N-7

Design of an Overlay Directional Coupler by a Full-Wave Analysis

L. Su, T. Itoh and J. Rivera*
Department of Electrical Engineering
University of Texas
Austin, TX 78731

Abstract

A full-wave analysis based on the spectral domain method is used for designing an overlay coupler. Calculated and measured results are presented.

Introduction

It is known that when the even and odd mode propagation constants are identical, the isolation of a directional coupler is theoretically infinite. However, in an inhomogeneous structure such as microstrip, this condition is not always satisfied. A dielectric overlay is one way to improve the isolation of a microstrip coupler, by which the difference in even and odd phase velocities can be greatly reduced.[1,2] To date, most of the designs of overlay couplers are based on the quasi-TEM approximation. In this paper, the spectral domain method[3] is used for a full-wave analysis with a view to designing an overlay coupler.

Analytical Process

Fig. 1 shows the cross section of the coupled overlay microstrip line. Note that a coupled microstrip is obtained by letting $H_3 \to \infty$ and $\varepsilon_2=1$ whereas an inverted strip configuration is realized by letting $\varepsilon_1=1$. Therefore, once the formulation for Fig. 1 is done, we can generate data for microstrip and inverted strip structures in addition to overlay microstrip.

Since the spectral domain method is now well known, we will not describe it in detail here. Basically, it solves the eigenvalue problem in the Fourier transform domain to obtain a pair of algebraic equations that relate the axial and transverse currents on the strips with the axial and tangential transverse electric fields at the interface containing strips. These solutions are subsequently transformed to a set of linear equations by Galerkin's procedure. This set is solved for the propagation constant β or the guide wavelength λ'. Choice of the basis functions in Galerkin's procedure is important and, here, we used those proposed by Schmidt and Itoh.[4] They have correct edge singularities and can be analytically Fourier transformed to Bessel functions for use in the spectral domain process. As a result of our convergence tests, we used three basis functions for calculations in this paper.

Once, the propagation constant is available, we can calculate all the field coefficients in the cross section. From these quantities we can compute the characteristic impedance which is in this paper defined as

$$Z_0 = 2\, P_{avg}/I_z^2$$

where P_{avg} is the average power transmitted and I_z is the axial strip current.

Numerical Results

Fig. 2 shows the dispersion characteristics for three types of coupled strip structures. From this figure, we find the following: the inverted configuration provides a frequency at which the even and odd mode phase velocities coincide whereas in the overlay construction the difference in phase velocities becomes very small though they never become equal.

Fig. 3 shows the characteristic impedance of these lines. The impedances of the overlay structures are much less frequency dependent.

From these figures, we find that a very narrow-band high performance coupler may be constructed from the inverted configuration. However, when wideband operation is desired as in most practical applications, the overlay configuration is preferred.

Design of Single Section Directional Coupler

From even mode and odd mode theory for analysing a coupler[5] we can design the directional coupler easily. We use a trial-and-error method as follows: a substrate is chosen first, then we calculate the characteristic impedance and propagation constant for the even mode and odd mode by varying the strip width W and the coupling section gap. Once the relation $Z^eZ^o = 50^2$ (Z^e and Z^o are even and odd mode characteristic impedance respectively) and the coupling requirements are reached, S can be determined. The coupled section length L can be found by use of the relation $\beta L = \frac{\pi}{2}$. When the coupling requirement isn't satisfactory or although it is satisfactory the S is too small, for fabrication we may choose another substrate which has larger thickness and/or higher dielectric constant and calculate again. We have calculated the parameters for 10db, 6db, and 3db, directional couplers. Since our fabrication facility is rather crude, only the 10db coupler was fabricated. Fig. 4 shows the structure and Fig. 5 presents the measured results for the microstrip directional coupler and the dielectric overlay microstrip line directional coupler. We can see that dielectric overlay can significantly improve the isolation. This agrees with the works by Paolino.[1] A simple calculation shows that the relative propagation constant difference between the even mode and the odd mode $\left|\frac{\beta e - \beta o}{\beta e}\right| \times 100\%$ is only 0.54% in the dielectric overlay case and 7.35% in the coupled microstrip case. Additional measurements for an inverted microstrip directional coupler showed that at low frequencies, the relative propagation constant difference is large, about 12.7%, so the isolation is very poor. Experimental results also showed that when the input transmission section is perpendicular to the coupled section, the dielectric overlay did not improve the isolation. This is due to the bend existing between the transmission line and the coupled line thus generating scattered waves. Dielectric overlays enhance the coupling of scattered waves, implying that isolation is deteriorating. In a configuration like Fig. 4 there is no measurable reflection caused by bends in the main line. From the network analysis[5] for any directional coupler, the magnitude of the reflected wave at the input port is equal to that of the wave appearing from the "isolated" port, implying that as the input VSWR increase, the isolation decreases. This shows that the structure shown in Fig. 5 seems to be optimum.

*J. Rivera is with TRW Inc., in Redondo Beach, CA 90278

Conclusion

In this paper, the spectral domain approach is used for studying the coupled dielectric overlay micro-strip. The numerical computations were carried out with a CDC Dual Cyber 170/750 computer. The typical computation time required for a structure at a given frequency was about 1.05 seconds. We designed and tested microstrip and overlay microstrip couplers. The frequency characteristics are presented.

Acknowledgment

This work was in part supported by Army Research Office Contract DAAG-29-K-0053 and in part by a grant from Texas Instrument, Equipment Group.

REFERENCES

(1) D. Paolino, "Overlay Coupler Design Using Spectral Domain Techniques", IEEE Trans. Microwave Theory Tech., Vol. MIT-26, pp. 646-649, September 1978.

(2) B. Sheleg and B. E. Speilman, IEEE Trans. Microwave Theory Tech., Vol. MIT-22, pp. 1216-1220, No. 12, December 1974.

(3) T. Itoh, "Spectral Domain Immitance Approach for Dispersion Characteristics of Generalized Printed Transmission Lines" IEEE Trans. Microwave Theory Tech., Vol. MIT-28, pp. 733-736, No. 7, July 1980.

(4) L. Schmidt and T. Itoh, "Characteristics of a Generalized Fin-Line for Millimeter Wave Integrated Circuits", International of Infrared and Millimeter Waves, Vol. 2 No. 3, 1981.

(5) R. Levy, "Directional Couplers", Advances in Microwaves, Vol. 1, pp. 115-206.

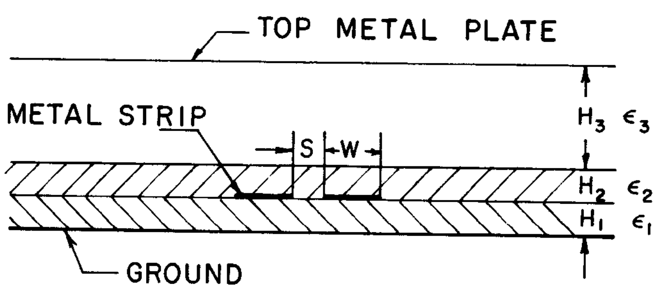

Fig. 1 Cross sectional view of coupled microstrip lines with a dielectric overlay

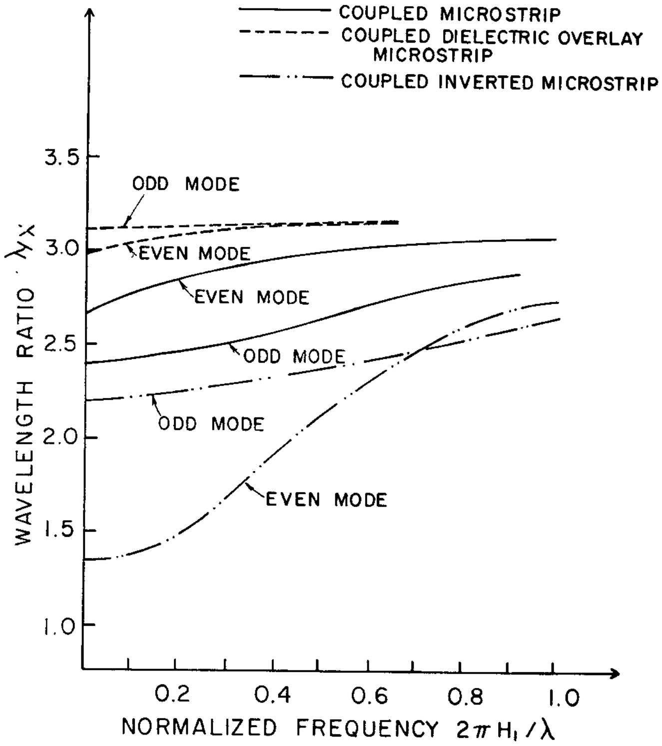

Fig. 2 Even and odd mode dispersion characteristics for $H_2/H_1 = 1.0$, $H_3/H_1 = 3.0$, $W/H_1 = 1.0$, $\varepsilon r_3 = 1.0$, and coupled microstrip: $\varepsilon r_1 = 10.0$, $\varepsilon r_2 = 1.0$, $S/H_1 = 0.4$; with dielectric overlay: $\varepsilon r_2 = 10.0$; coupled inverted microstrip: $\varepsilon r_1 = 1.0$, $\varepsilon r_2 = 10.0$, $S/H_1 = 0.15$.

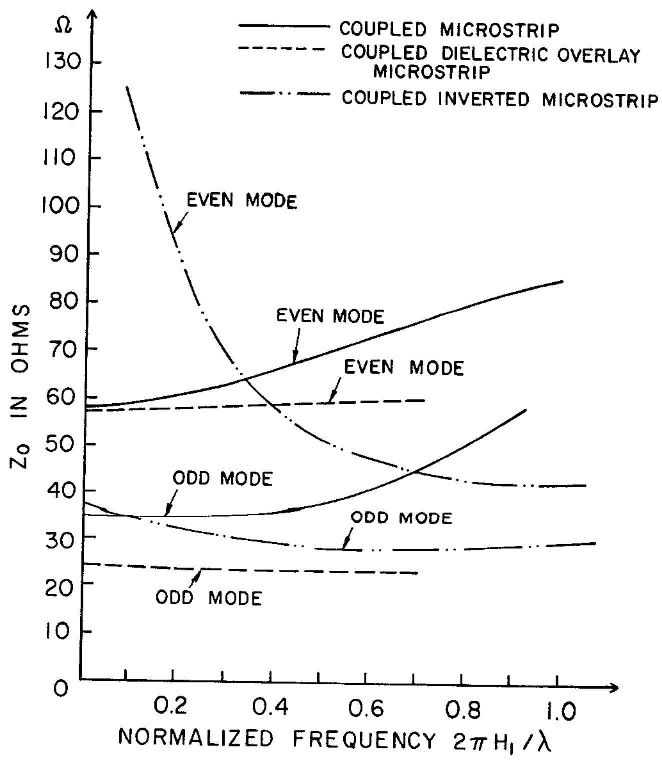

Fig. 3 Characteristic impedance vs. Frequency for the three structures.

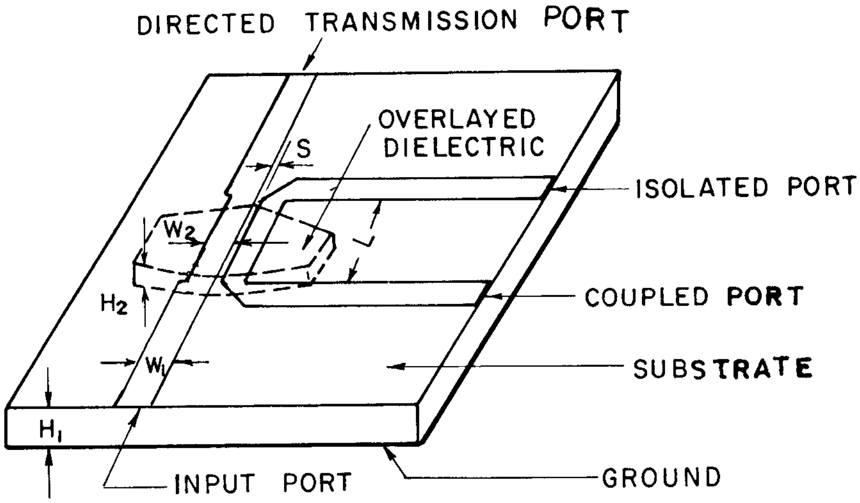

Fig. 4 Design of coupled microstrip lines with the dielectric overlay.

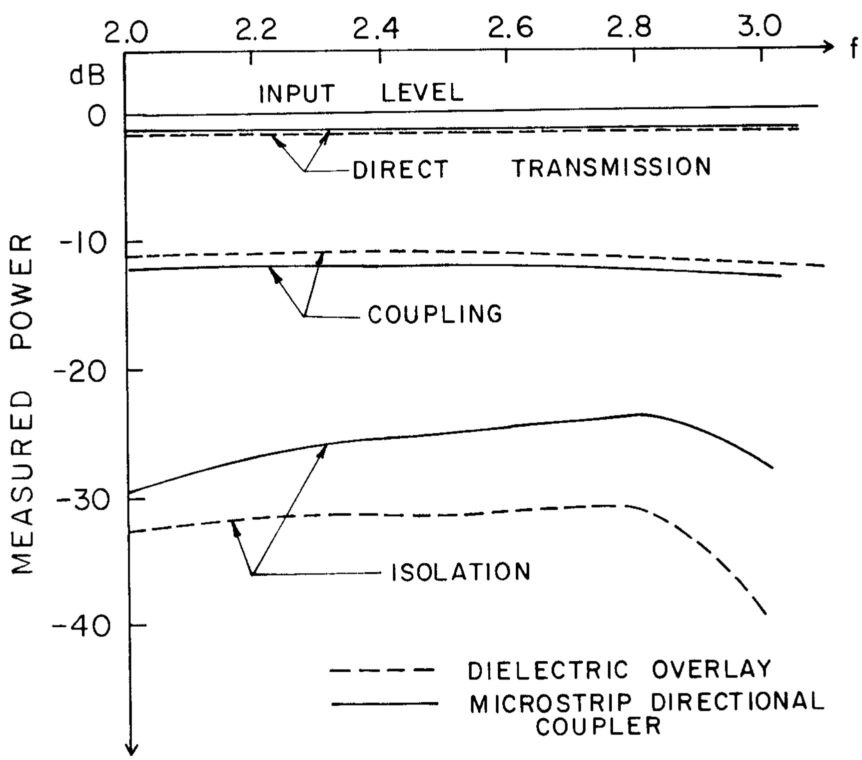

Fig. 5 Coupling and isolation of the coupled microstrips with and without the dielectric overlay.