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A Small Size 3-dB 0°/180° Microstrip Ring Couplers

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ABSTRACT

A new small size 3 dB microstrip ring couplers suitable for microwave integrated circuits (MICs) and monolithic microwave integrated circuits (MMICs) are presented. Area saving more than 85% of that of the conventional ring coupler can be achieved using the proposed configurations. Small size couplers based on the proposed configurations designed at 900 MHz have been implemented on RT/Duroid 5880 dielectric material. The theoretical and experimental results show favorable comparison.

I. INTRODUCTION

Hybrid couplers are used as components, in almost every RF system, such as power combiners and dividers, de(modulators), balanced mixers, image rejection mixers, balanced amplifiers and feed network in antenna arrays. The 0°/180° hybrid coupler is preferred in some applications, namely, mixers, modulators, and isolated power splitters since the isolation between its input ports may be independent of the value of the two balanced impedance loads [1]. The circumference of the conventional 0°/180° hybrid ring coupler is 1.5 λ_g. At the lower frequency of the microwave band such as mobile frequencies such size is too large for system integration and MMICs applications, since a large circuit area results in high chip cost. Several design techniques have been proposed to reduce the coupler size. 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 1 λ_g. However this technique requires a very tightly coupled line section that is difficult to fabricate with simple microstrip technology. The design of 3-dB reduced size hybrid ring based on $\lambda_g/6$ or $\lambda_g/8$ sections has been studied [3]. The circumference reported is 1.25 λ_g. Another approach to reduce the ring coupler size require; (1) using a small section of transmission line with a specified characteristic impedance instead of $\lambda_g/4$ line; and (2) replacing the three quarter wavelength line by a one-quarter-wavelength line with phase inverter [1,4]. Based on this approach the 1.5 λ_g circumference has been reduced to 0.67 λ_g [4]. Significant increase in bandwidth to exceed one octave has been obtained. The circuit is composed of a coplanar strips (CPS) ring and coplanar wave-guides (CPW) feed lines. In this case air bridges, which are potentially expensive, are needed. A crossover of the two strips on the ring is also required to achieve 180° phase shift (phase inverter). Design theory of a reduced size ring coupler using phase inverter in different topologies has been studied [1].

In this paper, new miniaturized 0°/180° ring coupler configurations are introduced. The replacement of each quarter wavelength line by its T-shape equivalence described early by the authors [5] for hybrid quadrature couplers will be introduced in section II.

This approach leads to more than 70% area saving ending up with 0.75 λ_g circumference. Further size reduction can be achieved by replacing the three quarter wavelength line by: (1) Π circuit equivalent, (2) a pair of coupled lines short circuited at their diagonal, or (3) the same line length in serpentine shape. These configurations will be described in section III. The proposed structures are suitable for hybrid MICs and MMICs applications. With this approach more than 85% area saving with respect to the conventional type can be achieved. A coupler operating at 0.9 GHz, have been designed and implemented in three different configurations. The design, simulation, and experimental results are presented in section IV, and are followed by concluding remarks in section V.

II. Ring coupler using T-shape section equivalent to $\lambda_g/4$ line

Conventional ring couplers utilize three sections of $\lambda_g/4$ line and a section of three quarter wavelength with 1.5 λ_g circumference as shown in Fig.1. The length of the quarter wavelength line can be reduced by making the T-shape circuit equivalent shown in Fig.2 [5]. The equivalence between (a) and (b) of Fig.2 results in

$$\tan\theta_1 = \frac{1}{M} \quad \text{and} \quad \tan\theta_2 = \frac{1}{K}(\cot\theta_1 - \tan\theta_1) \qquad (1)$$

Where $M=Z_1/Z_o$ and $K=Z_1/Z_2$. Z_o is the characteristic impedance of the quarter wavelength line. Z_1, θ_1, Z_2, and θ_2 are the characteristic impedances and electrical lengths of the series line and stub respectively, as shown in Fig.2. Fig.3 shows the variation of the stub length θ_2 against M or θ_T for different values of K. Where $\theta_T = 2\theta_1 = 2\tan^{-1}(1/M)$. Applying the circuit equivalent in Fig.1 leads to the ring coupler layout shown in Fig.4. It should be noted that θ_2 must be less than the electrical length of the ring radius, R, to avoid overlapping between the six stubs. This imposes the inequality

$$\theta_2 < R = 6\theta_1/\pi \quad \text{degrees} \qquad (\theta_1 \text{ and } \theta_2 \text{ in radian}) \qquad (2)$$

The unrealizable values of the circuit parameters, where θ_2 becomes greater than the ring radius, R, are marked by the dashed region in Fig.3. The stub widths should be taken into consideration while selecting its lengths.

III. Ultra-miniaturized hybrid ring coupler configurations

Further size reduction can be obtained by some arrangements to replace the three quarter wavelength line by a small size circuit equivalent. The following three configurations offer different ways to do that:

A. Using Π circuit equivalent

The length of the (3/4) λ_g line in the conventional coupler can be reduced by using its Π equivalent circuit shown in Fig.5. Using the familiar ABCD matrix, the appropriate Π circuit parameters can be adjusted to have similar response as the three quarter wavelength. Let the ABCD matrices of the three quarter wavelength line in Fig.5(a), a series line of electrical length θ_1 and characteristic impedance Z_1, and an open circuit stub of electrical length θ_2 and characteristic impedance Z_2 be denoted, respectively, by:

$$A_a = \begin{bmatrix} 0 & -jZ_o \\ \dfrac{-j}{Z_o} & 0 \end{bmatrix},\quad A_b = \begin{bmatrix} \cos\theta_1 & jZ_1 \sin\theta_1 \\ \dfrac{j\sin\theta_1}{Z_1} & \cos\theta_1 \end{bmatrix},\quad A_c = \begin{bmatrix} 1 & 0 \\ \dfrac{j\tan\theta_2}{Z_2} & 1 \end{bmatrix} \qquad (3)$$

The equivalence in Fig.5(b) can be achieved through

$$A_a = A_b A_c A_b A_c A_b \qquad (4)$$

The resultant circuit layout takes the shape shown in Fig.6. Overlapping between circuit stubs should be avoided while looking for the circuit parameters. such constrained equivalence has been solved using Mat- lab program.

B. Coupled line short circuited at its diagonal

With the aid of ABCD parameters it can be shown that, a coupled line of length L short circuited at its diagonal is equal to a transmission line of the same length L in series with 180° phase shift network [2]. Thus the three quarter wavelength line (270°) can be replaced by a pair of quarter wave coupled lines, short-circuited at their diagonals. Therefore, the ring coupler in Fig.4 can be reduced to the coupler in Fig.7 if the ring diameter is set equal to $\pi/4$. The appropriate circuit parameters that achieve this goal are: M=2.29, Z_1=162.13 Ω, θ_1=23.56°. Meanwhile, Z_2 and θ_2 can be selected from Fig.3. However, it is difficult to implement this configuration using the simple microstrip technology due to the tight coupling required.

C. Implementation of the three quarter line in serpentine form

In order to avoid the design complexity in case (A) and fabrication complexity in case (B) the three quarter wavelength line can be implemented in serpentine shape as shown in Fig.8. This will allow about 50% area saving relative to the reduced size coupler in Fig.4. The design parameters can be chosen similar to those in configuration (B). Separation between lines should be large enough to avoid parasitic coupling.

IV. Design cases and experimental results

In order to confirm and validate the proposed configurations, three 3-dB couplers are designed, simulated and measured at 900MHz. The couplers were fabricated on a RT/Duroid 5880 substrate with $\varepsilon_r = 2.2$ and thickness of 0.78 mm. The IE3D software has been used to simulate the designed couplers. The measurements have been performed using Agilent 8719ES network analyzer.

A. Coupler designed based on T-shape equivalent to $\lambda/4$ line (Fig. 4)

For realization using the available simple etching process, the smallest line width is limited by about $200\mu m$. This is a line of 158 Ω characteristic impedance on such a substrate. Thus M=Z_1/Z_o is fixed at 2.23 (for Z_o=70.7 Ω), θ_1=24.15°, the other circuit parameters can be selected either from Eq.(1) or Fig.3 Taking K=3.16, we get Z_2=50 Ω and θ_2=30°. The obtained coupler diameter is 64 mm compared to 118 mm of the conventional one.

The simulated and measured results are shown in Figs.9(a) and 9(b), respectively. From 0.840 to 1.16 GHz, the measured scattering parameters are $S_{11} < -14.5$ dB, $S_{21} = -3.78 \pm 0.55$ dB, $s_{31} = -2.895 \pm 0.335 dB$, s_{41} (isolation) < -16.3 dB. The measured phase difference between ports 1 and 4 when fed at port 2 varies from 189° at 0.84 GHz to 165.5° at 1.16 GHz. Frequency shift of 100 MHz has been observed. The relative band width is 32%. Due to the frequency shift noted, the coupler area will slightly greater than the theoretical estimation (29.4%). The coupler is now implemented on 32.66% of the area of the convential coupler at the measured center frequency (1GHz).

B. Coupler designed based on T-shape equivalent to $\lambda/4$ line and the implementation of $3\lambda/4$ line in form of serpentine shape (Fig. 8)

The same parameters in case A has been used, but in this case the $3\lambda/4$ line has been implemented in the form of serpentine shape. This reduces the area to its half compared to the design of case(A). The simulated and measured performances are given in Figs.9(c) and 9(d), respectively. The measured bandwidth is 300 MHz centered at 900 MHz. Within this band the scattering parameters are $S_{11} < -13$ dB, $S_{21} = -3.33 \pm 0.47$ dB, $S_{31} = -3.25 \pm 0.37$ dB, $S_{41} < -15 dB$. The measured phase difference between ports 1 and 4 when fed at port 2 varies from 182° at 0.75 GHz to 158.5° at 1.05 GHz. The area used is about 15% of the area of conventional coupler.

C. Coupler designed based on T-shape equivalent to $\lambda/4$ line and Π shape equivalent to $3\lambda/4$ line (Fig. 6)

In this case, the selection of the Π-shape equivalence parameters in Fig.5, and T-shape equivalence in Fig.2, should be optimized carefully in order to avoid overlapping between circuit stubs. Eqs. 3,4 have been solved using Mat-Lab program and the resultant dimensions are shown in Fig.6. The simulated and measured results are shown in Figs 9(e) and 9(f), respectively. The measured bandwidth is 300 MHz centered at 1 GHz. Within this band the scattering parameters are $S_{11} < -13$ dB, $S_{21} = -3.45 \pm 0.55$ dB, $S_{31} = -3.4 \pm 0.6$ dB, $S_{41} < -15$ dB. The measured phase difference between ports 1 and 4 when fed at port 2 varies from 200° at 0.85 GHz to 180° at 1.15 GHz. The actual area is 20.7% of the area of the conventional coupler.

V. Conclusion

A new 3-dB small size ring coupler configurations have been presented. Design curves have been introduced. In order to demonstrate the advantages of the design approach three couplers designed at 900 MHz have been simulated and implemented. Good agreement is established between theory and measured results. The area saving, relative to the conventional coupler, exceeds 67% and reaches 85%, for the coupler in Fig.8. The measured relative bandwidth of this coupler is 33.33% and not less than 30% for the other two cases The three implemented couplers in this paper do not need any lumped elements or via hole grounding and consequently have the advantages of low cost, simple fabrication process and excellent design accuracy. These hybrids are suitable for MICs and MMICs applications.

Reference

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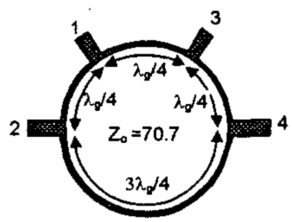

Fig.1 Layout of the conventional ring Coupler based on $\lambda/4$ line

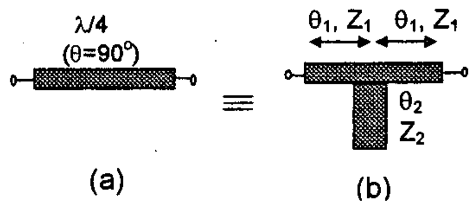

Fig.2 (a) $\lambda/4$ transmission line
(b) T-shape equivalent to $\lambda/4$ line

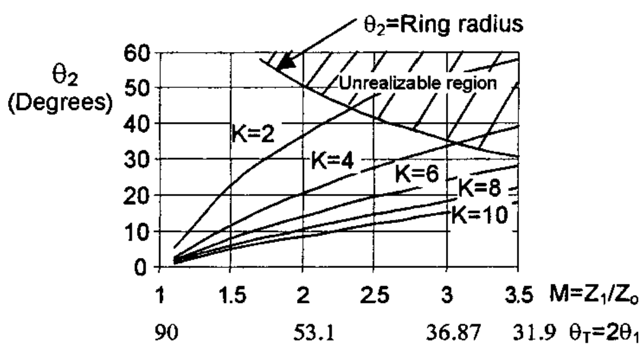

Fig.3 Design curves for the circuit in Fig.(2b) to be equivalent to $\lambda/4$ line in Fig.(2a)

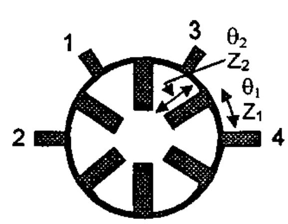

Fig.4 Ring coupler layout based on T-shape circuit equivalent in Fig.1

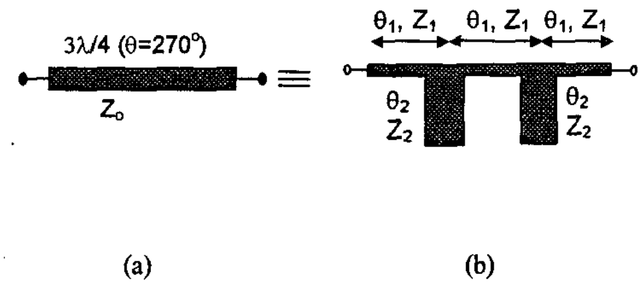

Fig.5 (a) $3\lambda/4$ transmission line
(b) Π -shape circuit equivalent to $3\lambda/4$

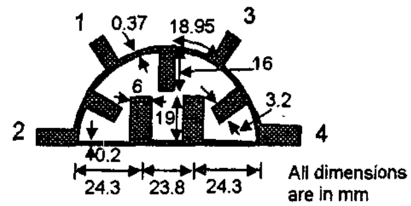

Fig.6 Layout of a compact coupler based on the T- shape circuit in Fig.2(b) and the Π circuit equivalent in Fig.5(b)

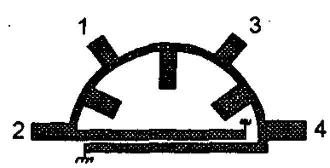

Fig.7 Layout of a compact coupler based on the coupled line short circuited at its diagonal

Fig.8 Layout of a compact coupler, the three quarter wavelength line formed in serpentine shape

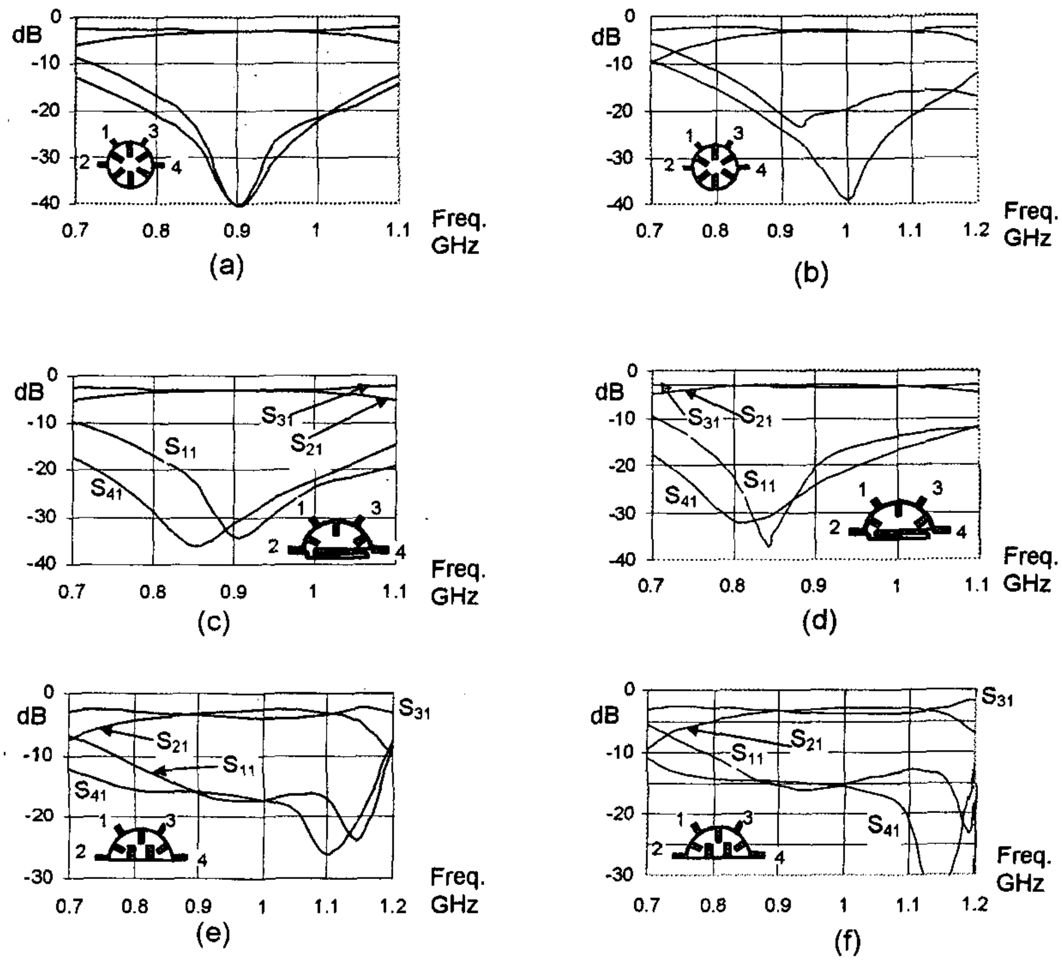

Fig.9 simulation and measured results of 3-dB ring coupler designed at 900MHz
(a), (c) and (e) are the simulated results performed by IE3D program
(b), (d) and (f) are the measured results performed by Agilent 8719Es network analyzer