Calculation of Capacitances of Symmetrical Triple Coupled CPW Transmission Lines and Multilayer CPW Broadside Coupled Lines Balun

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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, the quasi-TEM analyses of symmetrical triple coupled Coplanar Waveguide (CPW) transmission lines and multilayer CPW broadside coupled-line balun are successfully demonstrated using the COMSOL multiphysics. We specifically illustrate two electrostatic models of open three interconnected lines with two levels system. Also, we determine the quasi-static spectral for the potential distribution of the developed integrated circuits.

Keywords: Finite element method, Capacitance, IC Interconnect, CPW transmission lines.

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 symmetrical triple coupled CPW transmission lines and CPW broadside coupled-line balun. For example, a triple coupled CPW can be used for microwave applications as couplers for combining two independent signals [1] and as basis building blocks [2,3]. The matrices of capacitances per unit length of CPW transmission line 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 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 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 [4]. There are previous attempts at the problem. These include using the conformal mapping method [5], the spectral domain method [6], the potential integral formalization method [7].

In this work, we design two electrostatic models of symmetrical triple coupled CPW transmission lines and CPW broadside coupled-line balun 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. In this article, we specifically calculate the capacitances matrix and the potential distribution of the configurations.

2. Results and Discussions

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. For coupled multiconductor transmission 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 Fig. 1.

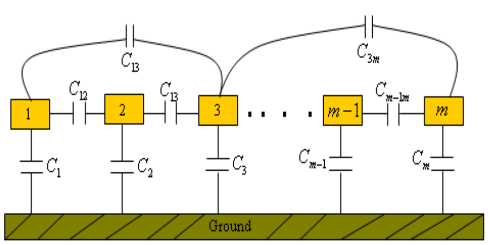

Figure 1. The per-unit length capacitances of a general m -conductor transmission line.

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

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

For a triple coupled CPW lines, the capacitance matrix can be defined as:

$$\begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \end{bmatrix} = \begin{bmatrix} C_{11} & -C_{12} & -C_{13} \\ -C_{12} & C_{22} & -C_{12} \\ -C_{13} & -C_{12} & C_{11} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \qquad (5)$$

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 [8]. 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.

In this paper, we consider two different models. Case A investigates the designing of symmetrical triple coupled Coplanar Waveguide transmission lines. For case B, we illustrate the modeling of multilayer CPW broadside coupled-line balun which is recently developed by the authors using the finite element method.

2.1 Modeling of Symmetrical Triple Coupled CPW Transmission Lines

In this section, we illustrate the modeling of symmetrical triple coupled Coplanar Waveguide transmission lines by focusing in calculating the static capacitance matrix [C] and the potential distribution. Figure 2 shows geometry with following parameters:

ε_r = dielectric constant = 12.9;

w = width of the corner conductors = 3mm;

t = thickness of the conductors = 0.01mm;

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

$s_1 = s_2$ = 0.2mm;

w_1 = 0.2mm;

w_2 =0.4 mm.

The geometry is enclosed by a 10×5 mm shield.

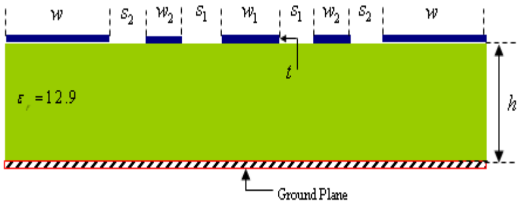

Figure 2. Cross section of triple coupled CPW lines with lower ground plane.

Figure 3 shows the 2D surface potential distribution of the triple coupled CPW lines with lower ground plane. In addition, Fig. 4 presents the electric potential plot as a function of arc-length, while, the contour plot is presented in Figures 5.

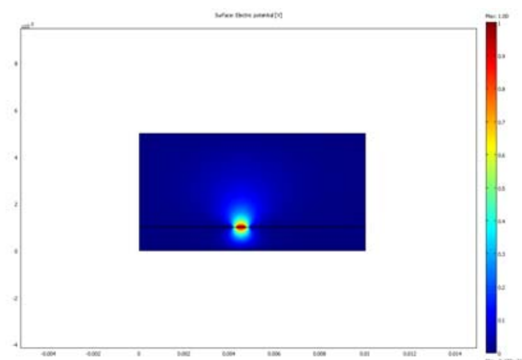

Figure 3. 2D surface potential distribution triple coupled CPW lines with lower ground plane.

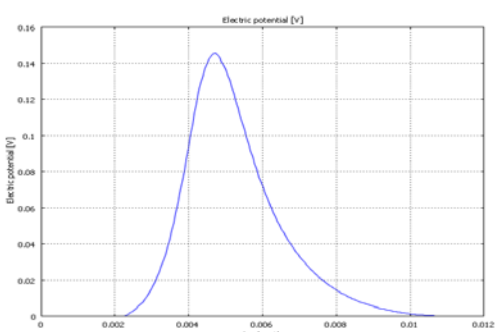

Figure 4. Potential distribution of triple coupled CPW lines with lower ground plane from (x,y) = (0,0) to (x,y) = (10,5) mm.

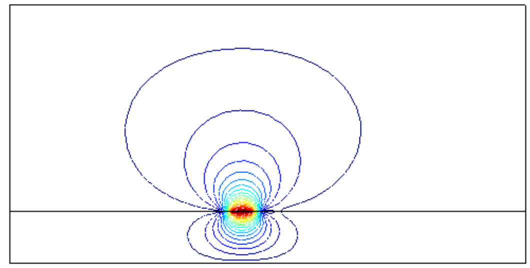

Figure 5. Contour plot of triple coupled CPW lines with lower ground plane.

Table 1 shows the COMSOL results for the capacitance per unit length of the model compared with the work of previous investigating using the potential integral formalization method, the conformal mapping method, and the spectral domain method. They are in good agreement.

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

Capacitance (pF/m)	Potential integral formalization method	Conformal mapping method	Spectral domain method	This approach
C_{11}	221.7	221.8	222.1	204.12
C_{12}	75.05	75.16	75.15	54.86
C_{13}	14.31	14.31	14.47	10.30
C_{22}	194.5	194.8	195.3	163.73

2.2 Modeling of Multilayer CPW Broadside Coupled lines Balun

In this section, we illustrate the modeling of multilayer CPW broadside coupled lines balun which is recently developed by the authors. Balun is a device which converts balanced to unbalanced transmission lines that join balanced structures and unbalanced structures transition [9]. Indeed, multilayer CPW broadside coupled lines balun is widely applied on microwave integrated circuit of wireless communication systems. Therefore, we focus here on the calculation of self and mutual (coupling) 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 the developed multilayer CPW broadside coupled lines balun. Figure 7 shows the electric potential plot as a function of arc-length of the model. The geometry of the model has the following parameters values:

ε_r = dielectric constant = 4.4;

w_1 = width of the lower middle conductor = 1.8 mm;

w_2 = width of the upper middle conductor = 1 mm;

w_3 = width of the upper corners conductors = 19.3 mm;

w_4 = width of the lower corners conductors = 18.9 mm;

t = thickness of the conductors = 0.01mm;

h_1 = height of the lower conductors from the ground = 1.6 mm;

h_2 = height of the upper conductors from the ground = 2 mm;

$s_1 = s_2$ = 0.2mm;

The geometry is enclosed by a 40×10 mm shield.

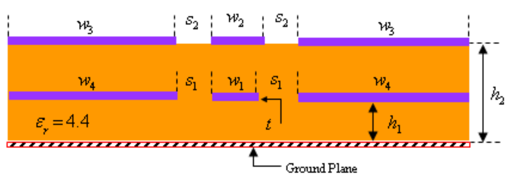

Figure 6. Cross section of multilayer CPW broadside coupled-line balun.

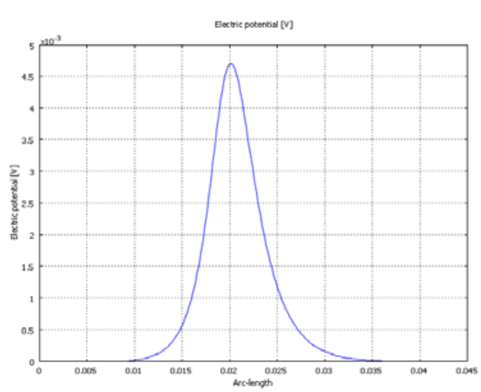

Figure 7. Potential distribution of multilayer CPW broadside coupled-line balun from (x,y) = (0,0) to (x,y) = (40, 10) mm.

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 Figure 6

Capacitance (pF/m)	This approach
C_{11}	325.89
C_{12}	-115.47
C_{21}	-115.47
C_{22}	159.49

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 symmetrical triple coupled Coplanar Waveguide (CPW) transmission lines and multilayer CPW broadside coupled-line balun systems. We computed the capacitance per-unit length matrices of the models and compared the results with other methods. Also, we identified the quasi-static spectral for the potential distribution of the developed integrated circuits. The results obtained in this research are encouraging and motivating for further study.

4. References

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