THE VIRTUES OF MIXING TANDEM AND CASCADE COUPLER CONNECTIONS

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The design of wideband coupled transmission line hybrids is complicated by the necessity of having the coupled lines in a close physical proximity to achieve the desired -3.01 dB coupling. The required coupling coefficient is particularly difficult to achieve for coupler designs covering greater than an octave. Several techniques have been used to overcome this limitation. The principal methods are the re-entrant coupler[1] and the tandem coupler[2] techniques. The re-entrant coupler employs a modification of the transmission line geometry of a single quarter-wave section to obtain the desired increase in coupling. The technique described in this paper is similar to the tandem coupler technique since a judicious connection of coupled quarter-wave line sections is employed to obtain the desired coupling enhancement rather than a modification of the line cross-section.

The tandem coupler technique as described by Shelton[2] is illustrated in Figure 1a. The method can be used for either symmetric or asymmetric couplers and where the couplers are either identical or dissimilar. Since there is no interaction between the couplers, the output of the resulting coupler may be calculated in a straightforward manner. An alternate method of obtaining a similar coupler performance is illustrated in Figure 1b. This coupler employs a cascade of single and tandem coupled sections to obtain wideband quadrature hybrid performance. This three-section coupler has been analyzed and found to have similar performance to the coupler illustrated in 1a. Thus, a reduction in path length is achieved by using the cascade-tandem connection. The asymmetric design illustrated in Figure 1c has a significant advantage over the two-section asymmetric design. It can be shown that by a proper selection of the coupling coefficients that a wideband magic-T design can be achieved. This is in contrast to the two-section asymmetric design where magic-T performance can be achieved over a significant bandwidth only by the addition of an external phase compensator[3].

The cascade-tandem coupler can be analyzed by use of the transmission matrices. Using the notation shown in Figure 2 and converting from scattering parameters, the transmission matrices may be shown to be:

$$\frac{1}{\delta}\begin{Vmatrix} 1 & 0 & 0 & -\gamma \\ 0 & \delta^2-\gamma^2 & \gamma & 0 \\ 0 & -\gamma & 1 & 0 \\ \gamma & 0 & 0 & \delta^2-\gamma^2 \end{Vmatrix}$$

for the single coupled lines where γ is the coupled signal level and δ is the direct signal level, and

$$\frac{1}{\Gamma}\begin{Vmatrix} 0 & -\Delta & 1 & 0 \\ \Delta & 0 & 0 & \Gamma^2-\Delta^2 \\ 1 & 0 & 0 & -\Delta \\ 0 & \Gamma^2-\Delta^2 & \Delta & 0 \end{Vmatrix}$$

for the tandem coupler, where Γ and Δ are the coupled and direct path signals. Thus, for any cascade combination of single and tandem coupled lines, the response can be calculated by matrix multiplication.

For the two-section coupler illustrated in Figure 1c, the resulting scattering parameters are:

$$S_{12} = \frac{\Delta + \gamma(\Gamma^2 - \Delta^2)}{1 - \gamma\Delta}$$

$$S_{14} = \frac{\Gamma\delta}{1 - \gamma\Delta}$$

By selecting the even mode impedances, Z_1, for the single coupled section and Z_2 for the tandem coupler, the performance of the device as a magic-T can be optimized. Optimum performance over an octave band is achieved with the impedances $Z_1 = 1.465$ and $Z_2 = 1.74$. These impedances give a device having a worst case amplitude imbalance of 0.255 dB and a worst case phase imbalance of 2.04 degrees. This band is arithmetically centered at the frequency where the coupled lines are a quarter-wavelength long. It has been noted that if only the amplitude of the coupling is of interest, a much greater bandwidth can be achieved for equivalent coupling performance.

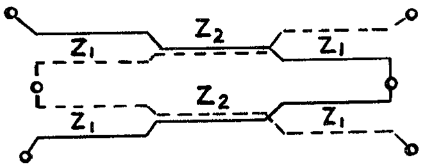
An experimental coupler was constructed in a three-layer strip transmission line package. The dielectric material used was Duroid, a micrifiber reinforced Teflon material. The center layer was chosen to be 0.040-inch thick and the two outer layers were 0.062-inch thick. These thicknesses were chosen to give the desired Z_2 = 1.74 coupling for complete overlap in the tandem coupler section. The measured performance of this magic-T is illustrated in Figure 3. Good agreement was obtained between the measured and theoretical data with a worst case measured phase imbalance of 5 degrees and an amplitude imbalance of 0.5 dB.

The tandem-cascade connection of couplers permits the designer an additional degree of freedom in the layout of coupled transmission line devices. It appears to have merit in the design of wideband quadrature couplers, magic-T's, and directional filters.

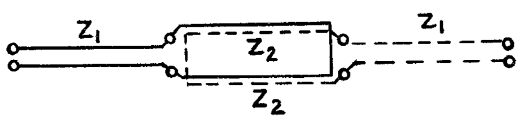
[1] S. B. Cohn, "The Re-Entrant Cross Section and Wideband 3 dB Hybrid Couplers," IEEE Transactions, Vol. MTT-11, pp. 254-258, July 1963.

[2] J. P. Shelton, J. F. Wolfe and R. C. VanWagoner, "Tandem Couplers and Phase Shifters for Multi-Octave Bandwidths," Microwaves, pp. 14-19, April 1965.

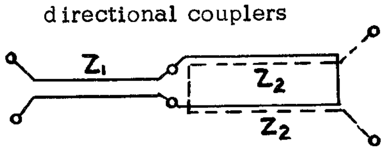
[3] D. I. Kraker, "Asymmetric Coupled-Transmission Line Magic-T," IEEE Transactions, Vol. MTT-12, pp. 595-599, November 1964.



1a. Tandem connection of two cascaded symmetrical couplers

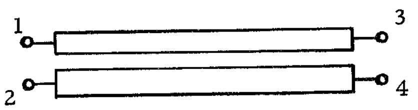


1b. Cascade-tandem connection of directional couplers



1c. Realization of Magic-T using cascade-tandem connection of directional couplers

Figure 1. Tandem and Cascade-Tandem Connection of Directional Couplers

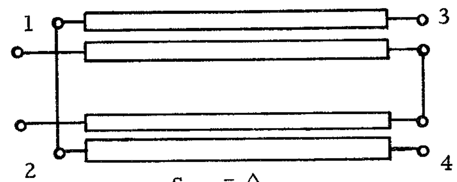


$s_{12} = \gamma$

$s_{13} = \delta$

$s_{11} = s_{14} = 0$

Single section coupler



$s_{12} = \Delta$

$s_{14} = \Gamma$

$s_{11} = s_{13} = 0$

Tandem coupler

Figure 2. Notation Used for Scattering and Transmission Matrices

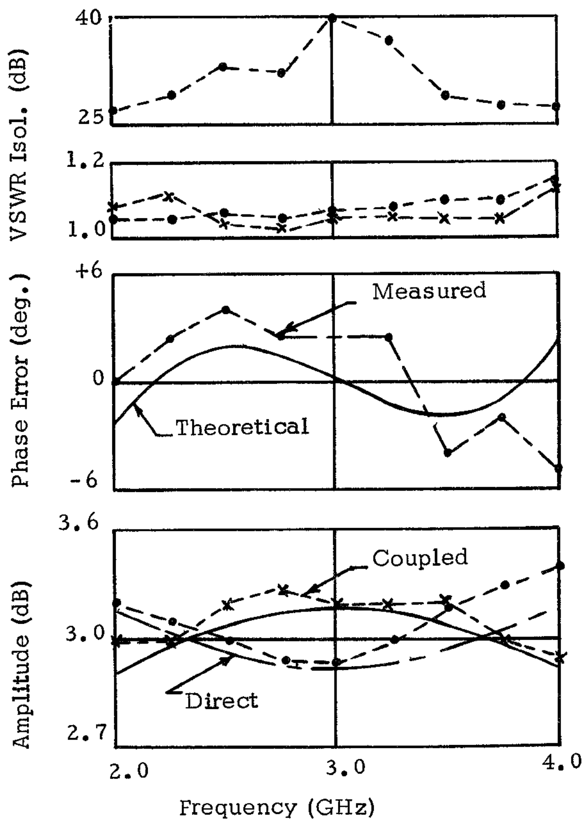


Figure 3. Theoretical and Measured Performance of the Cascade-Tandem Magic-T