Correspondence

A 5-MM Resonance Isolator*

The rectangular waveguide resonance isolator operating at frequencies from 3000 to 24,000 mc is a simple and compact device since the dc magnetic field requirements are relatively low. In the 5-mm range, however, resonance isolators are not practical if conventional ferrites are used because very high magnetic fields of about 20,000 oersteds are required to obtain resonance at these high frequencies. By using highly oriented Ferroxdure, resonance isolators in the millimeter range become feasible because of the high internal anisotropy field of 17,000 oersteds exhibited by this material.[1] Thus, with Ferroxdure a magnetic field of a few thousand oersteds is sufficient for resonance in the 5-mm region.

Such a 5-mm resonance isolator has been built and is shown in cross section in Fig. 1 and assembled in Fig. 2. A brief description of the assembly of this device might be of interest. A piece of highly oriented Ferroxdure was carefully ground to a thickness of 0.005 inch, a width of 0.021 inch, and a length of 2 inches. This material was then mounted on a strip of 0.020-inch thick laminated polystyrene using carbon tetrachloride and polystyrene as the adhesive. This strip served to space the ferrite from the waveguide wall by the proper amount. In addition, a strip of 0.010-inch thick laminated polystyrene was bonded to the other side of the ferrite in order to help concentrate the RF field in the ferrite.[2] The two strips of polystyrene also reinforced the fragile ferrite so that it could be handled without breakage. This composite sample was then placed in position against one wall of the waveguide and fastened to it, utilizing a long slim hypodermic needle to inject a mixture of carbon tetrachloride and polystyrene in the appropriate places.

The performance of the isolator at three different frequencies is shown in Fig. 3. It can be seen that reverse-to-forward ratios of better than 20 to 1 in db can readily be obtained at a given frequency by a proper choice of dc magnetic field. The VSWR was measured to be less than 1.1 even though no effort was made to match the device.

In order to permit the operation of the isolator over a wide range of frequencies with a high reverse-to-forward ratio, it is evident from Fig. 3 that the dc field must be varied as the frequency is changed. This magnetic field variation is accomplished by means of a variable shunt placed on top of the magnet as shown in Fig. 2. The shunt is varied by means of the screw which permits one to change the field in the gap from 1200 to 4300 oersteds. This unit has been used in test bench setups with at least a 20 to 1 ratio in db over the frequency range from 53 kmc to 58 kmc.

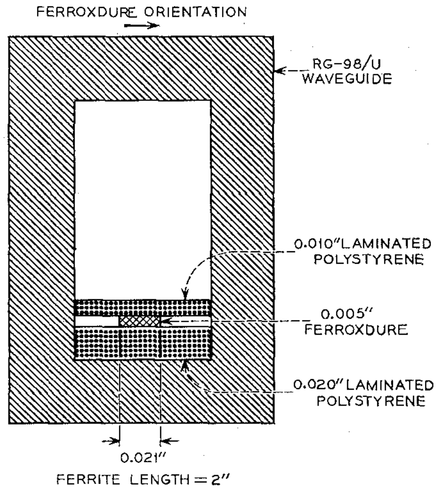

Fig. 1—Cross section of the 5-mm resonance isolator.

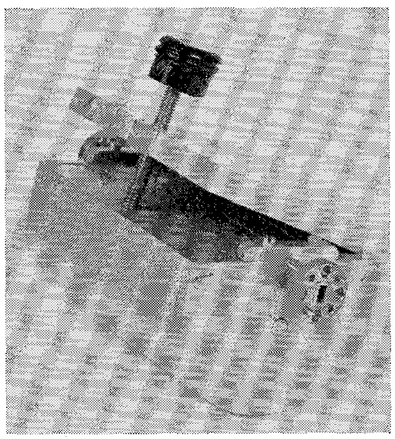
Fig. 2—Assembled 5-mm resonance isolator.

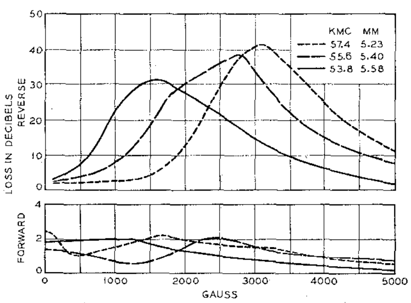

Fig. 3—Reverse and forward loss vs applied field at three frequencies for the 5-mm resonance isolator.

M. T. Weiss
F. A. Dunn
Bell Telephone Labs.
Holmdel, N. J.

* Received by the PGMTT, January 27, 1958.

[1] M. T. Weiss, "The behavior of ferroxdure at microwave frequencies," 1955 IRE Convention Record, pt. 8, pp. 95–99. Also see "Ferromagnetic resonance in ferroxdure," *Phys. Rev.*, vol. 98, pp. 925–926; May, 1955.

[2] M. T. Weiss, "Improved rectangular waveguide resonance isolators," IRE Trans. on Microwave Theory and Techniques, vol. MTT-4, pp. 240–243; October, 1956.

On Riblet's Theorem*

Riblet[1] presented the following theorem which is concerned with the synthesis of a quarter-wave impedance transformer: "The necessary and sufficient conditions that a rational function of p with real coefficients written in the form

$$Z(p) = \frac{m_1(p) - n_1(p)}{m_2(p) - n_2(p)} \tag{1}$$

with m_1 and m_2 odd or even and n_1 and n_2 even or odd, be the input impedance of a cascade of n equal-length transmission line sections terminated in a resistance are: 1) $Z(p)$ must be a positive real function of p, and 2) $m_1(p)m_2(p) - n_1(p)n_2(p) = C(p^2-1)^n$."

These two conditions are surely necessary, but are not sufficient. To illustrate, consider the following function, which meets the two conditions but is not realizable as a circuit of this kind:

$$Z(p) = \frac{m_1(p) + n_1(p)}{m_2(p) + n_2(p)} = \frac{2p^2 + 2p + 4}{3p + 1} \tag{2}$$

where $m_1(p) = 2p^2 + 4$, $n_1(p) = 2p$, $m_2(p) = 1$, $n_2(p) = 3p$. Clearly, $Z(p)$ is a positive real and

$$\begin{aligned} m_1(p)m_2(p) - n_1(p)n_2(p) &= (2p^2 + 4) - 2p \cdot 3p \\ &= -4(p^2 - 1)^1. \end{aligned}$$

Hence, $Z(p)$ satisfies the two conditions of the theorem. Let us try to realize $Z(p)$ through the use of Richards' theorem as indicated by Riblet.

$$Z_c = Z(1) = 2$$

$$\begin{aligned} Z_1(p) &= Z_c \frac{pZ(p) - Z_c}{-Z(p) + pZ_c} = \frac{1}{2}(p + 1) \\ &= \frac{m_1'(p) + n_1'(p)}{m_2'(p) + n_2'(p)} \end{aligned} \tag{3}$$

$$m_1'(p) = 1/2, \quad n_1'(p) = p/2$$

$$m_2'(p) = 1, \quad n_2'(p) = 0.$$

$Z_1(p)$ is positive real and

$$m_1'(p)m_2' - n_1'(p)n_2'(p) = 1/2 = 1/2 \cdot (p^2 - 1)^0.$$

$Z_1(p)$ meets the two conditions, but cannot be realized as a cascaded network of equal-length transmission line sections terminated in a resistance. This function should be realized as shown in Fig. 1. The total circuit representation of $Z(p)$ in (2) is shown in Fig. 2.

The following restriction must be added: "3) Assuming that the numerator and denominator of $Z(p)$ in (1) are prime to each other, the degrees of both the numerator and denominator must be equal to n."

* Received by the PGMTT, February 28, 1958.

[1] H. J. Riblet, "General synthesis of quarter-wave impedance transformer," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 36–43; January, 1957.

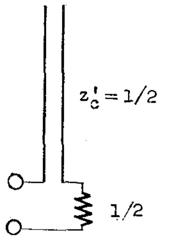

Fig. 1

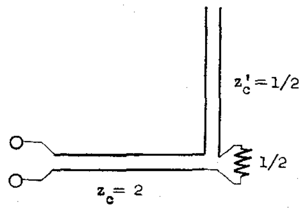

Fig. 2

It is apparent that this third condition is sufficient and mathematical induction will readily prove that it is necessary.

This additional restriction completes the necessary and sufficient conditions. This theorem may also be easily reduced from the writer's theorem 1 presented in anothe publication.[2]

Hiroshi Ozaki
Faculty of Engineering
Osaka University
Osaka, Japan

[2] H. Ozaki and J. Ishii, "Synthesis of transmission-line networks and the design of UHF filters," IRE Trans. on Circuit Theory, vol. CT-2, pp. 325–336; December, 1955. See theorem 1, p. 326.

Ferrite Directional Couplers with Off-Center Apertures*

Introduction

A recent study[1,2] of Bethe's small-hole coupling theory has led to an extension of his work to include the case where the coupling aperture is filled with an anisotropic ferrite. This new theory is applicable to any situation where Bethe's coupling theory is useful and is hindered chiefly by inadequate expressions for the magnetic dipole moments of the ferrite. Fortunately, simple expressions[3] for these magnetic dipole moments are available when the ferrite sample is small compared with the wavelength inside it. Experimental verification of this new coupling theory was obtained with a cross-guide coupler and with a collinear coupler for a centered coupling hole.[4] Since the new theory is equally applicable to situations where the coupling is off center,[5] this paper considers the theoretical and experimental aspects more fully. This seems especially worthwhile since other workers[6,7] have recently considered the case of an off-center aperture. However, their work was performed from either a different viewpoint or else less rigorously. The new coupling theory is quite general and can be used irrespective of waveguide configuration or propagating mode.

In this paper, simple expressions for the coupling and directivity of a cross-guide coupler and a collinear coupler will be presented with some experimental results. In all cases, the ferrite parameters were chosen to obtain a good correspondence between the theoretical and experimental curves of coupled power. Unfortunately, the sample size used was too large to expect exact agreement between theory and experiment.

Theoretical Results

The following theoretical expressions for the coupling and the directivity are good approximations when the coupling hole is small compared with wavelength and when the ferrite sample is small compared with the wavelength inside it. No attempt has been made to determine the limits of the validity of the approximate expressions although experiments indicate that the theory governing the behavior of the ferrite is too simplified for many applications.

The amplitudes of the normal modes excited in the secondary waveguide by a unit normal mode in the primary waveguide are given elsewhere for both the cross-guide coupler[8] and the collinear coupler.[9] The expressions we use below for the coupled power are valid only for two identical rectangular waveguides propagating the TE_{10} mode and for a round coupling hole of diameter d. The coupling hole location is given by x and ξ for $0 \leq x \leq a$ and for $0 \leq \xi \leq a$, where a is the width of the waveguide. The orientation of the waveguides and the definition of the three sets of axes are given in Fig. 1.

For the cross-guide coupler, let us consider the expression for the power coupled in both directions in the secondary waveguide when the coupling hole is located at a point of circular polarization; *i.e.*, when

$$\tan \frac{\pi x}{a} = \tan \frac{\pi \xi}{a} = \lambda_g/\lambda_c.$$

For this case, let us choose the frequency so that $\lambda_g = \lambda_c$. Thus, we obtain in db

$$C_{\perp}^{\pm} = C_0 + 20 \log \left| j(1-\chi_{ll})\Upsilon + R\Psi + \chi_{lm}\Omega \right| \quad (1)$$

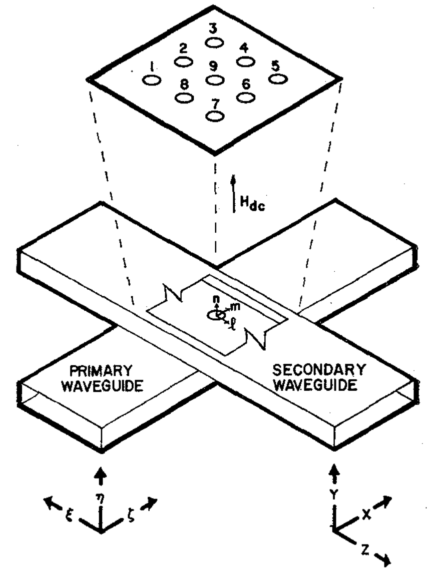

Fig. 1—Cross-guide directional coupler.

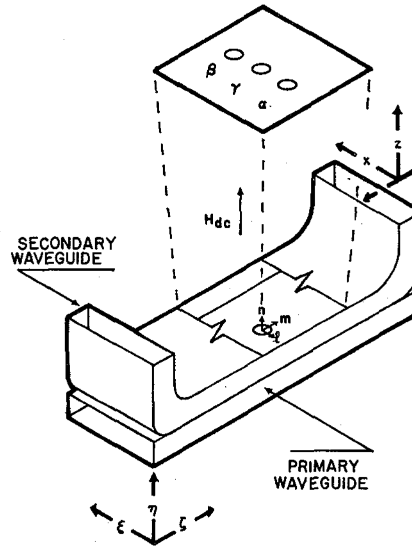

Fig. 2—Collinear directional coupler.

where

$$\Upsilon = \sin \frac{\pi}{a} (\xi \pm x)$$

$$\Psi = \sin (\pi x)/a \sin (\pi \xi)/a$$

and

$$\Omega = \cos \frac{\pi}{a} (\xi \mp x).$$

The upper and lower signs in the superscript indicate the power coupled in the positive and negative directions, respectively. All of the symbols used are defined elsewhere[10] except R which is defined as $R = QF_EF_H^{-1}$.

For the collinear coupler, the expressions under the same conditions are the following in db:

$$C_{\parallel}^{\pm} = C_0 + 20 \log \left| -(1-\chi_{ll})\Omega + j\chi_{lm}\Upsilon + R\Psi \right| \quad (2)$$

where the orientation of the axes is defined in Fig. 2. Eqs. (1) and (2) are given a further

* Received by the PGMTT, March 24, 1958. Presented at the 1957 Annual PGMTT Meeting, New York, N. Y., May 9, 1957.

[1] D. C. Stinson, "Coupling through an aperture containing ferrites," Ph.D. dissertation, Dept. of Elec. Eng., University of California, Berkeley, Calif.; 1956.

[2] D. C. Stinson, "Coupling through an aperture containing an anisotropic ferrite," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 184–191; July, 1957.

[3] *Ibid.*, see Appendix.

[4] *Ibid.*, pp. 188–189.

[5] *Op. cit.*, Ph.D. dissertation, Appendix E.

[6] R. W. Damon, "Magnetically controlled microwave directional coupler," *J. Appl. Phys.*, vol. 26, pp. 1281–1283; October, 1955.

[7] A. D. Berk and E. Strumwasser, "Ferrite directional couplers," Proc. IRE, vol. 44, pp. 1439–1446; October, 1956.

[8] Stinson, *op. cit.*, "Coupling through an aperture containing an anisotropic ferrite," (16).

[9] *Ibid.*, (12).

[10] *Ibid.*, (22) and (28).