IV-7. THE DESIGN AND CONSTRUCTION OF BROADBAND, HIGH-DIRECTIVITY 90° COUPLERS USING NON-UNIFORM LINE TECHNIQUES

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It is presently possible to obtain multi-octave bandwidth from a single coupler which employs several cascaded quarter-wavelength sections of uniformly-coupled line. A comprehensive bibliography covering progress in this field may be found in Reference 1. Unfortunately, the physical junctions between various quarter-wave sections in the usually employed TEM conductor geometries contribute reactive discontinuities which significantly degrade coupler directivity.

This paper describes a design which eliminates the abrupt interconnections between coupled sections. The coupling coefficient is gradually tapered from loose to tight coupling (in the center) and then back to loose coupling in a symmetrical manner to preserve the 90-degree character of the design. Since sudden changes in line geometry are absent, the isolation of the coupler is improved over that of stepped designs. The familiar condition, $\sqrt{Z_{oe} \cdot Z_{oo}} = 1$, must be observed throughout the coupler to insure that high isolation prevails.

The theory of design can be developed with the aid of the transmission line analogy.[1] Analysis and synthesis can be performed directly in the case of loose coupling. Under this assumption, one can show that coupling C at frequency ω is given by

$$C(\omega) = \frac{1}{2} \int_{o}^{d} e^{-2j \frac{\omega}{v}} \frac{d}{dx} \left[\log Z_{oe}(x) \right] dx \qquad (1)$$

where d is the overall coupler length, v is the velocity of propagation in the medium of interest, and Z_{oe} is the even mode impedance of the coupled lines. Coupling is essentially the Fourier transform of the rate of change of even-mode impedance. Synthesis can thus be performed by application of an inverse Fourier transformation. Since even-mode impedance of the coupler is symmetric about the coupler center, the derivative of the logarithm of this curve will be odd, as shown in Figure 1(a). It is convenient to shift axes in the integral to take advantage of this fact. One obtains:

$$C(\omega) = -je^{-j \frac{\omega}{v} d} \int_{-\frac{d}{2}}^{\frac{d}{2}} \sin 2 \frac{\omega}{v} u \cdot p(u)\, du \qquad (2)$$

where

$$p(u) = \frac{1}{2} \frac{d}{du} \left[\log Z_{oe}(u) \right].$$

The magnitude and phase of C(ω) are shown in Figure 1(b). By assuming a desired magnitude versus frequency characteristic and using phase as shown, one can, by inverse Fourier transformation, obtain the required function of coupling versus distance. A Scientific-Atlanta CF 1 Fourier integral computer has been used to perform this transformation. Higher order coupling theory can be obtained from the work of Youla [2] and has been applied in the design of nonuniform line couplers.

Two coupler classes have been considered. The first class consists of couplers for which p(u) increases monotonically from loose coupling at the coupler edge to tight coupling in the center, as illustrated in Figure 1. Figure 2 shows an etched board used to realize such a design in three-layer polyolefin stripline consisting of two 0.062-inch groundplane boards and one 0.010-inch centerboard. The measured response of this coupler is shown in Figure 3, along with the normalized first order description of the design. The minimum directivity of this coupler is 20 db up to approximately 7.5 GHz. A tandem coupler composed of two sections similar to the above design has been constructed for use in a phase-to-amplitude antenna processing system which operated successfully through 11 GHz.

The second class of coupler incorporates periodic zeros in the p(u) characteristic as shown in Figure 4. This class of coupler represents an improvement over the monotonic p(u) design in that the high frequency tail, evident in Figure 1, is eliminated (thereby increasing the mean coupling bandwidth product exhibited for a given center coupling level). Another advantage of the periodic p(u) design is that a closed form synthesis procedure has been developed which provides equal-ripple coupling response for this coupler. The procedure uses a function generated on a digital computer to weight the basic Fourier representation of band limited, constant level coupling so as to eliminate Gibb's phenomenon and preserve flat response under tight coupling conditions.

Preliminary work on very tight physical coupling indicates that a coupling coefficient of about 0.9 can be achieved in three-layer polyolefin stripline using 0.0015-inch centerboard and 0.062-inch ground plane boards. With such a geometry, it is possible to synthesize a periodic p(u), 3-db hybrid which exhibits more than two-octave bandwidth without resorting to tandem interconnection of several coupled sections. This configuration is shown in Figure 5. The measured response is given in Figure 6. Coupling variation exceeded the design tolerance of ±0.25 db primarily due to uncertainty in knowledge of the impedance of the stripline geometry. The stripline conductor width is approximately one-sixth of that corresponding to Z_o = 50 ohms in the tightly coupled center region (where conductor foil thickness approximately equals the thickness of the dielectric board separating the two lines). First trial measured isolation, however, was a minimum of 21 db from dc to beyond 7 GHz (18-db minimum directivity in the band of interest). A measurement program has been initiated to determine stripline impedances more accurately for improving both directivity and the coupling characteristic. Broader bandwidth couplers can be obtained by using tandem interconnections of several couplers without resorting to the extremely tight coupling levels described.

Recently, information has appeared on a tapered line coupler which also possesses broadband, high isolation characteristics.[3] The device, called a tapered line Magic T, is considerably longer than the symmetric tapered coupler, and relies on a single abrupt discontinuity to provide broadband coupling. The taper of the Magic T is very gradual so that, by design, little coupling is contributed by the taper itself within the band of interest. The symmetric tapered line coupler in contrast relies on (relatively) rapid variation of coupling with distance to provide the requisite overall coupling.

REFERENCES

1. E. G. Cristal, R. Young, "Theory and Tables of Optimum Symmetrical TEM Mode Coupled Transmission Line Directional Couplers," IEEE Transactions on Microwave Theory and Techniques, September 1965, pp. 545-558.
2. D. C. Youla, "Analysis and Synthesis of Arbitrarily Terminated Lossless Nonuniform Lines," IEEE Transactions on Circuit Theory, Vol. CT-11, No. 3, September 1964.
3. R. H. DuHamel, M. E. Armstrong, "A Wide-Band Monopulse Antenna Utilizing the Tapered Line Magic-T," Fifteenth Annual Symposium, Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio, in cooperation with the University of Illinois, October 12-14, 1965 at Monticello, Illinois.

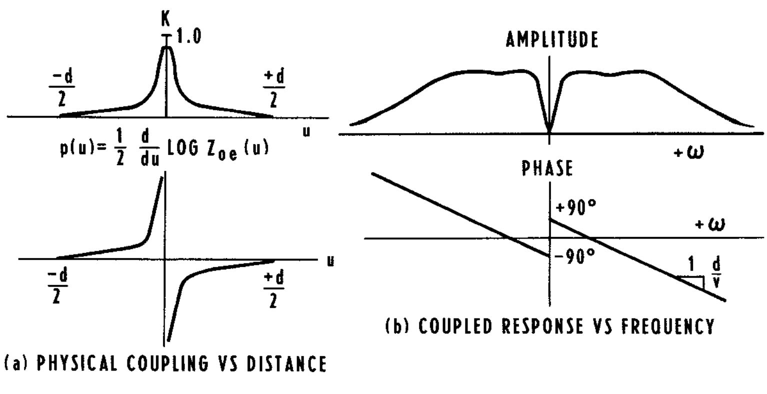

Figure 1 - First Order Coupling Characteristics

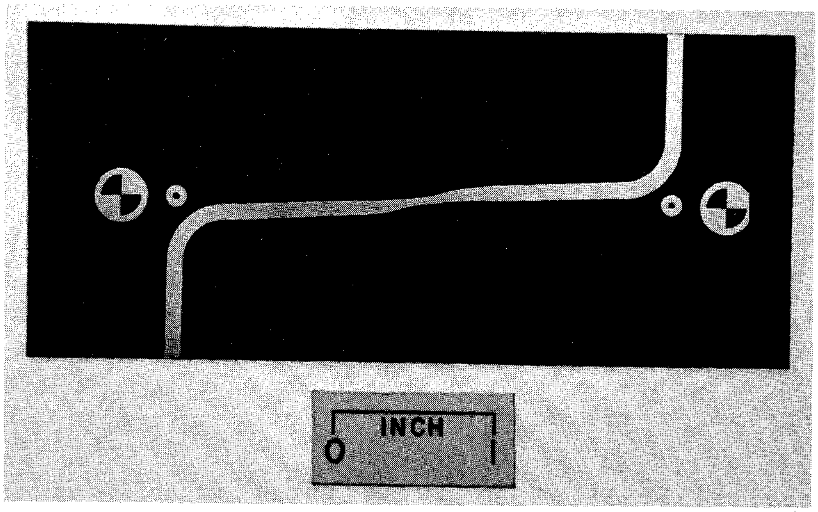

Figure 2 - Stripline Board Used in 7:1 Bandwidth Monotonic p(u) Coupler

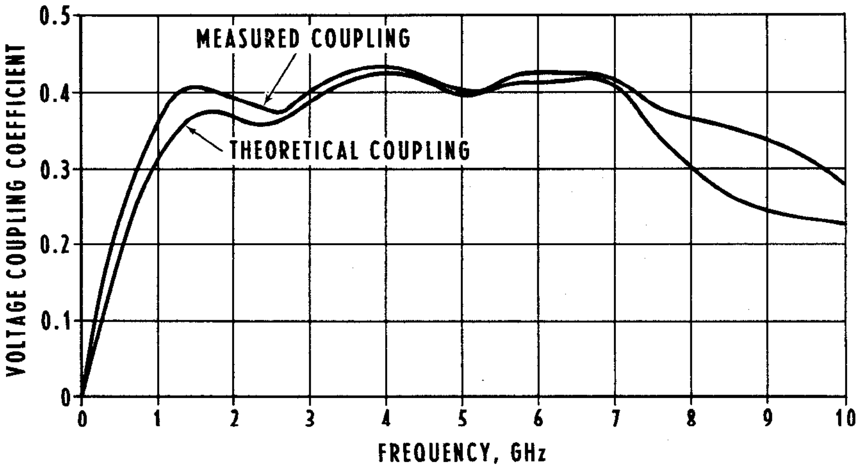

Figure 3 - 7:1 Bandwidth Monotonic p(u) Coupler Response

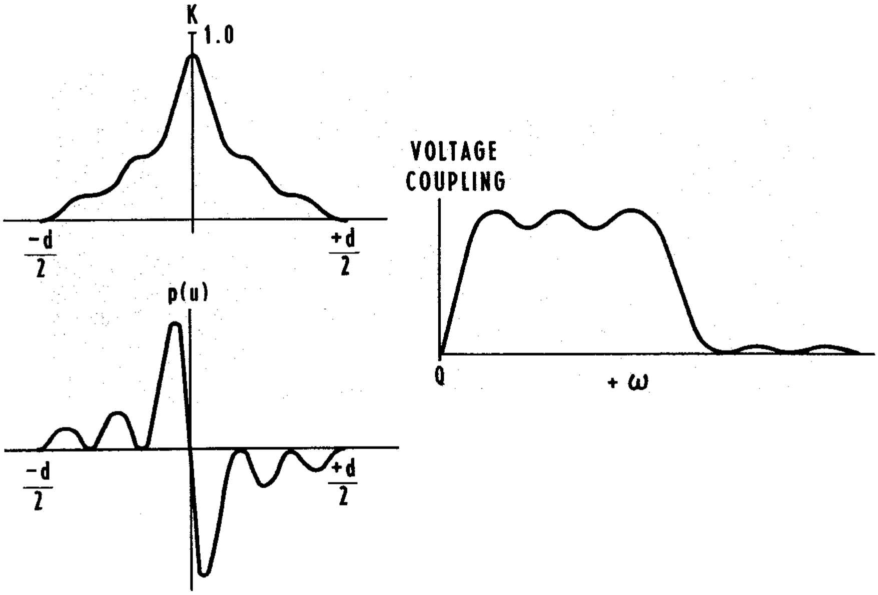

Figure 4 - Response of a Typical Periodic p(u) Coupler

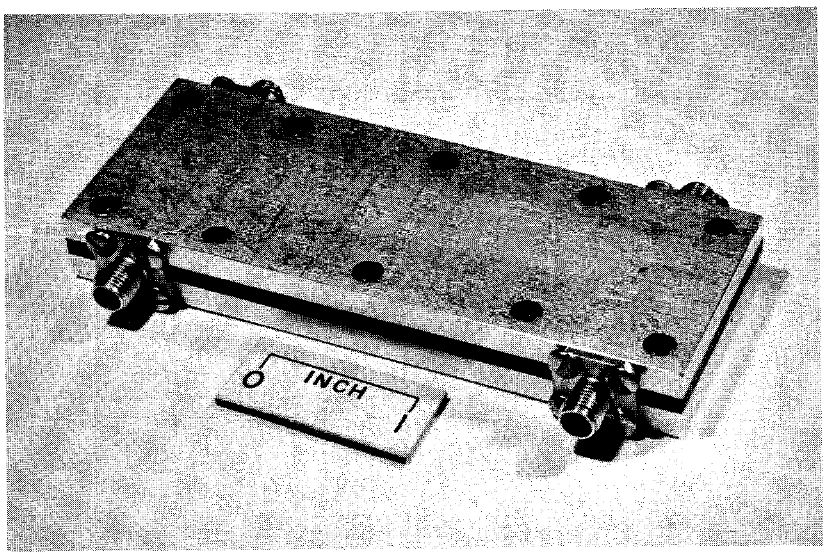

Figure 5 - Coupler Packaging

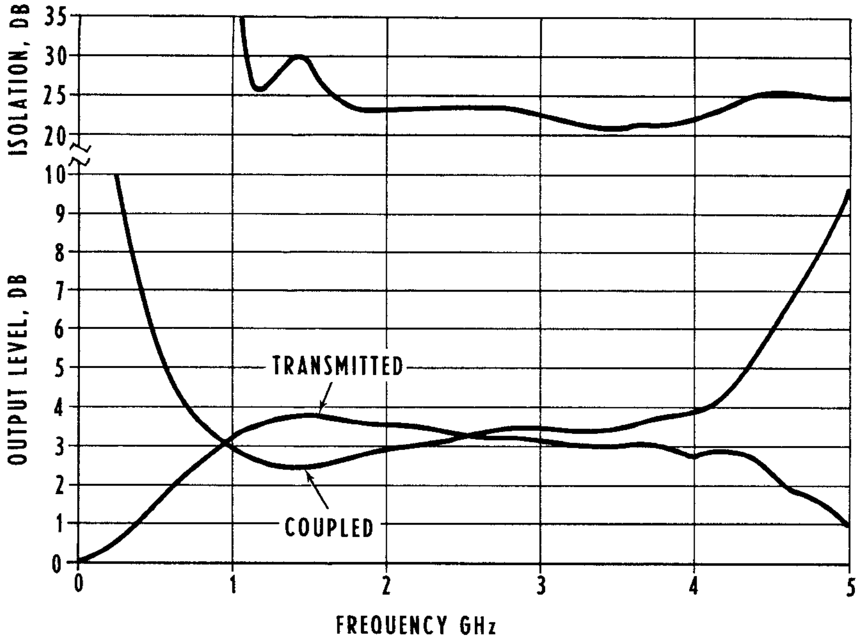

Figure 6 - Measured Performance of Periodic p(u), 3-db Hybrid