path. However, when $w = r_2 - r_1$ is decreased, stray fields around the circular conductor are increased and the influence of the shielding is significant even without strong coupling between circular ring modes and cavity modes. These phenomena must be taken into account in the computation if a resonator has to be completely enclosed with a shielding housing.

For the case of open structures, better approximations can be achieved using thin substrates and high dielectric permittivities.

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Design Analysis of Novel Coupling Structures for Multilayer MMIC's

Matthew Gillick, Ian D. Robertson, and Jai S. Joshi

Abstract—**Novel monolithic multilayered coupling structures are presented and their performances analyzed. These structures have reduced current crowding at their conductor edges compared to coplanar type coupling structures, and are particularly suitable for integration with multi-dielectric MMIC's. This paper presents the closed-form analytical expressions for the coupler's even and odd mode impedances and coupling coefficients derived using conformal mapping techniques. These direct formulas have the advantage of being well suited for the computer aided design analysis of MMIC's without the need for lengthy numerical modelling techniques.**

I. Introduction

Multilayer MMIC's have recently been receiving widespread attention [1]–[3]. Various small size novel coupling structures incorporating multi-dielectric layers have been proposed and analyzed [4]–[7]. This paper presents a new multilayer homogeneous coupling structure which offers reduced current crowding at the conductor edges, and is particularly suitable for integration with coplanar waveguide, slot line, and microstrip transmission lines. By having the transmission lines perpendicular to the ground plane(s), as shown in Fig. 1, the level of current crowding at the conductor edges may be reduced compared to coplanar type structures [8]. This is evident since the electric field distribution across two conductor surfaces is more uniform for a given conductor spacing when they are perpendicular, than when they are within the same plane. The fabrication of these couplers could be realized using newly developed multilayer MMIC technologies. A combination of successive wet etching, reactive ion etching or plasma etching of multi-dielectric layers could be used to fabricate a channel-shaped cut out, whereby perpendicular strip conductors may be realized.

II. Analysis of the Coupling Structures

The proposed coupling structures are illustrated in Fig. 1, where $2h$ is the total substrate thickness, $2s$ is the spacing between the coupled lines, and $2w$ is the gap width in the center ground plane. Structure B, has two additional ground shieldings parallel to the center ground plane, placed at a distance $h - r$ from each conductor strip. Throughout these multilayer structures, the dielectric substrate has a constant relative permitivity, ε_r. Shown in Fig. 2, is an example of the variation between the even and odd-mode electric field lines of structure A.

The following quasi-static analysis employs a sequence of conformal mappings to evaluate the even and odd mode capacitances of the couplers. The analytical approach used here isolates the even and odd modes in order to evaluate their impedances and subsequently the structure's coupling factors. For both structures the metallic

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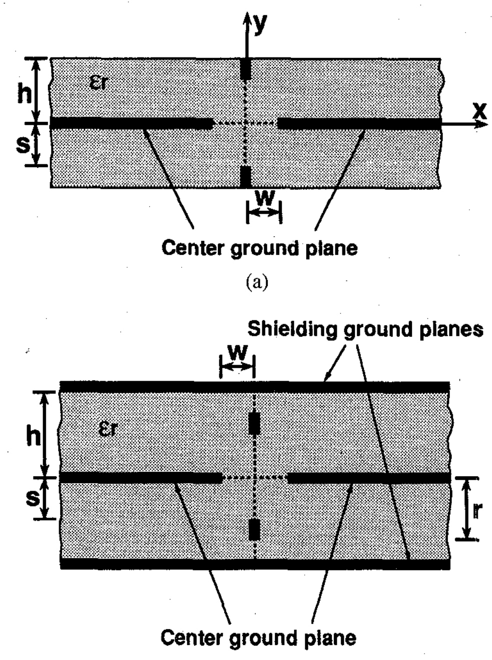

(b)

Fig. 1. Cross-sections of novel multilayer structure (a), with one uniplanar ground plane, and (b), with additional ground shieldings.

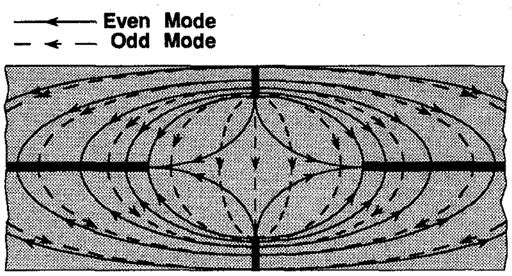

Fig. 2. Sketch of the even and odd-mode electric field lines for the coupling structure A.

conductors are assumed to be infinitely thin and perfectly conducting. All ground planes are assumed to be sufficiently wide as to be considered infinite.

A. Coupling Structure Without Ground Shielding

Due to the symmetrical nature of structure A, only the lower left quadrant need be considered for analysis, as shown in Fig. 3(a). By assuming that the field stays inside the dielectric structure, the air-dielectric interfaces may be considered as though a perfect magnetic wall hence equalising the even and odd mode phase velocities. This assumption would not be accurate for structures which have relatively thick conductors. For the even-mode case, the conformal mappings transform the z-domain into a finite image z_1-domain by

$$z_1 = \int_{t_0}^{t} \frac{dt}{\sqrt{t(t-t_3)(t-t_1)}}$$

where

$$t = \cosh^2\left(\frac{\pi z}{2h}\right) \tag{1}$$

The total capacitance per unit length, C_e, and the characteristic impedance, Z_{Oe}, for the coupler's even-mode is therefore given by

$$C_e = 2\epsilon_o \epsilon_r \frac{K(k_1)}{K(k_1')}$$

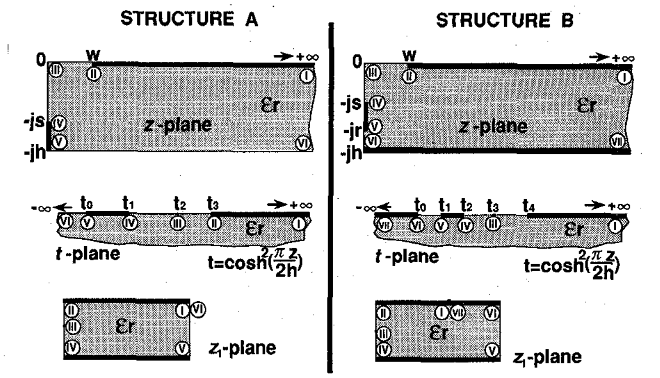

Fig. 3. Conformal transformations for evaluating the even mode capacitances per unit length of the two coupling structures.

where

$$k_1 = \frac{\cos\left(\frac{\pi s}{2h}\right)}{\cosh\left(\frac{\pi w}{2h}\right)} \tag{2}$$

and

$$Z_{Oe} = \frac{1}{C_e V_{ph}} = \frac{60\pi}{\sqrt{\epsilon_r}} \frac{K(k_1')}{K(k_1)} \tag{3}$$

and where $K(k)$ is the complete elliptical integral of the first kind, and $k' = (1-k^2)^{1/2}$ is the complementary modulus. For the odd-mode case, the line-section OW may be considered as though an electric wall, so that we may use the mapping:

$$z_1 = \int_{t_0}^{t} \frac{dt}{\sqrt{t(t-t_1)(t-1)}}. \tag{4}$$

Hence the total capacitance per unit length, C_o, and the characteristic impedance, Z_{Oo}, for the coupler's odd-mode is therefore given by

$$C_o = 2\epsilon_o \epsilon_r \frac{K(k_2)}{K(k_2')}$$

where

$$k_2 = \cos\left(\frac{\pi s}{2h}\right) \tag{5}$$

and

$$Z_{Oo} = \frac{1}{C_o V_{ph}} = \frac{60\pi}{\sqrt{\epsilon_r}} \frac{K(k_2')}{K(k_2)} \tag{6}$$

The even and odd-mode characteristic impedances of structure A, evaluated from (3) and (6), are plotted in Fig. 4, for variations in the normalized slot width, w/h, and conductor spacing, s/h. As expected, the center ground slot has no effect on the odd-mode characteristic impedance. To plot the coupling factor, as shown in Fig. 5, for geometrical variations of structure A, the common coupling expression for a quarter wave-length coupler at the center frequency is used:

$$C_{\text{dB}} = -20\log_{10}\left[\frac{\frac{K(k_1')}{K(k_1)} - \frac{K(k_2')}{K(k_2)}}{\frac{K(k_1')}{K(k_1)} + \frac{K(k_2')}{K(k_2)}}\right] \tag{7}$$

These plots demonstrate that the coupling is tightened for increases in the normalized gap width, w/h, and for decreases in the normalized conductor spacings, s/h. It is observed that coupling up to 3 dB can be achieved for small conductor spacings, s/t, and for large gap widths in the ground plane, w/h.

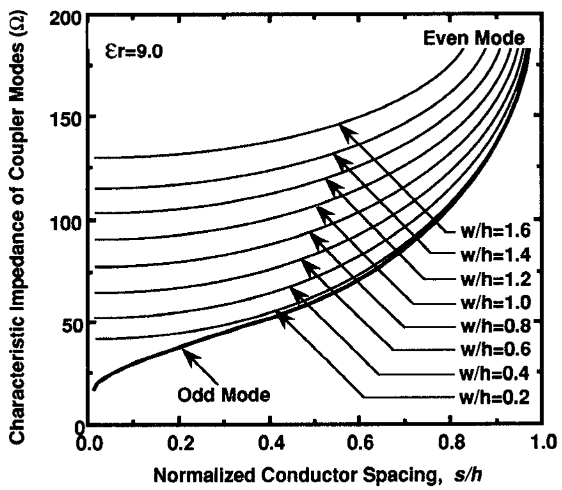

Fig. 4. Variation in the even and odd-mode characteristic impedances for the coupling structure A.

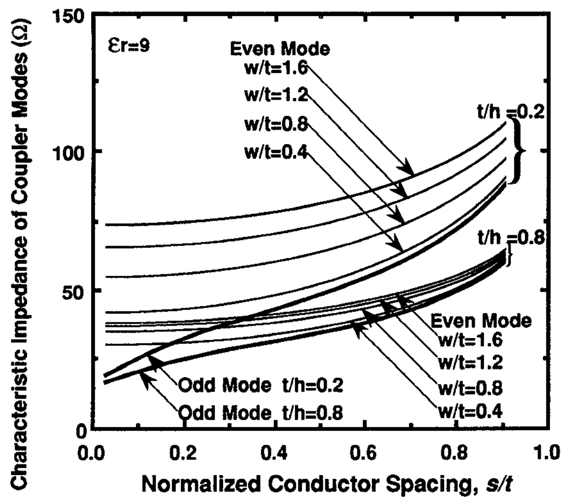

Fig. 6. Variation in the even and odd-mode characteristic impedances for the coupling structure B.

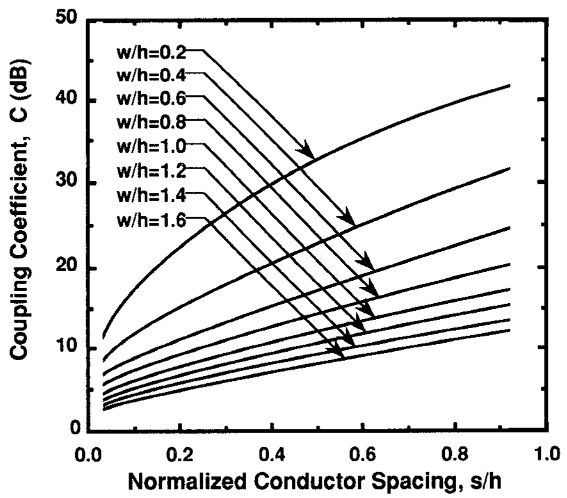

Fig. 5. Variation in the coupling coefficient, C_{dB}, for structure A, as a function of the normalized conductor spacing, for various normalized ground plane gap widths.

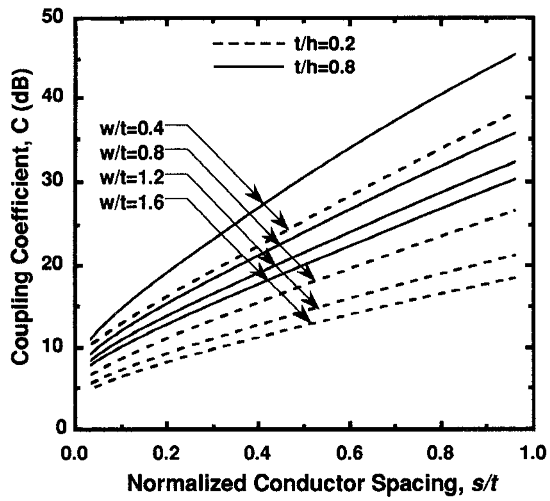

Fig. 7. Variation in the coupling coefficient, C_{dB}, for structure B, as a function of the normalized conductor spacing, for various normalized ground plane gap widths and for various normalized separations between the shielding ground planes.

B. Coupling Structure With Ground Shielding

For structure B, shown in Fig. 3(b), the even-mode capacitance per unit length is obtained by modeling the lower right quadrant as though the line segment OH is a magnetic wall. For the even-mode case, the capacitance per unit length, C_e, and the characteristic impedance, Z_{O_e}, are obtained using:

$$z_1 = \int_{t_0}^{t} \frac{dt}{\sqrt{t(t-t_4)(t-t_2)(t-t_1)}}$$

and

$$C_e = 2\epsilon_o\epsilon_r \frac{K(k_3)}{K(k_3')} \tag{8}$$

and

$$Z_{O_e} = \frac{60\pi}{\sqrt{\epsilon_r}} \frac{K(k_3')}{K(k_3)}$$

where

$$k_3 = \sqrt{\frac{\left[\cos^2\left(\frac{\pi s}{2h}\right) - \cos^2\left(\frac{\pi r}{2h}\right)\right]\cosh^2\left(\frac{\pi w}{2h}\right)}{\left[\cosh^2\left(\frac{\pi w}{2h}\right) - \cos^2\left(\frac{\pi r}{2h}\right)\right]\cos^2\left(\frac{\pi s}{2h}\right)}} \tag{9}$$

Similarly, for the odd-mode case,

$$z_1 = \int_{t_0}^{t} \frac{dt}{\sqrt{t(t-t_2)(t-t_1)(t-1)}}$$

and

$$C_o = 2\epsilon_o\epsilon_r \frac{K(k_4)}{K(k_4')} \tag{10}$$

and

$$Z_{O_o} = \frac{60\pi}{\sqrt{\epsilon_r}} \frac{K(k_4')}{K(k_4)}$$

where

$$k_4' = \frac{\tan\left(\frac{\pi s}{2h}\right)}{\tan\left(\frac{\pi r}{2h}\right)} \tag{11}$$

Fig. 6 shows the even and odd-mode characteristic impedances of structure B, for variations in w/r, s/r, and r/h. It is observed that the even and odd mode impedances decreases as the shielding ground planes are brought closer together. The coupling factor, as shown in Fig. 7, is determined from:

$$C_{\mathrm{dB}} = -20\log_{10}\left[\frac{\dfrac{K(k_3')}{K(k_3)} - \dfrac{K(k_4')}{K(k_4)}}{\dfrac{K(k_3')}{K(k_3)} + \dfrac{K(k_4')}{K(k_4)}}\right] \quad (11)$$

The coupling is shown to increase as the shielding ground planes are moved away from the coupled lines.

III. Conclusion

Two new monolithic multilayer coupling structures have been presented and their design characteristics have been derived using direct analytical formulas. These closed form expressions have been used to investigate the variations in structure mode impedances and coupling coefficients. The placing of coupled lines, perpendicular to their ground plane(s), provides an improved alternative to coplanar edged coupled lines, where conductor edge current crowding needs to be minimized.

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Rigorous Analysis of Iris Coupling Problem in Waveguide

Rong Yang and A. S. Omar

***Abstract*—In this short paper we present a new class of simple basis functions which explicitly take the edge conditions into consideration for solving waveguide iris coupling problem by using moment method. The good agreement between the results for some special cases for both parallel-plate waveguide and rectangular waveguide from the present work and that from previous publications demonstrate the correctness of the choice of the basis functions. Compared with previously published basis functions the basis functions introduced here are characterized by their simple form, generality and still with a similar fast convergence behavior.**

I. Introduction

Waveguide iris coupling mechanism is frequently employed in building microwave components such as waveguide filters and impedance matching systems. Various analysis approaches like Conformal Mapping, Variational Technique, Singular Integration Equation Method, Mode Matching Method and Moment Method have been developed in the past decades with success in dealing with such problems.

The core of the moment method for solving waveguide iris coupling problem lies in a suitable choice of a set of basis functions to represent the tangential electric field behavior in the plane of the coupling iris. A proper choice of such basis functions can drastically reduce the computation efforts with a faster convergence of the results. It has been shown in [1] and [2] that a set of basis functions which account for the edge condition of the coupling aperture can be of such an effect. But their choices of basis functions are complicated and not straightforward. In this paper we present a new class of simple-form basis functions which explicitly take the edge conditions of the coupling iris into consideration. Compared with the previous choices of basis functions the present one is free from complexity and more universal but with similar fast convergence behavior.

II. General Theory and choice of Basis Function

The moment method is a successful one in solving iris coupling problem and a detail description of the method can be found in [4]. Only a very brief introduction of the method will be made in this short paper for the sake of brevity.

The transverse electromagnetic field in the waveguides at both sides of the coupling iris are expanded in terms of the corresponding waveguide eigen modes. The electric field of the coupling aperture is expanded with respect to a set of suitable basis functions. The equality of the tangential electric fields at the two sides of the iris to the aperture field as well as the continuity of the tangential magnetic fields across the iris along with the application of Galerkin's method leads to an infinite set of algebraic equations relating the incident and reflected modal amplitudes in both waveguides, from which a description of the coupling structure in terms of e.g. the S parameter can be derived. A truncation of the above infinite system of equation must be made before a numerical evaluation is to be carried out.

Assuming that the coupling iris is of zero thickness the basis functions which are supposed to account for the singular behavior

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