2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Compact crossover based on artificial transmission line

Denis A. Letavin, Nikolay S. Knyazev
Ural Federal University
Ekaterinburg, Russia
d.a.letavin@urfu.ru

Abstract

This paper studies such microstrip device as crossover. The dimensions of this device were reduced by simple substitution of quarter-wave segments with an artificial transmission line consisting of a microstrip line with open-circuit stubs of various lengths connected to it. The entire design process was performed in AWR Design Environment 12 three-dimensional electrodynamic simulation software. A prototype with central frequency of 1000 MHz was produced based on the obtained calculations. Using the vector network analyzer, experimental dependencies were obtained. The obtained crossover surface area was reduced by 71% as compared to standard design.

1. Introduction

Today there is a broad variety of microstrip devices, for example phase inverters, power dividers, tees, crossovers etc. This paper studies the crossover layout, based on structural scheme shown in fig. 1. Wave resistance values used in the scheme: Z1=69.9 Ohm, Z2=48.3 Ohm, Z3=40.1 Ohm, Z4=31.9 Ohm. This device is used in cases when it is necessary to transmit the signal during intersection of microstrip segments. However, it is worth noticing that if such devices are used for low-frequency operation, their usage is impractical due to their large dimensions.

This is why it is necessary to reduce the dimensions of the device by various methods, along with preserving the characteristics within a broad frequency band. Various methods of miniaturization have been invented by now [1-18]. For example in [1] geometrical sizes are decreasing by quasi – lumped elements, periodical capacitance in [2], non – symmetrical T – shaped structures [3], retarding structures [4,5], fractals [6], high resistance structures [7], loaded lines [8], inter-digitated capacitor [9]. There are also a lot of other various methods of miniaturization of microstrip devices [10-13]. The latest author’s works involve development of small traditional microstrip couplers as well [14]-[18]. However, not all methods allow preserving the characteristics within a broad frequency band. This paper suggests using such design solution as substitution of all microstrip sections with artificial transmission lines.

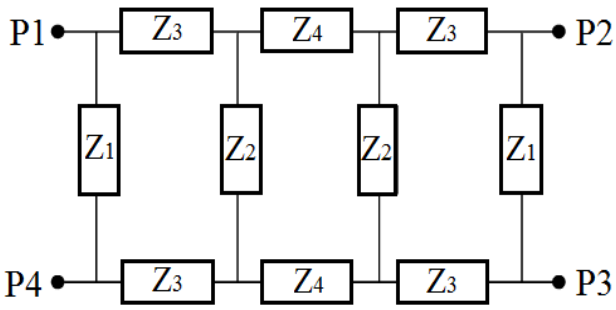

Figure 1. Crossover layout

2. Method

A crossover is a passive microwave device providing signal transmission during crossing of the lines. Usually such devices are used in antenna array beam-forming network circuits. Before circuit modeling a central frequency of 1 GHz was selected and FR-4 was selected as substrate material with dielectric permeability of ε = 4.4 and thickness of h = 1 mm

Special electromagnetic analysis software – AWR DE, was used in design process. With its help the layout of a conventional crossover was obtained (see fig.1). Fig. 2, 3 show its frequency characteristics, obtained as a result of circuit analysis. The device surface area equals 47.5 mm x 121.6 mm = 5776 mm^2.

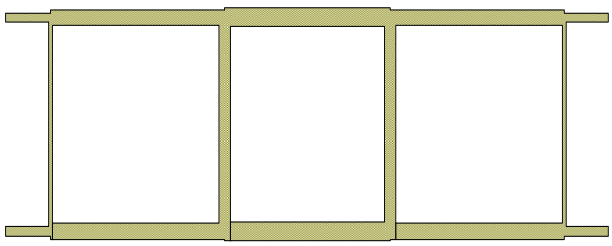

Figure 2. Conventional crossover layout

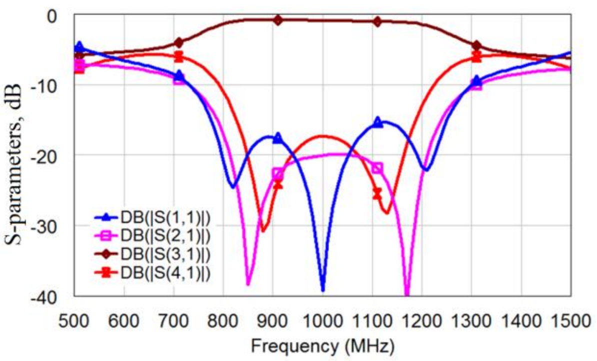

Figure 3. S-parameters versus frequency dependence

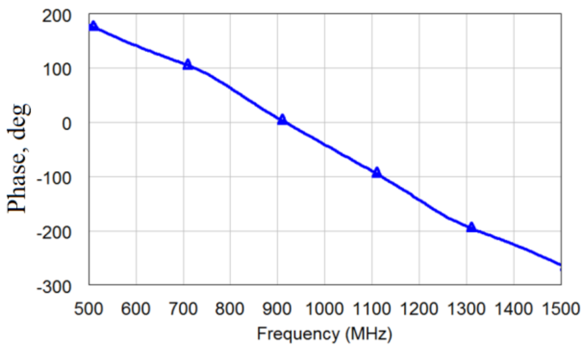

Figure 4. Output port phase

According to analysis results we can see that the working band by propagation ratio (1 dB from minimum loss level) is 447 MHz. The propagation ratio at central frequency equals -0.9 dB. Since the device is symmetrical, input change does not affect the propagation ratio. S11, S21, S41 matching and decoupling ratios are lower then -15 dB level throughout the entire working band. The propagation ratio phase value at the central frequency is 44°.

In order to eliminate such disadvantage as large dimensions, we performed the miniaturization process using artificial transmission lines. The artificial line consists of a microstrip line (inductor), to which open-circuit stubs of varying lengths are connected (capacitors). Such structures possess characteristics similar to those of conventional shape sections. Using such compact artificial lines allowed to obtain a compact layout, which is shown in fig. 5. Frequency characteristics obtained in the software are shown in fig. 6,7.

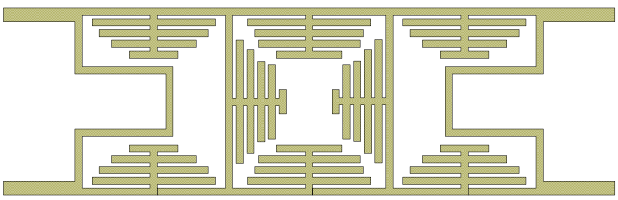

Figure 5. Compact crossover layout

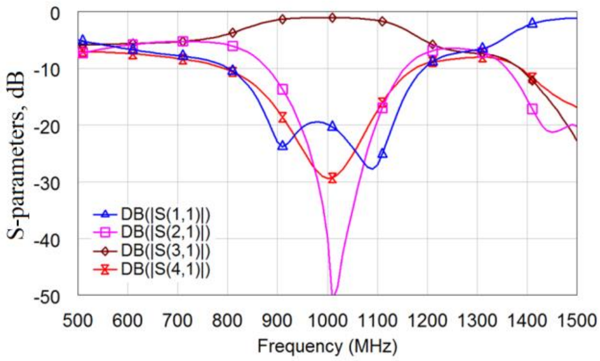

Figure 6. S-parameters versus frequency dependence

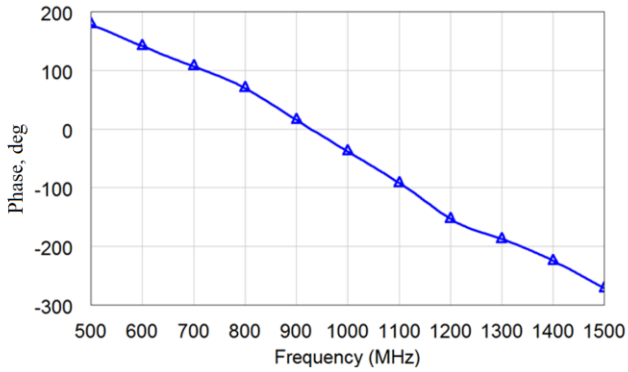

Figure 7. Output port phase

From the obtained results it can be seen that the crossover operates at a central frequency of 1000 MHz. The propagation ratio at the working frequency decreased to the value of 1.05 dB. The working band is 280 MHz. It is also seen that the uncoupling with non-operating outputs is provided at the level of -20 dB throughout the entire working frequency band. The output phase angle is 43°.

3. Measurement

Then, according to the obtained data, a crossover is produced by means of PCB etching. The surface area of the produced device is 26.1 mm x 64.4 mm = 1680.8 mm2. Its picture is shown in fig. 8. The frequency characteristics obtained with R&S vector network analyzer are shown in fig. 9-10.

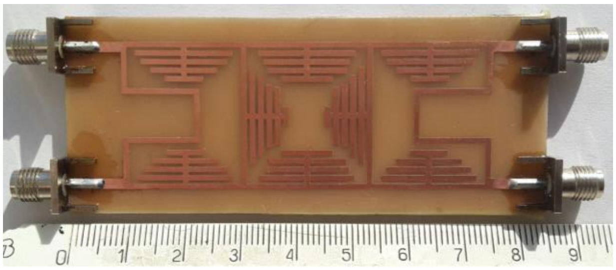

Figure 8. Compact crossover model

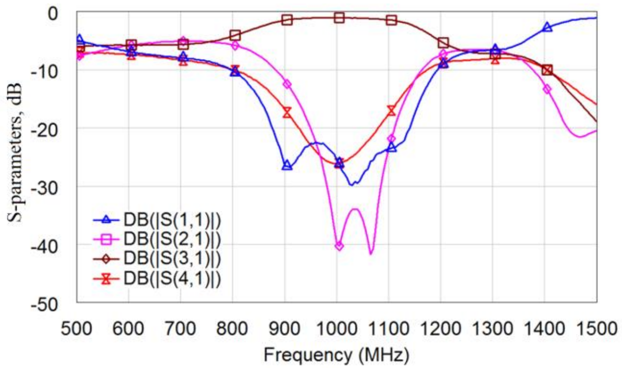

Figure 9. S-parameters versus frequency dependence

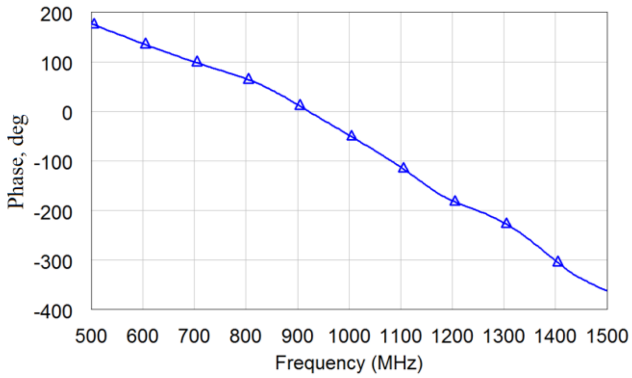

Figure 10. Output port phase

We determined from frequency dependencies that the crossover operates at the central frequency of 1000 MHz and has a working frequency band equal to 276 MHz. The propagation ratio at central frequency is -1.05 dB.

The coefficient of reflectivity of the input port is lower than -20 dB value throughout the entire frequency band. The output phase angle is 49°. All the obtained data are summarized in Table 1.

TABLE I. Compares the numerical and measured results

Parameters	**Standard**	**Compact**
Bandwidth, MHz	447	276
Relative band, %	44.6	27.6
Area, mm^2	5776	1680
Relative area, %	100	29
Center frequency, MHz	1001	1000
Phase output port, °	44	49

3. Conclusion

This paper describes successful reduction of crossover surface area by 71% as compared to conventional layout, by simply substituting the microstrip sections with artificial transmission lines. The entire process of creating the compact device is carried out in AWR DE 12 electrodynamic simulation software. A prototype was produced using the PCB etching method, and its dependencies were measured by R&S vector network analyzer. As a result of miniaturization, the propagation ratio value increased by 0.15 dB and reached the value of -1.05 dB. The working frequency band was reduced by 17%.

6. Acknowledgements

Author are grateful for the simulation software NI-AWR Design Environment provided by the National Instruments Company. The research was executed by the grant of the Ministry of education and science of the Russian Federation (project № 8.2538.2017/4.6). The research was performed on equipment of the Urals Federal University common use center.

7. References

1. S.-S. Liao and J.-T. Peng, "Compact planar microstrip branch-line couplers using the quasi-lumped elements approach with nonsymmetrical and symmetrical T-shaped structure," IEEE Trans. Microw. TheoryTech.,vol. 54, pp. 3508-3514, Sep. 2006.

2. K. W. Eccleston and S. H. M. Ong, "Compact planar microstripline branch-line and rat-race coupler," IEEE Trans. Microw. Theory Tech., vol. 51, pp. 2119-2125, Oct. 2003.

3. S.-S. Liao, P.-T.Sun, N.-C.Chin and J.-T.Peng, "A novel compact-size branch-line coupler," IEEE Microw.WirelessCompon.Lett. vol. 15, pp. 588-590, Sep. 2005.

4. J. Wang, B. Z. Wang, Y.-X.Guo, L.-C.Ong, and S. Xiao "A compact slow-wave microstrip branch-line coupler with high performance," IEEE Microw.WirelessCompon.Lett. vol. 17, pp. 501-503, Jul. 2007.

5. Wei-Shin Chang and Chi-Yang Chang, “A High Slow-Wave Factor Microstrip Structure With Simple Design Formulas and Its Application to Microewave Circuit Design,”IEEE Trans. Microw. Theory Tech., vol. 60, no. 11, pp. 3376-3383, Nov. 2012.

6. H.Ghali, and T. A. Moselhy, "Miniaturized fractal rat-race, branch-line, and coupler-line hybrids," IEEE Trans. Microw. Theory Tech., vol. 52, pp. 2513-2520, Nov. 2004.

7. C. W. Tang and M.-G.Chen, "Synthesizing microstrip branch-line coupler with predetermined compact size and bandwidth," IEEE Trans. Microw. Theory Tech., vol. 55, pp. 1926-1934, Sep. 2007.

8. Kimberley W. Eccleston, and Sebastian H.M. Ong, “Compact Planar Microstripline Branch-Line and Rat-Race Couplers,” IEEE Trans. Microw. Theory Tech., vol. 51, no. 10, pp. 2119-2125, Oct. 2003.

9. Kai-Yu Tsai, Hao-Shun Yang, Jau-Horng Chen, and Yi-Jan Emery Chen, “A miniaturized 2 dB Branch-Line Hybrid Coupler With Harmonics Suppression,” IEEE Microw. Wireless Compon.Lett., vol. 21, no. 10, pp. 537-539, Oct. 2011.

10. J. Zhu, Y. Zhou*, and J. Liu, “Miniaturization Of Broadband 3-Db Branch-Line Coupler,” Progress In Electromagnetics Research Letters, vol. 24 pp. 169-176, 2011.

11. Ashmi Chakraborty Das, Lakhindar Murmu, Santau Dwari, “A Compact Branch-Line Coupler Using Folded Microstrip Lines,” IEEE Microw. Wireless Compon. Lett., vol. 10, no. 7, pp. 1-3, Dec. 2013.

12. Chao-Wei Wang, Tzyh-Ghuang Ma, Chang-Fa Yang, “A new planar artificeal transmisiion line and its applications to a miniaturized butler matrix,” IEEE Trans. Microw. Theory Tech., vol. 55, no 12, pp. 2792-2801, Dec. 2007.

13. Kae-Oh Sun, Sung-Jin Ho, Chin-Chuan Yen, and Daniel van der Weide, “A Compact Branch-Line Coupler Using Discontinous Microstrip Lines,” IEEE Microw. Wireless Compon. Lett., vol. 15, no. 8, pp. 519-520, Aug. 2005.

14. H. Zhang and K.J. Chen, “A stub tapped branch-line coupler for dual-band operations,” IEEE Microw. Wireless Compon. Lett., vol. 17, no. 2, pp. 107-108, Feb. 2007.

15. Letavin, D.A., Mitelman, Y.E., Chechetkin, V.A., “Compact microstrip branch-line coupler with unequal power division”, 2016 24th Telecommunications Forum (TELFOR), 2016, TELFOR 2016, DOI: 10.1109/TELFOR.2016.7818850

16. Letavin, D.A., Mitelman, Y.E., Chechetkin, V.A., “Compact microstrip branch-line coupler with unequal power division”, 2017 11th European Conference on Antennas and Propagation, EuCAP 2017, DOI: 10.23919/EuCAP.2017.7928144

17. Letavin, D.A., Mitelman, Y.E., Chechetkin, V.A., “The branch-line couplers miniaturization method with microstrip filters”, 2017 International Applied Computational Electromagnetics Society Symposium - Italy (ACES), ACES 2017, DOI: 10.23919/ROPACES.2017.7916035