Uniplanar MIC Power Dividers Using Coupled CPW and Asymmetrical CPS

Lu Fan and Kai Chang
Department of Electrical Engineering
Texas A&M University
College Station, Texas 77843-3128, USA

ABSTRACT

Two uniplanar power dividers using coupled CPW and asymmetrical CPS have been developed for MICs and MMICs. These circuits provide substantially improved performance over a wide bandwidth compared to conventional microstrip power dividers. Measured results show that both power dividers have greater than 20 dB isolation, less than 0.4 dB insertion loss over a bandwidth of more than 30% centered at 3 GHz. Experimental results agree well with calculated ones.

I. INTRODUCTION

Power dividers are fundamental and important components widely used in various MIC applications such as balanced mixers, balanced amplifiers, phase shifters, and feed networks in antenna arrays. Many papers on power dividers have been published in the past decades [1-3]. The Wilkinson power divider, a popular two-way power divider/combiner, is a well-known example [4]. According to the phase between output ports, power dividers can be classified into two types: the in-phase dividing types and out-of-phase ones. The former are made of microstrip lines [5], while in the later case, coupled microstrip-slot lines are used [6]. Most previous work is based on microstrip structures because microstrip is the most mature and widely used transmission line. However, some shortcomings of microstrip include sensitivity to substrate thickness, difficulty of inserting shunt solid-state devices and the requirement of high impedance lines for dc biasing. In recent years, uniplanar transmission lines such as coplanar waveguide (CPW), slotline, and coplanar strip (CPS) have become a competitive alternative to microstrip in many applications (including both microwave hybrid and monolithic technologies). These transmission lines have advantages of small dispersion, simple realization of short circuited ends, easy integration with lumped elements or active components, and no need for via holes. Some attractive couplers using uniplanar structures have been reported [7-10]. To further extend uniplanar techniques to MIC and MMIC applications, additional uniplanar components are required. Therefore, this paper presents two new power dividers that have characteristics similar to those of microstrip circuits with the advantages of a uniplanar structure and better performance. The circuit analyses for the power dividers are based on simple transmission line models by the method of even-mode and odd-mode, and simulations of the circuits were performed using Libra. The measured results agree very well with the theoretical predictions.

II. COUPLED CPW POWER DIVIDERS

As mentioned above, power dividers are divided into the in-phase and out-of-phase types. This section describes uniplanar in-phase two-way power dividers Figure 1 shows the physical configurations of the power dividers. The circuits consist of a CPW input line, a quarter-wavelength coupled CPW, a mini size chip resistor, and two CPW outputs or two slotline outputs as shown in Figures 1(a) and 1(b), respectively. The equivalent transmission line model of the dividers is shown in Figure 2. The parallel transmission lines represent the coupled CPW operating in even-mode and odd-mode. The fundamental behavior of the dividers can easily be understood by examining the equivalent circuit in Figure 2. The input signal fed to port 1 propagates through the CPW and is then converted to the even mode of the coupled CPW. After propagation through the coupled CPW, it is divided into two components that both arrive in-phase at ports 2 and 3.

0-7803-3246-6/96/$5.00 © IEEE

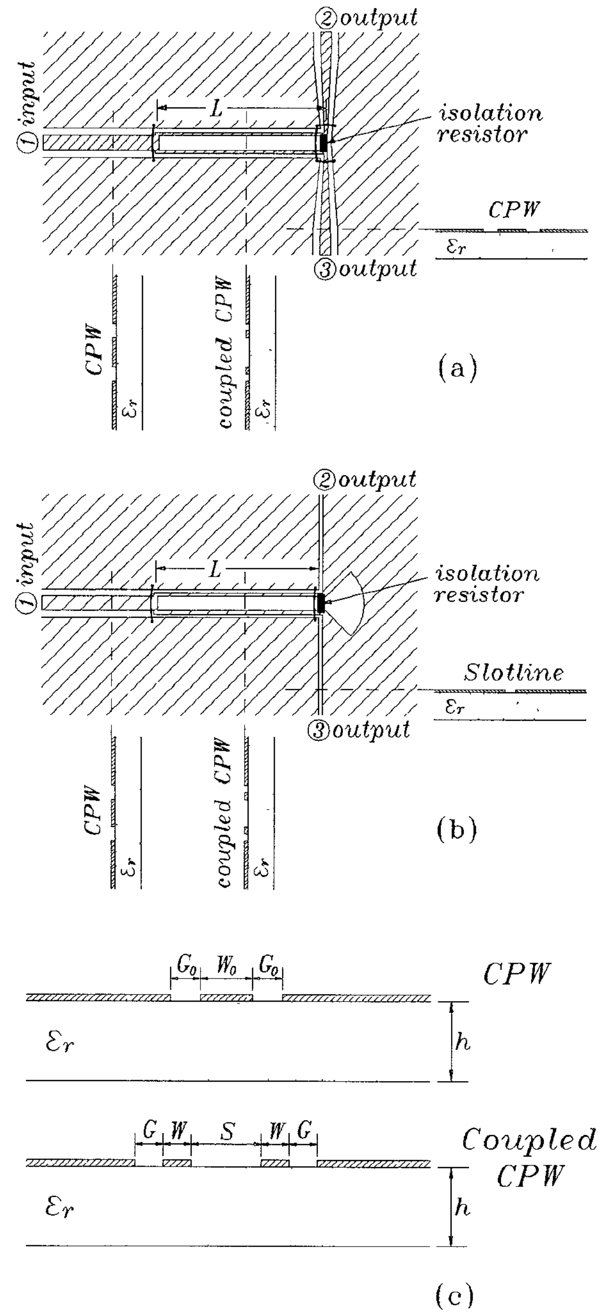


Figure 1. Circuit configurations of uniplanar CPW power dividers. (a) The power divider with CPW output arms and (b) with slotline output arms. (c) Cross sectional views of the CPW and coupled CPW.

The symmetrical circuit in Figure 2 is analyzed by the method of even-mode and odd-mode excitations of ports 2 and 3 with a load Z_0 connected to port 1 [2]. Figure 3 shows the equivalent circuits when ports 2 and 3 are excited by the even mode and odd mode. In Figure 3, R

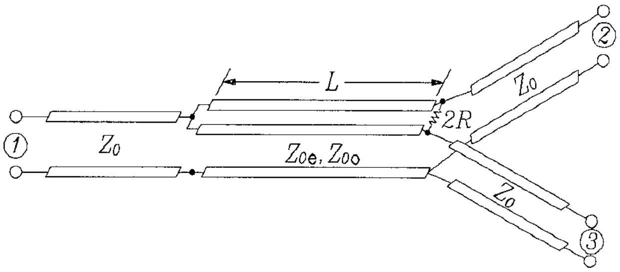


Figure 2. Equivalent transmission line model of the power dividers shown in Figure 1.

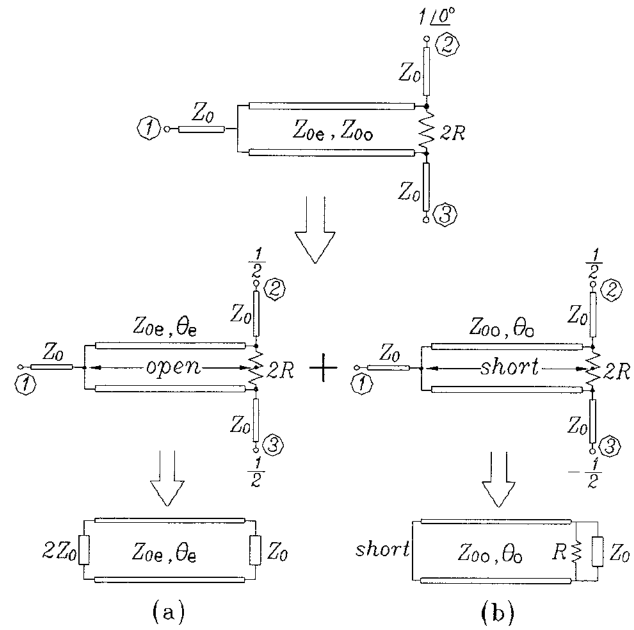


Figure 3. Equivalent circuits for the in-phase and out-of-phase excitations. (a) In-phase excited circuit and (b) out-of-phase excited circuit.

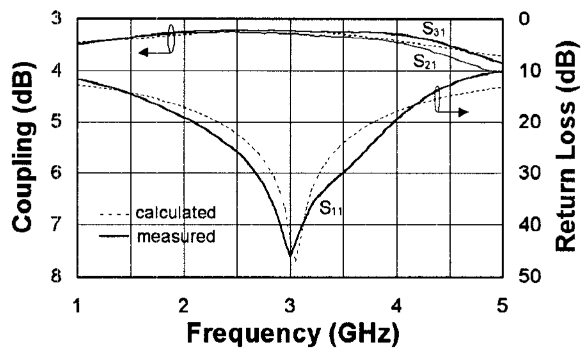
is an isolation resistor between ports 2 and 3, and θ_e, Z_{0e} and θ_o, Z_{0o} are the electrical length and characteristic impedance of the even mode and odd mode of the coupled CPW, respectively. If θ_e and θ_o be equal to 90°, then $Z_{0e} = \sqrt{2}Z_0$ and $R = Z_0$ are obtained. Although there is no restriction for Z_{0o}, it should be given a proper value easy to implement in practical circuits.

According to the above principal, uniplanar CPW power divider has been designed and fabricated on an RT/Duroid 6010 substrate (relative dielectric constant $\varepsilon_r = 10.8$, substrate thickness h = 1.524 mm, metal thickness t = 18 μm). The center frequency is 3.0 GHz. The characteristic impedances of the input/output CPWs were chosen as $Z_0 = 50\ \Omega$, resulting in the characteristic impedance $Z_{0e} = 71\ \Omega$ and isolation resistor $2R = 100\ \Omega$.

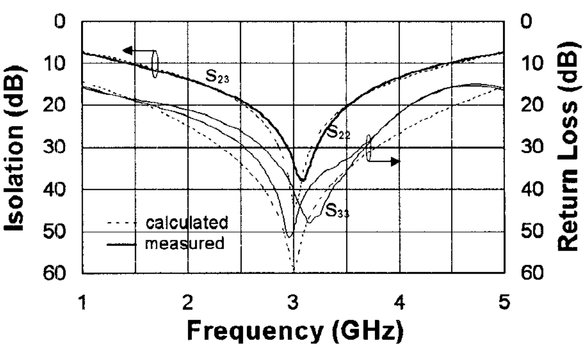
From these known values, simulation and synthesis for the practical circuit were performed using Libra. The relevant geometrical parameters are listed in Table I. It is important to note that the use of air bridges at the circuit's discontinuities prevents the coupled slotline mode from propagating on the CPW lines. The measurements were made on an HP-8510 network analyzer using standard SMA connectors. The insertion loss includes two coaxial-to-CPW transitions and 30 mm long input/output CPW lines.

Table I. The geometrical parameters of the uniplanar CPW power divider as shown Fig. 1(a). (All dimensions are in mm.)

I / O CPW		Coupled CPW			
W_0	G_0	W	G	S	L
0.62	0.33	0.17	0.1	0.8	10.74



(a)



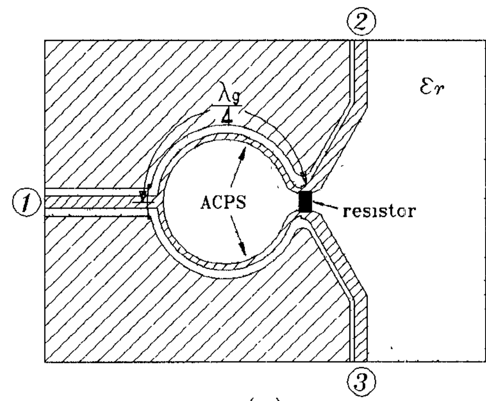
(b)

Figure 4. Measured and calculated frequency responses of the CPW power divider shown in Fig. 1(a) at center frequency of 3 GHz. (a) Coupling of 1-2 and 1-3 and 1-port's return loss. (b) 2-port's and 3-port's return loss and isolation between ports 2 and 3.

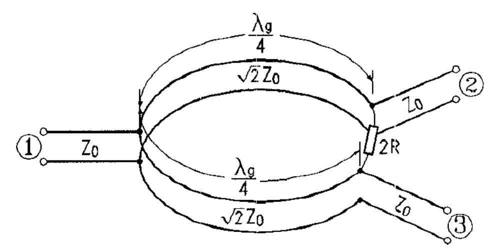
The practical circuit shown in Figure 1(a) was tested from 1 to 5 GHz. Figures 4(a) and (b) show the power divider's measured and calculated insertion loss, return loss and isolation. Over a 30% bandwidth centered at 3 GHz, Figure 4(a) shows that the insertion loss is less than 3.3 dB (3 dB for ideal coupling), and the input return loss is greater than 26 dB. The isolation between the two output ports is greater than 20 dB and the return loss of port 2 or 3 is greater than and 27 dB, as shown in Figure 4(b). Figures 4(a) and 4(b) also indicate that the experimental results agree very well with the calculations. The circuit shown in Figure 1(b) gave similar results to the circuit in Figure 1(a).

III. UNIPLANAR WILKINSON POWER DIVIDER

Figure 5(a) shows the circuit layout of the uniplanar Wilkinson power divider that is realized on one side of the substrate using coplanar waveguide (CPW) and asymmetrical coplanar strip (ACPS) transmission lines. The circuit consists of a CPW-ACPS tee junction, a pair of ACPS arms, a mini size chip resistor, and two ACPS



(a)



(b)

Figure 5. Asymmetrical coplanar strip (ACPS) power divider. (a) Circuit configuration and (b) equivalent transmission line model.

outputs. Unlike the divider in Figure 1, two arms of the divider in Figure 5(a) are separated without coupling. Figure 5(b) shows the equivalent transmission line model of the power divider.

Similar to the divider's case in section II, the uniplanar ACPS power divider was fabricated on a 1.524 mm-thick RT/Duroid 6010 (ε_r = 10.8) substrate. The center frequency is 3.0 GHz. The dimensions of the circuit are given as follows:

CPW feed lines: Z_0 = 50 Ω (center strip width W = 0.62 mm, gap size G = 0.33 mm)

ACPS output lines: Z_0 = 50 Ω (strip width Sacps = 0.7 mm, gap size Gacps = 0.1 mm)

ACPS arm's lines: $\sqrt{2}\,Z_0$ = 71 Ω (strip width Sacps = 0.4 mm, gap size Gacps = 0 3 mm)

ACPS arm's length: $\lambda g/4$ = 9.54 mm

Isolation resistor. 2R = 100 Ω.

To find the dimensions of the ACPS lines in the circuit, Sonnet software was used to perform syntheses. To eliminate the coupled slotline mode propagating on the ACPS lines, bonding wires have been placed at the power divider's CPW-ACPS tee junction. The tests were made on an HP-8510 network analyzer using standard SMA connectors from 1 to 5 GHz.

Figure 6 shows the power divider's measured frequency responses of coupling, isolation and input return loss. Over a 30% bandwidth centered at 3 GHz, the measured results show that the coupling of the power from port 1 to ports 2 and 3 are 3.34 dB and 3.37 dB, respectively. The isolation between ports 2 and 3 is greater than 21 dB, and the return loss is more than 22 dB both over a frequency range from 2.5 to 3.5 GHz.

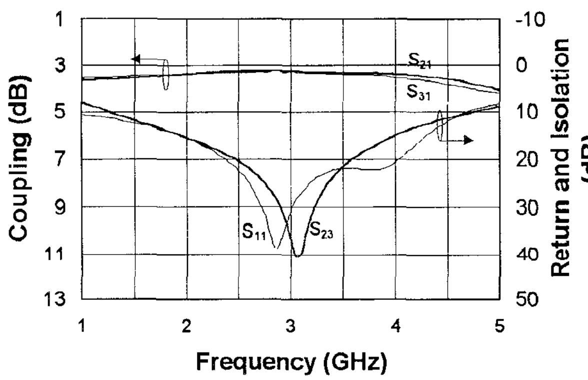


Figure 6. Experimental performance of the ACPS power divider. (a) Coupling, return loss and isolation. (b) Amplitude difference and phase difference.

IV. CONCLUSIONS

The design procedure and results of two newly developed uniplanar power dividers using coupled CPW or ACPS were described. The power dividers demonstrated good performance over a wide bandwidth as compared to conventional microstrip power dividers. With its advantages of a compact, simple, uniplanar structure and easy integration with solid-state devices, these uniplanar power dividers will be useful in many applications for MICs and MMICs.

REFERENCE

[1] E. J. Wilkinson, "An N-way hybrid power divider," *IRE Trans. Microwave Theory Tech.*, vol. MTT-8, pp. 116-118, Jan. 1960.

[2] S. B Cohn, "A class of broadband three-port TEM-mode hybrids," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, p. 110-116, Feb. 1968.

[3] R. B. Ekinge, "A new method of synthesizing matched broad-band TEM mode three ports," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, p. 81-88, Jan. 1971.

[4] S. Y. Liao, *Microwave Transistor Amplifiers Analysis and Design*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1984, p.176.

[5] L. I. Parad and R. L. Moynihan, "Split-tee power divider," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-13, p. 91-95, Jan. 1965.

[6] H. Ogawa, T. Hirota, and M. Aikawa, "New MIC power dividers using coupled microstrip-slot lines: Two-sided MIC power dividers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, p. 1155-1164, Nov. 1985.

[7] C. H. Ho, L. Fan, and K. Chang, "New uniplanar coplanar waveguide couplers," in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1994, pp. 285-288.

[8] D. Kother, B. Hopf, Th. Sporkmann, and I. Wolff, "MMIC Wilkinson couplers for frequencies up to 110 GHz," in *IEEE MTT-S Int. Microwave Symp. Dig.*, 1995, pp. 663-666.

[9] C. H. Ho, L. Fan, and K. Chang, "Broad-band uniplanar hybrid-ring and branch-line couplers," *IEEE Trans. Microwave Theory Tech*, vol MTT-41, pp. 2116-2125, Dec. 1993.

[10] C. H. Ho, L. Fan, and K. Chang, "New uniplanar coplanar waveguide hybrid-ring couplers and magic-Ts," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-42, pp. 2440-2448, Dec. 1994.