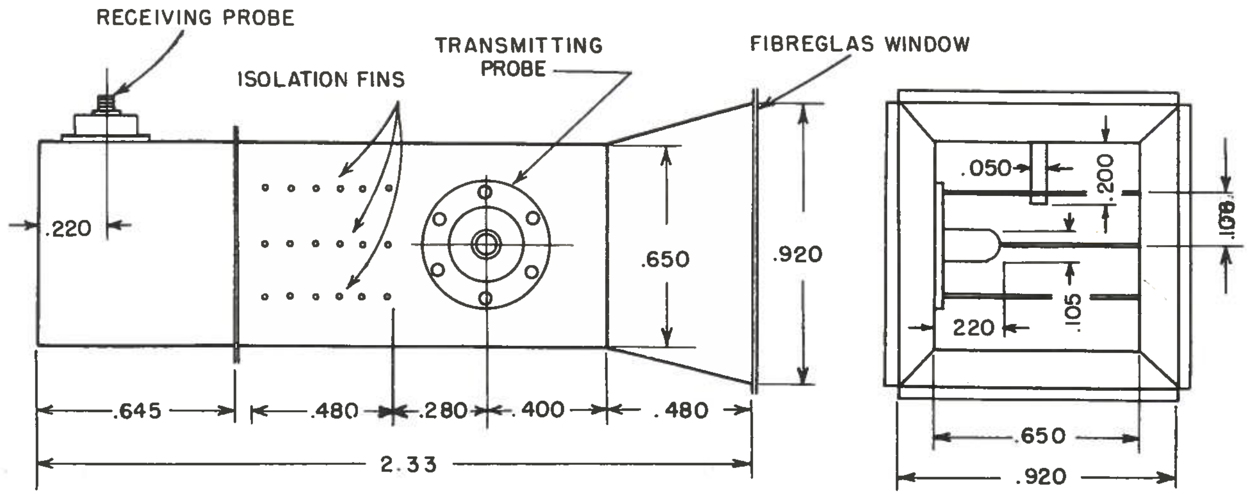

FIG. 4. DUAL-MODE TRANSMITTING-RECEIVING HORN (Dimensions in Wavelengths)

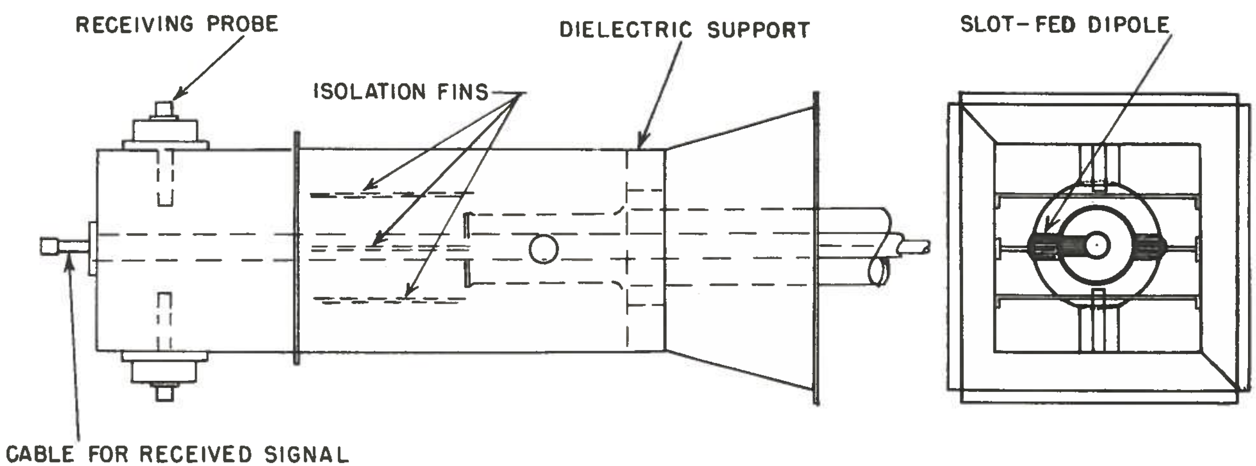

FIG. 5. CENTER-FED DUAL-MODE TRANSMITTING-RECEIVING HORN

preamplifier will run down inside the center conductor of the feeding transmission line and will emerge at a quarter-wave junction. Isolation of a similar order to that of the second type of horn described is expected.

ACKNOWLEDGMENT

The author is greatly indebted to Mr. W.A. Cumming for assistance in the design of the antennas.

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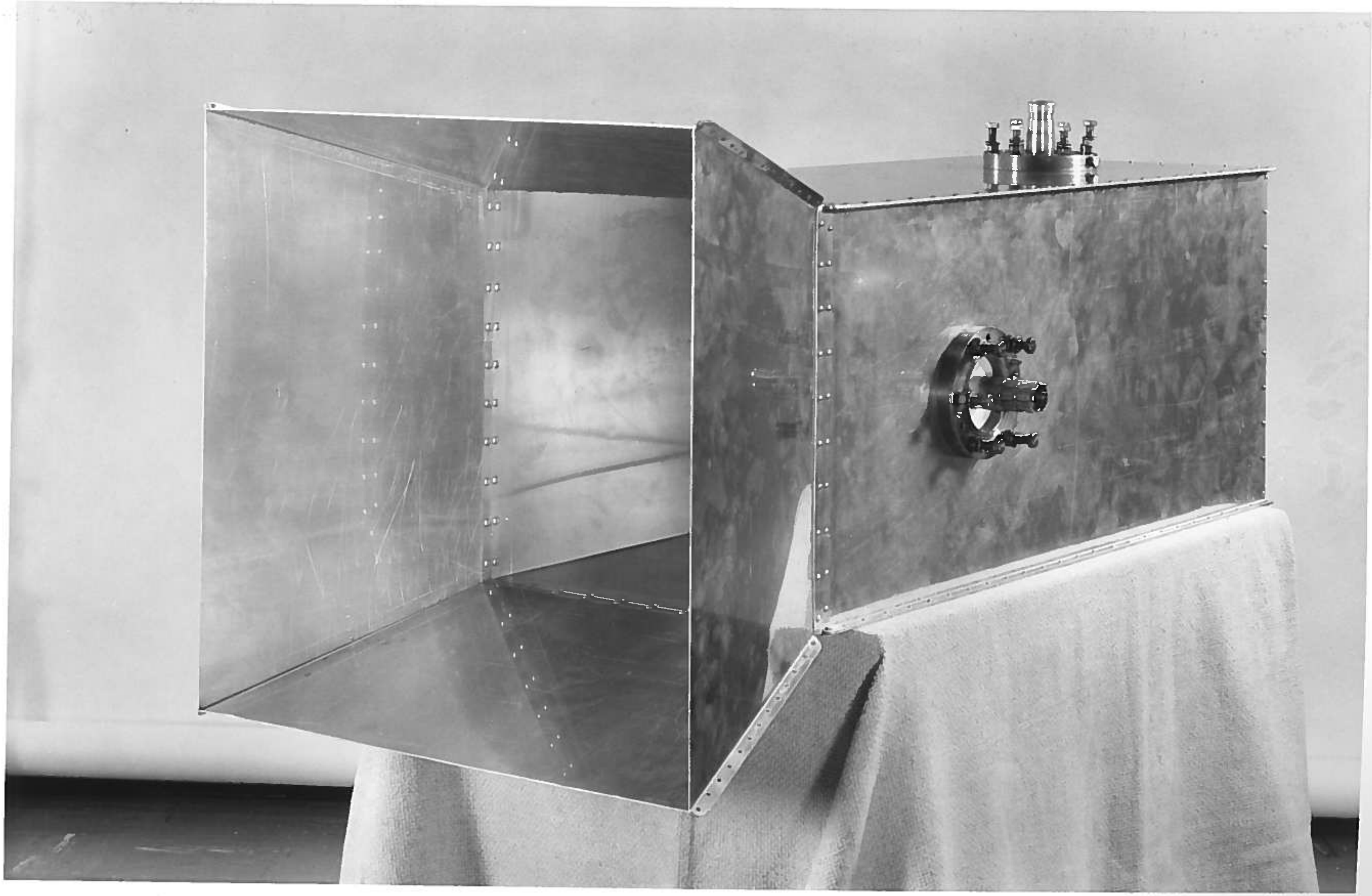

PLATE I 492-mc/s DUAL-MODE TRANSMITTING HORN

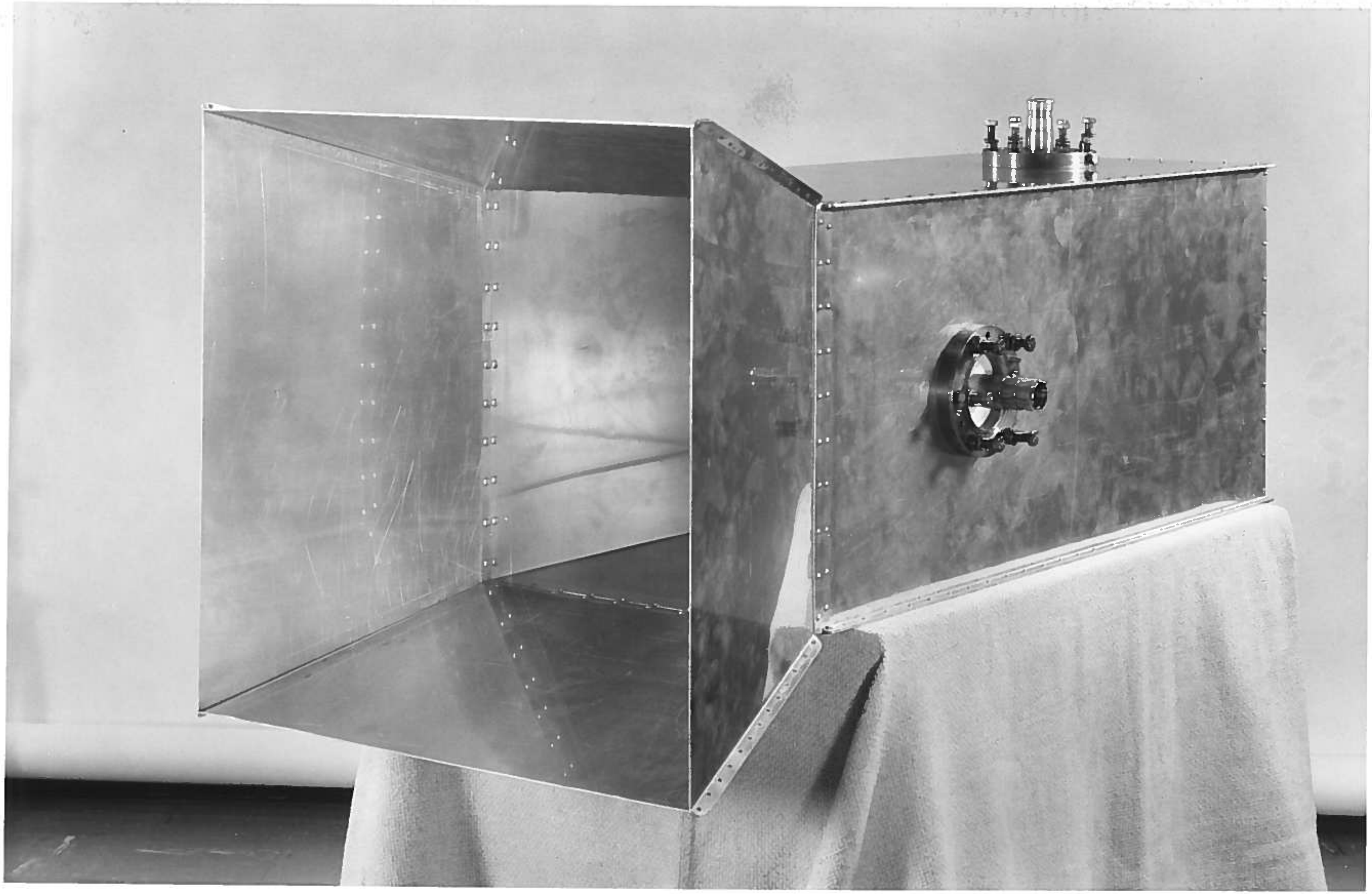

PLATE I 492-mc/s DUAL-MODE TRANSMITTING HORN

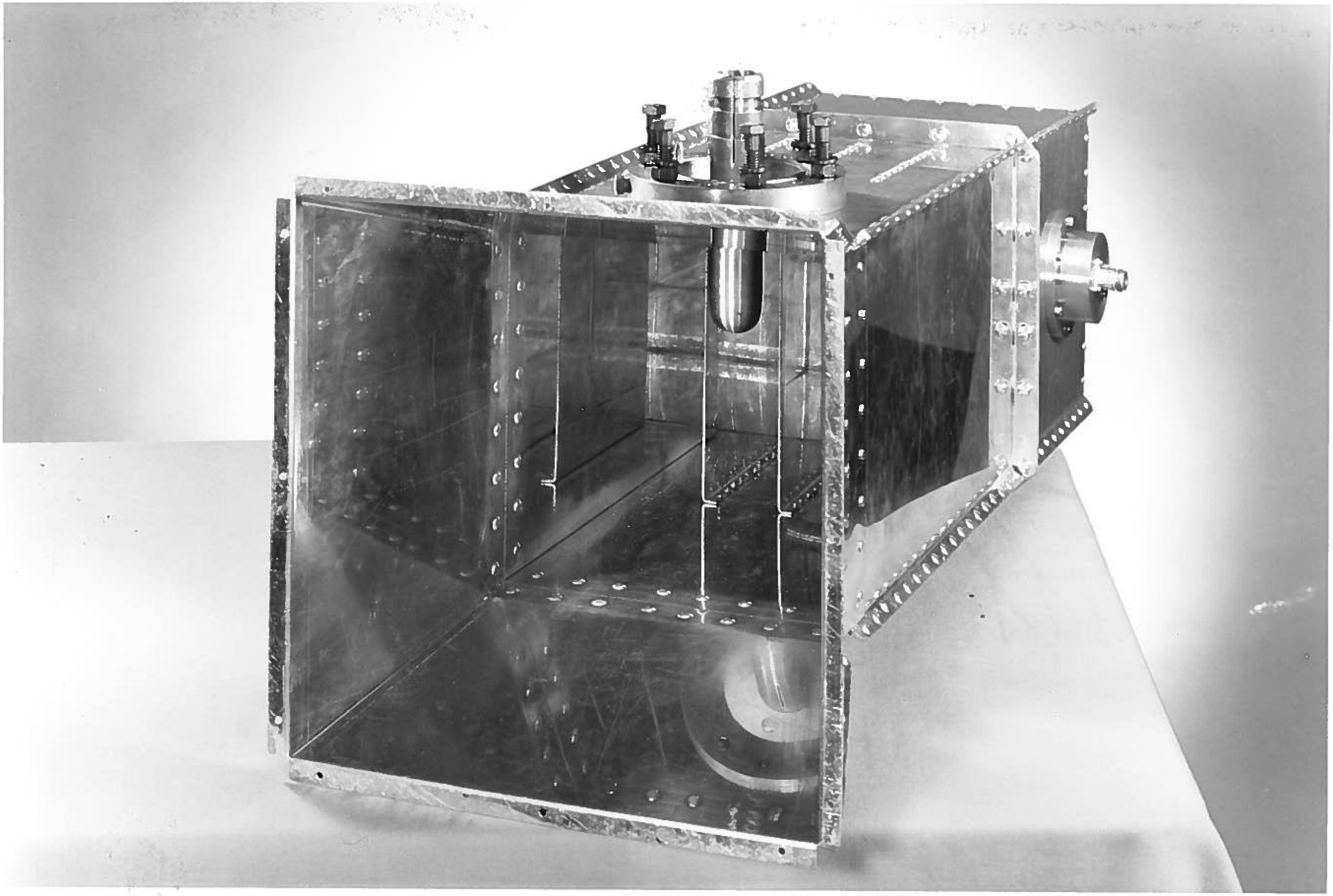

PLATE II 944-mc/s DUAL-MODE TRANSMITTING-RECEIVING HORN