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The Design of a Novel Compact Ultra-wideband (UWB) Power Divider

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Abstract—The design of a compact coplanar power divider with novel structure is presented by making a full use of the theories of microstrip-to-slotline transition. To obtain two in-phase signals over a wide frequency range, the two output branches are placed in the same layer. Moreover, a half-wavelength slotline is employed to expand the working frequency range. The presented compact power divider shows a low insertion and good return loss performance at input port. The simulated and measured results have shown a good agreement over the frequency range 2.2 GHz–11 GHz.

1. INTRODUCTION

Power divider is one of the indispensable components in numerous RF or microwave circuits such as modulators and demodulators, phase shifters, mixers and six-ports technique [1]. As we know, traditional Wilkinson divider is the most classical power divider, which has been widely used in lots of circuits and systems. In order to meet the needs of application, various improved Wilkinson power dividers have been proposed in [2–8]. For the sake of satisfying UWB application, new power dividers based on microstrip-to-slotline transition have been proposed [9–13]. In [9], Bialkowski and Abbosh propose a new power divider basing on slotline, where the two output arms were connected together. In [10], another power divider with two separated output branches is structured, whose measured results have shown better insertion losses at input port and output ports than the one proposed in [9]. In order to improve the performance of power divider, a tapered slot and a radial slot are introduced in [11].

In this paper, a novel compact coplanar power divider with the characteristic of 0° phase difference between two output phases is presented. This circuit consists of three microstrip-to-slotline transitions [14, 15]. Compared with the configurations proposed in [9–11], the two output arms of this compact power divider are located in the same layer, which are symmetrical to the input port (port 1). Three circular stubs, acting as compensated circular, are introduced. And two circular slots are also fabricated on the ground plane.

In the presented design, due to the coplanar configuration and introducing of circular stubs, the return loss at input port is better than the ones proposed in [9, 10] about 5 dB in the frequency range from 2.2 GHz to 11.5 GHz according to the simulation results. For the same return loss at input port, the frequency bandwidth is wider than the one proposed in [11].

2. CIRCUIT DESIGN

The novel structure of the proposed compact power divider is shown in Figure 1, which consists of two layers, top and bottom layers. The top layer contains one input arm and two output arms while the bottom layer contains an half-wavelength slotline, which is similar to the configuration proposed in [9]. However, the difference is that the two output arms are split and located on two sides of the input port symmetrically.

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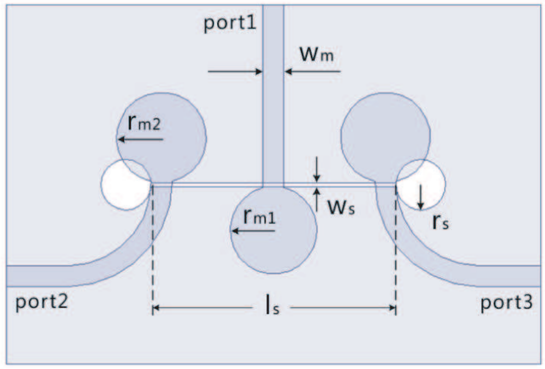


Figure 1. Configuration of the power divider.

The microstrip-to-slotline transition's equivalent circuit is a model of transformer. For the sake of acquiring perfect matching, the following expression must be satisfied.

$$z_m = z_s \times n^2 \tag{1}$$

z_m and z_s stand for the characteristic impedances of microstrip and slotline, respectively. n is the coupling coefficient, which can be acquired by calculating the following expression:

$$\begin{cases} n = \cos(2\pi h\mu/\lambda) - (\cot q) \cdot \sin(2\pi h\mu/\lambda) \\ q = 2\pi h\mu/\lambda + \tan^{-1}(\mu/v) \\ u = \sqrt{\varepsilon_r - (\lambda_0/\lambda_s)^2} \\ v = \sqrt{(\lambda_0/\lambda_s)^2 - 1} \end{cases} \tag{2}$$

h is the thickness of substrate, ε_r the relative dielectric constant, λ_0 the wavelength at center frequency in the air, and λ_s the effective wavelength at center frequency in slotline.

In order to make better connection with other circuits, the characteristic impedance of microstrip has been chosen to equal $50\,\Omega$. Radius r_m and r_s should be chosen close to $\lambda_m/12$ and $\lambda_s/12$, respectively [14]. λ_m and λ_s represent effective wavelength of microstrip and slotline at center frequency, respectively. l_s will not affect the frequency bandwidth. However, it will influence the ripple [15]. Therefore, l_s should not be chosen too long. In this design, it was chosen close to $\lambda_s/2$.

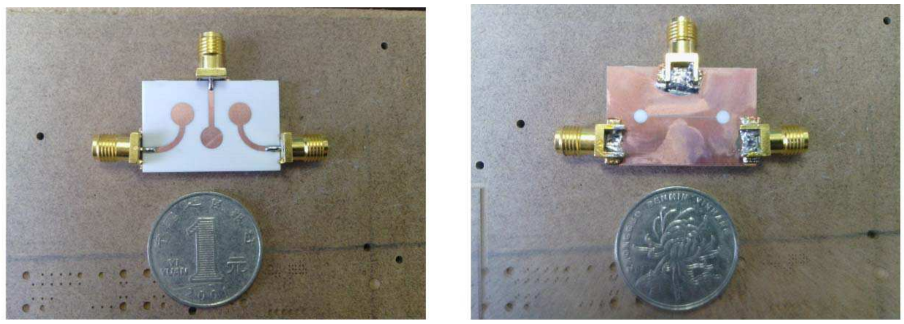
3. EXPERIMENTAL RESULTS AND ANALYSIS

The UWB power divider is designed and fabricated on Rogers 4003C substrate, whose dielectric constant, tangent loss and thickness are 3.38, 0.0023 and 0.508 mm, respectively. Figure 2 shows a photograph of the fabricated power divider. Making use of the designing theories and the simulation software HFSS v13.0, we can get the final values of the parameters on the power divider. The values are listed as following:

$$w_s = 0.2\,\text{mm}, \quad w_m = 1.17\,\text{mm}, \quad r_s = 1.4\,\text{mm}, \quad r_{m1} = 2.44\,\text{mm}, \quad r_{m2} = 2.52\,\text{mm}, \quad l_s = 16.53\,\text{mm}.$$

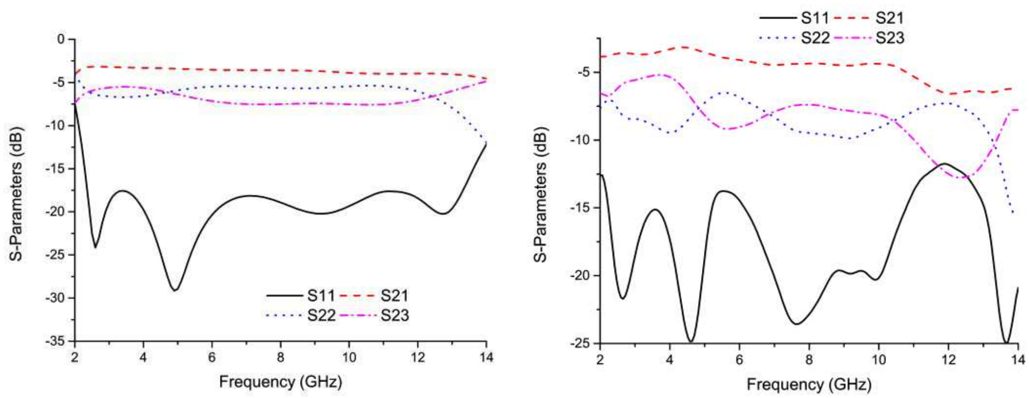
The simulated and measured results are exhibited in Figure 3 and Figure 4 and have a good consistency. In the frequency range 2.2 GHz–13.5 GHz, the simulated return loss S_{11} at input port is better than 15 dB. However, to equal value of return loss, the measured frequency bandwidth is 8.3 GHz (from 2.2 GHz to 10.5 GHz). The simulated and measured insertion losses S_{21} are better than 1 dB and 1.5 dB in the frequency range 2.2 GHz–11 GHz.

As we know, due to the inherent property of a three-port network, a reciprocal and lossless three-port network cannot obtain perfect impedance matching at all ports simultaneously. Therefore, the impedance matching at output ports (port 2 and port 3) are not as good as that at input port. The simulated return loss at output port S_{22} and isolation between output ports S_{23} are about -6 dB over the frequency range from 2.2 GHz to 12 GHz, while the measured results are about -7.5 dB over the frequency range from 2.2 GHz to 11 GHz.



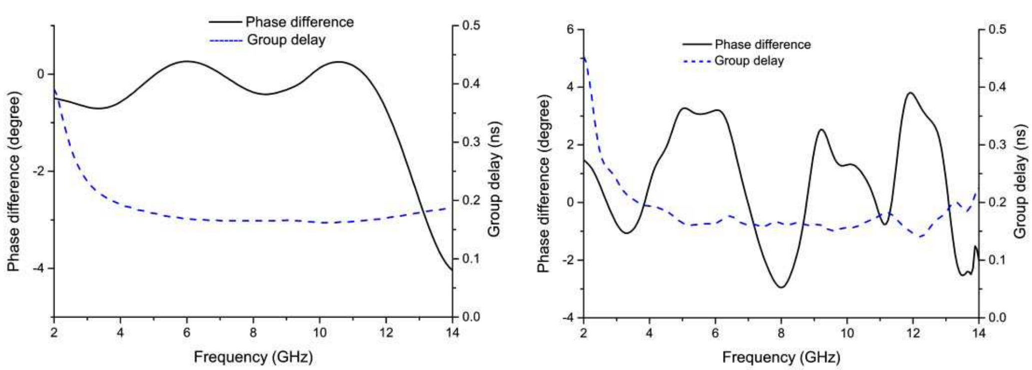
(a) (b)

Figure 2. Photograph of the power divider. (a) Top layer. (b) Bottom layer.



(a) (b)

Figure 3. Insertion loss, return loss and isolation of the novel power divider. (a) Simulated results. (b) Measured results.



(a) (b)

Figure 4. Insertion loss, return loss and isolation of the novel power divider. Phase difference and group delay. (a) Simulated results. (b) Measured results.

Figure 4 shows the simulated and measured results about phase difference and group delay. The measured phase difference between output ports is $0.3 \pm 3^{\circ}$. The simulated group delay is less than 0.4 ns, while the measured one is less than 0.45 ns. The errors between simulated and measured results are caused by the machining precision and welding technology.

4. CONCLUSION

A novel compact UWB in-phase power divider based on microstrip-to-slotline transition is designed and fabricated. By structuring the two output ports in the same layer and introducing the half-wavelength slotline and the circular stubs as the compensating circuits, the power divider can work well in wider frequency bandwidth than the ones proposed in [9–12]. And the measured results show a good return loss at input port and low insertion loss over the frequency range 2.2 GHz–10.5 GHz.

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