HIGH DIRECTIVITY MICROSTRIP COUPLERS USING DIELECTRIC OVERLAYS

Charles Buntschuh
Microwave Associates, Inc.
Burlington, MA 01803

Abstract

Coupled-line directional couplers in microstrip suffer from low directivity due to the inequality of the even and odd mode wave velocities. A dielectric overlay improves the directivity, but it also tightens the coupling and depresses the coupler impedance. Design curves are presented for making velocity-compensated 50 ohm couplers taking the changes in coupling and impedance into account.

Introduction

The transmission line properties and the practical circuit applications of parallel-coupled-line couplers in balanced stripline have been the subjects of active investigation since the middle fifties. Today, design techniques and data for coupled pairs in stripline and other homogeneous dielectric transmission line media are well-established and readily available for a wide variety of applications.[1,2]

In microstrip, because of its mixed dielectric, the phase velocities of the even and odd mode waves on coupled lines are not equal. This property alters the coupling characteristics of the lines, particularly decreasing their directivity.

The parameters of microstrip, and their frequency dependence have been calculated by numerous authors by a variety of mathematical techniques such that the theory relating the electrical to the physical parameters of the microstrip coupled pair is well understood. Several techniques for equalizing the velocities or reducing their difference, and improving coupler directivities have been reported,[3-6] but simple design procedures for these techniques have not been published.

The objective of the work reported here was to develop design data and procedures for octave-band, high-directivity couplers in microstrip using dielectric overlays, and to verify them experimentally.

Derivation of Design Curves

On a microstrip coupler, the even-mode has a higher effective dielectric constant and lower wave velocity than the odd mode. Therefore, the coupler appears electrically shorter to the even mode than to the odd mode. On alumina ceramic substrates the length differential will normally be under 12%. The principal consequence of this inequality is the degradation of coupler directivity. The coupler impedance $Z_k = \sqrt{Z_{oe} Z_{oo}}$ and the midband voltage coupling coefficient $k = (Z_{oe} - Z_{oo}) / (Z_{oe} + Z_{oo})$, defined for the ideal coupler, are only slightly perturbed and therefore remain useful parameters to describe the microstrip coupler.

A dielectric block covering the coupling gap and a portion of the lines will increase ε_{o-eff} more than it will ε_{e-ff} because of the odd mode's greater fringing fields above the dielectric. With the right amount of dielectric, both effective dielectric constants will be almost equal at a new value ε'_{eff}, which is slightly higher than the original ε_{e-eff}. The overlay will also increase the coupling and decrease the coupler impedandce. The design problem is to estimate the amount of coupling and impedance change caused by the overlay, and determine the parameters of an uncompensated coupler of correspondingly higher impedance and looser coupling.

The amount of coupling change can be accurately determined as follows. The voltage coupling coefficient without the overlay is

$$k = \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} ,$$

and with the overlay it is

$$k' = \frac{Z'_{oe} - Z'_{oo}}{Z'_{oe} + Z'_{oo}} = \frac{Z_{oe} - Z_{oo} g}{Z_{oe} + Z_{oo} g} = \frac{(1+k) - (1-k) g}{(1+k) + (1-k) g} , \qquad (1)$$

where $g = \sqrt{\varepsilon_{o-eff} / \varepsilon_{e-eff}}$.

The new coupling depends only on the ratio of odd and even mode dielectric constants and the coupling of the uncompensated coupler. It does not depend upon the final equalized value of ε'_{eff} nor on Z_k.

The impedance of the overlay coupler does depend on the final value of ε'_{eff}:

$$Z'_k = Z_k \sqrt{(\varepsilon_{e-eff} \cdot \varepsilon_{o-eff}) / \varepsilon'^{2}_{eff}} \qquad (2)$$

The design theory says nothing about how much dielectric to use; determining the "right amount" is left as an empirical task. Therefore, to estimate the likely values of ϵ'_{eff} and Z'_k, the following assumptions are made. In the limit, as the gap goes to zero, there are virtually no even mode fields above the gap. Only a very small overlay is required, and it will change only ϵ_{o-eff}. So, for $s = 0$, $\epsilon'_{eff} = \epsilon_{e-eff}$. As the gap becomes very wide, the fields of the even and odd modes become more and more alike. A very thick overlay is required--even though the two dielectric constants are not very different--increasing both effective dielectric constants substantially. Our initial guess was that they reached the average of ϵ_{e-eff} and ϵ_r; later experimental results indicated that $.55\,\epsilon_r + .45\,\epsilon_{e-eff}$ was a better choice with respect to the final coupler impedance. We then adopted the following simple formula to estimate intermediate values of ϵ'_{eff}:

$$\epsilon'_{eff} = \epsilon_{e-eff} + \frac{\epsilon_r - \epsilon_{e-ff}}{1.8}\left(1 - e^{-s/h}\right) . \quad (3)$$

Using Eqs. (1) - (3) and Z_k, k, ϵ_{e-eff} obtained with the Bryant and Weiss [7] computer program, we determined the line width, spacing and ϵ'_{eff} as functions of coupling for 50 ohm overlay couplers on $\epsilon_r = 10.0$ substrates as shown in Figures 1 and 2.

Experimental Results

Several single and multi-section couplers have been made and empirically tuned with dielectric overlays for optimum directivity. Figures 3 and 4 show the RF responses for a 3 dB hybrid composed of a tandem pair of 3-section 8.34 dB couplers and of a 2-section 20 dB coupler. The isolation of the 3 dB hybrid is greater than 22 dB and its VSWR under 1.25:1 over its useful bandwidth, while the minimum isolation of the 20 dB coupler is 35 dB and its VSWR is under 1.3:1. The insertion losses of the couplers are about 0.6 dB at mid-band, split evenly between the connectors and the microstrip circuit.

The circuits were on .025" AlSiMag 772 alumina substrates with a dielectric constant of 10.0 (± 0.3); the connectors were OSM-220-8873A hermetic type. Overlays were either alumina or a teflon-TiO_2 high-ϵ_r material ($\epsilon_r \sim 12$) from the 3M Company, cemented down with Eastman 910. Figure 5 shows the 3 dB hybrid with alumina overlays.

A number of single-section couplers, from 6 to 32 dB, centered near 3 GHz were tuned with the 3M material for high directivity over the 2-4 GHz band. The directivities ran from 34 dB on the 6 dB to 18 dB on the 32 dB coupler. The measured midband couplings, corrected for insertion loss, are in excellent agreement with the design curve as shown in Figure 2.

Conclusions

Design curves for high directivity microstrip couplers employing dielectric overlays have been derived, based on Bryant and Weiss' calculations. Experimental single and multisection couplers have been made with directivities exceeding 18 dB, and in excellent agreement with the design coupling values.

Acknowledgements

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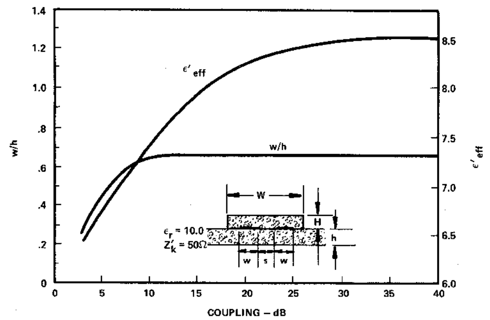

FIGURE 1 LINE WIDTH AND ϵ'_{eff} VS. COUPLING FOR 50Ω OVERLAY COUPLERS

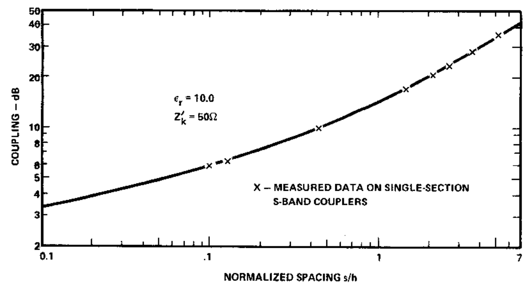

FIGURE 2 GAP WIDTH VS. COUPLING FOR 50Ω OVERLAY COUPLER

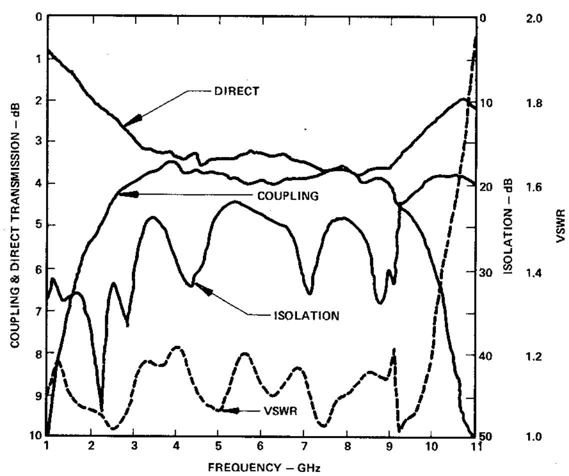

FIGURE 3 MEASURED RESPONSES OF C-BAND TANDEM 8.3 dB COUPLER, WITH DIELECTRIC OVERLAYS

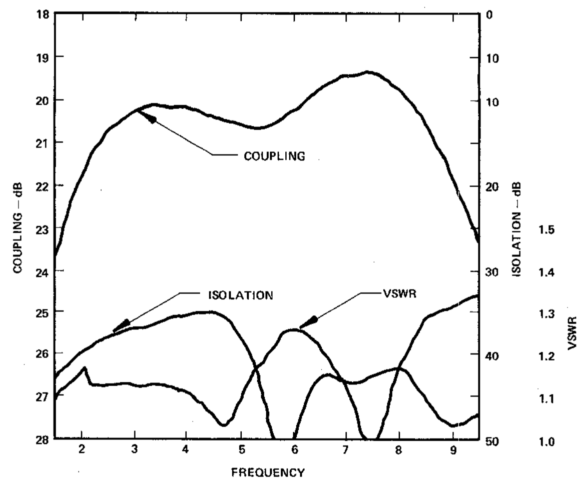

FIGURE 4 MEASURED RESPONSES OF 20 dB COUPLER WITH DIELECTRIC OVERLAYS

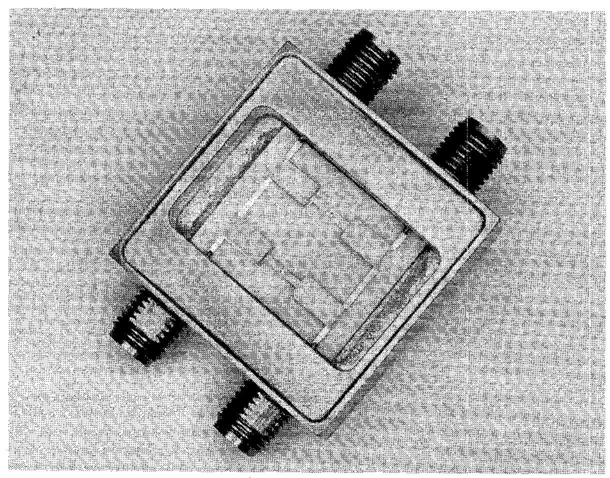

FIGURE 5 3 dB, TANDEM 8.34 dB C-BAND COUPLER

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