In the past pure metal shields were tried with little success[4,5] on surface wave structures. By selecting the value of the parameters of the line we can insure that the metal shield will not affect the fields in the beam waveguide.

A shielded-beam waveguide 10 ft long was constructed for a frequency of 141 Gc. The phase transformers are matched polystyrene doublets with a focal length of 6 inches. The lenses are matched by a double layer structure.[6] See Fig. 2. Goubau's parameter $a=\sqrt{(k/D)}\,R$ in our case is 2.42, where k = the free-space propagation constant, D = distance between phase transformers, R = radius of phase transformers.

The estimated total loss per lens is 0.12 db; this figure includes the diffraction loss, the absorption loss of the lens and matching layers ($\tan\delta = 2\times 10^{-3}$ for polystyrene). The measured loss was 0.15 db per lens; this figure was obtained by averaging the total loss of the line (11 lenses). A conical horn and two of the phase transformers were used to excite the beam waveguide. The launching loss was 1 db per horn.

Figs. 3 and 4 show the cross-sectional field configuration at the 11th lens and halfway between the 11th lens and a hypothetical 12th lens, respectively.

The transmission loss of the oversize waveguide is lower than that of the beam waveguide at 141 Gc. The shield on the beam waveguide does not seem to affect the fields in the beam waveguide for our value of parameters.

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[4] M. T. Weiss and E. M. Gyorgy, "Low loss dielectric waveguide," IRE Trans. on Microwave Theory and Techniques, vol. MTT-2, pp. 38–44; September, 1954.

[5] J. C. Wiltse, "An Investigation of Dielectric Waveguides for Use at High Microwave Frequencies," The Johns Hopkins University, Radiation Lab., Baltimore, Md., Tech. Rept. No. AF-64; April, 1959.

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A Wide-Band Rectangular-to-Circular Mode Transducer for Millimeter Waves*

Introduction

Mode transducers are used in microwave transmission systems to transform a certain mode of one waveguide into a predetermined mode of another waveguide. Of particular importance is the transformation from the rectangular TE_{10} mode to the circular TE_{01} mode because the circular mode has a low transmission loss and is frequently used where long waveguide runs are necessary.

The performance of a mode transducer is characterized by its VSWR and insertion loss in the operation band and its mode purity, given by the magnitudes of the unwanted modes generated in the transducer.

The circular mode transducer described in this communication employs a gradual transition from the rectangular to the circular cross section, as illustrated in Fig. 1. This design anticipates a wide-band and low-loss characteristic because no inherently frequency-sensitive elements such as $\lambda/4$ sections or coupling slots are used. The theoretical mode purity of a linear angle taper section (section 2 of the design used) is fairly high.[1] A systematic design method suggested by Solymar and Eaglesfield[2] for the design of gradual mode transducers was employed for designing taper section 1.

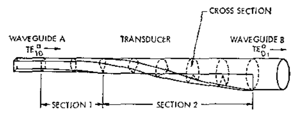

Fig. 1—Circular-mode transducer.

While the basic design concept of a gradual circular-mode transducer has been known for a long time,[3] the author is not aware of any published information on a specific design of such a transducer. The design and manufacture of a circular transducer for the entire band from 50 to 75 Gc is described below.

Theoretical Considerations

Through use of an equivalent circuit concept, a uniform waveguide can be represented by a set of uniform transmission lines, where each line corresponds to a propagation mode. The impedance and the propagation coefficient of each mode can be expressed by its eigenfunction (cross-sectional wave function) and its eigenvalue (cutoff wavenumber). If the waveguide has a gradually varying cross section, the same concept applies, but now each line has varying characteristics and there is coupling between the lines. If the taper is sufficiently gradual, the coupling can be neglected. Thus, if a single mode enters the transducer from waveguide A (see Fig. 1), it will travel along one transmission line and emerge at the end as a single mode of waveguide B. The particular mode excited in waveguide B depends on the shaping of the transducer.

The electromagnetic field in a waveguide of varying cross section can be described by the varying eigenfunction,[2] which changes gradually

$$\psi(x, y, z) = g_1(z)\psi_1(x, y) + g_2(z)\psi_2(x, y), \quad (1)$$

from the eigenfunction ψ_1 of the input mode to the eigenfunction ψ_2 of the output mode; g_1 and g_2 are monotonic differentiable functions of z, with $g_1(0)=1$, $g_1(L)=0$, $g_2(0)=0$ and $g_2(L)=1$. L is the length of the transducer.

If input and output modes are TE modes, the possible cross-sectional boundaries of the transducer are determined by the condition that the normal derivative of ψ vanishes at the boundary. In practice, it is sufficiently accurate to construct the boundary curves by graphically finding the orthogonal trajectories (ψ = constant) to the electric field lines. Successive cross sections have to be determined at sufficiently close intervals to establish continuity.

Design of the Circular Mode Transdcuer

The circular mode transducer consists of a series connection of two transducer sections. In section 1, shown in Fig. 1, the rectangular cross section of the input waveguide is flared to a sector of a circle. The rectangular TE_{10} mode is transformed into the sector TE_{01} mode. Section 2 opens the sector to the whole circle in a gradual angle taper, which transforms the sector TE_{01} mode to the circular TE_{01} mode.

The eigenfunction of the rectangular TE_{10} mode is

$$\psi_1 = K_1 \sin\left(\frac{\pi}{a}\,x\right), \quad (2)$$

where x is the coordinate parallel to the long side of the rectangular waveguide A. The eigenfunction of the sector and the circular TE_{01} mode is

$$\psi_2 = K_2 J_1\left(3.83\,\frac{r}{r_0}\right), \quad (3)$$

where J_1 = first-order Bessel function, K_1, K_2 = scaling factors, r = radial coordinate, r_0 = radius of the circle.

The mode functions for input and output of section 2 are the same, although the cross section changes (an equivalent case is the more familiar rectangular guide taper where the dimension of the smaller side of the guide changes). A linear angle taper 2 5 inches long was chosen for section 2 of the transducer.

Substituting (2) and (3) into (1), the eigenfunction of the transducer section 1 becomes

$$\psi(x, y, z) = K_1 g_1(z) \sin\left(\frac{\pi}{a}\,x\right) + g_2(z) K_2 J_1\left(3.14\,\frac{\sqrt{x^2+y^2}}{a}\right), \quad (4)$$

with $r=\sqrt{x^2+y^2}$. The dimensions of the input and the output waveguides were chosen to have the same cutoff number, which implies that $r_0 = 1.22\,a$, as introduced in (4).

Section 1 was made 0.7 inch long. To construct the cross-sectional mode patterns (E-field patterns) of section 1, it was necessary to determine the relative magnitudes of the two vector components, *i.e.*, the ratio K_1/K_2. To keep this ratio constant throughout section 1, it is a reasonable approximation to determine the sector angle at the end of section 1 such that the maximum magnitudes of the E vectors in the rectangular and sector cross sections are equal.

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[2] L. Solymar and C. C. Eaglesfield, "Design of mode transducers," IRE Trans. on Microwave Theory and Techniques, vol. MTT-8, pp. 61–65, January, 1960.

[3] S. E. Miller and A C. Beck, "Low-loss waveguide transmission," Proc. IRE, vol. 41, pp. 348–358; March 1953.

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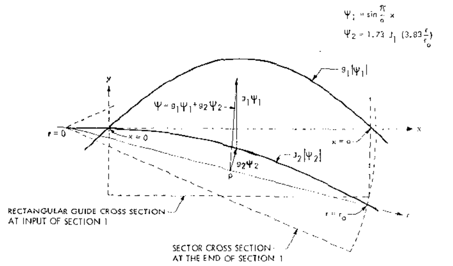


Fig. 2—Construction of vector field.

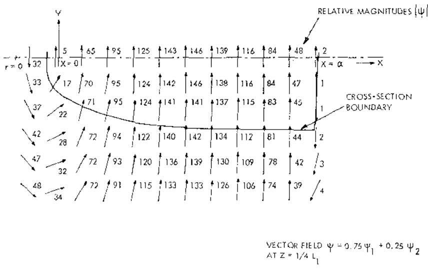


Fig. 3—Design of a cross-sectional boundary of transducer section 1.

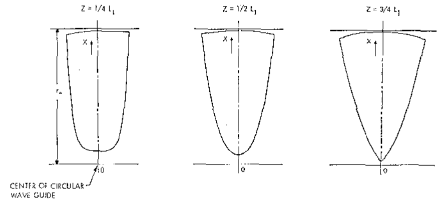
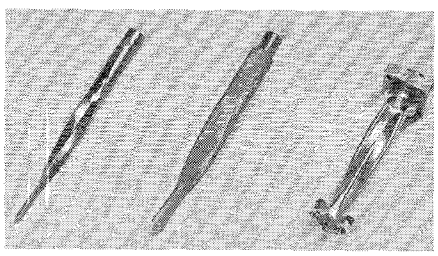


Fig. 4—Cross sections of transducer section 1.



(a) (b) (c)

Fig. 5—Three stages in manufacture of transducer.

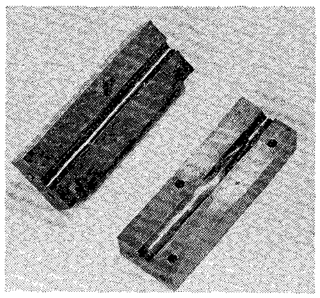


Fig. 6—Mold used for casting mandrels.

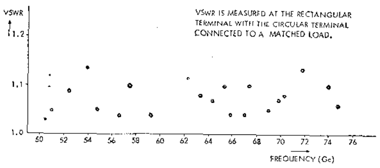


Fig. 7—VSWR of circular-mode transducer.

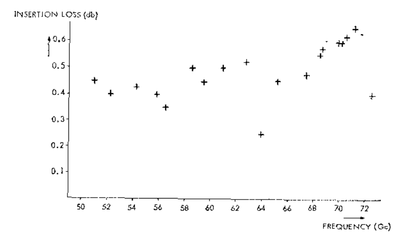


Fig. 8—Conversion loss of circular-mode transducer.

If losses are neglected, the power flow through the input and the output cross sections of transducer section 1 is equal, that is

$$\frac{ab}{2\eta_f}\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}\,E_{1\,\max}^2 = \frac{r_0^2\theta}{4\eta_f}\,\frac{\lambda}{\lambda_c}\,E_{2\,\max}^2, \quad (5)$$

where a, b = dimensions of rectangular guide, θ = sector angle, η_f = wave impedance of free space, $E_{1\,\max}$ = maximum E-field strength in rectangular guide, $E_{2\,\max}$ = maximum E-field strength in sector cross section at the end of section 1. Evaluating (5) for θ, with $E_{1\,\max} = E_{2\,\max}$

$$\theta = \frac{2ab}{r_0^2}\sqrt{\left(\frac{\lambda_c}{\lambda}\right)^2 - 1}. \quad (6)$$

At 60 Gc, θ is calculated to be approximately 42°, the angle used in the design.

Fig. 2 shows the construction of the vector field. The scaling factors have been taken to be $K_1=1$ and $K_2=1/0.58=1.73$, where 0.58 is the magnitude of the first maximum of J_1. The relative position of the input and output cross sections of section 1 is indicated by dashed outlines. The magnitudes of the vector components $g_1\psi_1(x)$ and $g_2\psi_2(r)$ for $g_1=0.75$ and $g_2=0.25$ are shown. Composition of the vectors is shown at point P and gives the resultant vector ψ.

Fig. 3 shows the vector field $\psi(x, y)$; numerical magnitudes (arbitrary scale) are indicated. A cross-sectional boundary as used in the design of section 1 is plotted in the figure. Fig. 4 shows three intermediate cross sections, which have been constructed for section 1, with the values chosen for g_1 and g_2 listed below. L_1 is the length of section 1.

	Cross section at		
	$\frac{1}{4}L_1$	$\frac{1}{2}L_1$	$\frac{3}{4}L_1$
g_1	0.75	.05	0.25
g_2	0.25	0.5	0.75

Manufacture of the Circular Mode Transducer

The transducer tube was manufactured by electroforming, through use of a cast mandrel. Fig. 5 pictures the results of three steps of the process; Fig. 5(a) shows a mandrel cast from the low-temperature alloy Cerrobase (255°F melting point). A high-quality cast surface can be achieved with simple gravity casting; the material is easy to handle and has a small shrinkage. Fig. 5(b) shows a mandrel after the electroforming process. A completed transducer, with the two flanges soldered on, is shown in Fig. 5(c). Over-all length, including flanges, is 3.3 inches; the inside diameter of the circular guide is 0.353 inch. The mold used to cast the mandrels is shown in Fig. 6. The mold consists of two steel blocks, with a cylindrical bore centered at their joint. A tapered cylindrical brass piece was fixed permanently to one block. The rectangular-to-sector portion was filed, polished, and checked with templates for the different cross sections.

Electrical Performance

The VSWR and the conversion loss of the transducer were measured in the frequency band between 50 and 75 Gc. A VSWR smaller than 1.15 was measured throughout the band and the conversion loss was approximately 0.6 db. The measured data are plotted in Figs. 7 and 8. The VSWR was measured while the circular end of the transducer was terminated in a matched load. The conversion loss was measured by using two transducers interconnected at the circular sides through a mode filter. The measured conversion loss, therefore, includes the resistive loss and the conversion loss to unwanted modes.

Noncircular mode levels generated in the transducer were in the order of −20 db, as estimated from measurements of the radiation field configuration from the open circular end of the transducer.

Conclusion

The technique described in Miller and Beck[3] was adapted to the design of a gradual circular mode transducer of relatively short axial length. High electrical performance was measured over the entire usable bandwidth of the rectangular input guide. Because the electrical performance of several transducer samples was the same within measurement tolerances, the manufacturing process used can be considered to be reproducible. The casting and electroforming process is relatively inexpensive, easy to control, and is suitable for production of large quantities.

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