Novel Filtering Power Divider with External Isolation Resistors

Yun-Long Lu, Shun Wang, Gao-Le Dai, and Kai Li

In this paper, a novel filtering power divider with external isolation resistors is presented. The proposed power divider can be considered as an integration of a bandpass filter and a Gysel power divider. Based on the circuit topology, a high-order filtering power divider can be easily realized. Odd- and even-mode models are employed to analyze the filtering and power splitting functions. For demonstration, a third-order filtering power divider operating at 1.5 GHz is designed and implemented. The measured results exhibit an isolation between the output ports that is better than 20 dB at around the center frequency.

Keywords: Filtering power divider, external isolation resistors, high order.

I. Introduction

Power dividers and bandpass filters are essential blocks in modern wireless and mobile communication systems. In many applications, power dividers and bandpass filters usually need to be cascaded to divide and filter signals [1]. To further reduce their number or the circuit size of RF/microwave systems and manufacturing costs, it is beneficial to integrate them into a single component. Efforts to integrate power dividers and bandpass filters have been proposed in the literature [2]–[7]. The most straightforward method is to cascade the filtering structure with a Wilkinson power divider to obtain the power dividing and filtering characteristics [2]. In [3]–[4], the quarter-wavelength impedance transformers in the conventional Wilkinson power divider have been replaced by bandpass filters. Besides this, the filtering and power splitting circuits are merged together so as to obtain a dual-purpose circuit [5], [7]. However, the aforementioned Wilkinson power dividers employ only internal resistors for isolation, which limits their high-power applications. There are a few reports on research relating to the integration of a bandpass filter and a power divider with external isolation resistors. In [8], a compact microstrip filtering power divider with one external isolation resistor is presented. In [9], a balanced-to-balanced Gysel power divider with bandpass filtering response is designed by Wu and others. Unfortunately, these circuit topologies are complex and propose difficulties for high-order design.

A novel third-order filtering power divider with external isolation resistors is presented in this paper. The proposed device consists of four half-wavelength resonators and two resistors, which can be viewed as the integration of a third-order bandpass filter and a Gysel power divider. The expected filtering and power splitting performances of this simple

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Yun-Long Lu (corresponding author, lyl1245@zju.edu.cn) and Kai Li (kaili@zju.edu.cn) are with the Department of Information Science & Electronic Engineering, Zhejiang University, China.

Shun Wang (swang@mail.ie.ac.cn) is with the Institute of Electronics Chinese Academy of Sciences, Beijing, China.

Gao-Le Dai (daigl@zju.edu.cn) is with the Ningbo Institute of Materials Technology & Engineering, Chinese Academy of Sciences, Ningbo, China.

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filtering power divider are analyzed, and the design methodology is presented. An experimental filtering power divider is fabricated to confirm the predicted results.

II. Design of Filtering Power Divider

The configuration of the proposed bandpass power divider is shown in Fig. 1. It consists of four half-wavelength resonators and two external isolation resistors. Based on an odd- and even-mode analysis, two of the half-circuit models can be formed along the horizontally symmetrical plane A-A′. Then, the theoretical three-port scattering parameters can be easily obtained as follows [1], [5], and [10]:

$$S_{11}=S_{11}^{\mathrm{e}}, \tag{1a}$$

$$S_{21}=S_{31}=\frac{S_{12}^{\mathrm{e}}}{\sqrt{2}}, \tag{1b}$$

$$S_{23}=\frac{\left(S_{22}^{\mathrm{e}}-S_{22}^{\mathrm{o}}\right)}{2}, \tag{1c}$$

$$S_{22}=S_{33}=\frac{\left(S_{22}^{\mathrm{e}}+S_{22}^{\mathrm{o}}\right)}{2}. \tag{1d}$$

Obviously, the three-port scattering parameters can be derived from the odd- and even-mode equivalent circuits. It is noted that the transmission coefficients (that is, S_{21} and S_{31}) are only related to the even-mode equivalent circuit. The proposed filtering power divider is operating at f_0 = 1.5 GHz with the 3 dB bandwidth of 6.0%. The details of the analysis of the odd- and even-mode models are as follows.

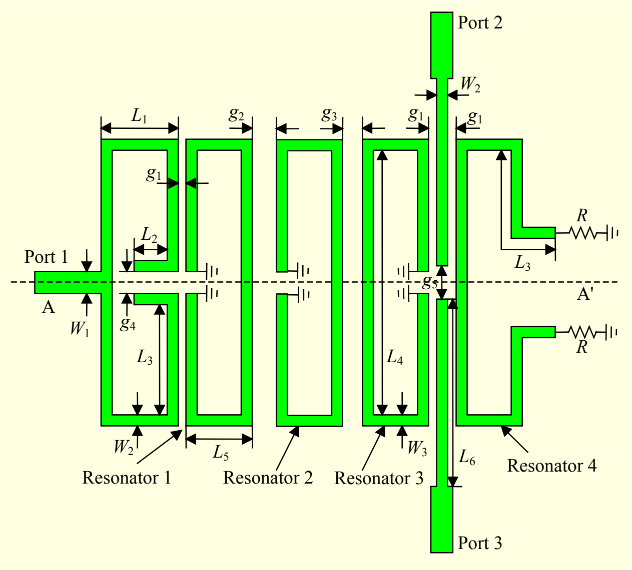

Fig. 1. Configuration of proposed filtering power divider.

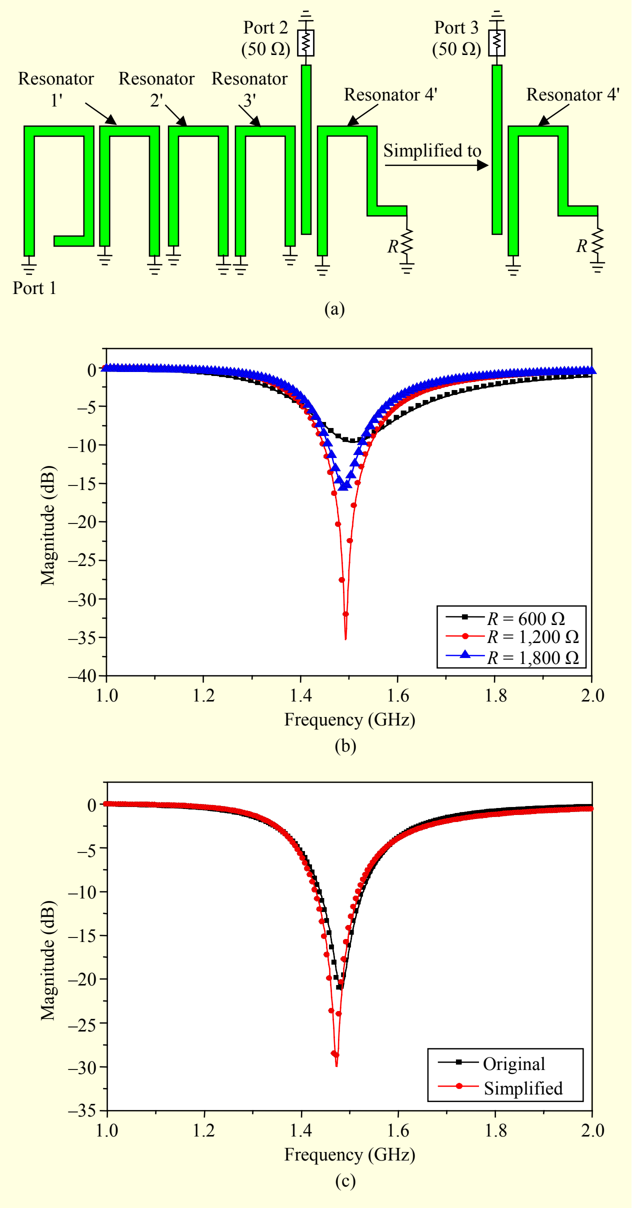

Fig. 2. (a) Odd-mode equivalent circuit, (b) S_{22} for various values of the isolation resistance, and (c) S_{22} for original and simplified odd-mode equivalent circuit at R = 1,200 Ω.

1. Odd-Mode Analysis

When odd-mode excitation is applied to ports 2 and 3, port 1 is short circuited due to the node voltage being equal to zero. Meanwhile, the four half-wavelength resonators become eight quarter-wavelength resonators, denoted as 1′, 2′, 3′, 4′, 1″, 2″, 3″, and 4″, and they are short circuited. For simplification purposes, only resonators 1′, 2′, 3′, and 4′ are adapted for analysis, as shown in Fig. 2. The fundamental resonant frequencies of the quarter-wavelength resonators are at $2f_0$. For the operating frequency f_0, the signal cannot be excited at resonators 1′, 2′, and 3′. Thus, the original odd-mode equivalent circuit can be simplified, as shown in Fig. 2(a). According to the design principle of a power divider, by tuning the external isolation resistor R, an impedance matching that of port 2 can be obtained, which is shown in Fig. 2(b). Figure 2(c) shows the responses of the original and simplified equivalent circuits at $R = 1{,}200\ \Omega$. Because of the impedance-transformer network, the resistance is much larger than that in conventional dividers.

2. Even-Mode Analysis

For the even-mode model, due to the external isolation resistor R, the RF signals cannot be excited at quarter-wavelength resonator 4′. Therefore, at the operating frequency f_0, the power coupled into resonator 4′ and consumed at external isolation resistor R can be ignored. The original even-mode equivalent circuit can be simplified, as shown in Fig. 3(a). The comparison of the original and simplified even-mode equivalent circuit is shown in Fig. 3(b).

From the viewpoint of the power divider, the even-mode equivalent circuit functions as an impedance transformer that converts the impedance at port 2 to that of port 1. Meanwhile, the even-mode equivalent circuit also acts as a filtering circuit.

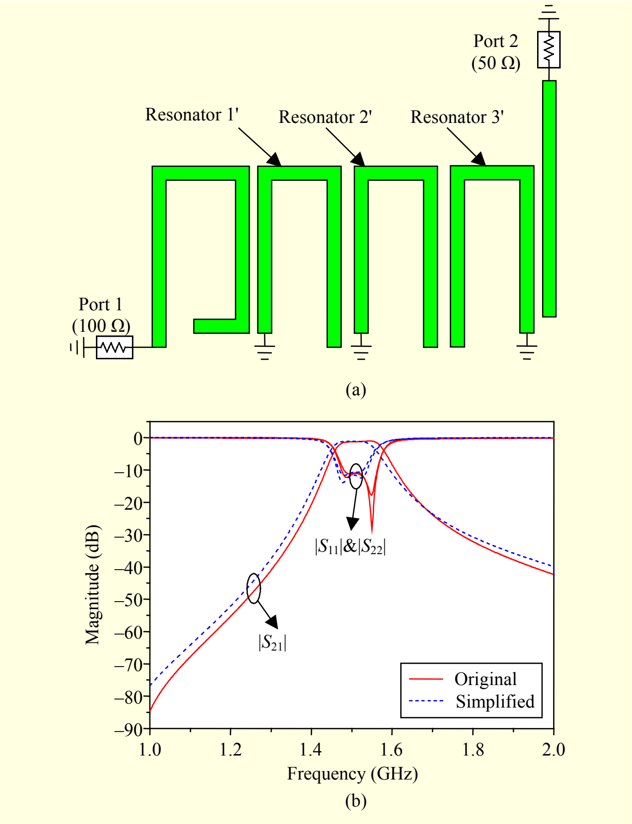

Fig. 3. (a) Simplified even-mode equivalent circuit and (b) simulated results of original and simplified even-mode equivalent circuit.

In this design, the filtering circuit is operating at 1.5 GHz with a 3 dB bandwidth of 6.0%. Thus, the coupling coefficients between the three resonators are as follows: $M_{12} = 0.057$ and $M_{23} = 0.057$. The simulated responses of the even-mode equivalent circuit are shown in Fig. 3(b), and adequate filtering performance is observed.

III. Circuit Implementation

The proposed device can be designed as follows [1]. Firstly, determine the geometry parameters of resonators to meet the resonant frequency. Secondly, design the external quality and coupling coefficient to get the required bandpass response by using the configuration in Fig. 3(a). Thirdly, alert the resistors to obtain the matching status at port 2, as shown in Fig. 2(a). Finally, symmetrically arrange the two filtering structures and resistors to form the filtering power divider shown in Fig. 1.

A demonstration filtering power divider is implemented on a Rogers RO4350 substrate, with a relative dielectric constant of 3.38, a thickness of 0.762 mm, and a dielectric loss tangent of 0.0027. The layout parameters in Fig. 1 are as follows: $L_1 = 4.95$ mm, $L_2 = 3.2$ mm, $L_3 = 12.45$ mm, $L_4 = 26.5$ mm, $L_5 = 4.5$ mm, $L_6 = 26$ mm, $W_1 = 1.8$ mm, $W_2 = 0.5$ mm, $W_3 = 0.5$ mm, $g_1 = 0.1$ mm, $g_2 = 0.95$ mm, $g_3 = 0.95$ mm, $g_4 = 0.6$ mm, $g_5 = 1.2$ mm, and $R = 1{,}200\ \Omega$. The overall size of this circuit is $0.46 \times 0.28\ \lambda_g^2$, where λ_g is the guided wavelength at the center frequency of the passband. The photograph of the fabricated filter is shown in Fig. 4.

The simulation is carried out using a high frequency structure simulator, and the results are measured on the network analyzer Agilent 8358E. Figure 5 shows the simulated and measured frequency responses of the proposed filtering power divider. The measured center frequency is 1.53 GHz, with a fractional bandwidth of 5.9%. The measured insertion loss of S_{21} and S_{31} are 5.90 dB and 5.89 dB, respectively, where the power divider provides an intrinsic 3 dB insertion loss. Besides this, the additional 2.9 dB insertion loss is attributed to the third-order coupled-resonator bandpass filter. From our simulation, the

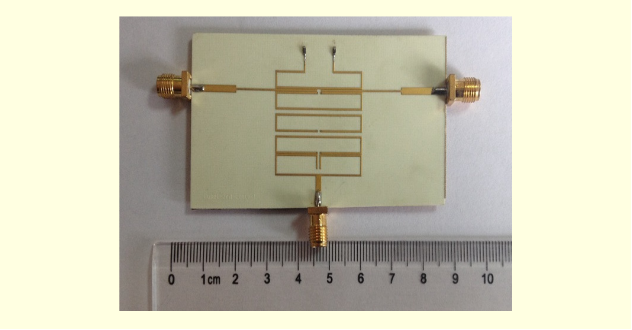

Fig. 4. Photograph of fabricated circuit.

Table 1. Comparison with previous work.

	Filter order	Insertion loss	High-order design	In-band isolation	Isolation resistors	Size (λ_g^2)
[4]	2	3.90 dB	Difficulty	> 8 dB	Internal	0.19 × 0.29
[5]	2	3.99 dB	Difficulty	> 20 dB	Internal	0.15 × 0.14
[6]	2	3.20 dB	Difficulty	> 15 dB	Internal	-
[7] (part 1)	2	4.60 dB	Easy	> 16 dB	Internal	0.11 × 0.15
[7] (part 2)	3	5.80 dB	Easy	> 15 dB	Internal	0.17 × 0.15
[7] (part 3)	4	6.00 dB	Easy	> 11 dB	Internal	0.12 × 0.26
[8]	2	4.40 dB	Difficulty	> 30 dB	External	0.19 × 0.19
This work	3	5.90 dB	Easy	> 16 dB	External	0.46 × 0.28

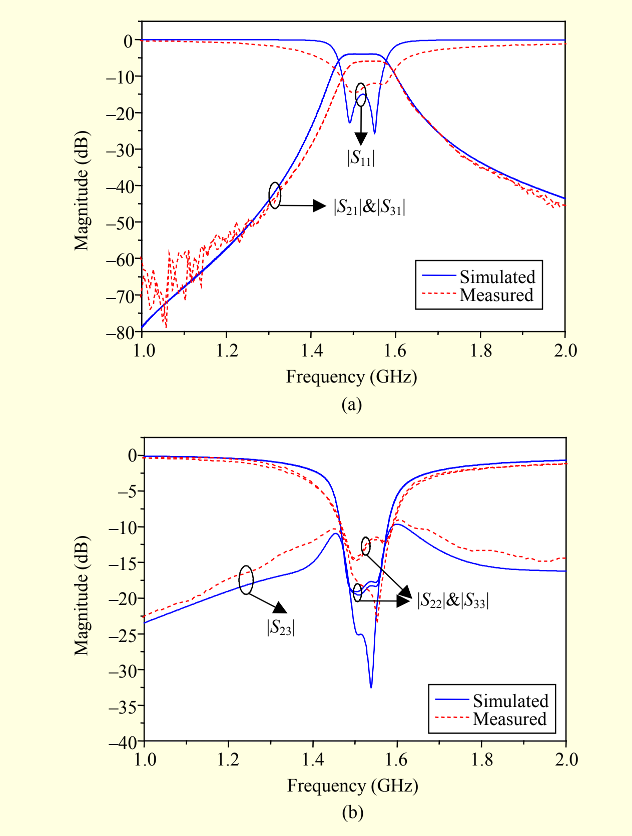

Fig. 5. Simulated and measured S-parameters of proposed power divider. (a) S_{11}, S_{21}, and S_{31} and (b) S_{22}, S_{33}, and S_{23}.

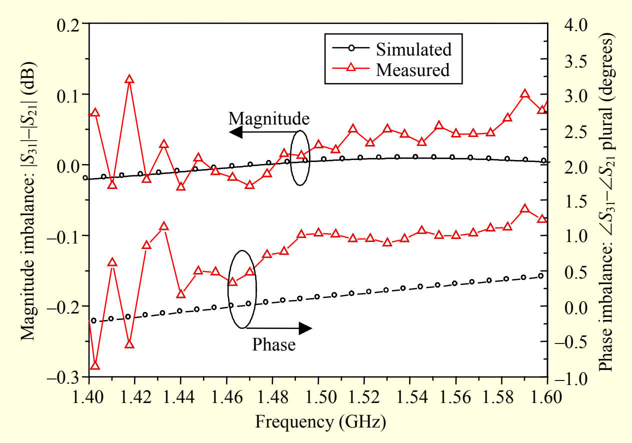

Fig. 6. Magnitude and phase imbalance.

insertion loss is mainly due to the conduct loss. The passband return loss of S_{11}, S_{22}, and S_{33} are greater than 10 dB. The isolation between output ports is better than 20 dB at around the center frequency. Meanwhile, the measured amplitude imbalance and phase imbalance are less than ±0.15 dB and between -1.0° and 1.5°, respectively, as shown in Fig. 6. The comparison is tabulated in Table 1. It is seen that the proposed circuit with external isolation resistors has decent in-band isolation. Moreover, the proposed circuit is suitable for high-order design.

IV. Conclusion

A novel third-order filtering power divider with external isolation resistors is presented. The proposed device can be viewed as the integration of a high-order bandpass filter and a Gysel power divider. The design methodology and experimental results have been presented. A respectable isolation of better than 20 dB between the output ports is achieved at around the center frequency. With the feature of external resistors, the proposed circuit is attractive for high-power wireless communications.

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Yun-Long Lu was born in Huzhou, Zhejiang, China, in 1984. He received his BS degree in electronic engineering from Ningbo University, Zhejiang, China, in 2007 and his MS degree in electronic engineering from Zhejiang University, China, in 2010. He is currently working toward his PhD degree at Zhejiang University from July to December 2008. He was a research assistant at Nanyang Technological University, Singapore. His research interests include antenna and RF/microwave active and passive circuit designs.

Shun Wang received his BS and MS degrees in electrical engineering from the China University of Geosciences, Beijing, China, in 2005 and 2008, respectively. Now, he is an assistant researcher at the Institute of Electronics, Chinese Academy of Sciences, Beijing, China. His main research interests are ionosphere radio detection technology and weak signal detection.

Gao-Le Dai was born in Zhejiang, China, in 1985. He received his BS and PhD degrees in electronic engineering from Peking University, Beijing, China, in 2007 and 2011, respectively. From September 2008 to January 2009, he was a research assistant with the City University of Hong Kong, China. From September 2009 to February 2010, he was a visiting PhD student with the National University of Singapore. From August 2011 to November 2012, he was working at the Department of Information and Electronic Engineering, Zhejiang University, Hangzhou, China, as an assistant professor. In 2012, he joined the Ningbo Institute of Materials Technology & Engineering, Chinese Academy of Sciences, Ningbo, China, as an associate professor. His research interests include antenna and RF/microwave active and passive circuit designs.

Kai Li was born in Xiao County, Anhui, China, in 1968. He received his BS degree in physics from Fuyang Normal University, Anhui, China, in 1990; his MS degree in radio physics from Xidian University, Shaanxi, China, in 1994; and his PhD degree in astrophysics from Shaanxi Astronomical Observatory, the Chinese Academy of Sciences, Shaanxi, China, in 1998. From August 1990 to December 2000, he was with the faculty of the China Research Institute Radiowave Propagation. From January 2001 to December 2002, he was a postdoctoral fellow at the Information and Communications University, Daejeon, Rep. of Korea. From January 2003 to January 2005, he was a research fellow at the School of Electrical and Electric Engineering, Nanyang Technological University, Singapore. Since January 2005, he has been a professor with the Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China. His current research interests include classic electromagnetic theory and radio wave propagation. He is a senior member of the Chinese Institute of Electronics and a member of the Chinese Institute of Space Science.