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# AN IMPROVED UWB NON-COPLANAR POWER DIVIDER

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**Abstract**—An improved UWB non-coplanar power divider is presented. Based on the theory of microstrip-to-slotline transition, the principle of this power divider is discussed. To improve the performances of the power divider, a tapered slot and a fan-shaped slot take the place of a circular slot in the circuit design. The simulated and measured results show a progressive return loss of input port.

## 1. INTRODUCTION

Power dividers play an important role in a variety of microwave circuits, feeding networks for antenna arrays, radar systems and other related fields. As we know, the classical Wilkinson power divider [1] and its improved structures have been presented in the previous papers [2–7]. On the other hand, the other forms of power dividers with different design methodologies have been proposed [8–12]. The input and output ports of these power dividers are coplanar. However, it is not suited to use in some fields, such as the six-port junction [13–15] including non-coplanar couplers [16–18]. In addition, the six-port technique is a suitable option as the ratio of complex amplitude measurements [19], and has been applied in many fields [20–23].

To solve these problems, non-coplanar power dividers, based on the multilayer technology, have been studied by the researchers [14, 24–26]. Two output ports are located at different metal layers. An out-of-phase power divider was designed based on the theory of microstrip-to-slotline transition in [14]. According to [24], an UWB multilayer slotline power divider with bandpass response was presented. In [25], an UWB non-coplanar out-of-phase power divider, employing parallel stripline-microstrip transitions, was implemented. A power divider via

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broadside coupling was introduced in [26]. In these power dividers, the input port and one output port appear on the same side, while another output port is on the opposite side.

In this paper, an improved UWB non-coplanar power divider with the characteristic of 180° out-of-phase between two outputs is presented. This circuit consists of a microstrip-to-slotline transition, a T-junction formed by a slotline and two arms of two microstrip lines. The differences between the power divider in [14] and the one in this paper are a tapered slot and a fan-shaped slot taking place of a circular slot to improve the impedance matching between them. Furthermore, this device does not use any resistive element. Therefore, it cannot offer a perfect match at its three ports for the inherent properties of a lossless three-port [27].

In the improved design, the input and output ports exhibit return losses of 15 dB and 6 dB respectively, across an ultra wide frequency band from 3 to 8.4 GHz, as demonstrated by simulations. Compared with the results in [14] (from 4.3 to 7 GHz), according to the same return loss of input port (more than 15 dB) and the same order of return losses of output ports (more than 8 dB), a power divider with wider bandwidth is obtained. The measured results show that the insertion losses are less than 4 dB, the return losses at input port and output ports are better than 11.3 dB and 5.5 dB respectively, and the phase difference between the two output ports is in the range from 177.3° to 179°, which illustrates the feature of frequency independence in the range from to 2.8 to 7.4 GHz. These results may be found sufficient in many applications, such as six-port junction or a push-pull type of amplifier.

## 2. CIRCUIT DESIGN

To ensure a non-planar configuration, the improved power divider is achieved in two layers of substrate, which need to close combine together. The circuit topology of power divider is listed as follows: Input port and one output port are placed at the top layer while another output port is placed at the bottom layer. In the middle layer, there is a narrow slotline ended with a tapered slot and a fan-shaped slot in the common ground plane. To expand the device's bandwidth, the compensation effects, based on one loaded quarter wavelength transmission line in the end of slotline and its deformed structures, should be carefully considered in circuit design [28]. Figure 1 shows the dimensional layouts of the improved power divider.

The differences of the improved power divider and the previous one in [14] are the slots in the common ground plane: the introduction

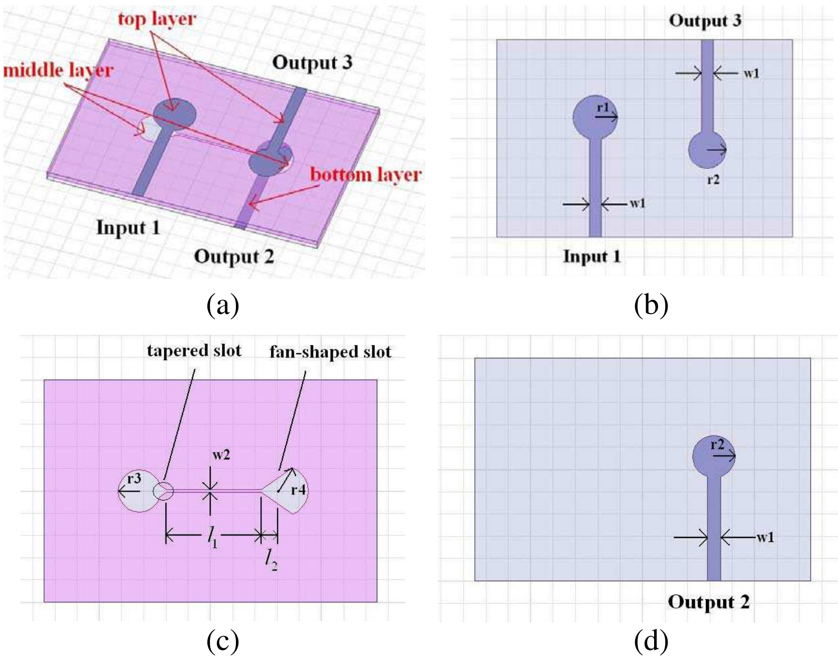


**Figure 1.** Configuration of the improved power divider. (a) The whole structure, (b) top layer, (c) middle layer, (d) bottom layer.

of a tapered slot and a fan-shaped slot are due to a better impedance matching characteristic for the microstrip-to-slotline transition, which can be equivalent to the coupler with coupling coefficient $n$. Under the above assumptions, the characteristic impedance of microstrip $Z_m$ and the characteristic impedance of slotline $Z_s$ have to meet the following requirement:

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

The coupling coefficient of the coupler can be expressed as [29]:

$$\begin{cases} n = \cos 2\pi \frac{h}{\lambda} u - \cot q_0 \sin 2\pi \frac{h}{\lambda} u \\ q_0 = 2\pi \frac{h}{\lambda} u + \tan^{-1}\left(\frac{u}{v}\right) \\ u = \left[\varepsilon_r - \left(\frac{\lambda}{\lambda_s}\right)^2\right]^{\frac{1}{2}} \\ v = \left[\left(\frac{\lambda}{\lambda_s}\right)^2 - 1\right]^{\frac{1}{2}} \end{cases} \tag{2}$$

$h$ and $\varepsilon_r$ represent the thickness of the dielectric substrate and the permittivity of the dielectric substrate, respectively. $\lambda$ and $\lambda_s$ represent the wavelength of the center frequency in air and the effective wavelength of the center frequency in slotline, respectively.

The essential property of T-junction structure of two output ports can achieve the equal magnitudes and 180° out-of-phase. The characteristic impedance of the input and output microstrip $Z_m$ is determined assuming $50\,\Omega$, which can be directly connected to SMA connectors. The characteristic impedance of slotline $Z_s$ is selected as $90\,\Omega$, which can be fabricated in practical. Therefore, the coupling coefficient $n$ between the microstrip and the slotline is about 0.75. The distance $l_1$ between the tapered slot and the fan-shaped slot is chosen to be about a quarter of the effective wavelength at the center frequency. Radius $r_1$ and $r_2$ of the circle in the end of the input and ouput microstrip can be selected to be around twice of microstrip width $w_1$. In addition, the dimensions of radius $r_3$ and $r_4$ are associated with the effective wavelength of the center frequency in slotline.

## 3. EXPERIMENTAL RESULTS

The improved power divider is designed and developed using a Rogers RT/duroid 4003 substrate with a dielectric constant of 3.38, with a thickness of 0.508 mm, and a dielectric loss tangent of 0.0023 at the frequency of 10 GHz, plus 17-μm-thick conductive coating. Using the proposed design method and with the help of the parameter sweep and optimization capability of the software Ansoft HFSSv13.0, these parameters of the power divider are found to be as follows: $w_1 = 1.2\,\text{mm}$, $w_2 = 0.19\,\text{mm}$, $r_1 = 2.25\,\text{mm}$, $r_2 = 1.9\,\text{mm}$, $r_3 = 1.9\,\text{mm}$, $r_4 = 2.2\,\text{mm}$, $l_1 = 8.58\,\text{mm}$, $l_2 = 2\,\text{mm}$, respectively.

The simulated results of the proposed power divider are shown in Figure 2. These results reveal that the signal power is equally divided

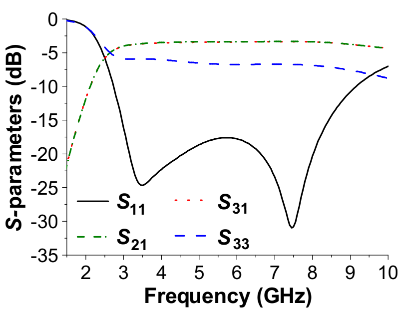


**Figure 2.** Simulated scattering parameters of improved power divider.

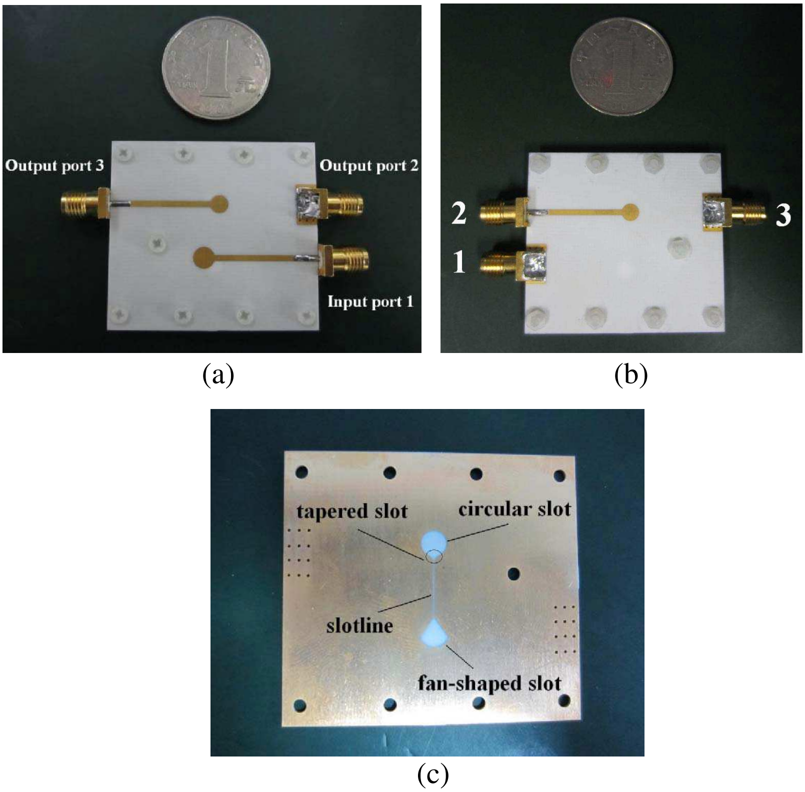


**Figure 3.** Photograph of improved power divider. (a) Top layer, (b) bottom layer, (c) middle layer.

in the two output ports at the frequency band from 3 to 8.4 GHz. Due to the inherent properties of the scattering matrix of a lossless three ports, the return losses of lossless power divider can't offer the perfect match at three ports. Therefore, the return losses at two output ports are sacrificed. However, they can be compensated by the next step circuits.

Figure 3 shows the photograph of the fabricated power divider, and the total size of the proposed power divider is 44 mm $\times$ 40 mm. Nine plastic screws are introduced into the installation structure to reduce the contribution of the electric field in device.

The $S$-parameters of the improved power divider, measured by the Agilent E8363B network analyzer, is shown in Figure 4. Over the frequency range from 2.8 to 7.4 GHz, the return losses at input port and two output ports are better than 11.3 dB and 5.5 dB respectively, the insertion loss is $-3.6\pm0.4$ dB, the amplitude consistency and the phase

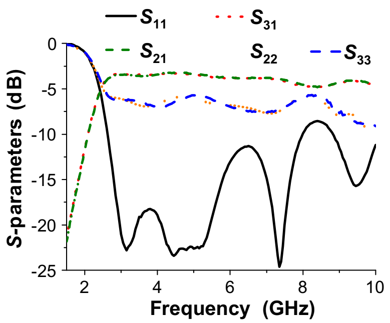


**Figure 4.** Measured scattering parameters of improved power divider.

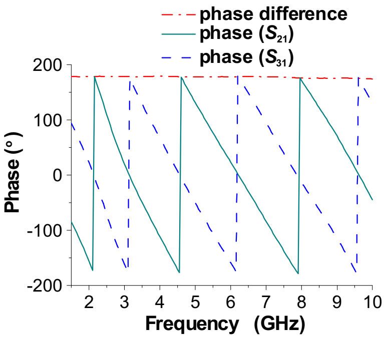


**Figure 5.** Measured phase difference of improved power divider.

difference are $\pm 0.15$ dB and $178.15° \pm 0.85°$, respectively. The return losses at two output ports may be found sufficient in many applications. The phase difference between two output ports is demonstrated in Figure 5. The differences between the simulated and measured results are due to the gap and asymmetry of two dielectric substrates, the interference of plastic screws and other aspects.

## 4. CONCLUSION

A non-coplanar UWB out-of-phase power divider is presented in this paper, which consists of a microstrip-to-slotline transition, a T-junction formed by a slotline and two arms of two microstrip line. To improve the performances of the power divider, a tapered slot, and a fan-shaped slot instead of a circular slot, are introduced into the circuit design. Compared with the simulated results in [14] (about 4.3 to 7 GHz), according to the same return loss for input port and the same order of return losses for output ports, a wider bandwidth (from 3 to 8.4 GHz) is obtained. The measured results of the improved power divider have shown a low insertion loss, less than 1 dB, a good return loss at input port and high phase stability (180°) over the bandwidth of 2.8 to 7.4 GHz.

## ACKNOWLEDGMENT

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