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Research Article

A Novel Filtering Power Divider Based on Ring Resonator

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In this paper, a compact dual-band filtering power divider (FPD) combined by conventional Wilkinson power divider and dual-mode resonators is proposed. The resonators submitting the quarter wavelength transmission line can act as a filter. The proposed resonator is composed of two cascading symmetrical ring branches connected to the ground in the middle. The inter-digital coupling structure constitutes the feed lines of the band-pass filter (BPF) operating at 2.45/5.8 G. The resonator with symmetrical structure is analyzed by the odd-even mode method in detail. The two resonant frequencies can be adjusted by the length of the stub separately. In addition, two isolation resistors are placed at proper position for ensuring the isolation effect. The proposed FPD is fabricated for verifying simulation results, and good agreements between the simulated and measured results are achieved here.

1. Introduction

With the increasing demand for technology in wireless communication system, diversified functions and miniaturization of wireless devices have attracted more attention..

As indispensable microwave components, power divider with the function of dividing/combining signal is the hotspot of research in antenna arrays, RF, and wireless communications [1–5B1B2B3B4B5]. Up to date, the Wilkinson power divider is one of the most popular circuits because of the characteristics of excellent isolation.

Poor band selectivity and operating in a signal center frequency restrict the application of the conventional Wilkinson power divider. Recently, new modified Wilkinson power dividers have been proposed for satisfying the development of microwave components.

In [1], by cascading the multi-section hybrid power divider, the synthesis method for increasing the bandwidth was proposed. A compact UWB power divider can be designed by various methods, such as complementary structures of microstrips to slotlines [2], multi-layer broadside-coupled structure [3], and multi-layer slotline structure [4]. The slotted microstrip cross junction method can also be used to achieve dual frequency [5]. A compact single circular patch FPD was proposed for improving bandwidths [6]. The out-of-phase FPD integrating impedance transformer was proposed, which realized inherent impedance transformation [7]. Defected ground structure (DGS) and inter-digital coupled-lines technologies were employing for achieving excellent wide band performances [8]. The structure consisting of complementary split ring resonator (CSRR) and an inter-digital capacitor was proposed for improving wide stop band and high selectivity [9].

Several efforts for integrating the power divider and band-pass filters (BPFs) have been proposed to meet the demand for size and frequency band operations. Coupled lines can be utilized to replace the quarter wavelength transmission line of Wilkinson power divider for realizing dual-band filtering power dividers [10–14]. The novel substrate integrated suspended line (SISL) technology was used in the design [14]. In these design schemes, the coupled lines play the role of filtering and splitting at the same time. For the FPD with the same structure, dual-composite right/left handed (CRLH) unit was adopted for achieving better isolation [15].

The dual-band Wilkinson power divider was achieved by adding the stub lines or modifying structure on the base of the conventional power divider [16–18]. In many design schemes, the Wilkinson power divider embedded with dual-mode or multi-mode resonators can show the desired central frequency and mode. The required power dividers can be realized by different resonators on dual-mode [19], tri-band [20], and quad-band [21], respectively.

In this paper, a compact dual-band Wilkinson power divider embedded with a dual-mode resonator is presented and analyzed. The proposed power divider operating at 2.45/5.8 G is very suitable for Wi-Fi application. The odd-even mode analytical method is utilized to guide the design process. According to the research on the current distribution of the proposed FPD, the design flexibility has been enhanced. By adjusting the length of stub, different central frequencies can be obtained for more application scenarios. The remarkable performance on insertion/return losses and frequency selectivity will be obtained by simulation and measured. Three more transmission zeroes (TZs) achieved by unique coupling structure and resonant mode reveal high-frequency selectivity.

2. Resonator Design and Analysis

The dual-band BPF which will be utilized in the Wilkinson power divider is analyzed in this section. The schematic diagram of the novel ring resonator known as multi-mode resonator (MMR) is given in Figure 1. The BPF combining two cascading MMRs and the feed lines of inter-digital coupling structure shows the center frequency at 2.45/5.8 G. The ring resonator is composed by two ring stubs and a shorted stub. It is very suitable to analyze the proposed resonator by the odd-even mode method for its symmetrical structure.

The equivalent circuit of even mode consisting of two open end stubs and one grounded end stub is shown in Figure 2(a). The following formula is the input admittance:

$$Yine = jY\frac{\tan\theta 2 + \tan\theta 3 - \cot\theta 5}{1 - (\tan\theta 3 - \cot\theta 5)\tan\theta 2} + jY\tan\theta 1. \quad (1)$$

According to resonant condition $Y_{ine} = 0$, the calculation equation of the resonant frequency is shown as

$$\begin{aligned}&\tan\theta 2 + \tan\theta 3 - \cot\theta 5 + \tan\theta 1+\\&\tan\theta 1\cdot\tan\theta 2\cdot(\cot\theta 3 + \cot\theta 4) = 0.\end{aligned} \quad (2)$$

In Figure 2(b), the equivalent circuit of odd mode consists of three grounded end stubs, the input admittance of which is expressed as

$$Yino = jY\frac{\tan\theta 2 - \cot\theta 3 - \cot\theta 4}{1 + (\cot\theta 3 + \cot\theta 4)\tan\theta 2} - jY\cot\theta 1. \quad (3)$$

Similar to the even mode, the resonant condition is $Y_{ino} = 0$. According to the calculation equation, the resonant frequency is derived as follows:

$$\begin{aligned}&\tan\theta 2 - \cot\theta 3 - \cot\theta 4 - \cot\theta 1-\\&\cot\theta 1\cdot\tan\theta 2\cdot(\cot\theta 3 + \cot\theta 4) = 0,\end{aligned} \quad (4)$$

$$\theta i = \beta li. \quad (5)$$

From formulas (2) and (4), f_e and f_o can be derived, respectively. The analysis process and related discussion of similar resonator are given in [21, 22]. The proposed resonator can only be analyzed using the odd-even mode method once. Because the even-mode equivalent circuit and odd-mode equivalent circuit are not symmetrical structures, these circuits cannot be analyzed by the same way again. So, the two resonant frequencies can be obtained separately from two equivalent circuits. Based on the analysis above, the proposed resonator is the dual-mode resonator with two resonant frequencies [20, 21].

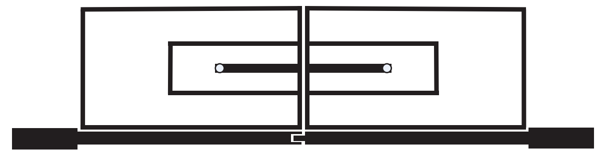


Figure 1: Schematic of the proposed ring resonator.

The coupling scheme of the resonators and feeding lines is given in Figure 3. One part of the energy is coupled through the cascaded dual-mode resonators, and the other part is coupled through the feeding lines.

The simulated results of the resonator presented in Figure 1 are shown in Figure 4. The above analysis may be confirmed by dual-band responses on the central frequencies of 2.45 G/5.8 G. Three transmission zeroes are produced owing to resonant mode and mixed electric and magnetic coupling, which contribute to high-frequency selectivity.

Because the filter given in Figure 1 must be utilized in the power divider, the interaction of the feed lines and resonators affects the performance of the power divider. So, the resonator and power divider will be analyzed together in the next section.

3. PD Design and Analysis

Based on the designed BPF above, the design schematic of dual-mode FPD is shown in Figure 5. The two BPFs constitute the two branches of the Wilkinson power divider. Adopting the scheme with two isolation resistors is to achieve better isolation effect.

Where the specific sizes are as follows: $W_1 = 1.2$ mm, $W_2 = 1.2$ mm, $W_3 = 0.25$ mm, $L_1 = 5$ mm, $L_2 = 9.44$ mm, $L_3 = 8.64$ mm, $L_4 = 4.05$ mm, $L_5 = 2$ mm, $L_6 = 3$ mm, $L_7 = 5.4$ mm, $L_8 = 0.65$ mm, $S_1 = 0.1$ mm, $S_2 = 0.12$ mm, $S_3 = 0.1$ mm, $R_1 = 200$ ohm, $R_2 = 200$ ohm, Rvia = 0.5 mm.

Because the whole FPD is symmetrical, a pair of resonators below will operate in the same way as the pair above. The same resonant frequency will ensure that the power divider works at the desired frequency point.

It is an effective way to determine which stub affects the resonant frequency by observing the current distribution of the FPD operating at resonant frequency point. When the proposed FPD operates at 2.45 G and 5.8 G, the diagram of current distribution is shown in Figure 6.

According to the diagram of current distribution, the change of resonant frequency could be analyzed easily. The length of L_3 is not proper to be changed in case of the feeding lines. Figure 7 shows the relationship between frequency and length of microstrip lines. The length of L_4

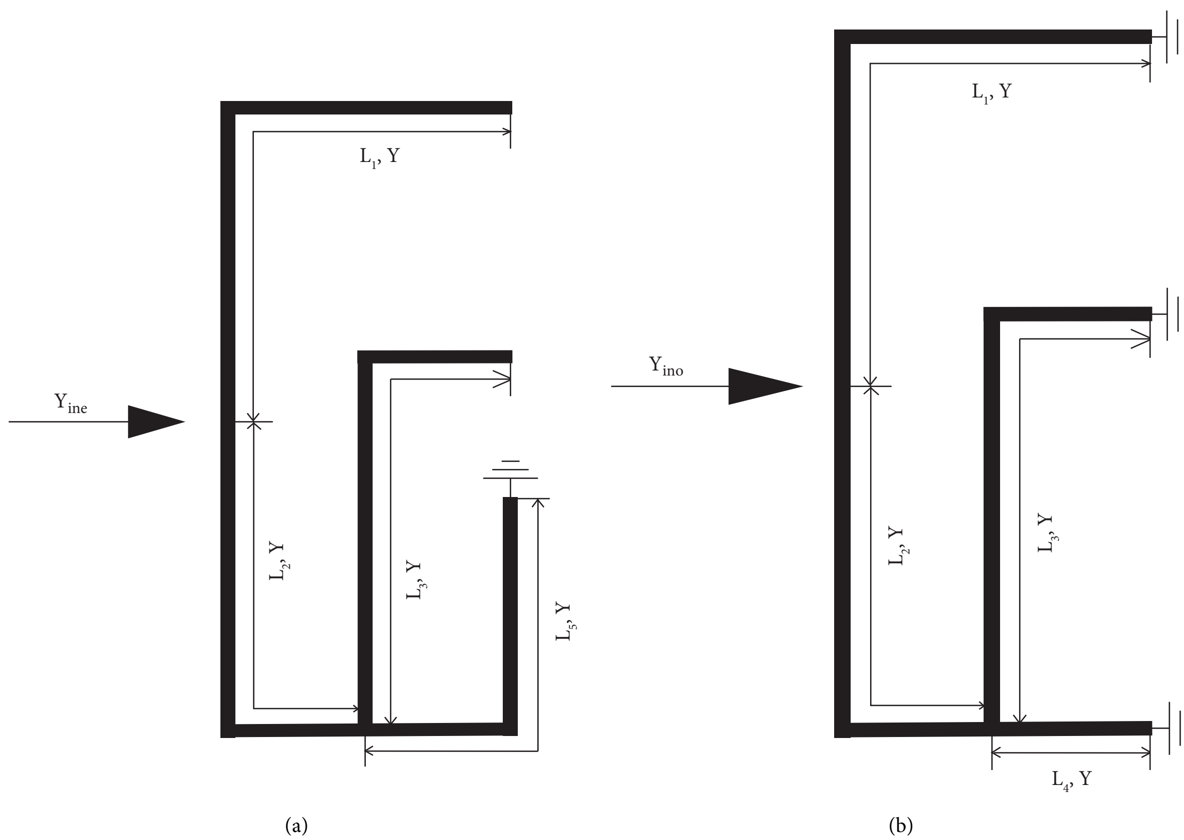


Figure 2: (a) Even-mode equivalent circuit. (b) Odd-mode equivalent circuit.

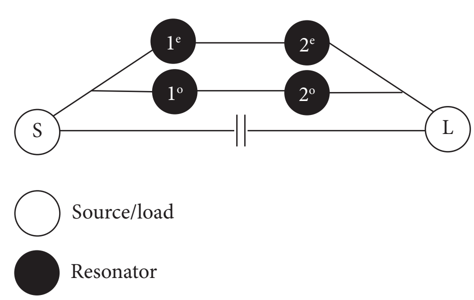


Figure 3: Coupling scheme of the proposed resonator.

and L_5 decides the change of resonant frequency. It can be concluded that f_1 depends on L_5, and L_5 has little effect on f_2. f_2 mainly depends on L_4, and L_4 has no effect on f_1. If the dimension of L_4 is too large, f_2 cannot complete the required resonance. Firstly, determine f_1 through adjusting L_5 and then determine f_2 by adjusting L_4 after determining f_1. So, the two resonant frequencies can be adjusted independently.

4. Analysis of Test Results

Based on simulation, the fabricated FPD is implemented for verifying the design method, the photograph of which is shown in Figure 8. The overall size of the PCB is 30 mm∗44 mm (0.46 λg × 0.68 λg, where λg is the guided wavelength at the center frequency of 2.45 GHz). The proposed FPD is fabricated using Rogers 4350 and the thickness of the substrate is 0.508 mm. The measured process is verified by Agilent vector network responses. The measured and simulated results are shown in Figure 9. Two pass-bands with sharp skirt ensure the frequency selectivity and three TZs contribute to the band-to-band rejection. Therefore, the filtering property of the proposed FPD is verified. At 2.45 G, the measured value is in good agreement with the simulated value. The insertion loss is less than 5 dB. At 5.8 G, the insertion loss is larger than the simulated value. The return loss is around 18 dB at 2.45 G and 28 dB at 5.8 G. The performance of isolation is better than −10 dB. Due to fabricating reasons, there is a certain deviation in the measured results.

Compared with some reported dual-band FPDs, the results of performance comparison are shown in Table 1.

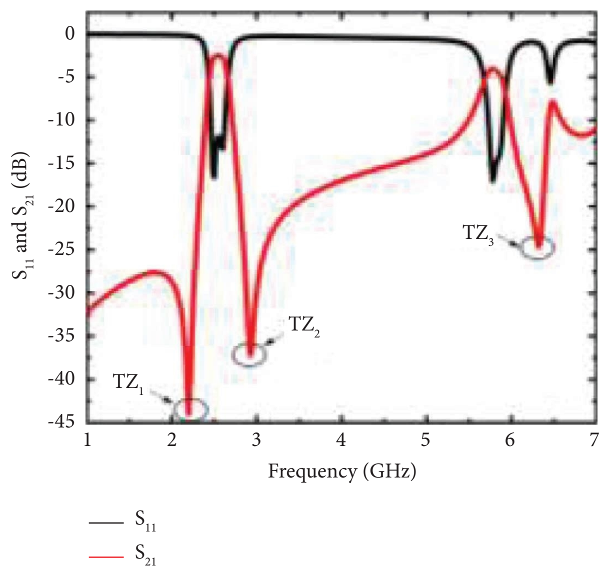


Figure 4: Simulation of S_{11} and S_{21} of the proposed resonator.

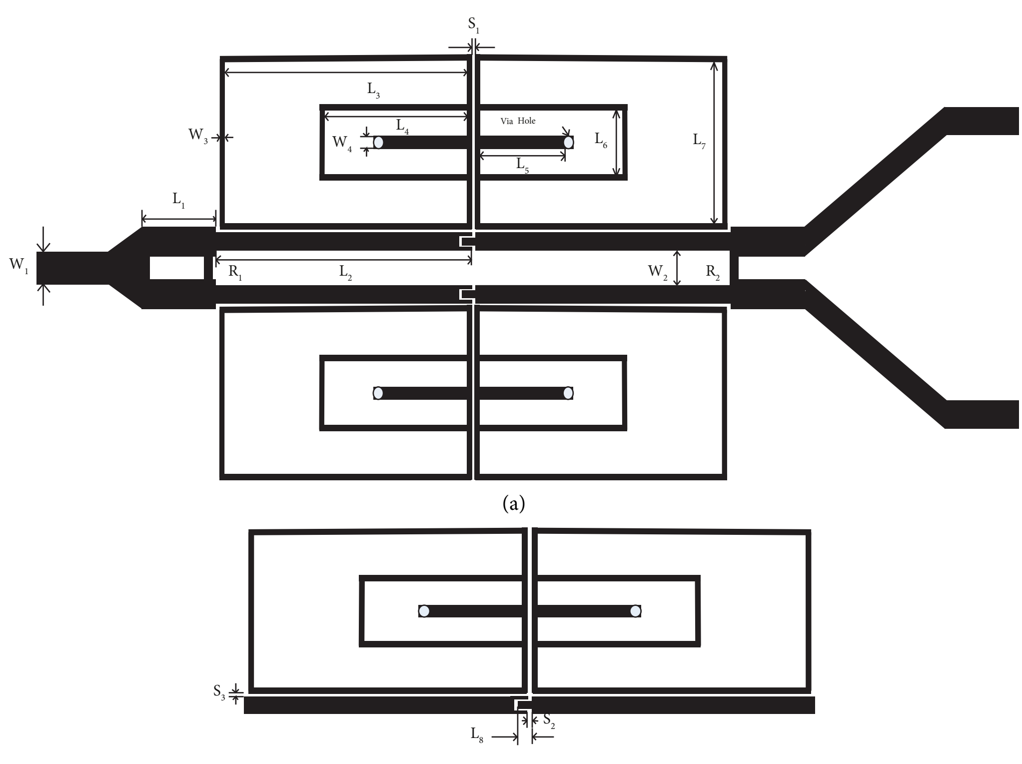
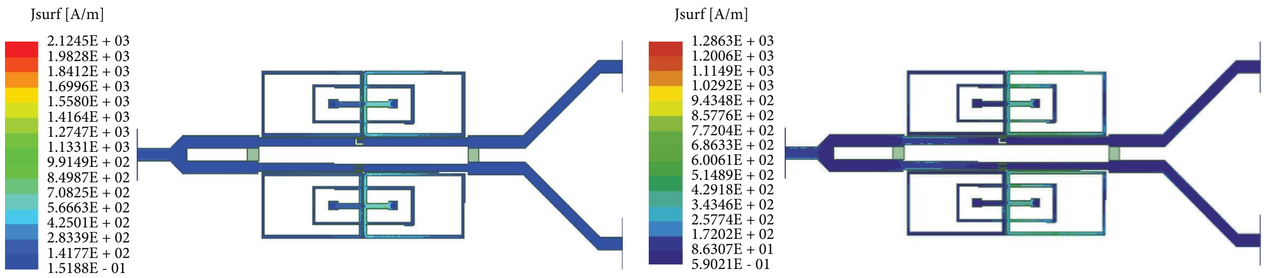
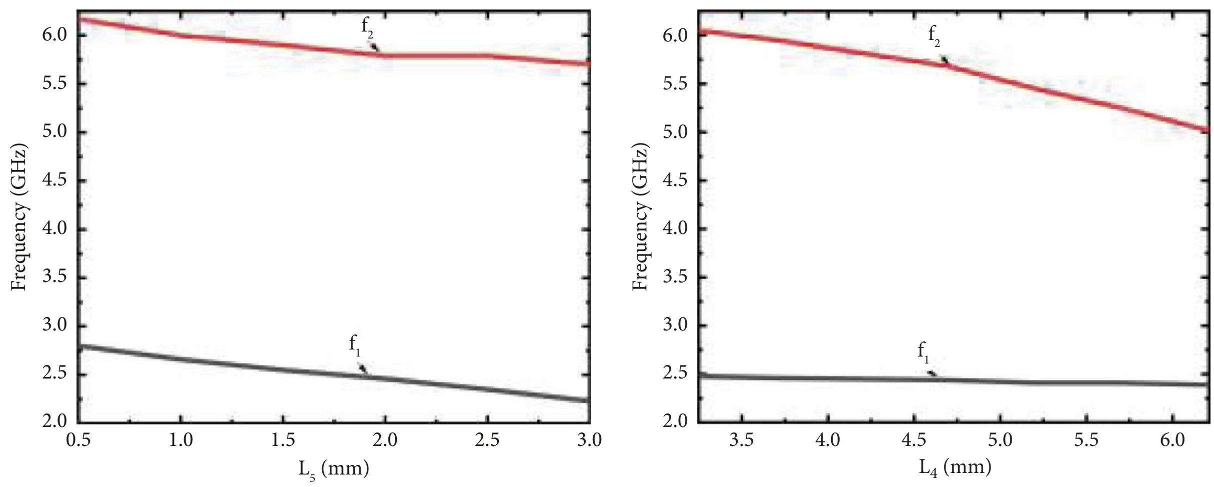


Figure 5: (a) Schematic of dual-mode filter power divider. (b) The size of inter-digital coupling lines.



(a) (b)

Figure 6: Current distribution of the resonator. (a) 2.45 G. (b) 5.8 G.



(a) (b)

Figure 7: Resonant frequency with varied dimensions. (a) L_5. (b) L_4.

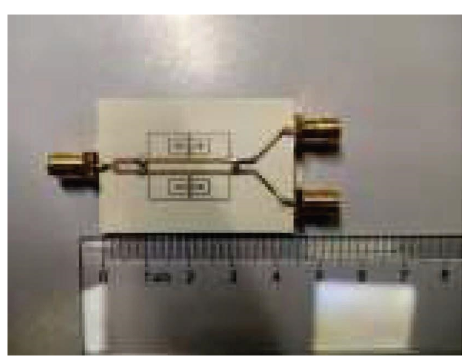


Figure 8: Photograph of the fabricated FPD.

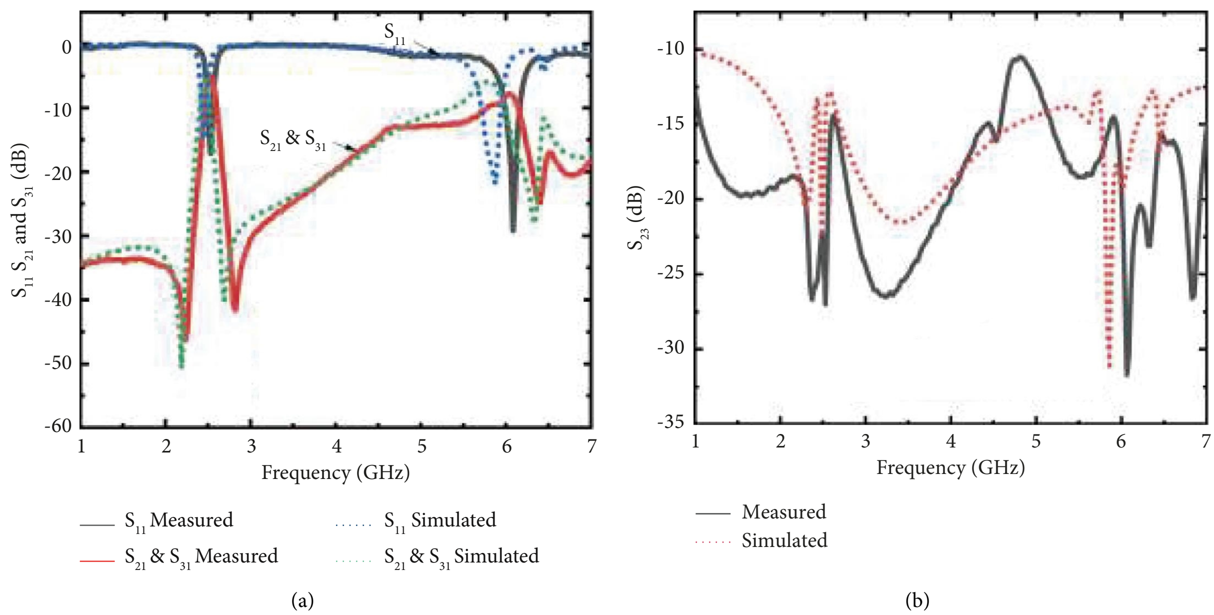


FIGURE 9: Measured and simulated S-parameters. (a) S_{11}, S_{21}, and S_{31}. (b) S_{23}.

TABLE 1: Comparisons with previous works.

Ref.	Center frequencies (GHz)	Insertion loss (dB)	Isolation (dB)	Size ($\lambda_g \times \lambda_g$)
[5]	1/3	7.5/7.5	11/10	0.28×0.5
[11]	2.3/3.5	4.2/4.5	19.0/18.6	0.28×0.37
[12]	2.43/5.06	3.8/4.4	24/19.8	0.67×0.68
[13]	2.45/5.13	3.89/4.39	10/12	0.29×0.3
[17]	1.8/2.96	3.9/4.0	11/12	0.45×0.6
This work	2.45/5.8	4.8/5.9	13/15	0.46×0.68

Due to the fact that the proposed FPD has similar performance as others, the design scheme in this paper is acceptable. The fact that the specific operating frequency meets the Wi-Fi application is the merit of this work.

5. Conclusion

On the base of designing and analyzing a novel resonator, the dual-band FPD with good performance is presented in this paper. Two pairs of cascading MMRs have been loaded at the two branches of the Wilkinson power divider, respectively. Experiments on the proposed FPD operating at 2.45/5.8 G are carried out to validate the design methodology. It exhibits excellent characteristics in terms of the low insertion loss and high return loss. A good in-band isolation is achieved due to two isolation resistors at the right position. These features of designing easily, flexible center frequency setting, and high selectivity will contribute to the application of the proposed FPD.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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