the design is available only for waveguide sizes WR-15, WR-12, and WR-10 although it is planned that variations of this same flange design will be made for the smaller waveguide sizes. The E.I.A. Task Group feels that this flange is simpler to make than the Philips flange. It was felt that the claw-type arrangement took considerably more complicated machining. It was the consensus, however, by the tests that were run at Lincoln Laboratories and Bell Telephone Laboratories, that the Philips flange and the E.I.A. proposed flange are electrically satisfactory and very nearly identical. Unfortunately, the proposed design is not pressurizable and therefore has to be redesigned and a task group of the E.I.A. has this under consideration.

Thus, it appears that the international position on millimeter waveguide flanges is as follows. With the U. S. National Committee unable to present at this time a flange design that is capable of meeting the criteria that have been established by the I.E.C. Committee on waveguide standardization, that is:

1) The flange must be asexual;
2) Capable of operation both pressurized and unpressurized;
3) Provide good electrical performance;
4) Relatively simple to machine and manufacture;

there is little to compete with the Philips flange as an International Standard.

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## Millimeter Transmission by Oversize and Shielded-Beam Waveguides*

A transmission line for the interconnection of systems was required for frequencies above 100 Gc. This requirement is different from the point-to-point propagation. For this particular application the transmission line should have low attenuation, reasonable manufacturing cost, simplicity in component construction and system adaptability.

After a careful evaluation of the presently known means of transmission for millimeter waves an oversize waveguide in a single mode (not necessarily the dominant mode) and an optical waveguide (beam waveguide) were chosen.

The attenuation of a standard waveguide has a prohibitively large value at frequencies above 100 Gc. The attenuation for any mode in a pipe of arbitrary cross section can be reduced by increasing the transverse dimensions of the waveguide. In the oversize waveguide a large number of modes can propagate if they are excited in any manner.

The larger the cross-sectional dimensions of the waveguide in relation to the wavelength of the propagating mode, the smaller the longitudinal component of the field becomes. When the longitudinal component is negligible compared with the transverse components of the electromagnetic field, the field is for all practical purposes a TEM mode and optical techniques can be used in the design of components.

The dominant mode in rectangular waveguide, the $H_{10}$ mode, was launched in a *C*-band waveguide (RG-95/U) 10 ft long, at 70 and 141 Gc.

Solymar's theory[1] for the spurious mode generation in a nonuniform line was used to obtain an estimate of the mode purity in a linear taper in rectangular waveguide. An expression for the $H_{30}$ mode was obtained for a symmetrical taper with a flare angle $\theta$ in the broad dimension (the $H_{30}$ is the higher order mode of largest amplitude to be excited in our work).

$$|H_{30}| \simeq \frac{3}{4}\left\{\left[\mathrm{Si}\left(\frac{\pi\lambda}{a_0\tan\theta}\right)-\mathrm{Si}\left(\frac{\pi\lambda}{a_1\tan\theta}\right)\right]^2 + \left[\mathrm{Ci}\left(\frac{\pi\lambda}{a_0\tan\theta}\right)-\mathrm{Ci}\left(\frac{\pi\lambda}{a_1\tan\theta}\right)\right]^2\right\}^{1/2} \quad (1)$$

where $a_0 < a_1$, $\lambda/2a_0 < 1.0$, $\mathrm{Si}(x)$ and $\mathrm{Ci}(x)$ are the conventional sine and cosine integral functions, $\lambda$ = free-space wavelength, $\theta$ = the flare angle in the *H* plane, $a_0$ = input broad dimension of the taper, $a_1$ = output broad dimension of the taper. The power of the $H_{10}$ mode is unity.

Eq. (1) has been plotted in Fig. 1 for a range of values applicable to this work. A flare angle of 2° was used in the linear taper from the RG-98/U to the *C*-band waveguide. The spurious modes should be under −10 db in relation to the dominant mode for this flare angle. For the 141 Gc transmission experiments a linear taper of a 1° flare angle was used in addition to join the *G*-band waveguide (0.075″×0.034″ ID) to the RG-98/U input of the other taper. The mode purity was checked by probing the field of the oversize waveguide. Table I shows the theoretical and experimental attenuation at 70 and 141 Gc.

The beam waveguide was developed by Goubau and associates.[2,3] The beam waveguide is an open structure, therefore a metallic shield was used to enclose the line to eliminate crosstalk or external noise.

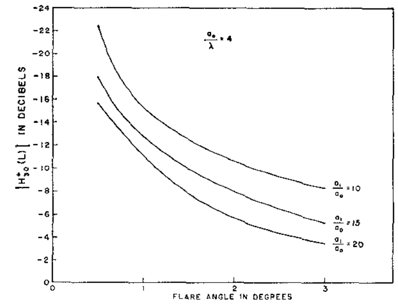


Fig. 1—Amount of $H_{30}^+$ mode vs flare angle.

TABLE I

| Frequency Gc | Attenuation—(Decibel/100 feet) Standard Silver Waveguide $\sigma = 6.1\times10^7$ mhos/meter | | 2″×1″ Aluminum Waveguide $\sigma = 3.54\times10^7$ mhos/meter | |
|---|---|---|---|---|
| | Theoretical | Measured | Theoretical | Measured |
| 70 | RG-98/U 41.0 | — | 2.8 | 4.0 |
| 141 | RG-138/U 99.0 | — | 4.0 | 6.0 |

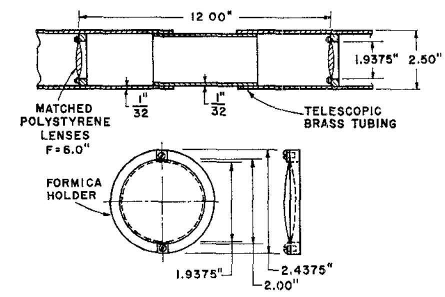


Fig. 2—Drawing of section of the shielded-beam waveguide.

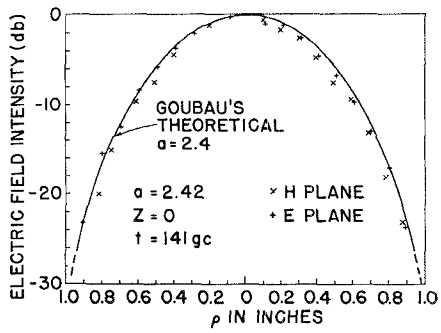


Fig. 3—Cross-sectional field configuration at $Z=0$.

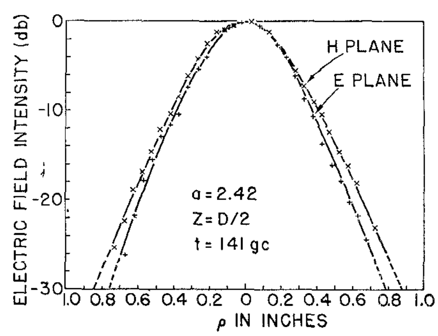


Fig. 4—Cross-sectional field configuration at $z=D/2$.

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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 ($\tan\delta=2\times10^{-3}$ 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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## 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.

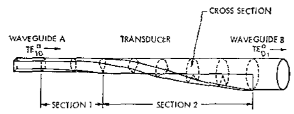


Fig. 1—Circular-mode transducer.

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 $\psi_1$ of the input mode to the eigenfunction $\psi_2$ 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 $\psi$ vanishes at the boundary. In practice, it is sufficiently accurate to construct the boundary curves by graphically finding the orthogonal trajectories ($\psi$ = 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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