BROAD-BANDING CIRCULAR POLARIZING TRANSDUCERS*

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A problem frequently encountered in microwave and antenna work is that of obtaining elliptically polarized waves of low axial ratio over extremely broad frequency bands. In an effort to reach a more satisfactory solution to this problem than is possible with present techniques, a theoretical study was conducted on several elliptically polarizing transducer configurations in circular waveguide (Fig. 1). The results of this study indicated that the bandwidth obtainable with dielectric slab type transducers could be broadened considerably by using shielded dielectric rod type transducers.

The first configuration investigated was an approximation of an elliptical waveguide oriented at 45 degrees to the incident TE_{11} mode or a circular waveguide with a thin dielectric slab at 45 degrees to the incident mode (Fig. 1a). The assumption was made, in analyzing this and all of the other configurations, that the orthogonal components of the incident wave both pass through circular sections of guide of sufficiently different diameters to give approximately a 90 degree phase difference at the center frequency. In the elliptical guide the phase shift difference between the two modes can be approximated by the expression:

$$\phi_d = \frac{2\pi L}{\lambda}\left[\sqrt{1 - (\lambda/\lambda_{c1})^2} - \sqrt{1 - (\lambda/\lambda_{c2})^2}\right] \qquad (1)$$

where ϕ_d = phase difference between modes

L = length of the transducer

λ = free space wavelength

λ_{c1} and λ_{c2} = cutoff wavelengths for the two orthogonal modes.

The axial ratio, since the magnitude of the two modes remain equal, is given by

$$\text{A.R.} = \tan\frac{\phi_d}{2} \qquad (\text{for } \phi_d \ \frac{\pi}{2})$$

$$\text{A.R.} = \cot\frac{\phi_d}{2} \qquad (\text{for } \phi_d \ \frac{\pi}{2}) \qquad (2)$$

It was then established that broader bandwidth (lower rate of change of relative phase as a function of λ) could be obtained with longer and larger transducing sections. However, even as the dimensions approach infinity the asymptotic rate

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of change remains undesirably high. In the limit the expression for this rate of change at the center frequency is

$$\lim_{\substack{L \to \infty \\ b \to \infty}} \left. \frac{d\phi_d}{d\lambda} \right|_{\lambda_o} = \frac{\pi}{2\lambda_o} \tag{3}$$

where b = radius of guide transducer.

Approximately the same rate of change was calculated below for the finite elliptical waveguide transducer. This fact demonstrates how soon diminishing returns are reached in attempting to increase bandwidth by increasing physical dimensions.

The axial ratio of an elliptical waveguide transducer of about 2-1/2 inches mean diameter and 8 inches in length was computed as a function of frequency over the range from 5,000 to 10,000 megacycles as a standard for comparison with other transducers. The computed data is plotted in Fig. 2 as the solid line curve. In Fig. 3 experimental data is compared with the theoretical curve for a thin dielectric slab transducer. The axial ratios at the lower frequencies are seen to be much less than those calculated by the approximate method used. Better agreement would be obtained with a true elliptical guide transducer. In spite of this disparity with experimental results, the calculated curves were employed for comparison with results calculated for other configurations when using the same simplifying assumptions.

A tapered elliptical or dielectric slab-equipped waveguide was next investigated to determine the advantages or disadvantages of a tapering cross-section (Fig. 1b). For this configuration the difference in phase shift can be expressed in terms of the integrals of the expressions appearing in Eq. (1) as in the following equation:

$$\phi_d = \frac{2\pi}{\lambda} \left[\int_o^L \sqrt{1 - (\lambda/\lambda_{c1})^2} \, dL - \int_o^L \sqrt{1 - (\lambda/\lambda_{c2})^2} \, dL \right] \tag{4}$$

and the axial ratio again obtained from Eq. (2). The axial ratio for a tapered elliptical waveguide transducer tapering from about 1-3/4 inches to 2-1/4 inches in mean diameter is plotted as a function of frequency in the dashed line curve in Fig. 2. The calculated bandwidth using the tapered waveguide transducer is seen to differ negligibly from that of the uniform transducer.

Previous experience with dimension insensitivity of dielectric rod transducers in tapered circular waveguide suggested the investigation of the double-tapered dielectric rod and circular waveguide (Fig. 1c). No simple expression is available for a waveguide with a cross-section of shielded dielectric rod, but the problem has been solved, and curves of guide wavelength vs. diameter are available in a Northwestern University Report[1]. These curves are shown in Fig. 4 as they appear in the above mentioned publication. The double-tapered guide was then approximated by ten sections of uniform guide, the phase shifts of which were taken from the curve of Fig. 4 and added to give the phase shifts of the two orthogonal modes and hence the axial ratios. A plot of the axial ratio then computed is given in Fig. 5 as the dashed-line curve. Although these calculations indicated some broadening of the bandwidth when low axial ratios were the criterion, the results, it was felt, did not warrant a verifying experimental study.

From the curves plotted for calculating the phase shift in the double-tapered shielded dielectric rod waveguide transducer, it appeared that a simple uniform shielded dielectric rod of the proper dimensions would exhibit broader band properties. The data from the curves of Fig. 4 was used to compute the phase shifts through 8 inch lengths of shielded dielectric rod guide which are plotted in Fig. 6. From this data the axial ratios of a uniform shielded dielectric rod transducer with a mean rod diameter of half the shield diameter were determined and plotted as a function of frequency in Fig. 4 as the solid line curve. This curve shows a very pronounced improvement in broadening the bandwidth. Following these preliminary tests the ratio "c" of rod to shield diameter was optimized by plotting the variation in phase difference between consecutive values of "c" between $b/\lambda = .3$ and $b/\lambda = .8$ from the data in Fig. 6. This plot appears in Fig. 7. The minimum change in phase difference between the modes propagating through the guide with $c = .1n$ and $c = .1(n + 1)$ occurs at $c = .65$. Since the maximum deviation in phase is 17 percent or ±8.5 percent for this value of c, a corresponding transducer should give less than a 1.15:1 axial ratio over a 2.65:1 frequency band.

Consequently, a rod with a diameter of 1.06 inches (65 percent of the diameter of the shield) and about 6 inches in length, exclusive of tapers, was constructed, and flats were cut on opposite sides to give an axial ratio of about 1.25:1 at the center frequency. A plot of the experimental data over the frequency range is given along with the theoretical curve in Fig. 8. An extremely broadband characteristic is shown, the axial ratio remaining below 1.30:1 in the entire range between 5,000 and 10,000 megacycles and an axial ratio below 1.50:1 over a 2.3:1 band. The transducing rod was then shortened slightly to give a lower axial ratio at the center frequency. The data measured on this transducer is plotted in Fig. 9. The axial ratio for this run remains below 1.20:1 over the range from 5,000 to 10,000 megacycles and is below 1.10:1 over most of this range. A longer rod with shallower flats would more closely approximate the theoretical case and should have a correspondingly broader band approaching that indicated by the theoretical analysis.

A photograph of the experimental model of the shielded dielectric rod transducer and radiating horn used to make the experimental tests is shown in Fig. 10.

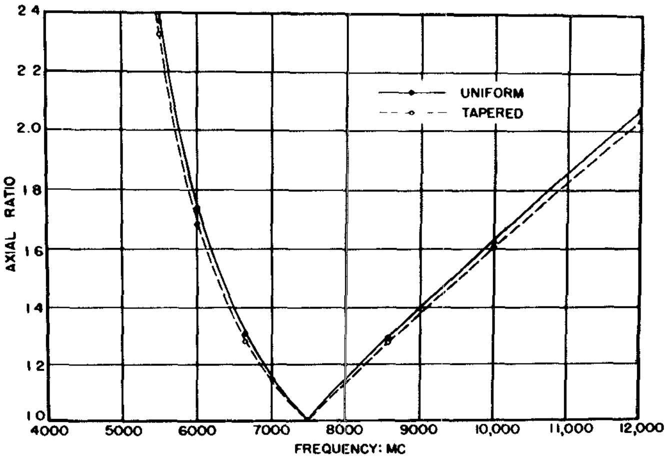
Helical antennas, commonly used for providing directional circularly polarized radiation, will give axial ratios of less than 1.50:1 over a 2:1 frequency range[2], but have unsatisfactory radiation patterns at extremes of the band. Acceptable radiation patterns are obtained over only a 1.7:1 frequency range. The shielded dielectric rod, however, when radiating as an open-ended waveguide or as a circular horn, provides excellent radiation patterns over very wide bands. Radiation patterns for both the helical[3] and shielded dielectric rod antennas are shown in Fig. 11 for the center frequency and the two extremes in a 2:1 frequency band.

In conclusion, the results of this study show that shielded dielectric rod transducers transform circular waveguide TE_{11} mode waves into elliptically polarized waves with low axial ratios over an extremely wide band while also providing satisfactory directional radiation patterns over the entire frequency range.

References

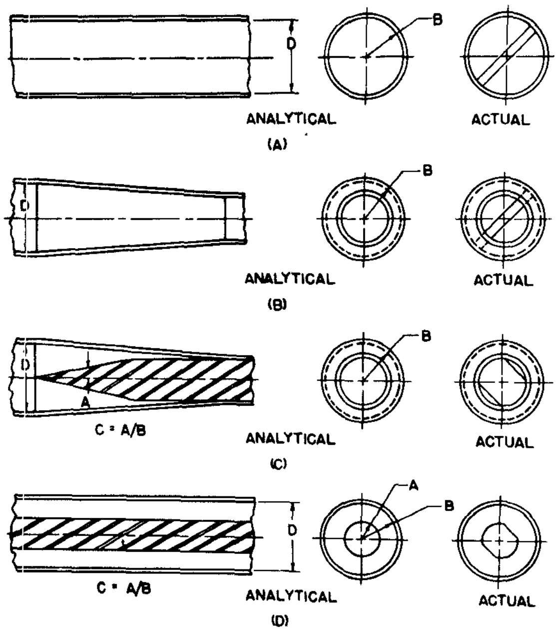
1. Wachowski and Beam, Shielded Dielectric Rod Waveguides, Final Report, Microwave Laboratory, Northwestern University, Evanston, Illinois, 1950, U.S. Army Signal Corps Contract No. W36-039sc-3824, p. 304.

2 and 3. Kraus, Antennas, McGraw-Hill Book Company, New York, 1950, Chap. 7.



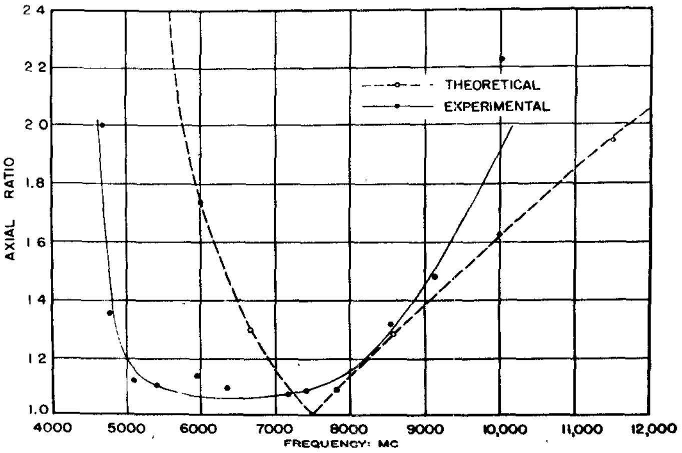
THEORETICAL AXIAL RATIO VERSUS FREQUENCY FOR UNIFORM AND TAPERED ELLIPTICAL GUIDE TRANSDUCERS

Fig. 2



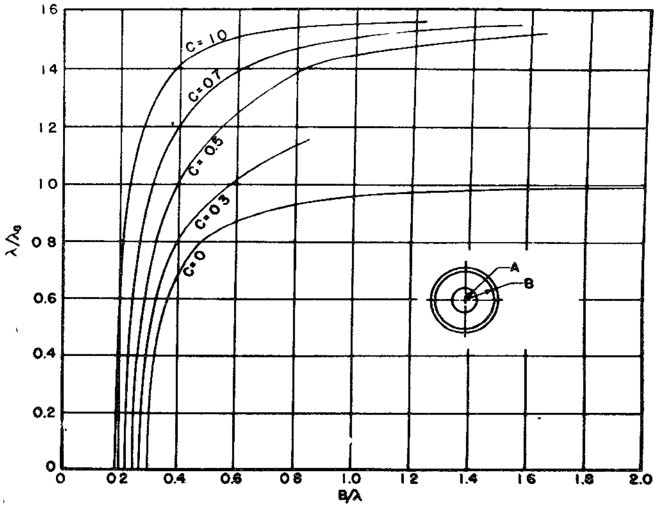
EXPERIMENTAL TRANSDUCER CONFIGURATIONS

Fig. 1



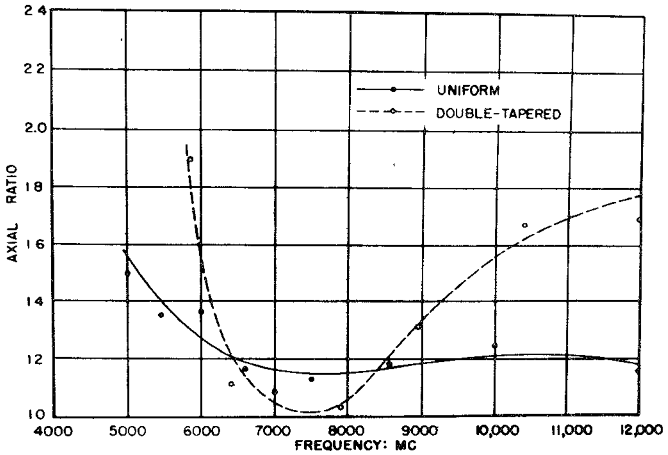
THEORETICAL AND EXPERIMENTAL AXIAL RATIO VERSUS FREQUENCY FOR A DIELECTRIC SLAB TRANSDUCER

Fig. 3



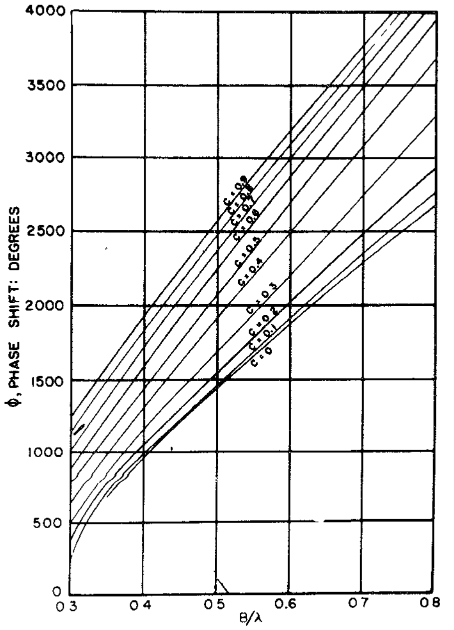
CHARACTERISTIC CURVES FOR HE_{11} MODE

Fig. 4



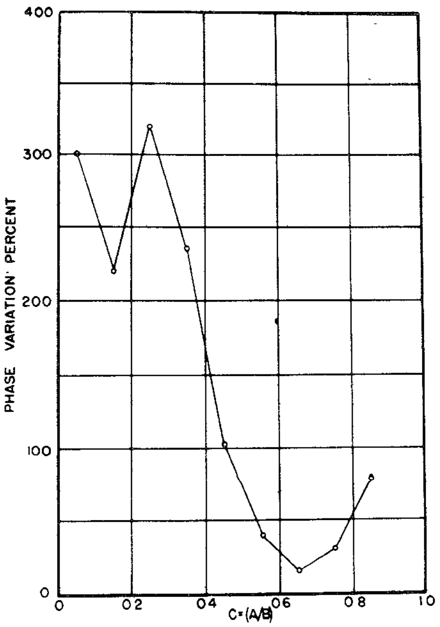
THEORETICAL AXIAL RATIO VERSUS FREQUENCY
FOR
SHIELDED DIELECTRIC ROD TRANSDUCERS

Fig. 5



CALCULATED PHASE SHIFT VERSUS B/λ
FOR
EIGHT-INCH LENGTH SHIELDED POLYROD GUIDES

Fig. 6



CALCULATED PERCENT PHASE VARIATION BETWEEN
EIGHT-INCH LENGTH GUIDES OF C=0.1N C=0.1(N+1)
FROM B/λ = 0.3 TO B/λ = 0.8 VERSUS C

Fig. 7

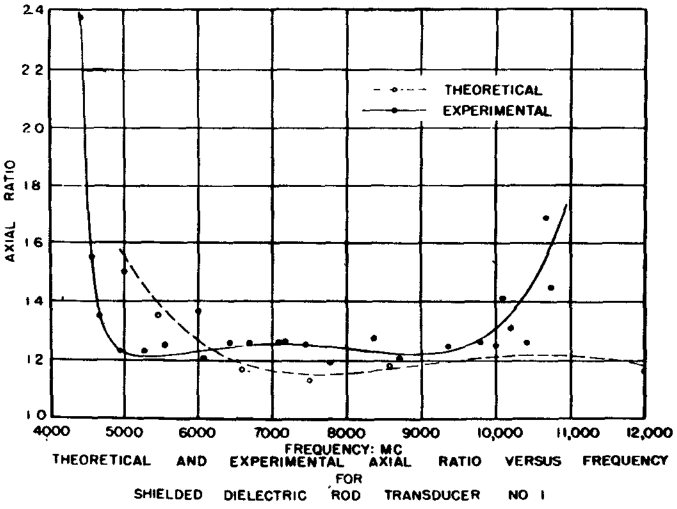


Fig. 8

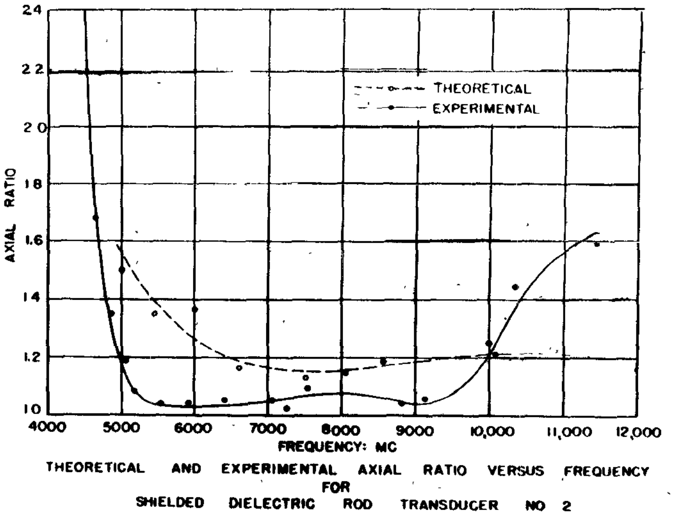


Fig. 9

Fig. 10 - Test antenna and transducer rod.

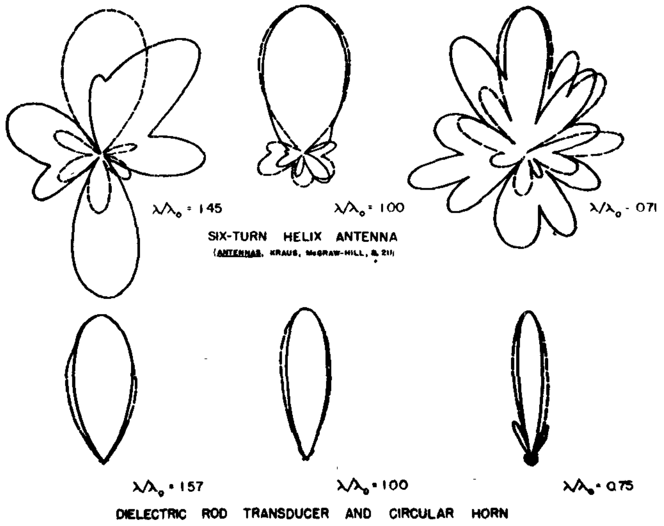


Fig. 11 - Radiation patterns of helix and transducer-horn antennas.