ANALYSIS AND EXPERIMENTAL EVALUATION OF DISTRIBUTED OVERLAY STRUCTURES IN MICROWAVE INTEGRATED CIRCUITS

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Introduction. Distributed microwave integrated circuits have in the past been fabricated by common etch-back techniques on metallized dielectric substrates resulting in simple microstrip transmission line structures for the passive circuitry. This paper discusses examples for the realization of improved circuit functions by overlaying dielectric and metallic films on the simple structure. The present discussion will be restricted to the passive part of hybrid integrated circuits, although analysis and techniques discussed here may also be useful for active devices and monolithics.

Analysis. The increased complexity of overlay structures consisting of several layers of dielectric and conductive films manifests itself also in the increased number of design variables. Two steps are necessary to obtain design data for microwave applications; field analysis and circuit analysis. Computer aided design was found to be extremely useful.

For field analysis of overlay structures, we applied well known finite difference approximations of LaPlace's equation in combination with a successive over-relaxation program on a digital computer.[1,2,3,4]

In this method, a fine net of rows and columns is superimposed upon the geometry to be analyzed. The electrostatic potential is calculated at each node point by relaxation from an assumed initial value to a relaxation accuracy of the order of 10^{-5} to 10^{-6}. By integrating the normal component of the E-field over a complete enclosure around the conductor, capacitance is determined. Repeating this process once with the dielectric material in place and one width removed, characteristic impedance and velocity of propagation are calculated.

First, this process was applied to the simple microstrip transmission line structure. Results will be compared to those obtained by previous authors.[5,6] For coupled lines, as shown in Figure 1, the so called odd mode case with opposite polarity on the two lines and the even mode case with the same polarity on both lines are analyzed separately, yielding odd and even mode characteristic impedance and velocity of propagation. Superposition then yields circuit parameters such as coupling, design impedance and isolation.

The standard coupling formula for direction couplers[7,8]

$$k = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} \qquad (1)$$

does not apply to coupled microstrip lines. Due to the presence of dielectric boundaries in the field region, the velocity of propagation in the odd mode differs from that in the even mode. Superposition, taking the difference phase shift into account, yields the coupling vectorial form, suitable for computer programming:

$$\vec{K} = N\left\{1 + \sum_{n=1}^{\infty}\left(\Gamma_{oe}{}^{2n} + \Gamma_{oe}{}^{(2n-1)}\right)\exp(-j2n\theta_e)\right\}$$
$$-M\left\{1 + \sum_{n=1}^{\infty}\left(\Gamma_{oo}{}^{2n} + \Gamma_{oo}{}^{(2n-1)}\right)\exp(-j2n\theta_o)\right\} \quad (2)$$

where

$$N = \frac{Z_{oe}}{Z_o + Z_{oo}} \qquad \Gamma_{oe} = \frac{Z_o - Z_{oe}}{Z_o + Z_{oe}} \qquad \theta_e = \frac{\omega}{V_{oe}}$$
$$M = \frac{Z_{oo}}{Z_o + Z_{oo}} \qquad \Gamma_{oo} = \frac{Z_o - Z_{oo}}{Z_o + Z_{oo}} \qquad \theta_o = \frac{\omega}{V_{oo}} \quad (3)$$

Similar analysis is presented for other four-port parameters such as isolation, optimum load and generator impedance, etc.

Results. For conventional microstrip parallel line couplers, as shown in Figure 1(a), analysis and test reveal problems severly restricting the range of applications. As shown in Figure 4, the spacing required for tight coupling becomes so small that prohibitively tight tolerances are required. Due to the difference in odd and even mode velocity, bandwidth and isolation are detrimentally affected as indicated by the results shown in Figure 2.

These problems can be solved by overlay techniques exemplified by Figure 1(b). Results obtained for this structure are given in Table I. Odd and even mode velocity now correlate closely. Results shown in Figure 3 indicate that good isolation and wide bandwidth can be obtained. Experimental verification for several overlay couplers will be presented. It will also be shown that tight coupling at reasonable spacings are achieved due to the presence of a floating coupling strip. Figure 5 shows an example of an overlay coupler in a test fixture. These results are also important for filter design in microwave integrated circuits, where a differential of even and odd mode velocities not only invalidates well known synthesis procedures but also affects performance. Other overlay structures have been theoretically analyzed and experimentally evaluated. Data and details on fabrication techniques will be given.

In conclusion, it is shown by analysis and experimental data that overlay techniques offer distinct advantages to the designer of microwave integrated circuits. Simple and inexpensive fabrication techniques will be discussed that are compatible with standard integrated circuit procedures.

TABLE I. Odd Mode and Even Mode Velocity of Propagation for Overlay Coupler of Figure 2(b)
w/b = 2.3, s/b = 1, h/b = 1

ϵ_r	$\frac{VOE}{C}$	$\frac{VOO}{C}$	$\frac{1}{\sqrt{\epsilon_r}}$
8	0.3559	0.3549	0.3536
15	0.2600	0.2593	0.2581
33	0.1754	0.1749	0.1741
60	0.1301	0.1297	0.1291
90	0.1062	0.1059	0.1054

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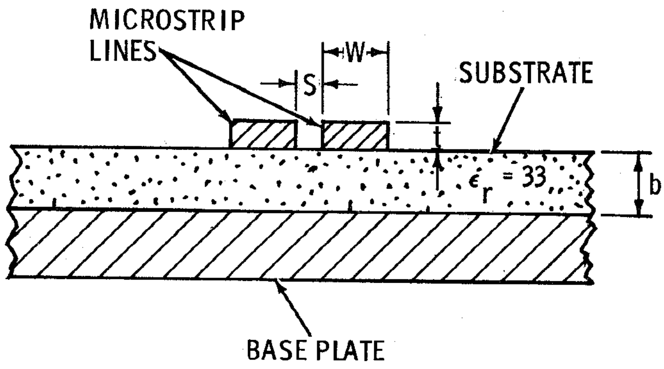
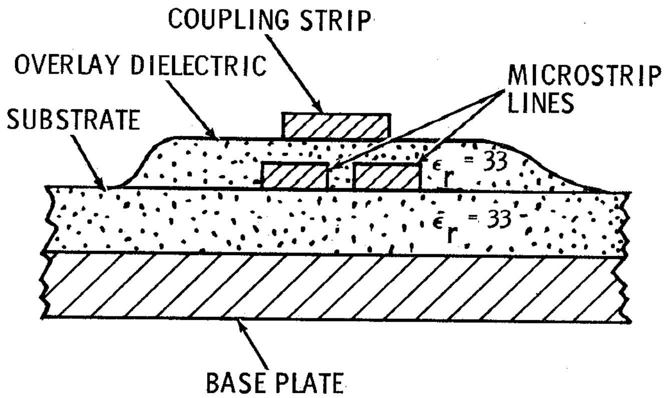


A CONVENTIONAL MICROSTRIP COUPLER



B OVERLAY PARALLEL LINE COUPLER

Figure 1. Coupled Microstrip Transmission Line Structures

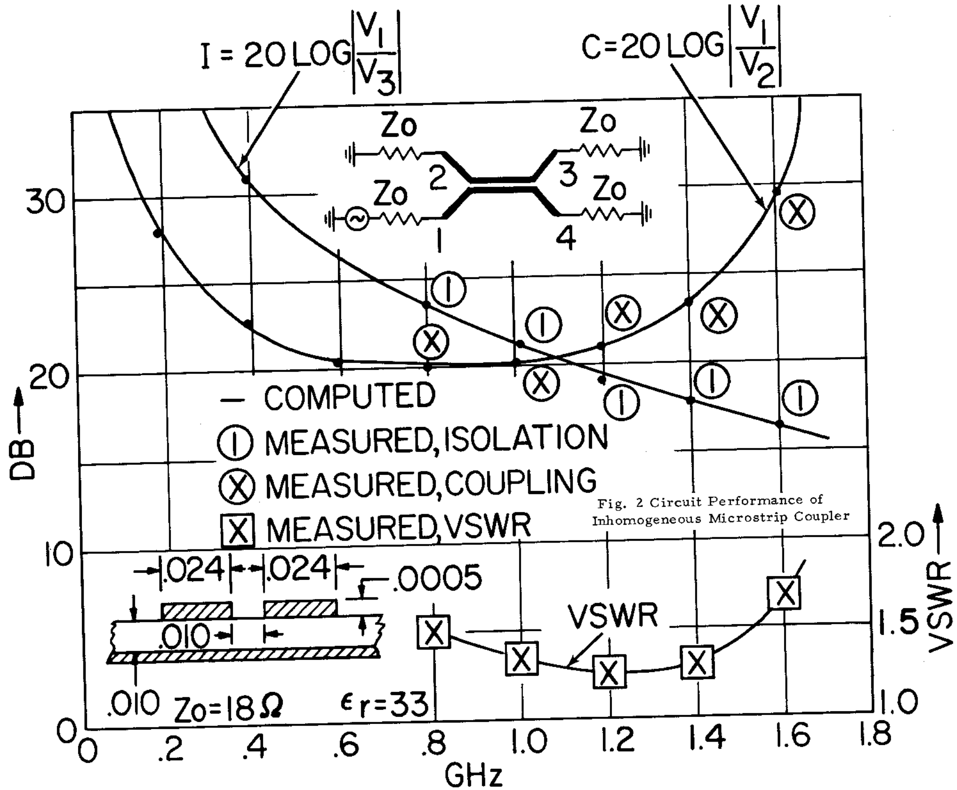


Fig. 2 Circuit Performance of Inhomogeneous Microstrip Coupler

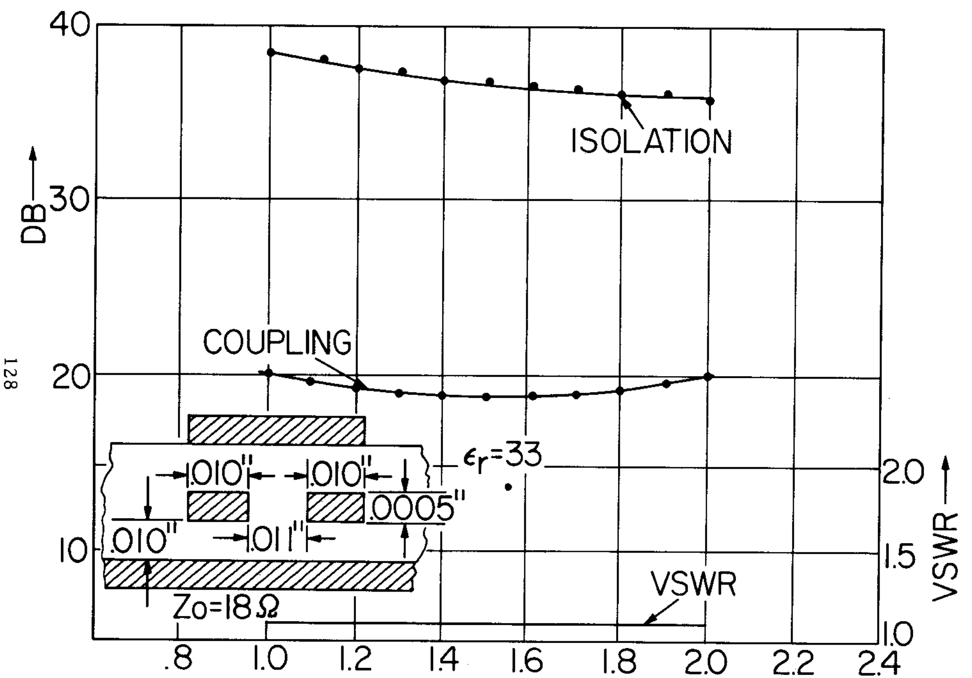


Figure 3. Computed Performance of Overlay Microstrip Coupler

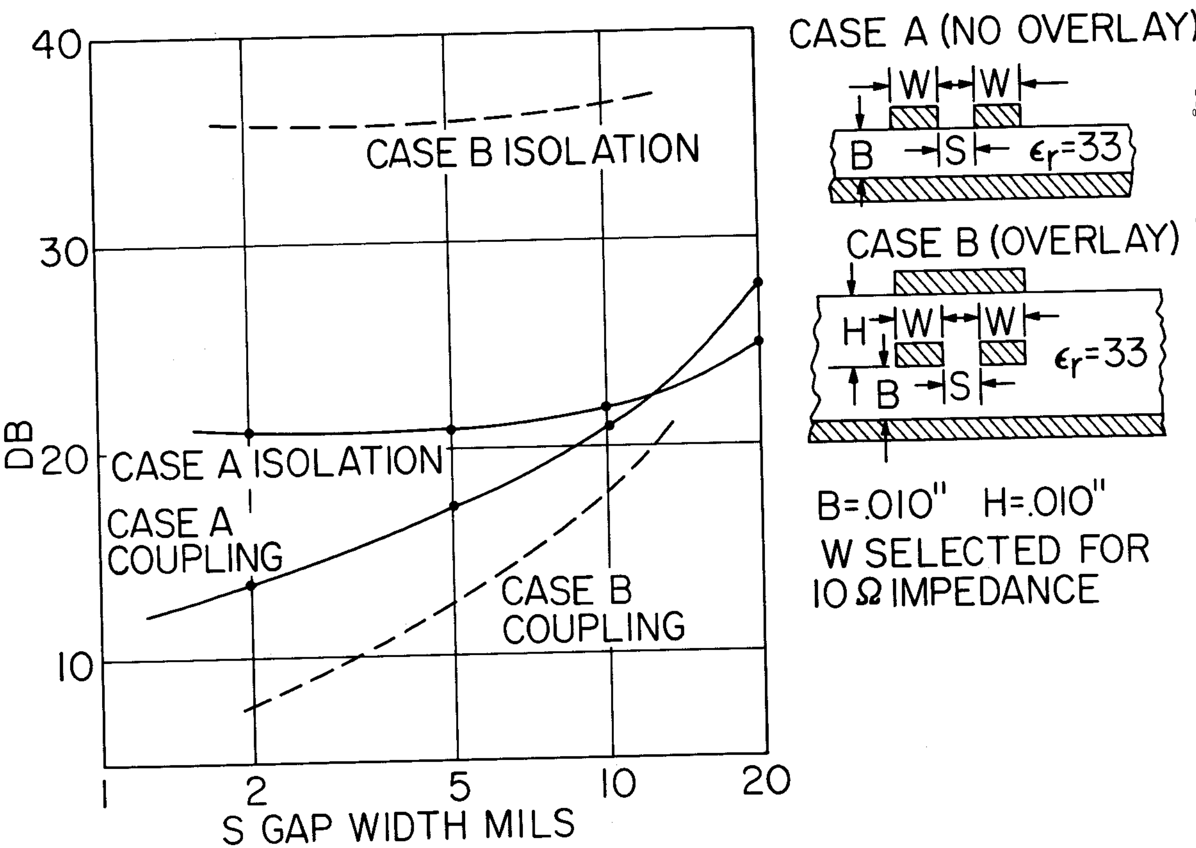


Figure 4. Coupling Vs. Gap For Overlay and Non-Overlay Microstrip Couplers

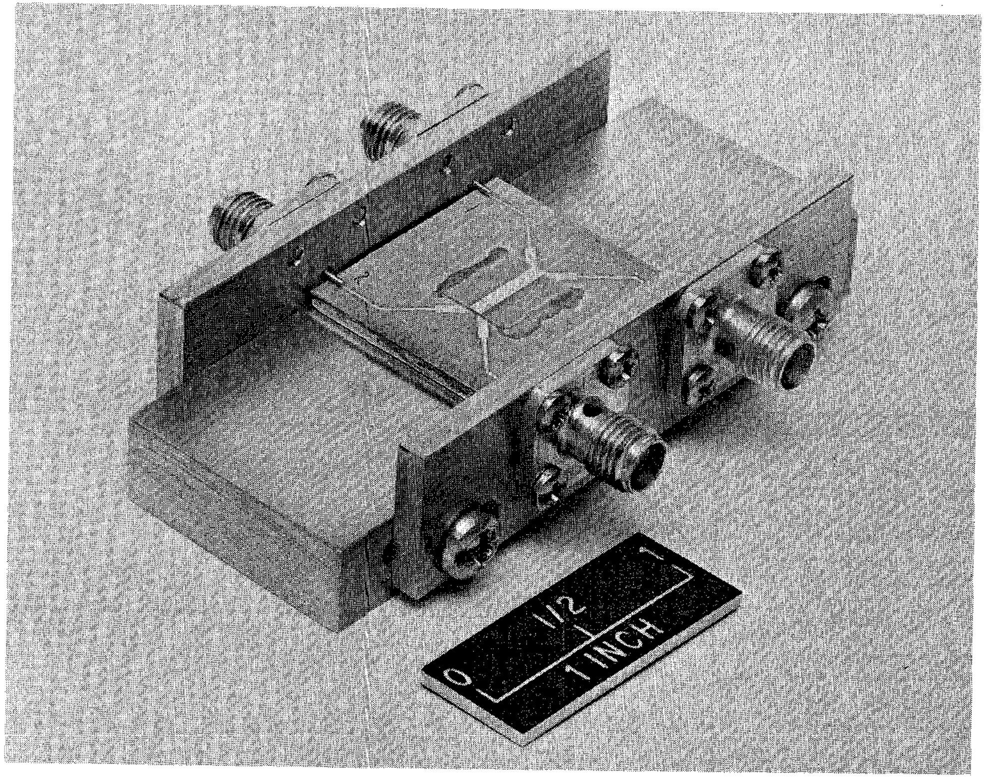


Figure 5. MIC Overlay Directional Coupler in Test Fixture