Electromagnetic Parameters Extraction for Integrated-circuit Interconnects for Open Three conductors with Two Levels Systems

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Abstract: The accurate estimate of values of electromagnetic parameters are essential to determine the final circuit speeds and functionality for designing of high-performance integrated circuits and integrated circuits packaging. In this paper, a new quasi-TEM capacitance and inductance analysis of multiconductor multilayer interconnects is successfully demonstrated using the finite element method (FEM) with COMSOL multiphysics. We specifically illustrate two electrostatic models of open three interconnected lines with two levels system. Indeed, excellent agreement with results from the previous methods is demonstrated.

Keywords: Capacitance, inductance, multiconductor transmission lines, finite element method, interconnect

1. Introduction

Today, the designing of fast electronics circuits and systems with increase of the integration density of integrated circuits has led to wide use and cautious analysis of multilayer and multiconductor interconnects. The matrices of capacitances per unit length and inductance per unit length of multilayered multiconductor quasi-TEM transmission lines are known as the essential parameters in designing of package, lossless transmission line system, microwave circuits, printed circuit board (PCB), multichip modules (MCM) design and high speed very large scale integration (VLSI) circuits. Therefore, the improvement of accurate and efficient computational method to analyze the modeling of multiconductor quasi-TEM transmission lines structure becomes an important area of interest. Also, to optimize the electrical properties of the integrated circuits, the estimate of the capacitance matrix and inductance matrix of multilayer and multiconductor interconnects in VLSI circuit must be investigated. Although, the computational values of self and coupling capacitance can also help engineers and designers to optimize the layout of the circuit [1]. There are previous attempts at the problem. These include using analytical and full-wave characterization [2], spectral domain method [3], the method of moments (MoM) [4,5],spectral domain approach (SDA) [6], Green's function approach [7,8], the method of lines (MoL) [9,10], finite difference methods (FDM) [10-12], and on-surface measured equation of invariance (OSMEI) method [13].

In this work, we design two electrostatic models of open three interconnected lines with two levels system using the finite element method (FEM) with COMSOL multiphysics package. Many industrial applications depend on different interrelated properties or natural phenomena and require multiphysics modeling and simulation as an efficient method to solve their engineering problems. Moreover, superior simulations of microwave integrated circuit applications will lead to more cost-efficiency throughout the development process. We specifically calculate the capacitance and inductance matrices and the potential distribution of the configurations.

2. Results and Discussion

The models are designed in two-dimensional (2D) using electrostatic environment in order to compare our results with some of 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. Recently, with the advent of integrated circuit technology, the coupled microstrip transmission lines consisting of multiple conductors embedded in a multilayer dielectric medium have led to a new class of microwave networks. Multiconductor transmission lines have been utilized as filters in microwave region which make it interesting in various circuit components. For coupled multiconductor microstrip lines, it is convenient to write [14-15]:

$$Q_i = \sum_{j=1}^{m} C_{sij} V_j \quad (i = 1, 2, \ldots, m) \quad , \qquad (1)$$

where Q_i is the charge per unit length, V_j is the voltage of j th conductor with reference to the ground plane, C_{sij} is the short circuit capacitance between i th conductor and j th conductor. The short circuit capacitances can be obtained either from measurement or from numerical computation. From the short circuit capacitances, we obtain

$$C_{ii} = \sum_{j=1}^{m} C_{sij} \quad , \qquad (2)$$

where C_{ii} is the capacitance per unit length between the i th conductor and the ground plane. Also,

$$C_{ij} = -C_{sij}, \qquad j \neq i \quad , \qquad (3)$$

where C_{ij} is the coupling capacitance per unit length between the i th conductor and j th conductor. The coupling capacitances are illustrated in Fig. 1.

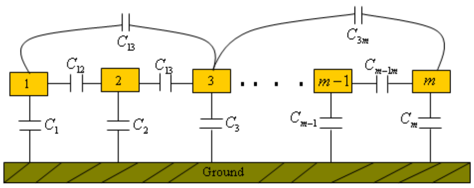

Figure 1. The per-unit length capacitances of a general m -conductor transmission line.

For m -strip line, the per-unit-length capacitance matrix [C] is given by [16]

$$[C] = \begin{bmatrix} C_{11} & -C_{12} & \cdots & -C_{1m} \\ -C_{21} & C_{22} & \cdots & -C_{2m} \\ \vdots & \vdots & & \vdots \\ -C_{m1} & -C_{m2} & \cdots & C_{mm} \end{bmatrix} \qquad (4)$$

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 an infinity and presence of remote objects and their potential influence on the field [17]. In all our simulations, the open models are surrounded by a $W \times H$ shield, where W is the width and H is the thickness.

The inductance and capacitance per unit length of multicondcutor transmission lines are related as

$$[L] = \mu_0 \varepsilon_0 [C_0]^{-1} \qquad (5)$$

where $[L]$ is the inductance matrix, ε_0 the permittivity of free space or vacuum, μ_0 the permeability of free space or vacuum, and $[C_0]^{-1}$ the inverse matrix of the capacitance of the multiconductor transmission line when all dielectric constants are set equal one.

In this paper, we consider two different models. Case A investigates the designing of open three interconnected lines with two levels system with one conductor embedded in the substrate. For case B, we illustrate the modeling of open three interconnected lines with two levels system with two conductors embedded in the substrate.

2.1 Modeling of Open Three Interconnected Lines with Two Levels System with One Conductor Embedded in the Substrate

In this section, we illustrate the modeling of open three interconnected lines with two levels system with one conductor embedded in the substrate by focusing in calculating the static capacitance matrix [C], inductance matrix [L], and the potential distribution. Figure 2 shows geometry with following parameters:

ε_{r1} = dielectric constant = 2.0;

ε_{r2} = dielectric constant = 1.0;

w = width of the conductors = 3mm;

s =distance between conductor 1 and 2 = 3mm;

t = thickness of the conductors = 0.01mm;

H_1 = height of dielectric layer 1 from the ground = 4mm;

H_2 = height of conductor 3 from the ground = 1mm;

The geometry is enclosed by a 27×20 mm shield.

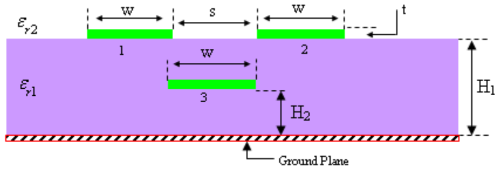

Figure 2. Cross section of open three interconnected lines with two levels system with one conductor embedded in the substrate.

Figure 3 shows the 2D surface potential distribution of the transmission lines.

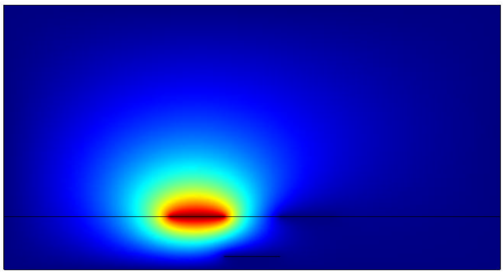

Figure 3. 2D surface potential distribution of open three interconnected lines with two levels system with one conductor embedded in the substrate.

Table 1 shows the COMSOL results for the capacitance per unit length of the model compared with the work of previous investigating using MoM and OSMEI methods. They are in good agreement.

Table 1 Capacitance matrix [C] of the model in Fig. 2.

Capacitance (pF/m)	MoM	OSMEI	Our work
C_{11}	40.729	39.265	41.762
C_{12}	-6.285	-6.351	-5.985
C_{13}	-10.745	-13.965	-10.935
C_{22}	40.729	39.054	41.762
C_{23}	-10.745	-13.746	-10.935
C_{33}	101.172	97.900	102.642

We extend the analysis to compute the inductance per unit length matrix [L] due to its importance role in the high-speed digital circuits [18] using equation (5):

The following electrical parameter inductance per unit length matrix ($[L]$),

$$[L] = \begin{bmatrix} 0.762 & 0.406 & 1.266 \\ 0.406 & 0.762 & 1.266 \\ 1.266 & 1.266 & 4.895 \end{bmatrix} \mu F/m \cdot$$

2.2 Modeling of Open Three Interconnected Lines with Two Levels System with Two Conductors Embedded in the Substrate

In this section, we illustrate the modeling of unshielded three interconnected lines with two levels system with two conductors embedded in the substrate which is recently developed by the authors. We focus on the calculation of self and mutual capacitances per unit length and inductance matrix [L] determine the quasi-TEM spectral for the potential distribution of the model.

In Fig. 4, we show the Cross-section of open three interconnected lines with two levels system with two conductors embedded in the substrate. The geometry of the model has same parameters values as in Figure 2 and it is enclosed with same value too.

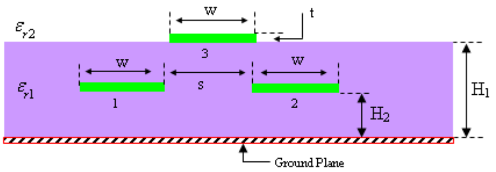

Figure 4. Cross section of open three interconnected lines with two levels system with two conductors embedded in the substrate.

Figure 5 shows the 2D surface potential distribution of the transmission lines. While, streamline plot was presented in Figures 8.

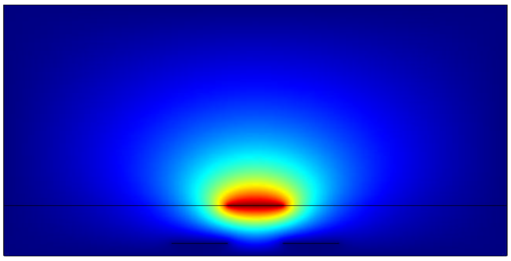

Figure 5. 2D surface potential distributions of open three interconnected lines with two levels s system with two conductors embedded in the substrate.

Table 2 shows the COMSOL results for the capacitance per unit length of the model we recently developed.

Table 2 Capacitance matrix of the model in Fig. 4.

Capacitance (pF/m)	Our work
C_{11}	42.311
C_{12}	-12.409
C_{13}	-12.409
C_{22}	99.532
C_{23}	-2.137
C_{33}	99.532

We also, compute the inductance per unit length matrix [L] of the model as:

$$[L]=\begin{bmatrix} 0.4541 & 0.0603 & 0.0603 \\ 0.0603 & 0.2286 & 0.0126 \\ 0.0603 & 0.0126 & 0.2286 \end{bmatrix} \mu F/m$$

3. Conclusions

This paper has demonstrated the use of the FEM method COMSOL multiphysics to solve open-region electrostatic problems involving 2-D models of open three interconnected lines with two levels system. We computed the capacitance and inductance per-unit length matrices of the models and compared the results with other methods. The results obtained in this research are encouraging and motivating for further study.

4. References

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