A DISCRETIZED INTEGRAL EQUATION APPROACH FOR SOLVING MICROSTRIP CIRCUITS EMBEDDED IN INHOMOGENEOUS WAVEGUIDES

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ABSTRACT

A novel fullwave hybrid technique using the method of lines in an integral equation approach (MOL/IE) is developed. The strength of the method lies in the numerical computation of the dyadic Green's function. The advantages of the technique are presented and validation is performed for 2D and 3D structures.

I. INTRODUCTION

Increased integration of microwave and digital integrated circuits within a single module housing has promoted the use of complex packaging geometries as shown in Fig. 1 [1]. Other applications of inhomogeneous waveguides include buried microstrip lines [2] and dielectric-ridge structures [3] to reduce the effect of crosstalk on the propagation of nanosecond pulses. Accurate modelling of these complex geometries requires powerful numerical tools to account for the irregular metallic housing and dielectric inhomogeneities contained within it. To this end, several fullwave approaches have been developed, including both differential and integral equation techniques. Among the differential equation discretization techniques, the method of lines (MOL) has been employed successfully to characterize strip-ridge waveguides [4]. However, it becomes computationally less efficient when analyzing structures involving either multiconductor transmission lines or relatively narrow conductor strips [5]. On the other hand, integral equation techniques (IE) are accurate for modelling arbitrary shaped conductor strips [6], but are not amenable to characterize finite dielectric inhomogeneities.

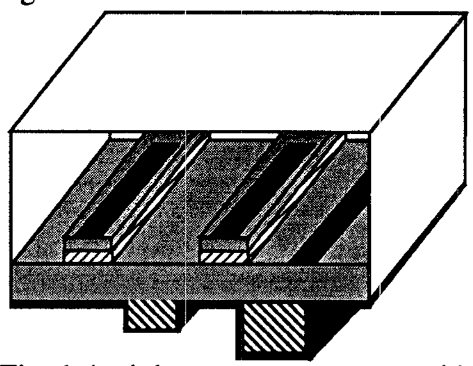

Fig. 1 An inhomogeneous waveguide

To overcome the shortcomings of these techniques, a new discretized integral equation approach (MOL/IE) is described in this paper. The method combines the advantages of the integral equation techniques to model precisely the conductor strips, and the generality of the MOL which can characterize a wide class of inhomogeneous structures. Other hybrid methods reported in the literature include the integral equation-mode matching technique (IEMM) [3] and the space-spectral domain approach (SSDA) [7].

II. APPROACH

In this method, the scattering superposition principle is applied to the generic multilayered ridged structure shown in Fig. 2, where the dyadic Green's function is expressed as the sum of an incident and a scattered component [8].

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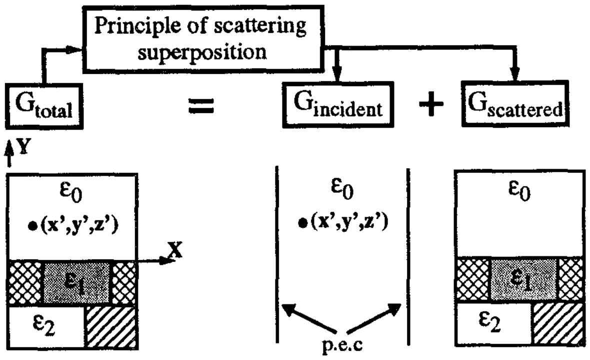

Fig. 2 Numerical computation of the dyadic Green's function

The incident part accounts for the radiation of a point source in a homogenous medium between two p.e.c. parallel plates, and is computed *analytically* using the eigenfunction expansion method. The scattered part accounts for the finite dielectric inhomogeneities, and is computed *numerically* by employing a MOL discretization in the *x*-direction. The total electric field in the structure is expressed as

$$\bar{E}(\bar{r}) = \int\int_{strips} \vec{G}_i(\bar{r};\bar{r}') \cdot \bar{J}(\bar{r}')\, ds' + \int\int_{strips} [\vec{G}_s(y,z;\bar{r}')] \cdot \bar{J}(\bar{r}')\, ds'$$

where the subscripts '*i*' and '*s*' stand for the incident and scattered fields, respectively. $\vec{G}_i(\bar{r};\bar{r}')$ is the analytically computed incident Green's function, $[\vec{G}_s(y,z;\bar{r}')]$ is the scattered Green's function which is computed by solving the governing wave equation using the MOL, and $\bar{J}(\bar{r}')$ is the induced surface current on the conductor strips. The application of the Dirichlet boundary condition on the strips leads to the formulation of the electric field integral equation (EFIE) which is solved for the unknown surface current using the method of moments.

III. RESULTS

First, the MOL/IE hybrid method is compared to both the IE technique [6] and the generic MOL [9] for the case of a shielded microstrip line on a homogeneous substrate. The convergence behavior of the effective dielectric constant ε_{eff}, based on the IE solution [6], is shown in Fig. 3 as a function of the number of lines for both the MOL/IE and the generic MOL. For such small strip width, the generic MOL requires 398 lines corresponding to 3 lines on the conductor strip, while the MOL/IE requires only 250 lines to achieve comparable accuracy. This reduction of the number of lines in the MOL/IE decreases the computation time by 70%, since the resulting matrix size is dependent on the number of expansion functions rather than the number of lines as in the MOL matrix. The MOL/IE is further validated for an inhomogeneous dielectric structure consisting of coupled microstrips with an air-groove. The effect of groove depth *h* on the propagation constants is displayed in Fig. 4 where the MOL/IE predicts the same behavior as the IEMM solution within 1% [3].

The MOL/IE technique provides a powerful tool for the analysis of inhomogeneous dielectrics along both the vertical and horizontal directions. The versatility of the method becomes even more apparent when applied to complex metallic packages, such as microwave high density integration modules (MHDI) [1]. A simplified model of such a circuit is analyzed in Fig. 5 where the dispersion characteristics are shown for different geometrical parameters.

The MOL/IE is further extended to the analysis of 3D inhomogeneous waveguides by altering the EFIE while maintaining a one-dimensional discretization of the MOL. This represents a great advantage over the generic MOL which requires 2D discretization along both longitudinal and transverse directions for the analysis of such geometries [9]. Validation of the 3D method is performed by comparing the scattering parameters of a right-angle bend in a homogeneous waveguide with a 3D IE approach [10], as shown in Fig. 6.

IV. DISCUSSION

The versatility of the MOL/IE approach comes from the ability to decouple the structure analytically into two parts, namely, the dielectric enclosure and the conducting strips, as in the IEMM technique [3]. However, unlike the IEMM, the fields in the MOL/IE are computed at discrete points throughout the dielectric enclosure irrespective of the number of homogeneous sections. An additional advantage of the MOL/IE is that it can easily account for doped substrates with non-uniform permittivity profile. The MOL/IE only requires a 1D discretization of the MOL for solving 3D problems, as does the SSDA [7]. However, the SSDA can hardly account for dielectric inhomogeneities in the waveguide cross section because the discretization is required to be in the propagation direction [7]. The MOL/IE can also account for vertical and transverse current components simultaneously which is not the case of the generic MOL.

IV. ACKNOWLEGEMENTS

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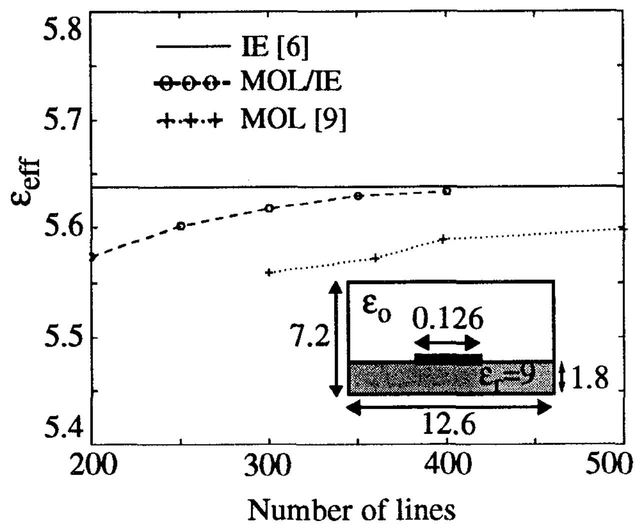

Fig. 3 The effective dielectric constant for a shielded microstrip line at 5 GHz (all dimensions are in mm).

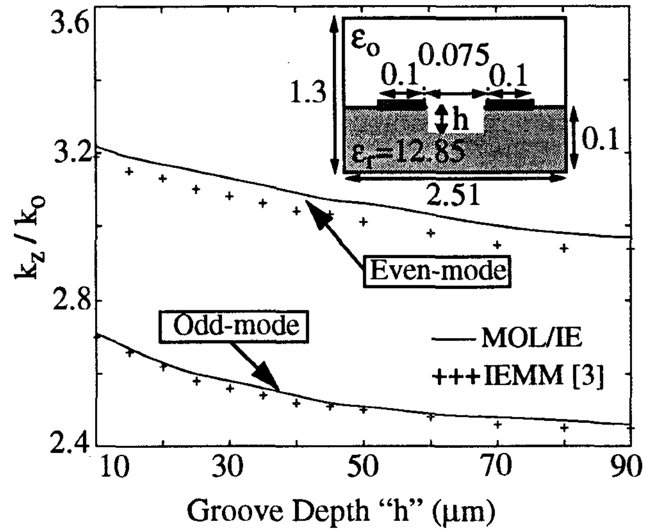

Fig. 4 The normalized propagation constant k_z/k_o versus groove depth for coupled strips with an air-groove at 94 GHz (all dimensions are in mm).

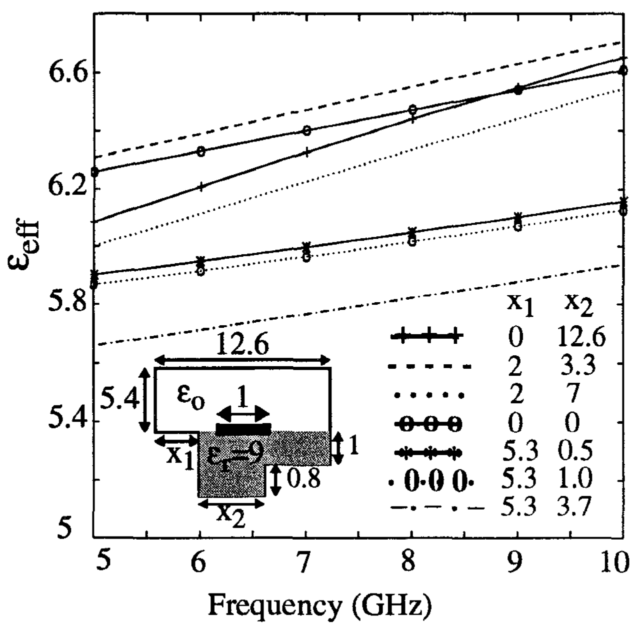

Fig. 5 Packaging effect on the dispersion characteristics of an MHDI model (all dimensions are in mm).

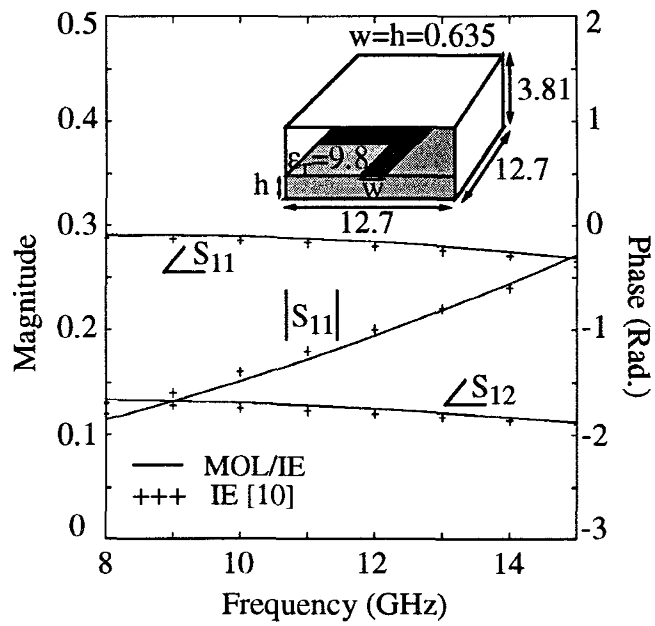

Fig. 6 Scattering parameters of right-angle bend discontinuity (all dimensions are in mm).