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A Compact UWB Single-Layer Out-of-Phase Power Divider Utilizing Microstrip-Slot Line Transitions

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ABSTRACT: A Compact Ultra-Wideband (UWB) single-layer power divider with the out-of-phase feature is proposed. UWB out-of-phase performance is obtained, using wideband microstrip-slot line transitions. All three ports are printed on a single dielectric substrate. The simulation and experimental results of the enhanced UWB power divider indicate stable phase characteristics, high impedance matching responses, and low insertion loss performances at the operating range of 2-12 GHz.

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1- Introduction

Power dividers are essential passive microwave elements, and are employed for splitting an input signal into two or more signals as outputs. They are widely used in most microwave systems, like push-pull power amplifiers, six-port networks, phase shifters, balanced mixers and antenna array feed networks [1][3]. T-junction is one of the most common examples of power dividers with one input and two outputs. Based on the phase difference between the outputs, a T-junction can be classified into out-of-phase and in-phase in process of dividing power. Designing of the power divider for in-phase operation is straightforward, such as the Wilkinson power divider. However, achieving out-of-phase operation is often more complicated, particularly when the structure is designed to perform across an UWB frequency range.

Several design techniques have been proposed in this regard. In [5], a power divider employing microstrip-slot line transitions has been presented. It shows acceptable performance as seen in simulation results. One of the drawbacks of this power divider is the structure that consists of a double-layer substrate. Apart from this, the microstrip ports are not on the same plane, which makes it incompatible to be integrated with other microwave circuits in wideband applications. A divider with out-of-phase operation utilizing microstrip-slot line coupling with 1-4 GHz frequency band and dimensions of 1 $\lambda_g \times 0.5\ \lambda_g$, has been presented in [6]. In [7], a wideband out-of-phase power divider has been presented based on T-junction and microstrip-slot line structure to obtain out-of-phase performance over a large frequency band in which return loss of input is better than 10 dB across 3.1 GHz to 10.6 GHz, and approximately 8 dB isolation between outputs is seen. Using a resistor and a capacitor, a power divider has been introduced in [13], which has a narrow band less than 1 GHz. Two types of dividers have been proposed in [14] using a multi-section Wilkinson power divider and microstrip-slot line transition. An out-of-phase power divider with arbitrary power division ratio has been presented in [15]. Based on the proposed structure, the out-of-phase power divider consists of a double layer substrate with frequency range from 0.6 GHz to 1.4 GHz. Using microstrip slot line transition, a balanced-to-unbalanced out-of-phase power divider has been reported in [16]. The structure consists of a two-layer substrate, four ports, and also a resistor to enhance isolation.

A novel compact out-of-phase power divider with planar configuration is introduced in this paper. One of the positives features of the proposed structure is not requiring any resistive elements in contrast to the structures introduced in [11] and [6]. The return loss of the part 1 is more than 10 dB from 2 GHz to 12 GHz. Moreover, the isolation between outputs is about 8 dB across the same frequency range. The structure is planar and can be easily integrated with conventional microstrip circuits. Additionally, all three ports of the proposed component are printed on one layer. Simulation and measurement results confirm that the performance is well and would be appropriate for most RF/microwave applications.

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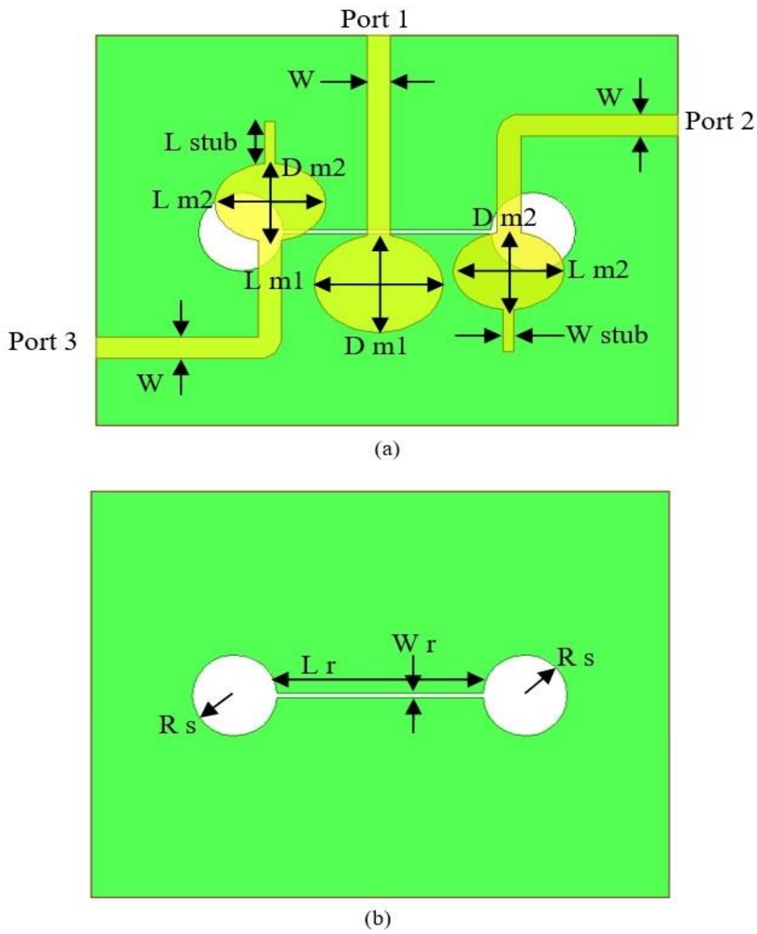


Fig. 1. Proposed divider. (a) Top, (b) Bottom.

2- Design Procedure

Fig. 1 indicates the construction of the designed structure. The device is formed of a single dielectric layer. The main part of the proposed power divider is microstrip–slot transitions. All ports of the proposed structure are on the top layer of the substrate. Additionally, the ground plane is embedded on the bottom layer. The configuration of the proposed power divider is designed so that the signal splits equally between two outputs with a 180° phase difference. A rectangular slot connected to two elliptical stubs is on the ground plane. Furthermore, the end of the lines is compensated with inductive elements to reduce the return loss and increasing the power coupling from microstrip to slot line and back. In the proposed design, the elliptical patches and circular slots are used for this aim. Any resistive elements are not used in the proposed structure. As can be demonstrated from Fig. 1, the final configuration is planar and can be integrated with microstrip components.

Furthermore, the proposed power divider exhibits UWB performance. The slot line impedance usually is chosen to be $2Z_0 \cong 120\ \Omega$, with the aim of making a compromise between obtaining 50 Ω impedance and manufacturing limitation. To obtain the proper width of the slot line, the procedures described in [9] and [10] can be used. Moreover, the length of the slot line is quarter wave length at $f_c = (f1 + f2) / 2$ in which $f1 = 2.2GHz$, $f2 = 11.5GHz$ and $f_c = 6.85GHz$, (1):

$$Lr = \frac{c}{4 f_c \sqrt{\varepsilon_e}} \tag{1}$$

in which ε_e is the effective dielectric constant and ε_r is the dielectric constant are calculated by (2):

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} \tag{2}$$

The width of the microstrip lines (W) is selected to have 50 Ω characteristic impedance. (W) can be calculated using the equations (3) to (6) founded in [4], in which Z_0 (3) is the characteristic impedance of a microstrip line, which varies with the ratio of W/d respect to 1, and d is the height of the substrate. Additionally, there is an accurate equation for W/d

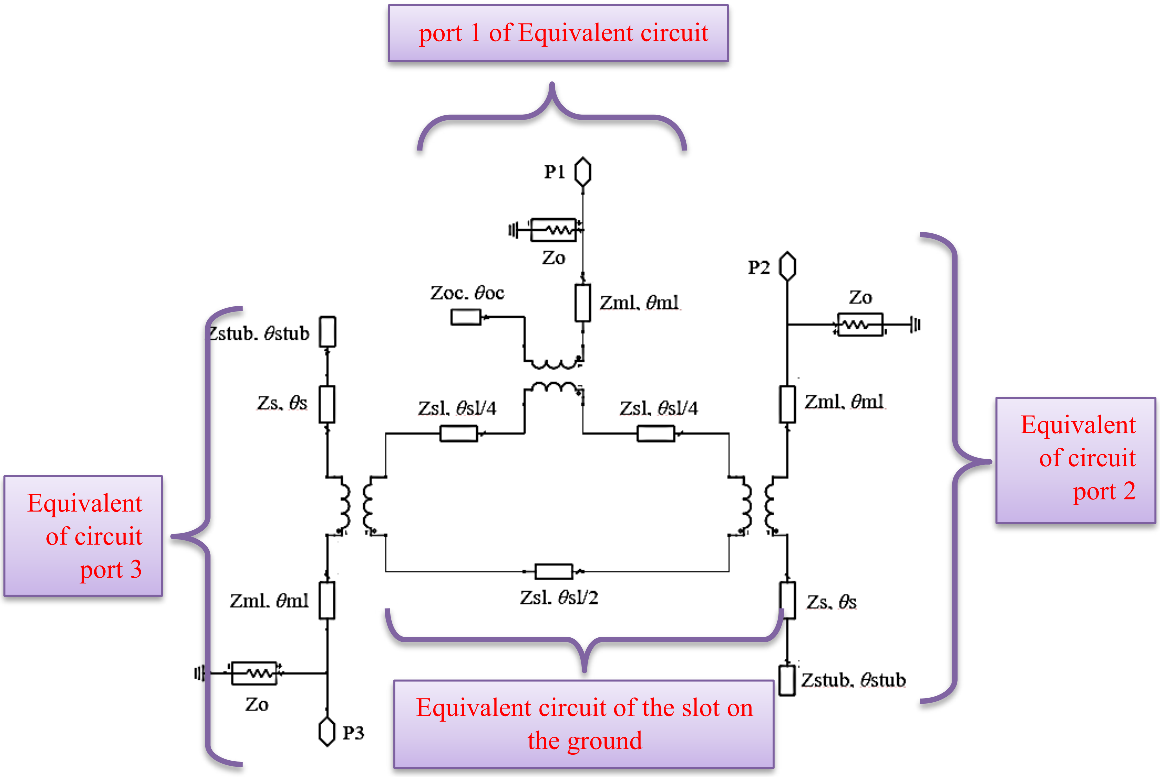


Fig. 2. Equivalent circuit of the structure

in (4). Although recently precise microwave software is able to calculate various parameters of different structures to decrease the need to use basic formulas, an overview to these relations can be beneficial to comprehend basic concepts. Two small open-ended stubs connected to elliptical patches are used to improve the bandwidth and increase isolation of the structure. The position and the dimensions of the stubs are obtained through optimization, with the aim of increasing the isolation between all ports. All the designed structure ports are on the same layer. Additionally, all are of microstrip type.

The operation of the proposed structure can be understood better by observing the circuit model of the designed structure. Fig. 2 illustrates the equivalent circuit of the proposed power divider. As shown in this figure, the connection between port 1, port 2 and port 3 is inductive coupling through the slot on the ground plane. Due to the symmetry of the slot line relative to port 1, Lr=λ/4 (θ_{sl}=90°) is divided equitably into two parts. Therefore, a typical signal from port 1 by coupling to the slot is divided into two equal signals. Crossing the slot line, these two signals are coupled to the arms connected to ports 2 and 3 by microstrip-slot line transitions. Since the arms connected to ports 2 and 3 are located at a point symmetrical to the slot line on the ground and also to the arm of port 1, out-of-phase operation between the signals received in the output ports appeared. $Zsl \cong 120\Omega$ is the impedance of the slot line. Zml is the impedance of the microstrip lines connected to an input and two outputs. Furthermore, θ is defined as the electrical length of the lines:

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right) & for\ W/d \le 1 \\ \frac{120\pi}{\sqrt{\varepsilon_e}[W/d + 1.393 + 0.667 ln(W/d + 1.444)]} & for\ W/d \ge 1 \end{cases} \quad (3)$$

$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A}-2} & for\ W/d < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] & for\ W/d > 2 \end{cases} \quad (4)$$

where:

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r}{\varepsilon_r}(0.23 + \frac{0.11}{\varepsilon_r})} \quad (5)$$

And:

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (6)$$

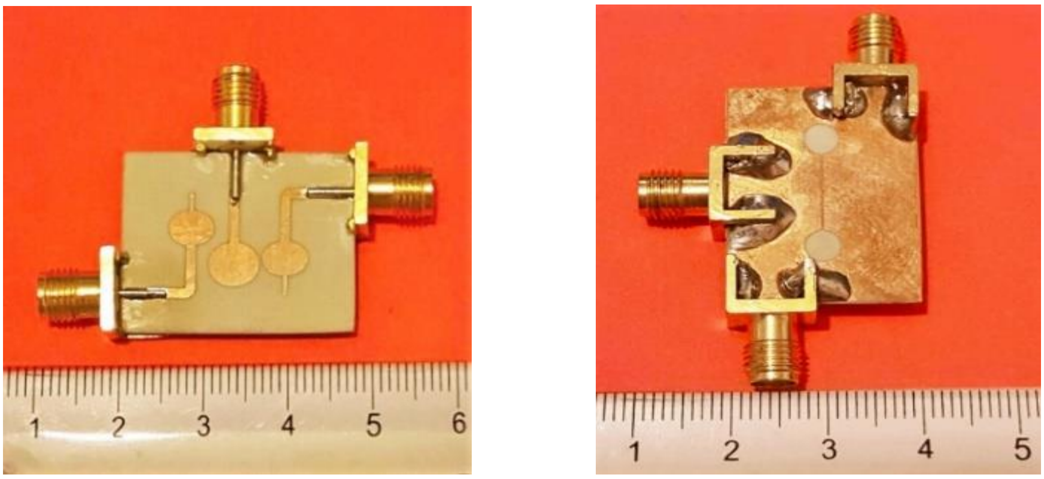


Fig. 3. Picture of fabricated prototype of the designed structure. top (left), bottom (right).

Table 1. Optimized Values of the Design Parameters

Parameter	Values (mm)	Parameter	Values (mm)
W	1.11687	L stub	2.16
L m1	6	W stub	0.5
D m1	5	R s	2
L m2	5.2	L r	9.72
D m2	4	W r	0.2

3- Results and Discussion

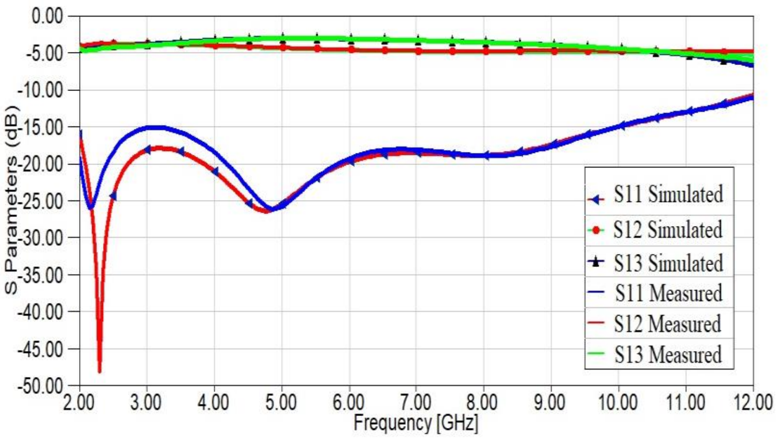
Following the stated considerations, design and fabrication of the final structure is realized. The fabricated structure is indicated in Fig. 3. The design of the proposed divider is completed and optimized with Ansoft HFSS v.15. Rogers RO4003 as the substrate with dielectric constant of 3.38, tangent loss of 0.0027 and thickness of 0.508 mm is chosen for the construction of the microstrip power divider.

The values of different parts of the proposed structure are optimized to reach appropriate operational characteristics over UWB frequency range. The final values are given in Table 1. The structure is compact with total dimension of $L = 27\,mm$ and $W = 20\,mm$. According to the wavelength, the final dimensions are around 0.75 $\lambda_g \times 0.5\ \lambda_g$, in which λ_g is aguided wavelength at the frequency of $6.85GHz$. This compares favorable against the structures in [12] with the length of 2.75 λ_g, in [5] with dimensions 1.25 $\lambda_g \times 1\lambda_g$, and in [6] with the length of 1 λ_g.

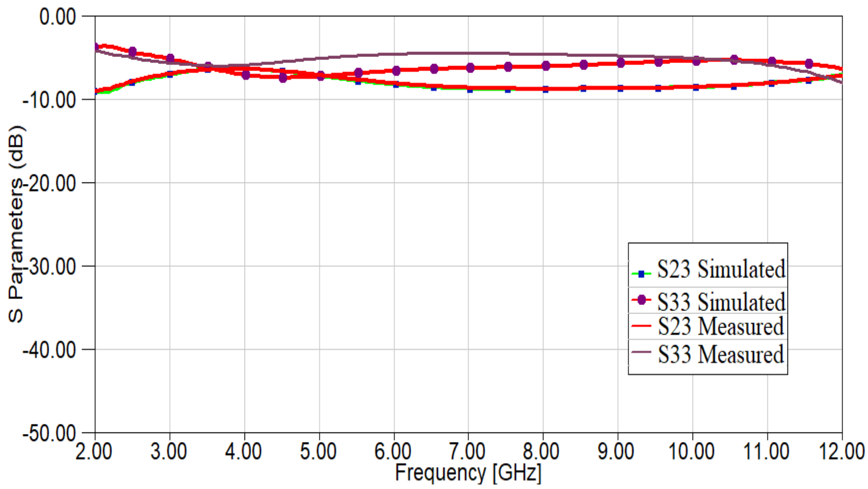
Fig. 4(a) exhibits simulated responses of the structure. The results show $S_{21} \cong S_{31} \cong$ 4 dB from 2 to 11 GHz. Moreover, the return loss of the input port is larger than 10 dB over the whole band and the isolation between ports 2 and 3 is almost 8 dB over the same band, which is usually sacrificed in a power divider. The average of return loss of output ports is about 6 dB from 2 to 12 GHz, as $S_{22} \cong S_{33}$, only S_{33} has been illustrated in Fig.4 (a).

Fig. 4(b) illustrates measured responses of the designed divider. The figure indicates a relatively good compromise between the results of the simulation and measurement. Reflection coefficient of the input and isolation between ports 2 and 3 are more than 10 dB and about 8 dB, respectively over the frequency band.

Fig. 5 exhibits the phase characteristic of the designed structure. As indicated in Fig. 5, $180^\circ \pm 5^\circ$ phase difference is seen after excitation from 2 to 12 GHz. Additionally, the measured phase difference between outputs is $180^\circ \pm 10^\circ$ from 2 to 12 GHz. Note that these slight amplitude and phase imbalance between simulation and measured responses is due to the loss of coaxial SMA connectors employed in the device.



(a)



(b)

Fig. 4. Simulated and measured frequency responses of the structure.

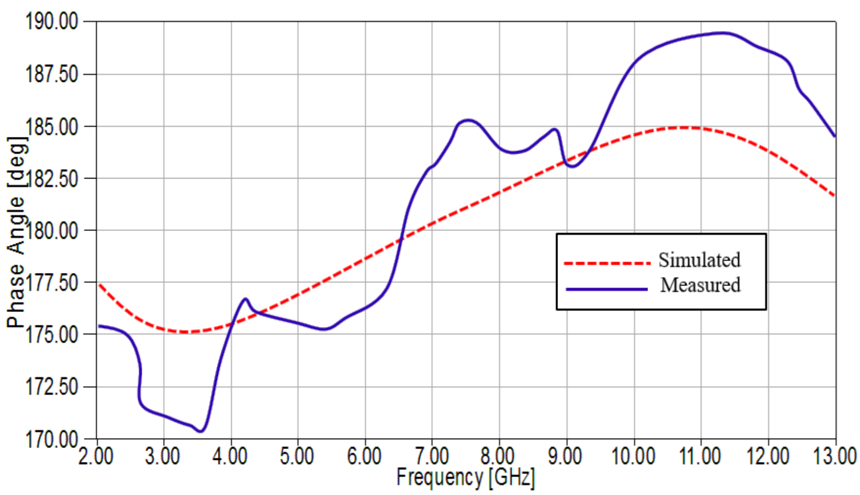


Fig. 5. Measured and simulated phase characteristic of the structure.

4- Conclusion

A compact out-of-phase power divider with one layer for UWB applications is introduced. All three ports of the proposed structure are formed by microstrip lines. The offered structure is planar and designed based on the combination of the microstrip and slot lines . The simulated and measured responses of the structure exhibit good agreement and show insertion loss about 1 dB, return loss more than 10 dB, and also good isolation of 8 dB from 2-12 GHz.

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