ANALYSIS AND MODELING OF COUPLED RIGHT ANGLE MICROSTRIP BEND DISCONTINUITIES

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ABSTRACT

Various coupled right angle microstrip bends encountered in microwave integrated circuits can be modeled in terms of four port networks consisting of equivalent excess discontinuity self and mutual inductances and capacitances associated with the coupled bends. Coupling parameters of two frequently encountered microstrip right angle bend configurations are computed by employing an iterative technique in a moment method formulation. The simulation of a rectangular spiral inductor is included to demonstrate the coupling effect of the investigated discontinuities.

INTRODUCTION

In the past various authors have employed the quasi static integral equation formulation in conjunction with the moment method to characterize a variety of microstrip discontinuities [1-6]. The respective models together with measurement and computer aided modelling techniques [7] are used intensively in the design of (M)MIC components. However, little attention has been given to the analysis of coupling effects between closely spaced discontinuities which are encountered in various circuit elements such as spirals and are accentuated in high density circuits. The present paper investigates the mutual coupling effect of rectangular bends and demonstrates their incorporation in a spiral inductor circuit model. The relatively large matrix size which is encountered in general coupling formulations is reduced by employing an iterative technique. This allows us to analyze coupled structures with similar computing requirements as for the case of isolated elements. The geometry of the structures considered in this paper and their circuits are shown in Fig. 1.

The present method applies triangular basis functions in the moment method formulation [8] which makes it easily adaptable to characterize arbitrary shaped discontinuities, e.g., chamfered coupled bends of variable angle. Triangular basis functions have been applied previously for scatterers and a microstrip via in a homogeneous region [9-11]. The corresponding potential integrals have been developed in [12].

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CALCULATION OF THE EXCESS CAPACITANCE MATRIX

The self and mutual capacitances for the coupled bends are computed by utilizing the integral equation for excess charge distribution in terms of residual strip potential. The kernel being the real space Green's function including all the images associated with the conducting as well as the dielectric interface. Only a finite number of images needs to be included in the computations. The residual potential being established by the excess charges of both conductors is formulated as

$$V_1(q_{e1},q_{e2}) = P_1 - U_1(q_1,q_2) \quad (1)$$

$$V_2(q_{e1},q_{e2}) = P_2 - U_2(q_1,q_2) \quad (2)$$

where subscripts 1 and 2 refer to the two conductors under consideration. P represent the constant potential on the strip surface. The operator U represents the electric field integral equation for the semi infinite line charges q. These line charges are precomputed and correspond to the charge distribution on the uniformly coupled microstrip lines at a distance sufficiently far away from the discontinuity. In the excess formulation the existence of q_1 and q_2 is defined such that no evaluation of source fields on the strip lines is performed. For example, the residual field on the lower arm of conductor 1 is calculated from the source charge q_2 that exists on conductor 2 and the source charge q_1 which exists on the extension of the lower arm of conductor 1 and its upper arm. A precise treatment of the excess charge concept is given in [10,11]. The operator V represents the electric field integral equation, relating the excess charge to the residual potential. In the moment procedure the excess charges are expanded in triangular subsectional basis functions of constant magnitude and tested at the centers of the triangles which results in an $(n_1+n_2)*(n_1+n_2)$ linear system, n_1 and n_2 being the number of expansion functions used on conductor 1 and 2, respectively. Instead of using (1) and (2), it is numerically more efficient to set up the residual potential formulation in an iterative manner which at step n is formulated as

$$V_1(q_{e1n}) = P_1 - U_1(q_1,q_2) - V_1(q_{e2(n-1)}) \quad (3)$$

$$V(q_{e2n}) = P_2 - U_2(q_1,q_2) - V_2(q_{e1(n-1)}) \quad (4)$$

resulting in two systems of order n1*n1 and n2*n2. Note, matrix elements depend on the geometry, dielectric constant and basis functions, they do not have to be recalculated. Furthermore, if LU decomposition of the linear system is used, the factorization needs to be applied only at the beginning of the algorithm and can be applied to subsequent iterative steps. For the investigated discontinuities the solution has converged after four to seven iterations.

The matrix form of the excess equivalent bend capacitance can be found from the total excess charges on the conductor 1 and 2 and the applied potential from the relation

$$\begin{bmatrix} Q_{e1} \\ Q_{e2} \end{bmatrix} = \begin{bmatrix} C_{11e} & C_{12e} \\ C_{21e} & C_{22e} \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} \quad (5), (6)$$

which relates the total excess charge on the conducting surfaces to the applied potential.

CALCULATION OF THE EXCESS INDUCTANCE MATRIX

The excess inductances associated with the coupled discontinuities are determined by computing the excess current distribution on the conducting surfaces from the magnetic field integral equation. The procedure is similar to the analysis of the via discontinuity in [11]. In the moment method procedure the current is approximated by triangular surface currents, also referred to as surface patch model [9].

The excess current distribution is found by computing the vector potential on the strip surface due to all currents and utilizing the boundary condition that the normal magnetic field be zero on the strip. The resulting integral equation for the excess current at step n can be formulated in an iterative manner as

$$m\cdot\nabla\times[A_1(J_{e1n})] = - m\cdot\nabla\times[A_1(J_1,J_2)] - m\cdot\nabla\times[A_1(J_{e2(n-1)})] \quad (7)$$

$$m\cdot\nabla\times[A_2(J_{e2n})] = - m\cdot\nabla\times[A_2(J_1,J_2)] - m\cdot\nabla\times[A_2(J_{e2(n-1)})] \quad (8)$$

where J_1 and J_2 are the current distributions that exist far away from the discontinuity and represent the current distribution on corresponding infinite lines without the discontinuity. In the discontinuity region these currents are defined such that continuous current flow is maintained. J_{e1n} and J_{e2n} are the solenoidal excess currents on strip 1 and 2 at the nth iteration, m is the unit vector normal to the conductor surface. In the moment method these currents are expanded as

$$J_{ei} = I_i \sum_{j=1}^{N_i} a_{ji}\cdot J_{ji}, \quad i = 1, 2 \quad (9)$$

where I_i is the total current on strip i, N_i refers to the number of interior nodes on conductor i and J_{ji} represent the basis functions around node j on conductor i, these are defined such as to guarantee current continuity around node j.

Excess inductances are determined from an excess flux formulation which leads to

$$L_{11e} = \frac{1}{I_1^2} \int A_1(J_1,J_{e1})\ J_1\ dS_1 \quad (10)$$

$$L_{12e} = \frac{1}{I_1 I_2} \int A_1(J_2,J_{e2})\ J_1\ dS_1 \quad (11)$$

$$L_{22e} = \frac{1}{I_2^2} \int A_2(J_2,J_{e2})\ J_2\ dS_2 \quad (12)$$

A grid generator was designed to automatically assign current nodes, directional basis functions, reference nodes and to identify the discontinuity region with appropriate current elements which assures continuous current flow through the discontinuity.

The algorithm was accelerated by two alternative optimizing schemes. A local error dependant element size was built iteratively by evaluating the residual flux through each element. Additional triangles are added where the local error exceeds a threshold. An optimum grid size was maintained in the sense of maximizing the smallest angles in the triangles [13,14]. An alternative algorithm was employed which makes use of a division scheme by means of a geometric series such that elements become smaller when the discontinuity region is approached. The latter algorithm has proven to be more efficient since the reevaluation of potential integrals is rather time consuming.

RESULTS

Results are presented in Fig. 2a and 2b for symmetrically coupled rectangular right angle bends of Fig. 1a to demonstrate the variation of the excess inductances and excess capacitances as a function of strip w/h ratio. Values for this case are normalized with respect to substrate height and the respective value for microstrip single and coupled lines. Results for the configuration of Fig. 1b are shown in Fig. 2c and 2d. A strip width of 1 m was assumed. Note that in both examples the spacing is equal to the width.

The four port discontinuity model was used to simulate the inductance of a 1-3/4 turn spiral inductor on a 110 μm substrate with a strip width of 8 μm and relative dielectric constant of 12.6 (Fig. 3). The inductance was modeled by subdividing the spiral into cascaded four ports and a two port, consisting of the coupled transmission line section, coupled corners, single corners and single transmission line section. For this case the potential integrals were evaluated over a distance of twice the substrate height. Another 1-3/4 turn spiral with a w/h ratio of 0.2 with 10 μm stripwidth on a GaAs substrate is shown to demonstrate the effect of the coupling at the right angled corner.

CONCLUSION

The moment method has been used to analyze rectangular coupled microstrip geometries. Quasi static results of coupled right angle bends were presented along with their equivalent circuit models which can be easily included in circuit simulators. These results were used in the simulation of a spiral inductor which leads to significant impedance changes.

ACKNOWLEDGEMENTS

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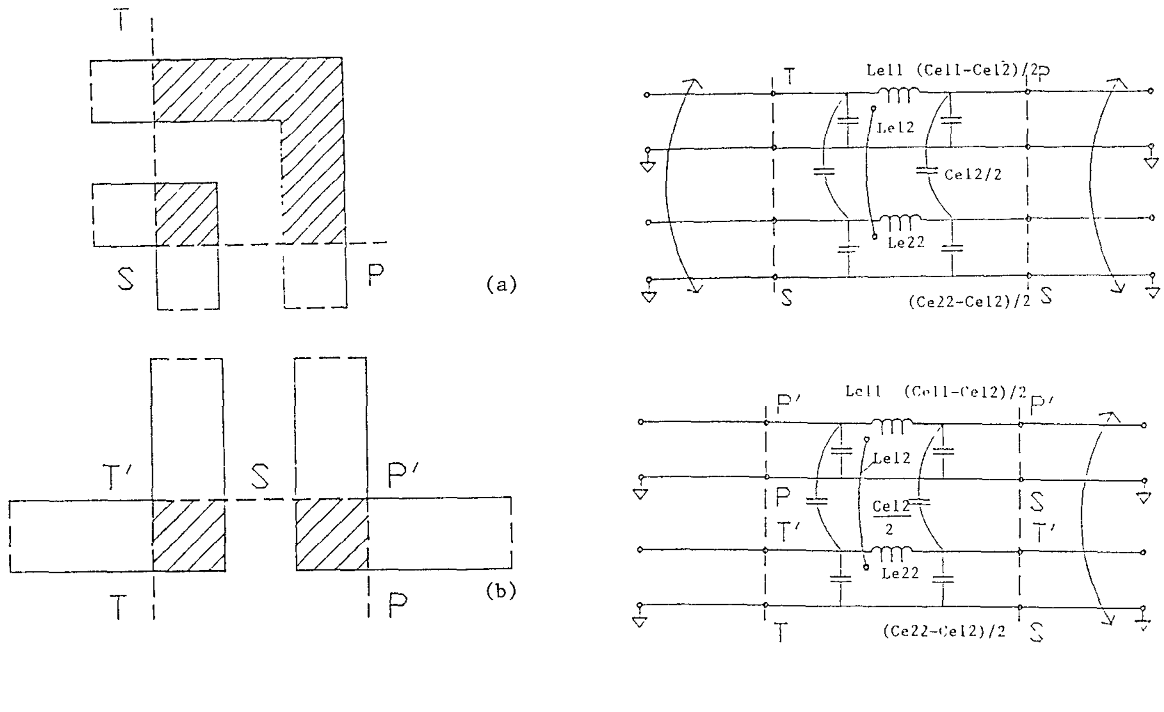

Figure 1: Equivalent Circuits for coupled Microstrip right angle bend Discontinuities.

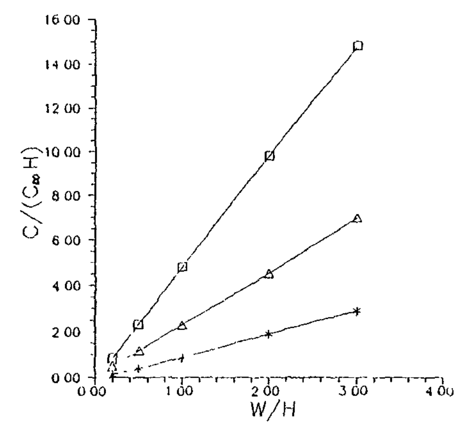

Figure 2a: Excess capacitances of coupled right angle bend four port of figure 1a.
□ ... C11e, * ... C22e, △ ... C12e.

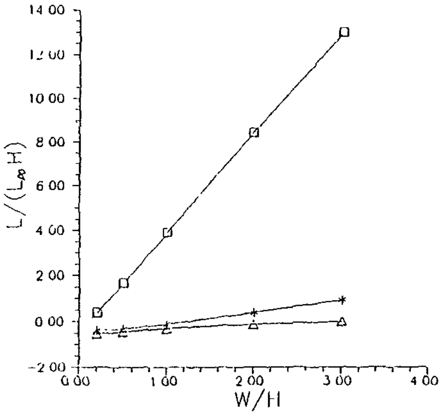

Figure 2b: Excess inductances of coupled right angle bend four port of figure 1a.
□ ... L11e, * ... L22e, △ ... L12e.

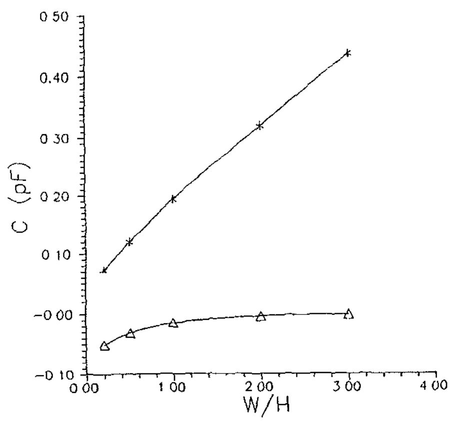

Figure 2c: Excess capacitances of coupled right angle bend four port of figure 1b.
* ... C11e, △ ... C12e.

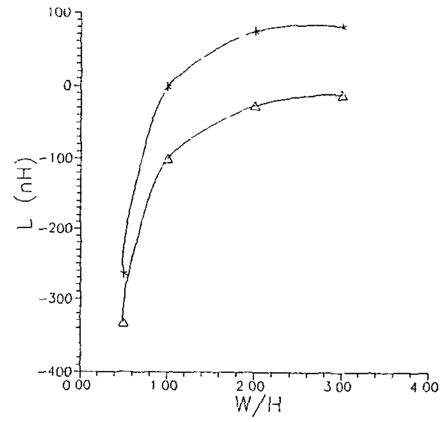

Figure 2d: Excess inductances of coupled right angle bend four port of figure 1b.
* ... L11e, △ ... L12e.

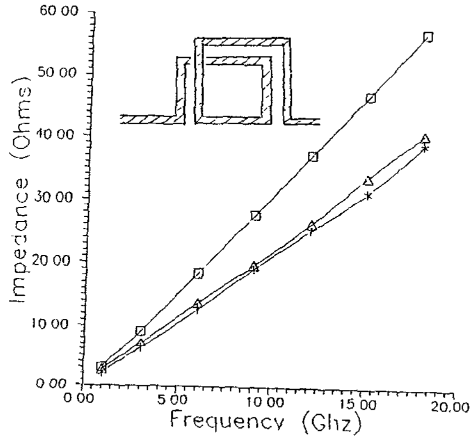

Figure 3: Simulated spiral inductance, W/H = 0.073
□ ... includes right angle microstrip bends only [7].
* ... includes microstrip bends and coupling between the bends.
△ ... measured data.

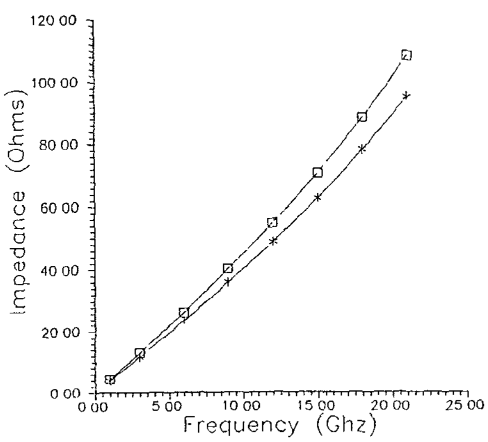

Figure 4: Simulated spiral inductance, W/H = 0.2
□ ... includes right angle microstrip bends only.
* ... includes microstrip bends and coupling between the bends.