A 180° Out-of-Phase Power Divider Using Asymmetrical Coplanar Stripline

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***Abstract*— This letter presents a new uniplanar 3-dB power divider using an asymmetrical coplanar stripline (ACPS) for microwave integrated circuit (MIC) and microwave and millimeter-wave integrated circuit (MMIC) applications. The circuit having 180° out-of-phase between two output ports provides good performance as compared to conventional microstrip power dividers. Experimental results for the power divider show an amplitude imbalance of 0.4 dB and a phase difference of 180° ± 1° over a wide bandwidth from 2.5 to 3.5 GHz.**

I. Introduction

POWER DIVIDERS are fundamental components extensively used in the realization of a variety of microwave circuits such as balanced mixers, data modulators, phase shifters, and feed networks in antenna arrays. The Wilkinson power divider, a popular two-way power divider/combiner, is a well-known example [1]. According to the phase between output ports, power dividers can be classified into two types: the in-phase dividing types and 180° out-of-phase ones. The former are made of microstrip lines [2], while in the later case, coupled microstrip-slot lines are used [3]. This double-sided circuit configuration, however, is not suitable for microwave and millimeter-wave (MMIC) implementation because it uses the back side of the substrate. Most previous work is based on microstrip structures, because the microstrip is the most mature and widely used transmission line. In recent years, uniplanar transmission lines such as coplanar waveguide (CPW), coplanar strip (CPS), and slotline have become a competitive alternative to microstrip in many applications. These transmission lines have the advantages of small dispersion, simple realization of short-circuited ends, easy integration with lumped elements or active components, and no need for via holes. More recently, asymmetrical uniplanar transmission lines (asymmetrical coplanar waveguide (ACPW) [4] and asymmetrical coplanar stripline (ACPS) [5]) have been used as alternatives to symmetrical ones because of the additional flexibility offered by the asymmetric configuration in the design of MIC's. The applications of ACPW to mixers [6] and attenuators [7] have been reported by Jaisson. To further extend the asymmetric uniplanar techniques to MIC and MMIC applications, additional uniplanar components are needed. This letter presents a new power divider that has characteristics similar to those of microstrip circuits with the advantages of a uniplanar structure and good performance. The circuit analyzes of the power divider are based on simple transmission line models by the method of even mode and odd mode. The syntheses of the ACPS lines have been conducted using Sonnet software.

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II. Circuit and Design

Fig. 1(a) shows the physical configuration of the 180° out-of-phase ACPS Wilkinson power divider that is realized on one side of the substrate using slotline and asymmetrical coplanar strip (ACPS) transmission lines. The circuit consists of an input slotline, a slotline-ACPS T-junction, a ACPS ring serving as two ACPS arms, a mini-size chip resistor, and two ACPS (or slotline) outputs. The slotline-ACPS T-junction of the divider is used as a phase inverter. Fig. 1 (b) shows the cross sections at two locations along the power divider. The equivalent transmission line model of the power divider is shown in Fig. 1(c). The fundamental behavior of the divider can easily be understood by examining the equivalent circuit. The input signal is fed to port 1 and then divided into two components with a 180° phase difference (made by the slotline-ACPS reverse-phase T-junction) to the ACPS arms. After propagating through the ACPS arms, the two components arrive 180° out-of-phase at ports 2 and 3.

The symmetrical circuit in Fig. 1(c) is analyzed by even-mode and odd-mode excitations of ports 2 and 3 with a load Z_0 connected to port 1. Fig. 2 shows the equivalent circuits when ports 2 and 3 are excited by the even and odd modes. In Fig. 2, R is an isolation resistor and θ and Z_{ACPS} are the electrical length and characteristic impedance of the two ACPS arms, respectively. By choosing θ to be equal to $90°$, $Z_{\text{ACPS}} = Z_0/\sqrt{2}$ and $R = Z_0/2$ are obtained.

III. Experimental Results

According to the criterion as mentioned above, the 180° out-of-phase ACPS power divider has been designed and fabricated on an RT/Duriod 6010 substrate (relative dielectric constant $\epsilon_r = 10.8$, substrate thickness $h = 1.524$ mm, metal thickness $t = 18$ μm). The center frequency is 3.0 GHz. The characteristic impedances of the input slotline and output ACPS lines were chosen as $Z_0 = 100$ Ω, resulting in the characteristic impedance of the two ACPS arms $Z_{\text{ACPS}} = 71$ Ω and the isolation resistance $R = 50$ Ω. If a $Z_0 = 50$ Ω is chosen, the Z_{ACPS} is 35 Ω, which is very difficult to implement using ACPS. From these known values, The dimensions of the circuit are given as follows:

Slotline input line: $Z_0 = 100$ Ω (gap size $G_0 = 1.2$ mm).

ACPS output lines: $Z_0 = 100$ Ω (strip width $W_{\text{acps}} = 0.3$ mm, gap size $G_{\text{acps}} = 0.4$ mm).

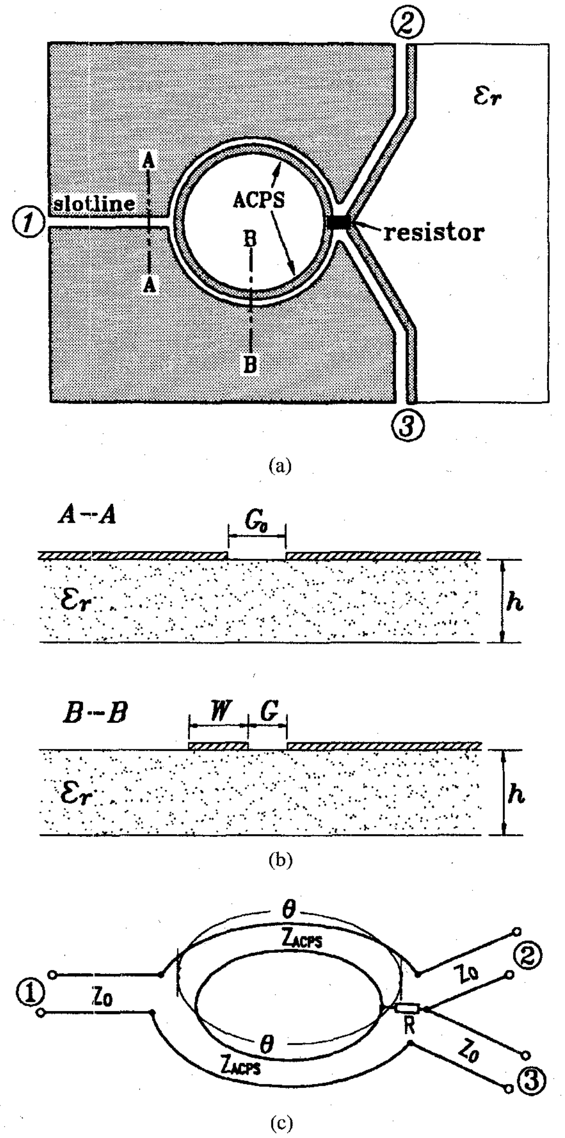

Fig. 1. Asymmetrical coplanar strip (ACPS) 180° out-of-phase power divider. (a) Circuit configuration. (b) Cross-sectional views of the slotline and ACPS. (c) Equivalent transmission line model.

ACPS arm's lines: $Z_{\text{ACPS}} = 71\ \Omega$ (strip width $W = 0.4$ mm, gap size $G = 0.3$ mm).

ACPS arm's length: $\lambda_g/4 = 9.54$ mm ($\theta = 90°$).

To find the dimensions of the ACPS lines in the circuit, Sonnet software was used to perform the syntheses. It is important to note that the bonding wires are not needed in this circuit. The measurements were made on an HP-8510 network analyzer using standard SMA connectors from 2 to 4 GHz. The insertion loss includes two coaxial-to-CPW/CPS transitions, a CPW-to-slotline transition, and 48-mm-long input/output lines.

The experimental data are shown in Fig. 3. Fig. 3(a) shows the power divider's measured insertion loss, return loss, and isolation. Over a 13% bandwidth centered at 3 GHz, the insertion loss ($|S_{21}|$ or $|S_{31}|$) is less than 3.8 dB (3 dB for ideal coupling), the input return loss ($|S_{11}|$) is greater than 20 dB, the return losses of ports 2 and 3 ($|S_{22}|$ and $|S_{33}|$) are greater than 23 dB, and the isolation ($|S_{32}|$) between the two output ports is greater than 20.5 dB. As shown in Fig. 3(b), the divider's output amplitude imbalance (0.3 dB) and phase difference (180° ± 1°) between ports 2 and 3 are excellent over a broad bandwidth because the phase reversal of the slotline-ACPS T-junction is frequency independent.

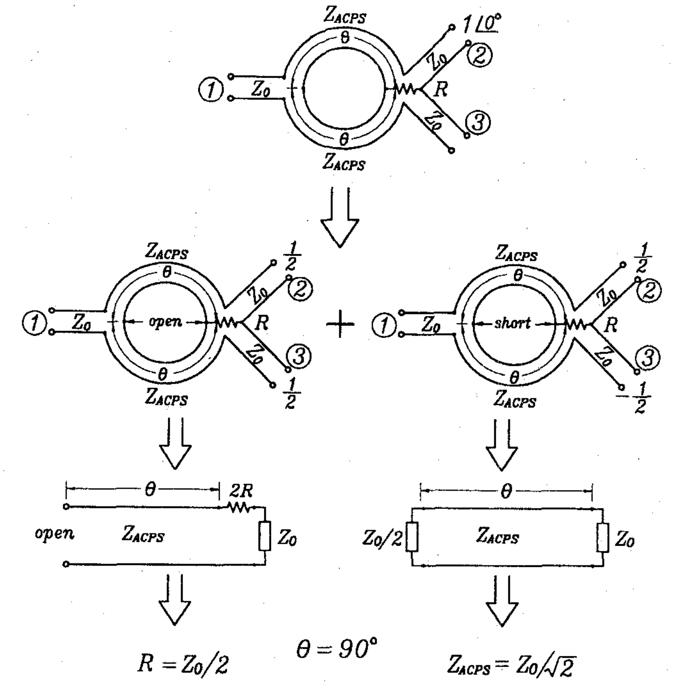

Fig. 2. Equivalent circuits of the ACPS 180° out-of-phase power divider for in-phase and out-of-phase excitations.

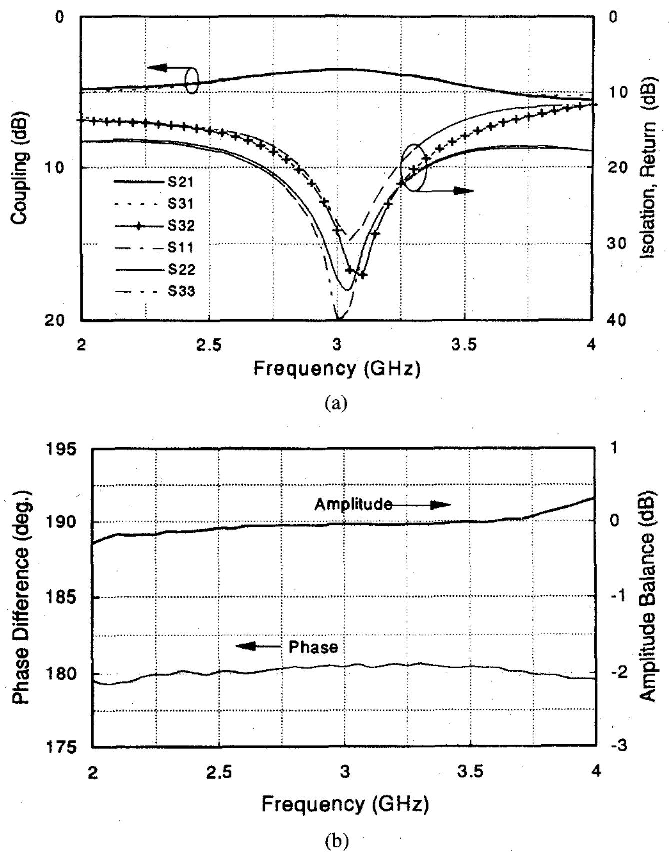

Fig. 3. Experimental performance of the 180° out-of-phase ACPS power divider. (a) Coupling, return loss, and isolation. (b) Amplitude imbalance and phase difference.

IV. Conclusion

The design procedure and results of a new 180° out-of-phase power divider using ACPS were described. The power divider demonstrated a good amplitude imbalance and phase difference over a wide bandwidth, but insertion loss, isolation, and return loss are over a narrow bandwidth as compared to the in-phase power dividers [8]. With its advantages of a compact, simple, uniplanar structure, and ease of integration with solid-state devices, this uniplanar power divider will be useful in many applications for MIC's and MMIC's.

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