# A Broad-Band Dual-Mode Circular Waveguide Transducer

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*Summary*—This paper describes a broad-band dual-mode waveguide transducer designed to couple two orthogonal $TE_{11}$ circular waveguide modes in separate rectangular waveguide ports. A compact, rugged, and economical junction has been developed to operate from 8600 mc to 9600 mc with a vswr of less than 1.15 at the rectangular port and a mode isolation of 50 db or greater.

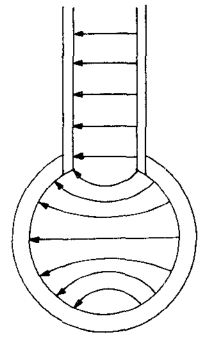
Developmental models are described to indicate the evolution from theory to the final model. Some problems encountered in attaining a small physical size are discussed in detail. The new junction has application to mode multiflexing, circular waveguide ferrite devices, circular polarization, and as a circular waveguide magic-T.

THE TRANSMISSION of more than one signal in a waveguide using a common frequency is possible by utilizing the various electromagnetic symmetries or "modes" as separate information channels. One of the practical problems associated with multiplexing of this type is to extract or excite energy in one mode independent of the other propagating modes.

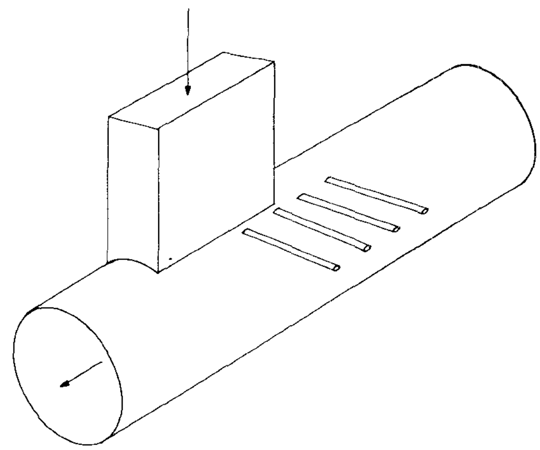
This has been done for single frequency operation by Ragan[1] and Kingdon[2] by taking advantage of the fact that two dominant $TE_{11}$ modes will propagate independently if orthogonally oriented within a circular waveguide. This paper describes the development of a broad-band dual-mode waveguide transducer which was designed to couple orthogonal $TE_{11}$ modes in 15/16-inch id circular waveguide to separate 0.4- by 0.9-inch rectangular ports over the band from 8,600 mc to 9,600 mc. The compact transducer which has been developed exhibits a high order of isolation between channels with a low input vswr over the band of frequencies considered.

## Mode Transformation and Isolation

The dominant rectangular waveguide mode ($TE_{10}$) can be made to couple to the dominant circular waveguide mode ($TE_{11}$) in the manner indicated in Fig. 1(a). Ordinarily, energy introduced in the rectangular arm will split at the junction and propagate in both directions down the circular guide, but by properly locating a short circuit in the circular guide, energy will be forced to propagate in one direction. The required short circuit may take the form of a plunger completely blocking the guide, a conducting septum, or a series of thin metallic pins located parallel to the $E$ field polarization as shown in Fig. 1(b). Thin obstacles of the septum or pin type not only produce the desired reflection of one mode, but also appear transparent to a similar mode polarized at right angles. Arranging two such transducers in tandem with a 90° angular relationship between the rectangular arms will permit independent excitation of orthogonal modes in the circular waveguide.



(a)



(b)

Fig. 1(a)—Transformation from the rectangular $TE_{10}$ mode to the circular $TE_{11}$ mode. (b) A side-arm transducer.

The isolation between the two modes, assuming mode purity, is a function of the deviation from the desired 90° angular relationship of the two rectangular arms and is given by

$$I_{db} = 20 \log \phi$$

where $\phi$ is a small angular deviation from 90° in radians. A plot of this function is shown in Fig. 2 where, for convenience in specifying mechanical tolerances, the angle of deviation is plotted in minutes. It can be seen from the curve that a high order of mechanical accuracy is necessary to achieve a mode isolation of 45 db or better.

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[1] G. L. Ragan, "Microwave Transmission Circuits," The McGraw-Hill Book Publishing Co., New York, N.Y., p. 369; 1948.

[2] B. E. Kingdon, "A circular waveguide magic-tee and its application to high power microwave transmission, *J. Brit. IRE*, vol. 13, pp. 275–287; May, 1953.

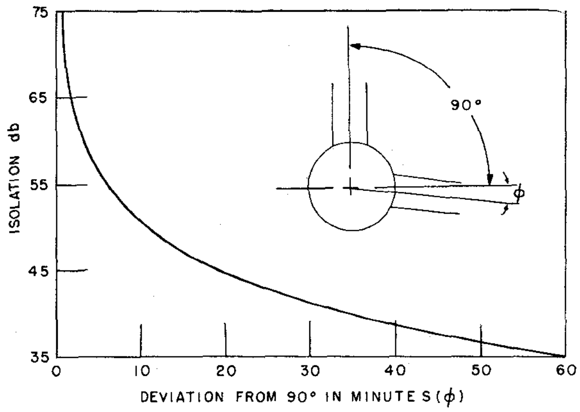


Fig. 2—Mode isolation vs the deviation from the 90° angular relationship of the rectangular arms.

## Developmental Models

The two experimental models shown in Fig. 3 were built embodying the preceding principles. The major difference between these transducers is in the configuration of the rear arm (*i.e.*, the arm furthest from the circular port). Four 1/16-inch diameter pins spaced $\frac{1}{4}$ inch apart were so positioned as to provide a fairly uniform amount of reflection over the frequency band at the side arm terminal. The size and position of a matching inductive iris for this terminal was computed by the use of established broadband matching techniques.[3,4]

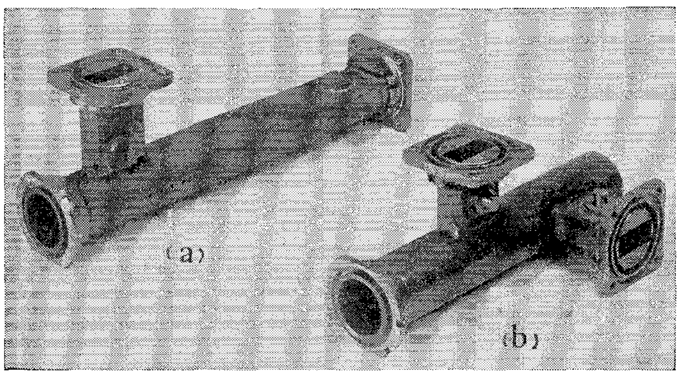


Fig. 3—(a) Two-arm transducer. (b) Tapered-arm transducer.

A further matching problem was encountered at the rear arm. The circular waveguide mode originating at this terminal will see a radiating aperture at the front arm. Although the front rectangular waveguide is beyond cutoff for this mode, some coupling will exist which will appear as undesirable reflections at the rear port. A wave filter in the form of thin vanes which are parallel to the axis of the circular guide and which provide a smooth continuation of the circular waveguide wall, was placed in the front arm to prevent distortion of this mode in the region of the front arm aperture. The effect of these vanes on the propagating mode in the front arm is negligible. Tests made on these completed models showed a mode isolation greater than 50 db and an input vswr less than 1.15 in both rectangular arms over the band.

Both of these early junctions, however, had disadvantages of being difficult to construct and physically bulky. In addition, a certain amount of structural weakness was inherent since assembly procedures dictated that the side arm be soft-soldered to the circular waveguide. The need for a more compact, rugged, and economical transducer was indicated and development proceeded along these lines.

## Compact Model

Two different methods of transforming from the $TE_{10}$ mode in rectangular guide to the $TE_{11}$ mode in the circular guide were used for the rear ports in the previous models. Another model was built using a stepped waveguide section to perform the required mode transformation. This stepped transition is produced by means of a broad-band dielectric transformer[5] designed to permit direct connection between the end of the 15/16-inch id circular guide and a rectangular waveguide equipped with a UG-40A/U choke flange. Use of this device for one port of the two-mode transducer reduced the length of the junction to half that of the tapered-arm version.

A further reduction in size was made by eliminating the section of rectangular waveguide in the side arm and mounting a UG-40A/U choke flange directly to the circular waveguide. A coupling aperture was made by milling an opening in the circular waveguide wall. The narrow dimension of this aperture was made equal to the narrow dimension of the rectangular waveguide in order to preserve the power handling capabilities of the device. Inductive matching elements were formed from the circular waveguide wall by making the broad dimension of the aperture less than that of the rectangular guide. It was impossible to obtain acceptable broadband matching by adjusting the aperture opening solely in the broad dimension. However, by plotting admittance data for various aperture sizes, it was possible to choose an opening which provided the proper vswr and phase dispersion to allow broad-band matching by means of a supplementary iris which could be located within the flange. This matching element may be seen in the photograph of the compact model shown in Fig. 4.

Measurements were made on this model and the results were generally good. However, an undesirable mode coupling resonance was noted near 9,400 mc. At this point the isolation between rectangular ports dropped abruptly from 50 db to about 30 db. The primary cause was found to be resonant reflections between the rear arm flange and the pins due to flange misalignment. This resonance could be shifted outside the band of interest by reducing the spacing between the flange and the pins, or can be prevented entirely by the insertion of a resistance card to absorb the reflection from the pins. The latter method was used in the model

[3] R. G. Fellers and R. T. Wiedner, "Broad-band admittance matching by use of irises," Proc. IRE, vol. 35, pp. 1080–1085; October, 1947.

[4] Ragan, *op. cit.*, p. 322.

[5] I. D. Olin, "Dielectric transformers for *x*-band waveguide," *Electronics*, vol. 28, pp. 146–148; December, 1955.

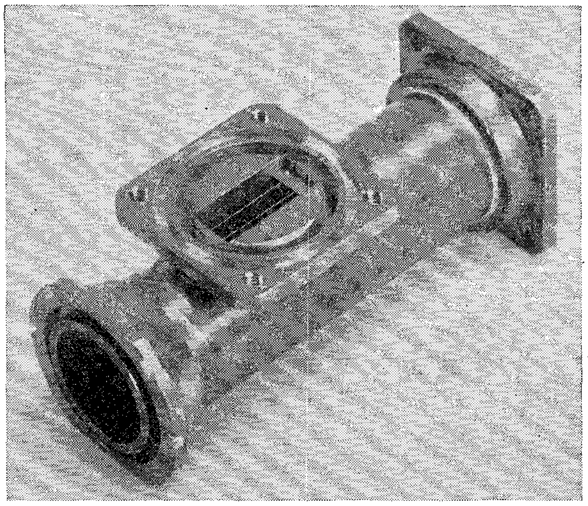

Fig. 4—Compact transducer.

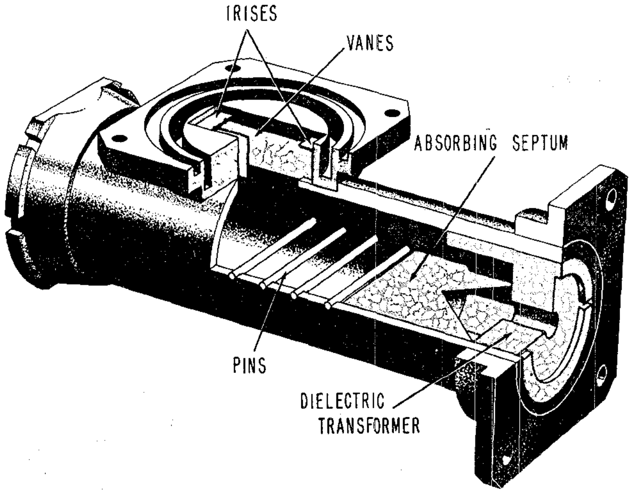


Fig. 5—Cutaway view of compact transducer.

described since development work was completed and the dimensions frozen at the time that the resonance was discovered.

With this modification the compact model now possesses electrical characteristics equal to those of the previous models. Input vswr to either rectangular arm is less than 1.15:1. Mode isolation is 50 db or greater over the band from 8,600 mc to 9,600 mc. The mechanical characteristics are far superior to the earlier versions, being of a more rugged construction and more economical to fabricate. Construction details are shown in Fig. 5. It can be seen from this view that the width of the vanes which form the wave filter was adjusted so that the matching iris would be in its proper position when seated on top of the vanes. Small slots cut in the narrow wall of the choke flange provide a convenient holding device while the vanes are being soldered. The critical dimensions which include the aperture size, the position of the pins with respect to the aperture and the position and size of the matching elements are indicated in Fig. 6.

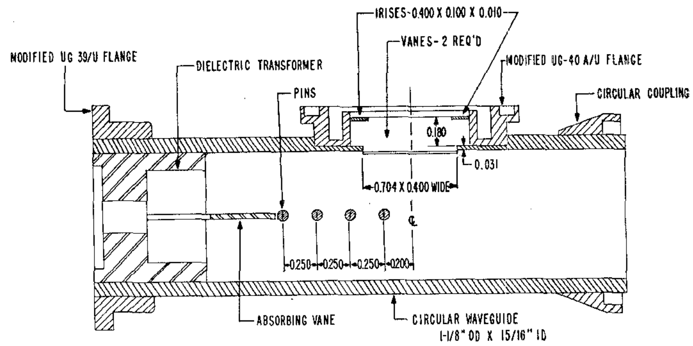


Fig. 6—Plan view of compact transducer showing critical dimensions.

## Conclusion

The compact dual-mode transducer which has been developed exhibits a high order of isolation between channels with a low input vswr for the frequency range considered and provides an effective means for mode multiplexing in circular waveguide. The junction also offers utility in the design of circular waveguide ferrite devices, such as isolators, duplexers, and circulators. Kingdon has suggested several other applications for this type transducer including balanced mixers, circular or elliptical polarizers, rotary joints, a variable power splitting bridge, and a circular waveguide magic-*T*.

## Acknowledgment

The author is indebted to Lt. I. D. Olin, U. S. Army, who did most of the original design and experimental work on the junction while at Naval Research Laboratory. The helpful suggestions received in discussions with P. J. Allen are greatly appreciated.

# Correction

Franklin S. Coale, author of the paper "A Switch Detector Circuit," which appeared on pages 59–61 of the December, 1955 issue of TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, has requested that the following information, omitted in his manuscript, be published by the editors.

The work for the paper was accomplished while Mr. Coale was a member of the Sperry Gyroscope Company under an Air Force Contract.

P. J. Sferrazza, of Sperry, developed a band-pass crystal switch at 3300 mc which gave a dynamic switching of greater than 44 db over a 10 mc bandwidth.