Small size phase shifter on compact structures

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Abstract. This article is devoted to the description of a miniature phase shifter of the reflective type. Its dimensions were reduced with the help of compact structures – they were replaced by structures, both quarter-wave segments and plug-in plumes allowing changing the phase at the output. Phase shifters are used in phased array antennas to change the phase on the emitters and thus change the amplitude-phase distribution, which leads to a change in the radiation pattern. For a large number of emitters, a large number of phase shifters are required, which is why at low frequencies they can occupy a sufficiently large area. For this reason, it is possible to use compact structures that have identical characteristics with transmission lines in a certain frequency band. Such replacement allows saving the occupied area of the power supply circuit of the antenna array (material saving), but at the same time reduces the permissible power. The design of a phase shifter with a Central frequency of 2 GHz, whose area was reduced by 63% in relation to the typical implementation of the design, was investigated.

1. Introduction
Phase shifters are designed for smooth or discrete phase change of the electromagnetic wave. Phase shifters are widely used in a variety of devices of microwave technology: radios, measuring devices, antenna systems, antenna arrays for the formation of the desired radiation pattern, directional couplers with adjustable coupling, matching devices, etc. The main requirements for phase shifters are: adjustable phase change of the electromagnetic wave (usually from 0 to 180°); a small amount of input attenuation; for phase shifters operating at high power levels, sufficient electrical strength. The reflecting type phase shifter is actually a two-pole, with the help of which it is possible to adjust the phase of the reflection coefficient, while its module is close to one. The ideal reflecting phase shifter is variable reactance, which can be implemented as a short-circuited or open loop of variable length. With additional elements, the phase shifter of the reflecting type turns into a phase shifter of the passing type. Phase shifters are actively used in power supply circuits of antenna arrays to change the radiation pattern (beam deflection). The dimensions of the phase shifters are associated with the operating frequency, the lower they are, the larger the area the device will occupy. This can be compensated by miniaturization of the structure, through the use of different structures with similar characteristics, it is possible to achieve similar characteristics with less space. Consider some of the miniaturization methods: In [1] the connector dimensions are reduced by quasi-centered elements, in [2] equivalent transmission lines, in [3] U-shaped containers, in [4] periodic capacitive loads, in [5] asymmetric T-shaped structures, in [6–8] low-pass filters, in [9] deceleration systems [10, 11] artificial power lines, in [12, 13] fractal structures, in [14] elements with high resistance. In this work, a compact design of the phase shifter at a Central frequency of 1 GHz will be considered.
2. Design
The typical topology of the phase shifter based on a directional coupler consists of a two-output coupler through which pin diodes are connected loops or idle, or short-circuit loop. Connecting or disconnecting these loops allows changing the output phase. Figure 2 shows the standard phase shifter implementation. Its area at a frequency of 1 GHz is 843 mm². As a substrate cheap microwave material FR-4 was used: dielectric constant of 4.4, thickness of 1 mm. The graph of S-parameters is shown in figure 2.3.

This design of the phase shifter is widely known - it is a directional coupler (two-port network) to the outputs of which plugs of idling are connected, or loops having contact with the ground. By connecting and disconnecting these loops, a phase change occurs at the output of the phase shifter. One of the disadvantages of this design at low frequencies is the large size. It is required to obtain a phase shifter, in which the construction with smaller sizes ensured the performance of the functional as in the standard construction. The task is achieved by the fact that in the phase shifter, instead of the traditional microstrip lines, compact structures are used. With this implementation, it is possible to use the internal space of the device, as well as to reduce the length of the connected loops. This method can effectively reduce the footprint of the device.

From the results obtained during the analysis it can be seen that the standard scheme provides a phase change of 90 degrees, the operating frequency band is determined as the band in which the phase changes, or as in this case is determined by the level of "minus" 10 dB phase shifter matching.

It is worth noting that this phase shift is fixed and will depend on the length of the loop. For example, for an idling loop, the longer it is, the larger phase shift can be obtained (it is necessary to take into

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**Figure 1.** Topology directional coupler  
**Figure 2.** S-parameters from frequency  
**Figure 3.** Phase on frequency
account that the signal passes to the end of the loop and is reflected, so it passes double length, because affects the magnitude of the phase).

In order to miniaturize the design, it is necessary to simulate compact structures that would allow maintaining efficiency, reduce the size of the device. Figure 4 shows one of the compact structure used, and figure 5.6 compares the characteristics of a conventional line and a compact structure.

![Figure 4. Topology of a quarter-wave segment and a compact structure](image)

![Figure 5. Phase on frequency](image)

It is seen that the compact structure has similar characteristics, namely it is the phase shift and the transmission coefficient in the frequency band of the device. It can also be seen that as the frequency increases, the gain value drops, which indicates that this structure behaves like a low-pass filter and will provide suppression of spurious harmonics.

Figure 7 shows the topology of the phase shifter with already installed compact structures. The connected loops are replaced by a decelerating structure in the form of line segments with high and low wave resistance. It was possible to reduce the area of the device by 63%. The characteristics of the phase shifter are shown in figures 8.9. From the results obtained during the analysis it can be seen that the standard scheme provides a phase change of 95 degrees.

![Figure 6. Frequency characteristics of a compact structure](image)
It is possible to apply the implementation of miniaturization with the help of compact structures for any other devices which include micro-stripe transmission lines. Their synthesis consists in obtaining a compact topology which has similar characteristics with the replaced segment. However, a more dense arrangement of elements to each other leads to negative consequences, this narrowing of the frequency band and an increase in losses in the band. Therefore, a material with lower dielectric loss should be used. To compare the characteristics of the standard and compact phasers, the results obtained are summarized in Table 1.

| Design  | Area, mm$^2$ | Bandwidth, MHz | Phase, deg. |
|---------|--------------|----------------|-------------|
| Standard| 843          | 450            | 90          |
| Compact | 312          | 400            | 90          |

3. Conclusion
The paper studies the phase shifter whose dimensions are reduced by the use of compact structures and decelerating structures, it is possible to reduce the area of the structure with a Central frequency of 2 GHz by 63%. However, as a result of miniaturization, the permissible power that such phase shifters can withstand has decreased. Therefore, eliminating one of the disadvantages of standard phase shifters, the reduction in the permissible power at which the phase shifter can operate.
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