UNIPLANAR DE RONDE'S CPW-SLOT DIRECTIONAL COUPLERS

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ABSTRACT

A new uniplanar de Ronde's CPW-slot directional coupler was developed with good amplitude characteristics and phase balance. The even-odd mode analysis of four-port networks with double symmetry was used to analyze the uniplanar de Ronde's couplers. A directional coupler with 5-dB coupling was designed and demonstrated over the frequency range of 2.4-3.4 GHz. The experimental results agree with the theoretical design.

I. INTRODUCTION

Hybrid couplers are indispensable components used in various MIC applications such as balanced mixers, balanced amplifiers, frequency discriminators, phase shifters, and feeding networks in antenna arrays. Some of the more commonly used are 180° and 90° hybrid couplers. Parallel-coupled transmission-line directional couplers, Lange couplers, and branch-line couplers are the fundamental 90° hybrids used in many printed microwave integrated circuit. In 1970 de Ronde [1] proposed a new coupler structure with a strip on top of the substrate and a slot in the ground plane. The de Ronde's strip-slot directional coupler can easily achieve 3-dB coupling. An empirical optimization technique for the de Ronde's strip-slot directional coupler was published by Garcia [2]. In 1974 Shiek [3] first analyzed the de Ronde's strip-slot directional coupler with the aid of the equivalent circuit of the branch-line coupler. The analysis showed that the de Ronde's strip-slot directional coupler is just a special case of the 3-branch directional coupler. In 1982 Hoffmann and Siegl [4] proposed a complete analysis of de Ronde's directional coupler using even-odd mode analysis of four-port networks with double symmetry. The scattering parameters of the couplers were derived and the compensated couplers were also demonstrated. Recently, Schoenberger *et al* [5] presented a slot-strip finline coupler which is complementary to the de Ronde's strip-slot directional coupler.

This paper describes a new uniplanar de Ronde's CPW-slot directional coupler. The new coupler uses parallel and series CPW-slotline connections. Both the CPW and slotline are on the same side of substrate. A truly uniplanar de Ronde's CPW-slot directional coupler with 5-dB coupling was demonstrated for use at 2.4-3.4 GHz. The experimental results agree with the theoretical design.

II. CPW-SLOT DIRECTIONAL COUPLERS

In recent years, uniplanar transmission lines have emerged as an alternative to microstrip in planar microwave integrated circuits. The uniplanar MIC does not use the back side of the substrate and allows easy series and shunt connections of passive and active solid-state devices. The use of uniplanar structures circumvents the need for via holes and reduces processing complexity.

Figures 1(a) and 1(b) show the physical configurations of the uniplanar de Ronde's CPW-slot directional coupler. The new coupler consists of a section of a CPW and a slotline which are in close proximity and are continuously coupled. The slotline coupling section with a compensation length L_S is terminated with a $\lambda_{gs}/4$ slotline short stub or a slotline radial stub on both ends, as shown in Figures 1(a) and 1(b), respectively. The purpose of adding an extended slotline section L_S is to compensate for the difference of phase velocity between the even- and odd-mode coupling. The output four ports are formed by two CPW-slotline tee junctions. Figures 2(a) and 2(b) show the equivalent transmission line model. The CPW-mode-excited coupling section of Figure 2 is modeled by a parallel connection of two transmission lines with characteristic impedance $Z'_C = 2Z_C$, where Z_C is the characteristic impedance of the coplanar waveguide in Figure 1. The slot-mode-excited coupling section is modeled by a series connection of a transmission line with a characteristic impedance of Z_S.

To analyze the uniplanar de Ronde's coupler, the even-odd mode analysis of four-port networks with double symmetry proposed by Hoffmann and Siegl [4] is used. Figure 3 shows the common four-port network with double symmetry with respect to planes P_1 P_1 and P_2 P_2. The scattering parameters S_{ij} can be expressed by even-odd mode excitations as [4]

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$$S_{11} = \frac{\Gamma_{ee} + \Gamma_{eo} + \Gamma_{oe} + \Gamma_{oo}}{4} \quad (1a)$$

$$S_{21} = \frac{\Gamma_{ee} - \Gamma_{eo} + \Gamma_{oe} - \Gamma_{oo}}{4} \quad (1b)$$

$$S_{31} = \frac{\Gamma_{ee} + \Gamma_{eo} - \Gamma_{oe} - \Gamma_{oo}}{4} \quad (1c)$$

$$S_{41} = \frac{\Gamma_{ee} - \Gamma_{eo} + \Gamma_{oe} - \Gamma_{oo}}{4} \quad (1d)$$

where Γ_{ee}, Γ_{eo}, Γ_{oe}, and Γ_{oo} represent the input reflection coefficients with certain combinations of even- and odd-mode excitations at ports 1, 2, 3, and 4. The first subscript e(o) denotes the combination of even- and odd-mode excitations at ports 1, 2, 3, and 4 making an open(short) circuit at the symmetry plane P_1 P_1. The second subscript e(o) denotes the combination of even- and odd-mode excitations at ports 1, 2, 3, and 4 making an open(short) circuit at the symmetry plane P_2 P_2. Figure 4 shows the definition of the reflection coefficients with double symmetry in the uniplanar de Ronde's coupler.

Characteristic impedances of the coupler lines in terms of coupling coefficient are given by [4]

$$Z_C = \frac{Z_0}{2}\sqrt{\frac{1+C}{1-C}} \quad (2)$$

$$Z_S = 2Z_0\sqrt{\frac{1-C}{1+C}} \quad (3)$$

where Z_0 is the terminating impedance, Z_C is the characteristic impedance of coplanar waveguide, Z_S is the characteristic impedance of slotline, and C is the coupling coefficient.

According to synthesis equations (2) and (3), a truly uniplanar de Ronde's CPW-slot directional coupler, as shown in Figure 1(b), with 5-dB coupling was built on a RT/Duroid 6010.8 (ε_r = 10.8) substrate with the following dimensions: substrate thickness h = 1.524 mm, impedance of the slotline feeds Z_{S0} = 50.82 Ω, slotline feeds line width W_{S0} = 0.07 mm, CPW impedance Z_C = 47.21 Ω, CPW center conductor width S_C = 0.43 mm, CPW gap size G_C = 0.23 mm, length of the CPW-slot coupling section $\lambda_{gc}/4$ = 10.57 mm, impedance of the slotline coupling section Z_S = 53.0 Ω, line width of the slotline coupling section W_S = 0.094 mm, radius of the slotline radial stub r = 6 mm, and angle of the slotline radial stub $\theta = 60^\circ$.

To test the coupler, a wide-band CPW-slotline transition [6,7] was used to connect to ports 1, 2, 3, and 4. The measurements were made using standard SMA connectors and an HP-8510 network analyzer. Figure 5(a) shows the measured frequency responses of power transmitting and coupling. The power coupling is 5.55 dB (including insertion loss) at the center frequency of 3 GHz. Figure 5(b) shows the measured return loss and isolation between ports 1 and 4. The return loss is more than 14 dB and the isolation is more than 17 dB at the center frequency. They are more than 11 dB over the octave bandwidth of 2-4 GHz. Figure 6 shows phase angles of ports 2 and 3. The phase difference between ports 2 and 3 is 90.3° at the center frequency, and $90^\circ \pm 7^\circ$ in the frequency range of 2-4 GHz. The 5-dB uniplanar de Ronde's CPW-slot directional coupler provides good coupling and phase performance as predicted.

III. CONCLUSIONS

A new uniplanar de Ronde's CPW-slot directional coupler was presented. The coupler uses coplanar waveguides and slotlines on one side of the substrate. A 5-dB uniplanar de Ronde's CPW-slot directional coupler was demonstrated and the experimental results showed good coupling and phase performances as predicted. With its advantages of a simple design procedure, compact size, uniplanar structure, and easy integration with solid state devices, this new uniplanar de Ronde's CPW-slot directional coupler should have many applications in hybrid and monolithic integrated circuits.

ACKNOWLEDGMENTS

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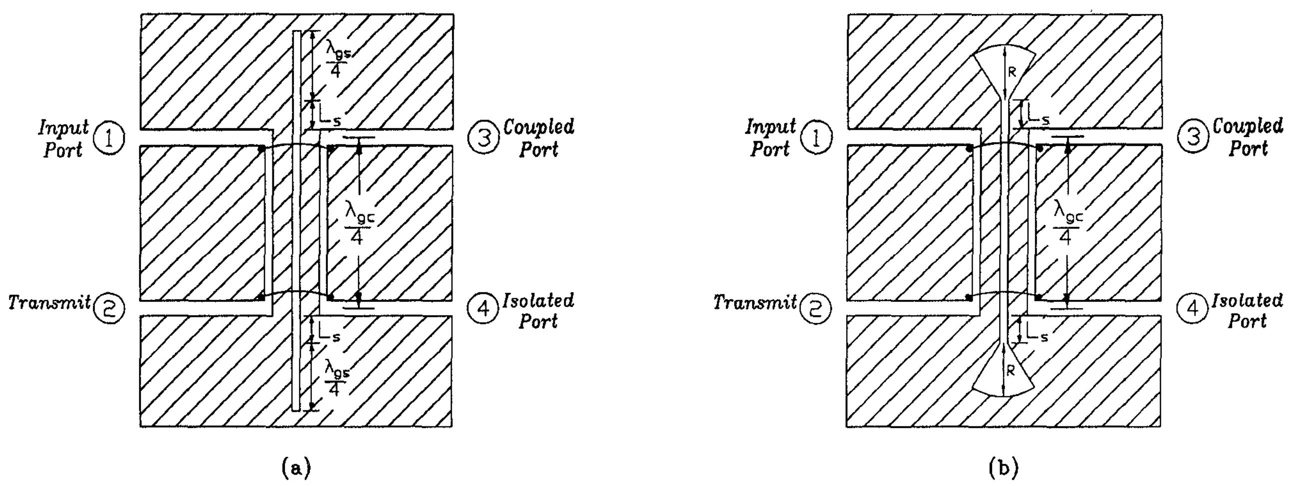


Fig. 1 Configuration of the uniplanar de Ronde's CPW-slot directional coupler with (a) $\lambda_{gs}/4$ slotline short stubs and (b) Slotline radial stubs on both ends of the slot-mode-excited coupling section.

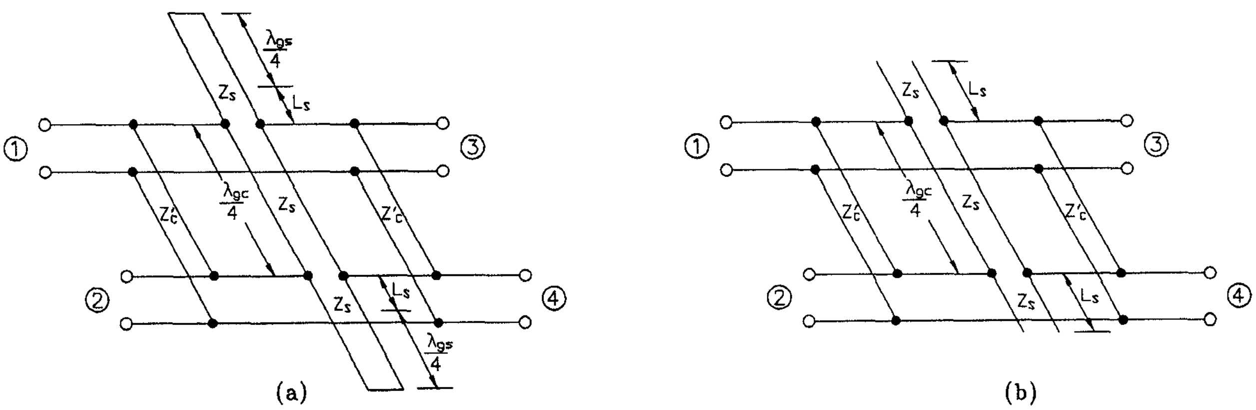


Fig. 2 Equivalent transmission line model for the coupler in Figure 1 with (a) $\lambda_{gs}/4$ slotline short stubs and (b) Slotline radial stubs on both ends of the slot-mode-excited coupling section.

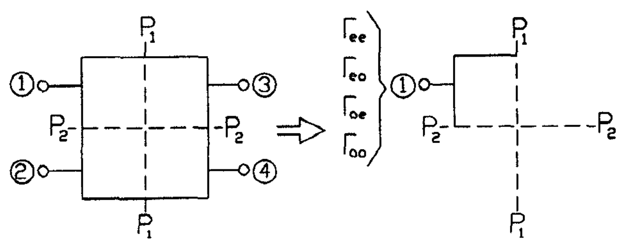


Fig. 3 Configuration of the common four-port network with double symmetry with respect to planes P_1 P_1 and P_2 P_2.

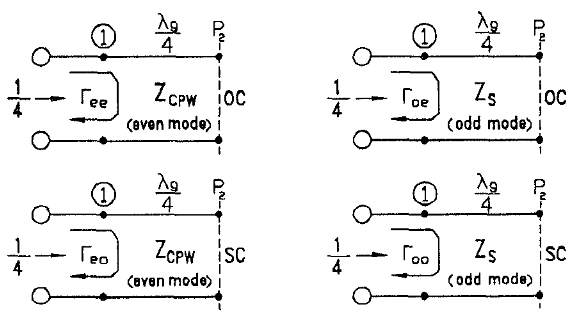
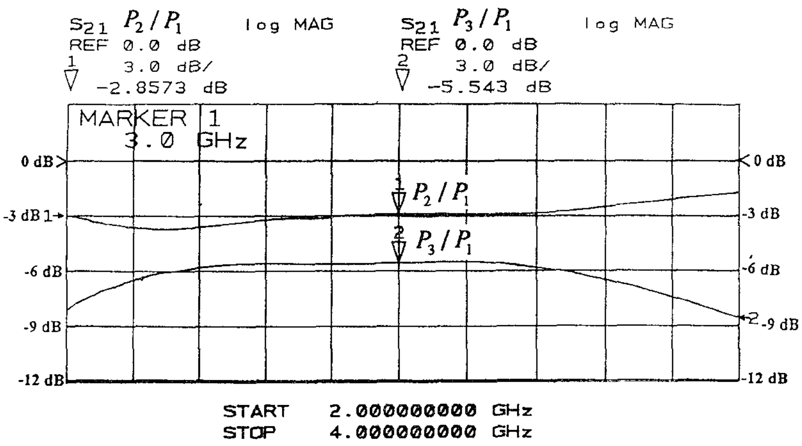
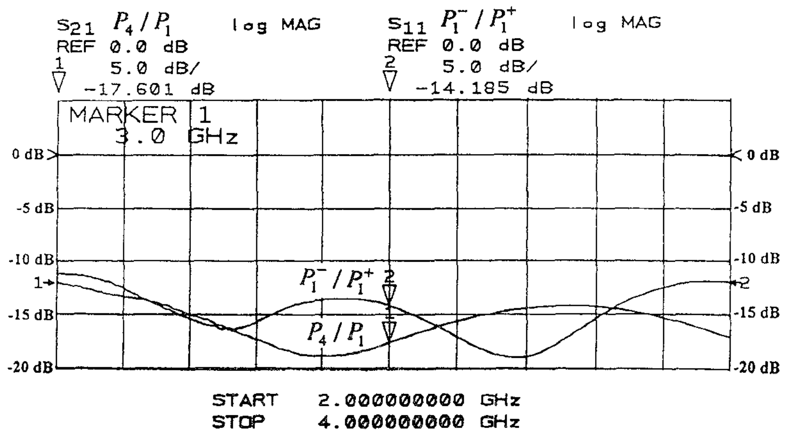


Fig. 4 Schematic expression of the reflection coefficients with double symmetry in the uniplanar de Ronde's coupler.



(a)



(b)

Fig. 5 Measured frequency responses of (a) Power transmitting and coupling, and (b) Return loss and isolation for the uniplanar de Ronde's CPW-slot directional coupler with 5-dB coupling.

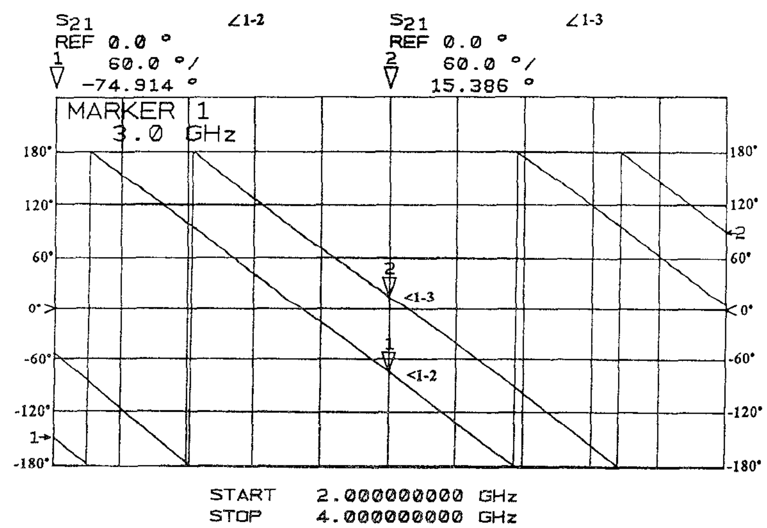


Fig. 6 Measured frequency responses of phase angles for the uniplanar de Ronde's CPW-slot directional coupler with 5-dB coupling.