UNIPLANAR HYBRID COUPLERS USING ASYMMETRICAL COPLANAR STRIP LINES

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ABSTRACT

This paper presents two uniplanar 3-dB hybrid couplers using asymmetrical coplanar strip (ACPS) for MIC and MMIC applications. The uniplanar rat-race hybrid coupler has less than 0.5 dB insertion loss, greater than 22 dB isolation, and 22.5 dB return loss over a 25% bandwidth centered at 3 GHz. The 180° reverse-phase hybrid coupler provides better performance as compared to conventional microstrip hybrid couplers. Experimental results show that the 180° hybrid coupler has a bandwidth of more than one octave from 2 to 4 GHz with ± 0.2 dB power dividing imbalance and ± 1.5° phase imbalance.

I. INTRODUCTION

Hybrid couplers are fundamental and important 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. Rat-race hybrids [1], reverse-phase hybrids [2], and cross-over hybrids [3] are well-known examples of 180° hybrid couplers. Most previous work is based on microstrip structures because microstrip is the most mature and widely used transmission line. However, In recent years, uniplanar transmission lines such as coplanar waveguide (CPW), coplanar strip (CPS) and slotline have become a competitive alternative to microstrip with increasing use in many applications. 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. Many attractive uniplanar 180° and 90° hybrids were proposed [4-5]. More recently, asymmetrical uniplanar transmission lines such as asymmetrical coplanar waveguide (ACPW) and asymmetrical coplanar strip (ACPS) have been used as alternatives to symmetrical ones because of the additional flexibility offered by the asymmetric configuration in the design of MICs. The applications of ACPW and ACPS to mixers [6], attenuators [7], and power dividers [8] have been reported. To further extend the asymmetric uniplanar techniques to MIC and MMIC applications, more uniplanar components are required. This paper presents two new uniplanar 180° hybrid couplers using ACPS. These couplers have characteristics similar to those of microstrip circuits with the advantages of a uniplanar structure and better performance. Based on equivalent transmission line models, the circuit analyses and simulations for the couplers are performed using Libra. The syntheses of the ACPS lines have been conducted using Sonnet. The measured results agree well with the calculated ones.

II. UNIPLANAR RAT-RACE HYBRID COUPLER

As mentioned above, to fully use the advantages of asymmetric uniplanar structures, additional asymmetric coplanar strip (ACPS) components need to be developed. This section describes an ACPS rat-race hybrid coupler. Figure 1 shows the physical configuration of the uniplanar rat-race hybrid coupler that is realized on one side of the substrate using CPW and ACPS transmission lines. The circuit consists of four CPW-ACPS Y-junctions and an ACPS hexagon-ring divided into three $\lambda_{g,ACPS}/4$ sections and one $3\lambda_{g,ACPS}/4$ section. The characteristic impedance of the ACPS hexagon-ring is $Z_{ACPS} = \sqrt{2}Z_{0C}$, where Z_{0C} is the characteristic impedance of the CPW feed lines. Based on this design, an experimental circuit was etched on a 0.635 mm-thick RT/Duroid 6010 (ε_r = 10.8) substrate with characteristic impedance: (i) Z_{0C} = 50 Ω for the four CPW feed lines, (ii) Z_{ACPS} = 71 Ω for the ACPS hexagon-ring. The center frequency is 3 GHz. To find the dimensions of the ACPS lines in the circuit, Sonnet software was used to perform the syntheses. To eliminate the coupled slotline mode propagating on the ACPS lines, bonding wires have been placed at the CPW-ACPS Y-junctions.

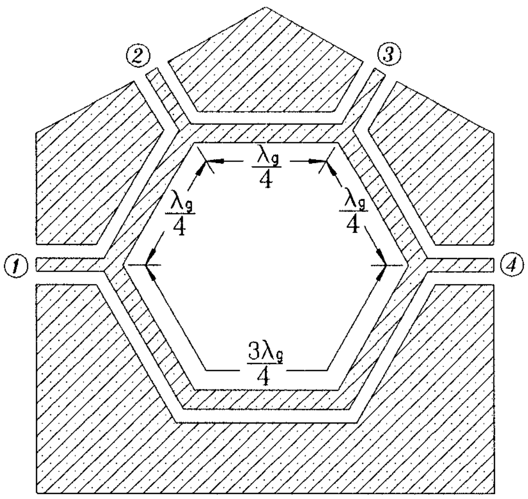


Figure 1. Circuit configuration of asymmetrical coplanar strip (ACPS) rat-race hybrid coupler.

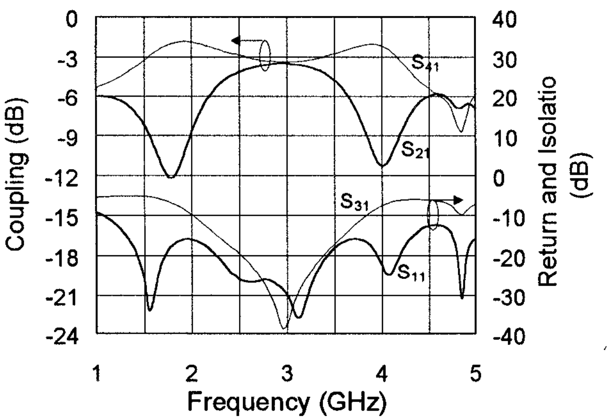


Figure 2. Measured coupling, return loss, and isolation for the ACPS rat-race hybrid coupler.

Figure 2 shows the rat-race hybrid coupler's measured insertion loss, return loss, and isolation. The measurements were made on an HP-8510 network analyzer using standard SMA connectors. Over a 750 MHz bandwidth centered at 3 GHz, the measured results show that the insertion loss ($|S_{21}|$ or $|S_{41}|$) is 3.5 ± 0.4 dB (3 dB for ideal coupling, the insertion loss includes two coaxial-to-CPW transitions and 40 mm long input/output CPW lines), the input return loss ($|S_{11}|$) is greater than 22 dB, and the isolation ($|S_{31}|$) is greater than 22.5 dB. Compared with the microstrip rat-race hybrid coupler with a typical bandwidth of 20%, the ACPS coupler has a bandwidth of 25%.

III. 180° REVERSE-PHASE HYBRID COUPLER

The rat-race hybrid coupler is the well-known and commonly used 180° hybrid. However, the 20-25% bandwidth of the rat-race coupler limits its applications to narrow-band circuits. To extend the bandwidth with a simple design procedure and uniplanar structure, this section presents a new uniplanar hybrid coupler consisting of a ACPS square-ring with four CPW feeds. The design technique substitutes one 180° reverse-phase ACPS section with a length of $\lambda_{g,ACPS}/4$ for the conventional rat-race phase delay section ($3\lambda_{g,ACPS}/4$). Since the phase reverse of the ACPS reverse-phase section is frequency independent, the resulting ACPS square-ring coupler has a broad bandwidth.

A. 180° reverse-phase ACPS section

Figure 3 shows the circuit configurations and the E-field distribution for the ACPS in-phase and out-of-phase sections. The out-of-phase section consists

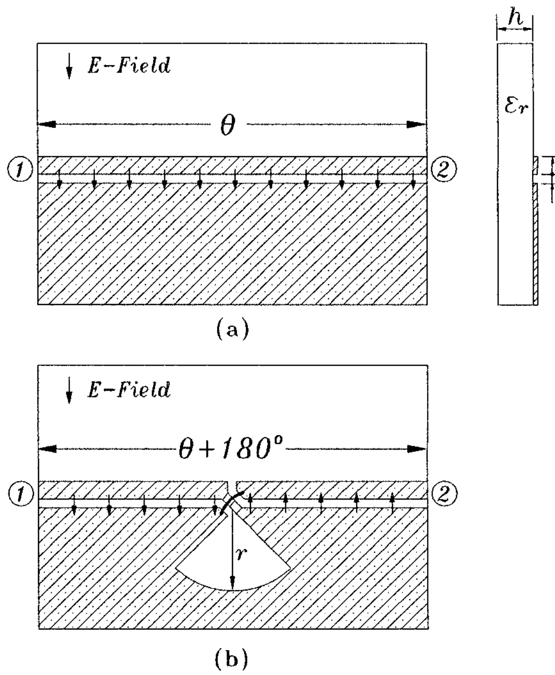


Figure 3. Circuit configurations and E-field distribution for (a) Asymmetrical coplanar strip (ACPS), and (b) ACPS 180° reverse-phase section.

of a slotline radial-stub and a bonding wire crossing over the ACPS transmission line. The arrows shown in Figure 3 indicate the electric fields in the ACPS lines. In Figure 3(a), the input signal fed to port 1 propagates through the ACPS and arrives in-phase at port 2. In Figure 3(b), the input signal fed to port 1 propagates through the ACPS crossover and arrives out-of-phase at port 2. Figure 4 shows the measured amplitude and phase differences between the circuits as shown in Figure 3. The maximum amplitude difference is 0.5 dB from 1 to 5 GHz. The maximum phase difference is $180^{\circ} \pm 5^{\circ}$ over the same frequency range.

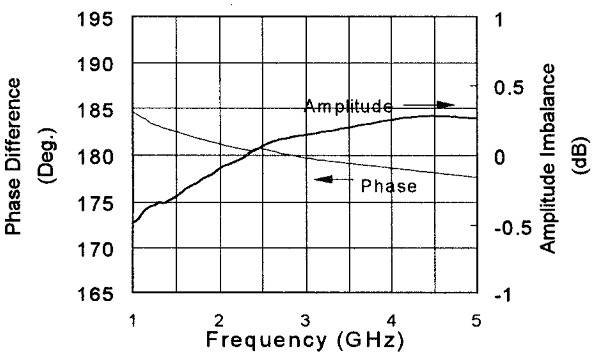


Figure 4. Measured amplitude and phase differences between the circuits shown in Figure 3.

B. 180° reverse-phase hybrid coupler

Figure 5(a) shows the circuit configuration of the new hybrid coupler consisting of four CPW-ACPS Y-junction and one ACPS square-ring (i.e., four ACPS arms; one of them with a 180° phase reversal). In Figure 5(a), ports E and H correspond to the E-arm and H-arm of the conventional waveguide magic-T, respectively. Ports 1 and 2 are the balanced arms. Figure 5(b) shows the equivalent transmission line model of the coupler. The twisted transmission line represents the phase reversal of the ACPS crossover. When the signal is fed to port H, it splits into two equal components that arrive at ports 1 and 2 in phase, but are canceled out at port E. When the signal is fed to port E, it splits into two equal components that arrive at ports 1 and 2 out-of-phase and are canceled out at port H.

Similar to the case of the rat-race coupler in Section II, the 180° reverse-phase hybrid coupler was fabricated on an RT/Duroid 6010 (ε_r = 10.8, h = 0.635 mm) substrate. The center frequency is 3 GHz. The simulation and synthesis for the practical circuit were performed using Libra and Sonnet. The circuit's geometrical parameters are listed as follows:

CPW feed lines: Z_{0C} = 50 Ω (strip width W = 0.6 mm, gap size G = 0.29 mm)

ACPS arm's lines: $\sqrt{2}Z_{0C}$=71 Ω (strip width W_{ACPS} = 0.4 mm, gap size G_{ACPS} = 0.27 mm)

ACPS arm's length: $\lambda_{g,ACPS}/4$ = 10.98 mm

slotline radial stub radius: r = 6 mm

slotline radial stub angle: = 90°.

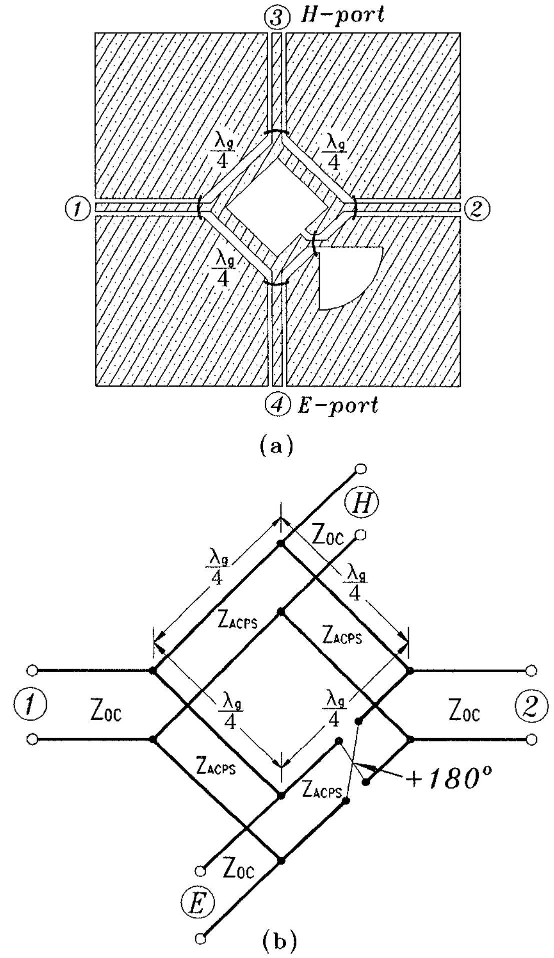
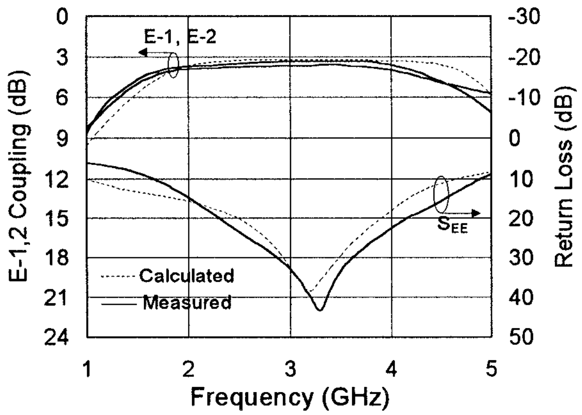
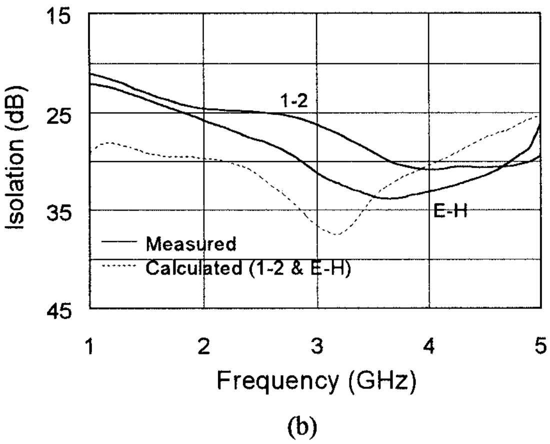


Figure 5. Asymmetrical coplanar strip 180° reverse-phase hybrid coupler. (a) Circuit configuration, and (b) equivalent transmission line model.

Adding air bridges at the circuit's discontinuities is important to prevent the coupled slotline mode from propagating on the CPW and ACPS lines. During testing, the circuit was connected to an HP-8510 network analyzer using standard SMA connectors. The insertion loss includes the loss of two coaxial-to-CPW transitions and 40 mm long input/output CPW lines which were not calibrated out. The measured and calculated data of the hybrid coupler are shown in Figure 6. Over an octave bandwidth from 2 to 4 GHz, Figure 6 shows that the E-port's couplings ($|S_{1E}|$ and $|S_{2E}|$) are less than 3.9 dB (3 dB for ideal coupling), the input return loss ($|S_{EE}|$) is greater than 15 dB, and the isolations ($|S_{EH}|$ and $|S_{12}|$) are greater than 23 dB. Figures 6(a) and (b) also indicate that the experimental results agree well with the simulations. An important feature of the coupler is that the output amplitude imbalance (± 0.2 dB) and phase imbalance (±1.5°) are excellent over a bandwidth from 2 to 4 GHz, because the crossover provides a perfect 180° phase shift in the whole frequency range. This is an advantage with respect to the microstrip implementations of the 180° hybrid coupler, where the $\lambda_g/2$ delay line gives a 180° phase shift only at the center frequency.



(a)



(b)

Figure 6. Measured and calculated frequency responses of the ACPS hybrid coupler. (a) Out-of-phase coupling of E-1 and E-2, and E-port's return loss. (b) Isolation of E-H and 1-2 ports.

IV. CONCLUSION

The design procedure and results of newly developed 180° hybrid couplers using ACPS were described. The uniplanar hybrid couplers demonstrated a good amplitude imbalance and phase difference over a wide bandwidth. With its advantages of a compact, simple, uniplanar structure and ease of integration with solid-state devices, these uniplanar hybrid couplers will be useful in many applications for MICs and MMICs.

V. ACKNOWLEDGMENT

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