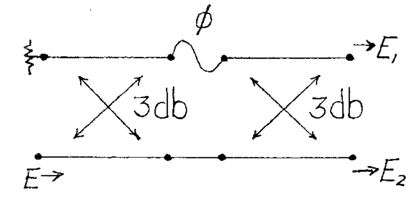

Fig. 1—Schematic of broad-band microwave discriminator.

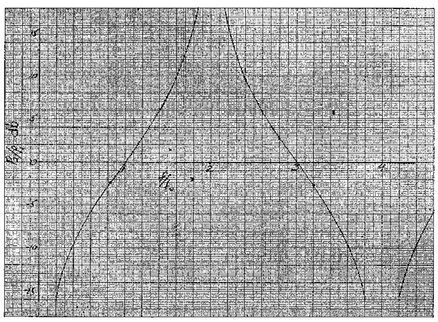

Fig. 2—Theoretical discriminator characteristic.

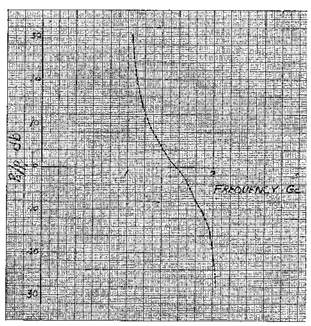

Fig. 3—Experimental data on broad-band microwave discriminator.

It is readily determined from (1) and (2) that

$$|E_1|^2 + |E_2|^2 = |E|^2 \tag{3}$$

and that the device is then 100 per cent efficient.

The ratio of output powers is

$$\frac{|E_2|^2}{|E_1|^2} = \frac{\rho_2}{\rho_1} = \tan^2 \frac{\phi}{2}. \tag{4}$$

Since ϕ is frequency dependent, the ratio of output power is also frequency dependent. Since $\phi = 2\pi(l/\lambda)$, (4) may be modified to

$$\frac{\rho_2}{\rho_1} = \tan^2 \frac{\pi l}{\lambda} \tag{5}$$

where l is the physical line length and λ is the wavelength in the line.

For TEM Propagation (coax), (5) may be written as

$$\frac{\rho_2}{\rho_1} = \tan^2 \pi l \frac{f}{c} \tag{6}$$

where c is the velocity of propagation in the line.

Eq. (6) may be normalized conveniently if the frequency at which l is a quarter wavelength is defined as f_0. Eq. (6) is then

$$\frac{\rho_2}{\rho_1} = \tan^2 \frac{\pi}{4} \frac{f}{f_0}. \tag{7}$$

A plot of (7) is shown in Fig. 2.

From Fig. 2 it is plain that arbitrarily wide or narrow percentage bandwidth may be achieved by suitable choice of the line length difference. Fig. 3 shows data obtained on an experimental coaxial discriminator. The differential line length was approximately three quarter wavelengths long at 1.5 Gc.

The discriminator described is highly efficient and capable of operation over bandwidths limited only by the hybrid.

The author wishes to thank Mr. Adelsberg of the Naval Material Laboratory, Brooklyn, N. Y., for the data on the 1–2 Gc discriminator.

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Frequency Response of Strip-Line Traveling-Wave Directional Filters*

Coale analyzed the single resonator strip-line traveling-wave filter shown in Fig. 1 by a perturbation method.[1] Design criteria were formulated relating loaded Q to pertinent circuit parameters. Experimentally it is observed that properly aligned filters exhibit a frequency response which is approximately Butterworth. The purpose of this communication is to show that the approximate frequency response of narrow bandwidth filters in the absence of dissipation and resonator discontinuities is theoretically Butterworth. Comments on the design problem are included as well as a discussion of the effects of resonator discontinuities.

The method of analysis employed makes use of the physical symmetry of the filter. By applying symmetric and antisymmetric excitation to two colinear arms of the filter as shown in Fig. 2, the four-port problem is reduced to that of solving two, two-port problems. The two, two-ports to be analyzed are shown schematically in Figs. 3 and 4. Making use of the image parameters derived by Jones and Bolljahn for the coupled lines,[2] and using $ABCD$ matrix notation it is readily shown that

$$T_S = \frac{2}{\begin{array}{l}2[\cos\phi\cosh 2\alpha + \sin\phi\sinh 2\alpha\cot 2\theta] \\ +j[\sin\phi(2\cosh^2\alpha - \sinh^2\alpha(\cot^2\theta + \tan^2\theta)) \\ \qquad -2\cos\phi\sinh 2\alpha\cot 2\theta]\end{array}} \tag{1}$$

$$\Gamma_S = j\frac{T_S}{2}([\sin\phi\sinh^2\alpha(\tan^2\theta - \cot^2\theta)] + \cos\phi\sinh 2\alpha(\cot\theta + \tan\theta)) \tag{2}$$

* Received April 9, 1963.

[1] F. S. Coale, "A traveling-wave directional filter," IRE Trans. on Microwave Theory and Techniques, vol. MTT-4, pp. 256–260; October, 1956.

[2] E. M. T. Jones and J. T. Bolljahn, "Coupled strip-transmission-line filters and directional couplers," IRE Trans. on Microwave Theory and Techniques, vol. MTT-4, pp. 75–81; April, 1956.

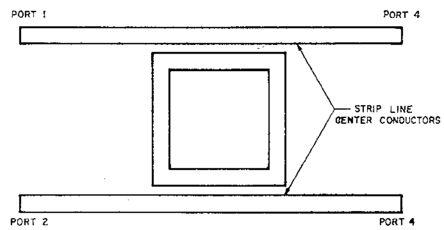
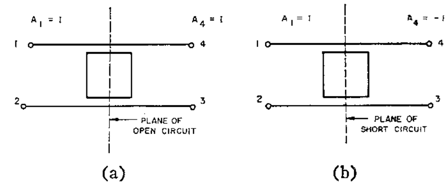


Fig. 1—Loop type strip-line directional filter.



(a) (b)

Fig. 2—Symmetrical and antisymmetrical excitation of the filter. (a) Symmetrical. (b) Antisymmetrical.

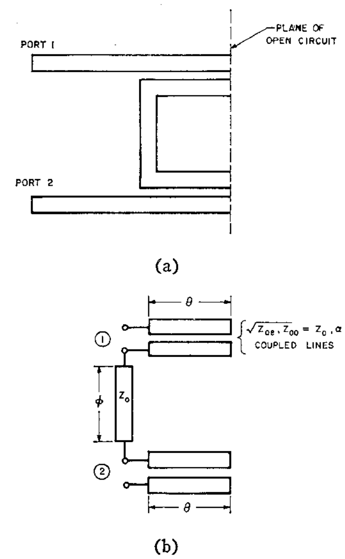


Fig. 3—Network for symmetrical excitation. (a) Two port with symmetrical excitation. (b) Equivalent circuit.

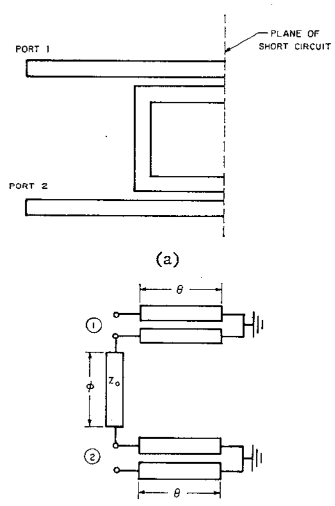


Fig. 4—Network for antisymmetrical excitation. (a) Two port with antisymmetrical excitation. (b) Equivalent circuit.

$$T_A = T_S \tag{3}$$

$$\Gamma_A = -\Gamma_S \tag{4}$$

where

$T_{S,A}$ = transfer function for symmetric and antisymmetric excitation, respectively,

$\Gamma_{S,A}$ = reflection coefficient.

Thus the outputs at the various ports are

$$A_1 = 0$$
$$A_2 = T_S$$
$$A_3 = 0$$
$$A_4 = \Gamma_S.$$

The frequency response of the network is given by

$$L = 10 \log_{10} \frac{1}{|T_S|^2}. \tag{5}$$

Assuming $2\theta = \phi$, the first resonance occurs at $\phi_0 = \pi/2$. In the vicinity of resonance, (4) becomes

$$T_S\Big|_{\substack{\phi \simeq \pi/2 \\ \phi = 2\theta}} = \frac{1}{(\cosh 2\alpha + \sinh 2\alpha)\cos\phi + j1} \tag{6}$$

For narrow bandwidth filters,

$$(\cosh 2\alpha + \sinh 2\alpha) \simeq 4\cosh^2 \alpha \simeq \frac{4Q_L}{\pi}$$

and

$$\cos\phi \simeq \pi/2 - \phi,$$

then

$$T_S \simeq \frac{1}{\frac{4Q_L}{\pi}(\pi/2 - \phi) + j1} \simeq \frac{1}{2Q_L\left(1 - \frac{2\phi}{\pi}\right) + j1}. \tag{7}$$

Since $\phi_0 = \pi/2$,

$$\left(1 - \frac{2\phi}{\pi}\right) = \frac{\phi_0 - \phi}{\phi_0}$$

and

$$2Q_L\left(\frac{\phi_0 - \phi}{\phi_0}\right) = \omega'.$$

Therefore,

$$L = 10 \log_{10} (1 + \omega'^2). \tag{8}$$

Eq. (8) is equivalent to the insertion loss formula for a single resonator Butterworth filter.

Practical development of traveling-wave directional filters in strip-line form is time consuming due to unavoidable discontinuities which exist in the loop. The effects of dielectric post supports and loop corners are to cause the resonant frequency to shift from the derived value and to produce a double resonance in the frequency response. These effects may be taken into account, at least approximately, by replacing the transmission lines which represent the loop sides in the above analysis by a line having image parameters Z_I and ϕ_I. The image line is derived so as to take discontinuities into account. Fig. 5 shows the procedure for a discontinuity whose equivalent circuit is in the form of a symmetrical Tee (such as a mitered corner). A difficulty in pursuing this method further lies in the fact that expressions for the equivalent circuit parameters of mitered bends are not readily available. (Mitered bends are normally used in practice since they present the minimum discontinutiy.) If right angle bends are considered[3] it is found that

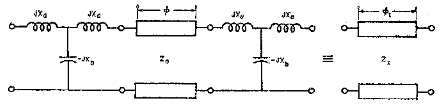


Fig. 5—Loop side equivalent with corner discontinuities.

1) The image impedance characteristics are poor.
2) The terminal planes at which the equivalent circuit is known extends well into the region of the coupled lines. Thus local fields become a problem.

In summary, it has been shown that narrow bandwidth strip-line traveling-wave filters yield a Butterworth response. A method of accounting for loop discontinuities has been suggested. Difficulties in applying the method are outlined. Work in this area is continuing.

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[3] A. A. Oliner and H. M. Altschuler, "Discontinuities in the center conductor of symmetric strip transmission line," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-8, pp. 328–339; May, 1960.

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Dr. Bady is a member of Phi Beta Kappa and Sigma Xi.

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From 1942 to 1945 he was employed as a special research associate by the Radio Research Laboratory of Harvard University, and also represented that laboratory as a technical observer with the U. S. Army Air Force in the Mediterranean theater of operations. He worked at Sperry Gyroscope Company, Great Neck, N. Y., from 1948 to 1953, where he held the position of research engineer in the microwave instruments and components department. From 1953 to 1960, he was with the Stanford Research Institute, Menlo Park, Calif., as head of the Microwave Group and, since 1957, as manager of the Electromagnetics Laboratory. In July, 1960, he joined Rantec Corporation, Calabasas, Calif., as Vice President and Technical Director.

Dr. Cohn is a member of Tau Beta Pi and Sigma Xi. He is a member and ex-chairman of the PTGMIT Administrative Committee.