New Small Size 3 dB 0°/180° Microstrip Coupler Configurations

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Abstract
New small size 3 dB microstrip 0°/180° coupler configurations are proposed and discussed. The coupler can be fabricated in square or ring form. The ring may be designed for symmetrical ports about either one axis or two axes. The proposed configurations introduce significant size reduction, which is the most important demand for microwave integrated circuits (MICs) and monolithic microwave integrated circuits (MMICs). Different couplers are designed, and simulated at 900 MHz. The designed coupler in square shape is simulated and implemented. Experimental results agree quit well with theoretical predictions.

I. Introduction

In the last few years, the rapid growth in wireless communication increases the demand of small size RF circuits. Hybrid couplers are fundamental components extensively used in microwave circuits. However, all branch line couplers, parallel line couplers, and hybrid ring couplers, including the rat race ring, consist of a common fundamental $\lambda/4$ transmission line section. At the lower microwave frequencies, the size based on this $\lambda/4$ section is unsuitable for many wireless applications. Much effort to reduce the size of hybrid couplers has been reported [1-5]. Recently, T-shaped and stepped impedance circuits equivalent to $\lambda/4$ line section have been used in hybrid quadrature branch line coupler [1]. The resultant coupler has been implemented on 36% of the area of that of the conventional one without any significant sacrifice in circuit performance. Different techniques have been used to reduce the size of the conventional ring coupler of 1.5λ circumference (see Fig. 1). A quarter wavelength pair of coupled lines short-circuited at their diagonal ends has been used to replace the three quarter wavelength line [2]. The circumference of such coupler has been reduced to 1λ. However this technique requires a very tightly coupled line section that is difficult to fabricate with simple microstrip technology. The use of $\lambda/6$ or $\lambda/8$ sections allows to reduce the circumference of the ring to 1.25 λ [3]. Another approach to reduce the ring coupler size requires; (1) using a small section of transmission line with a specified characteristic impedance instead of the $\lambda/4$ line; and (2) replacing the three quarter wavelength line by a one-quarter-wavelength line with phase inverter [4,5]. Based on this approach the 1.5λ circumference has been reduced to 0.67λ [4]. The circuit is composed of a coplanar strips (CPS) ring and coplanar wave-guides (CPW) feed lines. A crossover of the two strips on the ring is also required to achieve 180° phase shift (phase inverter.
In this paper, we propose several new small size 3 dB 0°/180° coupler configurations. The coupler can be designed in square form or ring with symmetric ports about either one axis or two axes. The couplers simulations are performed using the IE3D software.

II. Reduced size coupler configurations

The size of the conventional ring coupler, shown in Fig.1, can be reduced to the ring coupler with 4θ circumference shown in Fig. 2. The arms characteristic impedance Z_C is related to the electrical length θ and 50 Ω port impedance Z_O by [4]:

$$Z_C = Z_O\sqrt{2(1-\cot^2\theta)} \quad (1)$$

The range of the arm electrical length is $45^o < \theta < 90^o$, where θ is the arm electrical length at the center frequency. The phase inverter has been implemented by crossing over the two strips in case of coplanar strip technique, which is potentially expensive. In simple microstrip technology, the phase inverter can be implemented as a half wavelength line has the same characteristic impedance of the θ sections. In this case the resultant bandwidth will be narrow and will decrease as θ decreases. However, wider bandwidth can be obtained if θ is equal to 90^o at the center frequency [5]. The corresponding characteristic impedance of the arms is

$$Z_C = Z_O\sqrt{2(1-\frac{2}{10^{-(\frac{L}{20})}+1})} \quad (2)$$

Where L is the maximum in-band return loss specification. For L= ∞, the resultant ring coupler will be similar to the conventional one.

Some geometrical arrangements, suitable for microstrip technology, lead to the coupler structures shown in Figs 3-5:

A. Semi-circle shape with symmetric ports about one axis (Fig. 3)

In this case the $180^o + \theta$ line is designed in the free region inside the semi-circle as shown in Fig. 3. The minimum area can be achieved for $\theta=45^o$, which correspond to 12.5% of that of the conventional ring coupler. However, the resultant bandwidth in this case will be almost zero. Practically, θ should be greater than 45^o and can be determined for particular BW requirements. Simple software program such as Puff can predict quickly the coupler performance.

B. Ring shape with symmetric ports about the two axes (Fig. 4)

The line $180^o + \theta$, in this case is, formed inside the ring in circular shape. However, the inner line should be far enough from the outer one to avoid non-negligible coupling. Denote the electrical distance between the two bending lines and the two rings by θ_1 as shown in Fig. 4, the arms electrical length are given by

$$\theta = 0.5\,(\pi\,\theta_1 + 90) \quad (3)$$

C. Square shape (Fig. 5)

In this case, the coupler can be implemented in the square form of length θ where the $\theta + 180^o$ line takes the serpentine shape inside the square as shown in Fig. 5.

III. Design case and experimental results

A design example is introduced here in order to validate the proposed configurations. Duroid dielectric substrate RT/5880 with ε_r=2.2 and h=0.54 mm is used. For high compactness, the arms electrical length selected to be 50^o. The design is carried out at 900 MHz. The resultant characteristic impedance of the coupler arms calculated by eq. (1) is 38 Ω. It has been noted that better bandwidth can be achieved by increasing the characteristic impedance Z_c, calculated from eq. (1), of the arms of electrical length θ at the center frequency. This has been demonstrated by increasing the characteristic impedance from 38 Ω to 50 Ω keeping the arms length equal to 50^o at 900 MHz. The circuit layout in Fig. 5, which provide area equal to 10.7% of that of the conventional coupler, is used. The simulation results performed by IE3D are shown in Fig. 6. From 0.88 to 1.21 GHz, S11< -10 dB, S21 = -3.15 ± 0.35 dB, S31 = -3.5 ± 0.3 dB and S41< -14 dB. As a result of the increase in Z_c, the center frequency is shifted to 1.045 GHz with 31.5% bandwidth. The experimental results of this coupler are shown in Fig. 7. The measured results agree well with the simulation in Fig. 6 except the decrease in BW to 27.2% at the center frequency of 1.012 GHz. At this frequency the area of the coupler is 12% of that of the conventional ring one.

Conclusion

New small size configurations equivalent to 3 dB 0^o/180^o ring coupler have been proposed. The coupler in square shape has been designed simulated and measured. Good performances with 27.2% bandwidth centered at 1.012 MHz have been obtained. The coupler area is 12% of that of the conventional ring coupler. These configurations allow good flexibility for MICs and MMICs applications.

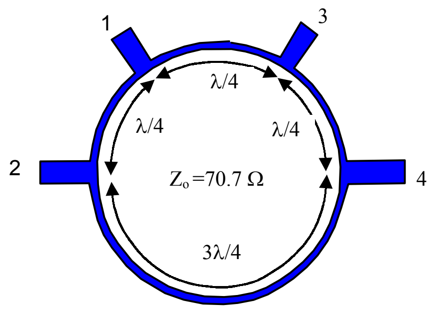

Fig. 1 Layout of the conventional ring coupler based on $\lambda_g/4$ line

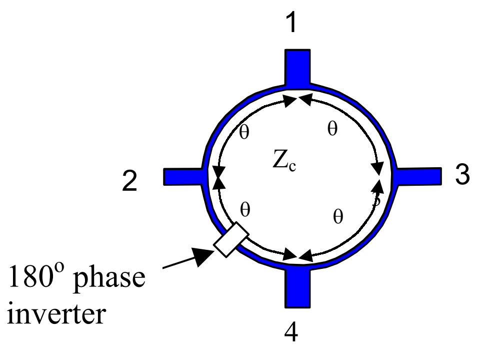

Fig. 2 Layout of small size ring coupler as presented in [4]

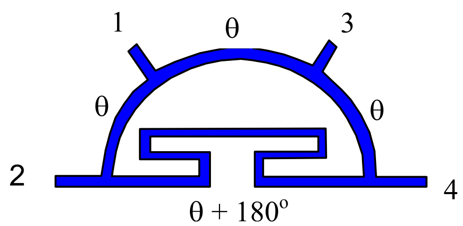

Fig. 3 Layout of small size ring coupler for asymmetrical feeding ports

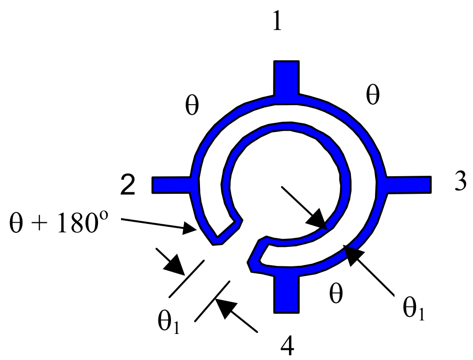

Fig. 4 Layout of small size ring coupler for symmetrical feeding ports

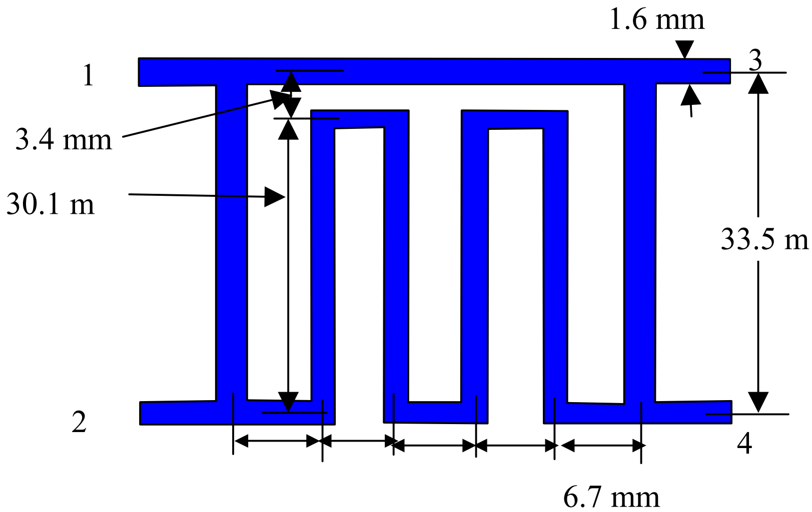

Fig. 5 Layout of square shape coupler designed and implemented on duroid RT/5880 substrate at 900 MHz

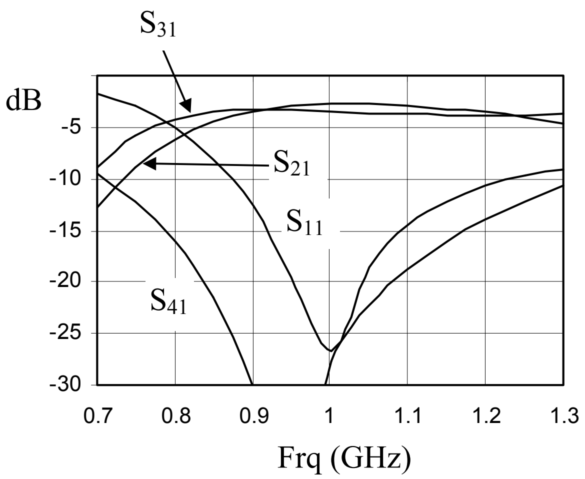

Fig. 6 Simulation results of the layout of the circuit in Fig. 5 (performed by IE3D)

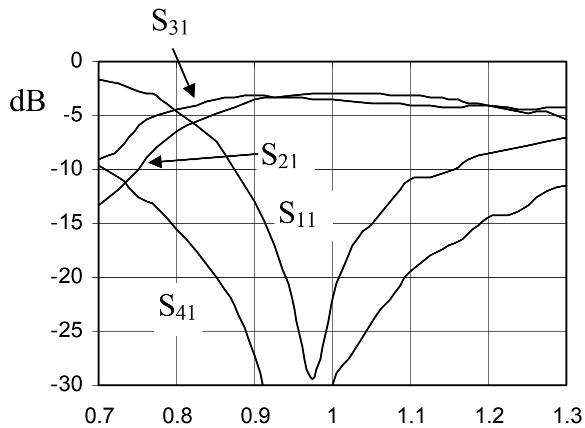

Fig. 7 Experimental results of the coupler layout shown in Fig. 5

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