Reduced Dimensions Planar Rat Race Coupler Design

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***Abstract*—The design of a rat race directional coupler was investigated in the Cadence AWR Design Environment program. By using low-pass filters instead of quarter-wave sections, it was possible to reduce the size of the device by 82.3%. In this case, the following deterioration of frequency characteristics occurred: narrowing of the operating frequency band by 19.3%, an increase in imbalance, and a decrease in matching. Also, the area of the compact double ring coupler was reduced by 84.5% while the bandwidth was narrowed by 29.2%.**

***Index Terms*—Filter, miniaturization, stub, coupler.**

I. Introduction

THE rat race directional coupler functions as a signal power divider with two phase differences, 0 and 180 degrees, depending on which port is considered to be the input port. The topology of such a device consists of four segments, three of which have an electrical length of 90 degrees, and the remaining 270 degrees. After combining such segments, a ring with a length of 1.5 wavelengths per line is obtained. Due to the fact that the wavelength and frequency are related, the lower the operating frequency of the device, the more area on the printed circuit board it will have. Therefore, at low frequencies, where the couplers turn out to be cumbersome, its miniaturization is actual, with the minimum possible deterioration of frequency characteristics. There are a lot of options for miniaturizing the spokesmen. Let's take a look at just a few. The following approaches are used to miniaturize tap-off devices: microstrip cells [1], T-shaped structures [2], dual-transmission lines [3], using C-SCMRC resonators with distributive equivalent circuit [4], artificial transmission lines [5, 10, 14, 15], resonators [6, 7, 13], circular defected ground structure [8], shunt-stub-based artificial transmission lines [9], multilayer LTCC [11, 12]. In the proposed work, a method is considered for obtaining a compact ring coupler by replacing all quarter-wave sections with low-pass filters. Also considered is a compact double ring coupler, which, due to the addition of one more circuit, increases the operating frequency band and dimensions.

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II. Design Coupler

A circular directional coupler is a type of power divider used in microwave technology. Using the Cadence AWR DE program and the built-in TXLine calculator, the topology of a standard coupler was calculated (Fig. 1). The well-known FR4 material acts as a substrate material, with ε = 4.4 and h = 1 mm, and as a central frequency of 1 GHz. The obtained frequency characteristics of the coupler in the AWR program are illustrated in Figures 2 and 3. The area of the device is 43 x 91.5 = 3934.5 mm^2.

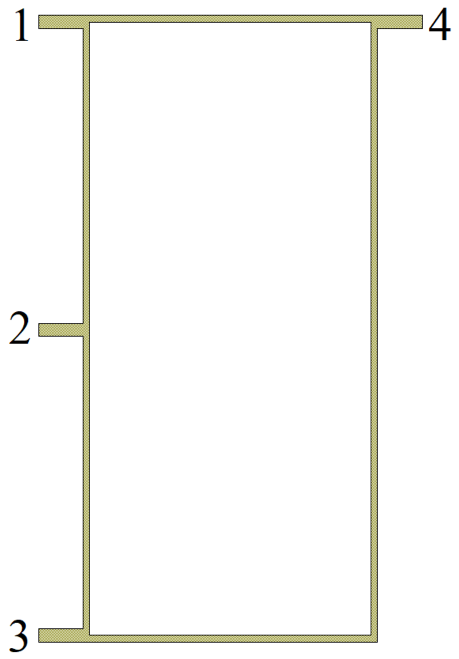

Fig. 1. Standard rat race coupler layout

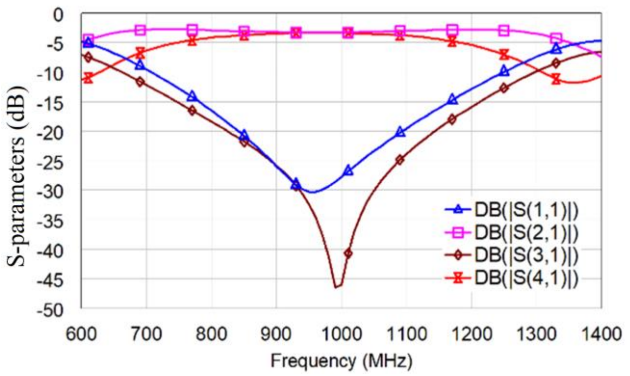

Fig. 2. S-parameter versus frequency plot for a standard rat race coupler

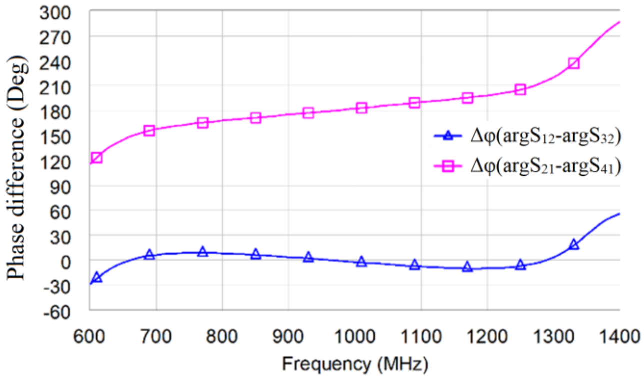

Fig. 3. The graph of the phase difference of the output signals depending on the choice of the input port (blue line - 1 input port, pink line - 4 input port)

According to the graphs obtained, it can be seen that the operating frequency band of the coupler at the isolation level "minus" 20 dB is 320 MHz (824-1144 MHz). The imbalance between the output signals of the structure in the frequency band does not exceed 1.3 dB. The area inside the coupler is not used in any way, which is an additional disadvantage of such a device. To reduce the size of the ring coupler, the required low-pass filters are initially calculated, which are used instead of the quarter-wave sections. For this purpose, a filter is calculated for the required wave impedance of 70.7 Ohm, which has a phase incursion of 90 degrees at a central frequency of 1 GHz. Filters can be implemented in a T-shaped or U-shaped circuit (Figure 4). They are completely equivalent to each other and can be used with equal efficiency. However, in our case, a U-shaped circuit was chosen, due to the fact that the extreme capacitive elements can be combined with the extreme elements from other filters, which can make it possible to more successfully fill the space inside the coupler. Low-pass filters can be calculated using the built-in iFilter tool in the Cadence AWR software.

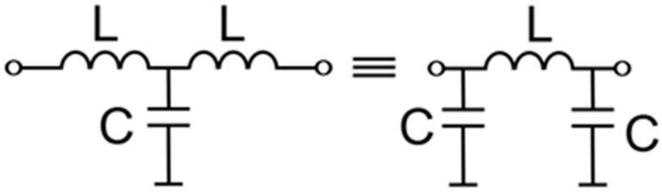

Fig. 4. T-shaped and U-shaped low-pass filter circuit

To calculate the ratings of CLC (capacitance - inductance - capacitance) elements, it is necessary to know the characteristic impedance of the transmission line, the parameters of the substrate material, the central frequency at which it is necessary to provide a phase shift of 90 degrees. After all filters are calculated, they are gradually installed instead of the quarter-wave sections of the coupler. The arrangement of the filter elements is carried out in such a way that there is no electrical contact between the elements of adjacent filters. After this procedure, an electrodynamic design calculation is performed, and if the frequency characteristics are unsatisfactory, then a forced optimization of the coupler design is performed in order to obtain the required characteristics. The topology of the compact ring coupler is shown in Figure 5. The obtained frequency characteristics of the compact coupler in the AWR program are illustrated in Figures 6 and 7.

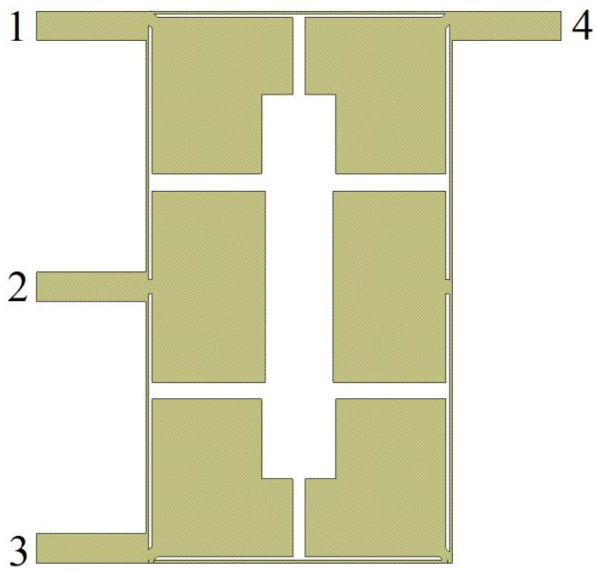

Fig. 5. Compact rat race coupler

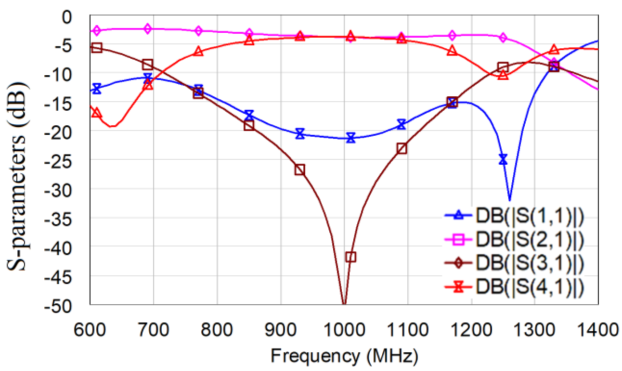

Fig. 6. S-parameter versus frequency plot for a compact rat race coupler

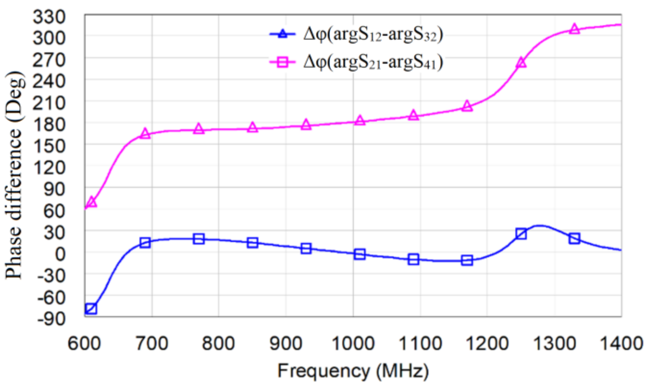

Fig. 7. The graph of the phase difference of the output signals depending on the choice of the input port (blue line - 1 input port, pink line - 4 input port)

By replacing the quarter-wave sections with low-pass filters and using the area inside the device, it was possible to reduce the area of the device by 82.3%. In a miniature version, the coupler has an area equal to 19.65 x 35.5 = 697.6 mm^2. According to the graphs obtained, it can be seen that the operating frequency band of the coupler at the isolation level "minus" 20 dB is 258 MHz (860-1118 MHz). The imbalance between the output signals of the structure does not exceed 1.1 dB. As a result of the miniaturization of the coupler, the operating frequency band was narrowed by 19.3%. The differences are primarily due to the incomplete coincidence of the characteristics of the quarter-wave sections and the elements installed instead of them. From the data in Table 1, you can compare the characteristics of the standard and miniature coupler.

TABLE I
COMPARATIVE DATA OF COUPLER

Parameters	Standard	Compact
bandwidth, MHz	320	258
Area, mm^2	3934,5	697,6
Relative area, %	100	17.7
Central frequency, MHz	1000	1000
The phase outputs on the central frequency, °	0 180	1.8 180.3

To increase the bandwidth of operating frequencies, an additional circuit is added to the design of the coupler, the length of which is equal to the wavelength in the line. To increase the bandwidth of the quadrature directional couplers, the addition of additional stub lines (cascading) is used. In the case of ring (common-phase-antiphase) taps, cascading is also used to increase the bandwidth. The dual ring coupler topology is shown in Figure 8. A single wavelength loop is added to the coupler design, with a characteristic impedance of 100 ohms. To further increase the strip, a third and subsequent circuit can be added, but this will lead to an increase in dimensions and complicate the design of the device. Low-pass filters are also asymmetrically designed to occupy the internal area of the coupler and further reduce the size of the device. The obtained frequency characteristics of the compact coupler in the AWR program are illustrated in Figures 9 and 10.

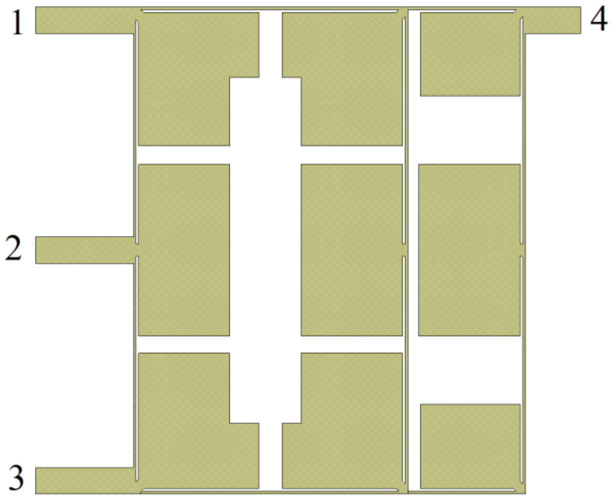

Fig. 8. Compact double rat race coupler

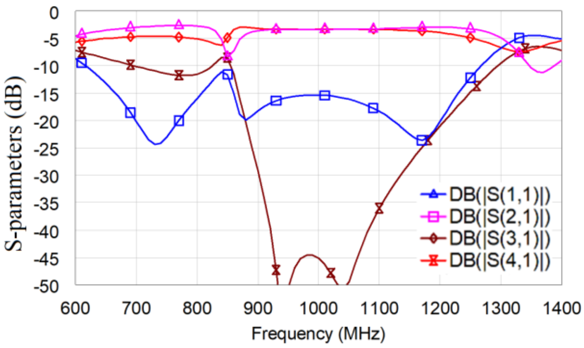

Fig. 9. S-parameter versus frequency plot for a compact double rat race coupler

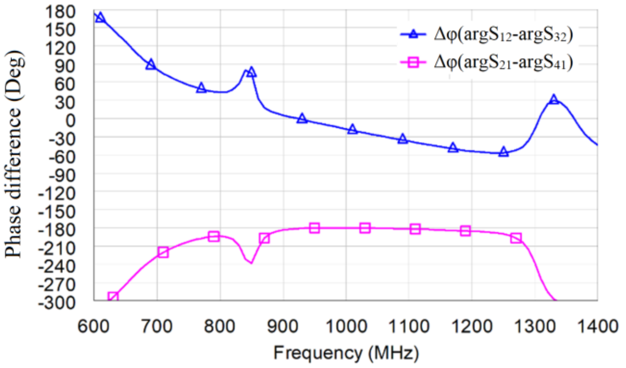

Fig. 10. The graph of the phase difference of the output signals depending on the choice of the input port (blue line - 1 input port, pink line - 4 input port)

By adding a loop, it was possible to increase the operating frequency band of the coupler to 329 MHz. At the same time, the area of the device increased to 977.2 mm^2. From the data in Table 2, you can compare the characteristics of the standard and miniature coupler.

TABLE II
COMPARATIVE DATA OF COUPLER

Parameters	Standard	Compact
bandwidth, MHz	465	329
Area, mm^2	6302	977.2
Relative area, %	100	15.5
Central frequency, MHz	1000	1000
The phase outputs on the central frequency, °	0 180	12 180

III. CONCLUSION

A miniature ring coupler obtained by replacing quarter-wave sections with low-pass filters is investigated in this work. Filter elements are located in the internal space of the device. All this made it possible to reduce the area of the coupler by 82.3% with a relative bandwidth of 25.8%, which is 19.3% less than that of a standard device. A double ring coupler was also obtained, the area of which is 84.5% less than the area of its standard implementation, with a relative bandwidth of 32.9%, which is 29.2% less than that of a standard device.

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