Novel Compact Three-Way Filtering Power Divider Using Net-Type Resonators

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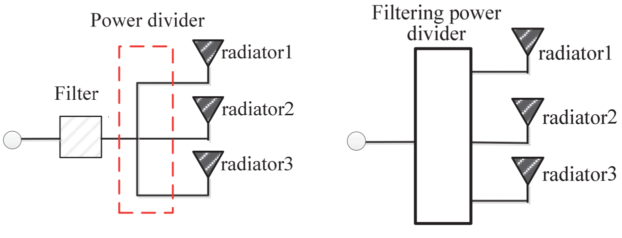
Abstract. *In this paper, we present a novel compact three-way power divider with bandpass responses. The proposed power divider utilizes folded net-type resonators to realize dual functions of filtering and power splitting as well as compact size. Equal power ratio with low magnitude imbalance is achieved due to the highly symmetric structure. For demonstration, an experimental three way filtering power divider is implemented. Good filtering and power division characteristics are observed in the measured results of the circuit. The area of the circuits is 14.5 mm × 21.9 mm or 0.16* $\lambda_g \times 0.24\,\lambda_g$*, where the* λ_g *is the guided wavelength of the center frequency at 2.1 GHz.*

Keywords

Power divider, bandpass response, three-way division, compact size, miniaturization

1. Introduction

Power dividers are widely used in microwave circuits and the feed systems in antenna arrays [1–3]. The filter is also a key element in modern wireless and mobile communication systems. In some applications, both the functions of power division and filtering are needed. They can be designed individually like it in Fig. 1(a). However, the overall circuit of the two components is bulky. Since most electronic devices become more and more compact, it is important to decrease the size of bandpass filters and power dividers. In response to this requirement, integrating the bandpass filtering and power division functions into a single device has been carried out, resulting in filtering power dividers as shown in Fig. 1(b). There are several design methods. The first one is to cascade the filtering circuit and the power divider to realize dual functions [4], [5]. A typical method is to use bandpass filters to replace the quarter-wave length transformers in power dividers [6–8]. The third one is to use coupled resonators with multiple ports to achieve both bandpass filtering and power division functions. However, the sizes of these circuits are not compact enough in many designs. To reduce the size, compact resonators are employed in many designs [9], [10], such as the net-type resonator. The resonator is chosen to cope with the divider design in [11]. Filtering responses are obtained and the circuit size can be significantly reduced. However, these methods of integrating the BPFs with power divider are focus on designing two-way circuits. Few researches of filtering power divider have carried on three-way cases.



(a) (b)

Fig. 1. (a) Cascaded filter and power divider; (b) Integrating filter with power divider.

There are different methods for designing three-way power dividers, such as the classical Wilkinson three-way power dividers. They can also be designed by cascading multiple two-way power dividers to form three-way power dividers [12–13]. In [14], three-way power dividers are designed based on tapered lines transformers. These methods are of great help in designing three-way power dividers. However, the filtering function has not been integrated.

In this paper, we present a novel three-way miniaturized filtering power divider. Four compact net-type resonators are symmetrically placed and the ports are also symmetrically tap-connected to the resonators. By using the symmetrical net-type resonators, both functions of miniaturized size and equal power ratio with low magnitude imbalance level are realized. Besides, the filtering character is also realized by the coupled resonators. Wide stopband is achieved due to the characteristic of the net-type resonator as analyzed in [10].

To verify the proposed idea, an experimental filtering power divider is fabricated. Good agreement between the simulated and measured results validates the proposed idea.

2. Three-way Filtering Power Divider Configuration

The proposed topology of the three-way filtering power divider is shown in Fig. 2. In the figure, the nodes

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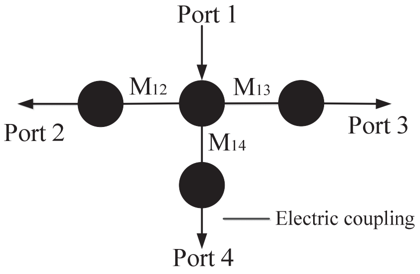


Fig. 2. The proposed topology for the filtering power divider.

represent resonators and the solid line presents the electric coupling between them. M_{ij} denotes the coupling coefficient between resonator *i* and resonator *j*. As shown in Fig. 2, the resonators are placed symmetrically and the coupling coefficient should set to be equal, e.g., $M_{12} = M_{13} = M_{14}$. By utilizing the coupled resonator configuration, the equivalent circuit between port 1 and each other port could form a filtering circuit and thus bandpass responses can be achieved.

To realize the proposed idea as well as miniaturization, compact resonator is needed to form the topology. The folded net-type resonator presented in [10] is chosen to fulfil the requirement due to its extremely small size and favorable performance. As shown in Fig. 3(a), the net-type resonator in this design consists of one short-ended transmission-line section and three open-ended transmission-line sections. The L_n is the length of the transmission lines and the impedance is labeled as Z_n, $n = 1, 2, 3, 4$. In this design $Z_1 = Z_2 = Z_3 = Z_4$ and $L_1 = L_2 = L_3 = L_4 = L$ are determined so that the circuit is symmetrical. Therefore, even-odd mode analysis can be applied. For the odd and even mode, the corresponding equivalent circuits are shown in Fig. 4(a) and (b), respectively. The resulting input admittance for odd-mode is given by:

$$Y_{in,odd} = \frac{Y_c}{j\tan\theta} \tag{1}$$

and the input admittance for even-mode is given by:

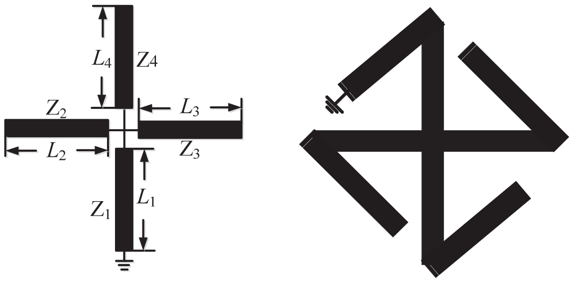
$$Y_{in,even} = Y_c \frac{\frac{1}{2}(jY_c\tan\theta + \frac{Y_c}{j\tan\theta}) + jY_c\tan\theta}{Y_c + \frac{1}{2}j(jY_c\tan\theta + \frac{Y_c}{j\tan\theta})\tan\theta} = \frac{(1-3\tan^2\theta)Y_c}{j\tan\theta(3-\tan^2\theta)} \tag{2}$$

where $\theta = \beta L$ is the electric length of the microstrip line, by enforcing $Y_{in,odd} = 0$ and $Y_{in,even} = 0$, resonance conditions corresponding to the odd and even modes are achieved. Thus, the fundamental resonant frequencies for the odd and even mode can be calculated as:

$$f_{odd} = \frac{c}{4L\sqrt{\varepsilon_e}} \tag{3}$$

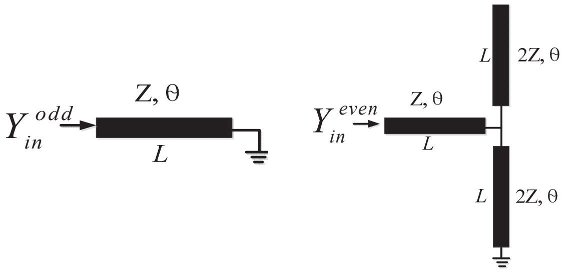
and

$$f_{even} = \frac{\tan^{-1}\sqrt{1/3}\,c}{2\pi L\sqrt{\varepsilon_e}}\ . \tag{4}$$



(a) (b)

Fig. 3. (a) Microstrip realization of a net-type resonator. (b) Net-type resonator of folded form.



(a) (b)

Fig. 4. (a) Odd-mode equivalent circuit. (b) Even-mode equivalent circuit of the net-type resonator.

Since the fundamental odd-mode resonant frequency is higher than the even-mode one, the even-mode resonance is utilized to form the passband for size reduction. As indicated by (4), the passband frequency can be controlled by altering the length *L*.

Based on above analysis, the net-type resonators as shown in Fig. 3(b) are selected to compose the three-way filtering power divider. They are folded in the same way which can greatly decrease the size of the circuit and ensure that the signal is transferred to each port identically. Meanwhile, each of the net-type resonators has the maximum electric-field intensity near the open ends so that the inter-resonator coupling can be easily realized.

Figure 5 shows the complete circuit which is composed of 4 compact net-type resonators. The resonators are placed symmetrically and the open ends of the resonators

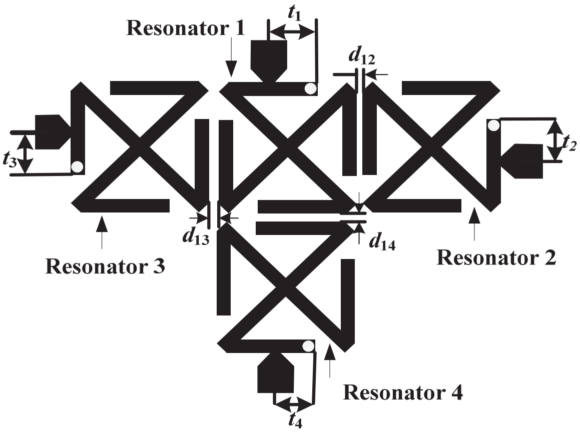


Fig. 5. Schematic layout of the three way filtering power divider.

are put closely to realize electric coupling between them. t_n is the distance between the port n and the short end of the resonator n, d_{ij} is the gap between the coupling end of resonators i and j.

3. Circuit Design

Based on the analysis above, the design procedures of the three-way filtering power divider are as follows. The first step is to determine the length of the resonators, depending on the required operating frequency. By altering the length of the resonators, required operating frequency is acquired. The second step is to obtain the required coupling coefficient k and external quality factor Q_e. It is convenient to adjust k by changing the gap between two coupling lines d_{12}, d_{13} and d_{14}. As for Q_e at the passband, it is mainly determined by the tap position of the 50ohm ports, i.e., the length t_1, t_2, t_3 and t_4. In this design, a Chebyshev lowpass prototype with 0.5 dB passband ripple is chosen, and the lumped circuit element values are selected to be: $g_0 = 1$, $g_1 = 1.4029$, $g_2 = 0.7071$, $g_3 = 1.9841$. The proposed filtering power divider has a 3-dB bandwidth of 10%. Accordingly, the k and Q_e can be calculated:

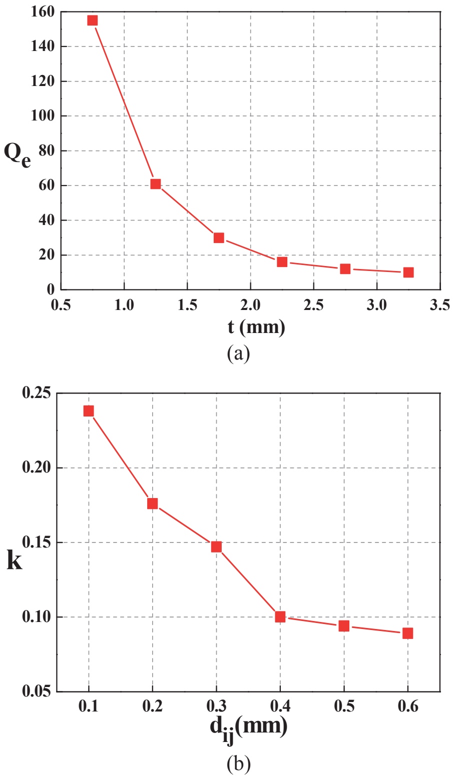
$$k = \frac{FBW}{\sqrt{g_1 g_2}} = 0.1 , \tag{5}$$

$$Q_e = \frac{g_0 g_1}{FBW} = 14 . \tag{6}$$

Figure 6 shows the coupling coefficient k and external quality factor Q_e against t_n and d_{ij}. To obtain the desirable k and Q_e, the dimensions are chosen as follows: $t_1 = t_2 = t_3 = t_4 = 2.4$ mm, $d_{12} = d_{13} = d_{14} = 0.4$ mm.

The circuit is fabricated on a Rogers RO4003 substrate which has a relative dielectric constant of 3.38, a thickness of 0.81 mm and a loss tangent of 0.0027. The overall size of the fabricated filtering power divider is 14.5 mm × 21.9 mm or 0.16 λ_g by 0.24 λ_g, where λ_g is the guided wavelength at the center frequency. The photograph of the fabricated design is shown in Fig. 7.

The simulation and measurement are accomplished by using IE3D and 8753ES network analyzer. Figure 8 shows the simulated and measured results. Good agreement between them is observed. The center frequency f_0 is located at 2.1 GHz with the fractional bandwidth of 10%. The measured passband insertion loss $|S_{21}|$, $|S_{31}|$, $|S_{41}|$ are approximately 1.17 dB, in addition to the 4.78 dB three-way power division loss. The magnitude imbalance is less than 0.2 dB, which is attributed to the symmetrical configuration. The measured return loss is better than 15 dB. As can be seen in Fig. 9, the filtering power divider obtains the rejection levels of around 20 dB up to more than 12 GHz ($5f_0$).



(a)

(b)

Fig. 6. (a) External quality factor Q_e. (b) Coupling coefficient k.

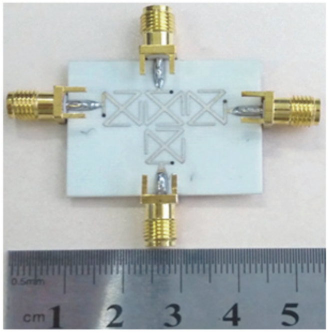


Fig. 7. The photograph of the fabricated filtering power divider.

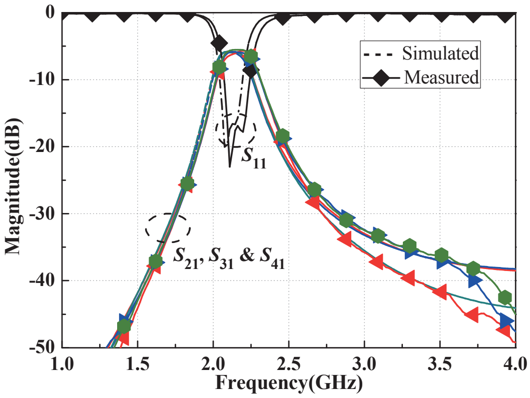


Fig. 8. Simulated and measured S-parameters of the proposed filtering power divider.

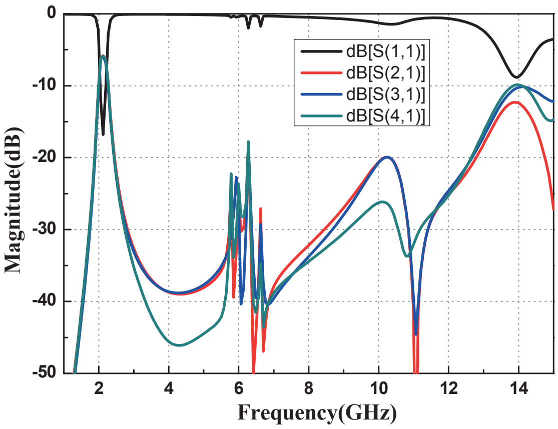


Fig. 9. Wideband response of the proposed filtering power divider.

4. Conclusion

In this paper, miniaturized three-way filtering power divider has been proposed. The design methodology and experimental results have been presented. The filtering power divider has a compact size due to the use of folded net-type resonators. Low magnitude imbalance, good filter characteristic and good rejection levels are achieved. The dual functions as well as compact size make it attractive for many applications.

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