A MICROSTRIP RE-ENTRANT MODE QUADRATURE COUPLER FOR HYBRID AND MONOLITHIC CIRCUIT APPLICATIONS

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ABSTRACT

The re-entrant mode TEM coupling method allows the MMIC design engineer to fabricate low loss couplers on either GaAs or Al_2O_3 substrates without the problems encountered in fabricating long fine line structures. In addition, since the odd mode energy is mainly contained in a high dielectric region rather than in air, the even and odd mode velocities are closely matched thus enabling the coupler to exhibit excellent VSWR and differential phase performance.

INTRODUCTION

A variety of backward coupling methods have been used to realize tightly coupled structures for microstrip and stripline applications. However, when hard substrates are employed, such as in the design of MIC's, tight coupling, which is required in the realization of broadband couplers, can usually be obtained only with interdigitated structures. Even if suspended techniques are used, coupling values tighter than -3 dB are still difficult to obtain in a planar media such as microstrip.

DESIGN

An alternate coupling design for microstrip applications, that does not require interdigitated transmission line conductors in order to achieve tight coupling, will be illustrated. The re- entrant mode technique, which was described for coaxial couplers by Seymour B. Cohn [1], and later for stripline by L. Lavendol [2], can be modified for microstrip applications. The coupling concept can be easily understood by considering the coaxial cross-section shown in Figure 1.

If a conducting shield (C) is placed around the inner conductors A and B, the shield forms a single conductor transmission line of impedance Z_{01} with the outer jacket. The transmission lines formed by the inner shield and center conductors A and B, exhibit a characteristic impedance Z_{02} with respect to the shield. Although it appears that the conductors are decoupled, it must be remembered that the shield (C) is floating and that the impedance Z_{01} is in series with the transmission lines of A-C and B-C, thus forming a mutually coupled media. Hence by bisecting the coupler's cross- section (Figure 2), the characteristic impedances, Z_{oe} and Z_{oo}, for the total structure can be found. The even mode impedance occurs between A (or B) and the outer jacket, assuming that the structure is bisected with a magnetic wall, and the odd mode impedance occurs when the structure is bisected with an electric wall.

Hence the even mode impedance can be defined as

$$Z_{oe} = Z_{02} + 2Z_{01}$$

and, the odd mode impedance can be expressed as

$$Z_{oo} = Z_{02}$$

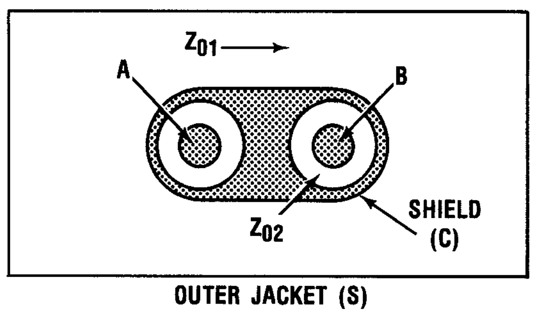

Figure 1. Re-entrant Mode Coaxial Coupler Cross-Section

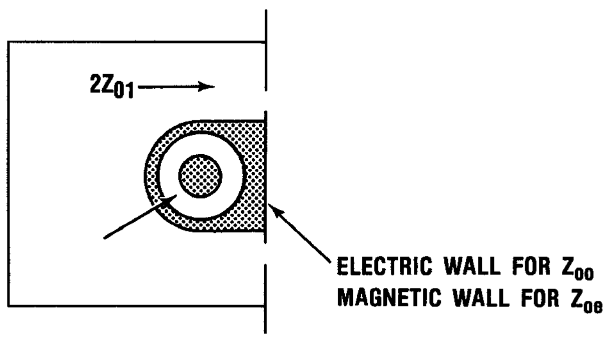

Figure 2. Boundary Conditions for Determining the Even and Odd Mode Impedances In Coupler Cross-Section

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As with any TEM mode coupler, the characteristic impedance Z_o and the coupling factor k can then be determined. Thus,

$$Z_o = (Z_{oo}Z_{oe})^{1/2}$$

and

$$k = \frac{Z_{02}}{Z_{01}+Z_{02}}$$

The coaxial structure can easily be converted to micro-strip by adding an additional film dielectric and conducting layer. The shield can be formed by the base conductor metal which is used by the rest of the interfacing circuits, while the conductors A and B are formed by plating a conductor on top of the dielectric film as is done in making a thin film or MIM (metal-insulator-metal) capacitors. The planar microstrip structure, which is compatible with either thin film or monolithic topologies, is shown in Figure 3. The coaxial approximations still apply to the microstrip structure since the dielectric film can be made very thin, thus isolating conductors A and B except through the floating strip. It is also evident that the coupling k can be made very large since Z_{02} can almost be made arbitrarily low by thinning the dielectric film.

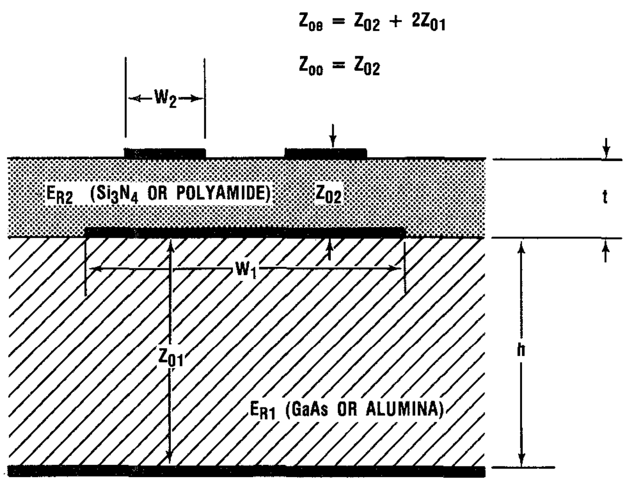

Figure 3. Microstrip Re-entrant Mode Coupler Cross-Section

The structure also has several other subtle advantages. Since strips A and B are coupled only through the shield, the gap between them need to be controlled providing it is sufficiently wide. The odd mode velocity is also dominated by the dielectric film which can have a permittivity close to that of the main substrate. Thus, the even and odd mode velocity ratios can be well matched. Because the velocities can be matched much closer than with a conventional Lange coupler, the broadband return loss and port-to-port differential phase (quadrature) performance exhibited in a microstrip re-entrant mode coupler can also be much better. Table 1 illustrates typical circuit dimensions for either a microstrip or monolithic quadrature coupler.

TABLE 1. TYPICAL CIRCUIT DIMENSIONS FOR VARIOUS MICROSTRIP COUPLERS

W_1 (mm)	w_2 (mm)	t (mm)	h (mm)	Z_{01} (Ω)	Z_{02} (Ω)
ALUMINA (E_{R1} = 9.9; E_{R2} = 3.7)					
0.254	0.0685	0.0075	0.381	59.83	18.14
GaAs (E_{R1} = 12.9; E_{R2} = 6.8)					
0.075	0.015	2.3 um	0.100	49.8	18.00
0.115	0.015	2.5 um	0.150	49.8	18.00
GaAs (E_{R1} = 12.9; E_{R2} = 3.7)					
0.115	0.015	.006	0.150	49.8	18.00

RESULTS

In order to evaluate the concept, a microstrip -3 dB quadrature coupler was fabricated on .381 mm thick alumina. A polyamide film, 0.0075 mm thick with a permittivity of 3.7, was used as the dielectric film layer. The coupler strip conductors were formed by plating gold to a thickness of about 3 to 4 μm on top of the polyamide film.

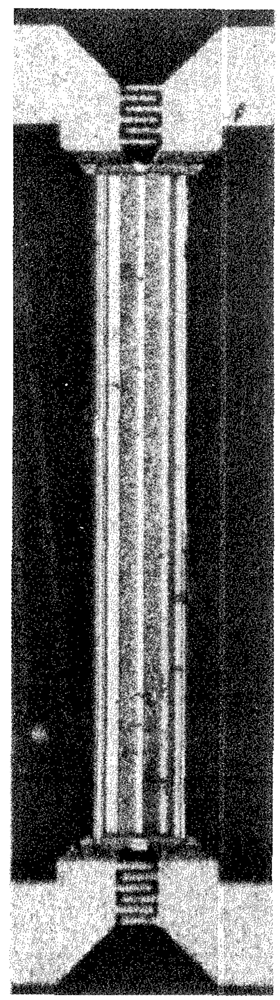

Figure 4. Re-entrant Mode Coupler Fabricated on an Alumina Substrate

The completed coupler is shown in Figure 4. Interdigitated capacitors, which were used for velocity compensating the coupler, were added on the substrate metal layer and can be seen in Figure 5. The transmission loss performance of the coupler is very similar to conventional microstrip designs (Figure 6a) while the input VSWR tends to be better (Figure 6b). The differential phase performance between coupler outputs, which is shown in Figure 7, is also quite respectable. A 180° balun was also designed using the coupler in series with a 90° Schiffman [3] section. The completed balun, shown in Figure 8, exhibited excellent amplitude and phase and balance (Figure 9).

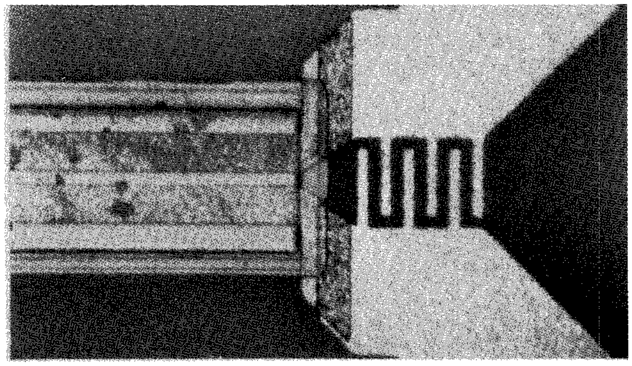

Figure 5. Velocity Compensation Interdigitated Capacitor

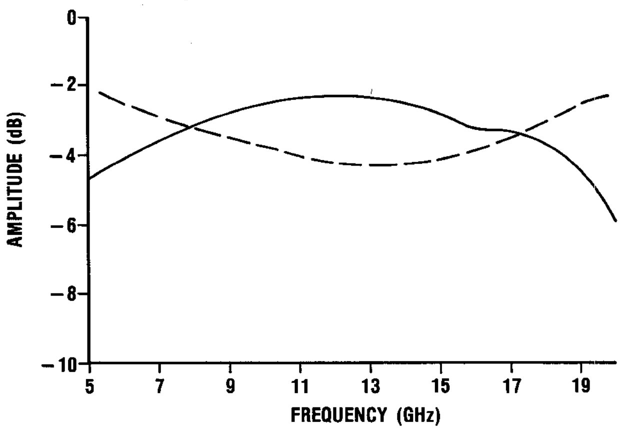

Figure 6a. Coupler Performance; Transmission Loss

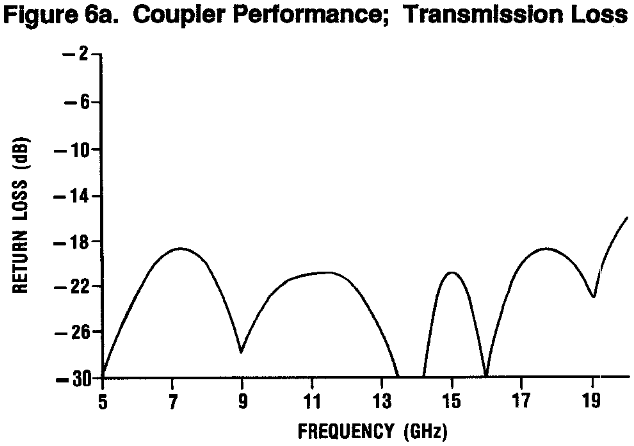

Figure 6b. Coupler Performance; VSWR

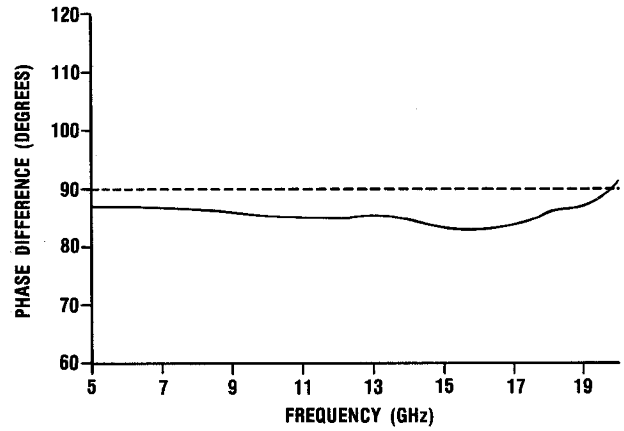

Figure 7. Quadrature Performance of -3 dB Coupler

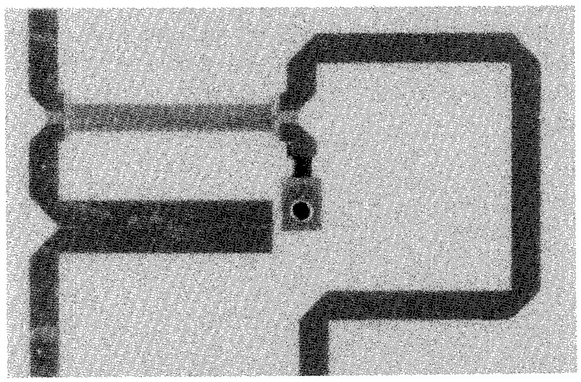

Figure 8. Microstrip 180° Balun Fabricated on an Alumina Substrate

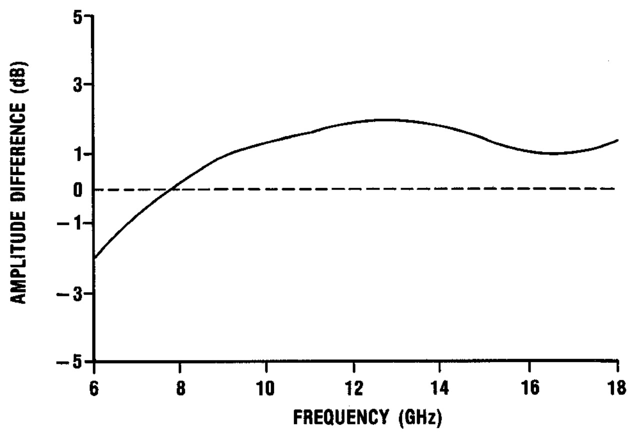

Figure 9a. Balun Performance; Amplitude

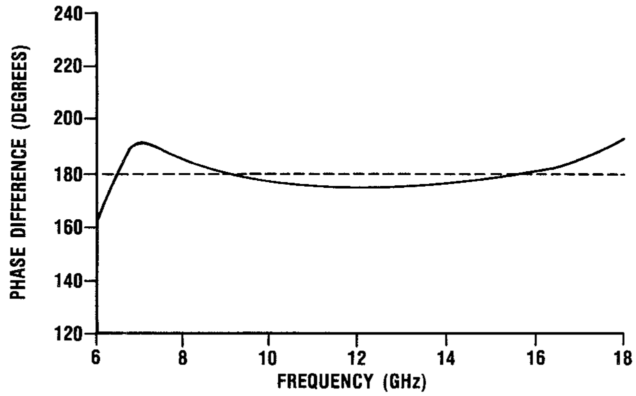

Figure 9b. Balun Performance; Phase

CONCLUSION

Because of the excellent coupler performance and design flexibility obtained with this technique, coupled structures which use to require multi- layer stripline or suspended substrate approaches, can now be easily fabricated and integrated with conventional MIC circuitry. The technique also allows the MMIC designer to fabricate very tightly coupled structures without the problems encountered with fine line lithography.

REFERENCES

[1] Seymour B. Cohn, "The Re-Entrant Cross Section and Wide-Band 3-dB Hybrid Couplers," IEEE Transactions on Microwave Theory and Techniques, pp. 254-258, July 1963.

[2] L. Lavendol and J. J. Taub, "Re- Entrant Directional Coupler Using Strip Transmission Line," IEEE Transactions on Microwave Theory and Techniques, pp. 700-701, September 1965.

[3] B. M. Schiffman, "A New Class of Broad-Band Microwave 90-Degree Phase Shifters," IRE Transactions on Microwave Theory and Techniques, pp. 232-237, April 1958.