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Quasi-TEM Analysis of Multiconductor Transmission Lines Embedded in Layered Dielectric Region

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Abstract: This paper presents the quasi-TEM two-dimensional (2D) approach for the analysis of multicondcutor transmission lines interconnect in single and two-layered dielectric region using the finite element method (FEM). FEM is especially suitable and effective for the computation of electromagnetic fields in strongly inhomogeneous media. We illustrate that FEM is as suitable and effective as other methods for modeling multiconductor transmission lines VLSI circuits. We mainly focus on designing of four-transmission lines embedded in two-layered dielectric media and five-transmission lines interconnect in single-layered dielectric medium. We compared some of our results of computing the capacitance matrix with those in the literature and found them to be in agreement.

Keywords: Capacitance per unit length, Multiconductor transmission lines, Finite element Method, Modeling

1. Introduction

The optimization of the electrical performance of microelectronic integrated circuits becomes an important factor when the signal speeds and components densities increase. Therefore, the accurate and efficient computational of self and mutual (coupled) capacitances of multicondcutor interconnect in very high speed integrated circuits is essential for scientists and researchers. The characteristics of microwave integrated circuits' analysis and design must be accomplished accurately in a short time. The significant advantages of printed circuits are somewhat offset by the electromagnetic complexity of the structure, because its inherent inhomogeneous nature makes accurate calculations difficult.

Several methods used for analyzing multiconductor transmission lines include the method of moments (MoM) [1-3], measured equation of invariance (MEI) [4-6], Fourier projection method (FPM) [7], matrix pencil method (MPM) [8], Fourier transform and mode-matching techniques (FTMM) [9], partial element equivalent circuit methods (PEEC) [10], method of line (MoL) [11], spectral domain analysis (SDA) [12], and finite difference method [13].

We use COMSOL, a finite element multiphysics package, in designing the four-transmission lines interconnect in two-layered dielectric media and five-transmission lines interconnect in single-layered dielectric medium structures. The FEM is especially suitable and effective for the computation of electromagnetic fields in strongly inhomogeneous media. Also, it has high computation accuracy and fast computation speed. We show that FEM is as suitable and effective as other methods for modeling multiconductor transmission lines VLSI circuits.

We compared some of our results of computing the capacitance-per-unit length with those in the literature. We specifically compared the modeling of designing of four-transmission lines interconnect in two-layered dielectric media with the method of moments, measured equation of invariance, and Fourier projection method. Also, results from the matrix pencil method, and Fourier transform and mode-matching techniques were compared for five-transmission lines interconnect in single-layered dielectric medium and found to be in agreement.

2. Results and Discussions

The models are designed with finite elements are unbounded (or open), meaning that the electromagnetic fields should extend towards infinity. This is not possible because it would require a very large mesh. The easiest approach is just to extend the simulation domain "far enough" that the influence of the terminating boundary conditions at the far end becomes negligible. In any electromagnetic field analysis, the placement of far-field boundary is an important concern, especially when dealing with the finite element analysis of structures which are open. It is necessary to take into account the natural boundary of a line at infinity and the presence of remote objects and their potential influence on the field shape [14]. In all our simulations, the open multiconductor structure is surrounded by a W X H shield, where W is the width and H is the thickness.

The models are designed in 2D using electrostatic environment in order to compare our results with the other available methods. In the boundary condition of the model's design, we use ground boundary which is zero potential ($V = 0$) for the shield. We use port condition for the conductors to force the potential or current to one or zero depending on the setting. Also, we use continuity boundary condition between the conductors and between the conductors and left and right grounds.

The quasi-static models are computed in form of electromagnetic simulations using partial differential equations.

In this paper, we consider two different models. Case A investigates the designing of four-transmission lines interconnect in two-layered dielectric media. For case B, we illustrate the modeling of five-transmission lines interconnect in single-layered dielectric medium. The results from both models are compared with some other results in the literature and found to be close.

2.1 Four-Conductor Transmission Lines

Figure 1 shows the cross section for four-conductor transmission lines with the following parameters:

ε_{r1} = dielectric constant of the dielectric material = 5.0
ε_{r2} = dielectric constant of the free space = 1.0
W = width of the dielectric material = 10mm
w = width of a single conductor line = 1mm
H_1 = distance of conductors 1 and 2 from the ground plane = 3mm
H_2 = distance of conductor 4 from the ground plane = 1mm
H_3 = distance of conductor 3 from the ground plane = 2mm
s = distance between the two coupled conductors = 1mm
t = thickness of the strips = 0.01mm

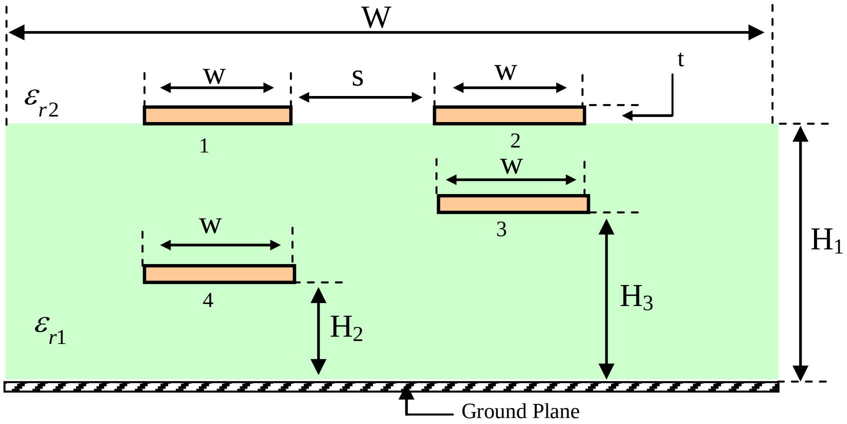

Figure 1. Cross section of four-conductor transmission lines.

The geometry is enclosed by a 10 X 10mm shield. From the model, we generate the finite elements mesh with 10,479 elements and number of degrees of freedom solved for 116,744, in solution time: 25.781 seconds as in Figure 2. Figure 3 shows the contour plot of the potential distribution with port 1 as input. The potential distribution along the line that goes from (x,y) = (0,0) to (x,y) = (10mm, 10mm) is portrayed in Figure 4.

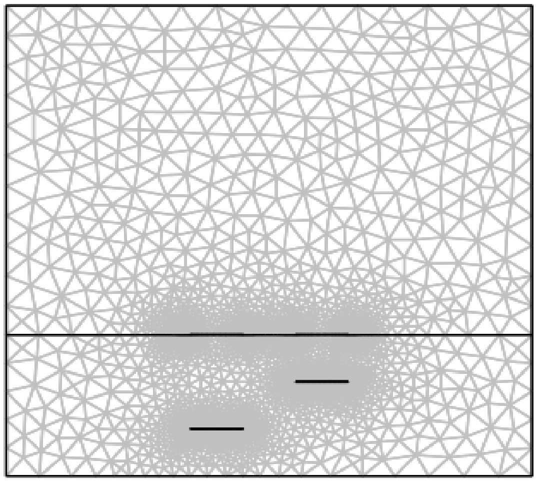

Figure 2. Mesh of four-conductor transmission lines.

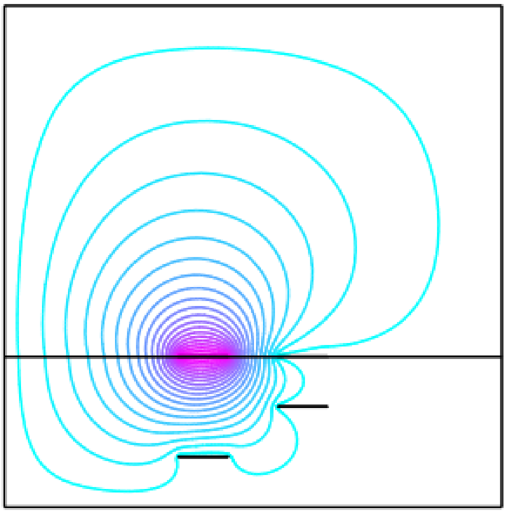

Figure 3. Contour plot of the potential distribution of four-conductor transmission lines with port 1 as input.

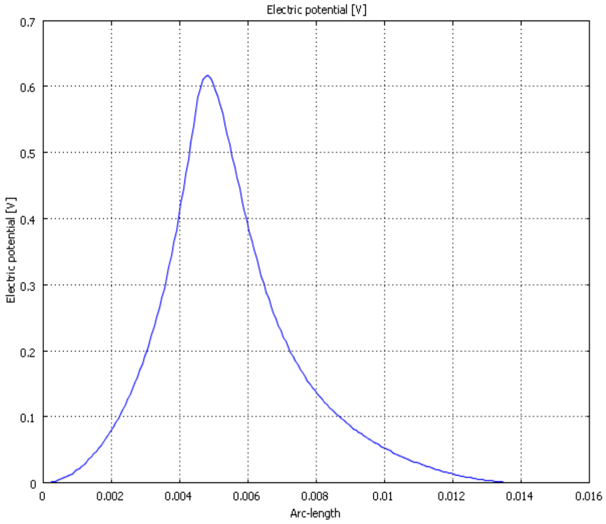

Figure 4. Potential distribution of four-conductor transmission lines using port 1 as input along a line from (x,y) = (0,0) to (x,y) =(10 mm, 10 mm).

Table 1 shows the finite element results for the capacitance-per-unit length of four-transmission lines embedded in two-layered dielectric media. It compares the results based on our work with those from other methods.

Table 1. Values of the Capacitance Matrix (in pF/m) for Four-Conductor Transmission Lines as Shown in Fig. 1

Capacitance per unit length	MoM[1-3]	MEI[4]	FPM[7]	This work
C_{11}	70.158	89.514	70.158	73.052
C_{12}	-12.842	-12.832	-12.839	-12.948
C_{13}	-12.960	-13.110	-12.967	-13.239
C_{14}	-22.240	-23.014	-22.230	-22.549
C_{22}	87.327	87.028	87.227	90.823
C_{23}	-54.195	-55.462	-54.234	-56.029
C_{24}	-4.052	-3.988	-4.049	-3.924
C_{33}	133.935	128.861	128500	139.354
C_{34}	-15.606	-14.935	-14.210	-16.520
C_{44}	141.170	141.312	135.940	145.967

2.2 Five-Conductor Transmission Lines

Figure 5 shows the cross section for the five-conductor transmission lines with the following parameters:

ε_{r1} = dielectric constant of the dielectric material = 2.0

ε_{r2} = dielectric constant of the free space = 1.0
W = width of the dielectric material = 31mm
w = width of a single conductor line = 3mm
h = distance of conductors from the ground plane = 1mm
s = distance between the two coupled conductors = 2mm
t = thickness of the strips = 0.01mm

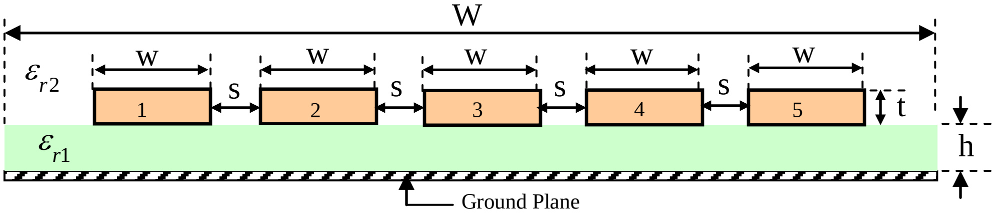

Figure 5. Cross section of five-conductor transmission lines.

The geometry is enclosed by a 31 X 5mm shield. From the model, we generate the finite elements mesh with 1,868 elements and number of degrees of freedom solved for 21,724, in solution time: 2.86 seconds as in Figure 6. Figure 7 shows the contour plot of the potential distribution with port 1 as input. The potential distribution along the line that goes from (x,y) = (0,1mm) to (x,y) = (31mm, 5 mm) is portrayed in Figure 8.

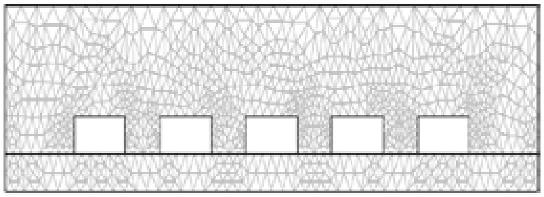

Figure 6. Mesh of the five-conductor transmission lines.

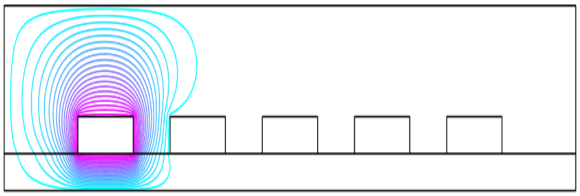

Figure 7. Contour plot of the potential distribution of the five-conductor transmission lines with port 1 as input.

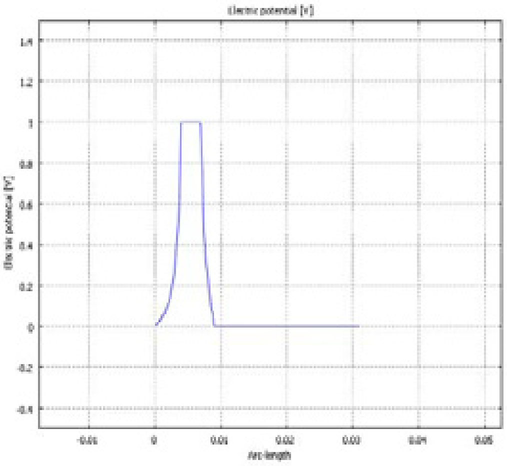

Figure 8. Potential distribution of the five conductor transmission lines with port 1 as input along the line from (x,y) = (0,1mm) to (x,y) = (31mm, 5mm).

Table 2 shows the finite element results for the capacitance-per-unit length of the five-transmission lines interconnect in single-layered dielectric medium. It compares the results from our work with those from other methods.

Table 2. Values of the Self and Mutual Capacitances Coefficient (in pF/m) for Five-Conductor Transmission Lines as Shown in Fig. 9

Capacitance per unit length	(MPM) [8]	(FTMM) [9]	This work
C_{11}	93.668	89.660	100.073
C_{12}	-8.453	-8.110	-5.983
C_{13}	-0.809	-0.795	-0.016
C_{21}	-0.345	-0.319	-5.983
C_{22}	95.329	92.173	100.899
C_{23}	-8.318	-7.962	-5.975
C_{24}	-0.758	-0.730	-0.016
C_{33}	95.341	92.145	100.816

Tables 1 and 2 provide the results of FEM in two-dimensional compared with other methods for the characteristics of two-layered multiconductor transmission lines and a single-layered multiconductor transmission lines with a thin strip thickness, respectively. The results of capacitance matrices for self and mutual capacitances, which are useful for the analysis of crosstalk between high-speed signal traces on the printed circuit board, are compared with other published data for the validity of the proposed method.

3. Conclusions

In this paper we have presented the modeling in 2D of four-transmission lines embedded in two-layered dielectric media and five-transmission lines interconnect in single-layered dielectric medium. We have shown that FEM is suitable and effective as other methods for modeling multiconductor transmission lines in VLSI circuits. Some of the results obtained using FEM with COMSOL multiphysics for the capacitance-per-unit length agree well with those found in the literature. The results obtained in this research are encouraging and motivating for further study.

4. References

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