Effects of Ferrite Strip Mounting Positions on Millimeter Wave Isolator Characteristics*

The position of the ferrite strip in a field displacement type isolator is an important problem. If x and L are defined as the mounting position of the ferrite strip and the width of the rectangular waveguide, respectively, as shown in Fig. 1, then, according to Soohoo,[1] Lax,[2] Fox, *et al.*,[3] and Button,[4] the optimum value of x ranges from $0.095L$ to $0.27L$. The sign of the directivity (backward to forward ratio of attenuation) for very thin ferrite strip is the same if $x < L/2$.

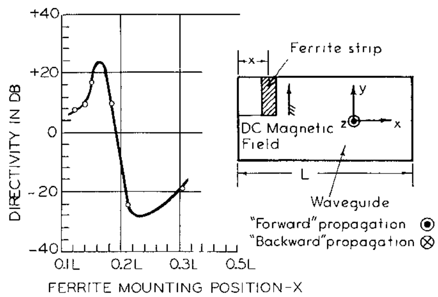

Fig. 1—Directivity and mounting position of ferrite strip.

The ferrite strip which the authors investigated was mounted on a polystyrene strip and was placed in RG-98/U waveguide as shown in Fig. 1. No attenuator film was coated on the ferrite strip in this case. The dimensions of the ferrite strip were 0.0117 inch×0.0325 inch×0.133 inch. The ferrite strip, made from a single crystal type sample LRR-1[5] ($BaFe_{12}O_{19}$, anisotropy field 18.4 koe, apparent density 5.13 g/cm^3) was magnetized in the direction of easy magnetization. External dc magnetic field was applied in this direction as shown in Fig. 1, and the isolator was tested at frequency of 58.3 kMc.

The optimum position of the ferrite strip in this case was $x = 0.16L$, which agreed with the results reported in the literature, but different results were obtained for directivity. The sign of directivity changed at $x = 0.19L$. This is considerably smaller than $x = L/2$ reported in the literature. The experimental results obtained are shown in Fig. 1. The optimum values of backward to forward ratio of attenuation are plotted against the mounting position x. The results can be interpreted as a selective resonance of the ferrite structure against combined spatial harmonics as indicated by an arbitrary scale in Fig. 2.

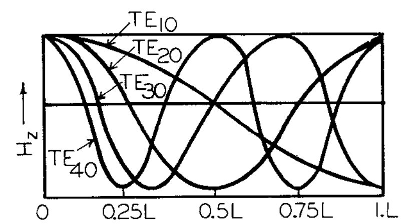

Fig. 2—Spatial harmonics in ferrite-loaded waveguide (arbitrary scale).

When the applied dc magnetic flux density was changed, many peaks appeared in the attenuation curve as shown in Fig. 3. Several examples near the transition region of the directivities are shown in the figure. For each position of the ferrite strip, almost the same numbers of peaks were detected for backward attenuation. All the peaks were found at approximately the same magnetic flux density, even though the heights of the peaks were different. It can be considered that the peaks are due to complicated selective structural resonance of ferrite and spatial harmonics. In a certain mounting position, some peaks were accentuated and others were reduced. The sign of directivity corresponding to peak No. 2 did not change over the range of $x = 0.109L$ to $0.303L$. It is thought that this is due to the local resonance with the TE_{10} mode. It is interesting to note that at the position where the directivity vanishes, most of the forward attenuation peaks are reduced as shown in Fig. 3(b).

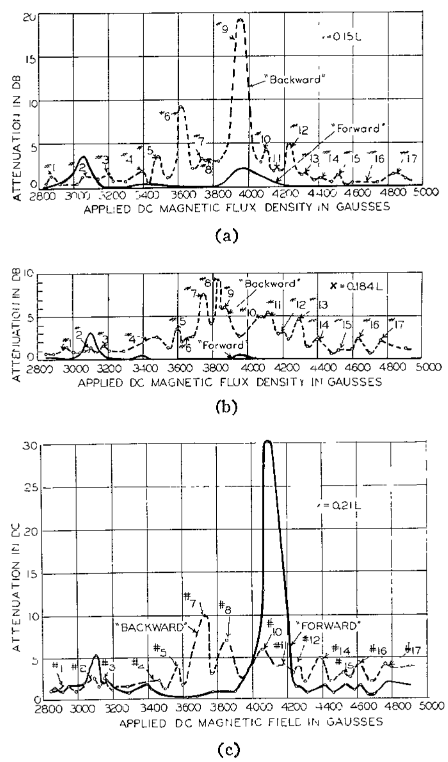

Fig 3—Magnetic resonance characteristics.

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[1] R. F. Soohoo, "Theory and Application of Ferrites," Prentice-Hall, Inc., Englewood Cliffs, N. J.; 1960.

[2] B. Lax, "Frequency and loss characteristics of microwave ferrite devices," Proc. IRE, vol. 44, pp. 1368–1386; October, 1956.

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[5] Supplied by A. O. Smith Corp.

An *L*-Band Loop-Type Coupler*

The design of loop couplers for various loop length has been reported by Lombardini, Schwartz and Kelly.[1] This device is useful for many applications as the over-all length can be held to about 6 inches, whereas a comparable multihole coupler must be on the order of several feet long. The loop-type device couples a TE_{10} waveguide mode from a RG-69/U to a TEM mode in a $\frac{3}{8}$-inch coaxial line. A comb-type coupler, for coupling a coaxial line to TE_{10} waveguide, was reported by Lombardini and Schwartz.[2] This device made use of a multiple-capacitive probe situated in a longitudinal slot in the top wall of the waveguide.

The scattering matrix of the four-port device of Fig. 1 is

$$S = \begin{bmatrix} s_{11} & s_{12} & s_{13} & s_{14} \\ s_{21} & s_{22} & s_{23} & s_{24} \\ s_{31} & s_{32} & s_{33} & s_{34} \\ s_{41} & s_{42} & s_{43} & s_{44} \end{bmatrix}. \qquad (1)$$

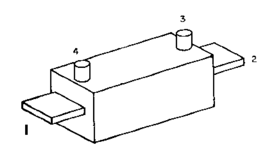

Fig. 1—A four-port device.

For matched ports, the principal diagonal elements of (1) will become zero:

$$s_{11} = s_{22} = s_{33} = s_{44} = 0.$$

The energy coupled to the loop will travel in the direction opposite to that of the incident energy, therefore,

$$s_{13} = s_{24} = s_{31} = s_{42} = 0.$$

For a lossless symmetrical network the uni-

* Received by the PGMTT, April 11, 1961.

[1] P. P. Lombardini, R. F. Schwartz and P. J. Kelly, "Criteria for the design of loop-type directional couplers for the *L*-band," IRE Trans. on Microwave Theory and Techniques, vol. MTT-4, pp. 234–239; October, 1956.

[2] P. P. Lombardini and R. F. Schwartz, "A new type of directional coupler for coupling coaxial line to TE_{10} waveguide," 1957 IRE Wescon Convention Record, pt. 1, pp. 22–29.

tary condition applies,[3]

$$S\tilde{S}^* = 1, \qquad (2)$$

where $\tilde{S}^*$ is the conjugate transpose matrix. Considering the off-diagonal element of (2),

$$s_{12}s_{32}^* + s_{14}s_{34}^* = 0 \qquad (3)$$

or

$$\theta_{12} - \theta_{32} = \pi + \theta_{14} - \theta_{34}, \qquad (4)$$

where θ_{12}, θ_{32}, θ_{14} and θ_{34} are the argument of s_{12}, s_{32}, s_{14} and s_{34}, respectively. From the principal diagonal element of (2),

$$s_{12}s_{12}^* + s_{14}s_{14}^* = 1 \qquad (5)$$

or

$$|s_{12}|^2 + |s_{14}|^2 = 1. \qquad (6)$$

By choosing the location of the reference planes

$$\theta_{14} = \theta_{32} = 0, \qquad (7)$$

(4) becomes

$$\theta_{12} + \theta_{34} = \pi. \qquad (8)$$

A loop-type coupler, with the coupling loop placed near the side wall of the waveguide, is shown in Fig. 2. This device was tested for 15 kw average and 10 Mw peak. The coupling variation over the full waveguide frequency range is shown in Fig. 3. This figure shows the coupling with the loop at the center of the waveguide and near the side wall. The increase in coupling value as a function of coupling-loop position is

$$C = 20 \log \left(\frac{1}{\cos \pi d} \right), \qquad (9)$$

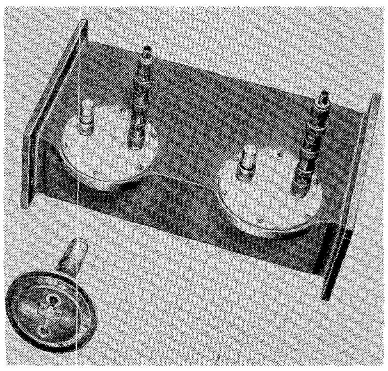

Fig. 2—Loop-type coupler.

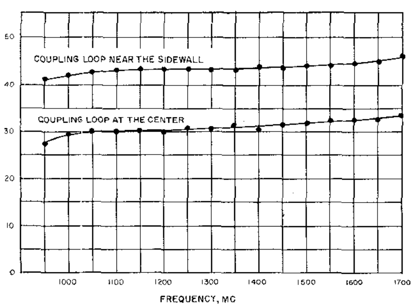

Fig. 3—Characteristics of loop-type coupler with coupling loop at the center and near the side wall.

where d is the displacement in fractions of the a dimension of the guide, and is measured from the center of the guide toward the side wall. The experimental and calculated values of this variation are shown in Fig. 4. Measurements were made at two frequencies differing by 10 Mc. The results show that the variation in coupling is frequency insensitive as indicated by (9). A minimum directivity of 30 db was achieved over 10 per cent of the band by adjusting the location, height and length of the rectangular-shaped plate situated around the coupling loop and grounded to the top wall of the waveguide. Fig. 5 indicates the change in directivity as a function of frequency. It is felt that a directivity greater than 40 db exists at the center frequency. This value could not be measured due to the lack of proper termination. A 50-Ω coaxial termination with VSWR of less than 1.03 was utilized with the auxiliary arm of the coupler.

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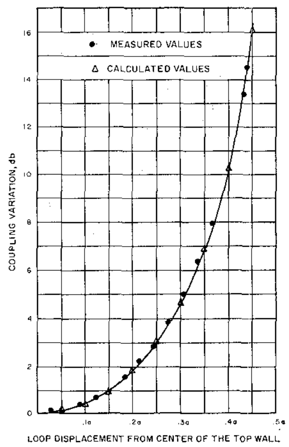

Fig. 4—Coupling variation as a function of loop position.

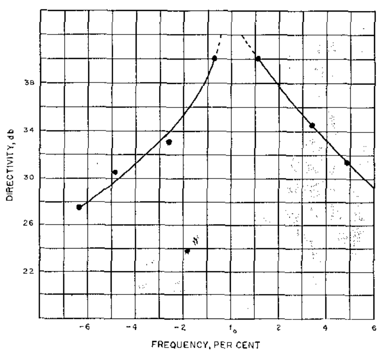

Fig. 5—Directivity vs frequency.

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[3] C. G. Montgomery, R. H. Dicke and E. M Purcell, "Principles of Microwave Circuits," McGraw-Hill Book Co., Inc., New York, N. Y., pp. 301–303; 1948.

The Cutoff Wavelengths of Composite Waveguides*

When electromagnetic waves propagate in waveguides of nonsimple cross section, no exact solution can be obtained by the conventional method of solving the wave equation by separation of variables. In such cases approximations are available such as perturbation methods, variational methods, etc.[1]

The Rayleigh-Ritz method has been used to obtain an approximate solution for the cutoff wavelength for waveguides with semicircular side walls and flat top and bottom walls, and for truncated-circular waveguides. See Figs. 1 and 2.

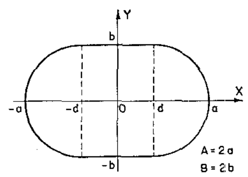

Fig. 1—Waveguide with flat tops and bottoms and semicircular side walls.

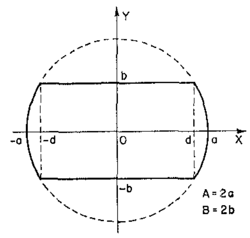

Fig. 2—Truncated-circular waveguide.

The results obtained for the cutoff wavelengths for waveguides of semicircular side walls and flat top and bottom walls disagree with the values shown by Montgomery, Dicke and Purcell[2] for aspect ratios of 0.406 and 0.450. From the nature of the problem and from experimental evidence it can be stated that the trial functions used to obtain the results[2] mentioned above was inferior to the one used here.

The boundary-value problem of electromagnetic waves propagating in a cylindrical waveguide can always be reduced to a simple two-dimensional problem.

If the longitudinal axis is in the z direction,

$$\nabla^2\psi_i(x, y) + k_i^2\psi_i(x, y) = 0, \qquad (1)$$

where $\psi_i(x, y)$ is the eigenfunction and k_i is the propagation constant for the ith mode, respectively.

If ψ_i satisfies either Dirichlet or Neumann boundary conditions, a variational expression for the eigenvalue k_i^2 exists,

$$k_i^2 \le \frac{\int |\nabla\psi_i|^2 d\sigma}{\int \psi_i^2 d\sigma} \qquad (2)$$

* Received by the PGMTT, March 14, 1961; revised manuscript received, April 17, 1961.

[1] P. M. Morse and H. Feshbach, "Methods in Theoretical Physics II," McGraw-Hill Book Co., Inc., New York, N. Y.; 1953.

[2] C. G. Montgomery, R. H. Dicke and E. M. Purcell, "Principles of Microwave Circuits," M.I.T. Rad. Lab. Ser., McGraw-Hill Book Co., New York, N. Y., vol. 8, p. 45; 1948.