Capacitance Computation of Multilayered and Multiconductor Interconnects Using Finite Element Method

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Abstract: The development and analysis of interconnects in inhomogeneous structures such as very large scale integration chips, printed circuit boards, and multichip modules are essential for next-generation electronic products. In this paper, we illustrate fast and sufficiently accurate computation of capacitance matrices of multilayered and multiconductor interconnects applying finite element method. We specifically design three-conductor transmission lines interconnect with three dielectric layers, and twelve-conductor transmission lines interconnect with five dielectric layers. Comparison of our numerical results with some other published data shows good agreement.

Keywords: Finite element method, multilayer, multiconductor, capacitance per unit length.

1. Introduction

Integrated circuit designers have often used multicondcutor transmission lines embedded in multilayer structure for high speed high density digital electronics system. The computations of multicondcutor transmission lines interconnect in multilayer dielectric media are essential in the optimization of the electrical properties of very high speed integrated circuits and multichip modules. For example, self and coupled capacitance can help the designers to optimize the layout of the circuits and the coupling parameters can help in predicting the amount of crosstalk noise in high frequency circuits. Therefore, the development of accurate and efficient computational method to analyze the designing of multicondcutor transmission lines embedded in multilayer dielectric media structure turn out to be an important area of interest for high performance integrated circuit technology.

Many researchers attempts at the problem using several methods such as method of moment [1-2], spectral domain Green's function approach [3], finite difference method [4], boundary element method (BEM) [5], Pade approximation method [6], Green's Function method [7], and geometry independent measured equation of invariance (GIMEI) [8].

We illustrate that our approach using finite element method (FEM) is suitable and effective as other methods for computation of capacitance matrix of inhomogeneous structure such as multiconductor interconnect in multilayer which commonly used in very large scale integration (VLSI), multichip modules (MCMs), and printed circuit board (PCB).

2. Discussion and Results

In this study, we design three-conductor transmission lines interconnect with three dielectric layers, and twelve-conductor transmission lines interconnect with five dielectric layers using FEM with COMSOL to calculate the capacitance matrix and then compare the results of our modeling with some methods in previous publications. We use FEM in modeling the multiconductor embedded in multilayered dielectric media structures, because FEM is especially suitable for the computation of electric and electromagnetic fields in strongly inhomogeneous media. Also, it has high computation accuracy and fast computation speed. In FEM self and coupled capacitances values are obtained from the potential distribution throughout the entire region by either an electric field or a potential energy approach in order to give the charge on each conductor, whereas in BEM they obtained directly from conductor charge distributions [9].

2.1 Three-Conductor Transmission Lines Interconnect with Three Dielectric Layers

In this section, we illustrate the modeling of three-line interconnects structure with three dielectric layers having a flat dielectric interface by focusing on the calculation of the capacitance matrices. Figure 1 shows the geometry of the model with the parameter values. From the model, we plot the streamline plot of the potential distribution, when the mesh consists of 3492 elements as shown in Figure 2.

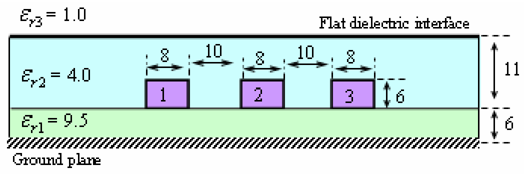

Figure 1. Cross-section of three-conductor transmission lines interconnect with three dielectric layers.

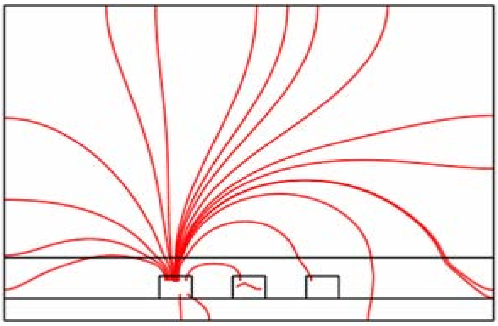

Figure 2. Streamline potential distribution plot of three-conductor transmission lines interconnect with three dielectric layers using port 1 as input.

Figure 3 is plot of the potential distribution of the model from (x,y) = (0,0) to (x,y) = (0.12, 0.85) m using port 1 as input with solution time 0.406 s.

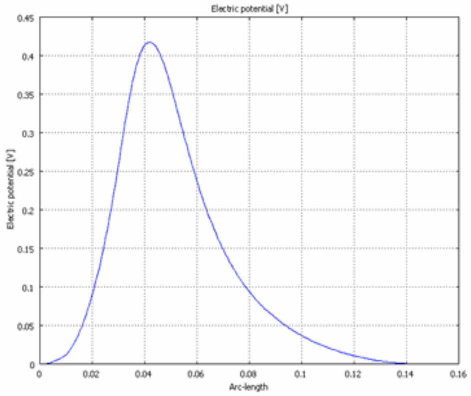

Figure 3. Potential distribution plot of three-conductor transmission lines interconnect with three dielectric layers from (x,y) = (0,0) to (x,y) = (0.12, 0.85) m using port 1 as input.

Table 1 shows the comparison with the pervious work of calculated values of capacitance matrix of the three-conductor line system embedded in three dielectric layers. We observe that our method has closer capacitance values to the boundary element method than the other methods.

Table 1: Capacitance matrices (in pF/m) of three-conductor transmission lines interconnect with three dielectric layers

Computational Method	Capacitance matrix [C] (in pF/m)
Boundary Element Method [5]	$[C]=\begin{bmatrix} 269.5200 & -34.8680 & -1.2567 \\ -34.8680 & 277.7500 & -34.8680 \\ -1.2567 & -34.8680 & 269.5200 \end{bmatrix}$
Pade Approximation Method [6]	$[C]=\begin{bmatrix} 266.4595 & -34.8126 & -1.3023 \\ -34.8126 & 274.7433 & -34.8126 \\ -1.3023 & -34.8126 & 266.4595 \end{bmatrix}$
Green's Function Method [7]	$[C]=\begin{bmatrix} 268.1350 & -34.7780 & -1.2590 \\ -34.7780 & 276.3150 & -34.7780 \\ -1.2590 & -34.7780 & 268.1350 \end{bmatrix}$
Our Work (FEM)	$[C]=\begin{bmatrix} 270.7835 & -34.9431 & -1.0247 \\ -34.9431 & 278.7173 & -34.9084 \\ -1.0247 & -34.9084 & 270.7451 \end{bmatrix}$

2.2 Twelve-Conductor Transmission Lines Interconnect with Five Dielectric Layers

In this section, we demonstrate the modeling of the shielded twelve-conductor transmission lines interconnect with five dielectric layers by finding the capacitance matrices. Figure 4 shows the geometry of the model with the parameters values, while Figure 5 shows the 2D surface potential distribution of the structure using port 1 as input.

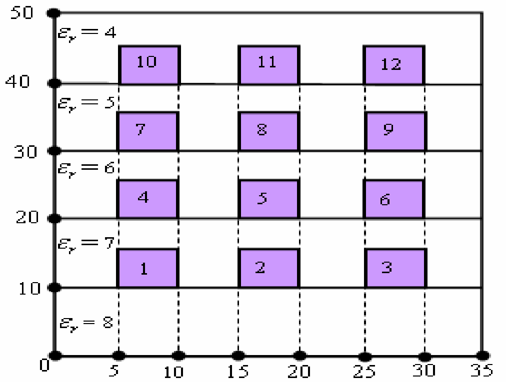

Figure 4. Cross-section of the twelve-conductor transmission lines interconnect with five dielectric layers.

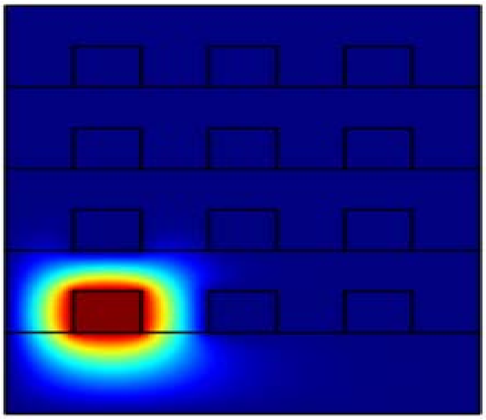

Figure 5. 2D surface potential distribution of the twelve-conductor transmission lines interconnect with five dielectric layers using port 1 as input.

Table 2 shows the FEM results for the self capacitance per unit length of the twelve-conductor transmission lines interconnect with five dielectric layers. They are compared with geometry independent measured equation of invariance (GIMEI) method and boundary element method (BEM). They are not too close.

Table 2: Calculated values of self capacitance (in pF/m) coefficients for the twelve-conductor transmission lines interconnect with five dielectric layers

Self Capacitance $(C_{ii}) = C_i$	GIMEI [8]	BEM [5]	Our Work
C_1	322.8	316.2	367.384
C_2	366.7	391.5	359.744
C_3	325.2	316.5	367.305
C_4	307.9	309.5	340.654
C_5	344.1	364.1	337.117
C_6	309.0	309.5	340.644
C_7	258.1	260.5	286.762
C_8	289.3	306.1	283.630
C_9	258.7	260.5	286.656
C_{10}	165.3	161.9	235.185
C_{11}	203.0	214.7	232.966
C_{12}	165.7	161.9	235.085

3. Conclusions

In this paper, we have presented the modeling of three-conductor transmission lines interconnect with three dielectric layers, and twelve-conductor transmission lines interconnect with five dielectric layers. We computed the capacitance matrix, self capacitance per unit length of the models respectively and identified their potential distribution. Some of results obtained efficiently using finite element method (FEM) for the electrical parameters agree well with those found in the literature.

4. References

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