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A New Printed Microstrip UWB Power Divider with Notched Band

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Abstract—In this paper, a new printed ultra-wideband (UWB) power divider with notched band using square ring multiple-mode resonator (SRMMR) is presented. The characteristics of the proposed SRMMR are investigated by using even- and odd-mode analysis. Then, the initial UWB performance is achieved by introducing SRMMR to the basic Wilkinson power divider. Finally, a pair of parallel coupled lines is embedded into the SRMMR to achieve a desired notched band inside the UWB passband. The central frequency and the bandwidth of the notched band can be easily controlled by the electrical length and coupling coefficient of the coupled lines. To validate the design concept, a novel printed UWB power divider with notched band centered at frequencies of 5.8 GHz is designed and measured. The simulated and measured results indicate that it has a low insertion loss and good return loss performance at all the three ports, and a high isolation between the two output ports across the UWB bandwidth from 3.1 to 10.6 GHz with a small size of $0.46\lambda g \times 0.69\lambda g$, where λg is the guided wavelength at 6.85 GHz.

1. INTRODUCTION

Power dividers play an important role in communication systems, such as transceivers, phase arrays, and power amplifiers, due to their easy design and good performance. The most popular power divider is the Wilkinson power divider, which obtains completely matched output ports with sufficiently high isolation between them. However, it has less than 20% fractional bandwidth. With the rapid growth of unlicensed use of ultra-wideband (UWB) for radar imaging system, short-range broadband communication, and indoor wireless communications systems, there has been tremendous interest in exploration of various UWB components allocated $3.1 \sim 10.6$ GHz band. To achieve this goal, a few typical methods to design UWB power dividers have been developed so far [1–5].

In [2], multi-section Wilkinson power dividers have to be cascaded, which increases the size and the insertion loss to obtain wider bandwidth. However, the fractional bandwidth is not ideal. In [3], the waveguide power divider with high power capacity and very low insertion loss is designed. However, the waveguide structure is large and inflexible. In [4], the parallel-coupled lines and stepped-impedance open-circuited stubs are directly cascaded to construct UWB power dividers, which will increase fabrication cost. In [5], the multilayer broadside-coupled structure is used to obtain a compact UWB performance, but the multi-layer structure is hardly compatible with the existing microwave-integrated circuit. Moreover, the existing wireless networks such as 5.8 GHz WLAN signals can interfere with UWB networks, thus compact power dividers with notched band are emergently required to reject these interfering signals.

In this paper, a novel UWB power divider with notched band based on square ring multiple-mode resonator (SRMMR) is proposed and designed. The resonance properties of the proposed SRMMR with two pairs of resonance modes are theoretically analyzed. Then, the UWB performance is obtained by introducing SRMMR to the basic Wilkinson power divider. Finally, a pair of parallel coupled lines

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is embedded into the SRMMR to achieve a desired notched band. The central frequency and the bandwidth of the notched band can be easily controlled by the electrical length and coupling coefficient of the coupled lines. To validate the design concept, a novel printed UWB power divider with notched band centered at frequencies of 5.8 GHz is designed and measured. Both simulated and experimental results are provided with good agreement.

2. INITIAL UWB POWER DIVIDER

Figure 1 shows the layout of the proposed initial UWB power divider. The microstrip line $l_0 = \lambda g/4$ is used to achieve good impedance match at port 1. An isolation resistor R is placed at the end of l_7. Notice that meander transmission lines are also utilized in the design to further reduce the power divider size. The layout of the equivalent circuit of the square ring resonator is shown in Fig. 2.

To illustrate the design theory, the resonance characteristics of the initial UWB power divider with various dimensions are analyzed with HFSS 11.0. The proposed UWB power divider is fabricated using Rogers 4003B with a thickness of 0.508 mm, relative dielectric constant of 3.38 and loss tangent of 0.009. All the dimensions are selected as follows: $l_0 = 6$ mm, $l_1 = 5.7$ mm, $l_2 = 2.9$ mm, $l_3 = 4.4$ mm, $l_4 = 2.1$ mm, $l_5 = 4.1$ mm, $l_6 = 2.0$ mm, $l_7 = 5.7$ mm, $l_8 = 1.5$ mm, $w_0 = 1.1$ mm, $w_1 = 0.7$ mm, $w_2 = 0.7$ mm, $w_3 = 0.5$ mm, $w_4 = 0.1$ mm, $w_6 = 1.2$ mm, $w_7 = 0.6$ mm, $r_0 = 0.3$ mm. The size of the whole circuit is 20 mm × 30 mm.

The even- and odd-mode analysis method can be employed to the proposed initial UWB power divider for the symmetry characteristics of the new structure. The simple schematic of the square ring multiple-mode resonator is shown in Fig. 2, while the odd- and even-mode equivalent circuits are shown in Figs. 3(a) and (b).

From port 1 to port 2, two transmission paths with characteristic admittance Y_2 and Y_3 are introduced, and a shorted stub with characteristic admittance Y_4 and electrical length θ_4 is connected

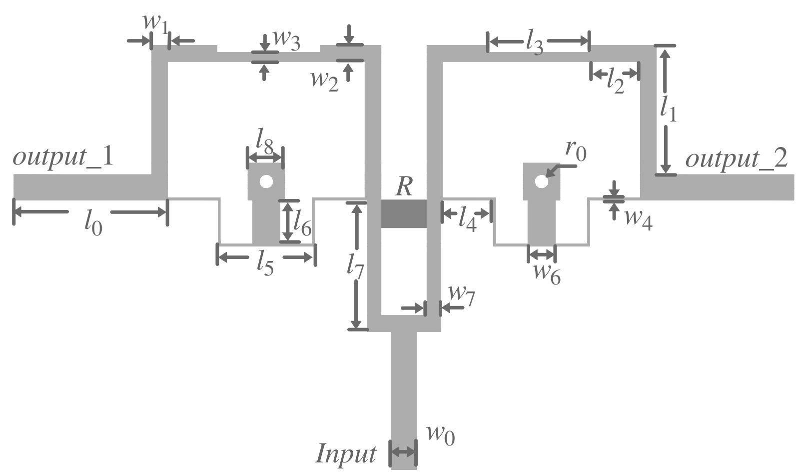

Figure 1. Layout of the proposed initial UWB power divider.

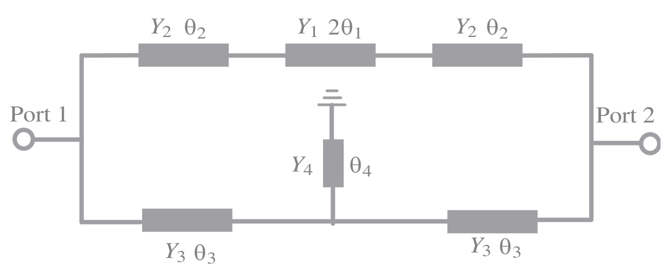

Figure 2. Schematic of the proposed square ring multiple-mode resonator.

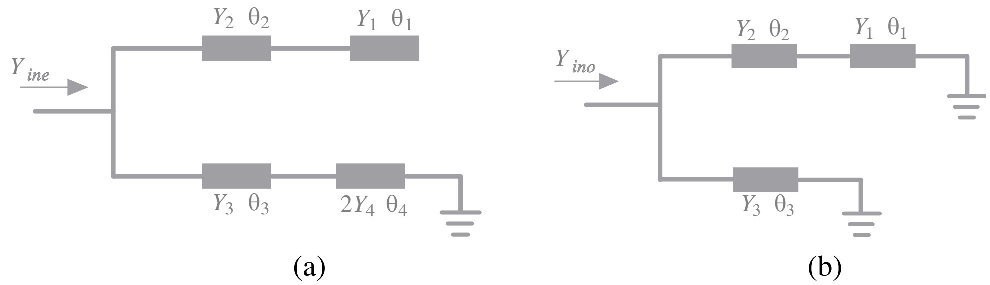

Figure 3. The Equivalent circuit model of the proposed square ring multiple-mode resonator. (a) Even mode circuit model. (b) Odd mode circuit model.

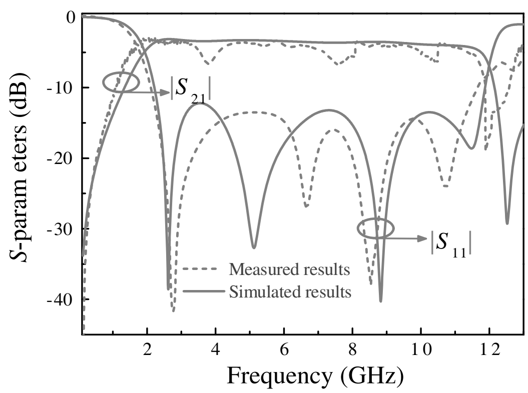

Figure 4. Simulated and measured performance of the initial UWB power divider.

to the center of the second transmission path. The characteristic impedance at port 1 is $50\,\Omega$. When the even-/odd-mode signals are excited from ports 2 to 1, a virtual open/short appears along the centre of the square ring resonator. In the even mode, the stepped impedance stub is divided in half along the plane of symmetry. In the odd mode, the plane of symmetry can be considered as a ground plane, with no current flowing through the isolation resistor. The even/odd-mode input admittance Y_{ine}/Y_{ino} of Fig. 3 can be illustrated as:

$$Y_{ino} = -jY_3 \cot\theta_3 - j\frac{Y_1 \cot\theta_3 - jY_2 \tan\theta_2}{Y_2 + Y_1 \cot\theta_1 \tan\theta_2} \tag{1}$$

$$Y_{ine} = jY_2\frac{Y_1 \tan\theta_1 + Y_2 \tan\theta_2}{Y_2 \tan\theta_2 - Y_1 \tan\theta_1 \tan\theta_2} - jY_3\frac{Y_4 \cot\theta_4 + 2Y_3 \tan\theta_3}{2Y_3 + Y_4 \cot\theta_4 \tan\theta_3} \tag{2}$$

As analyzed in [2], due to the symmetry of the square ring resonator, the resonance frequencies can be calculated when $Y_{ine}/Y_{ino} = 0$ from the one end of the even- and odd-mode circuit. Hence, it cannot solve the expressions for the two pairs of resonance modes directly. Thus, another two odd-mode resonator frequencies f_{odd1} ($\theta_1 = 120°$, $4f_0/3$) and f_{odd2} ($\theta_1 = 180°$, $2f_0$) can be realized. As we can see, the bandwidth of the UWB power divider decreases as Y_3 increases, and f_0 increases as θ_4, Y_4 increase. In this way, the bandwidth for the passband of the UWB power divider with the SRMMR can be conveniently controlled by varying the characteristic matrix Y_3, Y_4 and θ_4 when Y_1, Y_2 and θ_1, θ_2 are fixed. Therefore, by properly tuning the dimensions of the SRMMR, a new compact microstrip UWB power divider can be achieved with a wanted bandwidth.

The measurement was carried out on the network analyser Agilent 85052D. The measured and simulated results are shown in Fig. 4. As we can see from Fig. 4, the fabricated UWB power divider has a passband from 2.1 GHz to 11.7 GHz. The return loss is under -10 dB and the insertion loss close to 3 dB, which ensures a good transmission performance in the passband.

3. UWB POWER DIVIDER WITH NOTCHED BAND

The electrical length of a pair of parallel coupled lines is θ_n, and its even- and odd-mode characteristic admittances are Y_{ne} and Y_{no}, as shown in Fig. 5(a). Fig. 5(b) gives its corresponding equivalent circuit model [6, 7]. The input and output ports are defined as port 1 and port 2, while port 3 and port 4 are terminated with an open circuit and a short circuit, respectively. Assume that the characteristic admittances of port 1 and port 2 are both equal to the characteristic admittance of the parallel coupled lines $Y_n = (Y_{ne} * Y_{no})^{1/2}$. Then, the return loss of the input and output ports and the insertion loss from port 1 to port 2 can be calculated using the following equations [8, 9].

$$S_{11} = \frac{(Y_n - Y_{11})(Y_n + Y_{22}) + Y_{12}Y_{21}}{(Y_n + Y_{11})(Y_n + Y_{22}) - Y_{12}Y_{21}} \tag{3a}$$

$$S_{22} = \frac{(Y_n + Y_{11})(Y_n - Y_{22}) + Y_{12}Y_{21}}{(Y_n + Y_{11})(Y_n + Y_{22}) - Y_{12}Y_{21}} \tag{3b}$$

$$S_{12} = S_{21} = \frac{-2Y_{12}Y_n}{(Y_n + Y_{11})(Y_n + Y_{22}) - Y_{12}Y_{21}} \tag{3c}$$

where Y_{11}, Y_{12}, Y_{21}, Y_{22} are its two port Y-parameters and can be represented as

$$Y_{11} = j\frac{Y_{ne} + Y_{no}}{2}\tan\theta_n$$
$$Y_{12} = Y_{21} = j\frac{Y_{ne} + Y_{no}}{2}\sin\theta_n$$

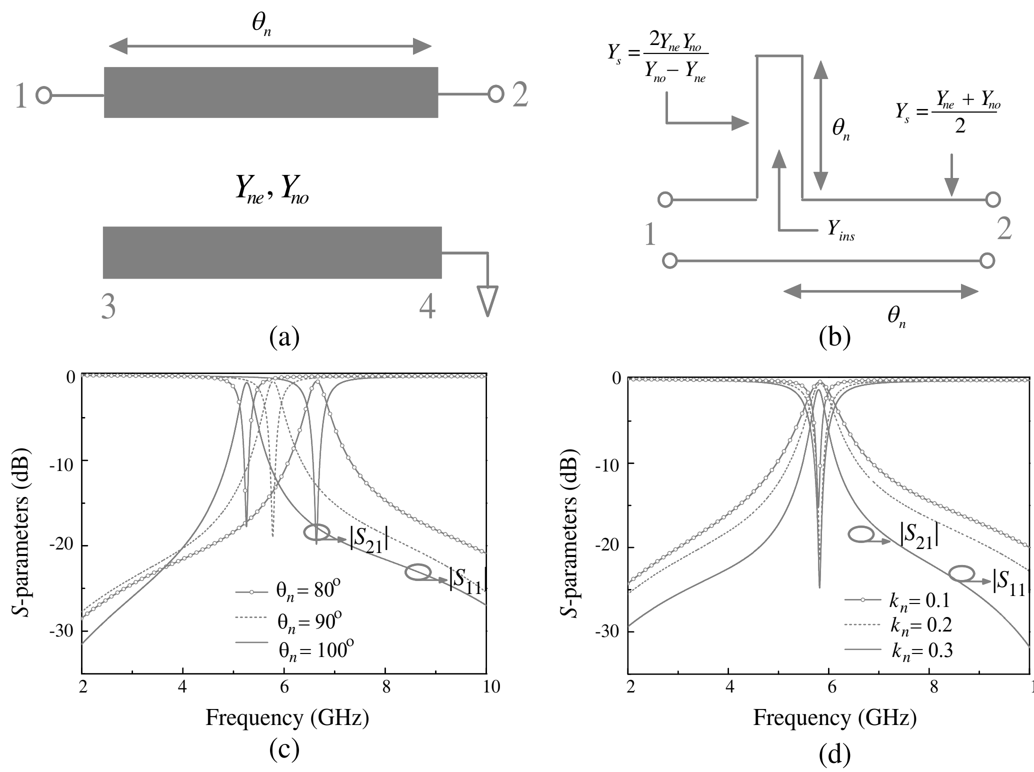

Figure 5. (a) Schematic of the parallel coupled lines. (b) Equivalent circuit of the parallel coupled lines. (c) Effect of the electrical length θ_n at $f_n = 5.8\,\text{GHz}$ on the central frequency of the notched band ($k_n = 0.2$ fixed). (d) Effect of the coupling coefficient k_n on the bandwidth of the notched band ($\theta_n = 90^\circ$ at $f_n = 5.8\,\text{GHz}$ fixed).

$$Y_{22} = -j\frac{2Y_{ne}Y_{no}\left(Y_{ne}+Y_{no}\right)}{\left(Y_{no}^2-Y_{ne}^2\right)\tan\theta_n - 4Y_{ne}Y_{no}\cot\theta_n}$$

In Fig. 5(b), when $\theta_n = 90°$ at f_n, the input admittance of the series short-circuited stub $Y_{ins} = -jY_s \cot\theta_n$ goes to zero, which blocks the power transfer from port 1 to port 2 and generates a notched band at f_n. Fig. 5(c) shows several different θ_n at $f_n = 5.8$ GHz affecting the notched band, and only when $\theta_n = 90°$, the central frequency of the notched band will be just at 5.8 GHz. Fig. 5(d) depicts that the bandwidth of the notched band is controlled by the coupling coefficient $k_n = (Y_{no}-Y_{ne})/(Y_{no}+Y_{ne})$ of the parallel coupled lines. And the stronger the coupling of the coupled lines is, the wider bandwidth of the notched band will be.

The frequency characteristics of the parallel coupled lines with various dimensions are investigated by HFSS 11.0 as shown in Fig. 6. It can be seen that the frequency locations of notched bands move down simultaneously with the increase of dimensions of l_{e1}. Therefore, by appropriately adjusting the parallel coupled lines dimensions, the notched band can be achieved at desired frequencies.

When a pair of the above-mentioned parallel coupled lines is embedded into the SRMMR of the proposed initial UWB power divider, a novel printed UWB power divider with a notched band is proposed and designed as shown in Fig. 7. Compared with the above initial UWB power divider, the

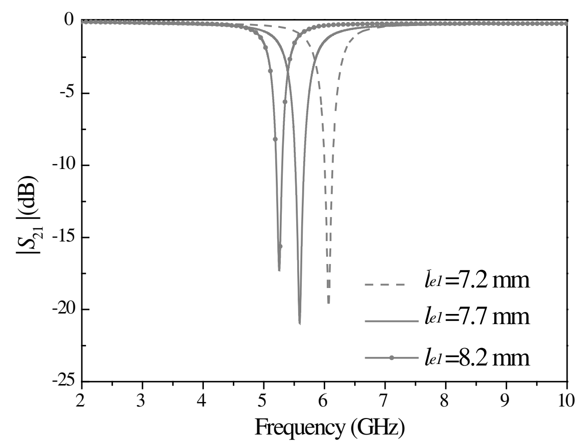

Figure 6. Simulated S-parameters of parallel coupled lines for various dimensions.

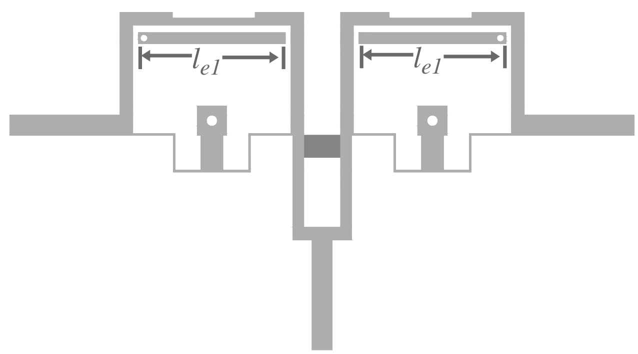

Figure 7. Layout of the proposed UWB power divider with notched band.

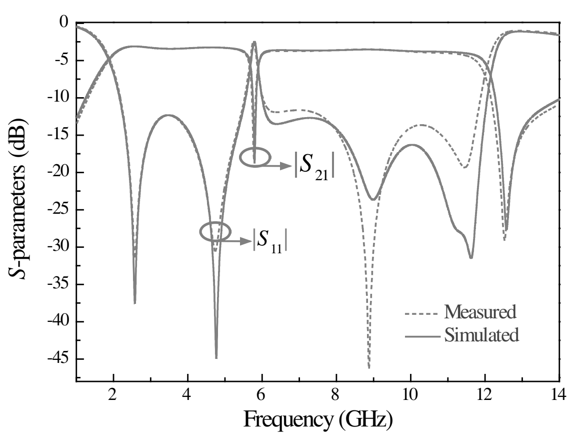

Figure 8. Simulated and measured S-parameters of the designed UWB power divider with notched band.

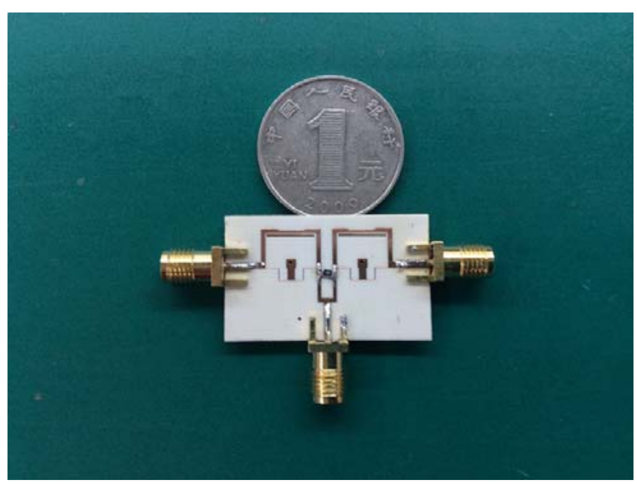

Figure 9. Photograph of the proposed UWB power divider with notched band.

physical dimensions of the UWB power divider with a notched band do not change dramatically, which indicates a simple notched-band design procedure. Fig. 8 plots the full-wave simulated and measured S-parameters of the proposed UWB power divider with a notched band. Single notched band is measured at 5.8 GHz with the notched fractional bandwidth of 1.9%. Fig. 9 shows a photograph of the fabricated UWB power divider with a notched band. The overall size of the designed UWB power divider is only $20 \times 30\,\mathrm{mm}^2$, which corresponds to a compact electrical size of $0.46\lambda g \times 0.69\lambda g$.

4. CONCLUSION

In this work, a high-performance UWB power divider with a highly rejected notched band using square ring multiple-mode resonator (SRMMR) has been successfully implemented and investigated. The characteristics of the proposed SRMMR are investigated by using even- and odd-mode analysis. Then, the initial UWB performance is achieved by introducing SRMMR to the basic Wilkinson power divider. Finally, a desired notched band inside the UWB passband is achieved by embedding a pair of parallel coupled lines into the SRMMR. The notched-bands can be easily tuned to the desirable frequency location by controlling the parameters of the parallel coupled lines. The proposed power divider covers the frequency range for the UWB systems, between 2.1 GHz and 11.7 GHz, with a rejection band around WLAN. The introduced parallel coupled lines are simple and flexible for blocking undesired narrow band radio signals appeared in UWB band. Outstanding performance can be realised for broadband power divider with small size, which is now widely demanded in UWB applications. To summarise, the proposed power divider is very useful for modern UWB wireless communication systems owing to its marked properties of simple topology, compact size, and excellent performance.

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