Modeling of Multiconductor Microstrip Systems on Microwave Integrated Circuits

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Abstract The microstrip line is widely used as the planar transmission line in microwave integrated circuits and high speed interconnecting buses. In this paper, we use COMSOL multiphysics to study multiconductor microstrip systems on microwave integrated circuits. We specifically illustrate the modeling of open four and five conductors systems. We successfully demonstrated the calculation of the capacitance matrices for the models and their quasi-static spectral of the potential distribution on microwave integrated circuits. Indeed, excellent agreement with the computational results of the models from the Galerkin method and parallel lines propagating TEM waves method is demonstrated. Also, we determine the potential distribution plots of the developed microwave integrated circuits.

Keywords: Capacitance per unit length, Multiconductor transmission lines, Finite element method, Microwave integrated circuits.

1. Introduction

Nowadays, the designing of fast electronics circuits and systems with increase of the integration density of integrated circuits led to wide use and cautious analysis multiconductor interconnects. Multiconductor transmission lines are commonly used in microwave integrated circuits and high speed interconnecting buses. As the transversal size multiple-conductor transmission lines are reduced, adjacent conductors are electromagnetically coupled so that they must be considered as multimode waveguides [1]. Computation of the capacitances per unit length of multiconductor quasi-TEM transmission lines are known as the essential parameters in designing of package, lossless transmission line system, microwave circuits, and very large scale integration 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 multiconductor interconnects in very high-speed integrated circuit must be investigated. The computational values of self and mutual capacitance can also help engineers and designers to optimize the layout of the circuits.
There are previous attempts at the problem include using the analytical modelization of multiconductor quasi-TEM transmission lines [2], spectral domain method [3], the method of moments (MoM) [4,5], the spectral domain approach (SDA) [6], the Green's function approach [7,8], the method of lines (MoL) [9,10], the domain decomposition method (DDM), the finite difference methods (FDM) [10], the Galerkin method [11], the on-surface measured equation on invariance (OSMEI) method [12], and parallel lines propagating TEM waves method [13] .

In this work, we design open four and five conductors systems 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 self and mutual capacitances and the potential distribution of the configurations.

2. Results and Discussions

The models are designed in 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.
In this paper, we consider two different models. Case A investigates the designing of open four conductors system. In case B, we illustrate the modeling of open five conductors system.

2.1 Modeling of Open Four Conductors System

In Figure 1, we show the cross section for open four conductors system and its parameters are:

ε_r = dielectric constant = 9.8;

$w_1 = w_2 = w_3 = w_4$ = width of the conductors = 0.102 mm;

t = thickness of the conductors = 0.01mm;

h = height of the conductors from the ground = 1mm;

d = distance between the centers of two conductors = 0.173 mm;

$s = d - w$ = 0.071mm;

The geometry is enclosed by a 5×5 mm shield.

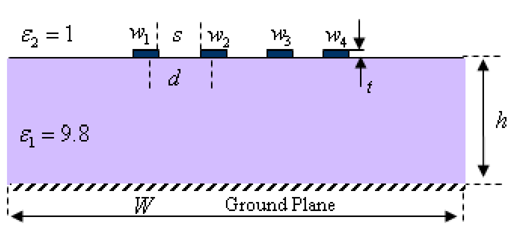

Figure 1. Cross-section of open four conductors system.

Figure 2 shows the two-dimensional (2D) surface potential distribution of the transmission lines, the mesh plot is presented in Figures 3, and the streamline plot in figure 4. Table 1 shows the statistical properties of the mesh.

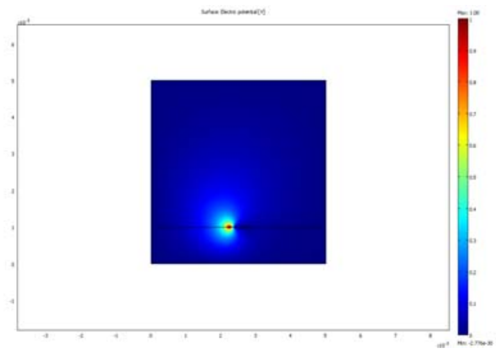

Figure 2. 2D surface potential distribution of open four conductors system.

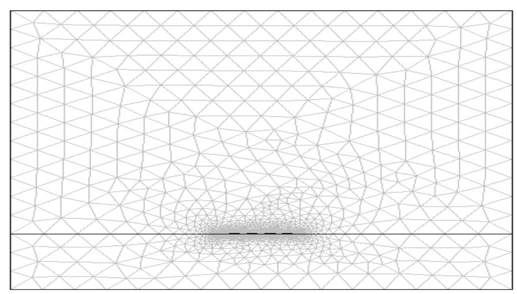

Figure 3. Mesh plot of open four conductors system.

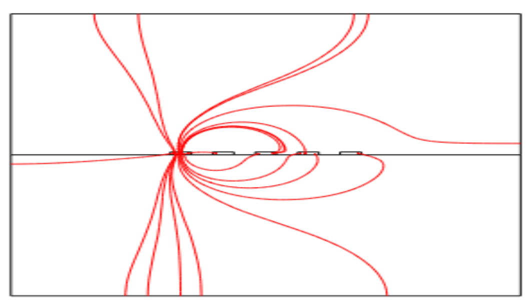

Figure 4. Streamline plot of open four conductors system.

Table 1: Mesh statistics of the model

Items	Value
Number of degrees of freedom	6434
Total Number of mesh points	1559
Total Number of elements	3055
Triangular elements	3055
Quadrilateral	0
Boundary elements	204
Vertex elements	24

Figure 5 presents the electric potential plot as a function of arc-length of the model. In addition, Figure 6 shows the comparison analysis of potential distribution of the model with and without dielectric substrate. It is observed that the peak value of electric potential is decreased as the dielectric is placed in the substrate.

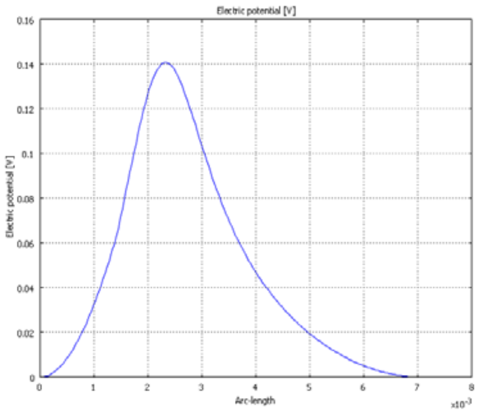

Figure 5. Potential distribution of open four conductors system from (x,y) = (0,0) to (x,y) = (5,5) mm, using port 1 as input.

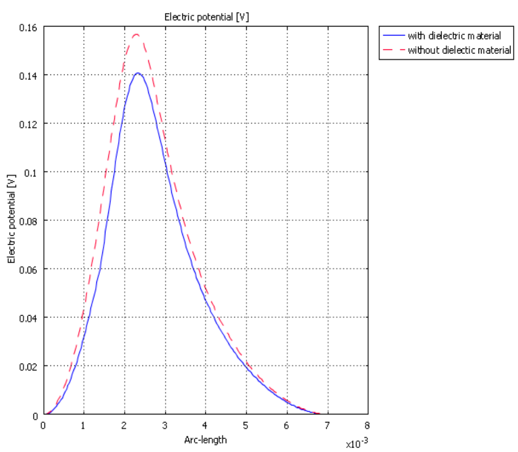

Figure 6. Comparison analysis of potential distribution of the model with and without dielectric substrate.

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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:

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

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,

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

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 Figure 7.

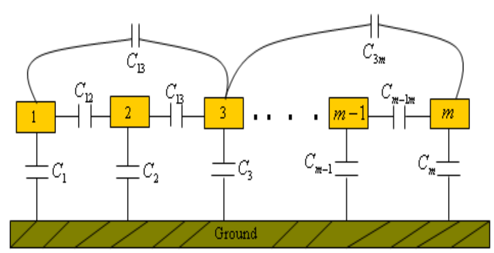

Figure 7. The per-unit length capacitances of a general m -conductor transmission line.

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

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

Table 2 shows the COMSOL results for the capacitance per unit length of the model compared with the work of previous investigators using Galerkin and parallel lines propagating TEM waves methods. They are in good agreement.

Table 2: Capacitance matrix [C] of the model in Figure 1

Capacitance (10^{-11} F/m)	Galerkin method	Parallel lines propagating TEM waves method	Our work
C_{11}	4.75	4.96	10.71
C_{12}	5.82	5.85	4.55
C_{13}	1.14	0.96	1.12
C_{14}	0.62	0.47	0.587
C_{22}	2.89	2.78	11.27
C_{23}	5.34	5.43	4.84

The above results show the finite element results for the self and mutual capacitances per unit length of the open four conductors system.

2.2 Modeling of Open Five Conductors System

In this section, we illustrate the modeling of open five conductors system. We focus on the calculation of self and mutual capacitances per unit length and determine the quasi-TEM spectral for the potential distribution of the model.

In Figure 8, we show the cross-section of open five conductors system and its parameters summarized as:

ε_r = dielectric constant = 2.5;

$w_1 = w_3 = w_5$ = width of the conductors = 0.16 mm;

$w_2 = w_4$ = width of the conductors = 0.47 mm;

t = thickness of the conductors = 0.01mm;

h = height of the conductors from the ground = 0.8 mm;

d = distance between the centers of two conductors = 0.385 mm;

$s = d - w$ = 0.07 mm;

The geometry is enclosed by a 9×4 mm shield.

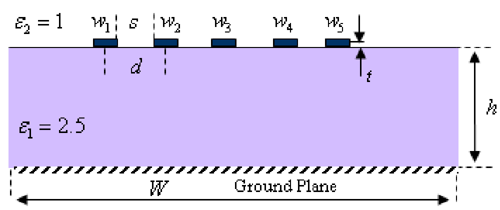

Figure 8. Cross-section of open five conductors system.

Figure 9 shows the 3D surface potential distribution of the transmission lines. Table 3 shows the statistical properties of the mesh.

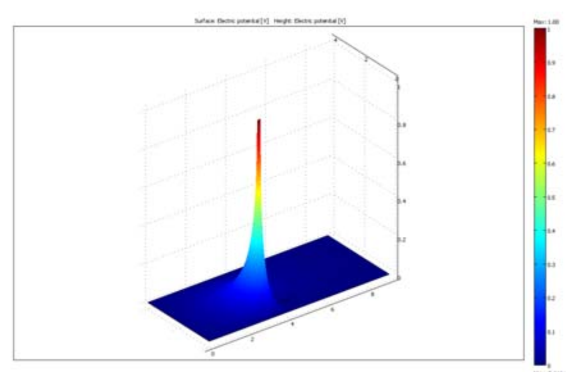

Figure 9. 3D surface potential distributions of open five conductors system.

The mesh plot of the model is presented in Figures 10, and the contour plot in Figure 11. Table 3 shows the statistical properties of the mesh.

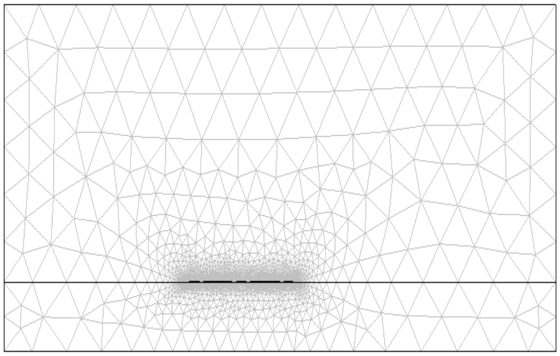

Figure 10. Mesh plot of open five conductors system.

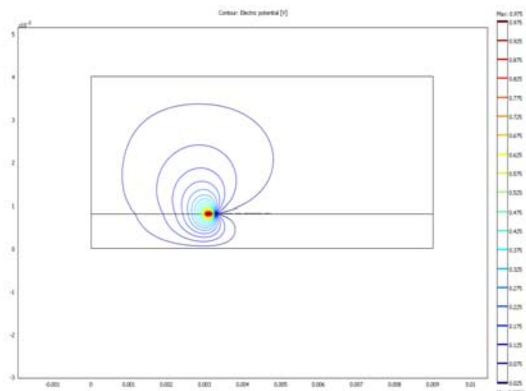

Figure 11. Contour plot of open five conductors system.

Table 3: Mesh statistics of the model

Items	Value
Number of degrees of freedom	10351
Total Number of mesh points	2466
Total Number of elements	4876
Triangular elements	4876
Quadrilateral	0
Boundary elements	349
Vertex elements	26

Figure 12 presents the electric potential plot as a function of arc-length of the model. In addition, Figure 13 shows the comparison analysis of potential distribution of the model with and without dielectric substrate. It is observed that the peak value of electric potential is slightly decreased as the dielectric is placed in the substrate.

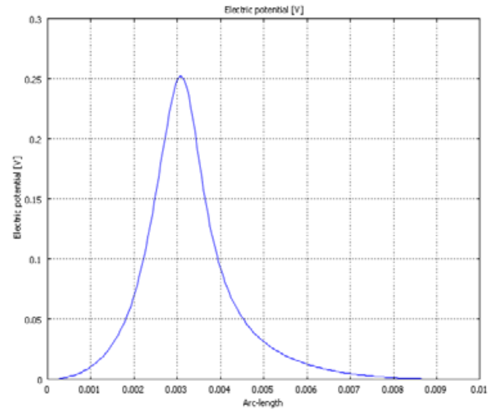

Figure 12. Potential distribution of open five conductors system from our (x,y) = (0,0) to (x,y) = (9,4) mm,, using port 1 as input.

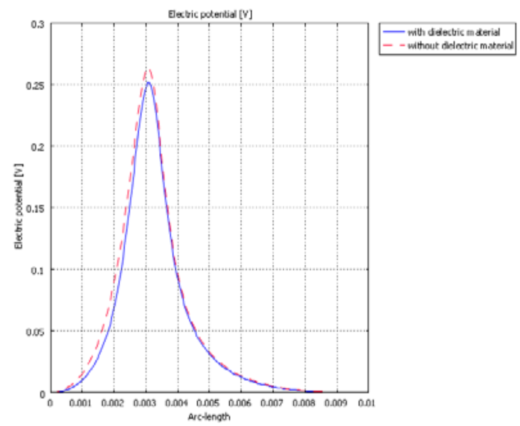

Figure 13. Comparison analysis of potential distribution of the model with and without dielectric substrate.

Table 4 shows the COMSOL results for the capacitance per unit length of the model compared with the work of previous investigators using Galerkin and parallel lines propagating TEM waves methods. They are in good agreement.

Table 4: Capacitance matrix [C] of the model in Figure 8

Capacitance (10^{-11} F/m)	Galerkin method	Parallel lines propagating TEM waves method	Our work
C_{11}	1.7989	1.878	4.2847
C_{12}	2.5982	2.250	2.4721
C_{13}	0.0876	0.0376	0.0767
C_{14}	0.0789	0.0917	0.06436
C_{15}	0.0228	0.0361	0.0162
C_{22}	2.2511	2.354	7.3107
C_{23}	2.3521	2.062	2.2573
C_{24}	0.5745	0.553	0.4973
C_{33}	0.8550	0.851	5.4387

3. Conclusions

In this paper we have presented the modeling in 2D of designing of quasi-TEM open four and five conductors systems using FEM with COMSOL multiphysics. We computed the capacitance-per-unit length matrices of the models. Also, we determine the quasi-TEM spectral for the potential distribution of the multiconductor transmission lines in multilayer dielectric media. The results obtained in this research are encouraging and motivating for further study.

4. References

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