New Compact 3 dB $0^o/180^o$ Microstrip Coupler Configurations

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Abstract: Compact 3 dB $0^o/180^o$ microstrip couplers in ring and square configurations are proposed and discussed. In a ring form, the coupler 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 1 GHz. The IE3D software is used in order to validate the design procedure. The designed coupler in ring shape is simulated and implemented. The experimental results agree well with the theoretical prediction.

Keywords: Compact ring coupler, Hybrid ring, Microstrip, MMICs

I. Introduction

In recent years, the rapid growth in wireless communications has increased the demand for small size RF circuits. Hybrid couplers are fundamental components in microwave circuits and include branch line couplers, parallel line couplers, hybrid ring couplers, and the rat race ring. A fundamental component of all these couplers is the $\lambda/4$ transmission line section. At the lower microwave frequencies, the size based on this $\lambda/4$ section is unsuitably large for many wireless applications. Much effort to reduce the size of hybrid couplers has been reported [1-6]. 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 one wavelength λ. 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 reducing the circumference of the ring to 1.25λ [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 strip (CPS) ring and coplanar waveguide (CPW) feed lines. Air bridges are then needed to avoid the excitation of an even mode. A crossover of the two strips on the ring is also required to achieve 180^o phase shift (phase inverter). These techniques tend to increase the fabrication cost which is one of the most important parameters of MIC. Compact ring $0^o/180^o$ couplers using T-shaped sections to replace the $\lambda/4$ lines have been introduced recently by the authors [6].

In this paper, we propose new small size 3 dB $0^o/180^o$ coupler configurations. The coupler can be designed in square form or ring shape with symmetric ports about either one axis or two axes. The various configurations can be fabricated with simple low cost microstrip technology. The reduced size coupler configurations are discussed in the next section followed by the simulation and experimental results. 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 impedances Z_C are related to the electrical length θ and $50\,\Omega$ 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. In simple microstrip technique, the phase inverter can be implemented as a half wavelength line having the same characteristic impedance of the θ sections. In this case the resultant bandwidth is narrow and decreases 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

$$Z_c = Z_o \sqrt{2\,\left(1-\frac{2}{10^{-\left(\frac{L}{20}\right)}+1}\right)} \quad (2)$$

where L is the maximum in-band return loss specification. For L= ∞ the resultant ring coupler will be similar to the conventional one. In the following, some proposed geometrical arrangements, suitable for microstrip technology, are given and they 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 between ports 2 and 4 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 a particular BW requirement as described in the next section. A simple software program such as Puff can quickly predict 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 a circular shape. However, the inner line should be far enough from the outer one to avoid any significant coupling. Denote the electrical distance between the two bending lines and the two rings by θ_1 as shown in Fig. 4. For small θ_1, the arms electrical length can be approximated by

$$\theta \approx 0.5\,(\pi\theta_1 + 90^0). \quad (3)$$

C. Square shape (Fig. 5)

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

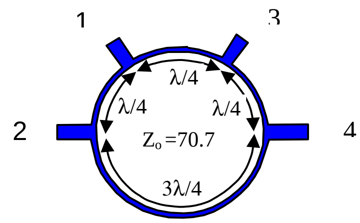

Fig. 1 Layout of the conventional ring coupler based on $\lambda_g/4$ line.

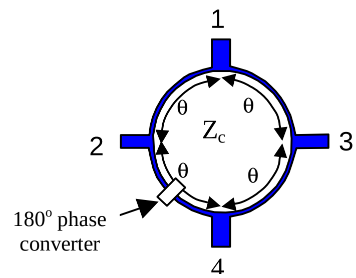

Fig. 2 Layout of a small size ring coupler derived from the theory in [4].

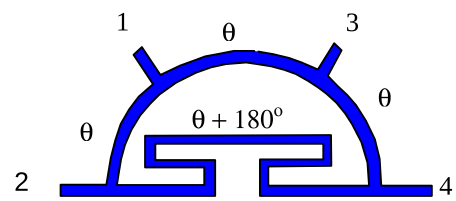

Fig. 3 Layout of small size ring coupler for asymmetrical feeding ports.

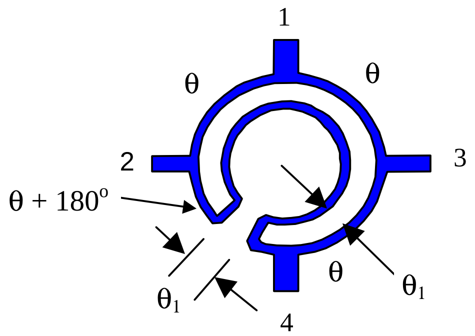

Fig. 4 Layout of small size ring coupler for symmetrical feeding ports.

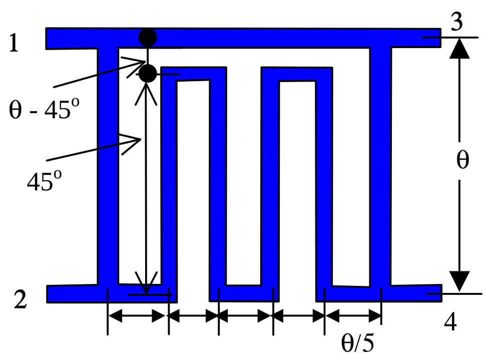

Fig. 5 Layout of square shape coupler.

III. Design Procedure and performance Trade-off

The couplers proposed herein are based on the implementation of the 180° phase inverter by half-wavelenth line using special arrangement as shown in Figs. 3-5. So, the expected performance of all configurations will be approximately the same. The difference may be occurring only due to the unwanted coupling between the lines that are too close to each other. This can be eliminated by optimizing the structure to keep lines as far as possible. The coupler design can start by plotting the bandwidth and the area used, with respect to the area of the conventional type (Fig.1), against the arm electrical length θ as shown in Fig. 6. The relative bandwidth (BW) is calculated for ideal transmission line elements under the following limits:

Port matching < -10 dB
Coupling -2.5 to -4 dB
Isolation < -15 dB
Output phase balance when fed at E-port =180° ± 12°
Output phase balance when fed at H-port= 0° ± 10°

Fig. 6 shows that the relative bandwidth increases as θ increases. The maximum bandwidth is obtained for the conventional type, i.e when θ = 90°. It is also noted that the area used decreases as θ decreases. As shown in this figure, the most compact structure is that of circular shape of Fig. 4. The used area can be reduced to 13.7 % of the conventional type when θ = 50°. In this case, the corresponding percentage BW is 17.7%. Fig. 7 shows the characteristic impedance (Z_c) of the coupler arms calculated from (1). The characteristic impedance decreases as θ decreases. For high compactness, this will add some constraints on the selection of the substrate material since the line width increases as Z_c decreases. The increase of line width may cause the lines to be very close causing a strong coupling. Fig. 6 is used to determine the arm electrical length for a given bandwidth, and the corresponding characteristic impedance can be calculated from Fig.7.

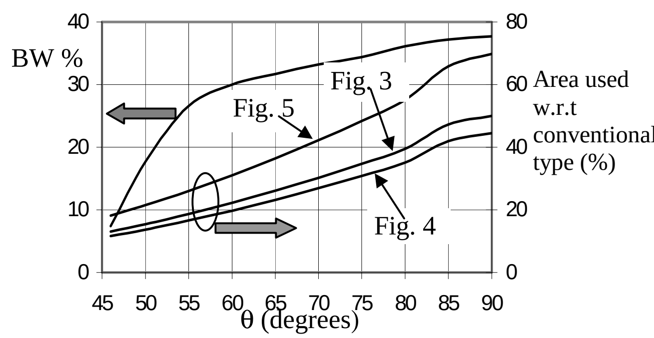

Fig. 6 Relative bandwidth and percentage area used with respect to the conventional coupler of Figs. 3-5.

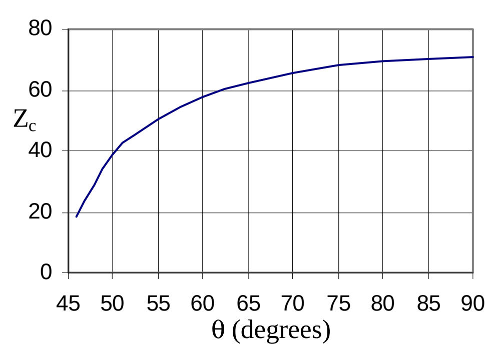

Fig. 7 Arms characteristic impedance Z_c against arms electrical length θ.

IV. Design Cases and Experimental Results

We introduce here different design cases in order to validate the proposed configurations. Duroid dielectric substrate RT/5880 with ε_r =2.2 and h=0.51 mm is used.

For high compactness and acceptable line width, the arms electrical length are selected to be 55^o. The design is carried out at 1 GHz. The resultant characteristic impedance of the coupler arms is 50Ω (Fig. 7). Therefore the arms width and length are 1.6 and 33.3 mm, respectively. The simulation results performed by Puff software and based on ideal transmission lines are shown in Fig. 8. Within the band 0.95 to 1.1 GHz, S11< -10.5 dB, S21 = -3.25 ± 0.35 dB, S31 = -3.5 ± 0.6 dB and S41 (isolation)< -22 dB. For this design, the ratio of the circuit layout area relative to that of the conventional ring coupler is 18.5%, 16.6%, and 26 % for circuits in Fig. 3, Fig.4 and the square shape in Fig. 5, respectively. However, wide band couplers can be designed based on (2). In this case the arms length will be 90^o at 1 GHz and the characteristic impedance is 64Ω for 20 dB return loss at the center frequency. The expected ratio of the circuit layout area with respect to that of the conventional ring coupler will be, 50%, 44%, and 70 % for circuits in Fig. 3, Fig.4 and Fig. 5., respectively.

As an example, the layout of the coupler shown in Fig. 4 is implemented. The arms length is 33.3 mm (θ = 55^o) and θ_1=6.6^{o,} which is 4 mm. The inner and outer radii are 17.4, and 21.2 mm, respectively. The simulation results performed by the IE3D are shown in Fig. 9. Between 0.88 and 1.15 GHz, S11< -10 dB, S21 = -3.15 ± 0.35 dB, S31 = -3.5 ± 0.3 dB and S41< -14 dB. At this case the area of coupler is approximately 17% of that of the conventional ring one, as expected from Fig. 6. The experimental results of this coupler are shown in Fig. 10. It is seen that the measured results agree well with the simulation in Fig. 9.

Conclusion

New small size configurations acting as a 3 dB 0^o/180^o ring coupler have been proposed. The coupler can be designed for narrow or wide band operations with significant size reduction in both cases although the size reduction is less in the wide band case. The coupler in square shape has been designed, simulated and measured. Good performance with 27% bandwidth centered at 1.015 GHz has been obtained. The coupler area is 17% of that of the conventional ring coupler. The proposed configurations allow good flexibility for MICs and MMICs applications.

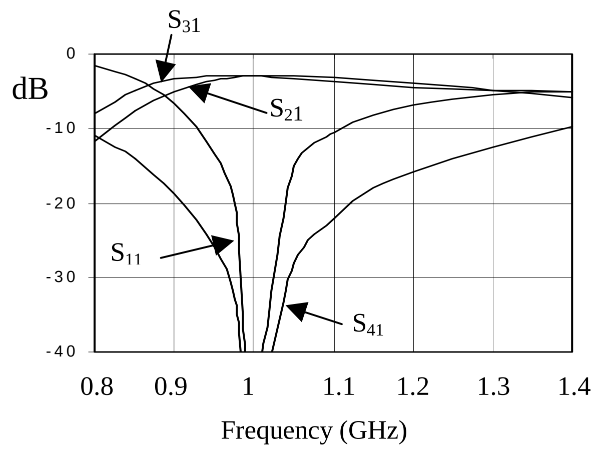

Fig. 8 Simulation results based on ideal transmission line performed using Puff software for narrow band case.

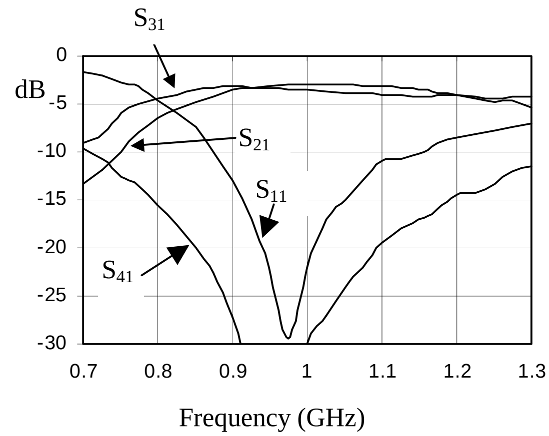

Fig. 9 Simulation results, performed by IE3D, of the layout of the circuit in Fig. 4.

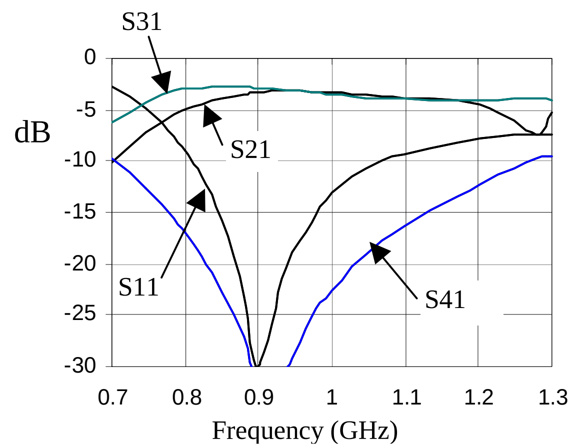

Fig.10 Experimental results of the coupler layout shown in Fig. 4.

References

[1] A. F. Sheta, A. Mohra, S. F. Mahmoud, “A new class of miniature quadrature couplers for MIC and MMICs applications,” *Microwave Opt. Technol. Lett*., vol. 43, no. 3, pp. 215-219, August 2002.

[2] S. Mar, “A wide band stripline hybrid ring,” *IEEE Trans. Microwave Theory Tech*., vol. MTT-16, p. 361, June, 1968.

[3] D. I. Kim and G. S. Yang, “Design of new hybrid-ring directional coupler using $\lambda_g/8$ or $\lambda_g/6$ sections,” *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 1779-1783, Oct. 1991.

[4] M. H. Murgulescu, E. Moisan, P. Legaud, E. Penard, and I. Zaquine, “New wideband $0.67\lambda_g$ circumference 180^o hybrid ring coupler,” *Electron. Lett*., vol. 30, pp. 299-300, Feb. 1994.

[5] T. Wang and Ke Wu, “Size reduction and band broadening design technique of uniplanar hybrid ring coupler using phase inverter for M(H)MIC’s,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-47, no. 2, pp. 198-206, Feb. 1999.

[6] A. Mohra, A. F. Sheta, S. F. Mahmoud, “A small size 3 dB 0o/180o microstrip ring couplers,” *J. of Electromagn. Waves and Appl.*, vol. 17, no. 5, 707-718, 2003.

Biography

Ashraf Shouki Seliem was born in Egypt in 1963. He received the B.Sc degree in Electronics and communications from Shoubra Faculty of Engineering in 1986. He received the M.Sc. and Ph.D. degrees in Electronics and communications from Ain Shams University, Cairo, Egypt, in 1994 and 2000, respectively. He is currently working with the Electronics Research Institutes. His current research interests include microstrip antennas, computer aided design of planar and uniplanar of MICs and MMICs.

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