ELECTROMAGNETIC FIELD COUPLING TO MULTICONDUCTOR TRANSMISSION LINES IN MULTI-LAYERED MEDIA

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Abstract - *An accurate and efficient method for the analysis of incident field coupling to traces in inhomogenous media is described. The method is based on the application of physical optics in combination with boundary matching technique. In addition to accounting for the inhomogeneity of the medium, this method provides significant CPU improvement over conventional techniques.*

I-INTRODUCTION

The current trend towards more complex designs and higher operating frequencies has made signal integrity a challenging task. In addition, electrically long interconnects function as spurious antennas to pick up emissions from other nearby electronic systems. Various simulation techniques have been proposed for the analysis of incident field coupling to interconnects [1][2]. These techniques, in general consider the medium surrounding the interconnects homogeneous as far as the incident field is concerned. Imposing such conditions for inhomogenous structures gives wrong results at relatively high frequencies. In this paper, an efficient method is proposed which accounts for the inhomogenous media. It is based on the assumption that the traces are embedded in a planarly layered medium and requires the calculation of the fields in each layer separately [3][4]. Physical optics is used to obtain the fields within the layered medium without requiring extensive CPU time unlike computationally expensive methods which discretize the problem domain and/or boundaries.

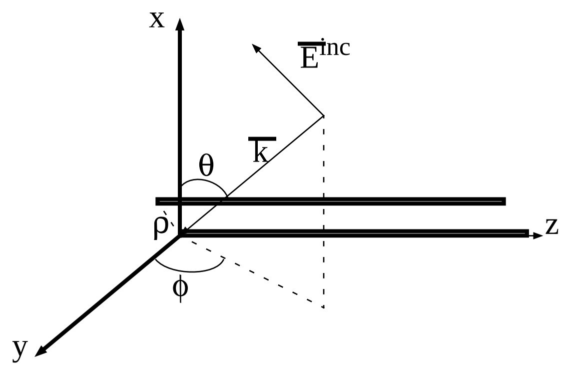

Fig. 1: Coordinate definitions

II-EXTERNAL FIELD COUPLING

Voltages and currents at both ends of the lines due to the external field excitation can be calculated in terms of the transverse component of the incident field and the axial component along the conductors. Assuming conductors extending in z-direction, the forced Telegrapher's equations in the frequency domain are as follows [5]

$$\frac{\partial}{\partial z}I(z) + \boldsymbol{G}V(z) + j\omega\boldsymbol{C}V(z) = -\boldsymbol{G}\int_0^h E_t^{inc}(\rho, z)d\rho - j\omega\boldsymbol{C}\int_0^h E_t^{inc}(\rho, z)d\rho \quad \textbf{(1)}$$

$$\frac{\partial}{\partial z}V(z) + j\omega\boldsymbol{L}I(z) + \boldsymbol{R}I(z) = -\frac{\partial}{\partial z}\int_0^h E_t^{inc}(\rho, z)d\rho + E_z^{inc}(h, z) - E_z^{inc}(0, z) \quad \textbf{(2)}$$

In these equations, I(z) and V(z) are the current and voltage waves propagating along the lines; **R**, **L**, **C** and **G** are per unit length resistance, inductance, capacitance and conductance, respectively. E_t^{inc} and E_z^{inc} are transverse and axial components of the incoming field and h is the separation between the lines (Fig.1). In this paper, the aim is to find the modified E_t^{inc} and E_z^{inc} fields in the presence of the dielectric substrate with the conductors removed in order to account for the medium inhomogeneity.

III-CALCULATION OF THE FIELDS IN THE LAYERED MEDIA

To simplify the calculation of the field, the following assumptions are made: 1) The incident field is a plane wave, 2) the substrate extends to infinity in the yz-plane 3) the incident field in the absence of the dielectric medium and traces is known. A plane wave incident on a planarly layered inhomogenous media undergoes multiple reflections and refractions at the interface of the adjacent layers. The resultant fields are sum of the upward and downward travelling waves in each layer. Applying the boundary conditions results in the following basic equations at each interface [6]

$$K_{i,1+i}\left(A_{y,i}e^{-jk_{x,i}h_i} - B_{y,i}e^{jk_{x,i}h_i}\right) = A_{y,i+1}e^{-jk_{x,i+1}h_i} - B_{y,i+1}e^{jk_{x,i+1}h_i} \tag{3}$$

$$A_{y,i}e^{-jk_{x,i}h_i} + B_{y,i}e^{jk_{x,i}h_i} = A_{y,i+1}e^{-jk_{x,i+1}h_i} + B_{y,i+1}e^{jk_{x,i+1}h_i} \tag{4}$$

where k_i is the wavenumber in the i^{th} layer. The A_i and B_i are the amplitudes of the waves in the i^{th} layer travelling in the same direction as the incident and reflected waves, respectively. According to Snell's law, the incident, reflected and refracted waves lie in the same plane. In this case, a general incident field can be decomposed into its TE and TM components, for which

$$K_{i,1+i} = \frac{k_{x,i}}{k_{x,i+1}} \tag{5}$$

for a TE wave and,

$$K_{i,1+i} = \frac{k_i\cos\theta_{i+1}}{k_{i+1}\cos\theta_i} \tag{6}$$

for a TM wave.

IV-LINKING TO CIRCUIT SIMULATION

The solution of (1) and (2), can be written as,

$$\begin{bmatrix}\boldsymbol{V}(l)\\ \boldsymbol{I}(l)\end{bmatrix} = \boldsymbol{T}(s)\begin{bmatrix}\boldsymbol{V}(0)\\ \boldsymbol{I}(0)\end{bmatrix} + \boldsymbol{b}(s) \tag{7}$$

where the far end voltage and current ($V(l)$ and $I(l)$) are related to the near end voltage and current ($V(0)$ and $I(0)$). The state transmission matrix $T(s)$ represents the transmission line stamp, and the vector $b(s)$ represents the lumped effect of the incident field coupling.

Various techniques [7] are available for interconnect simulation. Some of these approaches are extendable to the case of incident fields. For example, the simulation can be done in the frequency domain by simply solving the MNA equations at each frequency point, or in the time domain by using FFT or a variations of the method of characteristics[1]. Another useful approach is based on the recently introduced moment matching techniques for circuit simulation[2][8]. This technique allows for very efficient generation of a time domain macromodel that can be incorporated in conventional nonlinear circuit simulators such as SPICE. Moment matching techniques require the calculation of the moments of the vector $b(s)$ in (7). This added complexity is however offset by significant CPU savings, especially in large interconnect networks, and the ability to handle nonlinear terminations[9].

V-NUMERICAL EXAMPLES

The test structure considered is a dielectric board sandwiched between two traces (Fig. 4). Per-unit-length parameters are calculated as C=41 pF/m for epoxy-glass **(**ε_r**=**4.5**)** and C=97 pF/m for silicon **(**ε_r**=**11.7**)** with L=0.83 μH/m. For all cases, matched terminations (R_L=142Ω for epoxy-glass and R_L=93Ω for silicon) are assumed at both ends. Comparison between the proposed method (Approach I) and the conventional analysis (Approach II) which considers the inhomogeneity of the medium only in the calculation of per unit length parameters is made in the time domain with a gaussian pulse envelope for the incident field. The pulse amplitude and duration are taken as 1000 V/m and 0.62 nsec, respectively.

The results for a TM polarized plane wave incidence ($\theta=30^o$, $\phi=-90^o$) are shown in Fig. 2 and Fig. 3, for epoxy-glass and silicon substrates, respectively. It is obvious that neglecting the medium inhomogeneity leads to erroneous results. In addition, several other cases were simulated for varying incidence angles. It was observed that the error due to neglecting the medium inhomogeneity increases at larger elevation angles θ and higher values of the relative permittivity.

VI-CONCLUSIONS

An accurate and efficient method was described for the analysis of incident field coupling to high-speed interconnects in inhomogenous media. Physical optics technique was used for the field calculations, thus providing significant CPU improvement over full wave methods while maintaining comparable accuracy. The results have shown that the common approach of neglecting the effect of the medium inhomogeneity in the field calculation produces erroneous results. The presented approach provides an efficient solution to this problem.

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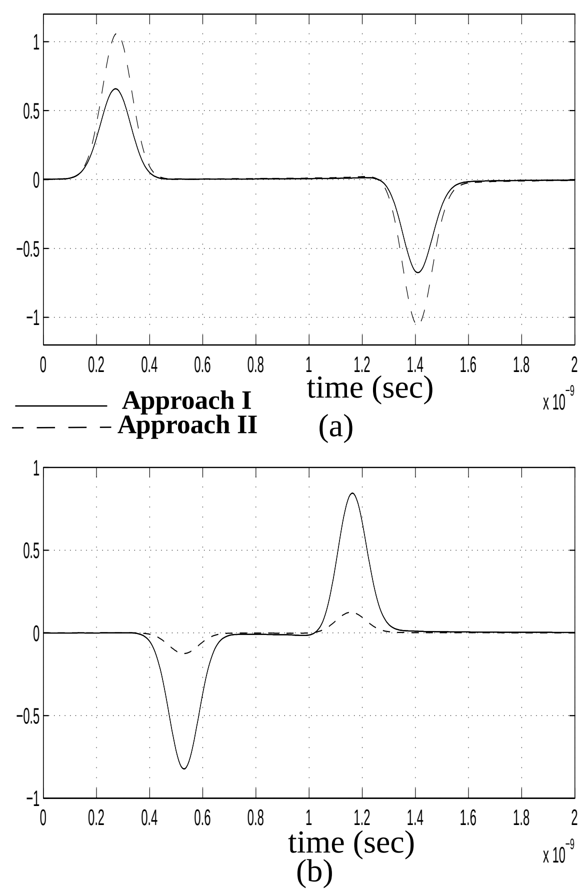

Fig. 2: Coupled voltage waveform at (a) near end, (b) far end of the trace (ε_r**=4.5).**

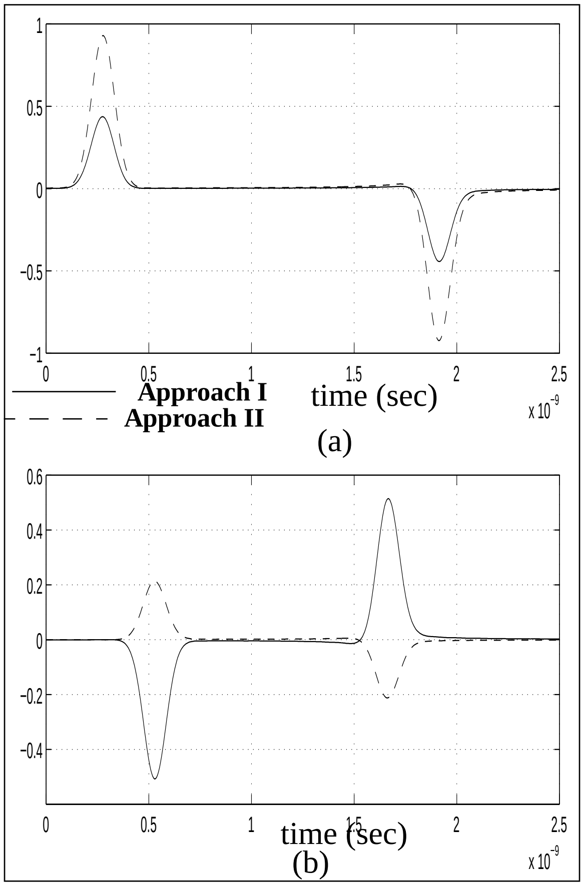

Fig. 3: Coupled voltage waveform at (a) near end, (b) far end of the trace (ε_r=11.7).

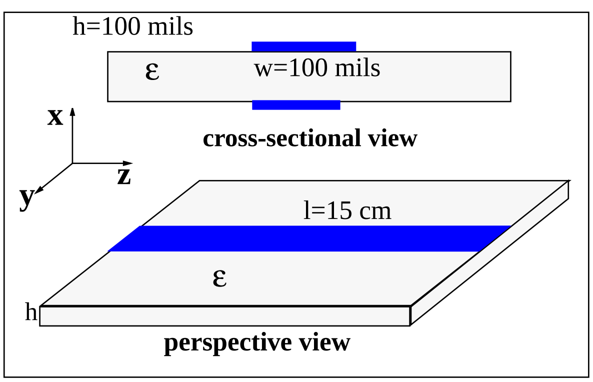

Fig. 4: Test Structure

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