ACCURATE CHARACTERIZATION OF CROSS-OVER AND OTHER JUNCTION DISCONTINUITIES IN TWO-LAYER MICROSTRIP CIRCUITS

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ABSTRACT

A mixed-potential spatial-domain integral equation approach is used to model the coupling and junction effects when microstrip structures in two different layers of a common substrate are crossing each other. In particular, some canonical four port and three port junctions are characterized by applying a Galerkin method with linear basis functions for the currents.

I. INTRODUCTION

With the recent advances in the fabrication of monolithic microwave and millimeter-wave integrated circuits (MMIC) it is not difficult to foresee the development of multi-layered planar MMIC circuits in a near future. Several questions naturally arise; among them: how significant the coupling is when transmission structures in different layers are crossing each other, or more importantly, how one can effectively use this kind of coupling to channel signals from one structure to another without physically connecting them together with via holes. Good examples can be found in the design of cross-over between two microstrip transmission lines at an arbitrary angle and transition between a terminated microstrip line in one layer and a staggered microstrip structure in the second layer. In addition to on-chip MMIC circuit design, multilayer microstrip structures also have important applications in multi-chip-module packaging, and in integrated microstrip antenna arrays.

The modeling of localized coupling and junction effects among various microstrip structures in a multilayered substrate closely follows the modeling of microstrips on a substrate with a single layer. We recently developed a moment-method based integral equation technique called P-Mesh, to accurately model the single-layer microstrip junctions. The method is now extended to include structures with a two-layered substrate. A new general algorithm for efficient computation of the corresponding Green's functions was devised for this purpose.

II. FORMULATION

Consider a two-layered planar structure with an arbitrary configuration of microstrip conductors (Figure 1). The mixed-potential electric field integral equation is obtained by enforcing a proper boundary condition for the total tangential electric field on the microstrip surface at each layer,

$$\sum_{i=1}^{2}\left(\frac{-j\eta_0 k_0^2}{2\pi}\right)\iint_{S_i}\left[G_{Mi}^{(p)}\ (\overline{X},\overline{X}') - \frac{1}{k_0^2}\nabla_t\nabla'_t \cdot G_{Ei}^{(p)}\ (\overline{X},\overline{X}')\right] \cdot \bar{J}_{S\,i}(\overline{X}')dS'_i - Z_{Si}\bar{J}_{S\,i}(\overline{X}) = -\overline{E}_{inc}^{(p)}$$

$$\overline{X} = (x,y) \qquad ; \qquad p = 1,2 \qquad (1)$$

where $\bar{J}_{Si}$ and Z_{Si} are the electric surface current and the surface impedance of S_i, respectively; $\overline{E}_{inc}^{(p)}$ is the tangential (incident) electric field impressed at the p-th surface. $G^{(p)}_{Mi}$ and $G^{(p)}_{Ei}$ are the Green's Functions of Magnetic and Electric types, respectively, evaluated at the p-th layer due to a source at the i-th layer. The formal expressions for G_E and G_M are obtained by solving the Helmholtz equation subject to the boundary conditions at each interface. We note that the time convention exp(+jωt) is used in equation (1).

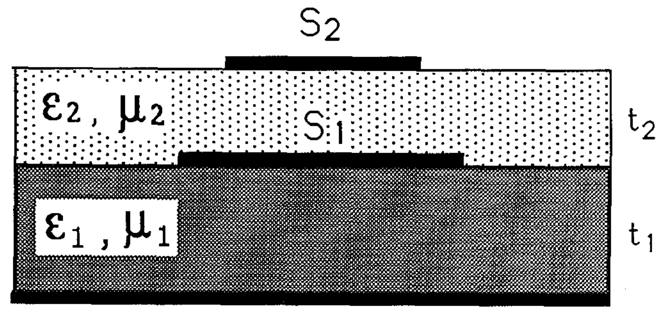

Figure 1: A Two-Layer Microstrip Structure

Typical Sommerfeld integrals involved in the Green's functions appearing in (1) are of the form:

$$G(z,\rho) = \int_0^{\infty} \tilde{G}(z,\lambda^2)\, J_0(k_0\rho\lambda)\lambda d\lambda \qquad (2)$$

$$\rho = \sqrt{x^2 + y^2}$$

where J_0 is the Bessel function of order zero. In general the spectral-domain Green's function $\tilde{G}(z,\lambda^2)$ exhibits discrete (surface-wave poles) as well as branch-cut singularities in the complex λ-plane and thus requires a careful numerical evaluation of the integral in (2). Also $G(z,\rho)$ in (2) exhibits $1/\rho$ singularity which should be extracted out before proceeding with a numerical evaluation of these integrals. To efficiently compute the remaining part of the integral, we have developed a new contour of integration, shown in Figure 2. This contour avoids all the singularities on the real axis, and therefore is particularly suited to multi-layered media where the precise location of the surface-wave poles are difficult to isolate.

In order to solve (1) numerically, $\bar{J}_s(X)$ is first approximated by a set of basis function, $\bar{H}_m(X)$:

$$\bar{J}si(\bar{x}) = \sum_{m=1}^{Mi} I_m^{(i)}\, \bar{H}m(\bar{x}) \qquad ; \qquad \bar{x} = (x,y) \qquad (3)$$

where $\bar{H}_m(X)$ is defined in a subregion, or multiple of regions on the surface of the microstrip conductor. Use of the Galerkin method in (1) now yields the following matrix equation:

$$\sum_{i=1}^{2}\sum_{m=1}^{Mi} Im^{(i)}\, Zmn = Vn^{(p)}$$

$$p = 1,2 \text{ and } n = 1,2,\ldots Mi \qquad (4)$$

where Z_{mn} and V_n can be computed individually.

The above matrix equation can now be solved for $\bar{J}_{s1}$ and J_{s2}, using the so-called mesh current representation for the basis function as applied to triangular and/or rectangular cells [1]. Once the current distributions are accurately computed, the scattering parameters can be extracted out by employing a de-embedding procedure.

III. NUMERICAL RESULTS

The cross-over of two microstrip transmission lines on different layers (Figure 3) is used as an example. The scattering parameters of such a structure is shown in Figure 4 over a wide frequency. It was found that the nature of the coupling can be explained by the charge or capacitive coupling in the common area where the two microstrip lines are staggered. Inductive coupling, on the other hand, was found not as significant in this case, except in the case when the intersecting angle is small, so that the two lines are nearly parallel. The effect of coupling is also substantially stronger for the upper microstrip than the lower microstrip, i.e. $|S_{33}|$ versus $|S_{11}|$. This is mainly due to the fact that the field associated with the lower microstrip is mainly confined to the region between the strip and the ground plane.

Other examples concerning the scattering parameter of multi-conductor microstrip for broadband couplers and hybrids will be presented.

REFERENCES

[1] J.X. Zheng and D.C. Chang, "Numerical modeling of Chamfered Load and other microstrip junctions of general shape in MMICs", IEEE/MTT International Microwave Symposium, pp. 709-712, Dallas, TX, May 1990.

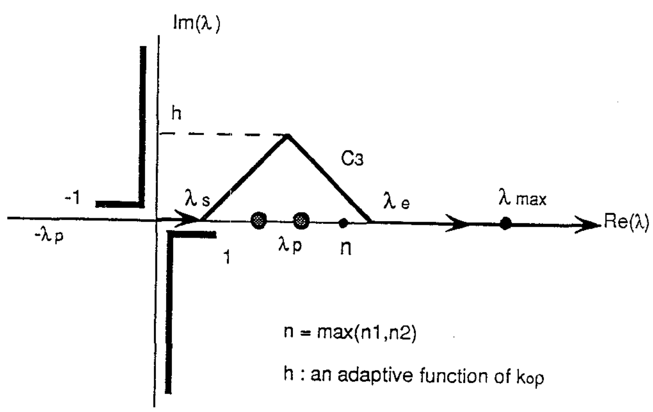

Figure 2: The integration contour for the Sommerfeld integrals.

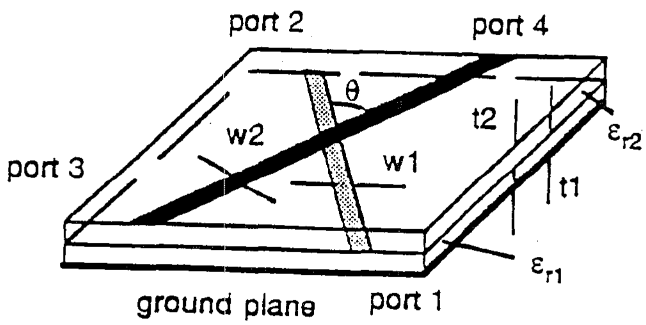

Figure 3 : Cross-over of two microstrip transmission lines.

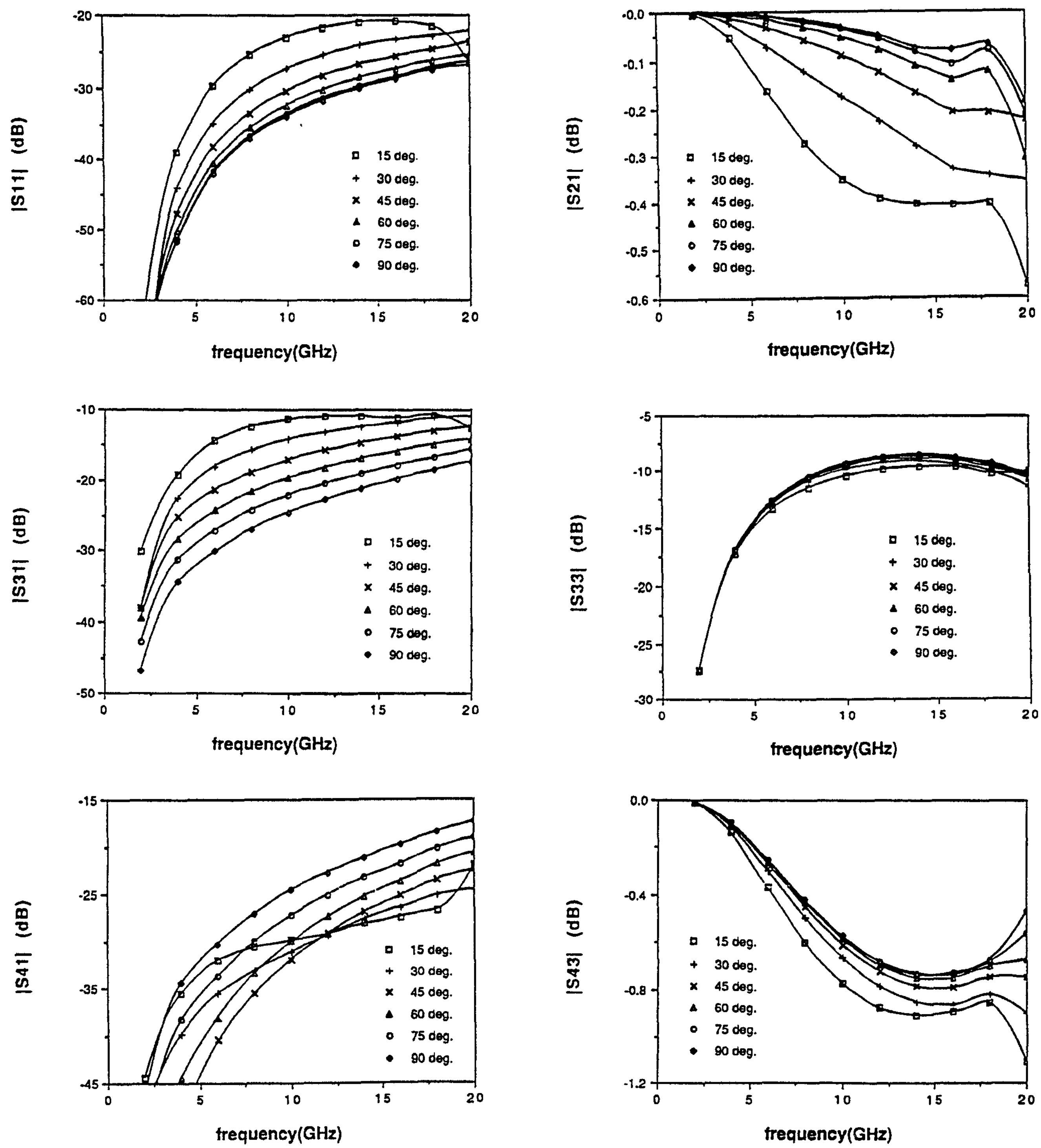

Figure 4 : The S-parameters for the microstrip cross-over; $t_1 = t_2 = 0.1905$ mm, $w_1 = w_2 = 0.381$ mm, $\varepsilon_{r1} = \varepsilon_{r2} = 2.2$, $\sigma = 4.55 \times 10^7$ s/m.