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Novel Filtering Power Divider Using Multiple Internal Resistors

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Abstract—In this paper, we present a novel 3rd filtering power divider with high in-band isolation. The proposed device employs six quarter-wavelength resonators and six internal isolation resistors symmetrically arranged to require the power division and filtering function. Based on the circuit topology, the multiple resistors can be integrated to obtain a good isolation and port impedance matching. Compared to the conventional power divider with bandpass response, the new device is easy to realize a high-order design with a good isolation. For demonstration, a prototype operating at 1.5 GHz with more than 20 dB in-band isolation is implemented. Simulated and experimental results agree well, validating the proposed methodologies.

1. INTRODUCTION

In modern wireless and mobile communication systems, power dividers and bandpass filters play an important role. In many applications, the power dividers and bandpass filters usually need to be connected up to divide and filter signals [1–5]. In order to further reduce circuit size and manufacturing cost, it is beneficial to integrate them into a single component.

Recently, a few integrated designs have been developed [6–14]. In [6–8], the filtering and power splitting functions are realized by cascading a filtering structure with a Wilkinson power divider. This straightforward method occupies a considerable area. An alternative method is to merge the filter and power divider to obtain the dual functions [9–12]. However, these circuit topologies are difficulty for high-order design. Shao et al. and Chen et al. present several power dividers with high-order Chebyshev- and quasi-elliptic bandpass responses [13, 14]. Unfortunately, only a single internal isolation resistor can be employed in the circuit topology. This drawback restricts the improvement of in-band isolation with the filter-order increasing.

In this paper, a novel 3rd filtering power divider with multiple internal isolation resistors is presented. Based on the circuit topology, a high-order filtering circuit and multiple internal isolation resistors can be integrated together. Benefitting from the multiple resistors structure, the in-band isolation and port impedance matching can be improved. For verification, a sample of 3rd filtering power divider is designed, which consists of six quarter-wavelength resonators and six internal isolation resistors. Good power division and bandpass responses are observed in the experiment.

2. ANALYSIS OF THE PROPOSED DUAL-BAND FILTER

Figure 1 shows the configuration of the proposed 3rd filtering power divider. It consists of six quarter-wavelength resonators arranged symmetrically, which denoted resonators 1, 2, 3 and 1′, 2′, 3′. Six resistors are integrated among the resonators and coupled-line input/output (I/O) structures. When the signal arrivals at port 1, its power can be equally divided into two parts and coupled to the six quarter-wavelength resonators. Based on the odd- and even-mode analysis, two of half circuit models can

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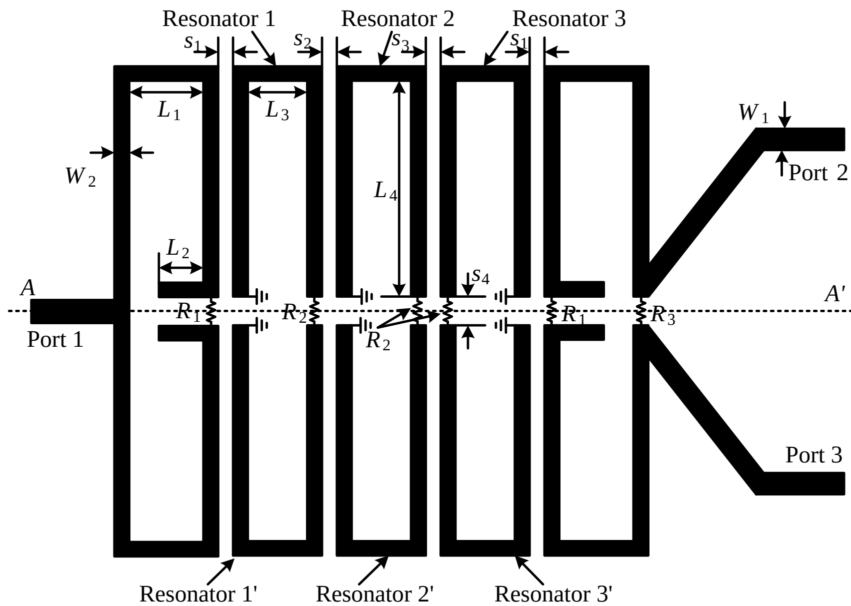

Figure 1. Configuration of the proposed bandpass power divider.

be formed along the horizontally symmetrical plane A-A'. Then, the theoretical three-port scattering parameters can be easily obtained as follows [1, 9]

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

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

$$S_{32} = \frac{(S_{22}^{e} - S_{22}^{o})}{2} \tag{1c}$$

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

Obviously, the three-port scattering parameters can be derived from the odd- and even-mode equivalent circuits. It is noted that the transmission coefficients, i.e., S_{21} and S_{31}, are only related to the even-mode equivalent circuit. The proposed filtering power divider is operating at 1.5 GHz with the 1-dB bandwidth of 6.7%, and the details analysis of odd- and even-mode models is as follows.

2.1. Even-mode Analysis

If even-mode excitation is applied to the filtering power divider, there is no current flowing through the multiple internal isolation resistors. Therefore, the isolation elements can be ignored in this case, as shown in Figure 2(a). According to the design principle of power divider, the coupled-resonators function as impedance transformer converts the impedance at port 2 to port 1. Meanwhile, the even-mode equivalent circuit acts as a bandpass filter.

The topology of equivalent filtering circuit is shown in Figure 2(b). The solid and dash lines denote the electrical and magnetic couplings, respectively. In this design, the filtering circuit operates at 1.5 GHz with 1-dB bandwidth of 6.7%. Thus, the coupling coefficients among the three resonators are as follows: $M_{12} = 0.057$ and $M_{23} = 0.057$. The filter can be designed following the procedure in [15]. The simulated responses are shown in Figure 3, and good filtering performance is observed.

2.2. Odd-Mode Analysis

When odd-mode excitation is applied to ports 2 and 3, the port 1 is short circuited due to the node voltage is zero. The equivalent circuit is shown in Figure 4. From the view of power divider, the coupled

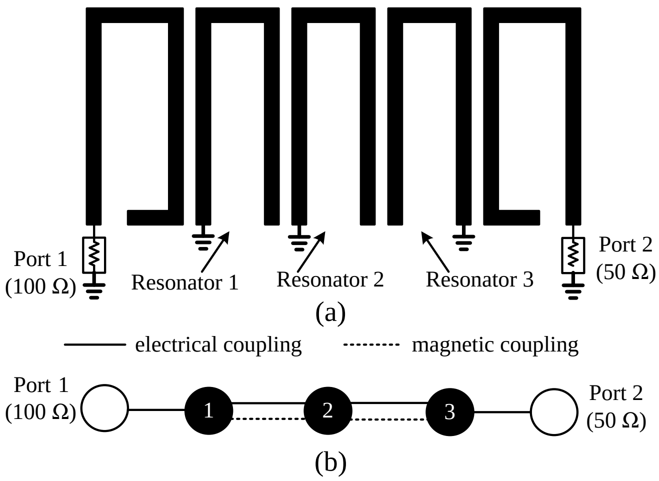

Figure 2. (a) Even-mode equivalent circuit. (b) Schematic of the even-mode equivalent circuit.

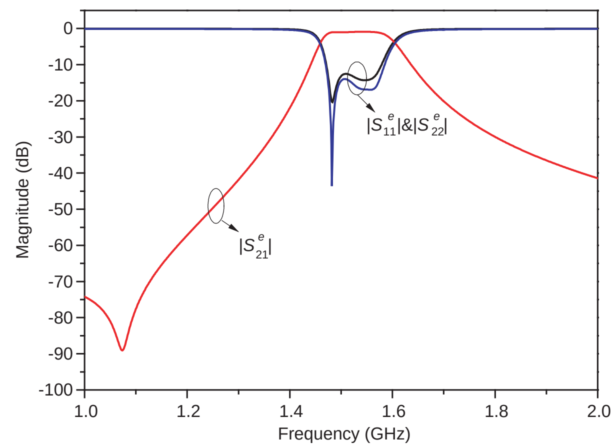

Figure 3. Responses of even-mode equivalent circuits.

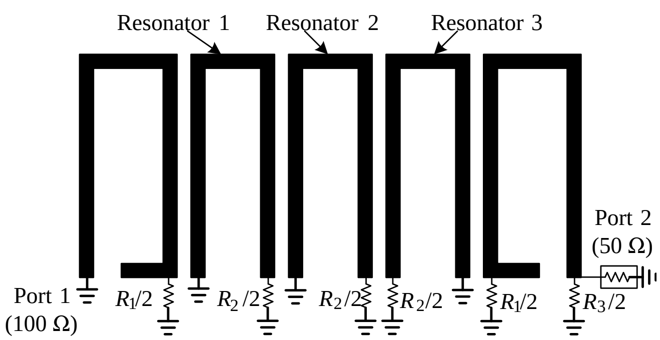

Figure 4. Odd-mode equivalent circuit.

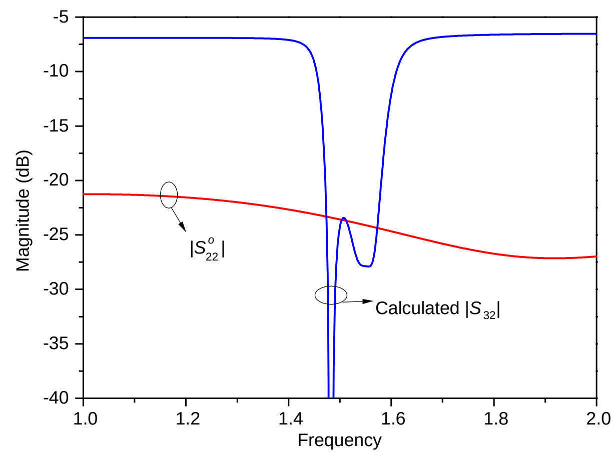

Figure 5. Simulated $|S^o_{22}|$ and calculated isolation $|S_{32}|$.

resonators function as impedance transformer converts the multiple isolation resistors to matching the port 2. The matching can be realized by tuning the resistance or changing the inter-resonator coupling strengths. However, if the coupling strength is altered, the filtering responses will be changed. Here, the matching of port 2 is mainly fulfilled by tuning the isolation resistors R_1, R_2 and R_3. Due to the multiple isolation resistors structure, the difficulty of impedance matching can be decreased. Figure 5 illustrates the matching of port 2 after the multiple isolation resistors ($R_1 = 200\,\Omega$, $R_2 = 100\,\Omega$ and $R_3 = 200\,\Omega$) tuned. Meanwhile, the isolation between the output ports can be calculated with S^e_{22} and S^o_{22}, which is also shown in Figure 5. Obviously, the isolation is more than 20 dB over the passband.

3. CIRCUIT IMPLEMENTATION

To design the filtering power divider, the design procedures can be summarized as follows [13, 15]. Firstly, determine the geometry parameters of resonators to be resonant at the centre frequency. Secondly, design the external quality and coupling coefficient to get the bandpass response with given specification by using the configuration in Figure 2(a). Thirdly, alert the multiple resistors to obtain the matching status at port 2 as shown in Figure 4. Finally, arrange the two structures, even- and odd-mode equivalent circuits, as well as the resistors to form the filtering power divider shown in Figure 1.

A demonstration filtering power divider is implemented on the Rogers RO4350 substrate, with the relative dielectric constant of 3.38, the thickness of 0.762 mm and the dielectric loss tangent of 0.0027. The layout parameters in Figure 1 are as follows: $L_1 = 5.9\,\text{mm}$, $L_2 = 2.25\,\text{mm}$, $L_3 = 3.5\,\text{mm}$, $L_4 = 12.95\,\text{mm}$, $W_1 = 1.7\,\text{mm}$, $W_2 = 0.5\,\text{mm}$, $s_1 = 0.15\,\text{mm}$, $s_2 = 0.95\,\text{mm}$, $s_3 = 0.9\,\text{mm}$, $s_4 = 0.6\,\text{mm}$, $R_1 = 200\,\Omega$, $R_2 = 100\,\Omega$ and $R_3 = 200\,\Omega$. The overall size of this circuit is $0.35 \times 0.21\lambda_g^2$, where λ_g is the guided wavelength at the center frequency of passband. A photograph of the fabricated filter is shown in Figure 6.

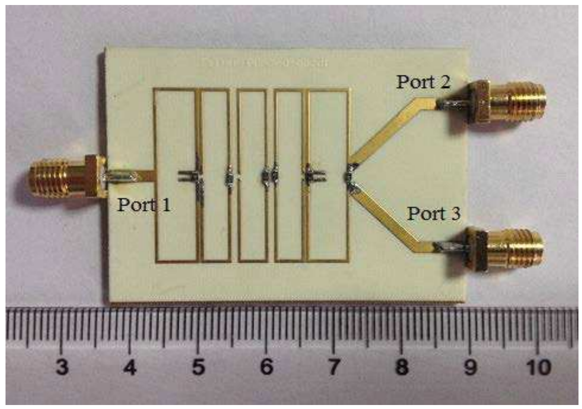

Figure 6. Photograph of fabricated circuit.

The simulation is carried out using HFSS, and the results are measured on the network analyzer Agilent 8358E. Figure 7 shows the simulated and measured frequency responses of the proposed filtering power divider. The measured center frequency is 1.52 GHz, with the fractional bandwidth of 6.58%. The measured insertion losses of S_{21} and S_{31} are approximately 5.48 dB and 5.56 dB. The passband return losses 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 ±0.1 dB and between 1.9° and 3.14°, respectively, as shown in Figure 8. The comparison is tabulated in Table 1. It is seen that the proposed circuit is suitable for high-order filtering power divider design and has a good isolation over the pass band.

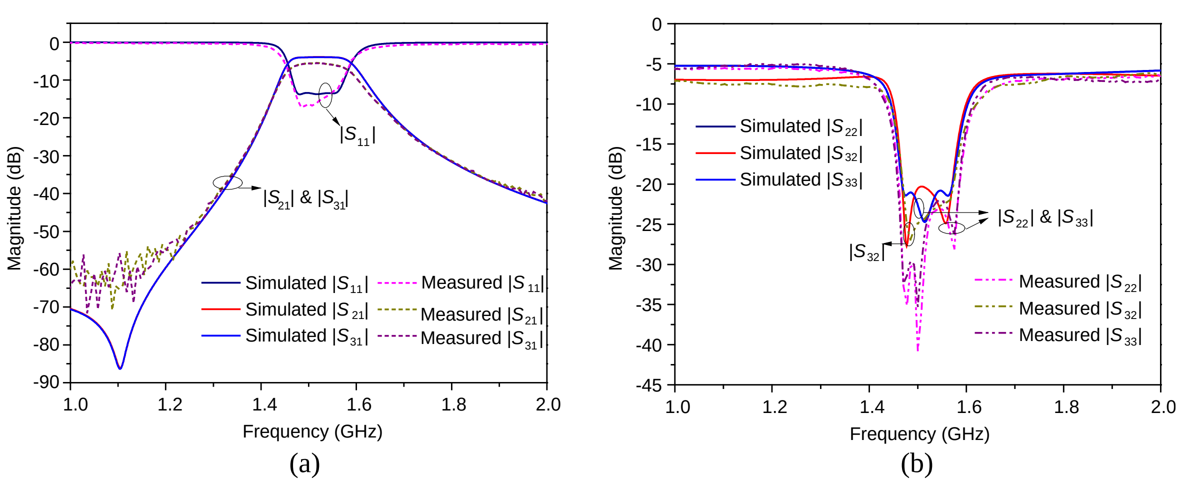

Figure 7. Simulated and measured S parameters of proposed power divider. (a) S_{11}, S_{21} and S_{31}. (b) S_{22}, S_{33} and S_{32}.

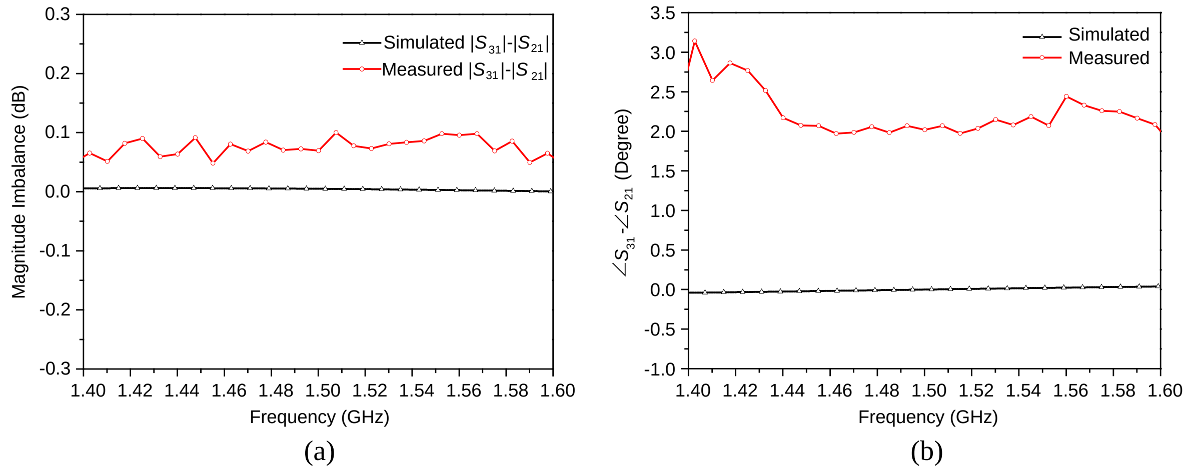

Figure 8. (a) Magnitude imbalance. (b) Phase imbalance.

Table 1. Comparison with previous work.

	Filter order	IL (dB)	FBW (%)	High-order design	In-band isolation	Isolation resistors	Size (λ_g^2)
[10]	2	3.9	10.1	Difficulty	> 8 dB	1	0.19×0.29
[11]	2	3.99	6.5	Difficulty	> 20 dB	1	0.15×0.14
[12]	2	4.4	3.5	Difficulty	> 30 dB	1	0.19×0.19
[13]	4	6.4	5	Easy	> 15 dB	1	0.49×0.38
[14] (Part 1)	2	4.6	4.5	Easy	> 16 dB	1	0.11×0.15
[14] (Part 2)	3	5.8	4	Easy	> 14 dB	1	0.17×0.15
[14] (Part 3)	4	6	4.2	Easy	> 11 dB	1	0.12×0.26
This work	3	5.56	6.58	Easy	> 20 dB	6	0.35×0.21

4. CONCLUSION

A novel filtering power divider with high in-band isolation is presented. The proposed device employs six quarter-wavelength resonators and six internal isolation resistors arranged symmetrically to achieve the power division and filtering function. Compared to the conventional power divider with bandpass response, the proposed device is easy to realize a high-order design with a good isolation. The design methodology and experimental results are presented. With the high in-band isolation, the proposed filtering power divider is attractive for wireless communication systems.

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