Finite Element Analysis of Multiconductor Interconnects in Multilayered Dielectric Media

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Abstract: Due to complexity of electromagnetic modeling, researchers and scientists always look for development of accurate and fast methods to extract the parameters of electronic interconnects and package structures. In this paper, we illustrate modeling of multiconductor interconnects in multilayered dielectric media using finite element method. We specifically determine the capacitance per unit length of four transmission lines in two-layered dielectric and three thin striplines embedded in a three-layered dielectric between two ground planes. Comparison of our results with other available methods is demonstrated with good agreements.

Keywords: Finite element method, multiconductor transmission lines, capacitance per unit length, multilayered dielectric media.

1. Introduction

In recent years, we have observed a magnificent application and development in the complexity, density, and speed of operations of integrated circuits (ICs), multichip modules (MCMs), and printed circuit-board (PCB). For examples, MCMs are extensively used to reduce interconnection delay and crosstalk effects in complex electronic systems. Multiconductor transmission lines embedded in multilayered dielectric media are known as the basic interconnection units in ICs and MCMs, and have been characterized with the distributed circuit parameters such as capacitance C, inductance L, and characteristic impedance Z matrices under quasi-TEM conditions. Also, these distributed circuit parameters are very important factor in the electrical behavior and performance of other microwave integrated circuits (MIC) and very large scale integration (VLSI) chips. To optimize electrical properties of IC interconnects such as minimization of the length of the interconnection lines, an adequate attenuation must be given to the geometrical size of their transverse cross sections; the estimation of the transmission line parameters requires being accurate for system design.

Multiconductor multilayered structures are essential for ICs, MCMs, and PCB systems, due to its important effects on the transmission characteristics of high-speed signals. Therefore, in this work, we apply the finite element method (FEM) for parameter extraction for two-dimensional (2-D) interconnects embedded in planar multilayered dielectric media.

Many researchers have presented various kinds of methods for solving the problem. These include equivalent source and measured equation of invariance method [1], method of moment [2], variational technique with spectral domain approach [3], boundary element method [4], multipole accelerated technique [5], finite difference method [6], Green's function approach [7-8], method of lines [9-10], complex image method [11], and integrated equation method [12].

We illustrate that our method using FEM is suitable and effective as other methods for modeling of inhomogeneous quasistatic multiconductor interconnects in multilayered dielectric media.

In this work, we design four transmission lines in two-layered dielectric and three thin striplines embedded in a three-layered dielectric between two ground planes using FEM with COMSOL focusing on the calculation of the capacitance per unit length matrix of the multiconductor interconnects in multilayered dielectric media and then compare the results of our modeling with some previous works.

2. Discussion and Results

In any electromagnetic field analysis the placement of far-field boundary is an important concern, especially when dealing with open solution regions. It is necessary to take into account that the natural boundary of a line at infinity and the presence of remote objects and their potential influence on the field shape [13]. In all our simulations, the coplanar structures is surrounded by a w X h shield, where w is the width and h is the thickness of the shield. 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.

We use FEM with COMSOL, a multiphysics software, in our computations because it is suitable for the computation of electric and electromagnetic fields in strongly inhomogeneous media and it has high computation accuracy and fast computation speed.

In the following subsections, we demonstrate our work on modeling four transmission lines in two-layered dielectric and three thin striplines embedded in a three-layered dielectric between two ground planes. Our computation is focused on calculating the capacitance per unit length matrix of the multiconductor interconnects in multilayered dielectric media.

2.1 Four Transmission Lines in Two-layered Dielectric

In this section, we illustrate the modeling of four transmission lines in two-layered dielectric by focusing only on the calculation of the capacitance per unit length. Figure 1 shows the geometry of the model. The four conductors have same dimension as following: Their thickness is equal to 0.2mm and their width is 0.4mm; the gap between either conductor 1 and conductor 2, or conductor 3 and conductor 4 is 0.4mm; the thickness of the dielectric layers is equal to 0.4mm. The geometry is enclosed by a 5 X 5 mm shield. The shielded is not included in Fig. 1 but it is included in Fig. 2. Figure 2 shows the mesh for the four transmission lines in two-layered dielectric with zero conductivity. Figure 3 shows potential distribution in contour plot, while Figure 4 shows potential distribution from (0,0) to (5,5) mm.

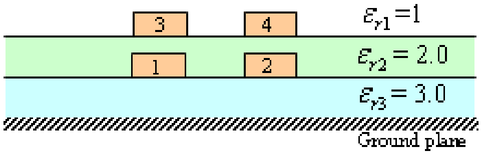

Figure 1. Cross-section of four transmission lines in two-layered dielectric.

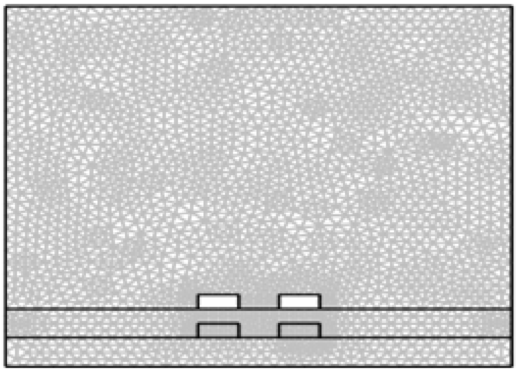

Figure 2. Mesh of four transmission lines in two-layered dielectric.

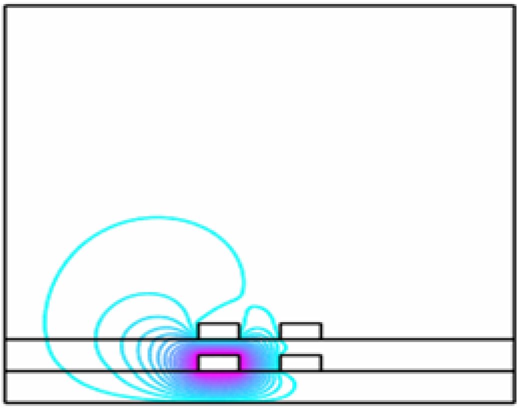

Figure 3. Contour plot of four transmission lines in two-layered dielectric with conductor 1 as input port.

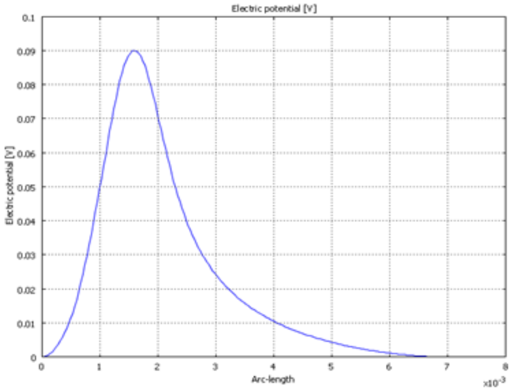

Figure 4. Potential distribution of four transmission lines in two-layered dielectric from (x,y) = (0,0) to (x,y) = (5mm,5mm).

Table 1 shows the FEM results for the capacitance matrix of the structure compared with the equivalent source and measured equation of invariance method [1] and method of moment [2]. They are agreeable with those calculated by other methods.

Table 1: Values of capacitance matrix (in pF/m) coefficients for the four transmission lines in two-layered dielectric

Capacitance matrix ($C_{ij} = C_{ji}$) and C_{ii}	Reference [1]	Reference [2]	Our Work
C_{11}	118.6782	118.8939	121.42140
C_{22}	118.6782	118.8939	121.31480
$C_{12} = C_{21}$	-14.12380	-12.40722	-12.80115
$C_{13} = C_{31}$	-47.56560	-46.51373	-47.89646
$C_{14} = C_{41}$	-3.287823	-3.465765	-3.347192
$C_{23} = C_{32}$	-3.287823	-3.465765	-3.347454
$C_{24} = C_{42}$	-47.56560	-46.51373	-47.87691
C_{33}	71.34295	68.89765	71.42175
C_{44}	71.34295	68.89765	71.40666
$C_{34} = C_{43}$	-8.583216	-9.186853	-8.980377

2.2 Three Thin Striplines Embedded in a Three- layered Dielectric between Two Ground Planes

In this section, we demonstrate the modeling of three thin striplines embedded in a three-layered dielectric between two ground planes by focusing only on the calculation of the capacitance per unit length. Figure 5 shows the geometry of the model with the parameters values. The geometry is enclosed by a 5 X 1 mm shield. The shielded is not included in Fig. 5 but it is included in Fig. 6. Figure 6 shows the mesh for the three thin striplines embedded in a three-layered dielectric between two ground planes with zero conductivity. Figure 7 shows potential distribution in contour plot, while Figure 8 shows potential distribution from (0,0) to (5,1) mm.

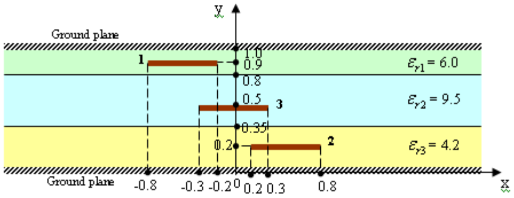

Figure 5. Cross-section of three thin striplines embedded in a three-layered dielectric between two ground planes.

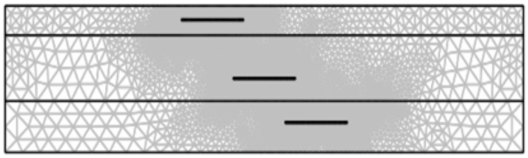

Figure 6. Mesh of three thin striplines embedded in a three-layered dielectric between two ground planes.

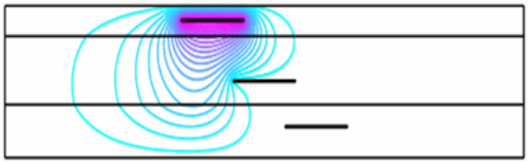

Figure 7. Contour plot of three thin striplines embedded in a three-layered dielectric between two ground planes referring to conductor 1.

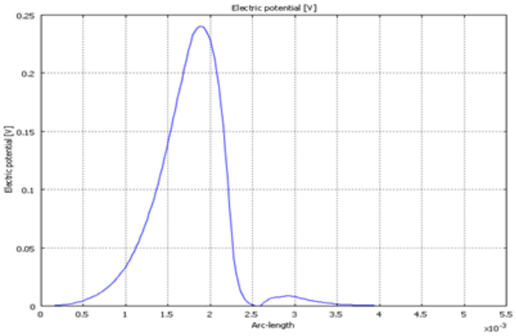

Figure 8. Potential distribution of three thin striplines embedded in a three-layered dielectric between two ground planes from (x,y) = (0,0) to (x,y) = (5,1)mm.

Tables 2 and 3 show the FEM results for the capacitance matrix of the structure of the model with dielectric constants as in Fig. 4 and when all dielectric constants are set equal to one, respectively. The results are compared with the pervious work and found to be in good agreement.

Table 2: Values of capacitance matrix (in F/m) coefficients for the three thin striplines embedded in a three- layered dielectric between two ground planes

Capacitance matrix ($C_{ij} = C_{ji}$) and C_{ii}	Reference [2]	Reference [3]	Our Work
C_{11}	0.4900 x 10^{-9}	0.5115 x 10^{-9}	0.5611 x 10^{-9}
C_{12}	-0.5737 x 10^{-12}	-0.5929 x 10^{-12}	-0.5721 x 10^{-12}
C_{13}	-0.6457 x 10^{-10}	-0.6972 x 10^{-10}	-0.7330 x 10^{-10}
C_{22}	0.2459 x 10^{-9}	0.2572 x 10^{-9}	0.2663 x 10^{-9}
C_{23}	-0.6138 x 10^{-10}	-0.6659 x 10^{-10}	-0.7181 x 10^{-10}
C_{33}	0.2865 x 10^{-9}	0.2977 x 10^{-9}	0.3081 x 10^{-9}

Table 3: Values of capacitance matrix (in F/m) coefficients when all dielectric constants are equal to one for the three thin striplines embedded in a three-layered dielectric between two ground planes

Capacitance matrix ($C_{oij} = C_{oji}$) and C_{oii}	Reference [3]	Reference [4]	Our Work
C_{o11}	0.7773 x 10^{-10}	0.8110 x 10^{-10}	0.8924 x 10^{-10}
C_{o12}	-0.1036 x 10^{-12}	-0.1075 x 10^{-12}	-0.1045 x 10^{-12}
C_{o13}	-0.7193 x 10^{-11}	-0.7812 x 10^{-11}	-0.8264 x 10^{-11}
C_{o22}	0.5212 x 10^{-10}	0.5445 x 10^{-10}	0.5594 x 10^{-10}
C_{o23}	-0.9788 x 10^{-11}	-0.1068 x 10^{-10}	-0.1141 x 10^{-10}
C_{o33}	0.3876 x 10^{-10}	0.4040 x 10^{-10}	0.4181 x 10^{-10}

3. Conclusions

In this paper, we have presented modeling of four transmission lines in two-layered dielectric and three thin striplines embedded in a three-layered dielectric media between two ground planes. We computed the capacitance matrix of the multiconductor interconnects in multilayered dielectric media and identified their potential distribution. The results obtained efficiently using finite element method (FEM) for the electrical parameters (C) agree well with those methods found in the literature.

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