Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

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To cite this article: Denis A. Letavin 2019 *J. Phys.: Conf. Ser.* **1391** 012109

Journal of Physics: Conference Series **1391** (2019) 012109 doi:10.1088/1742-6596/1391/1/012109

Reduced directional coupler through the use of artificial cells

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Abstract. This paper presents the topology of the directional coupler that carries out the power division of 1 to 3. The area of the proposed device was reduced by 72.5% due to the use of artificial cells, whose characteristics are equivalent to quarter-wave segments, with smaller dimensions. Using the NI-AWR Environment 14 program, the topology of the proposed device was developed, with an operating frequency of 1 GHz and on the FR-4 material. Then, using a photolithography, a prototype of the coupler was made and its characteristics were measured using a R&S vector network analyser.

1. Introduction
One of the most well-known designs of directional couplers consists of four microstrip segments with an electrical length of 90 degrees. Depending on the wave impedances of these lines, it is possible to realize the most diverse division factors of input power. A coupler is a fully symmetric reciprocal four-arm device (eight-port), which makes the directed selection of a certain part of the high-frequency signal from one (main) to another (additional) channel. With perfect matching, one of the shoulders of the additional channel is untied, and the power does not enter it. The input power is distributed in the other two (working) arms of the directional coupler in accordance with the selected power dividing ratio between the channels, and the voltages in the working arms have a phase shift equal to 90°. The disadvantages of this design include parasitic harmonics at multiple frequencies, also large dimensions at low frequencies (for example, at 1 GHz). Therefore, in order to eliminate these disadvantages, artificial transmission lines (ATLs) are introduced into the topology of the directional coupler, which perform the functions of quarter-wave segments, and the length and width of the ATLs is chosen from the condition of optimal matching. Currently, the literature describes a large variety of different design solutions aimed at miniaturization of directional couplers [1] - [10]. It is also worth noting that as a result of the miniaturization of the coupler, it is not possible to keep its characteristics unchanged, as there is a reduction in the working band and an increase in losses in the passband. This paper proposes the topology of the coupler, whose dimensions were reduced using microstrip cells.

2. Method
The aim of the work is to ensure the minimum dimensions of the coupler while maintaining the frequency characteristics of the device without global changes. Figure 1 shows the topology of a directional coupler with a dividing input power of 1 to 3, obtained using the AWR Design Environment. The traditional coupler operates at a center frequency of 1 GHz, and is designed for a FR4 substrate with a dielectric constant of 4.4 and a thickness of 1 mm. The dependence of S-parameters on the frequency for such a coupler is shown in graphs 2 and 3. Wave resistance for a coupler with such a division of the input power was carried out using the following formulas [11]:

$$Z_1 = Z_{in} k, \quad Z_2 = Z_{in} \frac{k}{\sqrt{1-k^2}}, \tag{1}$$

where Z_{in} – input impedance of all ports, k - power ratio between the outputs.

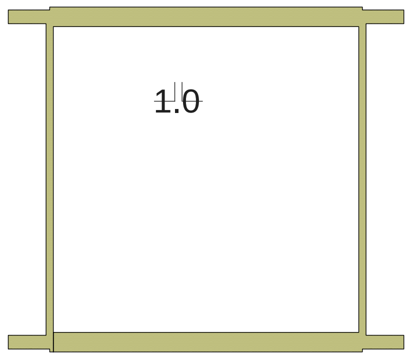

Figure 1. Standard implementation of directional coupler

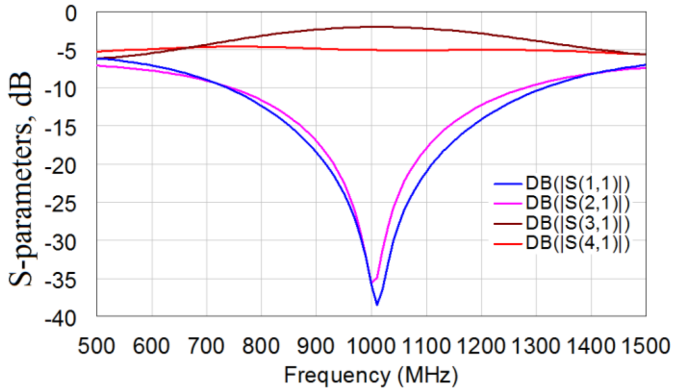

Figure 2. Graph of S-Parameters versus Frequency

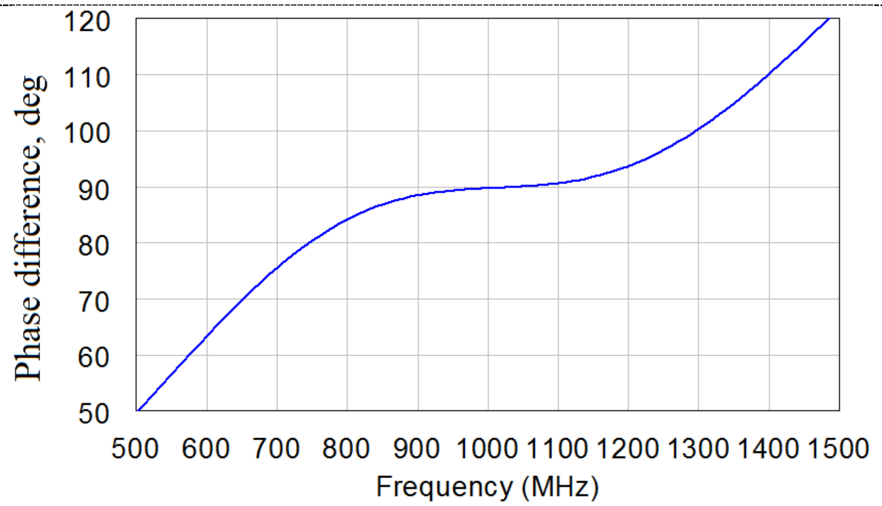

Figure 3. The graph of the phase difference between the transfer coefficients of the responder

The area of the device is 1939.2 mm^2. The band of operating frequencies estimated by the decoupling level “minus” 20 dB is 147 MHz (14.7%). Transmission factors S41 and S31 are -2 and -5 dB at the center frequency. In this case, the phase difference between the transfer coefficients is 90 degrees. The next step after the implementation of the standard design of the coupler is to simulate microstrip cells for the required characteristics - the minimum transmission coefficient, and a phase shift of 90 degrees at the center frequency of the device. After replacing each segment by the proposed cells, it is necessary to perform forced optimization, aimed at obtaining the optimal characteristics of the device. In the process of miniaturization, the free space inside the coupler is actively used. Figure 4 shows the topology of the compact coupler obtained in AWR. The results of the simulation analysis for this design are shown in Figures 5 and 6.

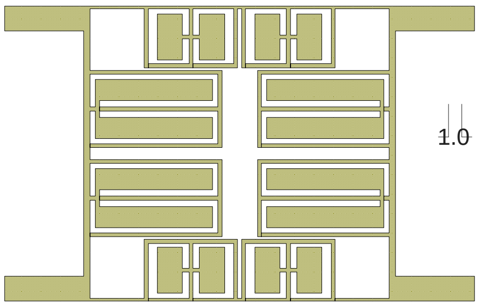

Figure 4. Microstrip Cell Compact Coupler Topology

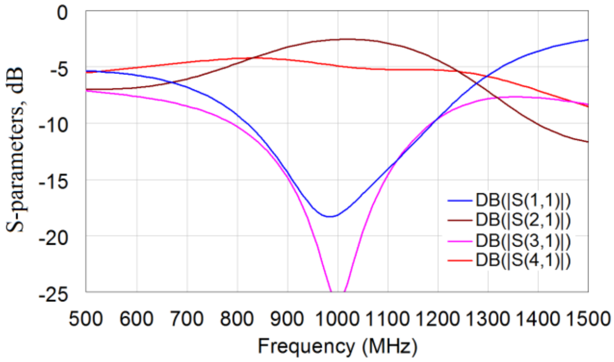

Figure 5. Graph of S-Parameters versus Frequency

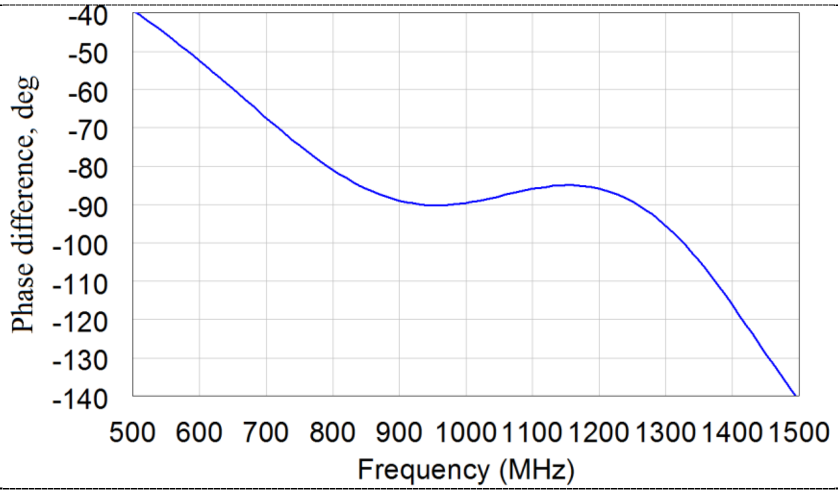

Figure 6. The graph of the phase difference between the transfer coefficients of the responder

The area of the device is 533.25 mm^2 (which is 72.5% less compared to the standard design). The band of operating frequencies estimated by the decoupling level “minus” 20 dB is 95 MHz (9.5%). Transmission factors S21 and S41 are -2.5 and -4.9 dB at the center frequency. In this case, the phase difference between the transfer coefficients is equal to 89.5 degrees. It can be seen that the frequency band decreased by 5.2% and the change in imbalance between transmission coefficients. The narrowing of the frequency band, due to the fact that the phase-frequency characteristics for the microstrip cell and the quarter-wave segment coincide at a certain frequency. Then the cells have large losses in the band, which increase as they pass through each cell. It is also important to take into account the mutual influence of neighboring elements from different microstrip cells. In order to evaluate the results of modeling in practice, a prototype of a compact coupler was manufactured. Figure 8 shows a photograph of the prototype before installing the microwave connectors. Using a vector network analyzer R&S ZVA24 experimental graphs were obtained, which are shown in Figures 9, 10.

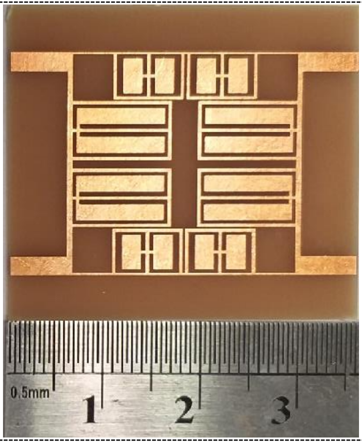

Figure 7. Microstrip Cell Compact Coupler Topology

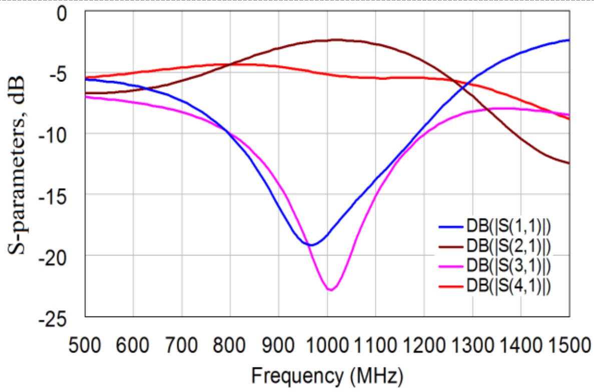

Figure 8. Graph of S-Parameters versus Frequency

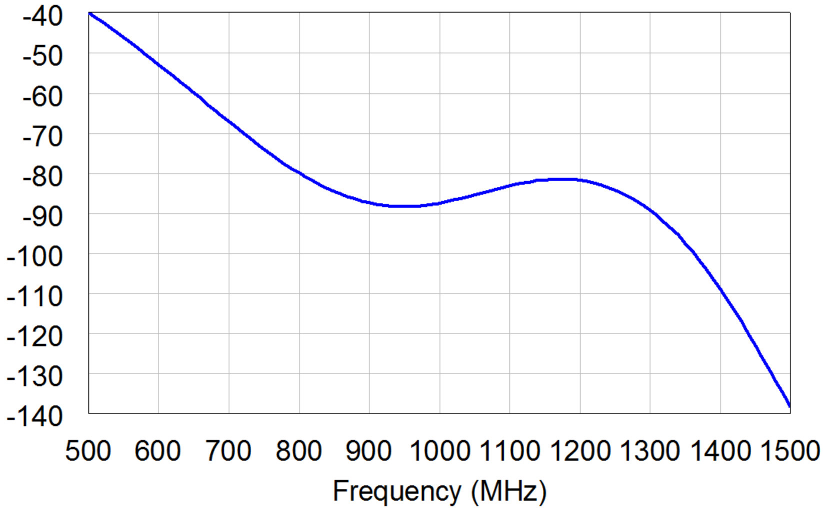

Figure 9. The graph of the phase difference between the transfer coefficients of the responder

According to the obtained results, it is clear that the operating frequency band, estimated by the level of isolation "minus" 20 dB, is 80 MHz (8%). Transmission factors S21 and S41 are -2.4 and -5.2 dB at the center frequency. In this case, the phase difference between the transfer coefficients is 87.6 degrees. It can be seen that the frequency band decreased by 6.7%. The difference between experimental and theoretical characteristics may be due to the following reasons - these are insignificant differences in dielectric permittivity (since a cheap material was chosen, its dielectric permittivity may vary within small limits), manufacturing tolerances (inaccuracy in the implementation of structural elements of a standard design does not contribute significantly changes, in contrast, when it comes to compact structures that have high resistance segments, or small gaps, when moving away from tannogo values may vary substantially the characteristics of the device).

3. Conclusion

The paper presents the design of a compact coupler with a division of the input power of 1 to 3 on the FR4 substrate. The coupler operates at 1 GHz center frequency and has a bandwidth of 6.7%. The device area was reduced from 1939.2 mm^2 to 533.25 mm^2 (miniaturization of the area of a standard coupler by 72.5%). Miniaturization was carried out through the effective use of microstrip cells with equivalent characteristics of microstrip segments with an electrical length of 90 degrees. A prototype was also made, whose characteristics were measured using a R&S vector network analyzer.

4. 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.

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