Finite Element Analysis for Five Transmission Lines in Multilayer Dielectric Media

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ABSTRACT

Development of very high speed integrated circuits is currently of great interests for today technologies. This paper presents the quasi-TEM approach for the accurate parameters extraction of multiconductor transmission lines interconnect in single, two, and three-layered dielectric region using the finite element method (FEM). We illustrate that FEM is as accurate and effective for modeling multilayered multiconductor transmission lines in strongly inhomogeneous media. We mainly focus on designing of five-conductor transmission lines embedded in single-, two-, three-, and four-layered dielectric media. We compute the capacitance matrices for these configurations. Also, we determine the quasi-TEM spectral for the potential distribution of the multiconductor transmission lines in multilayer dielectric media.

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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 of multilayer and multiconductor interconnects. 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]. Computations of the matrices of capacitances 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, 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 of multilayer and multiconductor interconnects in very high-speed integrated 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.

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], spectral domain approach (SDA) [6], Green’s function approach [7,8], the method of lines (MoL) [9,10], domain decomposition method (DDM), and finite difference methods (FDM) [10].

In this work, we design five-conductor transmission lines in single, two, and three-layered dielectric region using the finite element method (FEM). 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. THEORY FOR THE PROBLEM FORMULATION OF MULTICONDUCTOR INTERCONNECTS IN MULTILAYERED DIELECTRIC MEDIA

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. 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 [11-12]:

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

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

$$C_{ii} = \sum_{j=1}^{m} C_{sij}, \tag{2}$$

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

$$C_{ij} = -C_{sij}, \quad j \neq i \quad , \tag{3}$$

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. 5.

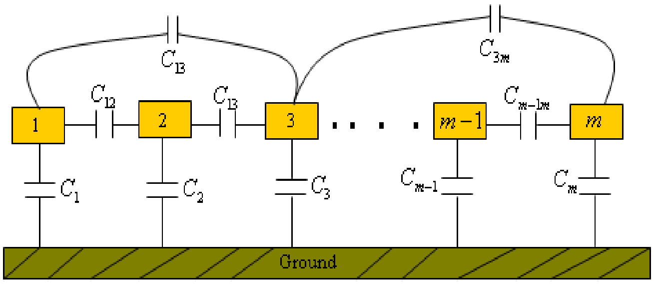

Figure 1. The per-unit length capacitances of a general m-conductor transmission line.

For m-strip line, the per-unit-length capacitance matrix [C] is given by [13]:

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

3. RESULTS AND DISCUSSION

In this paper, we consider four different models. Case A investigates the modeling of five-conductor transmission lines in single-layered dielectric medium. In Case B, we illustrate the modeling of five-conductor transmission lines in two-layered dielectric media. Case C investigates the modeling of five-conductor transmission lines in three-layered dielectric media. Case D investigates the modeling of five-transmission lines in four-layered dielectric media

3.1 Modeling of Five-Conductor Transmission Lines in Single-layered Dielectric Medium

In Figure 2, we show the cross section for five-conductor transmission lines in single layered dielectric region and its parameters.

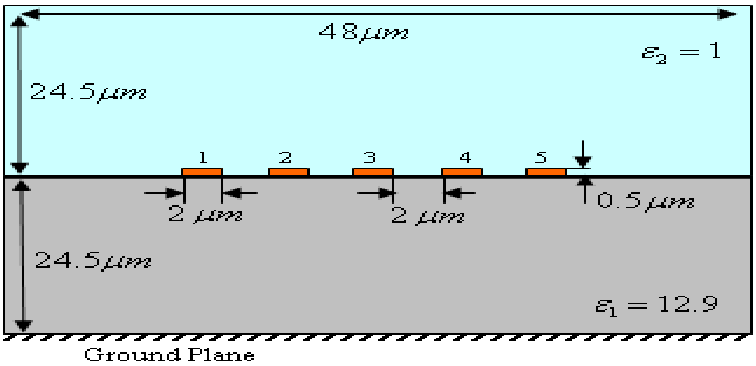

Figure 2. Cross-section of five-conductor transmission lines in single layered dielectric region.

Figure 3 shows the 2D surface potential distribution of the transmission lines, while streamline plot is presented in Figures 4.

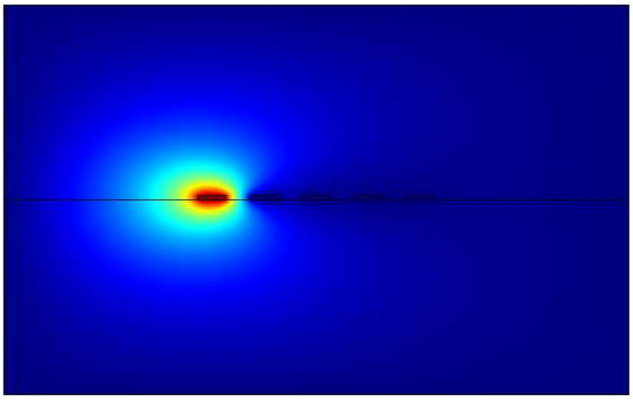

Figure 3. 2D surface potential distribution of five-conductor transmission lines.

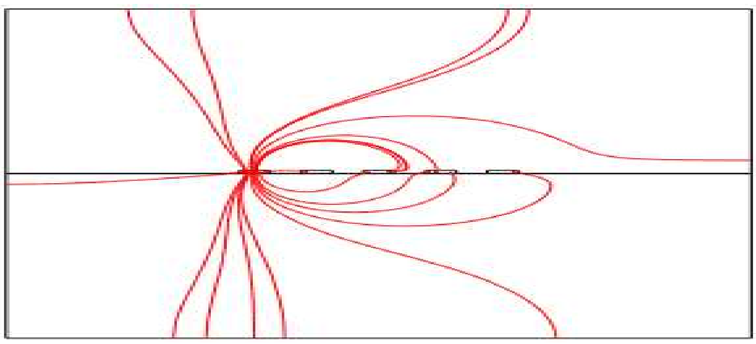

Figure 4. Streamline plot of five-conductor transmission lines in single layered dielectric region.

From our model, Figure 5 shows the potential distribution of the five-conductor transmission lines from (x,y) = (0,0) to (x,y) = (48,49) μ m, using port 1 as input.

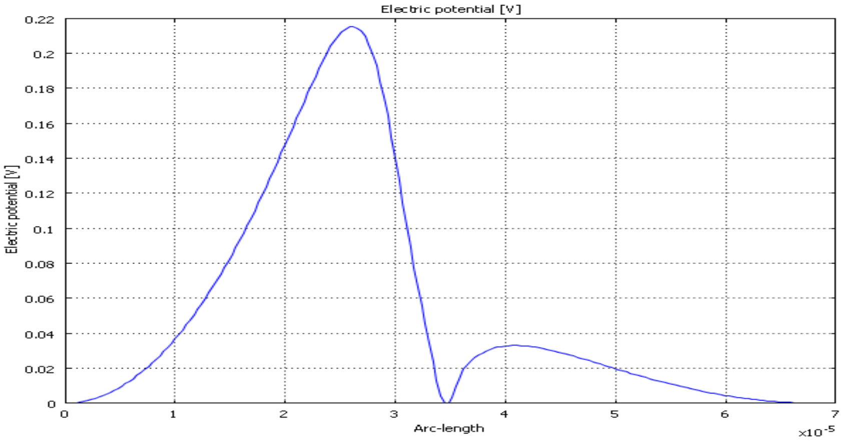

Figure 5. Potential distribution of five-conductor transmission lines in single layered dielectric region from (x,y) = (0,0) to (x,y) = (48,49) μ m, using port 1 as input.

The following electrical parameter capacitance per unit length matrix ($[C]$) is obtained as:

$$[C]=\begin{bmatrix} 140.2 & -60.7 & -11.7 & -4.7 & -2.9 \\ -60.7 & 165.8 & -56.2 & -10.1 & -4.7 \\ -11.7 & -56.2 & 166.5 & -56.2 & -11.7 \\ -4.7 & -10.1 & -56.2 & 165.8 & -60.7 \\ -2.9 & -4.7 & -11.7 & -60.7 & 140.2 \end{bmatrix} pF/m^{.}$$

The above results show the finite element results for the self and mutual capacitances per unit length of the five- transmission lines interconnect in single-layered dielectric medium.

3.2 Modeling of Five-Conductor Transmission Lines in Two-layered Dielectric Media

In this section, we illustrate the modeling of five-transmission lines interconnect in two-layered dielectric media. 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 Fig. 6, we show the Cross-section of five-transmission lines interconnect in two-layered dielectric media and its parameters.

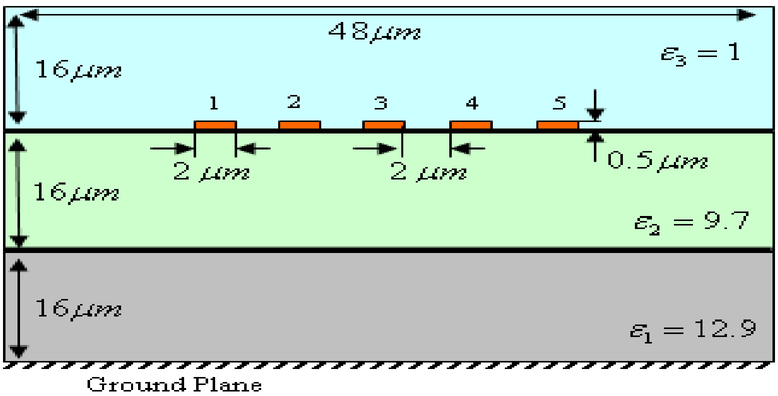

Figure 6. Cross-section of five-conductor transmission lines in two-layered dielectric media.

Figure 7 shows the 2D surface potential distribution of the transmission lines, while streamline plot is presented in Figures 8.

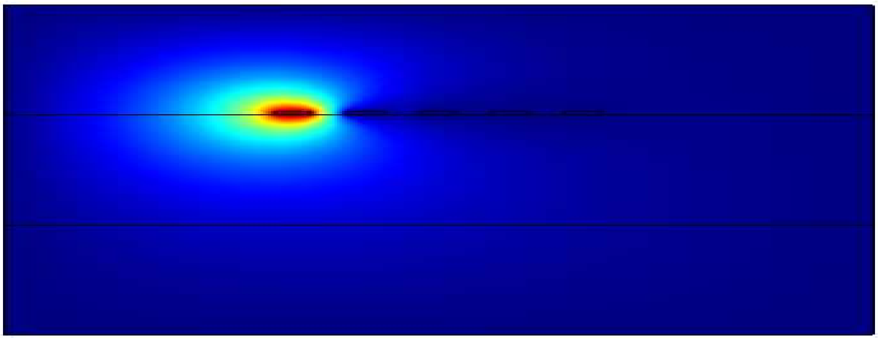

Figure 7. 2D surface potential distributions of five-transmission lines in two-layered dielectric media.

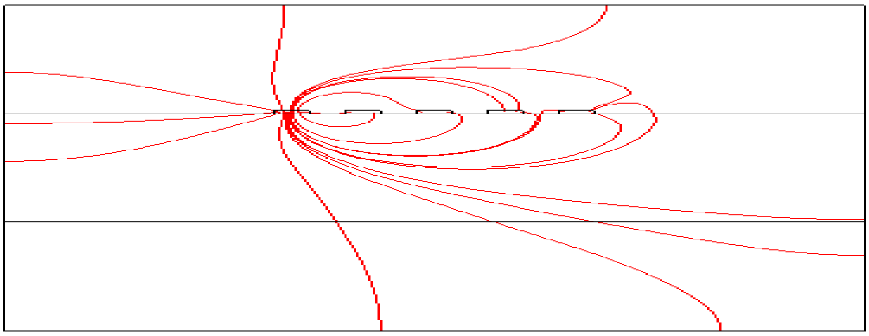

Figure 8. Streamline plot of five-conductor transmission lines in two-layered dielectric media.

From our model, Figure 9 shows the potential distribution of the five-conductor transmission lines in two-layered dielectric media from (x,y) = (0,0) to (x,y) = (48,48) μm.

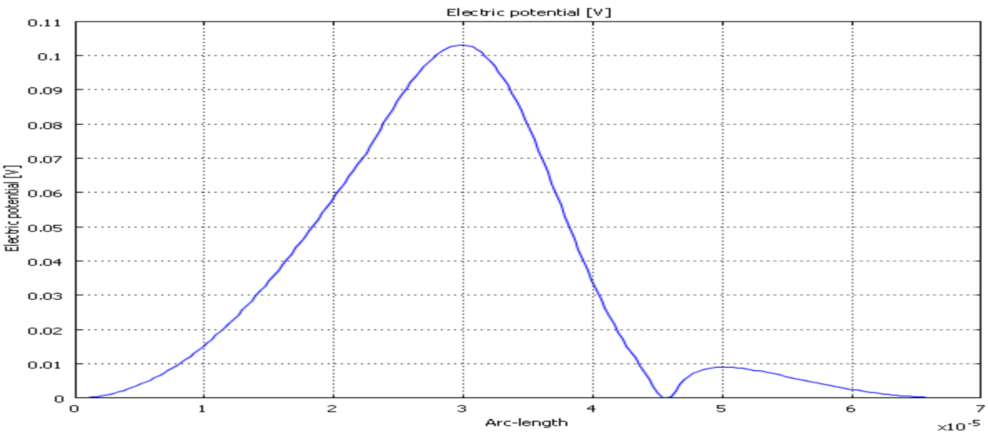

Figure 9. Potential distribution of five-conductor transmission lines two-layered dielectric media.

The following electrical parameter capacitance per unit length matrix ($[C]$),

$$[C] = \begin{bmatrix} 108.7 & -47.2 & -9.0 & -3.7 & -2.3 \\ -47.2 & 128.8 & -43.8 & -7.8 & -3.7 \\ -9.0 & -43.8 & 129.3 & -43.8 & -9.0 \\ -3.7 & -7.8 & -43.8 & 128.8 & -47.3 \\ -2.3 & -3.7 & -9.0 & -47.3 & 108.7 \end{bmatrix} pF/m$$

3.3 Modeling of Five-Conductor Transmission Lines Interconnect in Three-layered Dielectric media

In this section, we illustrate the modeling of five-conductor transmission lines in three-layered dielectric media. 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. The results of capacitance matrices for self and mutual capacitances are useful for the analysis of crosstalk between high-speed signal traces on the printed circuit board.

In Fig. 10, we show the Cross-section of five-conductor transmission lines in three-layered dielectric media and its parameters.

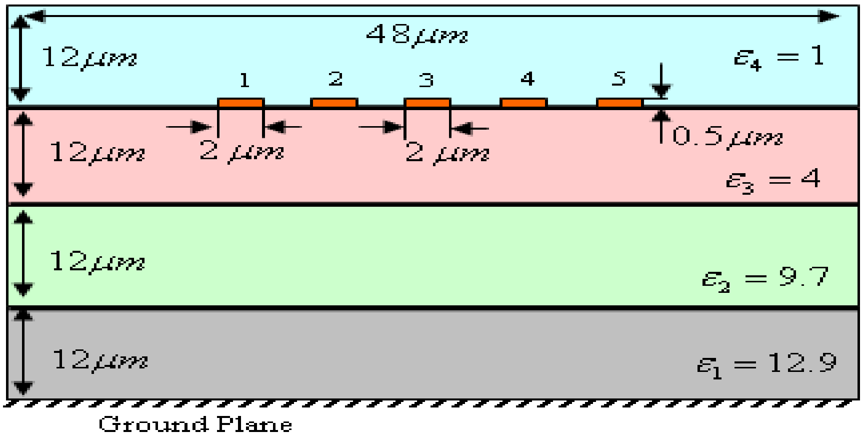

Figure 10. Cross-section of five-conductor transmission lines in three-layered dielectric media.

Figure 11 shows the 2D surface potential distribution of the transmission lines, while streamline plot was presented in Figures 12. For the model, Figure 13 shows the potential distribution of the five-conductor transmission lines in three-layered dielectric media from (x,y) = (0,0) to (x,y) = (48,48) μm .

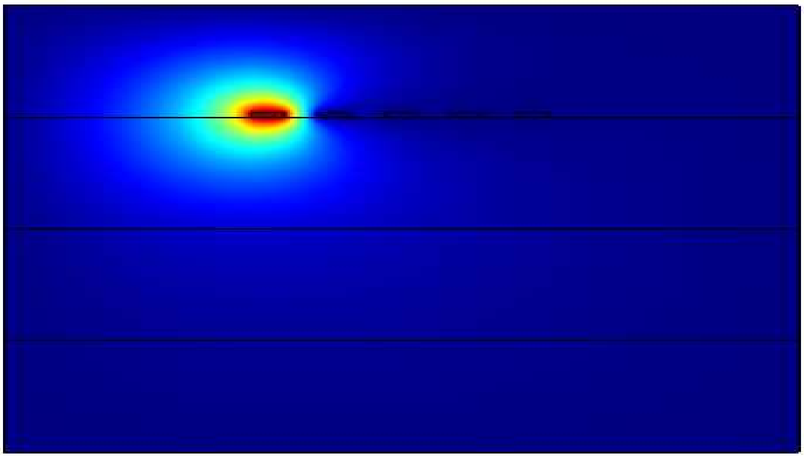

Figure 11. 2D surface potential distributions of five-conductor transmission lines in three-layered dielectric media.

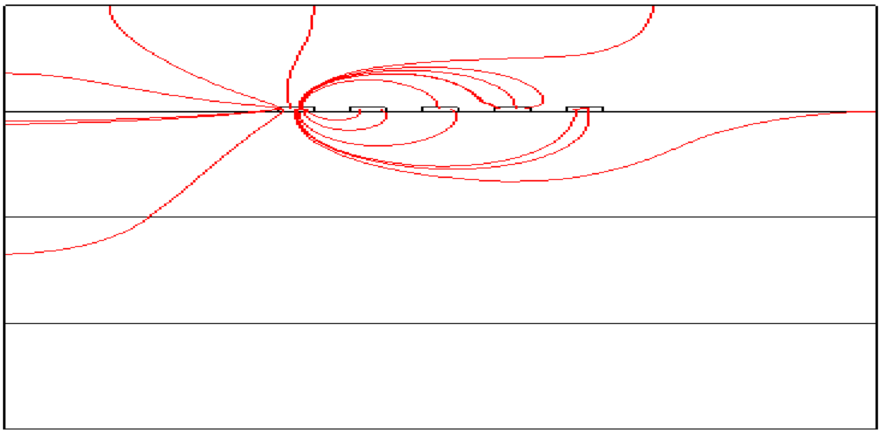

Figure 12. Streamline plot of five-conductor transmission lines in three-layered dielectric media.

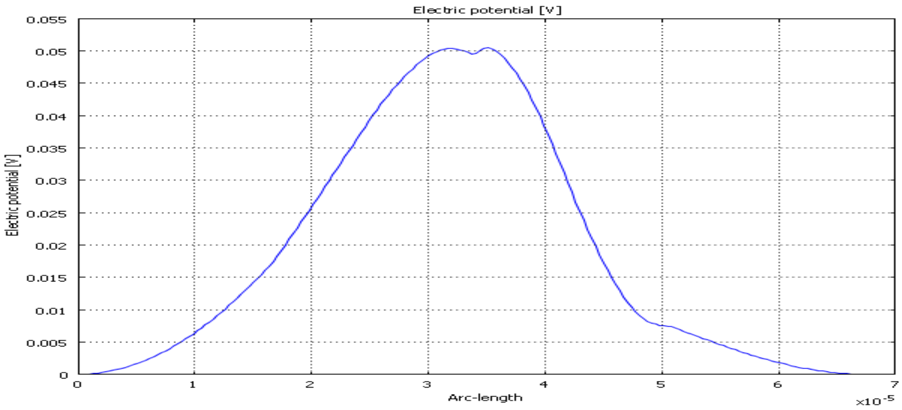

Figure 13. Potential distribution of five-conductor transmission lines in three-layered dielectric media.

The following electrical parameter capacitance per unit length matrix ($[C]$) is obtained

$$[C]=\begin{bmatrix} 53.6 & -22.8 & -3.8 & -1.3 & -0.7 \\ -22.8 & 63.4 & -21.3 & -3.3 & -1.3 \\ -3.8 & -21.3 & 63.6 & -21.3 & -3.8 \\ -1.3 & -3.3 & -21.3 & 63.4 & -22.8 \\ -0.7 & -1.3 & -3.8 & -22.8 & 53.6 \end{bmatrix} pF/m^{\cdot}$$

3.4 Modeling of Five-Conductor Transmission Lines in Four-layered Dielectric media

In this section, we illustrate the modeling of five-conductor transmission lines in four-layered dielectric media. 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 Fig. 14, we show the Cross-section of five-conductor transmission lines in four-layered dielectric media and its parameters.

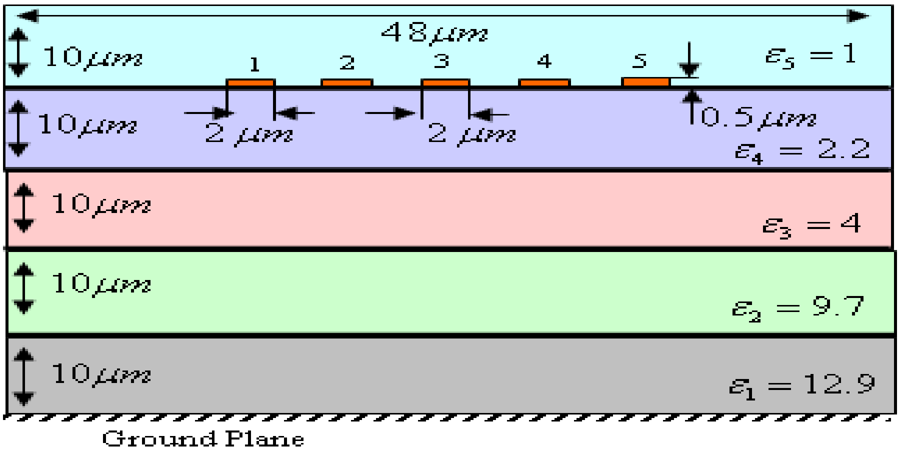

Figure 14. Cross-section of five-conductor transmission lines in four-layered dielectric media.

Figure 15 shows the 2D surface potential distribution of the transmission lines, while streamline plot was presented in Figures 16. For the model, Figure 17 shows the potential distribution of the five-conductor transmission lines in four-layered dielectric media from (x,y) = (0,0) to (x,y) = (48,50) μm.

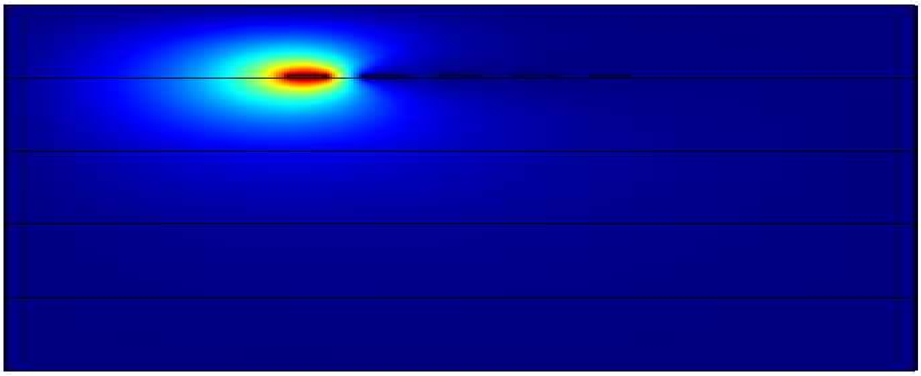

Figure 15. 2D surface potential distributions of five-conductor transmission lines in four-layered dielectric media.

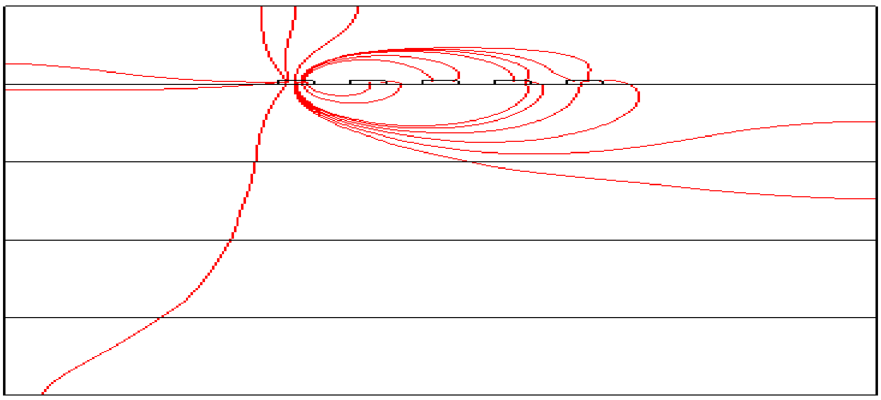

Figure 16. Streamline plot of five-conductor transmission lines in four-layered dielectric media.

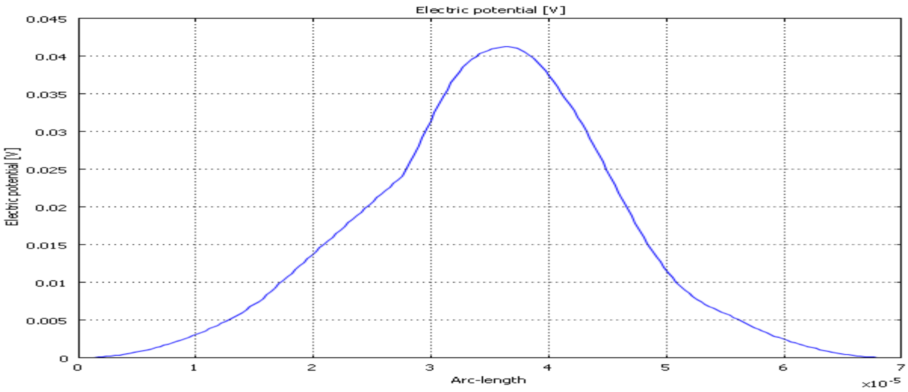

Figure 17. Potential distribution of five-conductor transmission lines in four-layered dielectric media.

The following electrical parameter capacitance per unit length matrix ($\left[C\right]$) is obtained.

$$[C]=\begin{bmatrix} 36.0 & -15.2 & -2.3 & -0.8 & -0.4 \\ -15.2 & 42.6 & -14.3 & -2.0 & -0.8 \\ -2.3 & -14.3 & 42.8 & -14.3 & -2.3 \\ -0.8 & -2.0 & -14.3 & 42.6 & -15.2 \\ -0.4 & -0.8 & -2.3 & -15.2 & 36.0 \end{bmatrix} pF/m^{\cdot}$$

Based on the four models, we observe that the capacitance per unit length of the multiconductor decreases as the number of layers increases.

4. CONCLUSION

In this paper we have presented the modeling in 2D of quasi-TEM five-transmission lines interconnect in lines interconnect in single-, two-, three- and four-layered dielectric region using FEM. 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.

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