Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2015, Article ID 658102, 7 pages
http://dx.doi.org/10.1155/2015/658102

Research Article

Compact Unequal Power Divider with Filtering Response

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Received 16 November 2014; Accepted 30 December 2014

Academic Editor: Nima Chamanara

We present a novel unequal power divider with bandpass responses. The proposed power divider consists of five resonators and a resistor. The power division ratio is controlled by altering the coupling strength among the resonators. The output ports have the characteristic impedance of 50 Ω and impedance transformers in classical Wilkinson power dividers are not required in this design. Use of resonators enables the filtering function of the power divider. Two transmission zeros are generated near the passband edges, resulting in quasielliptic bandpass responses. For validation, a 2 : 1 filtering power divider is implemented. The fabricated circuit size is $0.22\,\lambda_g \times 0.08\,\lambda_g$, featuring compact size for unequal filtering power dividers, which is suitable for the feeding networks of antenna arrays.

1. Introduction

Power dividers are widely used in radio frequency (RF) front-ends, such as in power combining networks and antenna arrays [1, 2]. The power ratio of the conventional Wilkinson power divider is controlled by adjusting the characteristic impedance of the branch lines. Impedance transformers are required at the two output ports in unequal power divider designs [3]. Based on the schematic of the classical Wilkinson power divider shown in Figure 1, lots of power dividers have been designed in recent years, including the high power division ratio dividers [4], the arbitrary power division ratio ones [5], out-of-phase ones [6], dual-band ones [7, 8], and spurious-suppressed ones [9, 10].

Apart from power dividers, bandpass filters (BPFs) are also essential parts in many RF front-ends. The two kinds of passive components consume a large area. To reduce the size, they can be integrated [11–18]. In [11, 12], the quarter-wavelength transformers in Wilkinson power dividers are replaced by BPFs. This method can also be used to design unequal power dividers [13]. The filtering circuits can also be used to replace the impedance transformers at the output ports of unequal power dividers, resulting in dual functions [14]. However, the circuit size of the above two unequal designs needs to be reduced. For miniaturization, the filtering and power splitting circuits can be highly integrated together [15–18]. However, this method has not been applied to unequal filtering power divider designs.

In this paper, a novel unequal power divider with filtering responses is proposed. The circuit consists of a half-wavelength resonator and four quarter-wavelength resonators as well as an isolation resistor. By adjusting the coupling strength among the resonators, unequal power division ratios can be obtained. All the ports have the impedance of 50 Ω and the impedance transformers are not required at the output ports. The quasielliptic bandpass responses are obtained by using cross coupling. Based on the proposed idea, an example circuit is designed with the compact size of $0.22\,\lambda_g \times 0.08\,\lambda_g$, where λ_g is the guided wavelength at the operating frequency. Good power division and bandpass responses are observed in the experiment.

2. Analysis and Design of the Proposed Filtering Unequal Power Divider

Figure 2 shows the schematic diagram of the proposed filtering power divider with the port impedance of 50 Ω. The

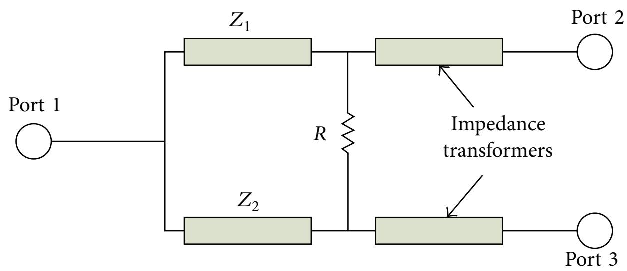


Figure 1: Schematic of the classical Wilkinson power divider.

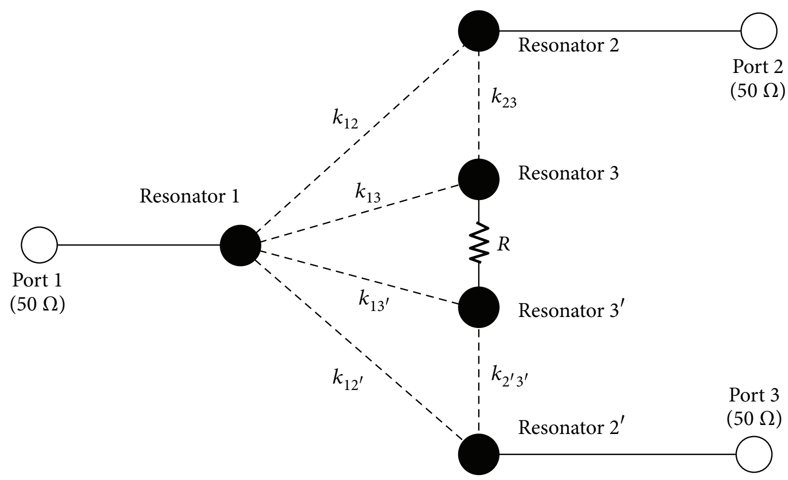


Figure 2: The schematic diagram of the proposed filtering power divider.

circuit consists of five resonators and a resistor. Ports 1, 2, and 3 are connected to resonators 1, 2, and $2'$. Resonators 2 and 3, $2'$ and $3'$ are coupled to resonator 1. This is the same as the equal filtering power divider design in [17]. However, the coupling strengths are different in this design to obtain an unequal power ratio. If the coupling strength among resonator 1 and resonators 2 and 3 is different from that among resonator 1 and resonators $2'$ and $3'$, the power injected to resonator 1 will be unequally split. Thus, the unequal power division ratio can be realized by altering the coupling strength, which is different from classical unequal Wilkinson power dividers as shown in Figure 1. Moreover, the port impedance is 50 Ω and the impedance transformers at the output ports in Figure 1 are not required, resulting in compact size. In order to realize good matching and high isolation between ports 2 and 3, a resistor is added between resonators 3 and $3'$.

The circuit can be analyzed by the even-odd-mode method. When even-mode excitation is applied at ports 2 and 3, the voltages at both sides of isolation resistor are equal to ensure that there is no current flowing through the isolation resistor. Thus, the resistor can be eliminated, resulting in the circuit shown in Figure 3(a). For odd-mode excitation, opposite polarity voltages are applied to ports 2 and 3. Then the overall structure can be divided into simple circuits as shown in Figures 3(b) and 3(c). However, due to the existence of the coupling in the circuit, it is difficult to calculate the resistance. Herein, we use the simulation to choose the resistance for good matching and high isolation between ports 2 and 3. As shown in Figure 4, various kinds of resistance result in different matching status at ports 2 and 3 as well as different isolation effect between ports 2 and 3. Taking into account the port matching and isolation, the resistance is chosen as 6.8 kΩ.

As for the filtering responses, resonators 1, 2, and 3 as well as resonators 1, $2'$, and $3'$ form two filtering networks and thus bandpass responses can be realized, which is similar to the design in [17]. Figure 5(a) shows the filtering network between port 1 and port 2 (or port 3). It consists of three resonators. The solid and dash lines denote the electrical and magnetic couplings, respectively. Figure 5(b) shows the bandpass response of the filtering network. Two transmission zeros are generated at both sides of the passband by crossing coupling, resulting in high selectivity.

Based on the above schematic, a filtering power divider is designed with the 2 : 1 power ratio. Figure 6 shows the microstrip configuration of the proposed circuit. Resonator 1 is a half-wavelength one and the others are quarter-wavelength ones. To realize the required unequal power ratio and obtain good filtering performance, the coupling strengths among the resonators are determined as follows: $k_{12} = 0.08$, $k_{13} = 0.31$, $k_{23} = 0.1$, $k_{12'} = 0.01$, $k_{13'} = 0.2$, and $k_{2'3'} = 0.04$. The coupling strengths among resonator 1 and resonators 2 and 3 are stronger than the corresponding ones among

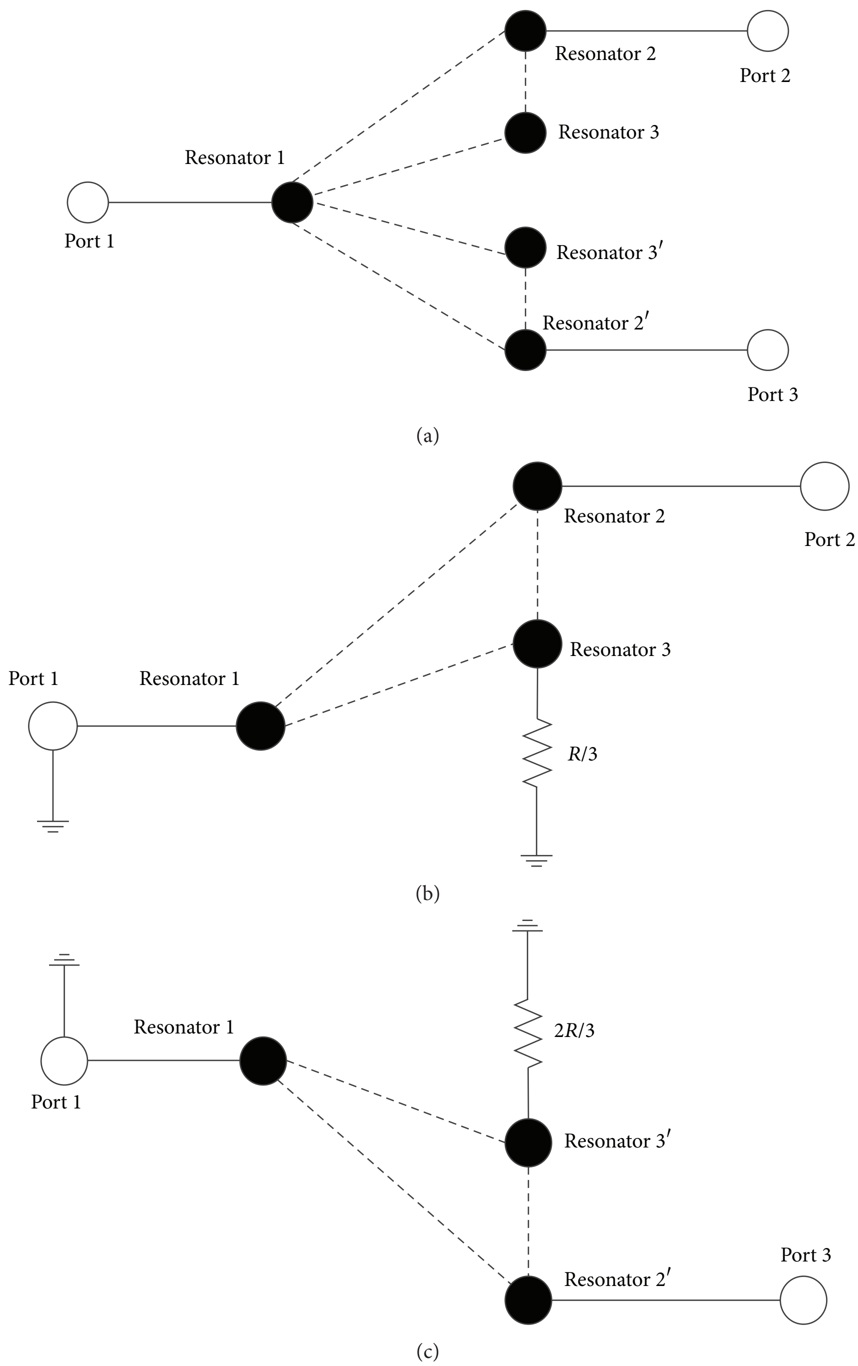


FIGURE 3: (a) The schematic diagram of the even-mode circuit; (b), (c) the schematic diagram of the odd-mode circuit.

resonators 1, 2′, and 3′. Thus more power is coupled to port 2, resulting in the 2 : 1 power division ratio.

The proposed filtering unequal power divider can be designed as follows. Firstly, the desired passband frequency can be obtained by controlling the length of the resonators to be half or quarter guided wavelength. Secondly, the resonators are combined using the configuration in Figure 3 and the coupling strengths are tuned to realize the power ratio and bandpass responses. The third step is to adjust the resistance to obtain the good isolation and port matching.

3. Experiment

For demonstration, a 2 : 1 filtering power divider is implemented. The substrate used in this design has a relative dielectric constant of 3.38, a thickness of 0.81 mm, and a loss tangent of 0.0027. The dimensions are chosen as follows: W = 0.5 mm, L_1 = 7 mm, L_2 = 3.5 mm, L_3 = 3.5 mm, L_4 = 18.7 mm, L_5 = 9 mm, L_6 = 3.9 mm, L_7 = 0.8 mm, L_8 = 23.3 mm, L_9 = 0.8 mm, L_{10} = 8.2 mm, L_{11} = 20.3 mm, L_{12} = 3.3 mm, L_{13} = 7.8 mm, L_{14} = 0.7 mm, L_{15} = 1.9 mm, L_{16} = 12.9 mm, L_{17} =

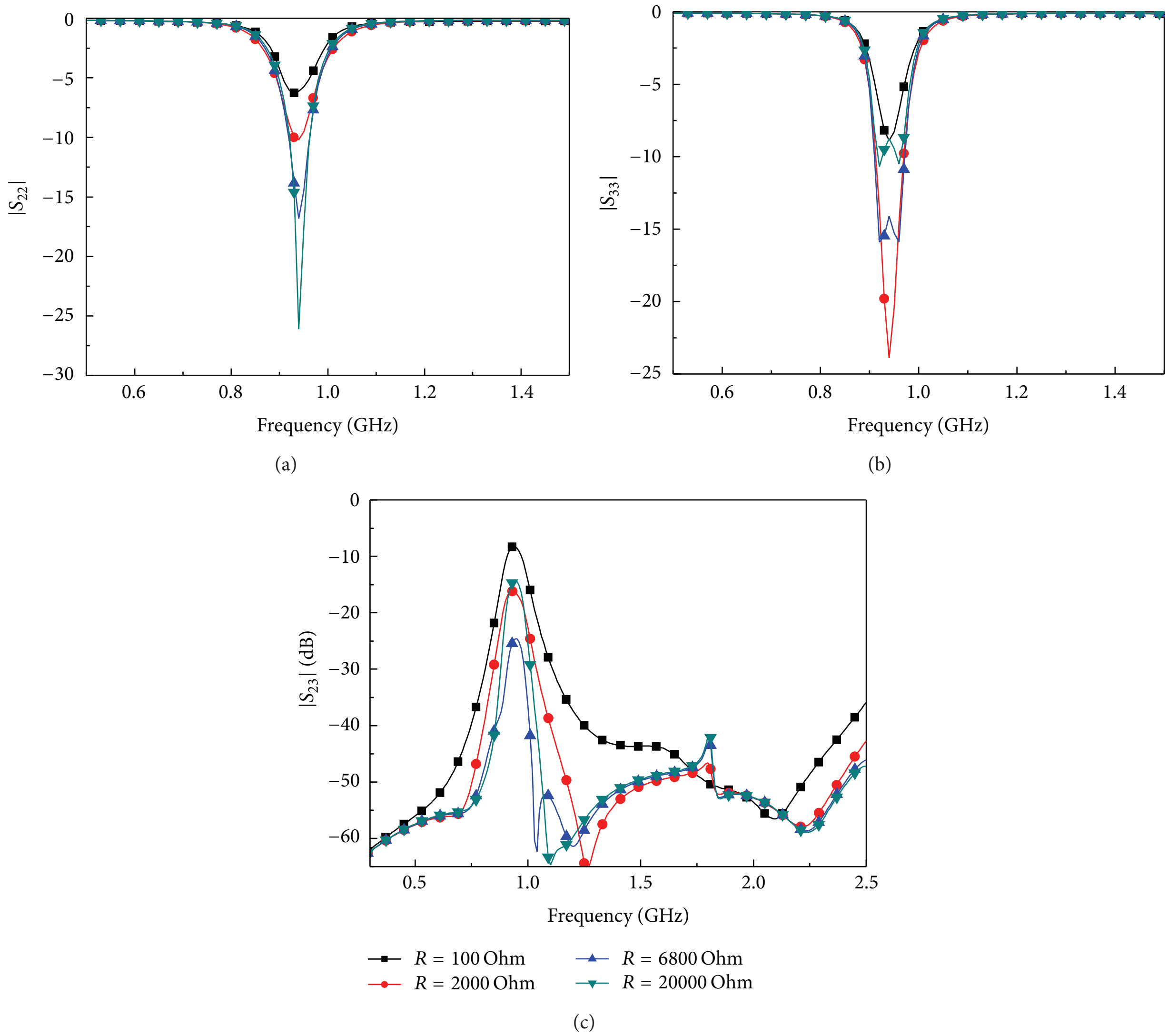


Figure 4: Various values of the isolation resistance for (a) S_{22}, (b) S_{33}, and (c) S_{23}.

1.7 mm, L_{18} = 20.9 mm, L_{19} = 4.8 mm, L_{20} = 1.8 mm, L_{21} = 4 mm, L_{22} = 25.3 mm, L_{23} = 7.4 mm, L_{24} = 2.7 mm, L_{25} = 27.3 mm, L_{26} = 4.9 mm, g_1 = 0.15 mm, g_2 = 0.15 mm, g_3 = 0.3 mm, g_4 = 0.25 mm, and R = 6.8 kΩ. The overall size of the fabricated filter is 44.1 mm × 17.2 mm (or $0.22\,\lambda_g \times 0.08\,\lambda_g$). The photograph of the fabricated filter is shown in Figure 7.

The simulation is carried out using IE3D and the results are measured on the network analyzer Agilent E5071C. As shown in Figure 8, the measured center frequency f_0 is 920 MHz, with the fractional bandwidth of 6.5%. The measured S_{21} and S_{31} are −2.76 dB and −5.78 dB, respectively. Since the ideal S_{21} and S_{31} are −1.7 dB and −4.7 dB for 2 : 1 unequal power divider, it indicates that the proposed design obtains 2 : 1 power ratio with the insertion loss of 1.1 dB and magnitude imbalance of less than 0.1 dB. It is noted that both the filtering and power division functions are integrated and the loss can be considered low. The passband return loss of S_{11}, S_{22}, and S_{33} is greater than 20 dB. The isolation is higher than 17 dB from DC to $2.6 f_0$. Two transmission zeros are generated at 0.75 GHz and 1.2 GHz, resulting in quasielliptic bandpass responses. The comparison with other works is tabulated in Table 1. It is seen that the proposed circuit has a small size and a relative high isolation in a wide frequency range up to $2 f_0$.

4. Conclusion

This paper has presented a compact unequal power divider with quasielliptic bandpass responses. A new method has been proposed to design the unequal power dividers by altering the coupling strength among the resonators. No impedance transformer is required at the two output ports. The design methodology and experimental results have been presented. Good performance has been obtained together with the compactness. The unequal filtering power division responses and compact circuit size make the proposed circuit useful for feeding networks of antenna arrays.

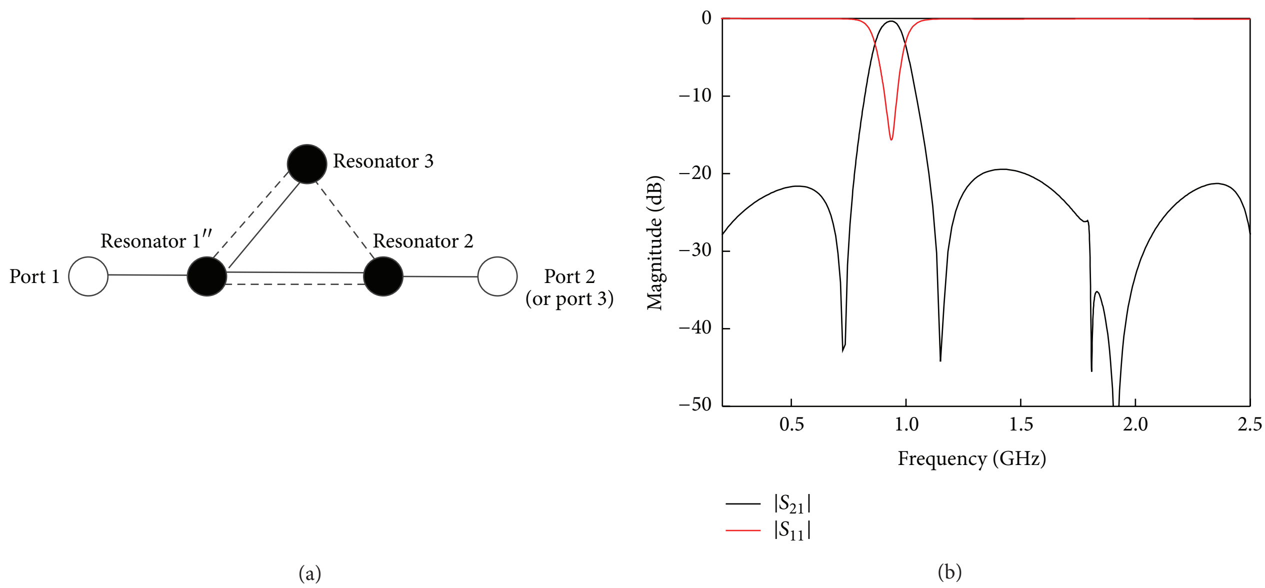


Figure 5: (a) The filter network between port 1 and port 2 (or port 3); (b) bandpass response of the filtering network.

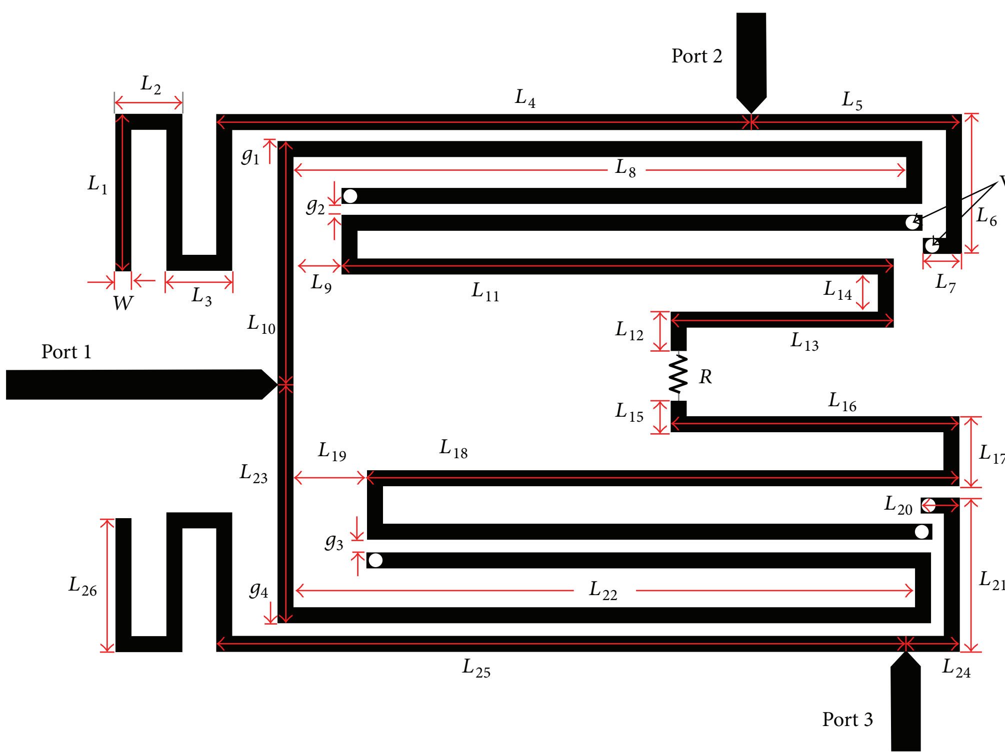


Figure 6: Configuration of the microstrip filtering unequal power divider.

Table 1: Comparison with previous work.

	f_0 (GHz)	In-band isolation (dB)	Isolation up to $2f_0$	Size (λ_g^2)	Bandpass response
[10]	2.65	>22	>5	0.009	No
[11]	2.4	>15	>5	0.174	Yes
[16]	2.05	>20	>10	0.125	Yes
[17]	0.92	>20	>20	0.021	Yes
This work	0.92	>17	>17	0.018	Yes

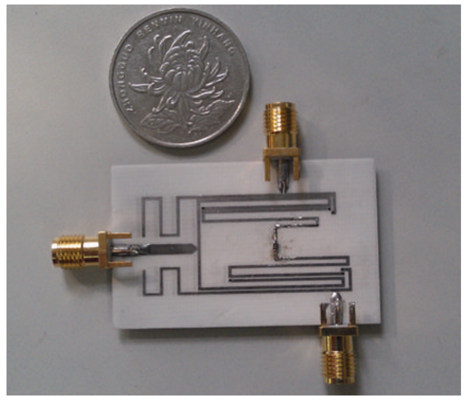
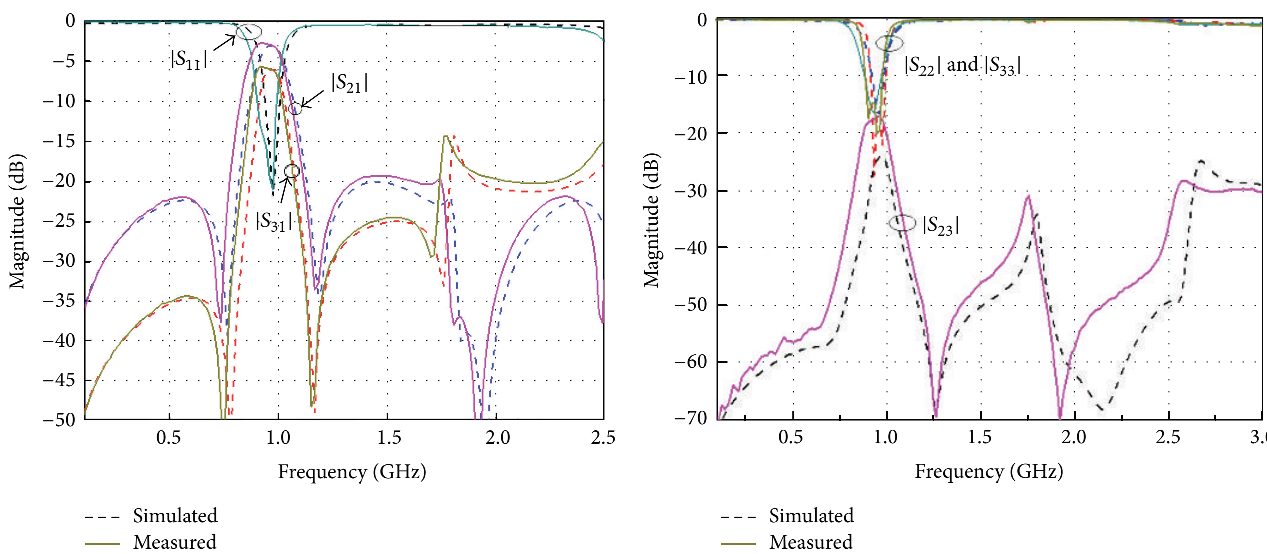


Figure 7: The photograph of the fabricated filter.



(a) (b)

Figure 8: Simulated and measured results of the filtering power divider.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

This work is supported by NSFC under Grant no. 61271060 and by Guangdong Natural Science Funds under Grant S2012010008742.

References

[1] F.-F. Fan, Z.-H. Yan, and W. Wang, "Wideband circularly polarized SIW antenna array that uses sequential rotation feeding," *International Journal of Antennas and Propagation*, vol. 2014, Article ID 534539, 8 pages, 2014.

[2] H. Zhang, R. Chantalat, F. Torres, M. Thevenot, T. Monediere-and, and B. Jecko, "Low-profile array of wire patch antennas," *International Journal of Antennas and Propagation*, vol. 2009, Article ID 830931, 8 pages, 2009.

[3] Y. Wu, Y. Liu, S. Li, and C. Yu, "Extremely unequal Wilkinson power divider with dual transmission lines," *Electronics Letters*, vol. 46, no. 1, pp. 90–91, 2010.

[4] Z. Zhang, Y.-C. Jiao, S. Tu, S.-M. Ning, and S.-F. Cao, "A miniaturized broadband 4 : 1 unequal wilkinson power divider," *Journal of Electromagnetic Waves and Applications*, vol. 24, no. 4, pp. 505–511, 2010.

[5] J.-L. Li and B.-Z. Wang, "Novel design of wilkinson power dividers with arbitrary power division ratios," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 6, pp. 2541–2546, 2011.

[6] Y. L. Lu, G.-L. Dai, and K. Li, "A novel unequal broadband out-of-phase power divider using DSPSLs," *ETRI Journal*, vol. 36, no. 1, pp. 116–123, 2014.

[7] L. Xi and Y. Lin, "A novel design of dual-band Wilkinson power divider with simple structure and wide band-ratios characteristics," *Journal of Electromagnetic Waves and Applications*, vol. 28, no. 13, pp. 1635–1641, 2014.

[8] D.-J. Eom and S. Kahng, “Fully printed dual-band power divider miniaturized by CRLH phase-shift lines,” *ETRI Journal*, vol. 35, no. 1, pp. 150–153, 2013.

[9] M. Hayati, S. Roshani, S. Roshani, and F. Shama, “A novel miniaturized Wilkinson power divider with n th harmonic suppression,” *Journal of Electromagnetic Waves and Applications*, vol. 27, no. 6, pp. 726–735, 2013.

[10] J. Wang, J. Ni, Y.-X. Guo, and D. Fang, “Miniaturized microstrip wilkinson power divider with harmonic suppression,” *IEEE Microwave and Wireless Components Letters*, vol. 19, no. 7, pp. 440–442, 2009.

[11] J.-Y. Shao, S.-C. Huang, and Y.-H. Pang, “Wilkinson power divider incorporating quasi-elliptic filters for improved out-of-band rejection,” *Electronics Letters*, vol. 47, no. 23, pp. 1288–1289, 2011.

[12] Y. C. Li, Q. Xue, and X. Y. Zhang, “Single-and dual-band power dividers integrated with bandpass filters,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 61, no. 1, pp. 69–76, 2013.

[13] L. Gao and X. Y. Zhang, “Novel 2:1 Wilkinson power divider integrated with bandpass filter,” *Microwave and Optical Technology Letters*, vol. 55, no. 3, pp. 646–648, 2013.

[14] P.-H. Deng and L.-C. Dai, “Unequal wilkinson power dividers with favorable selectivity and high-isolation using coupled-line filter transformers,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 60, no. 6, pp. 1520–1529, 2012.

[15] K. Song and Q. Xue, “Novel ultra-wideband (UWB) multilayer slotline power divider with bandpass response,” *IEEE Microwave and Wireless Components Letters*, vol. 20, no. 1, pp. 13–15, 2010.

[16] S. S. Gao, S. Sun, and S. Xiao, “A novel wideband bandpass power divider with harmonic-suppressed ring resonator,” *IEEE Microwave and Wireless Components Letters*, vol. 23, no. 3, pp. 119–121, 2013.

[17] X. Y. Zhang, K.-X. Wang, and B.-J. Hu, “Compact filtering power divider with enhanced second-harmonic suppression,” *IEEE Microwave and Wireless Components Letters*, vol. 23, no. 9, pp. 483–485, 2013.

[18] W. Q. Pan, J. X. Xu, Q. F. Su, and X. L. Zhao, “Novel compact filtering power divider with harmonic suppression,” *Progress in Electromagnetics Research C*, vol. 53, pp. 127–133, 2014.