II-8 A STRIPLINE DIRECTIONAL COUPLER UTILIZING A NON-HOMOGENEOUS DIELECTRIC MEDIUM

J.E. Dalley

Bell Telephone Laboratories, Inc.

In the conventional 3 db directional coupler, shown schematically in Figure 1a, equal output signals appear at ports 2 and 3 when port 1 is used as the input. No signal appears at port 4. The effective dielectric constant for the even mode (ϵ_{re}) must be approximately equal to the effective dielectric constant for the odd mode (ϵ_{ro}) to assure equal propagation velocities which are essential for this type of coupler.

The coupler described in this paper, and shown schematically in Figure 1b, utilizes a non-homogeneous dielectric to obtain unequal odd and even mode propagation velocities. The non-homogeneous dielectric is formed by depositing thin-film conductors on a hard dielectric substrate which is placed between two ground planes as shown in Figure 1c. For the configuration shown, ϵ_{re} is nearly unity since very few electrical field lines pass through the dielectric substrate. On the other hand, the odd mode is heavily loaded by the substrate dielectric constant and $\epsilon_{ro} > \epsilon_{re}$ when the relative dielectric constant (ϵ_1) is greater than unity. This causes odd mode to propagate more slowly than the even mode and the electrical length of the coupler for the odd mode is greater than the electrical length for the even mode. If ϵ_1 and the coupler geometry are properly chosen, the even and odd mode signals add in such a way that no signal appears at port 3, and equal signals with 90° phase difference appear at ports 2 and 4. The simplicity of fabrication and the fact that the output ports are conductively connected to each other and isolated from the input and null ports make this coupler attractive for use with balanced transistor amplifiers similar to those recently described. [1,2]

In order to better understand the theory of the coupler and to develop a basis for design, the work of Jones and Bolljahn[3] was extended to include the nonhomogeneous dielectric case. Equations for the driving point impedance and for the voltages appearing at ports 2, 3, and 4 were derived and programmed for solution on a digital computer. Solutions were obtained at many frequencies for several sets of conditions. Reducing the computer data confirmed that the ratio of the odd mode to the even mode propagation constants dominates the coupler design and performance. This ratio can be expressed as

$$P = \sqrt{\epsilon_{ro}/\epsilon_{re}} \quad (1)$$

It was found that the return loss and the isolation were both theoretically infinite at one frequency which was designated as f_1 and used to define the normalized frequency

$$F = f/f_1 \quad (2)$$

A coupling factor was also defined as

$$A = \sqrt{Z_{oe}/Z_{oo}} \quad (3)$$

where Z_{oe} snd Z_{oo} are the even and odd mode characteristic impedances of transmission line A (Figure 1c) in the presence of line B with the appropriate mode excitation applied to both transmission lines.

The output from each port was plotted and the results were summarized to form the basis for design curves. Figure 2 shows the coupler outputs and the phase between ports 2 and 4 for a value of P = 3.0. A_1 is defined as the value of A required for equal output voltage at ports 2 and 4 at F = 1.0. The slight overcoupling obtained by setting A/A_1 = 1.025 restricts the deviation from the 3 db level at ports 2 and 4 to ± 0.13 db over a 20% bandwidth. The phase difference between ports 2 and 4 is 90 ± 0.4 degrees over the same bandwidth. The output from port 3 and the return loss curves are coincident from F = 0.95 to F = 1.05. They differ by only 1 db at the edges of a 30% bandwidth, hence, only the return loss curve is shown. The return loss degrades symmetrically as the normalized frequency deviates from 1.0. Furtunately, the mismatch is easily compensated by simple techniques. The compensated return loss curve shown was obtained by using a quarter-wavelength shorted stub connected to port 1. This gives a minimum return loss of 33 db over the 20% bandwidth. More elaborate compensation methods may be employed, if desired, to obtain wider bandwidths at a specified return loss.

A value of P = 3.0 cannot be achieved with present substrates which are suitable for thin-film circuits since ϵ_{re} is always greater than unity and ϵ_{ro} must be less than ϵ_t which is approximately 9.0 for alumina substrates. Changing P shifts the center of the coupling passband (f_2) with respect to f_1 as shown by Figure 3. Using a practical value of P = 2.41 resulted in the theoretical curves of Figure 4.

The coupling factor (A) required for a given value of V_2/V_4 at f_2 is a function of P and curves are given in Figure 5 for values of P ranging from 2.2 to 3.0.

The experimental points shown in Figure 4 are for an uncompensated coupler using a Coors AD94 alumina substrate with a thickness of 0.05 inch and a nominal relative dielectric constant of 8.9. The experimental results for the same coupler are shown in Figure 6 with a compensating shorted stub connected to port 1. The slight increase in coupling when compensation is applied is typical. The small differences between the theoretical and experimental results of Figures 4 and 6 are due to the fact that the return loss at F = 1.0 for the uncompensated coupler was only 29.5 dB, due to improper adjustment of the coupler parameters, instead of the infinite value as assumed for the theoretical model. With more careful adjustments of the conductor line widths and the ground-plane spacing, return loss values of greater than 50 dB at F = 1.0 have been observed.

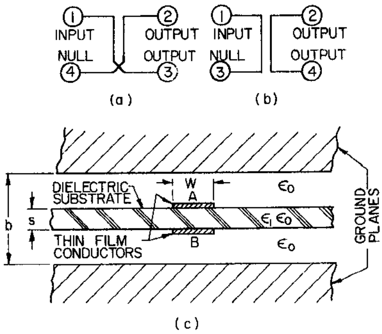
For the compensated coupler, a theoretical bandwidth of 17% with a return loss of greater than 25 dB was predicted and a 22 dB return loss was actually achieved at the worst point in this bandwidth. The minimum return loss can be increased to approximately 27 dB by moving the point at which compensating stub is connected a short distance toward the generator.

Acknowledgement

Part of the work reported in this paper was conducted under Contract No. DA-30-069-AMC-333(Y) sponsored by the U.S. Army.

References

1. K.M. Eisele, R.S. Engelbrecht and K. Kurokawa, "Balanced Transistor Amplifiers for Precise Wideband Microwave Applications", ISSCC Digest of Technical Papers, pp. 18-19, 1965.
2. R. S. Engelbrecht and K. Kurokawa, "A Wideband Low Noise L-Band Balanced Transistor Amplifier", Proc. of the IEEE, Vol. 53, No. 3, pp. 237-247, March 1965.
3. E.M.T. Jones and J.T. Bolljahn, "Coupler Strip-Transmission-Line Filters and Directional Couplers", IRE Transactions on Microwave Theory and Techniques" pp. 75-81, April 1956.



(a) SCHEMATIC OF CONVENTIONAL COUPLER

(b) SCHEMATIC OF NEW COUPLER

(c) CROSS SECTION OF NEW COUPLER

FIGURE 1

THEORETICAL COUPLER RESPONSE WITH P = 3.0

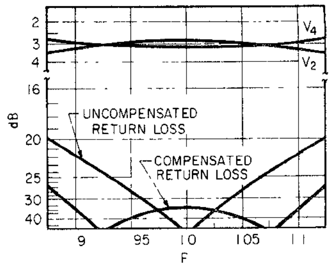


FIGURE 2

P AS A FUNCTION OF f_2/f_1

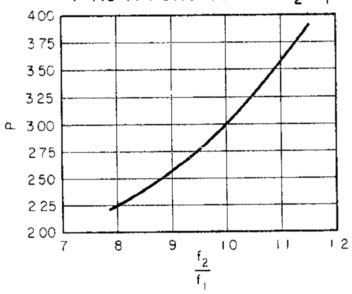


FIGURE 3

COUPLER RESPONSE WITH P=2.41

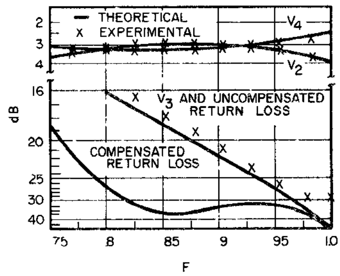


FIGURE 4

COUPLING PARAMETER AT f_2

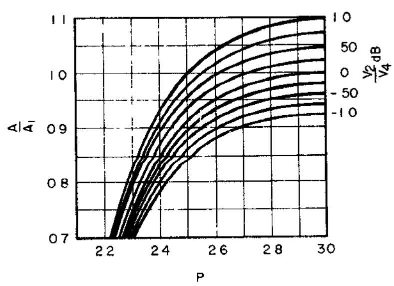


FIGURE 5

EXPERIMENTAL COUPLER RESPONSE WITH ϵ_1=8.9

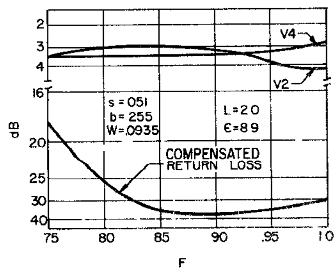


FIGURE 6