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Compact Ultra-Wideband In-Phase Multilayer Power Divider

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Abstract—A novel compact ultra-wideband (UWB) in-phase multilayer slotline power divider with high isolation is presented as a complement in slotline power divider field. The new structure proposed in this paper overcomes the shortcoming that power divider based on slotline almost cannot obtain high isolation between output ports. Based on the equivalent-circuit of microstrip-to-slotline transition and the method of odd-mode and even-mode analysis, the designing expressions of the proposed compact power divider have been obtained. The simulated and measured results have shown good agreement, and both of which have also shown that all the ports of the novel compact in-phase power divider have good impedance matching, and shown high isolation between the output ports over the band 3.4 GHz–12 GHz.

1. INTRODUCTION

Power divider is one of the most important microwave devices, which plays an irreplaceable role in microwave and RF circuits such as six-ports junctions, mixers, and radar systems, etc. As we know, traditional Wilkinson divider, which can obtain good impedance matching and perfect isolation at single frequency point, is the most classical power divider [1–4]. For the sake of extending applications, power dividers based on microstrip-to-slotline transitions were proposed [5–10]. In [5], a compact coplanar UWB out-of-phase power divider based on microstrip-to-slotline transition [11, 12] was proposed, which could obtain good impedance matching only at input port. In [8], an improved UWB non-coplanar power divider was put forward, in which a tapered slot and a fan-shaped slot were introduced to take place the circular slot. The new structure indeed improved the performance of return loss at input port.

However, the proposed structures in [4–7] cannot obtain high isolation between output ports and realize good impedance matching at all ports simultaneously. In order to obtain good impedance matching at all ports and high isolation between output ports, isolation resistors were introduced in [13–15]. In [13], the isolation resistor was placed on PEC1 and PEC2 in mid layer to get the isolation. Yet its working wideband was not wide enough. In [14], the resistor was placed between the output ports through a via hole on the dielectric substrate and ground. Nevertheless, appropriate length of resistor and distance between the output ports have to chosen to make them contact perfectly.

In this article, a novel UWB multilayer in-phase power divider based on microstrip-to-slotline transition is presented. This new power divider abandons traditional configuration, whose output arms are placed closely on the top layer so that the isolation resistor can be soldered on them easily. The simulated and experimental results, which exhibit good agreement, have shown that the proposed novel power divider has good impedance matching at all ports, high isolation and excellent amplitude and phase balance between output ports over the band 3.4 GHz–12 GHz.

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2. CIRCUIT DESIGN

The configuration of the novel UWB power divider is shown in Figure 1. The layout of this compact power divider abandons the traditional structure with a quarter-wavelength slotline which is replaced by a shorter one. By introducing appropriate compensating stubs, UWB frequency response can be obtained. The input port (port 1) is placed in the bottom layer, while the two output ports (port 2 and port 3) are placed on the top layer closely, and the slot is etched in the middle layer as is shown in Figure 1.

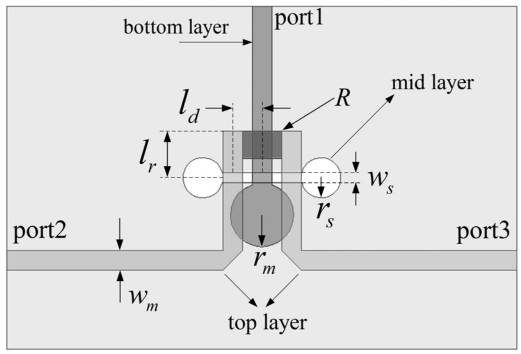


Figure 1. Configuration of the presented UWB power divider.

The proposed power divider employs microstrip-to-slotline transition. In order to obtain a flat frequency response in the operating band, one circular open-circuit microstrip-line stub is designed at the end of input branch, and two circular short-circuit slot-line stubs are etched at the ends of slotline. The equivalent lengths of the stubs are about $\lambda_m/4$ and $\lambda_s/4$, respectively. λ_m and λ_s represent the wavelength of microstrip line and slotline at center frequency, respectively. The length of output open stub is l_r, and the distance between input arm and output arm is l_d.

Because of the symmetrical configuration, the method of odd- and even-mode method can be applied to this new UWB power divider. The equivalent-circuit models are shown in Figure 2(a). θ_m, θ_s, θ_d, and θ_r are the equivalent electrical length of the homologous transmission line. Figure 2(b) exhibits the odd-mode equivalent circuit. While the odd-mode signals are applied to the output ports, the amplitude at the middle point of isolation resistor and input port is zero. Therefore, the input impedance at port 1 is zero. The input impedance at port 2 can be given by following expression

$$Z_{in}^{o} = Z_{os1} + \frac{Z_0\left(\dfrac{R}{2} + jZ_0\tan\theta_r\right)}{Z_0 + j\dfrac{R}{2}\tan\theta_r} \tag{1}$$

where

$$Z_{os1} = \frac{n^2}{\dfrac{1}{jZ_s\tan\theta_s} + \dfrac{Z_s + \dfrac{2Z_0\cot\theta_m\tan\theta_d}{n^2}}{Z_s\left(jZ_s\tan\theta_d - \dfrac{j2Z_0\cot\theta_m}{n^2}\right)}}$$

In order to obtain good impedance matching at output ports, the input impedances at port 2 and port 3 should equal the characteristic impedance of microstrip line, namely $Z_{in}^{o} = Z_0$. So we can get the following expression about the value of isolation resistor R.

$$R = \frac{2Z_0(jZ_0\tan\theta_r - Z_0 + Z_{os1})}{jZ_0\tan\theta_r - jZ_{os1}\tan\theta_r - Z_0} \tag{2}$$

Due to $\theta_m = \pi/2$, $\theta_s = \pi/2$, then

$$Z_{os1} = jn^2 Z_s \tan\theta_d$$

Because of $\theta_d \ll \pi/4$, namely $\tan\theta_d \ll 1$, Z_{os1} is a small value which can be ignored compared with $jZ_0 \tan\theta_r - Z_0$. Then (2) can be simplified as

$$R \approx 2Z_0 \tag{3}$$

Figure 2(c) exhibits the even-mode equivalent circuit as a double-ports network. While the even-mode signal are applied to output ports, there is no current flows through the isolation resistor. The input impedance at ports 1 and 2 can be given by the following expression, respectively.

$$Z_{in1}^e = \frac{n^2 Z_s(Z_{es1} + jZ_s \tan\theta_d)}{Z_s + jZ_{es1}\tan\theta_d} - j2Z_0 \cot\theta_m \tag{4}$$

$$Z_{in2}^e = \frac{n^2}{\dfrac{Z_s + jZ_{es2}\tan\theta_d}{Z_s(Z_{es2} + jZ_s\tan\theta_d)} + \dfrac{1}{jZ_s\tan\theta_s}} - jZ_0\cot\theta_r \tag{5}$$

where

$$Z_{es1} = \frac{1}{\dfrac{n^2}{Z_0 - jZ_0\cot\theta_r} + \dfrac{1}{jZ_s\tan\theta_s}}$$

$$Z_{es2} = \frac{2Z_0 - j2Z_0\cot\theta_m}{n^2}$$

Then, expressions $Z_{in1}^e = 2Z_0$ and $Z_{in2}^e = Z_0$ must be satisfied so that the input and output ports can get good impedance matching. If $\theta_r \approx \frac{\pi}{2} - \theta_d$, the characteristic impedance of slotline can be determined by

$$Z_s \approx \frac{2Z_0}{n^2} \tag{6}$$

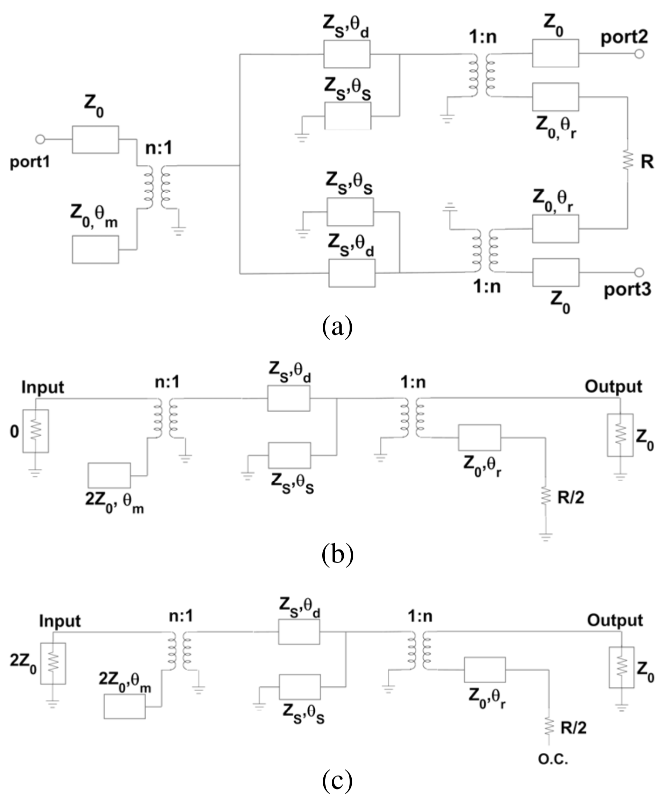


Figure 2. (a) Equivalent circuit of the UWB slotline power divider. (b) Odd-mode circuit model. (c) Even-mode circuit model.

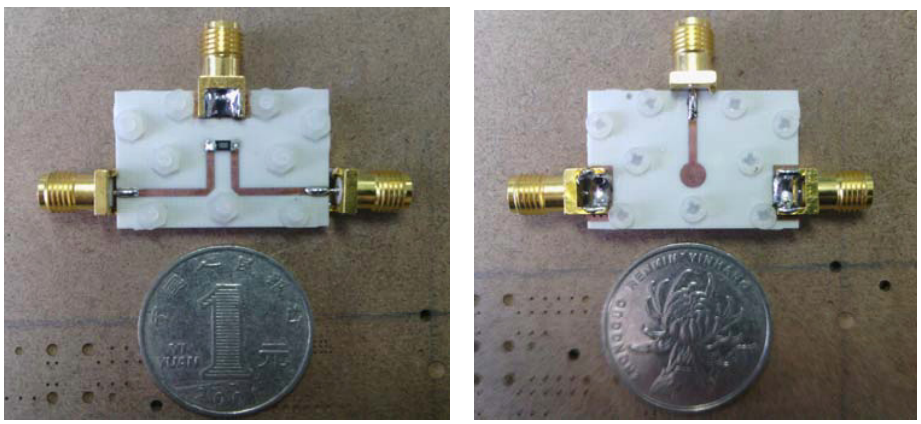
The above expressions offer some references for the dimensions of the novel power divider. The final dimensions can be obtained by making use of simulation software HFSS 13.0.

3. EXPERIMENTAL RESULTS

The presented compact UWB in-phase multilayer power divider has been designed and fabricated on Rogers 4003C substrate, whose dielectric constant is 3.38, loss tangent 0.0023, and thickness 0.508 mm. Figure 3 shows pictures of the compact power divider. The final dimensions of the presented power divider are listed as following:

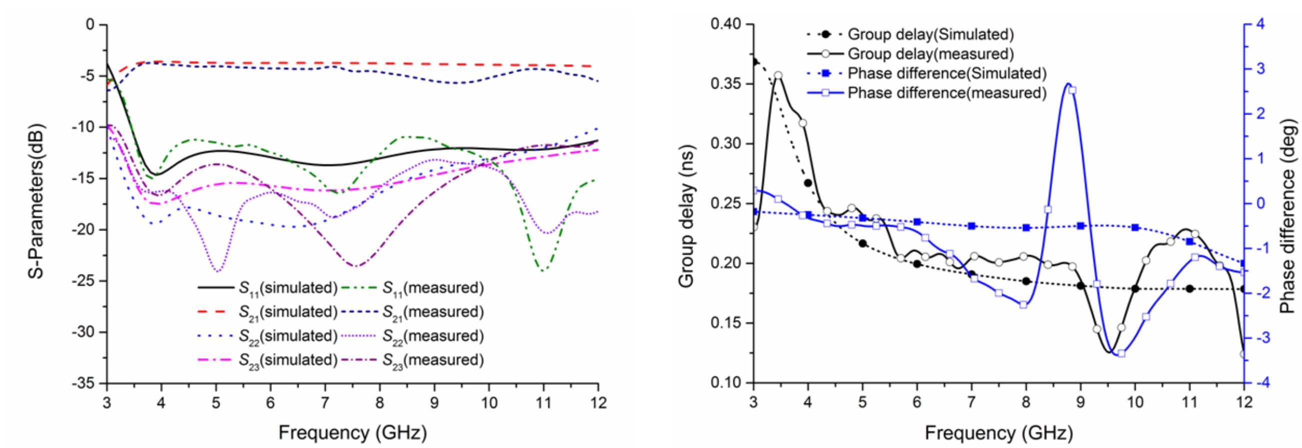
$$w_m = 1.16\,\text{mm},\ w_s = 0.6\,\text{mm},\ r_s = 1.17\,\text{mm},\ r_m = 1.86\,\text{mm},\ l_r = 2.43\,\text{mm},\ l_d = 1.72\,\text{mm},\ R = 100\,\Omega.$$

The simulated and measured results, as shown in Figure 4, exhibit a good agreement. In Figure 4(a), the measured return loss at input port is more than 11 dB from 3.5 GHz to 12 GHz, while the simulated value is greater than 12 dB over the same frequency range. The measured return loss at output port is more than 13 dB over the band 3.5 GHz–12 GHz. The measured isolation between output ports is better than 13 dB from 3.5 GHz to 10.1 GHz, and better than 11 dB from 10.1 GHz to 12 GHz, while the simulated value is about 15 dB from 3.5 GHz to 12 GHz. The insertion loss is about 2 dB. The



(a) (b)

Figure 3. Photographs of the presented compact UWB power divider. (a) Top layer. (b) Bottom layer.



(a) (b)

Figure 4. Experimental results of the compact UWB power divider. (a) Insertion loss, return losses, and isolation. (b) Phase difference and group delay.

flatness of group delay is less than 0.25 ns, which exhibits excellent linearity as shown in Figure 4(b). The measured phase difference is about $\pm 3.5^\circ$ over the range 3 GHz–12 GHz.

4. CONCLUSION

A novel compact UWB in-phase multilayer power divider, which is constructed by microstrip-to-slotline transitions, has been designed and fabricated. New circuit structure is designed and utilized so that the isolation between output ports and the impedance matching at output ports can be improved. In addition, the designing methods have been studied by making use of odd-mode and even-mode analysis, and the validity of the designing methods have been verified by the simulated and measured results, which have shown good agreement over the UWB band.

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