Modeling of open-coupled homogeneous striplines

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ABSTRACT

Coupled striplines are used extensively as the basic building blocks for directional couplers and filters in low temperature cofired ceramic. In this paper, we present the modeling of coupled striplines in a homogeneous medium of free space between two parallel ground planes using the finite element method (FEM). FEM is especially suitable and effective for the computation of electromagnetic fields in strongly inhomogeneous media. We illustrate that FEM is as suitable and effective as other methods for modeling coupled stripline circuits.

We mainly focus on designing of vertical plate broadside-coupled stripline, broadside-coupled stripline, edge-coupled symmetric stripline, asymmetrical coupled stripline, and asymmetrical broadside-coupled stripline. We compared some of our results of computing the capacitance per unit length with those in the literature and found them to be in agreement.

INDEX TERMS

Capacitance per unit length, Coupled stripline, Finite element method, Modeling

I. INTRODUCTION

Hybrid microwave-integrated circuits and monolithic microwave integrated circuits are extensively developed as small, light, and highly functional components for microwave and millimeter-wave communication systems. The characteristics of microwave integrated circuits' analysis and design must be accomplished accurately in a short time. The significant advantages of printed circuits are somewhat offset by the electromagnetic complexity of the structure as its inherent inhomogeneous nature makes accurate calculations difficult.

The computation of capacitance for coupled stripline is considered essential in designing microwave and advanced integrated circuits in order to optimize the electrical properties of the integrated circuits. Knowledge of the self and mutual (coupling) capacitance can also help the designers to optimize the layout of the circuit. Accurate methods for determining the capacitance for different geometries for striplines in modern design techniques have become an area of interest to scientists and researchers. For example, asymmetric coupled striplines are used as building blocks for filters and directional couplers due to their impedance transform nature and flexibility. Several methods used for analyzing coupled striplines include the method of moments [1], variational technique [2]-[4], integral equation technique [5]-[7], unified analytical method [8], design procedures [9], [10], and least-squares fitting [11].

We use COMSOL, a finite element multiphysics package, in designing the vertical plate broadside-coupled stripline, broadside-coupled stripline, edge-coupled symmetric stripline, asymmetrical-coupled stripline and asymmetrical broadside-coupled stripline structures. COMSOL is a software package used in modeling and simulating engineering technology and science problems. Many industrial applications depend on different interrelated properties or natural phenomena and require multiphysics modeling and simulation. Moreover, superior simulations of microwave integrated circuit applications will lead to more cost-efficiency throughout the development process. The finite element method (FEM) is especially suitable and effective for the computation of electromagnetic fields in strongly inhomo-

geneous media. Also, it has high computation accuracy and fast computation speed. We show that FEM is as suitable and effective as other methods for modeling-coupled stripline circuits.
We compared some of our results of computing the capacitance-per-unit length with those in the literature. We specifically compared the modeling of asymmetrical-coupled stripline with the variational technique and method of moment. Also, results from the integral equation technique and variational technique were compared for asymmetrical broadside-coupled stripline and found to be in agreement.

II. RESULTS AND DISCUSSIONS

In any electromagnetic field analysis, the placement of far-field boundary is an important concern, especially when dealing with the finite element analysis of structures, which are open. It is necessary to take into account the natural boundary of a line at infinity and the presence of remote objects and their potential influence on the field shape [12]. In all our simulations, the open stripline structure is surrounded by a w X h shield, where w is the width and h is the thickness.

In this paper, we consider five different models, A to E. For cases A, B, and C, we make our own models, which are not validated by other people's work. Models D and E are compared with other results in the literature and found to be close. The basic steps for modeling each case using COMSOL are provided in [13], [14].

A. Vertical Plate Broadside-Coupled Stripline

Figure 1 shows the cross section for vertical plate broadside-coupled stripline with the following parameters:
ε_r = dielectric constant = 1
W = width of the grounded shield = 30mm
w_1 = width of the strip line 1 = 1mm
w_2 = width of the strip line 2 = 1mm
h = height of the shield = 5mm
h_1 = distance of the strips from the ground = 1mm
s = distance between the two coupled strips = 2mm
t = thickness of the strips = 0.01mm

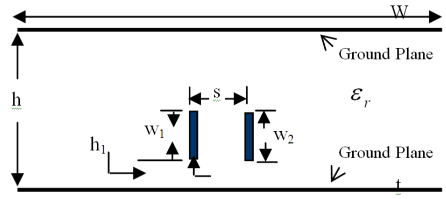

Figure 1. Cross section of vertical plate broadside-coupled stripline

The geometry is enclosed by a 30 X 5mm shield. From the model, we generate the finite elements mesh with 12,516 elements as in Figure 2. Figure 3 shows 2D surface potential distribution with port 1 as input, while Figure 4 depicts the 3D surface potential distribution of the model. The potential distribution along the line that goes from (x,y) = (0,0) to (x,y) = (30mm, 5mm) is portrayed in Figure 5. Figure 6 shows the contour plot of the potential distribution, while Figure 7 depicts the arrow plot of the potential distribution. Figure 8 is the streamline plot of the potential distribution for the model.

Table I shows the finite element results for the capacitance-per-unit length of vertical plate broadside-coupled stripline, which are based on our work.

Table I. Values of the capacitance coefficient (in F/m) for vertical plate broadside-coupled stripline

Capacitance Per Unit Length	Value
C_{11}	2.5194×10^{-11}
C_{12}	-4.4912×10^{-12}
C_{21}	-4.4912×10^{-12}
C_{22}	2.5194×10^{-11}

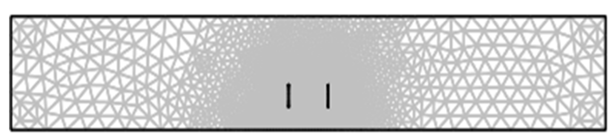

Figure 2. Mesh of vertical plate broadside-coupled stripline

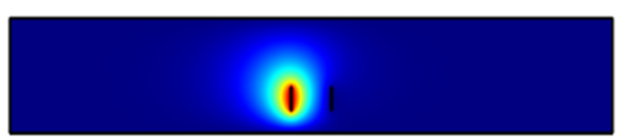

Figure 3. 2D surface potential distribution of vertical plate broadside-coupled stripline with port 1 as input

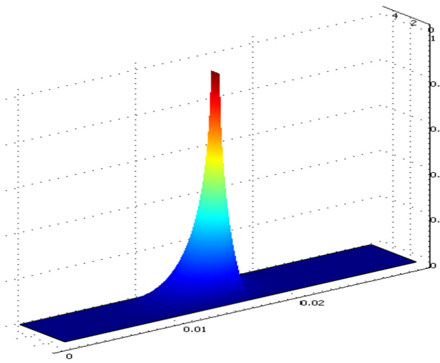

Figure 4. 3D surface potential distribution of vertical plate broadside-coupled stripline with port 1 as input

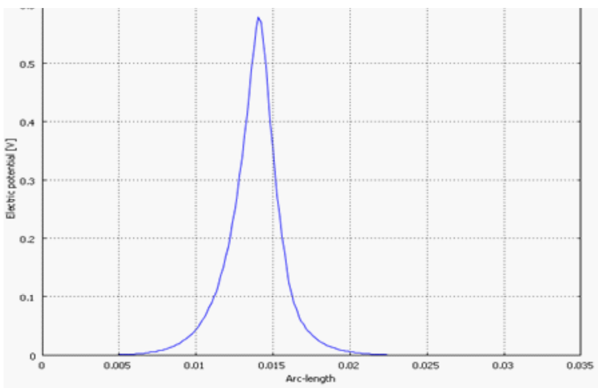

Figure 5. Potential distribution of vertical plate broadside-coupled stripline using port 1 as input along a line from (x,y) = (0,0) to (x,y) =(30mm, 5mm)

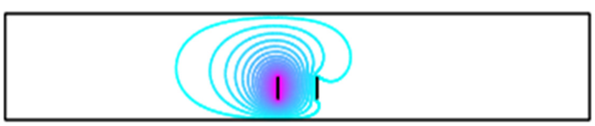

Figure 6. Contour plot of the potential distribution of vertical plate broadside-coupled stripline with port 1 as input

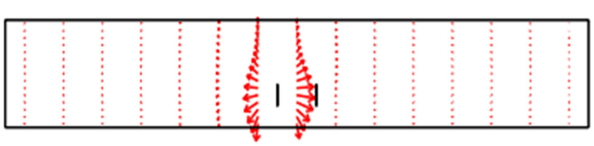

Figure 7. Arrow plot of the potential distribution of vertical plate broadside-coupled stripline with port 1 as input

Figure 8. Streamline plot of the potential distribution of vertical plate broadside-coupled stripline with port 1 as input

B. Broadside-Coupled Stripline

Figure 9 shows the cross section for the broadside-coupled stripline with the following parameters:

ε_r = dielectric constant = 1
W = width of the grounded shield = 30mm
w_1 = width of the strip line 1 = 1mm
w_2 = width of the strip line 2 = 1mm
h = height of the shield = 5mm
h_1 = distance of strip line 1 from the ground = 1mm
s = distance between the two coupled strips = 2mm
t = thickness of the strips = 0.01mm

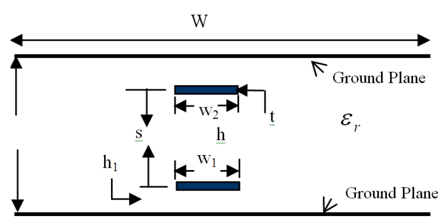

Figure 9. Cross section of broadside-coupled stripline

The geometry is enclosed by a 30 X 5mm shield. From the model, we generate the finite elements mesh with 4,920 elements as in Figure 10. Figure 11 shows 2D surface potential distribution with port 1 as input, while Figure 12 depicts the 3D surface potential distribution of the model. The potential distribution along a line from (x,y) = (0,0) to (x,y) = (30mm, 5mm) is portrayed in Figure 13. Figure 14 shows the contour plot of the potential distribution, while Figure 15 depicts the arrow plot of the potential distribution. Figure 16 is the streamline plot of the potential distribution for the model

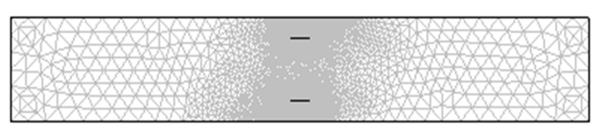

Figure 10. Mesh of the broadside-coupled stripline

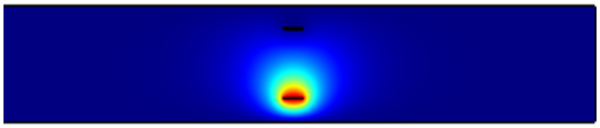

Figure 11. 2 D surface potential distribution of the broadside-coupled stripline

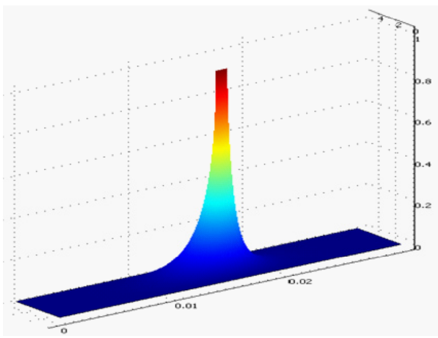

Figure 12. 3D surface potential distribution of the broadside-coupled stripline with port 1 as input

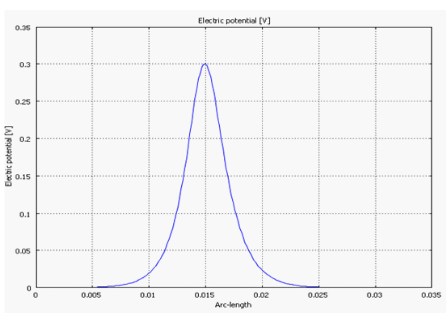

Figure 13. Potential distribution of the broadside-coupled stripline using port 1 as input along the line from (x,y) = (0,0) to (x,y) = (30mm, 5mm)

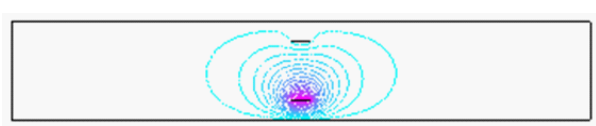

Figure 14. Contour plot of the potential distribution of the broadside-coupled stripline with port 1 as input

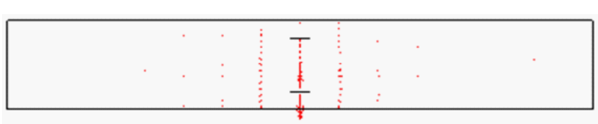

Figure 15. Arrow plot of the potential distribution of the broadside-coupled stripline with port 1 as input

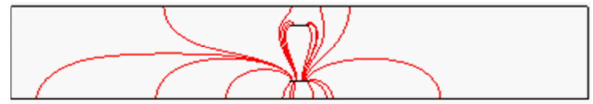

Figure 16. Streamline plot of the potential distribution of the broadside-coupled stripline with port 1 as input

Table II shows the finite element results for the capacitance-per-unit length of the broadside-coupled stripline which are based on our work.

Table II. Values of the capacitance coefficient (in F/m) for broadside-coupled stripline

Capacitance Per Unit Length	Value
C_{11}	2.7819 X 10^{-11}
C_{12}	-2.8387 X 10^{-12}
C_{21}	-2.8387 X 10^{-12}
C_{22}	2.7931 X 10^{-11}

C. Edge-Coupled Symmetric Stripline

Figure 17 shows the cross section for edge-coupled symmetric stripline with the following parameters:

ε_r = dielectric constant = 1
W = width of the grounded shield = 30mm
w_1 = width of the strip line 1 = 3mm
w_2 = width of the strip line 2 = 3mm
h = height of the shield = 5mm
h_1 = distance of the strips from the ground = 1mm
s = distance between the two coupled strips = 2mm
t = thickness of the strips = 0.01mm

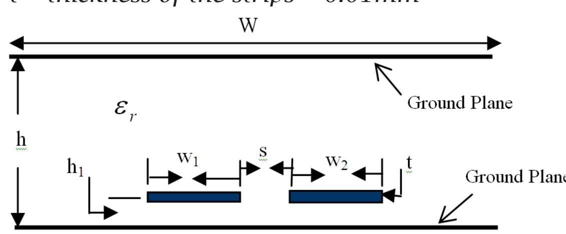

Figure 17. Cross section of edge-coupled symmetric stripline

We enclosed the geometry with a 30 X 5 mm shield. Figure 18 shows the finite element mesh with 59,700 elements, while Figure 19 depicts the 3D potential distribution of the edge-coupled symmetric stripline in a homogeneous medium (free space) between ground planes using port 1 as input. The potential distribution along a line from (x,y) = (0,0) to (x,y) = (30mm, 5mm) is portrayed in Figure 20. The contour plot of the edge-coupled symmetric stripline using node 1 as input is shown in Figure 21. The arrow plot of the potential distribution using port 1 as input is presented in Figure 22. Also, the streamline plot of the potential distribution with port 1 as input is shown in Figure 23.

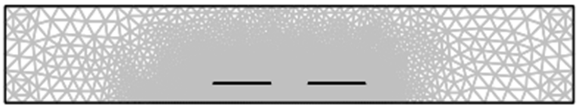

Figure 18. Mesh of edge-coupled symmetric stripline with port 1 as input

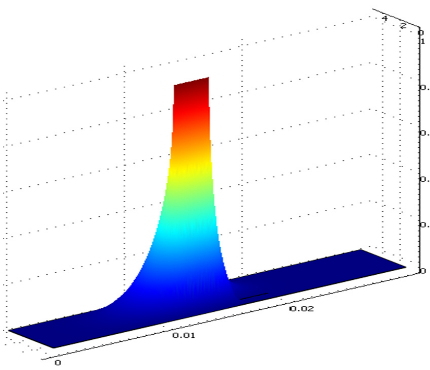

Figure 19. 3D surface potential distribution of edge-coupled symmetric stripline using port 1 as input

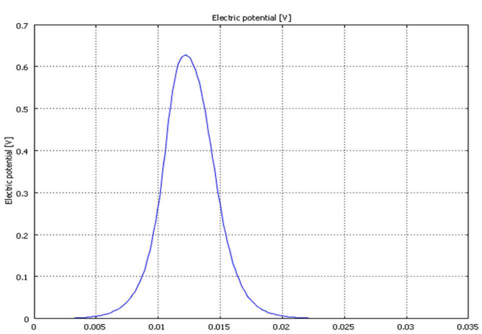

Figure 20. Potential distribution of edge-coupled symmetric stripline using port 1 as input along the line from (x,y) = (0,0) to (x,y) = (30mm, 5mm)

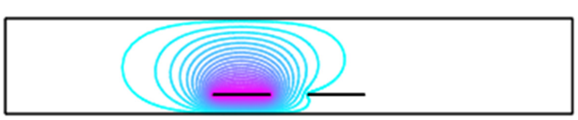

Figure 21. Contour plot of edge-coupled symmetric stripline using node 1 as input

Figure 22. Arrow plot of the potential distribution of edge-coupled symmetric stripline using port 1 as input

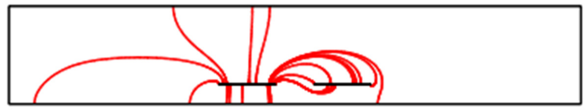

Figure 23. Streamline plot of the potential distribution of edge-coupled symmetric stripline with port 1 as input

Table III shows the finite element results for the capacitance-per-unit length for edge-coupled symmetric stripline based on our work.

Table III. Values of the capacitance coefficient (in F/m) for edge-coupled symmetric stripline

Capacitance Per Unit Length	Value
C_{11}	5.1052 X 10^{-11}
C_{12}	-2.4573 X 10^{-12}
C_{21}	-2.4573 X 10^{-12}
C_{22}	5.1052 X 10^{-11}

D. Asymmetrical-coupled Stripline

Figure 24 shows the cross section for asymmetrical-coupled microstrip line with the following parameters:

ε_r = dielectric constant = 1
W = width of the grounded shield = 30mm
w_1 = width of the strip line 1 = 3mm
w_2 = width of the strip line 2 = 3mm
s = distance between the two coupled strips = 2mm
h = height of the grounded shield = 3mm
h_1 = distance of the strip line 1 from the ground = 1mm
h2 = distance of the strip line 2 from the ground = 0.5mm
t = thickness of the strips = 0.01mm

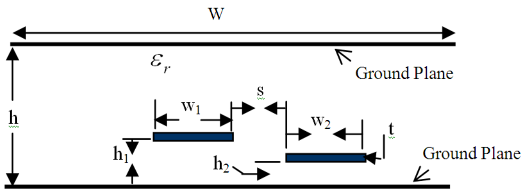

Figure 24. Cross section of asymmetrical-coupled stripline

The geometry is enclosed by a 3 X 30 mm shield. Figure 25 shows the finite element mesh with 13,324 elements, while Figure 26 depicts the 2D potential distribution of the asymmetrical-coupled stripline in a homogeneous medium between ground planes using port 1 as input. The potential distribution using port 1 as input along the line from (x,y) = (0,0) to (x,y) = (30mm, 3mm) is portrayed in Figure 27. The contour plot of edge-coupled symmetric stripline using node 1 as input is shown in Figure 28.

Figure 25. Mesh of asymmetrical-coupled stripline using node 1 as input

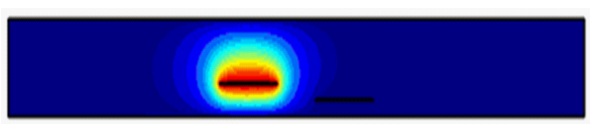

Figure 26. 2D surface potential distribution of asymmetrical-coupled stripline using node 1 as input

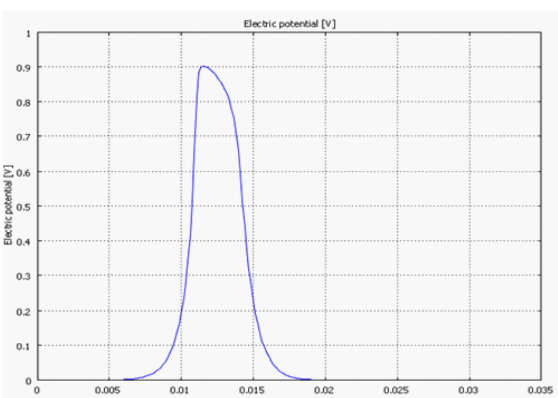

Figure 27. Potential distribution of asymmetrical-coupled stripline using port 1 as input from (x,y) = (0,0) to (x,y) = (30mm, 3mm)

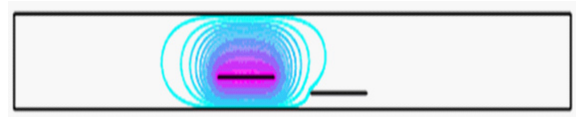

Figure 28. Contour plot of asymmetrical-coupled stripline using node 1 as input

Table IV shows the finite element results for the capacitance-per-unit length for asymmetrical-coupled stripline. The results compare well with the work of previous investigations.

Table IV. Values of the capacitance (in F/m) coefficients for asymmetrical-coupled stripline

	Reference [1]	Reference [2]	Our Work
C_{11}	0.5466×10^{-10}	0.5600×10^{-10}	0.5637×10^{-10}
C_{12}	-0.9439×10^{-12}	-1.0620×10^{-12}	-1.0926×10^{-12}
C_{21}	-0.9439×10^{-12}	-1.0620×10^{-12}	-1.0926×10^{-12}
C_{22}	0.7994×10^{-10}	0.8200×10^{-10}	0.8249×10^{-10}

E. Asymmetrical Broadside-Coupled Stripline

Figure 29 shows the cross section for asymmetrical broadside-coupled stripline with the following parameters:

ε_r = dielectric constant = 1
W = width of the grounded shield =10mm
w_1 = width of the strip line 1 = 1mm
w_2 = width of the strip line 2 = 1, 0.5, and 0.05mm
h = height of the grounded shield = 1mm
h_1 = distance between the two coupled strips = 0.2mm
t = thickness of the strips = 0.01mm

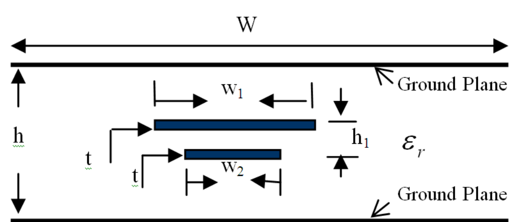

Figure 29. Cross section of asymmetrical broadside-coupled stripline

The geometry is enclosed by a 1 X 10mm shield. Figure 30 shows the mesh of asymmetrical broadside-coupled stripline with 7,152 elements, when w2 = 0.05mm while the 2D potential distribution is shown in Figure 31. The potential distribution using port 1 as input along the line from (x,y) = (0,0) to (x,y) = (10mm, 1mm) is portrayed in Figure 32.

Figure 30. Mesh of asymmetrical broadside-coupled stripline using node 1 as input

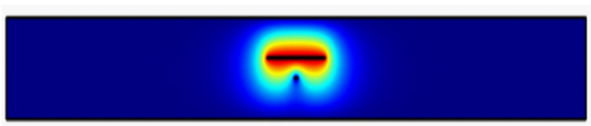

Figure 31. 2D surface potential distribution of asymmetrical broadside-coupled stripline using node 1 as input with w2 = 0.5mm

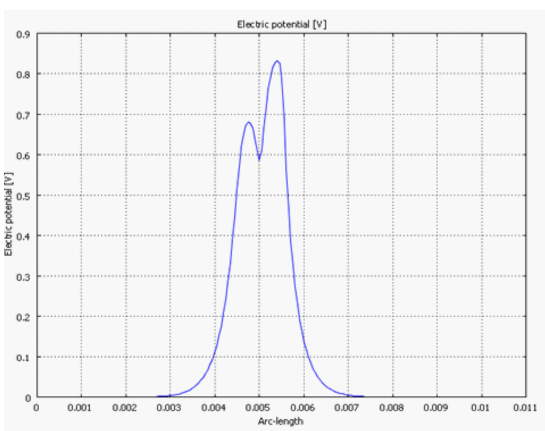

Figure 32. Potential distribution of asymmetrical broadside-coupled stripline using port 1 as input along the line from (x,y) = (0,0) to (x,y) = (10mm, 1mm)

Table V shows the finite element results for the capacitance-per-unit length for asymmetrical broadside-coupled stripline. The results are compared with the work of previous investigations and found to be in agreement.

Table V. Values of the capacitance coefficient (in F/m) for asymmetrical broadside-coupled stripline

w_1	1	1	1
w_2	1	0.5	0.05
C_{11} [Ref. 5]	8.0780 X 10^{-11}	7.2318 X10^{-11}	5.9648 X10^{-11}
C_{12} [Ref. 5]	-4.7349 X10^{-11}	-3.1106 X10^{-11}	-1.0911 X10^{-11}
C_{22} [Ref. 5]	8.0780 X10^{-11}	4.9144 X10^{-11}	1.6941 X10^{-11}
C_{11} [Ref. 2]	8.0761 X10^{-11}	7.2318 X10^{-11}	5.9655 X10^{-11}
C_{12} [Ref. 2]	-4.7322 X10^{-11}	-3.1106 X10^{-11}	-1.0920 X10^{-11}
C_{22} [Ref. 2]	8.0753 X10^{-11}	4.9135 X10^{-11}	1.6932 X10^{-11}
C_{11} [Our Work]	8.493006 X10^{-11}	7.56275 X10^{-11}	6.206936 X10^{-11}
C_{12} [Our Work]	-5.047388 X10^{-11}	-3.328982 X10^{-11}	-1.227162 X10^{-11}
C_{22} [Our Work]	8.437171 X10^{-11}	5.167065 X10^{-11}	1.876906 X10^{-11}

III. CONCLUSION

In this paper we have presented the modeling of vertical plate broadside-coupled stripline, broadside-coupled stripline, edge-coupled symmetric stripline, asymmetrical- coupled stripline, and asymmetrical broadside-coupled stripline. We have shown that FEM is suitable and effective as other methods for modeling coupled stripline circuits. Some of the results obtained using FEM with COMSOL multiphysics for the capacitance-per-unit length agree well with those found in the literature. The results obtained in this research are encouraging and motivating for further study.

IV. ACKNOWLEDGMENT

The authors thank the National Science Foundation (NSF) for their financial support of this research project.

V. REFERENCES

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