An embodiment of a compact circular directional coupler for maritime communications equipment

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Abstract. The article is devoted to the design and configuration of a circular directional coupler with a small size for maritime communications equipment. In the course of the work, the model of the device and its characteristics were analyzed. It has been determined that a compact device has a significantly smaller area while having comparable characteristics. The process of miniaturization itself consisted in replacing traditional quarter-wave segments with their analogies implemented on a printed circuit board in the form of inductive and capacitive elements.

1. Introduction
A coupler in the maritime industry is a device designed to divide and add power. Since its inception, the coupler has found many different uses in microwave technology. The principle of operation of such a device is based on the passage of a signal through a set of quarter-wave segments, and at the outputs it is either summed up or destroyed. The taps can be designed to separate a signal with a phase difference of 90 degrees, or with a selectable phase difference depending on the input of 0 and 180 degrees. Such devices have different implementation on a substrate, differing in the number of quarter-wave sections used in the design, as well as in wave impedances.

At low frequencies, the performance of the device is no different from that of the device at high frequencies. However, the main difference between devices operating at different frequencies is their size. At low frequencies, the coupler can take up too much space, which limits its use for some applications. From the formula that determines the wavelength in the line, it can be seen that with decreasing frequency, the value of the wavelength will increase, and then the dimensions of the coupler. This shows the relevance of research aimed at obtaining structures with compact dimensions and characteristics at the level of standard devices. In order to compare the results obtained in the work, with the known results on miniaturization of similar devices, table 1 is compiled, reflecting the results of other authors on miniaturization of couplers. A number of papers [1] - [21] were considered. Each approach described in the work has its own advantages and disadvantages. This article discusses the development of a compact circular directional coupler, which can be used in power supply circuits of antenna arrays in a small volume. This is due to the fact that at low frequencies in some cases it is preferable to use devices with compact dimensions and good manufacturability. Also, the proposed compact coupler has comparable efficiency with the considered methods in databases.
Table 1. Miniaturization methods efficiency.

| Miniaturization methods                                      | Reduce size, % | Center frequency, GHz |
|-------------------------------------------------------------|----------------|-----------------------|
| Conventional microstrip line                               | 100            | -                     |
| [1] Bending line                                            | 56             | 3.25                  |
| [5] Symmetric Equivalent Circuits                           | 50             | 1                     |
| [6] Two-layer substrate with rectangular slots in the ground plane | 38             | 2.45                  |
| [9] Source-load coupling                                    | 30             | 2.4                   |
| [11] Artificial line segments                               | 25             | 0.9                   |
| [12] Asymmetric $\pi$-structures                            | 24             | 0.9                   |
| [13] High impedance lines and loops                        | 19             | 0.9                   |
| [15] Artificial transmission line                           | 10             | 1                     |
| [16] Periodically capacitive load                           | 49             | 1.8                   |
| [17] Asymmetrical T-shape structures                        | 45             | 2.4                   |
| [13] Equivalent Structures                                  | 31             | 1.8                   |
| [12] Electrodynamic structures                              | 30             | 1.8                   |
| [2] Compact Structure                                       | 30.1           | 1                     |
| [3] Artificial transmission line                            | 28.1           | 1                     |
| [18] Quasi-lumped elements                                  | 27.5           | 0.9                   |
| [4] Artificial transmission line                            | 27.5           | 1                     |
| [21] Fractal technique                                      | 24.7           | 2.4                   |
| [10] Compact Structure                                      | 24.7           | 1                     |
| [7] Artificial transmission line                            | 21.2           | 0.9                   |

2. Design
The division of microwave power can be considered on the example of a ring directional coupler, in which, with input lines with a resistance of 50 Ohm, the segments of the coupler itself have a resistance of 70 Ohm. This ensures that the input power is divided equally between its outputs. Using programs for modeling and calculating such devices, a coupler with an operating frequency of 1 GHz and a FR4 substrate was assembled. The topology of such a device is shown in figure 1.

![Standard Broadband Coupler Topology](image1)

Figure 1. Standard Broadband Coupler Topology.

![Divider S-parameter plot](image2)

Figure 2. Divider S-parameter plot.
The transmission of microwave power from the input of the device to its outputs is carried out via microstrip lines, and depending on the selected port, the signals will have a phase difference of 0 or 180 degrees. The area of the device with such initial data is 3956 mm$^2$. The characteristics of the device are shown in figures 2 and 3.

3. Materials and methods
The presented results of the electrodynamic analysis of the device make it possible to judge that the coupler operates in the frequency band of 818 - 1138 MHz, and the transmission coefficients are 3.45 dB. FR4 will serve as the substrate material for all devices.

When implementing a compact version of the coupler, it is necessary to provide characteristics similar to the described characteristics of a conventional design. Artificial transmission lines can reduce the area of the device without significant changes in performance. For a ring coupler, it is necessary to calculate artificial lines with a characteristic impedance of 70 ohms. In general, artificial lines consist of inductors and capacitors. To compare the dimensions of the proposed lines instead of quarter-wave segments, figure 4 is shown. The characteristics of such lines are shown in figures 5 and 6.

Figure 3. Divider phase difference graph.

Figure 4. Comparison of the dimensions of conventional sections and artificial transmission lines.

Figure 5. S-parameter versus frequency plot for conventional and artificial transmission lines.
4. Results

The free space inside the coupler allows you to use it for miniaturization and place elements of artificial lines there. In terms of performance, it can be seen that artificial and conventional lines differ over a wide range, and this can affect the performance of a compact device. Therefore, a promising direction is the creation of such artificial lines that would coincide in a wider band with the characteristics of traditional segments. Figure 7 shows the topology of a compact coupler with an area of 890 mm². The characteristics obtained as a result of the calculation are shown in figures 8 and 9.

Figure 6. Phase incursion of conventional segments and artificial transmission lines.

Figure 7. Compact divider.

Figure 8. S-parameter versus frequency for a compact coupler obtained in AWR.

Figure 9. Phase difference between gear ratios at the bridge output.
The presented results of the electrodynamic analysis of the device make it possible to judge that the coupler operates in the frequency band 850 - 1151 MHz, and the transmission coefficients are 4.1 dB. As mentioned earlier, the differences in characteristics are associated with differences in the characteristics of conventional and artificial lines. For a complete comparison of the results of miniaturization, the information is summarized in Table 2.

Table 2. Comparative data of tappers.

| Parameters                | Area, mm² | Reduce size, % |
|---------------------------|-----------|----------------|
| bandwidth, MHz            | 320       | 301            |
| area, mm²                 | 3956      | 890            |
| Relative area, %          | 100       | 22.5           |
| Central frequency, MHz    | 1000      | 1000           |
| The phase outputs, °      | 0, 180    | 89             |

5. Conclusion
During the work, a circular directional coupler for marine applications was modeled, which at an operating frequency of 1 GHz has an area of 890 mm². This value is 77.5% less than the area of a conventional device with an area of 3956 mm². It was also found that the compact coupler operates in the 301 MHz band, which is 2% less than the traditional implementation of such a device. The use of artificial lines made it possible to obtain a device whose dimensions are small, and the characteristics did not deteriorate much compared to the traditional model.

References
[1] Letavin D A Journal of Communications Technology and Electronics 63 933-5
[2] Ashmi C D and Murmu L 2013 International Conference on Microwave and Photonics (ICMAP 2013) 1–3
[3] Letavin D A 2018 AEU-Int. J. of Electronics and Communications 99 8-13
[4] Letavin D A 2019 8th International Conference on Mathematical Modeling in Physical Science (IC-MSQUARE 2019) 1-5
[5] Ahn H R and Nam S IEEE Transactions on Microwave Theory and Techniques 63 1067-78
[6] Ausordin S F, Rahim S K A, Seman N and Dewan R A 2013 IEEE Business Engineering and Industrial Applications Colloquium (BEIAC 2013) 156-60
[7] Letavin D A 2019 International Multi-Conference on Engineering, Computer and Information Sciences (SIBIRCON 2019) 43-6
[8] Letavin D A 2019 IEEE East-West Design and Test Symposium (EWDTS 2019) 1-3
[9] Lin T W, Wu J Y and Kuo J T 2016 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM 2016) 1-3
[10] Letavin D A 2019 IEEE East-West Design and Test Symposium (EWDTS 2019) 13-6
[11] Ostankov A V Moscow: Scientific Technologies. Series "Natural and Technical Sciences", № 1. -2016
[12] Letavin D A 2019 Radiation and Scattering of Electromagnetic Waves (RSEMW 2019) 168-70
[13] Letavin D A 19th International Multidisciplinary Scientific Geoconference (SGEM 2019) 85-91
[14] Phani K and Barik K V AEU - International Journal of Electronics and Communications 70 738-42
[15] Letavin D A 19th International Multidisciplinary Scientific Geoconference (SGEM 2019) 435-42
[16] Qiuyi W, Yimin Y, Ying W, Xiaowei S and Ming Y 2016 IEEE MTT-S International Microwave Symposium (IMS 2016) 1-4
[17] Koziel S and Bekasiewicz A 2016 IEEE/ACES International Conference on Wireless Information
Technology and Systems (ICWITS) and Applied Computational Electromagnetics (ACES) 1-2

[18] Eccleston K W and Ong S H M IEEE Trans. Microw. Theory Tech. 51 2119–2125

[19] Letavin D A 19th International Multidisciplinary Scientific Geoconference (SGEM 2019) 409-16

[20] Letavin D A 2018 6th IEEE Radio and Antenna Days of the Indian Ocean (IEEE RADIO 2018) 1-6

[21] Liao S S, Sun P T, Chin N C and Peng J T IEEE Microw. Wireless Compon. Lett. 15 588-90