A novel compact planar magic-T using CPS and microstrip-to-CPS transition

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Abstract This letter proposes a novel planar magic-T employing microstrip lines and a coplanar stripline (CPS) integrating a microstrip-to-CPS transition. The proposed magic-T uses a CPS instead of the slot line used in conventional planar magic-Ts to reduce the radiation loss. Defected ground structures (DGSs) are also used to suppress undesired common modes. This circuit has several attractive advantages in comparison with the conventional similar designs such as excellent amplitude and phase performance, compactness, and widely useable structure using a microstrip-to-CPS transition. The design, analysis and prototype parameters are discussed, followed by the measured and simulated results of the proposed magic-T.

key words: magic-T, microstrip line, coplanar stripline, defected ground structure

Classification: Microwave and millimeter-wave devices, circuits, and modules

1. Introduction

Microwave hybrid is one of the essential components in many wireless applications, and used in microwave circuits and advanced antennas such as phase shifters [1], balanced mixers [2, 3], power dividers [4, 5] and beam steering antennas [6, 7, 8, 9, 10, 11, 12]. Magic-Ts are well known as a 180° hybrid, which acts as an in-phase/anti-phase power combiner/divider. Since the magic-Ts are often integrated with other microwave circuitry, it is necessary to be simple, small and easy to be integrated. Waveguide magic-Ts, which have an advantage of a low insertion loss, consist of a solid E- and H-arm [13, 14, 15, 16]. However, the waveguide magic-Ts are relatively large to be integrated with other microwave circuits in RF front ends. Therefore, many planar magic-T structures have been proposed to reduce the size. There are magic-Ts miniaturized using LTCC technology [17], substrate integrated waveguide [18, 19] and NRD-guide [20]. Other planar magic-Ts usually use microstrip lines and slot lines [21, 22, 23, 24, 25, 26, 27, 28, 29, 30]. These magic-Ts are easy to be integrated with microwave circuits and antennas due to their simple structures. However, conventional planar magic-Ts, which use slot lines, have a large radiation loss.

In this letter, we propose a novel planar magic-T employing microstrip lines and a coplanar stripline (CPS) with defected ground structures (DGSs). Since the proposed magic-T consists of microstrip lines, a CPS, DGSs and a radial stub, it can be realized by a double-side single-layer substrate and it is much smaller than conventional rat-race hybrids using long transmission lines. Moreover, the proposed magic-T has lower insertion loss than the similar structures [28, 29, 30]. It is also integrating a microstrip-to-CPS transition. The transition achieves a planar magic-T having only four unbalanced ports using a microstrip line. Therefore, it is easy to connect to microwave circuits and antennas. The design, analysis and prototype parameters are discussed, followed by the measured and simulated results to verify the performance of the proposed magic-T.

2. Structure and behavior

Fig. 1 shows the structure of the proposed magic-T. It consists of three microstrip lines and a CPS with DGS 1 formed just under the CPS. The CPS is connected to a microstrip-to-CPS transition using a radial stub and DGS 2. The CPS is short-circuited at a point quarter-wavelength away from the intersection with the microstrip lines. In the proposed magic-T, the slot line used in conventional planar magic-Ts is replaced by a CPS to reduce the radiation loss. The DGSs suppress undesired common mode signals, which propagate between the CPS and ground conductor. When the characteristic impedance of the microstrip line connected to Port 1 is $Z_0$, those of the microstrip lines connected to Port 3 and 4 have to be $2Z_0$, and the characteristic impedance of the CPS has to be $4Z_0$ for the perfect matching with proper terminations.

The magic-T, which is a four port network, acts as a power combiner/divider. When a signal is fed to Port 1, the signal is divided into two in-phase signals with the same amplitude, and they emerge at Port 3 and 4. The signal does not propagate to Port 2 due to the difference of the propagation modes of the microstrip line and CPS. On the other hand, when a signal is fed to Port 2, the signal is divided into two anti-phase signals with the same amplitude and they also...
emerge at Port 3 and 4. On the contrary, when in-phase signals are fed to Port 3 and 4 with the same amplitude, they are combined and emerge at Port 1 only. In case of anti-phase signals, the combined signal emerges at Port 2 only. Since the radial stub of the microstrip-to-CPS transition leads the virtual short, the microstrip line mode translates to the CPS mode. In addition, the transition from the microstrip line to the CPS becomes smooth by employing the DGS.

### 3. Design, simulation and measurement results

Fig. 2 shows photographs of the prototype magic-T designed and fabricated on a Polytetrafluoroethylene (PTFE) substrate with a thickness of 0.8 mm and permittivity of 2.15. The design center frequency is 5 GHz. The intrinsic area of the magic-T surrounded by the broken lines is $42 \times 25$ mm. All port impedances are transformed to 50 $\Omega$ for the measurements. The dimensions of the radial stub are $\theta = 80^\circ$ and $R = 8.0$ mm. Moreover, the sizes of DGS 1 and 2 are respectively designed $6 \times 11$ mm and $6 \times 19$ mm to suppress the common mode signal and to match the transition. The size of the circuit is small because only one quarter-wavelength shorted-end CPS is used in this structure. Furthermore, since all four ports are microstrip lines in the same plane, it is easy to be integrated with other microstrip circuits and antennas.

Keysight Technologies’ Advanced Design System (ADS) and a vector network analyzer (HP8510C) are used for the simulation and measurement, respectively.

#### 3.1 Effect of DGS

The proposed magic-T employs a DGS to suppress undesired common mode signals, which propagate between the CPS and ground conductor.

Fig. 3 shows the simulated common mode suppression of the proposed magic-T with and without the DGS. The common mode suppression is 10.5 dB at 5 GHz by employing the DGS and improved by 6 dB compared to the magic-T without a DGS.

#### 3.2 Simulation and measurement results

Fig. 4 shows the measured and simulated reflection coefficients of the proposed magic-T. The measured and simulated results are shown by the solid and broken lines, respectively. The red, blue, green and light blue lines are $S_{11}$, $S_{22}$, $S_{33}$, and $S_{44}$, respectively. The return loss is better than 10 dB in a frequency range from 4.6 to 5.8 GHz for all ports.

Fig. 5 shows the measured and simulated transfer characteristics of the proposed magic-T. The red and blue lines in Fig. 5(a) are the in-phase signals $S_{31}$ and $S_{41}$, respectively. The insertion loss is better than 0.65 dB in a wide frequency range.
range from 4.5 to 6.6 GHz. The anti-phase signals $S_{32}$ and $S_{42}$ shown in Fig. 5(b) also provide better than 0.65-dB insertion loss from 4.6 to 5.8 GHz. Good agreement between measured and simulated results was obtained.

Fig. 6 shows the measured and simulated phase differences between Port 3 and 4. The red and blue lines are the phase differences when fed to Port 1 and Port 2, respectively. The in-phase and anti-phase difference are $0^\circ \pm 4^\circ$ and $180^\circ \pm 4^\circ$ in a wide frequency range from 3.7 to 6.6 GHz and 4.4 to 6.8 GHz, respectively. It shows that almost perfect phase characteristics close to the ideal ones of $0^\circ$ and $180^\circ$ are obtained.

Fig. 7 shows the measured and simulated isolation characteristics. The amplitude of $S_{21}$ and $S_{43}$ are $-15$ dB or less in a wide frequency range from 3.6 to 7.0 GHz.

Fig. 8 shows the measured and simulated amplitude imbalances. The in-phase/anti-phase amplitude imbalances are $\pm 0.4$ dB from 4.6 to 5.9 GHz.

Table I shows the comparison of magic-Ts with similar structures. The operation band was defined by the reflection coefficients better than $-10$ dB. The proposed magic-T has lower insertion loss than the similar structures [28, 29, 30].

### 4. Conclusion

In this letter, a novel compact planar magic-T using a CPS and microstrip-to-CPS transition has been proposed. Since the proposed magic-T is designed using microstrip lines and a CPS, the performance of the magic-T is improved. Furthermore, the proposed magic-T has been miniaturized in comparison with the conventional rat-race hybrids. Nevertheless, the proposed magic-T has been compared with similar structures.
theless, since all four ports are of microstrip lines in the same plane due to the microstrip-to-CPS transition, it can be applied to many applications such as microstrip circuits and antenna applications. The measured return losses and insertion loss are better than 10 dB and 0.65 dB from 4.6 to 5.8 GHz for all ports. The measured in-phase and anti-phase differences are ±4° from 4.4 to 6.8 GHz. The measured isolation is better than 15 dB in a wide frequency range from 3.6 to 7.0 GHz. The in-phase/anti-phase amplitude imbalances are ±0.4 dB from 4.6 to 5.9 GHz.

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