THE ANALYSIS AND REDUCTION OF CROSSTALK ON COUPLED MICROSTRIP LINES USING NONUNIFORM FDTD FORMULATION

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ABSTRACT

A FDTD formulation with nonuniform mesh for inhomogeneous lossy media has been derived and applied to reduce crosstalk on models of high speed computer and millimeter wave integrated circuits. Our investigation shows that the use of PEC cover and PEC doping between coupled microstrip lines reduces the crosstalk by approximately 15dB over a very wide frequency range.

INTRODUCTION

With the dramatic increase in clock speeds for computers and the increased use of millimeter wave integrated circuits (MMIC), the interest in analyzing and reducing the crosstalk between lans on chips has become significantly important. The MMIC configurations for such devices present a challenge because of the wide difference of materials and geometries employed for fabrication. Quasi-TEM as well as full wave models have been employed for analysis using integral and differential equations approaches. Most of the attention in the published literature has been on techniques for analysis of crosstalk; however, we have recently addressed several techniques for crosstalk reduction [1-4]. Among the techniques we have proposed and used are an air gap between lines, conducting doping between lines, and covers of different types (dielectric and/or conducting) or combinations thereof.

In the present study the finite difference time domain (FDTD) techniques applied to the analysis of crosstalk reduction on models of high speed computer and millimeter wave integrated circuits is employed. The analysis of coupled microstrip lines includes models with air gap, PEC or lossy material doping, and PEC covered configurations as illustrated in Figure 1. The FDTD technique is formulated with nonuniform mesh for inhomogeneous lossy media. A voltage source with internal resistance and matching resistive elements at the passive ports along with an appropriate outer absorbing boundary conditions have been applied to truncate the infinite computational space. Standard fast Fourier transform techniques have been used to obtain frequency domain data from the time domain response.

NONUNIFORM FDTD FORMULATION

The FDTD formulation for layered dielectrics, based upon the boundary conditions and the first order expansion of tangential field components was derived, and good agreement was obtained between theoretical results and measured data [5]. Based on this same principle, the basic FDTD formulation is extended here to the 3-D nonuniformly meshed inhomogeneous dielectric objects. The FDTD formulations for nonuniformly meshed homogeneous dielectrics, uniformly meshed homogeneous dielectrics, nonuniformly meshed layered dielectrics, and uniformly meshed layered dielectrics can be obtained from this formulation as special cases [4]. In the present formulation, the 3-D computational space is meshed in three orthogonal directions with different cell sizes in each of the three directions. The cell sizes along a given direction are also allowed to differ from each other. Consider, for example the four cells V_1, V_2, V_3 and V_4 around the z component of the electric field are made of four different dielectrics. With a plane passing through the mid point of the four cells and perpendicular to the z direction and the edges of the cells, the four cells model will be cut into two halves. The projection of this plane into the x-y plane is shown in Figure 2. The interfaces between different cells are shown as contours C_{12}, C_{23}, C_{34} and C_{41}. Denoting the region number by the integer k (k=1,2,3,4) with ϵ_k, σ_k being the electric

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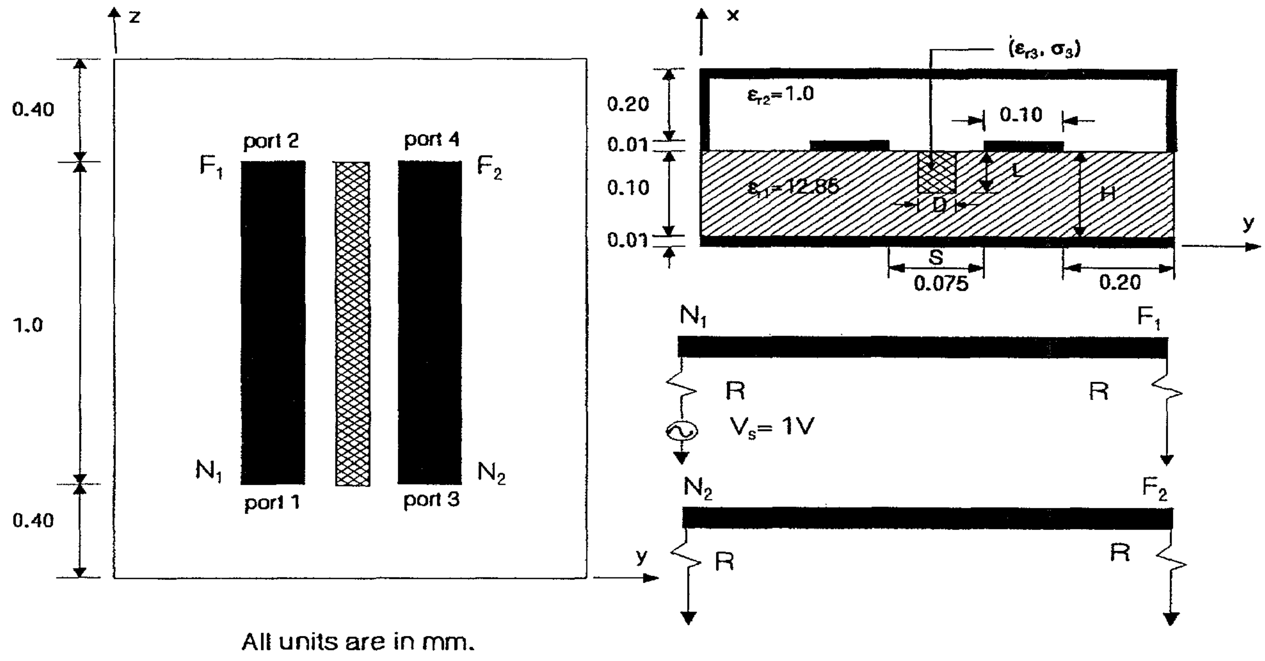

Figure 1. Geometry of the coupled microstrip line.

permmitivity and conductivity of the medium in region V_k, respectively, one can use Maxwell's equations to express E_z as

$$\frac{\partial E_z}{\partial t} = \frac{1}{\epsilon_k}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right)\Big|_k - \frac{\sigma_k}{\epsilon_k}E_z \qquad (1)$$

Since the normal component of the magnetic field is continuous across the interface of different dielectrics, i.e. H_x is continuous across the contour C_{12} and C_{34} and H_y across the contour C_{41} and C_{23}. The derivatives of these magnetic field components along the direction of these contours should be continuous. Based on this continuity of the magnetic field components, one can write four different expressions for the derivative of E_z given by equation (1). After mathematically manipulating these expressions, the following equations that define the E_z in terms of the four cells parameters are obtained, i.e.

$$\frac{\partial E_z}{\partial t} = C_x \delta H_x + C_y \delta H_y + C_z E_z$$

$$\delta H_x = H_x(P_2) - H_x(P_4)\ ,\ \delta H_y = H_y(P_1) - H_y(P_3)$$

$$C_x = \frac{\alpha_{22}+\alpha_{21}}{\alpha_{11}\alpha_{22}-\alpha_{12}\alpha_{21}}\ ,\ C_y = \frac{\alpha_{12}+\alpha_{11}}{\alpha_{11}\alpha_{22}-\alpha_{12}\alpha_{21}}$$

$$C_z = \frac{1}{\epsilon_1}\left[\frac{\beta_1\alpha_{22}+\beta_1\alpha_{21}+\beta_2\alpha_{11}+\beta_2\alpha_{12}}{\alpha_{11}\alpha_{22}-\alpha_{12}\alpha_{21}} - \sigma_1\right]$$

$$\alpha_{11} = \epsilon_1\delta x_1 + \epsilon_2\delta x_2\ ,\ \alpha_{12} = (\epsilon_1 - \epsilon_2)\delta x_2$$

$$\alpha_{21} = (\epsilon_1 - \epsilon_4)\delta y_2\ ,\ \alpha_{22} = \epsilon_1\delta y_1 + \epsilon_4\delta y_2$$

$$\beta_1 = (\sigma_1\epsilon_2 - \sigma_2\epsilon_1)\delta x_2\ ,\ \beta_2 = (\sigma_1\epsilon_4 - \sigma_4\epsilon_1)\delta y_2$$

If the partial derivative of E_z with respect to time is approximated using the central difference, and E_z on the right side in the above equation is represented by the average in time, then the FDTD updating equation for the E_z can be easily obtained. As for the corresponding E_x and E_y components, the derivation procedure follows in a similar manner. It should be noted however that the FDTD expressions for the magnetic field components based on the standard Yee's algorithm do not need any modifications since they are based on the modified expressions of the electric field components.

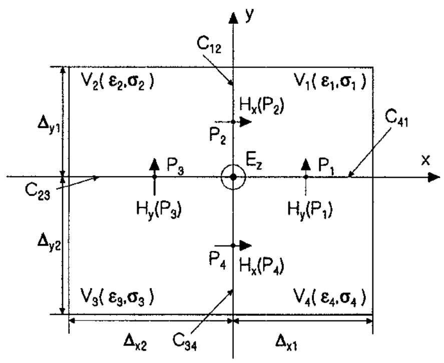

Figure 2. Plane cut of the nonuniform four-cell model surrounding the z component of the electric field.

SAMPLE NUMERICAL RESULTS

The influence of time and spatial domain parameters in the FDTD algorithm on the numerical results has been studied and discussed. The numerical results obtained by the developed nonuniformly meshed FDTD algorithm have been compared with available numerical data and measured results for similar geometries, and excellent agreement have been obtained [4]. The computational resources (CPU time and memory) required by the developed FDTD algorithm are found to be significantly less than that is needed by a uniformly meshed FDTD technique. This FDTD formulation has been applied to analyze and reduce crosstalk between microstrip lines by creating an air notch, inserting a PEC doping or lossy dielectric material between the lines, and by placing a PEC cover on top of the lines. A sample of our numerical results is shown in Figure 3, where the S parameters for the four different configurations listed in Table 1 are presented. In this example, case "a" represents a standard transmission line consisting of two conducting lines above a grounded dielectric substrate, case "b" represents a transmission line with a PEC cover on top of the conducting lines, case "c" represents a transmission line with a PEC doping between the lines, and case "d" represents a transmission line with a PEC doping and PEC cover. It is very clear from the figure that the coupling on the passive line at ports 3 and 4, are greatly reduced when comparing case "d" to case "a". The reduction in coupling is approximately 15 dB at the near end and 10 dB at the far end over a very wide frequency range (10 to 90 GHz).

ACKNOWLEDGMENT

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Table 1: The parameters for the transmission line geometries of cases "a" to "d" (NPEC ≡ without PEC cover, PEC ≡ with PEC cover).

Case	Geometry parameters	R (Ω)	Mesh size (Nx,Ny,Nz)
a	$\epsilon_{r3}=\epsilon_{r1}$, $\sigma_3=0$, NPEC	38.00	10,18,41
b	$\epsilon_{r3}=\epsilon_{r1}$, $\sigma_3=0$, PEC	35.24	10,18,41
c	$\sigma_3=\infty$, NPEC L/H=0.2, D/S=0.2	30.95	10,17,41
d	$\sigma_3=\infty$, PEC L/H=0.2, D/S=0.2	29.46	10,17,41

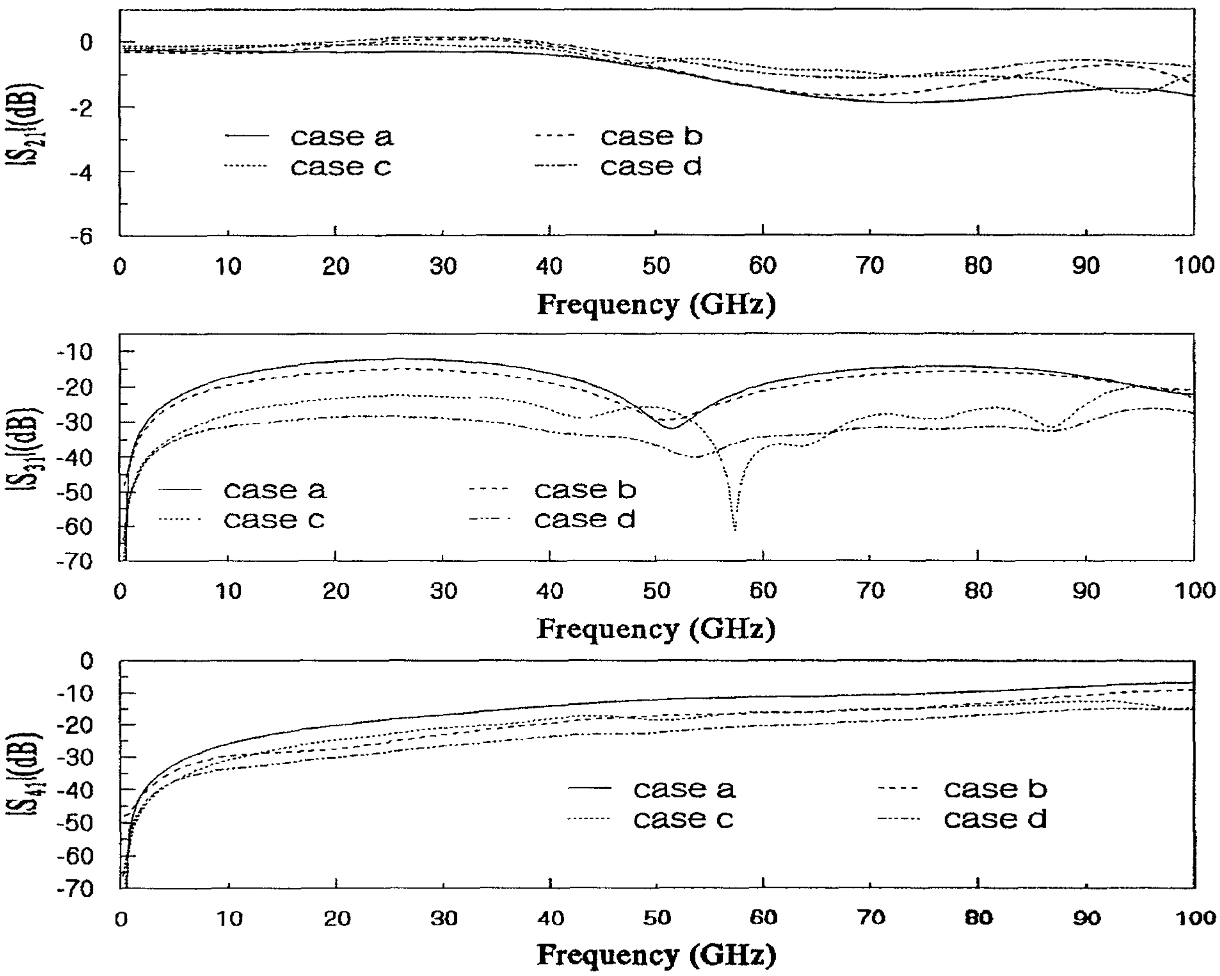

Figure 3. S parameters for cases “a” to “d” listed in Table 1.