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DESIGN OF SEVERAL POWER DIVIDERS USING CPW-TO-MICROSTRIP TRANSITION

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Abstract—Based on the theory of microstrip-to-slotline transition, a series of power dividers with CPW-to-microstrip transition is developed. These power dividers can be made to be coplanar or non-coplanar structure, and the phase difference between the two output ports can be flexibly achieved in phase or out of phase. Two microstrip feed lines couple the energy from the two slots of the CPW with equal magnitude, thus realizing CPW-to-microstrip transition. An in-phase power divider and an out-of-phase one are designed, fabricated and measured. The measured results show that the power dividers provide good return loss, low insertion loss, and stable phase between the two output ports over the operating frequency band.

1. INTRODUCTION

Microwave circuits and modules are usually based on planar technologies, such as microstrip or coplanar waveguide (CPW), which are characterized by compact size, low weight, low cost and easy integration. Since each microstrip and CPW has its exclusive advantages over the other, some applications such as multilayer microwave integrated circuits require the flexibility to use integrated microstrip and CPW circuits [1]. Power dividers are key components extensively used in microwave circuits. To ensure the compatibility of CPW and microstrip technologies, broadband power dividers with CPW-to-microstrip transitions are needed. There are many studies about CPW-to-microstrip transitions [2–4]. According to the principle of the microstrip-to-slotline transition, an alternative CPW-to-microstrip transition was recently developed using two pairs of

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open-circuited microstrip and short-circuited slotline stubs with radial shape [4].

According to the phase difference between the two output ports, power dividers can be divided into two types: in-phase dividing types and out-of-phase ones. The former ones are often made of microstrip lines [5], while the later cases are designed with microstrip-slot lines [6]. A 180° phase difference is required in some applications such as push-pull type circuits [7]. Wilkinson power divider is the most commonly used device to achieve in-phase or out-of-phase signal division [7–9]. In order to achieve wideband performance, several quarter wavelength sections have to be used, leading to a relatively large size in comparison with the operational wavelength. Based on the theory of microstrip-to-slotline transition, some out-of-phase types were designed [10–12]. Utilizing the series type T-junction formed by a slotline and two arms of a microstrip line, a UWB out-of-phase coplanar power divider is employed [10]. Since then, several similar structures have been presented. A UWB multilayer slotline power divider is designed in [11]. Another improved UWB non-coplanar power divider is presented in [12], which employs a tapered slot and a fan-shaped slot to take place of the circular slot in the circuit design.

Based on the theory of microstrip-to-slotline transition, a series of ultra wideband power dividers with CPW-to-microstrip transition is designed in this article. Two microstrip feed lines of the power divider couple the energy from the two slotlines of CPW, thus a power divide, which is also a CPW-to-microstrip transition, is achieved. By locating the two microstrip feed lines in the same direction, an in-phase power divider is obtained. While in the opposite direction, an out-of-phase one is achieved. By locating the two microstrip feed lines in different layers, a non-planar power divider is obtained. So these power dividers can be designed to be coplanar or non-coplanar structure, and the phase difference between the two output ports can be flexibly achieved in phase or out of phase. Both the proposed in-phase power divider and the out-of-phase one are designed, fabricated and measured. The experimental results of the developed power dividers show the performance of broad bandwidth, excellent input impedance matching, desirable phase difference between the two output ports and low insertion loss.

2. IN-PHASE POWER DIVIDER

Configuration of the proposed in-phase power divider is shown in Fig. 1. The CPW feed port is the input port (port 1), whereas the output ports (port 2, 3) are located at the end of the two microstrip feed lines. Two

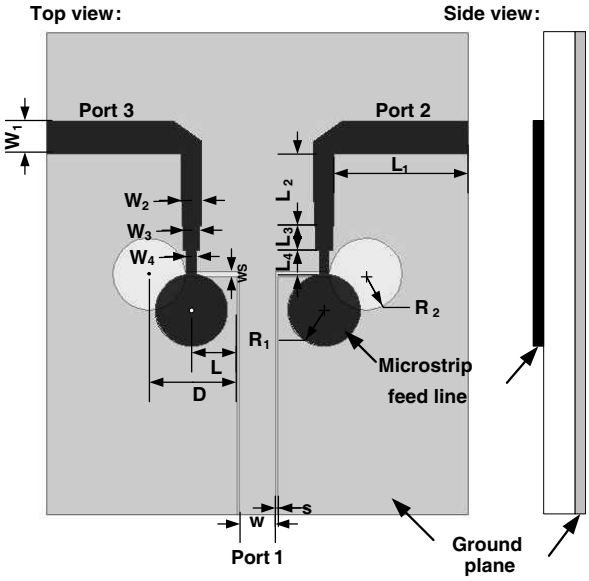


Figure 1. Configuration of the in-phase power divider.

slotlines of CPW are placed in the opposite direction, at the end of which two circle slots are etched. The microstrip-to-slotline transition is a typical conventional broadband balun, which can be equivalent to a coupler with the coupling coefficient n. The impedance transition can be calculated as follows:

$$Z_m = Z_S \times n^2 \tag{1}$$

where $Z_m = 99\,\Omega$ and $Z_s = 105\,\Omega$ are the characteristic impedance of the microstrip and the slotline, respectively. The coupling coefficient of the coupler can be noted as [13]:

$$n = \cos 2\pi \frac{h}{\lambda} u - \cot q_0 \sin 2\pi \frac{h}{\lambda} u = 0.97 \tag{2}$$

where

$$q_0 = 2\pi \frac{h}{\lambda} u + \tan^{-1}\left(\frac{u}{v}\right)$$

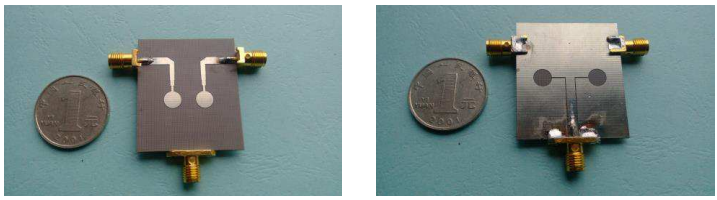
$$u = \left[\varepsilon_r - \left(\frac{\lambda}{\lambda_s}\right)^2\right]^{\frac{1}{2}}$$

$$v = \left[\left(\frac{\lambda}{\lambda_s}\right)^2 - 1\right]^{\frac{1}{2}}$$

h is the thickness of the dielectric substrate, ε_r the permittivity of the dielectric substrate, and λ and λ_s represent the wavelength of the center frequency in air and the effectively wavelength of the center frequency in slotline, respectively.

By optimizing two stepped microstrip feed lines, the transition between the impedance Z_m and the characteristic impedance Z_0 has been obtained over a broad bandwidth. The characteristics impedance Z_0 equals to $50\,\Omega$. Finally, the optimized impedance transitions are as follow: $Z_1 = 68\,\Omega$ and $Z_2 = 76\,\Omega$.

The simulation and optimization work of the in-phase power divider was carried out using the commercial software Ansoft HFSSv13.0. The proposed in-phase power divider is built on a substrate with a thickness of 1 mm, relative dielectric constant of 2.65, and loss tangent of 0.0017. The final dimensions (shown in Fig. 1) of the in-phase power divider are: $R_1 = 3\,\text{mm}$, $R_2 = 3\,\text{mm}$, $L_1 = 11.1\,\text{mm}$, $L_2 = 6\,\text{mm}$, $L_3 = L_4 = 2\,\text{mm}$, $W_1 = 2.7\,\text{mm}$, $W_2 = 1.7\,\text{mm}$, $W_3 = 1.4\,\text{mm}$, $W_4 = 0.8\,\text{mm}$, $w = 3\,\text{mm}$, $s = 0.2\,\text{mm}$, $ws = 0.4\,\text{mm}$, $L = 4.5\,\text{mm}$. The power divider is fabricated. Fig. 2 shows the photograph of the fabricated in-phase power divider, and the overall size is $40\,\text{mm} \times 35\,\text{mm}$.



(a) (b)

Figure 2. Photograph of the in-phase power divider. (a) Top view, (b) bottom view.

With the help of the software Ansoft HFSSv13.0 and the Agilent E8363B network analyzer, S-parameters of the in-phase power divider are simulated and measured, as shown in Fig. 3. The simulated and measured results reveal that the power of the input port is equally divided into the two output ports, and the return loss is better than 11 dB from 2 GHz to 10 GHz. The simulated insertion loss is around 1 dB from 2 GHz to 7.8 GHz, while the measured 1 dB insertion loss bandwidth is 115% (from 2 GHz to 7.5 GHz). As is shown in Fig. 4, the measured phase difference between the two output ports is $0° \pm 1°$, which proves the power divider to be an in-phase type with good performance.

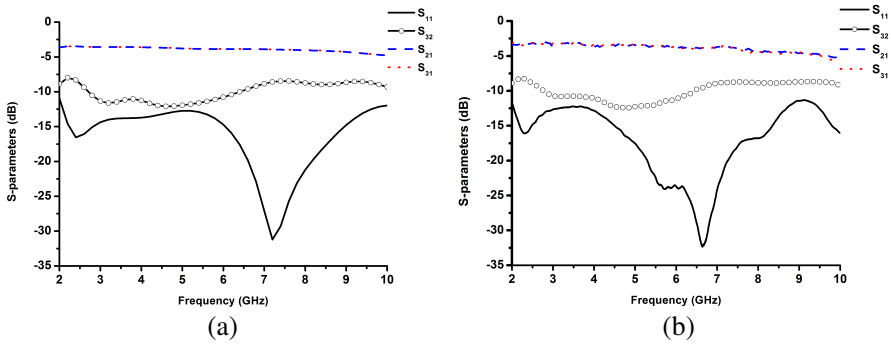


Figure 3. Scattering parameters of the in-phase power divider. (a) Simulated results, (b) measured results.

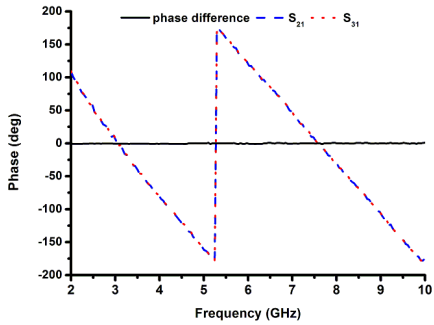


Figure 4. Measured phase characteristics of the in-phase power divider.

3. OUT-OF-PHASE POWER DIVIDER

When one of the two microstrip feed lines of the in-phase power divider is placed to the other side of the slotline, an out-of-phase power divider is obtained. Configuration of the out-of-phase power divider is shown in Fig. 5. Since the dimensions w and s of the input CPW port and the width W_1 of the microstrip ports are determined assuming $50\,\Omega$ characteristic impedance, all the three ports can be connected to SMA connectors directly.

The out-of-phase power divider is developed, simulated and measured in the same way with the in-phase power divider. And the out-of-phase power divider has the same dimensions with the in-phase power divider. The photograph of the fabricated out-of-phase power divider is shown in Fig. 6.

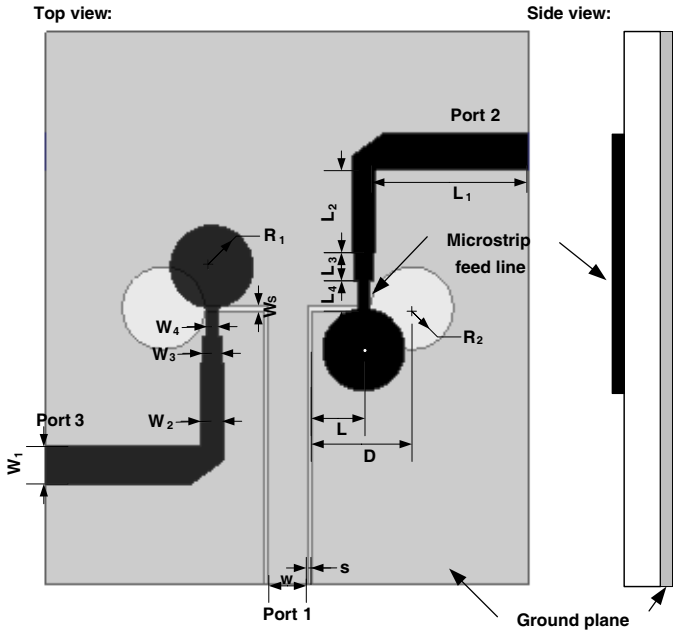
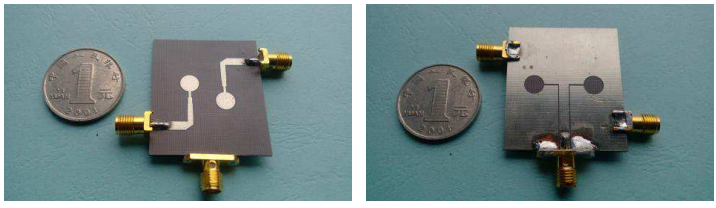


Figure 5. Configuration of the out-of-phase power divider.



(a) (b)

Figure 6. Photograph of the out-of-phase power divider. (a) Top view, (b) bottom view.

Using the commercial software ANSOFT HFSSv13.0 and the Wiltron 37269A vector network analyzer, the proposed power divider is simulated and measured. As is shown in Fig. 7, the simulated and measured return loss is better than 10 dB from 2 GHz to 10 GHz, and the insertion loss is less than 1.1 dB from 2 GHz to 6.3 GHz. The phase characteristics of the power divider are shown in Fig. 8. The measured phase difference between the two output ports is $180° \pm 5°$ over the operating band, which reveals that the power divider is an out-of-phase type.

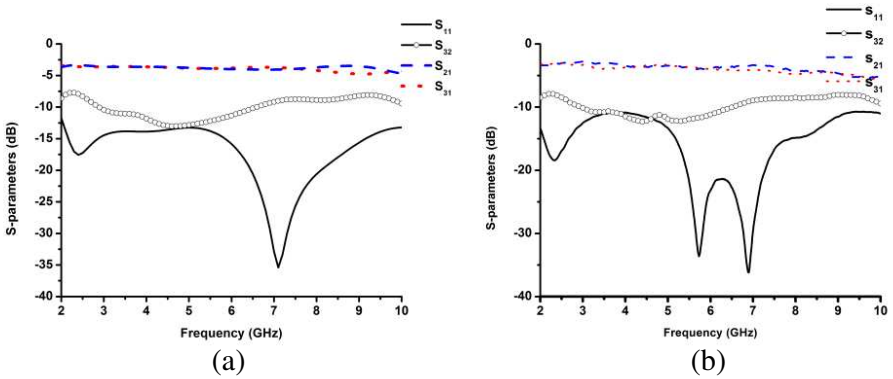


Figure 7. Scattering parameters of the out-of-phase power divider. (a) Simulated results, (b) measured results.

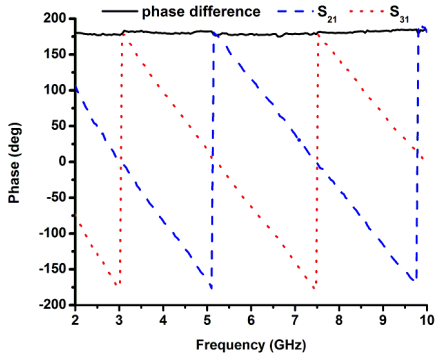


Figure 8. Measured phase characteristics of the out-of-phase power divider.

4. NON-COPLANAR OUT-OF-PHASE POWER DIVIDER

In some fields [14, 15], the output ports of the power dividers need to be located at different metal layers. Then non-coplanar power dividers are needed. The power dividers proposed above can easily be transformed into a multilayer structure. By placing one more substrate under the ground of the power divider presented above and locating one of the two output feed lines on the new substrate, a non-coplanar power divider is obtained. As shown in Fig. 9, the input port (port 1) is located at the middle layer, whereas one of the output ports is at the top layer and

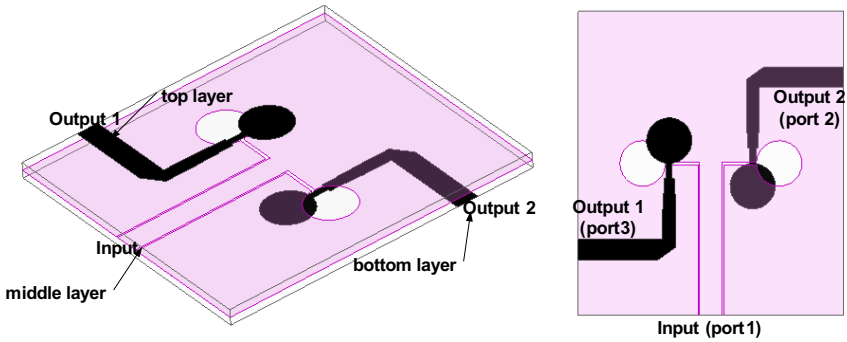


Figure 9. Configuration of the non-coplanar power divider.

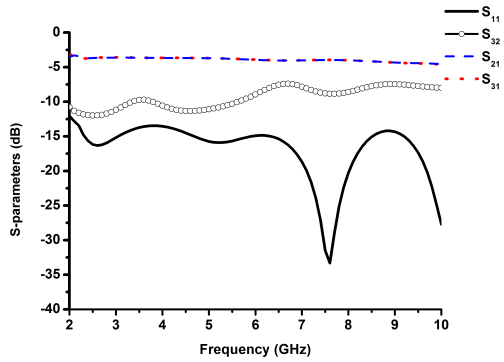


Figure 10. Simulated scattering parameters of the non-coplanar power divider.

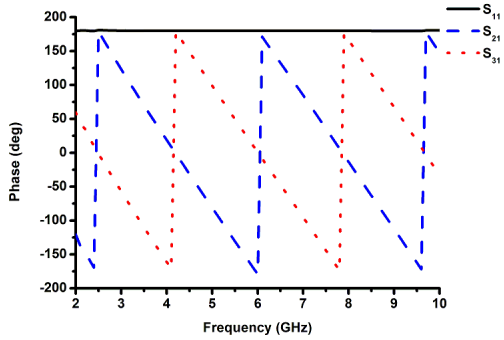


Figure 11. Simulated phases of transmission coefficients of the non-coplanar power divider.

the other one is at the bottom layer. By placing the feed lines in the proper direction, 0° or 180° phase difference between the two output ports can easily be achieved.

The proposed non-coplanar power divider has the same dimensions as the coplanar power divider presented above. The simulated S-parameters are shown in Fig. 10. The results show that the input port of the non-coplanar power divider has a return loss better than 12 dB ranging from 2 GHz to 10 GHz. The bandwidth of the 1 dB insertion loss is 120% (from 2 GHz to 8.1 GHz). The simulated phases of transmission coefficients of the power divider are shown in Fig. 11, and the phase difference between the two output ports is $180° \pm 1°$ over the operating band.

5. CONCLUSIONS

Several power dividers based on the theories of microstrip-to-slotline and CPW-to-microstrip transition have been presented in this paper. The planar power divider can flexibly be converted between an in-phase type and an out-of-phase type, which can also be designed to be a non-coplanar structure with the same dimensions. Placing the two output feed lines in the same direction, the in-phase type power divider is obtained, while in the opposite direction, out-of-phase type. For the application in multilayer circuits, a non-coplanar power divider is designed, in which case, one more substrate is added onto the other side of the ground plane and one of the two microstrip feed lines is located on the new substrate. The simulated and measured results show that the proposed power dividers have good return loss, low insertion loss and good phase stability over their operating bands. Thus, these structures can be flexibly utilized in many applications to serve as broadband power divider and CPW-to-microstrip transition.

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