Comparison of the miniaturization efficiency of the coupler using the bends of quarter-wave segments

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Abstract. This article analyzes the efficiency of micropolice bending line for miniaturization compared to artificial transmission lines. Simple bending of the line allows reducing the area of the coupler only by no more than 50%, this is due to the limited space inside the coupler. While the artificial transmission lines can provide a reduction in the area of more than 60%.

1. Introduction
Nowadays, the directional responders are the basic device in various radio devices, for example, power splitters. The microstrip two-loop coupler consists of four quarter-wave segments, whose geometry is calculated depending on the operating frequency and the parameters of the substrate. With increasing frequency, the length of the segments will decrease, but at low frequencies it is possible to get a coupler that is not always convenient for use in radio engineering systems, because of its large area. Therefore, in the literature you can find a large number of works related to the problem of reducing the size of the couplers. The easiest and fastest way to reduce the area of the coupler is to bend its quarter-wave segments into its internal space. Another method is to replace the four-wave segments with artificial transmission lines, which, due to a set of elements, can significantly reduce the size of the coupler. Consider some of the work associated with reducing the size of the directional coupler [1-17]. For example, in the work [1], the reduction of dimensions using quasi-concentrated elements was proposed, in [2] equivalent transmission lines, in [3] U-shaped capacitances, in [4] periodic capacitive loads, in [5] asymmetric T-shaped structures, in [6-8] low-pass filters, in [9, 10] slow-down systems, in [11, 12] artificial transmission lines, in [13-15] fractal constructions, in [16] high-resistance elements, in [17] loaded loops, in [18] interdigital capacitors, bending lines [19]. Each of the described methods allows reducing the dimensions of the coupler. However, this requires a preliminary calculation of the necessary elements, which complicates the process of designing such devices. In this paper, a miniaturization method based on the bending of a microplane line is considered, and a comparison with a compact coupler based on moderating lines is made.

2. Design
Figure 1 shows the topology of a directional coupler that divides the power equally between its two outputs. As the substrate material, a widely used and cheap FR4 material with a dielectric constant 4.4 was chosen. Then, the design of standard taps at the central frequency of 1.5 GHz with different substrate thicknesses of 1, 1.5 and 2 mm was implemented. This made it possible to analyze how the thickness of
the substrate affects the effectiveness of reducing the size of the coupler. A compact coupler was also designed based on the well-known approach described in [20].

Figure 2 shows the topology of a coupler with a substrate thickness of 1 mm, in which the bends of quarter-wave segments are realized in the form of a meander while preserving their previous length. This made it possible to use the space inside the coupler and reduce its size.

The area of the coupler at the center frequency of 1.5 GHz is 528.36 mm2. The frequency characteristics of the coupler are shown in Figure 3.

**Figure 1.** Topology directional coupler

**Figure 2.** Topology of the directional coupler is 1 mm thickness

**Figure 3.** Frequency characteristics of the tap for 1 mm

### 3. Materials and methods

Based on Figure 3, it is clear that the coupler operates at a central frequency of 1.5 GHz and has a working frequency band (at a decoupling level of 20 dB) of 11.1%. Some characteristics for comparison are summarized in table 1.

**Figure 4.** Topology of the directional coupler is 1.5 mm thickness

**Figure 5.** Frequency characteristics of the tap for 1.5 mm
Figure 4 shows the topology of the coupler with a substrate thickness of 1.5 mm, in which quarter-wave segments are also bent. It should be noted that with an increase in the thickness of the substrate, there was an increase in the width of the microstrip line, because of this, the area of the coupler was reduced by a smaller amount compared to the substrate thickness of 1 mm.

The area of the coupler with a substrate thickness of 1.5 mm is 693.42 mm$^2$. The frequency characteristics of the coupler are shown in Figure 5.

Based on Figure 5, it is clear that the coupler operates at a central frequency of 1.5 GHz and has a working frequency band (at a decoupling level of 20 dB) of 11.1%. Some characteristics for comparison are summarized in table 1.

The area of the coupler with a substrate thickness of 1.5 mm is 693.42 mm$^2$. The frequency characteristics of the coupler are shown in Figure 5.

Based on Figure 5, it is clear that the coupler operates at a central frequency of 1.5 GHz and has a working frequency band (at a decoupling level of 20 dB) of 11.1%. Some characteristics for comparison are summarized in table 1.

Table 1. Comparison of standard coupler

| Substrate thickness, mm | Area, mm$^2$ | Reduce size, % | Bandwidth based on 20 dB isolation level, MHz |
|------------------------|-------------|---------------|---------------------------------------------|
| 1 mm                   | 1017.12     | -             | 169                                         |
| 1 mm (bend)            | 528.36      | 48.05         | 168                                         |
| 1.5 mm                 | 1145.82     | -             | 168                                         |
| 1 mm (bend)            | 693.42      | 39.48         | 168                                         |
| 2 mm                   | 1294.56     | -             | 166                                         |
| 2 mm (bend)            | 890.52      | 31.2          | 167                                         |

Increasing the thickness of the substrate leads to an increase in the width of the microstrip line, which complicates the process of reducing the size. This is due to the fact that the free area inside the coupler decreases, and the overall dimensions of the submerged segments in the inner space of the coupler increase. Then the most efficient design of the coupler with a substrate thickness of 1 mm was compared with a compact coupler on the retarding structures.
4. Results
Figure 8 shows the topology of the compact coupler at a frequency of 1.5 GHz. Quarter-wave segments are replaced by a retarding structure in the form of series-connected inductances and capacitance. Such structures have a smaller length and similar characteristics with interchangeable segments.

![Figure 8. Compact coupler](image)

![Figure 9. Frequency response of a compact coupler](image)

Figure 9 shows the frequency characteristics of a compact coupler at a central frequency of 1.5 GHz with a FR4 substrate, a dielectric constant of 4.4 and a thickness of 1 mm. The construction area is 492.48 mm². The operating frequency band is 7.86%. The imbalance between the transfer coefficients and their magnitude also increased. For comparison, all characteristics are summarized in table 2.

| Substrate thickness, mm | Area, mm² | Reduce size, % | Bandwidth based on 20 dB isolation level, MHz |
|------------------------|-----------|----------------|-----------------------------------------------|
| 1 mm                   | 1017.12   | -              | 169                                           |
| 1 mm (bend)            | 528.36    | 48.05          | 168                                           |
| Compact coupler        | 492.48    | 51.58          | 118                                           |

It is seen that the compact coupler has the greatest efficiency in miniaturization, to reduce the size. However, the coupler on curved segments has comparable performance, but it is worth noting that the compact coupler on decelerating structures can be modified and get a smaller area. For this, it is possible to bend the structures inwards.

If simple and fast miniaturization is required, then undoubtedly it is enough to simply bend the microstrip segments. However, when substantial miniaturization is required, it is necessary to resort to artificial segments that have comparable characteristics with the characteristics of traditional segments.

5. Conclusion
In this paper, a study was conducted on how the thickness of the substrate affects miniaturization with the help of bending lines in the form of a meander. This approach has greater efficiency on thin substrates, since the width of the segments is not large. So, on a FR4 substrate with a thickness of 1 mm, it was possible, due to simple bends, to get the area of the coupler 40% less compared to the standard design. This coupler was also compared with a compact coupler, which is implemented on decelerating structures in the form of a series connection of inductance and capacitance. Miniaturization on bends is limited, unlike miniaturization on artificial lines.

References
[1] Liao S S and Peng J T 2006 *IEEE Trans. Microw. TheoryTech.* 54 3508–14
[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 195–8
[4] Eccleston K W and Ong S H M 2003 *IEEE Trans. Microw. TheoryTech.* **51** 2119–25
[5] Liao S S, Chin N C and Peng J T 2005 *IEEE Microw. Wireless Compon. Lett.* **15** 588–90
[6] Letavin D A 2018 *Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM 2018)* pp 192–4
[7] Letavin D A 2017 *Int. Applied Computational Electromagnetics Society Symposium (ACES 2017)* pp 63–4
[8] Letavin D A 2017 *Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM 2018)* 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** 501–3
[10] Chang W S and Chang C Y 2012 *IEEE Trans. Microw. TheoryTech.* **60** 3376–83
[11] Letavin D A 2018 *J. of Communications Technology and Electronics* **63** 933–5
[12] Ghali H and Moselhy T A 2004 *IEEE Trans. Microw. TheoryTech.* **52** 2513–20
[13] Zhu J, Zhou Y and Liu J 2011 *Progress In Electromagnetics Research Letters* **24** 169–76
[14] Letavin D A 2018 *IEEE Radio and Antenna Days of the Indian Ocean (RADIO 2018)* pp 192–4
[15] Tang C W and Chen M G 2007 *IEEE Trans. Microw. TheoryTech.* **55** 1926–34
[16] Eccleston K W and Ong S H 2003 *IEEE Trans. Microw. TheoryTech.* **51** 2119–25
[17] Tsai K Y, Yang H S, Chen J H and Cheng Y J 2011 *IEEE Microw. Wireless Compon. Lett* **21** 537–9
[18] Das A C, Murmu L and Dwari S 2013 *Int. Conf. on Microwave and Photonics (ICMAP 2013)* pp 176–9
[19] Sun K O, Ho S J, Yen C C and Weide D V 2005 *IEEE Microwave and wireless components letters* **15** 519–20