A NEW WIDE-BAND AND REDUCED-SIZE UNIPLANAR MAGIC-T

Lu Fan, Sridhar Kanamaluru and Kai Chang

Department of Electrical Engineering
Texas A&M University
College Station, TX 77843-3128, U.S.A.

ABSTRACT

This paper presents a new reduced-size uniplanar magic-T using coplanar waveguide (CPW) and a slotline ring that is 20% smaller than comparable designs. The circuit provides good amplitude and phase characteristics over a broad bandwidth. Experimental results show that the magic-T has a maximum power dividing imbalance of 0.4 dB and a maximum phase imbalance of 2.5° over the entire 1.6 octave bandwidth from 2 to 6 GHz.

INTRODUCTION

Magic-Ts are widely used as 0° and 180° power dividers or combiners in microwave circuits such as balanced mixers [1], amplifiers and frequency discriminators. Uniplanar magic-Ts are preferred for planar microwave integrated circuits because they allow easy series and shunt connections of passive and active solid-state devices without via holes [2]-[5]. However, the precision fabrication required for the three in-phase designs in [2] makes the circuit difficult to manufacture. In [5], the feed port is a slotline which is not convenient for most applications. The coupler design in [3,4] is based on quarter wavelength sections that limit the bandwidth.

This paper presents a novel reduced-size uniplanar magic-T using a CPW-slotline ring with four CPW feeds. The circuit is small in size (circumference is only 0.8 λ_g) and has wide band operation. The wide band operation is achieved by using an out-of-phase CPW-slotline tee junction. This junction has a very broad bandwidth instead of the conventional 180° phase delay section of a hybrid coupler. The characteristics of the out-of-phase CPW-slotline T-junction are presented first. The equivalent circuit and design principles of the new uniplanar magic-T are presented next. Experimental results agree very well with the theoretical design.

CPW-SLOTLINE TEE JUNCTIONS

The CPW-slotline T-junction described here serves as a mode convertor between CPWs and slotlines. Fig. 1 shows the circuit configuration and a schematic diagram of the E-field distribution for the out-of-phase T-junction. The out-of-phase tee junction consists of one CPW tee junction and two CPW-slotline transitions. The arrows shown in Fig. 1 indicate the electric fields in the CPWs and slotlines. The E-fields in the two arms of the CPW tee are directed towards the CPW center conductor. The CPW-to-slotline transition on the left CPW arm will produce an E-field in the +y-direction at port 1. However, the E-field in the right CPW arm will produce a -y-directed slotline E-field at port 2.

Based on the above principle, an out-of-phase CPW-slotline tee junction was built on a 1.524 mm-thick RT/Duroid 6010 (ε_r = 10.5) substrate with characteristic impedances: Z_{co}=50 Ω for the four CPW feed lines, Z_c = 66.9 Ω for the CPW arms, and Z_s = 66.9 Ω for the slotline. Fig. 2 shows the measured amplitude and phase differences. The maximum amplitude difference is 0.35 dB from 1.8 to 7.9 GHz. The maximum phase deviation from 180° is 2.5° over the frequency range of 1 to 7.5 GHz.

REDUCED-SIZE UNIPLANAR MAGIC-T

Fig. 3(a) shows the circuit configuration of the new magic-T consisting of one out-of-phase and three in-phase CPW-slotline tee junctions. The out-of-phase T-junction serves as a phase inverter. In Fig. 3(a), ports E and H correspond to the E- and H-arm of the conventional waveguide magic-T, respectively. Ports 1 and 2 are the balanced arms. Fig. 3(b) shows the equivalent transmission line model of the magic-T. The twisted transmission line represents the phase reversal of the CPW-slotline T-junction. 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 components that arrive at ports 1 and 2 out-of-phase and are canceled out at port H.

The characteristic impedance of slotline Z_s and CPW Z_c in terms of CPW feed line impedance Z_{co} (usually 50 Ω) and θ

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(the electric length of a quarter of the slotline ring circumference) are given by [6]

$$Z_s = Z_c = Z_o\sqrt{2(1-\cot^2\theta)} \quad (1)$$

According to equation (1), the minimum θ is obviously 45°. Simulations indicate that wide band operation is obtained for values of θ which are smaller in the allowed range. In this design θ = 72° (i.e. $\lambda_{gs}/5$) was chosen, resulting in the characteristic impedances Z_s, Z_c = 66.9 Ω. The magic-T has been fabricated on a RT/Duroid 6010 substrate (ε_r = 10.5, h=1.54 mm, metal thickness t = 18 μm). The center frequency is 4.0 GHz. The radius of the radial stub at the CPW-slotline transitions is 5 mm. The radial stub angle is 45°. It is important to use air bridges at the magic-T's discontinuities to prevent 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. Touchstone software was used to simulate the circuit.

Fig. 4 shows the magic-T's measured and calculated transmission, return loss and isolation, respectively. For the E-port's power division (i.e. out-of-phase mode coupling) shown in Fig. 4(a), the insertion loss is less than 0.7 dB at the center frequency of 4 GHz. Similar results were obtained for the H-port's power division. The measured and calculated isolations between E- and H-port and ports 1 and 2 are shown in Fig. 4(b). As shown Fig. 4, the calculated results agree very well with the measured results. Fig. 5 shows that the output amplitude and phase imbalances are excellent over a broad bandwidth. The measured performances are summarized in Table I.

CONCLUSIONS

A wideband uniplanar hybrid magic-T was developed. It has a circumference of only 0.8 λ_{gs} which is 20% smaller compared to the sizes of conventional couplers. The magic-T demonstrated good performance over a bandwidth of 1.6 octave. Experimental results agree well with the simulated ones.

ACKNOWLEDGMENTS

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Table I. Summary of measured performances of the magic-T.

Parameter		Measured (dB)	Frequency (GHz)	Bandwidth (octave)
Coupling	S_{1E}, S_{2E}	3.9 ± 0.3	2.8 - 5.9	> 1.075
	S_{1H}, S_{2H}	3.9 ± 0.3	2.15 - 6.0	> 1.48
Return Loss	S_{11}, S_{22}, S_{EE}, S_{HH}	> 12	2.9 - 6.15	> 1.08
Isolation	port 1 and 2	> 18	1.0 - 6.6	> 2.5
	port E and H	> 30	1.0 - 7.7	> 2.5
Imbalance	E-1/E-2	< 0.4	1.8 - 6.3	> 1.8
	H-1/H-2	< 0.4	1.0 - 5.9	> 2.5
	phase E-1/E-2	181°±1.5°	2.0 - 7.15	> 1.8
	phase H-1/H-2	< 2.5°	1.0 - 6.4	> 2.5

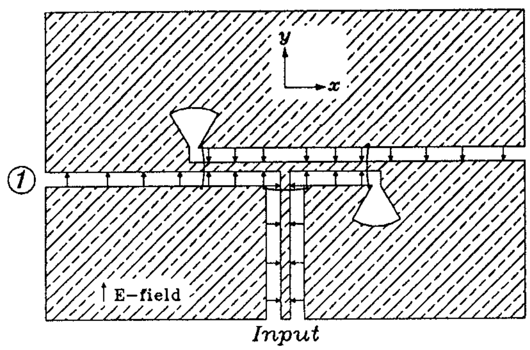

Fig. 1. Circuit configurations and schematic diagrams of E-field distribution for uniplanar out-of-phase tee junction.

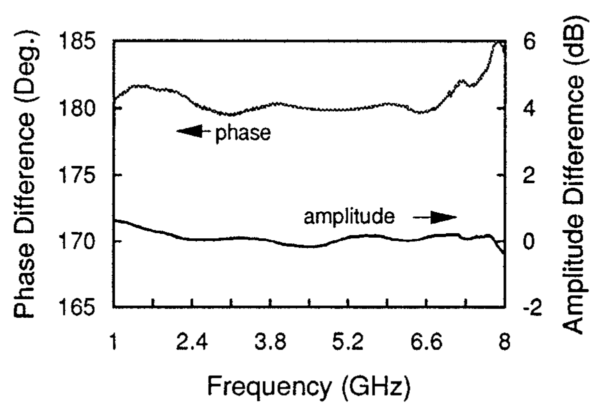

Fig. 2. Measured amplitude and phase differences for the CPW-slotline out-of-phase tee junction.

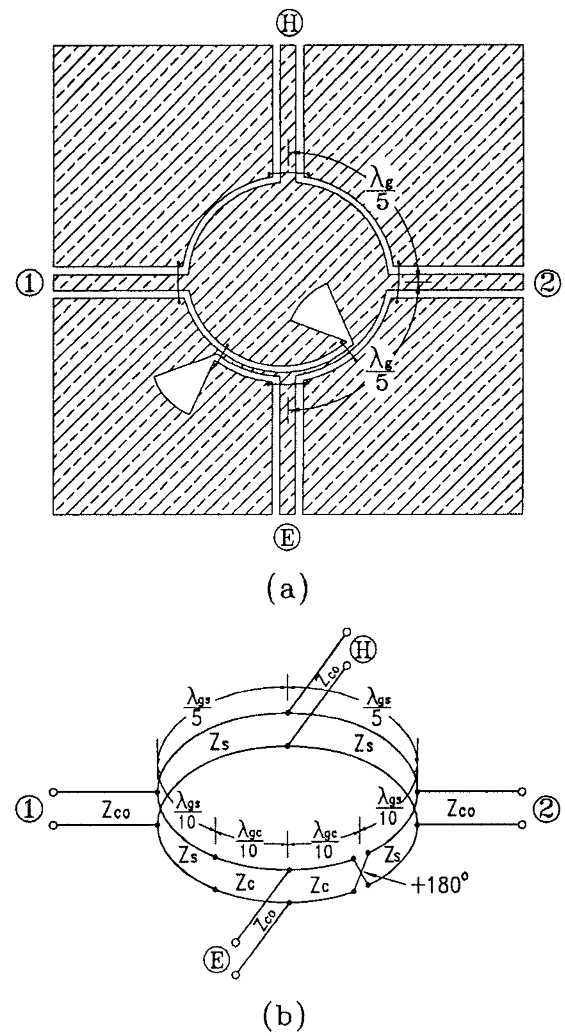

Fig. 3. Uniplanar hybrid magic-T (a) Circuit configuration and (b) Equivalent transmission line model.

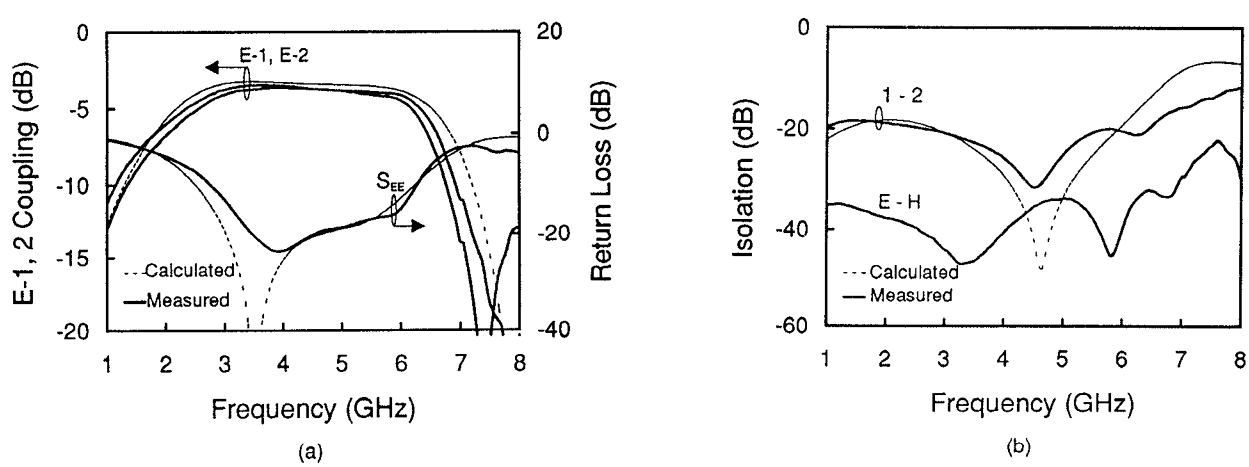

Fig. 4. Measured and calculated frequency responses of magic-T (a) Out-of-phase coupling of E-1, E-2 and E-port's return loss (b) Isolations of E-H and 1-2.

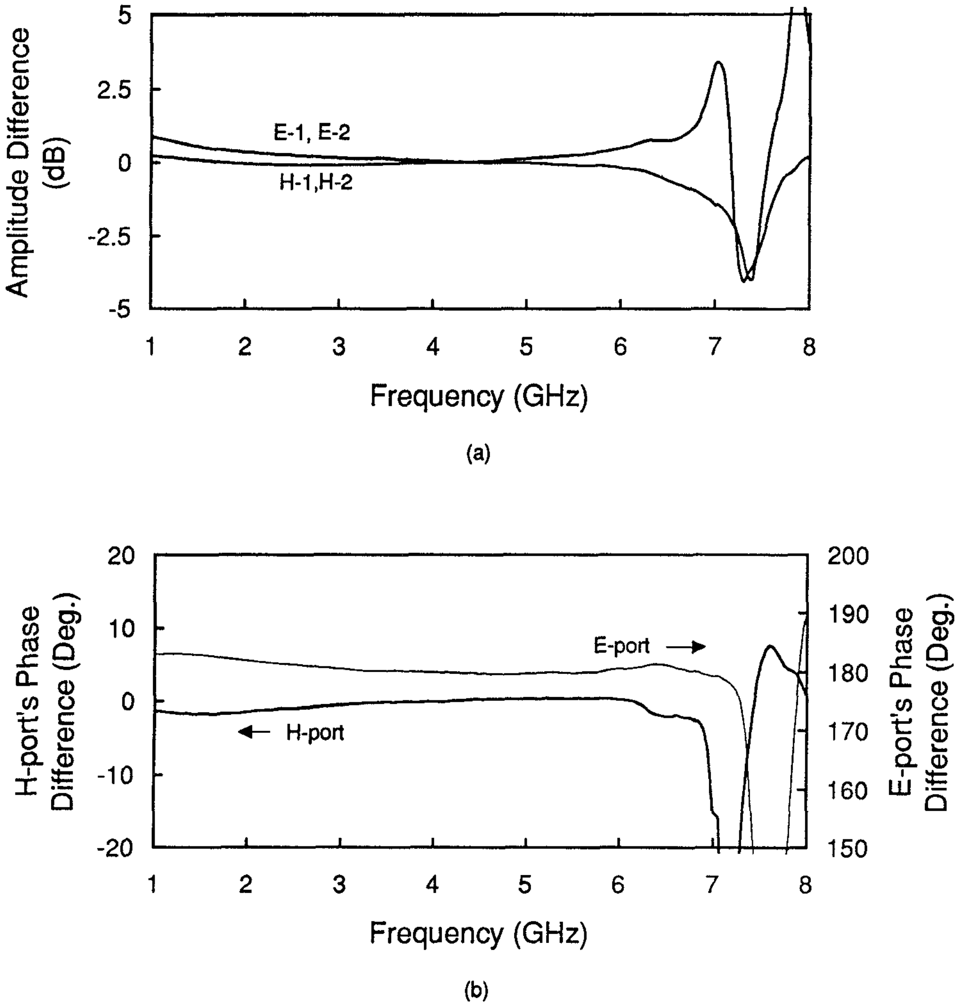

Fig. 5. Measured frequency responses of magic-T (a) Amplitude imbalance (b) Phase imbalance.