Directional coupler on compact structures

L Q Hung
Vietnam Maritime University, Hai Phong, 180000, Vietnam
E-mail: hung.luuquang@vimaru.edu.vn

Abstract. This article describes a miniature directional coupler design with two connected loops and a central operating frequency of 2 GHz. The dimensions of such a coupler have been reduced with the help of compact structures, which, in turn, reduces the cost of material. Thus, the splitter with a central frequency of 2 GHz takes only 341 mm², which is 45% less than the traditional design at the same frequency.

1. Introduction
Planar couplers are widely used due to their useful properties, which are used in the implementation of radio devices. The directional coupler divides the input power equally between its output with a phase difference of 90 degrees. This makes it possible to use them in the implementation of phase shifters and antenna arrays. As with many microwave devices, their dimensions are associated with the operating frequency: with its increase, the size decreases, and vice versa, with a decrease in the frequency, the size increases. Such a dependence of the dimensions on frequency has led to a new direction in the art of miniaturization.

A standard coupler provides a uniform power distribution between the two outputs and consists of identical 35 Ohm and 50 Ohm segments in pairs. Some of the ways to reduce square ties are considered. For example, in [1] it is proposed to reduce the size using quasiconcentric elements, in [2] is equivalent to the transmission lines, in [3] U-shaped containers, in [4] periodic capacitive loading, asymmetrical T-shaped structure [5], the low-pass filters in [6–8], system slowing down [9, 10], artificial transmission lines in [11-13], fractal structures in [14, 15], in [16] the high-resistance elements, [17] – loaded hinges and other [18-20]. In this paper, we consider a size reduction approach that allows reducing the area of the coupler by means of synthesized compact structures.

2. Design
It is known that the standard coupler with two connected loops divides the power in equal proportions and consists of two segments at 35 Ohms and two segments at 50 Ohms. The length of such segments corresponds to a quarter of the wavelength at the central frequency. As a substrate material, cheap material FP4 with dielectric constant of 4.4 and thickness of 1 mm was chosen. This material was developed by Central standard connection 2 GHz. The area of such a device was equal to 622 mm². Figure 1 shows the topology of this connector. Figure 2 shows the dependence of the parameters S on the frequency, and Figure 3 shows a phase versus frequency graph.
The operating frequency range of such a device is 225 MHz or 11.25%. The phase difference between the outputs is 90 degrees. This design has the disadvantage of large sizes, which are not always suitable. Therefore, compact structures with similar characteristics with traditional segments were proposed and synthesized.

3. Materials and methods
A comparison graph of the phase characteristics of structures and segments is shown in Figure 5. In figure 4, one can compare the size of the segments. The compact structure, designed for 50 Ohms and with a central frequency of 2000 MHz, has dimensions of 4.3 x 14 mm. At the same time, the quarter-wave segment for the same conditions has dimensions of 1.9 x 20.8 mm. We can see that the structure has the same phase shift at the central frequency as the segment, but has a shorter length. This makes it possible to effectively use them in the design of the branch and get a significant reduction in its size with a slight deterioration in performance. Figure 6 shows the frequency response of one compact structure.
Figure 4. Topology of a quarter-wave segment and a compact structure with an impedance of 35 Ohm

Figure 5. Phase on frequency

Figure 6. Frequency characteristics of a compact structure

Figure 7 shows the topology of a compact coupler on such structures. The area of this design is 341 mm². This is only 7.8% of the area of the standard coupler. The frequency characteristics of the coupler obtained in the program are shown in Figure 8, and the phase response is presented in Figure 9.

Figure 7. Compact coupler topology

Figure 8. S-parameters from frequency
Figure 9. Phase on frequency

The phase difference at the outputs of the device is 89 degrees. These designs can be used in other designs on the elements. Through the use of these structures, there was a narrowing of the frequency band and a reduction in transmission coefficients.

4. Results

To verify the calculations, a prototype of a compact device was made which is shown in figure 10, and its measured characteristics are shown in figure 11. A comparison of the characteristics of the compact and standard design is presented in table 1.

Figure 10. Photo of a directional coupler

Figure 11. S-parameters from frequency

| Table 1. Comparison of couplers |
|----------------------------------|
| Design             | Area, mm² | Reduce size, % | Bandwidth based on 20 dB isolation level, MHz |
|--------------------|-----------|----------------|-----------------------------------------------|
| Standard coupler   | 622       | -              | 225                                           |
| Compact coupler    | 341       | 45.2           | 158                                           |

Improving the efficiency of miniaturization is possible due to the modification of compact structures and their location in the coupler area. However, this may lead to a further deterioration in the performance of the device.

5. Conclusion

In this paper, a compact directional coupler has been developed, the dimensions of which are reduced using compact structures. These structures have a smaller length, due to which the area of the structure has smaller dimensions. Due to the fact that the characteristics of structures and segments coincide at
the center frequency, a workable structure is obtained. The area of such a coupler at the center frequency of 2000 MHz is 341 mm$^2$, which is 45.2% less than the area of the coupler on standard quarter-wave segments. Reducing the operating frequency band by only 4%. This approach can be used for other designs.

References
[1] Liao S S and Peng J T 2006 IEEE Trans. Microw. TheoryTech. 54 3508-3514
[2] Letavin D A 2018 AEU-Int. J. of Electronics and Communications 99 8-13
[3] Letavin D A 2018 Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices EDM 2018 pp 195-198
[4] Eccleston K W and Ong S H M 2003 IEEE Trans. Microw. TheoryTech. 51 2119-2125
[5] Liao S S, Chin N C and Peng J T 2005 IEEE Microw. Wireless Compon. Lett. 15 588-590
[6] Letavin D A 2018 Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices EDM 2018 pp 192-194
[7] Letavin D A 2017 Int. Applied Computational Electromagnetics Society Symp. ACES 2017 pp 63-64
[8] Letavin D A 2017 Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices EDM 2017 pp 99-101
[9] Wang J, Wang B Z, Guo Y X, Ong L C and Xiao S 2007 IEEE Microw. Wireless Compon. Lett. 17 501-503
[10] Chang W S and Chang C Y 2012 IEEE Trans. Microw. TheoryTech. 60 3376-3383
[11] Letavin D A 2018 Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices EDM 2018 pp 185-188
[12] Letavin D A 2018 J. of Communications Technology and Electronics 63 933-935
[13] Ghali H and Moselhy T A 2004 IEEE Trans. Microw. TheoryTech. 52 2513-2520
[14] Zhu J, Zhou Y and Liu J 2011 Progress In Electromagnetics Research Letters 24 169-176
[15] Letavin D A 2018 IEEE Radio and Antenna Days of the Indian Ocean RADIO 2018 pp 192-194
[16] Tang C W and Chen M G 2007 IEEE Trans. Microw. TheoryTech. 55 1926-1934
[17] Eccleston K W and Ong S H 2003 IEEE Trans. Microw. TheoryTech. 51 2119-2125
[18] Tsai K Y, Yang H S, Chen J H and Cheng Y J 2011 IEEE Microw. Wireless Compon. Lett 21 537-539
[19] Das A C, Murmu L and Dwari S 2013 Int. Conf. on Microwave and Photonics ICMAP 2013 pp 176-179
[20] Sun K O, Ho S J, Yen C C and Weide D V 2005 IEEE Microwave and wireless components letters 15 519-520