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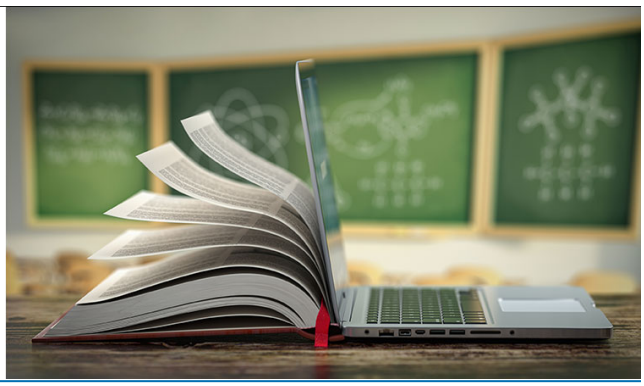

Design of miniature directional coupler with wide bandwidth

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Abstract. Miniature directional coupler with wide bandwidth consisting of compact structures and curved lines has been developed. The type of structures was chosen in such a way as to achieve the greatest possible coincidence of their characteristics in the bandwidth with the characteristics of quarter-wave sections. The area of the developed coupler is 69.8% less than the area of the same device in its standard version. Device modeling was performed in the Cadence AWR program. It is shown that miniaturization of the directional coupler caused deterioration of such characteristics as operating frequencies band, preservation of the phase differences between the outputs in a wide frequencies band, and attenuation in the band. A model of the coupler was made, which allowed us to confirm experimentally the correctness of calculations in AWR.

1. Introduction

The directional couplers used in practice have different characteristics, for example, different power ratios between outputs, different bandwidths and signals phases at the output of the device. The specific implementation of the coupler is calculated according to the required task. However, the most popular among the couplers are quadrature couplers and broadside-antiphase couplers. Quadrature directional couplers with wide bandwidth in standard and compact performance will be reviewed in our work. Getting a wide band is achieved by adding several quarter-wave loops connected at a distance of a quarter of a wavelength from each other. This addition of loops increasing the band of the device, affects its overall size and increasing longitudinal dimensions. When working at low frequencies, this affects the most. With the decrease of operating frequency length of quarter-wave sections is increases, and the area of the coupler is increases with it. For some applications the size requirements are critical and it is necessary to find a way to fix this problem. Over the past 20 years various implementation options for miniature directional couplers have been proposed [1] – [19]. However, not every design has a serious reduction in size and preservation of characteristics. In our work we used modern software CADENCE AWR, we modeled and then manufactured a miniature directional coupler, which area was reduced by replacing quarter-wave sections with compact structures.

2. The main part

Directional couplers are usually implemented as distributed structures (sections of transfer lines). The main characteristic of couplers is the division of input power between outputs in the necessary ratios. Cadence AWR DE 14 was chosen for the design of couplers. It is a full-fledged platform for the development and modeling microwave devices.

A coupler implemented on two identical quarter-wave sections in pairs is shown in figure 1. The substrate material is FR4 $\varepsilon = 0.4$ and thickness is 1 mm. Frequency characteristics, obtained by analyzing the standard coupler are shown in figure 2 and figure 3. At a central frequency of 1.8 GHz

traditional coupler occupies 2760 mm^2 on a microwave substrate. Inside the coupler there is a massive area formed by closed quarter-wave sections.

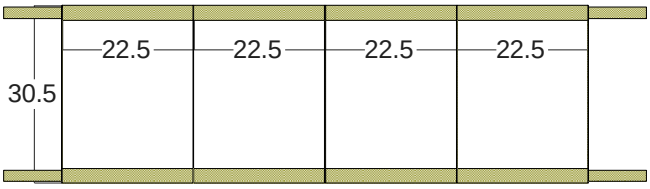

Figure 1. Layout of a standard coupler

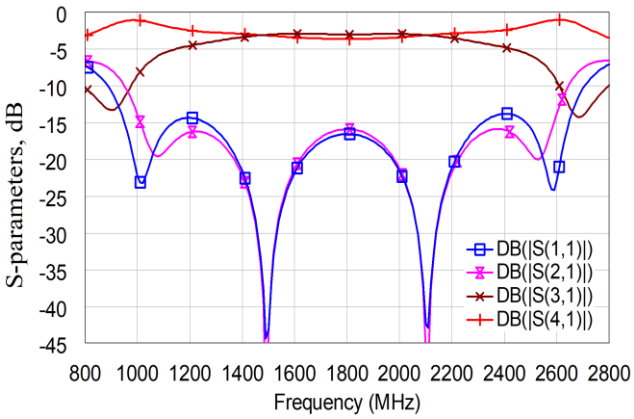

Figure 2. Graph of S-parameters from the frequency of the standard coupler.

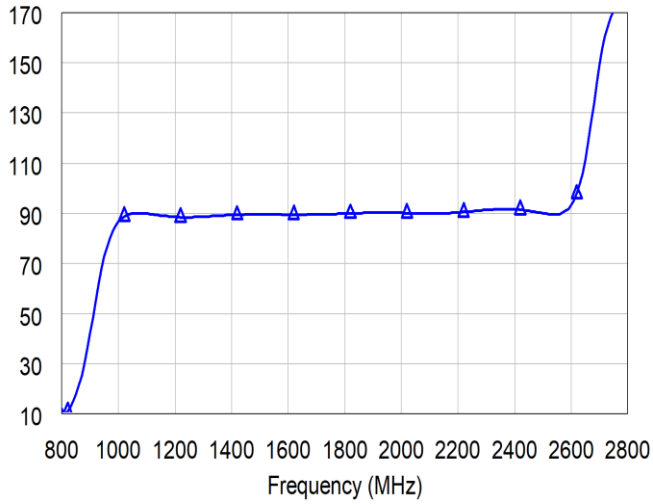

Figure 3. Graph of the phase difference between the outputs of the coupler.

It can be seen, that standard coupler operates in the frequency band 1000-2600 MHz (estimated at -15 dB) in the same band the phase difference between the outputs will remain and is equal to 90 degrees. The next step was to miniaturize the coupler using compact structures. When synthesizing compact structures, it is important that they have as much similar characteristics as possible in the bandwidth with quarter-wave sections. This will allow the installation of such structures without significant losses in the functioning of the coupler. To increase the efficiency, all structure elements should be placed in the inner space of the coupler. Topology of the coupler with curved lines and installed compact structures is shown in figure 4. The area of this coupler on the same substrate and operating frequency

as a standard model is equal to 833 mm^2 (69.8% less than standard). The graphs obtained during the numerical analysis of the device are shown in figure 5 and figure 6.

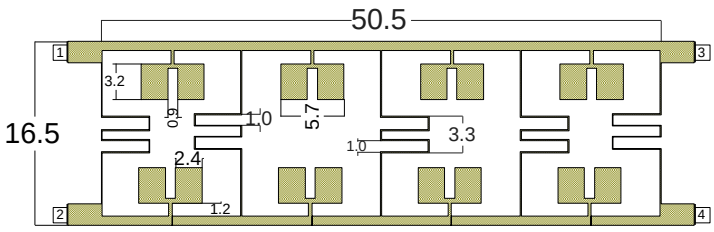

Figure 4. Layout of the compact broadband coupler.

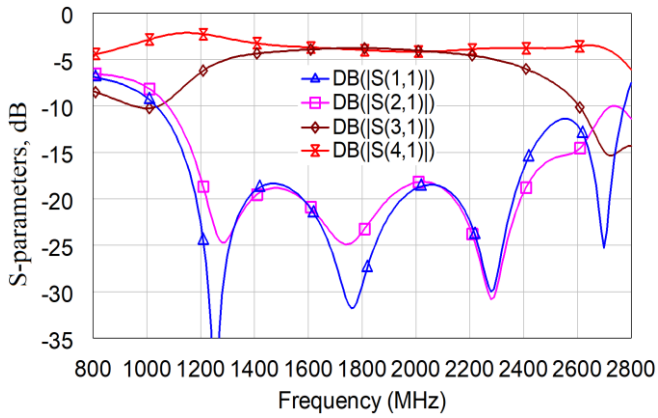

Figure 5. Graph of S-parameters from the frequency of the compact coupler.

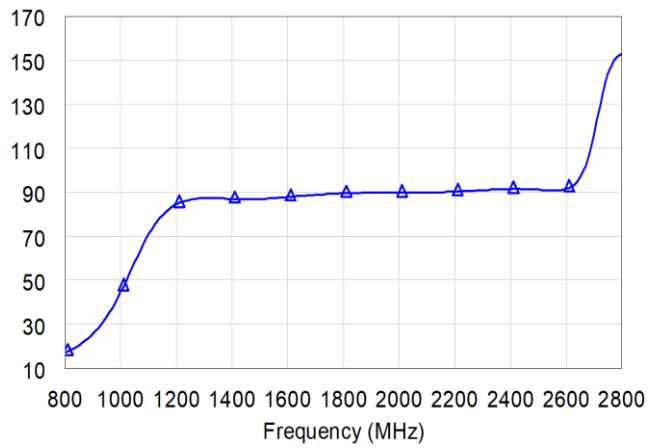

Figure 6. Graph of the phase difference between the outputs of the compact coupler.

It can be seen that the compact coupler is operating in frequency band 1200-2600 MHz, the narrowing of the band is caused by a discrepancy in the phase-frequency characteristics of conventional sections and compact structures. The 90-degree phase difference between outputs is maintained in the frequency band 1200-2600 MHz. Miniaturization also affected the amount of attenuation in the band, it increased by 0.3 dB, and the imbalance between the transfer coefficients has also increased. Using photolithography, a prototype of a miniature coupler was made (figure 7). The field experiment was conducted using high-precision equipment from Rode&Shwarz. Experimental characteristics are shown in figure 8 and figure 9.

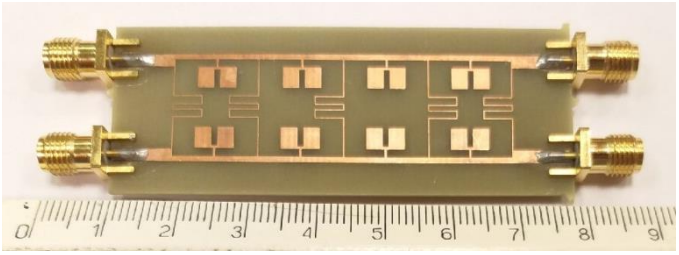

Figure 7. The model of the compact broadband coupler.

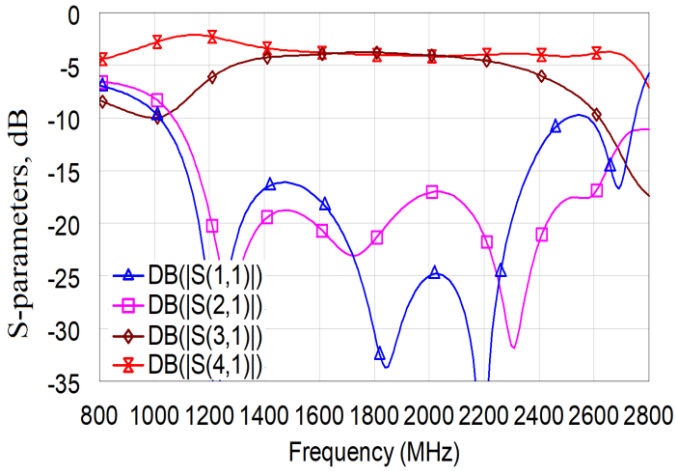

Figure 8. Graph of S-parameters from frequency for the layout.

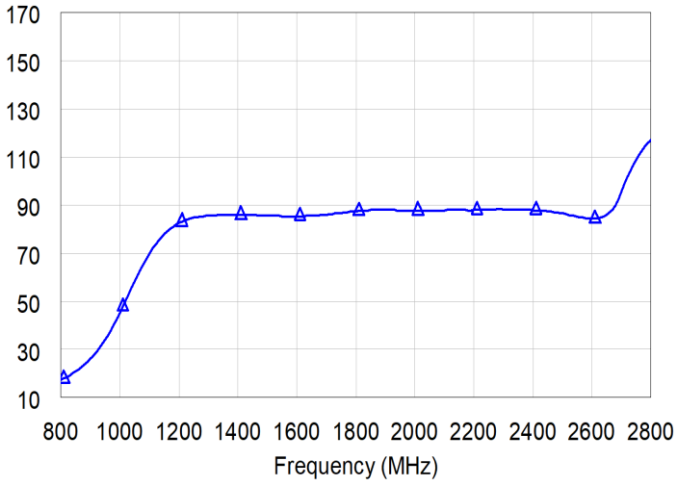

Figure 9. Graph of the phase difference between the outputs of the layout.

It can be seen that the model is operating in frequency band 1200-2400 MHz. These characteristics are in agreement with the simulation results. Theoretical and experimental results for standard and compact couplers are presented in table 1. Discrepancies in theoretical and experimental characteristics can be explained by inaccuracy of reproduction of the elements that make up the device.

Table 1. Comparison of the numerical and measured results

Parameters	**Standard**	**Compact**
Bandwidth, MHz	1600	1200
Area, mm^2	88.9	66.67
Relative Area, %	2760	833
Central Frequency, MHz	100	30.2
The Phase Outputs	90	89.9

3. Conclusion

The use of compact structures instead of standard sections demonstrates the principal possibility of miniaturization of couplers with good preservation of its characteristics. All devices were modeled in the AWR software. Based on the simulation results, a coupler was manufactured, assembled on a FR4 substrate. It operates at a frequency of 1 GHz and has an area that 69.8% less than a standard device's area. In addition, field experiment was performed. It showed high convergence of calculated and measured characteristics. Developed coupler can be used in different microwave devices, where it is needed to divide the microwave power.

ACKNOWLEDGMENTS

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