A Novel Crossover Design Based on Parallel Coupled Lines Structure

Diksha Thakur, Vishakha Thakur,Salman Raju Talluri
Department of Elect. & Comm., Jaypee Univerisity of Information Technology, Solan, India

Abstract: The theme of this paper is present a simple design of crossover based on parallel coupled lines structure. The coupling between two parallel coupled lines has been used to diver the signal to the coupled port. Theoretical and numerical simulations have been verified by full wave electromagnetic simulations. A crossover operating at 2.5 GHz has been simulated on Roger's 5880 material with a dielectric constant of 2.2 with a substrate height of 0.508 mm. These simulations are in good agreement with the numerical simulations. A comparison has been made with the crossover of same dimensions by replacing the parallel coupled lines structure with a high impedance transmission line. From the numerical and full wave simulations, it is observed that the crossover with parallel coupled lines structure is providing better results in terms of return loss, isolation, coupling and directivity.

Keywords: Scattering parameters, crossover, even-mode analysis, odd-mode analysis, parallel coupled lines, and branch line coupler.

I.   Introduction

Crossover is a microwave device used in beam-forming networks such as Butler matrix [1]. It is a symmetrical four port network. Various designs of crossovers have been presented in literature such as in [2] open circuited coupled lines are used with branch line crossover to obtain dual band at 0.75/1.22 GHz and short-circuited coupled lines are used for the tri-band crossover at 0.71/1.0/1.32 GHz. Dual band crossovers are designed by replacing inner and outer microstrip lines with dual-band structures in [3] and three section branch line coupler in [4]. Miniaturized crossover is presented in [5] using cascaded sections of branch line coupler. There is 30% size reduction as compared to the conventional structure which is achieved by replacing the transmission line by artificial transmission line (ATL). A planar symmetrical structure is presented in [6] which is based on double ring design.

The parallel coupled lines are used in [2] are to make the crossover either as a dual band or as a tri-band. However, this paper presents a new design of crossover using the parallel coupled lines [7]. Two transmission lines are said to be coupled lines when they are in close proximity to each other such that power can be coupled from one transmission line to other transmission line. This coupling property has been used in the design of crossover.

This paper is organized in the following manner. Section II provides the theoretical analysis of the proposed crossover. Section III presents the numerical simulations. Section IV presents the full wave electromagnetic simulations while Section V concludes the paper.

II.   Theoretical analysis

Fig.1 represents the geometry of the proposed crossover using the parallel coupled lines structure. This device is symmetrical about the vertical axis of symmetry. This is identical to the branch line coupler. However the main difference between the branch line coupler and the proposed structure is the dimensions and the values of the series branch and shunt branch impedances. In branch line coupler, both the series branch and shunt branch are equal to quarter wavelength. Here the series branch is quarter wavelength while the shunt branch length is half wavelength. This has been taken so as to provide the coupling between the upper closed loop and lower closed loop. If this has to work as a crossover, the

input is given at port-1 has to completely appear at only port-3 and there should be no trace of signal at port-2 and port-4. There should be no signal at port-1 aw well in terms of return signal. Port-1 to port-2 relation is expressed by insertion loss, port-1 to port-3 will be expressed as coupling, and port-1 to port-4 will be expressed by isolation.

Parallel coupled lines form a four port network. The parallel coupled lines structure is usually represented in even mode and odd mode impedances. The characteristic impedance of the parallel coupled line is taken as the average of even mode and odd mode impedances. Fig.2 represents the similar crossover so as to make comparison with proposed crossover with parallel coupled lines structure by replacing the parallel coupled lines structure with a transmission line. The characteristic impedance of the transmission line is assumed to have the same value as that of the parallel coupled lines structure. Both these structures have been analyzed using the even and odd mode analysis.

Fig.3 represents the equivalent circuit of even mode analysis. In even mode, port-1 and port-2 are excited with the same signals with same polarity. Hence there will be no current flowing from port-1 to port-2 at the axis of symmetry and hence it will be replaced with open circuit. In odd mode, port -1 and port-2 are excited with same signals but with opposite polarities (if port-1 is positive then port-2 is negative) and hence there will be a current flowing from port-1 to port-2. Since the port -1 is at higher potential (positive) and port-2 is at lower potential (negative), there has to be a zero potential in between these ports. Due to symmetry, this zero potential occurs at the axis of symmetry. Hence for the odd-mode equivalent circuit, the ports at vertical symmetric axis have been replaced with short circuits. Fig.4 represents the odd-mode equivalent circuit of the proposed crossover.

The overall scattering parameters have been obtained by deriving the even mode scattering parameters and odd mode scattering parameters using the equations from Eqn.1 to Eqn.4 [8].

$$S_{11} = \frac{S_{11}^e + S_{11}^o}{2} \qquad (1)$$

$$S_{12} = \frac{S_{11}^e - S_{11}^o}{2} \qquad (2)$$

$$S_{13} = \frac{S_{14}^e - S_{14}^o}{2} \qquad (3)$$

$$S_{14} = \frac{S_{14}^e + S_{14}^o}{2} \qquad (4)$$

Here S_{11}^e is the reflection coefficient of the even mode equivalent circuit. S_{14}^e is the transmission coefficient (from port-1 to port-4) of the even mode equivalent circuit. In the same manner, S_{11}^o is the reflection coefficient of the odd mode equivalent circuit while S_{14}^o is the transmission coefficient (from port-1 to port-4). Only S_{11}, S_{12}, S_{13} and S_{14} are given here. The other scattering parameters can be determined using the symmetry property of the scattering matrix.

In order to get S_{11}^e and S_{14}^e, the ABCD parameters of the z_l of length $\lambda/8$ (with respect to Fig.3) has been obtained. This is connected in cascade with a transmission line (vertical branch) of length $\lambda/4$ with an impedance of z_h. Now this section is connected with a parallel coupled lines structure. The conditions that must be incorporated for the parallel coupled lines structure are represented in Fig.5 for both even and odd modes. Usually, the parallel coupled lines are represented in impedance parameters as shown below. Here Z_e is the even mode impedance of parallel coupled lines structure. Z_o is the odd mode impedance of parallel coupled lines structure. Since port-1 and port-2 of the parallel coupled lines (these port numbers are with respect to Fig.5) are connected for the shunt transmission lines in the equivalent circuit model, it is required to obtain the impedance parameters of the parallel coupled lines structure by treating it as a two port network. For this two port network, port-1 and port-2 are the input and output ports. Remaining two ports are kept at open circuit. Hence the Z_{11} and Z_{12} are the impedance parameters of the open circuited parallel coupled lines structure. Here θ is the electrical length of the transmission line.

$$Z_{11}^{oc} = Z_{11} = -\frac{j}{2}(Z_e + Z_o)\cot\theta \qquad (5)$$

$$Z_{12}^{oc} = Z_{12} = -\frac{j}{2}(Z_e - Z_o)\cot\theta \qquad (6)$$

However the Z_{11} and Z_{12} are different for short circuited parallel coupled lines, since the conditions existing at port-3 and port-4(of parallel coupled lines structure) are short circuited. Hence, the modified the Z_{11} and Z_{12} are obtained by putting a condition of $v_3 = 0$ and $v_4 = 0$. After some algebraic simulations, the Z_{11} and Z_{12} for odd mode are obtained as from Eqn.7 to Eqn.10

$$Z_{11}^{sc} = Z_{11} + (Z_{13} \times T_1) + (Z_{14} \times T_2) \qquad (7)$$

$$Z_{12}^{sc} = Z_{12} + (Z_{13} \times T_2) + (Z_{14} \times T_1) \qquad (8)$$

$$T_1 = \frac{Z_{12} \times Z_{14} - Z_{11} \times Z_{13}}{(Z_{11})^2 - (Z_{12})^2} \qquad (9)$$

$$T_2 = \frac{Z_{12} \times Z_{13} - Z_{11} \times Z_{14}}{(Z_{11})^2 - (Z_{12})^2} \qquad (10)$$

These Z parameters of o PCL are converted into ABCD parameters by Eqn.11 to Eqn.14.

$$A = \frac{Z_{11}}{Z_{12}} \qquad (11)$$

$$B = \frac{Z_{11}^2 - Z_{12}^2}{Z_{12}} \qquad (12)$$

$$C = \frac{1}{Z_{12}} \qquad (13)$$

$$D = \frac{Z_{11}}{Z_{12}} \qquad (14)$$

Then the overall ABCD parameters are obtained by multiplying the five cascade sections namely $\lambda/8$ length series branch, vertical transmission line of length $\lambda/4$, parallel coupled lines structure of length $\lambda/8$, another vertical transmission line of length $\lambda/4$ followed by another horizontal transmission line of length $\lambda/4$. These overall ABCD parameters will be converted in to scattering parameters. The same procedure must be done for odd mode as well. Then the overall scattering parameters for the entire structure can be found using Eqn.1 to Eqn.4.
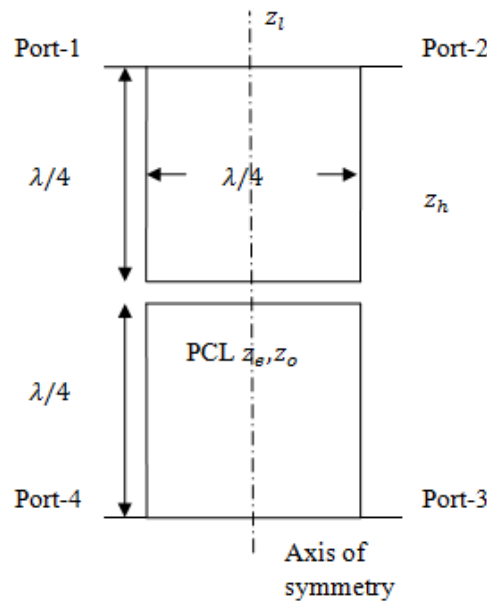

Fig.1 Geometry of proposed crossover using PCLs structure.
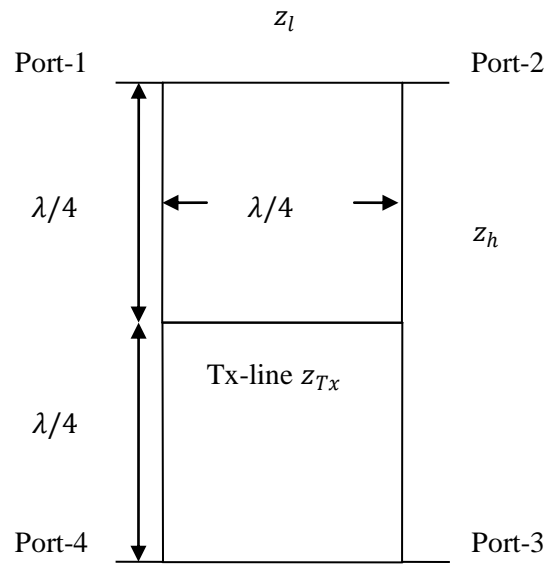
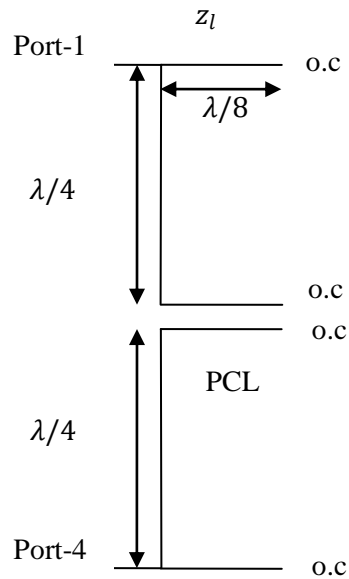Fig.2 Geometry of crossover with transmission line.

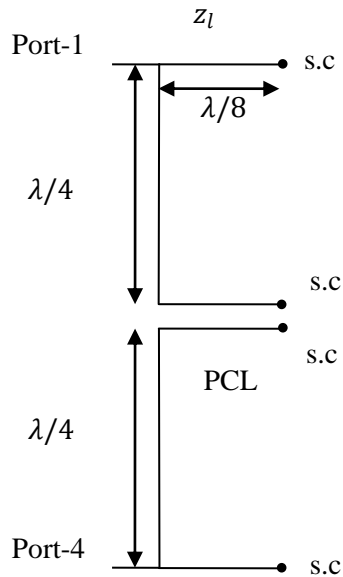Fig.3 Even mode equivalent circuit of proposed crossover using PCLs structure.

Fig.4 Odd mode equivalent circuit of proposed crossover using PCLs structure.
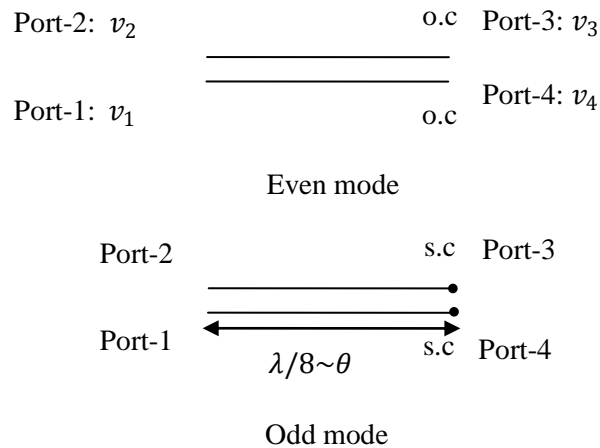
Fig.5 PCLs structure conditions for even mode and odd mode.

III.   Numerical Simulations

In order to observe the scattering parameters, numerical simulations have been carried out using MATLAB [9]. Numerical simulations have been performed with normalized values of impedances and electrical lengths. Impedance of port feed lines (z_f) has been taken as unity. An optimization has been performed so as to make S_{13} is eqaual to 1. From this optmization, the impedance of sereis branch (z_l) has obtained as 0.5. Impedance of the shunt branch (z_h) has been obtained as unity. For the parallel coupled lines structure, the even mode impedance (z_e) has been obtained as 3 and the odd mode impedance (z_o) has been obtained as 1. The characterstic impedance of the parallel coupled line is the average of odd mode impedance and even mode impedance. Hence the characterstic impedance of the parellel coupled lines structrure   is 2. In order to compare this with the simple transmission line

IJEE
0973-7383

International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 10 • Issue 2 pp. 614-623 June 2018-Dec 2018 www.csjournals.com

connection, the impedance of the connecting transmission line (z_{tx}) has been taken as 2 and comparison has been made between these two cases.

Fig.6 represents the charactersics of crossover with parallel coupled lines structure. From this figure it is observed that at $\pi/2$ radians S_{11}, S_{12}, and S_{14} are zero while S_{13} is unity.
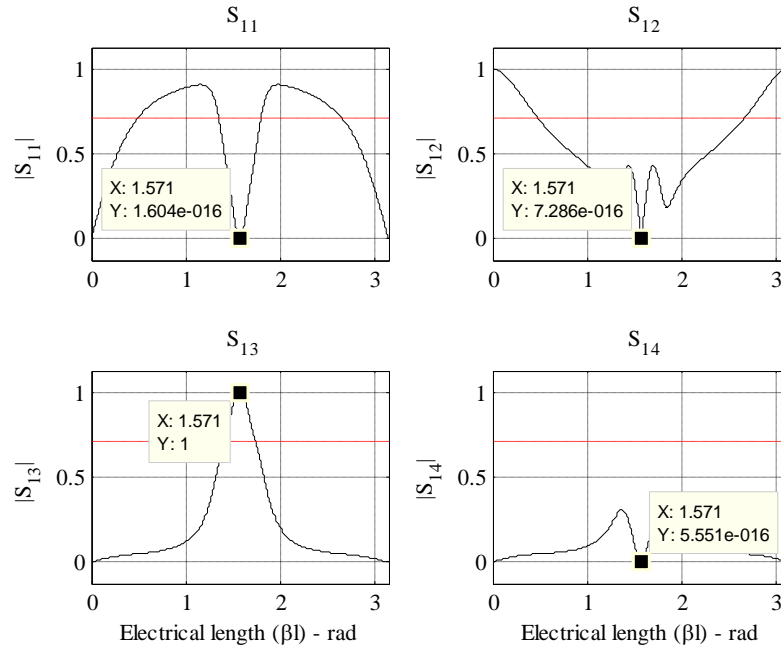

Fig.6 Scattering parameters of crossover with PCLs structure.

Fig.7 represnets the comparison of scattering parameters of crossover with parallel coupled lines structure and with crossover of transmission line structure. From this figure, it is observed that proposed crossover is better than the transmission line crossover. As for the transmission line crossover is concerned, magnitude of S_{13} is not 0dB for the values considered. However with the parallel coupled lines crossover, the magnitude is 0dB. This suggets the advantage of the proposed crossover.
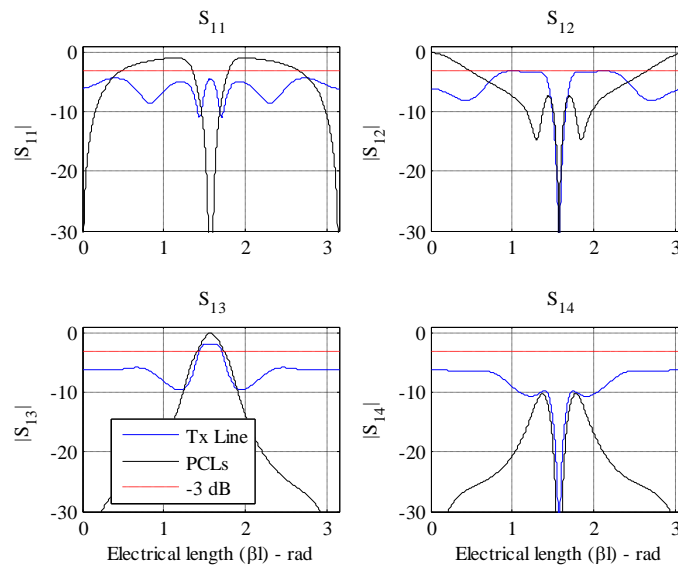

Fig.7 Comparison of PCLs structure crossover with transmission line crossover.

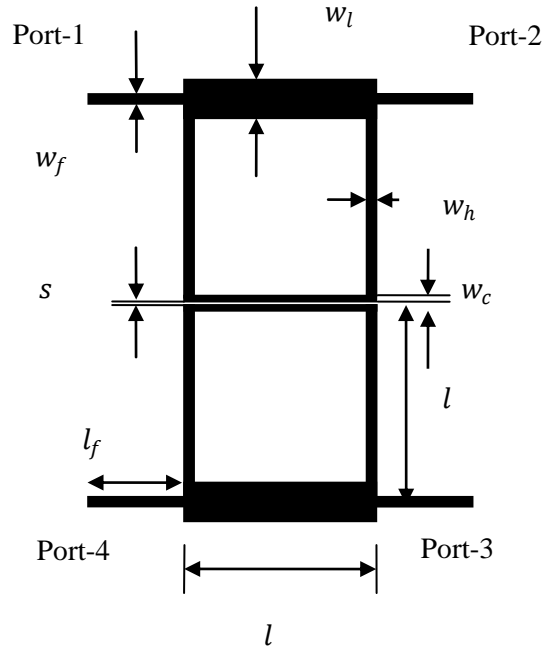## IV.   Full wave electromagnetic simulations

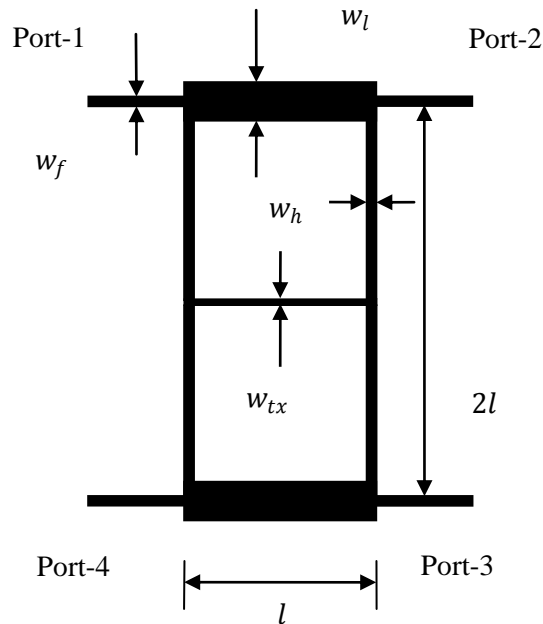Fig.8 Microstrip layout of the proposed crossover using PCLs structure.

Fig.9 Microstrip layout of crossover with a transmission line.

Full wave electromagnetic simulations have been performed for both the crossovers. Fig.8 and Fig.9 are the layouts of proposed crossovers on microstrip. The dimensions for these layouts are mentioned in Table. I along with the material that has been used. These dimensions have chosen so as to operate the crossover at 2.5 GHz.

Table. I

| S.No	Parameter	Value
1	Length of the series branch l	23.2 mm
2	Length of feed line l_f	10 mm
3	Width of feed line w_f	1.4 mm
4	Impedance of feed line z_f	50 Ohms (approx.)
5	Width of low impedance line w_l	3.5 mm
6	Impedance of low impedance line z_l	25 Ohms (approx.)
7	Width of high impedance line w_h	1.4 mm
8	Impedance of high impedance line z_h	50 Ohms (approx.)
9	Width of the PCLs structure w_c	0.3 mm
10	Spacing between the PCLs s	0.1 mm
11	Material	Rogers 5880
12	Dielectric constant	2.2
13	Loss tangent	0.0009
14	Thickness of substrate	0.508 mm
15	Thickness of copper cladding	0.035 mm
16	Width of transmission line connection	0.3 mm
17	Impedance of transmission line connection z_{tx}	100 Ohms (approx.)
18	Operating frequency of the crossover	2.5 GHz
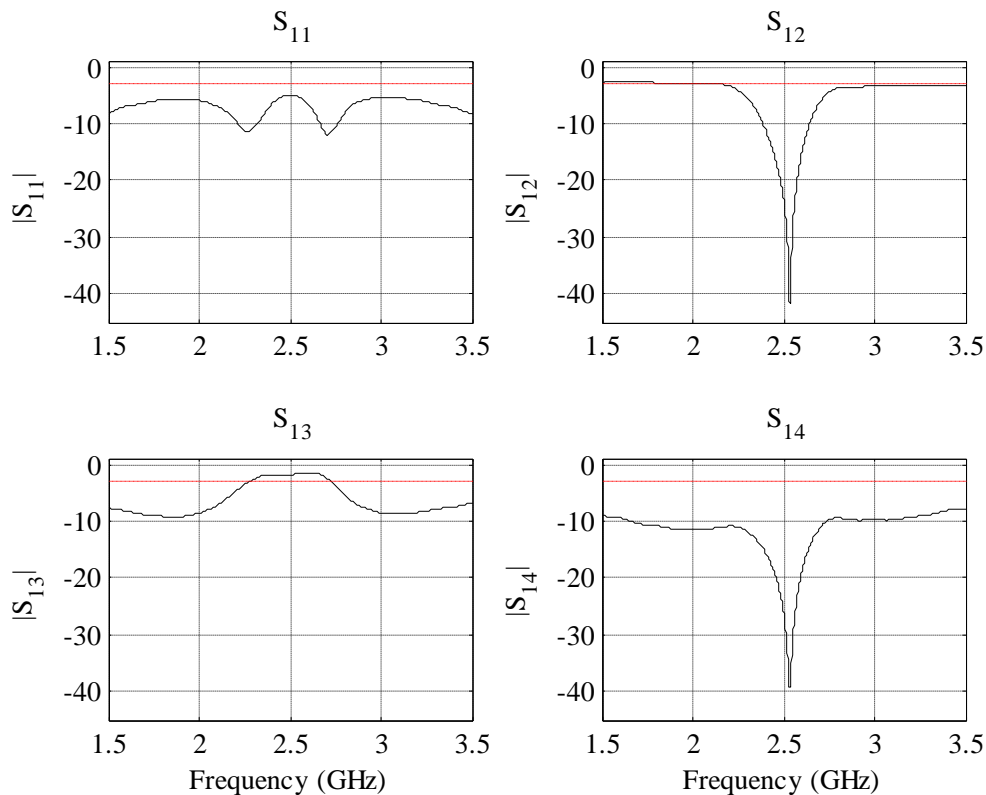
Fig.10 S-parameters of crossover with Tx-line from full wave electromagnetic simulations.

Fig.10 and Fig.11 represents the full wave electromagnetic simulations of crossover with transmission line crossover and proposed crossover with parallel coupled lines structure. Here all scattering parameters are exactly similar to that of numerical simulations mentioned in the previous section.
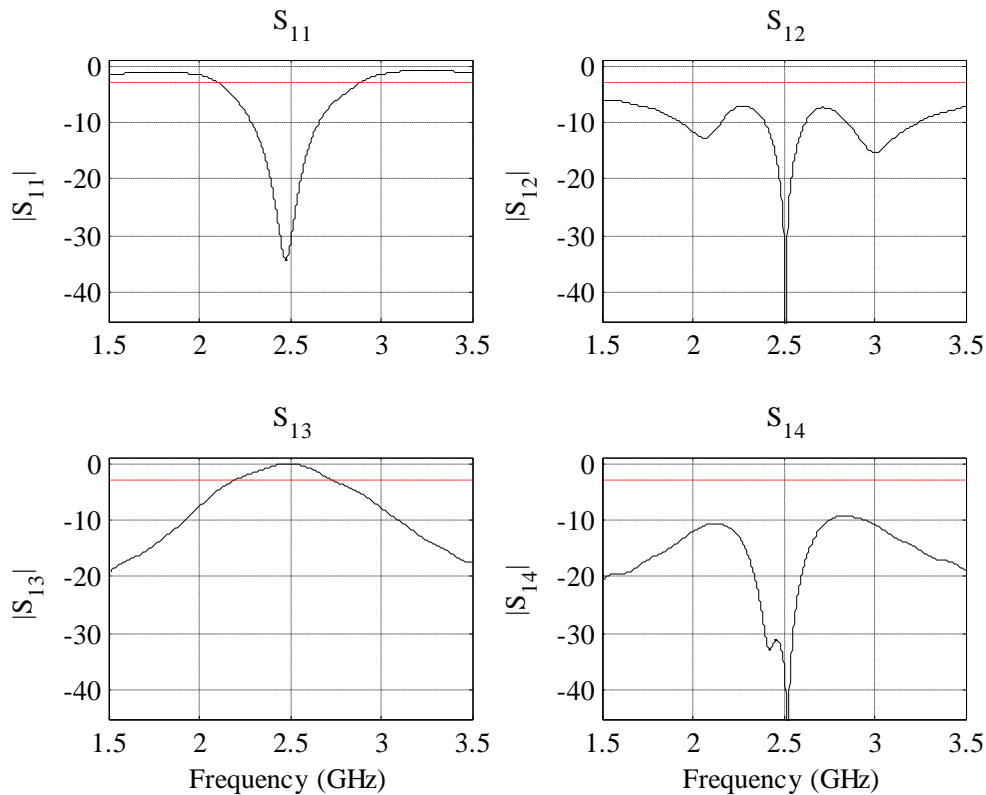

Fig.11 S-parameters of crossover with PCLs structure from full wave electromagnetic simulations.

V.   Conclusion

A simple new crossover using parallel coupled lines has been presented in this paper. Theoretical and numerical analysis has been performed. Numerical simulations have been verified by the full wave electromagnetic simulations. It is found out that there is a good agreement between both the simulations. The main limitation of this layout is fabrication difficulties. It is difficult to design the parallel coupled lines structure with the thickness of 0.3mm and with a separation of these lines at 0.1mm.

References

[1] Moody, H. "The systematic design of the Butler matrix." IEEE Transactions on Antennas and Propagation 12.6 (1964): 786-788.
[2] Feng, Wenjie, Yu Zhao, and Wenquan Che. "Multi-band crossovers with high passband isolation based on loaded coupled lines." IET Microwaves, Antennas & Propagation 12.8 (2018): 1339-1344.
[3] Shao, Jin, et al. "A fully symmetrical crossover and its dual-frequency application." IEEE transactions on microwave theory and techniques 60.8 (2012): 2410-2416.
[4] Wong, Fai-Leung, and Kwok-Keung M. Cheng. "A novel, planar, and compact crossover design for dual-band applications." IEEE transactions on microwave theory and techniques 59.3 (2011): 568-573.

[5] Verdu Tirado, Jordi, Endika Bernaola, and Pedro de Paco. "A Compact Microstrip Crossover Based on Capacitively-Loaded Artificial Transmission Lines Branch-Line Sections." Progress In Electromagnetics Research 68 (2017): 121-126.

[6] Chen, Yuan, and Swee-Ping Yeo. "A symmetrical four-port microstrip coupler for crossover application." IEEE transactions on microwave theory and techniques 55.11 (2007): 2434-2438.

[7] Cohn, Seymour B. "Parallel-coupled transmission-line-resonator filters." IRE Transactions on Microwave Theory and Techniques 6.2 (1958): 223-231.

[8] Pozar, David M. Microwave engineering. John Wiley & Sons, 2009.

[9] MathWorks, M. A. T. L. A. B. "the Mathworks." Inc., Natick, MA (2010).