Dual-band Bandpass Filter with Good Selectivity and Stopband Rejection

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Abstract— Dual-band dual-mode bandpass filters with good selectivity and wide upper-stopband performance based on circular ring resonator is presented. The two first-order degenerate modes are excited and split to form the first passband, while one of the third-order degenerate modes forms the second passband together with a second-order degenerate mode. After installing two parallel-coupled-line sections on a ring at the two ports with 90°-separation, five transmission zeroes are produced for the rejections between the two passbands and in the stopband. A dual-band filter with the two transmission poles in each passband is designed and measured, the measured filter shows good agreement with the simulated.

1. INTRODUCTION

As one of the essential microwave components, dual-band bandpass filters are highly desired in modern dual-band wireless communication systems [1, 2]. Therefore, various design approaches have been proposed. Microstrip ring resonators have been used to design various microwave circuits such as filters, mixer and oscillators and so on [3, 4]. By using the coexisting of the two degenerate orthogonal mode, a dual-band passband filter can be achieved [5]. Due to the characteristics of compact size, high-Q factors, and sharp rejection skirt, the ring resonators have been analyzed deeply and comprehensively in many reports [6–9]. In [6], the dual-band bandpass filter with adjustable first- and second-order resonator was presented by using stepped-impedance ring resonator. However, there is only a single transmission pole in the second passband for a single ring resonator filter. In [7], two dissimilar ring resonators with different resonant frequencies were utilized to achieve the desired dual-band passband performance, while the solutions need more design consideration and larger overall size. In [8], dual-band bandpass filter based on a signal ring resonator were designed. However, these structures need many perturbation elements to be installed along the ring. In [9], a dual-band bandpass filter was presented using a single rectangular ring resonator, but the out-of-band rejection and the selectivity are not good enough.

In this paper, a dual-band BPF using a single microstrip circular ring resonator has been presented. The two transmission poles are generated in each passband after installing two coupled-line sections at two excitation ports. A common two-port excitation angle of 90°-separation with the cooperation of the parallel-coupled feed line, five transmission zeroes are generated and controlled to provide a good isolation and wide upper stopband. A dual-band filter is designed and measured to demonstrate the good in-band matching and the good rejections outside the desired dual passbands.

2. FILTER DESIGN

2.1. Characteristic of Proposed Resonator

Figure 1 shows a configuration of the proposed quadruple-mode circular ring resonator. It consists of a circular ring resonator with two open ended stubs, where R, w and w_s are the radius and the widths of the square ring and open stubs, respectively. Because the resonator is an even symmetrical structure, its operating mechanism can be discussed by an even- and odd-mode analysis. Its equivalent circuits are depicted in Figs. 1(b), (c). Z_s and θ_s are the characteristic impedance and the electrical length of the loaded open-circuited stub on the ring. Z_l and Z_r respect the two oppositely oriented input impedances at the same position, the input impedances with superscript "e" and "o" are the even- and odd-mode impedances, respectively.

According to the Transmission line theory and odd-even mode analysis method, the resonant frequencies under the even- and odd-mode excitation satisfy [10]

$$Z_l^e + Z_r^e = 0 \tag{1}$$
$$Z_l^o + Z_r^o = 0 \tag{2}$$

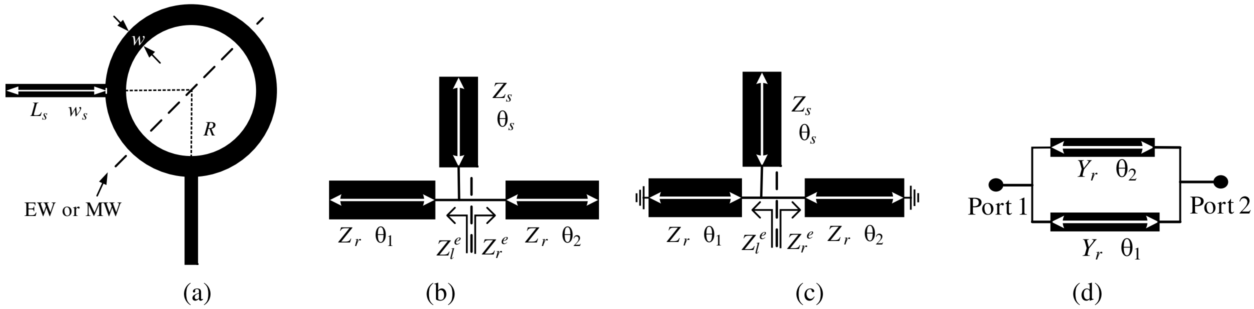


Figure 1: (a) Layout of proposed circular ring resonator; (b) Even-mode equivalent circuit; (c) Odd-mode equivalent circuit; (d) Circuit for obtaining transmission zero frequencies.

where $Z_l^e = -j\frac{Z_r}{\tan\theta_1+\tan\theta_s}$, $Z_r^e = -\frac{jZ_r}{\tan\theta_2}$, $Z_l^o = -jZ_r(\frac{\tan\theta_1\tan\theta_s}{\tan\theta_1-\tan\theta_s})$, $Z_r^e = jZ_r\tan\theta_2$.

Figure 1(d) is used for obtaining these transmission zeroes. The transmission zero frequencies are obtained when $Y_{21} = Y_{12} = 0$, where the admittance matrices are calculated by adding upper and lower Y-parameter of the two paths connected in shunt between port 1 and 2, and the calculated results are expressed by

$$\sin\theta_1 + \sin\theta_2 = 0 \quad (3)$$

where $\theta_2 = 3\theta_1$, so, the transmission zeros appear at $\theta_2 = (2n-1)\times 90°$, $n = 1, 2, 3, \ldots$.

Figure 2 shows the frequency responses of the circular ring resonator under a weak coupling. It can be seen that all the resonant frequencies become smaller as θ_s increase. The first two resonant frequencies f_1 and f_2 split from each other as θ_s increase, while the third and fourth resonances f_3 and f_4 further move close to each other and thus form a second passband. The fifth resonance f_5 becomes the first spurious frequency of this dual-band filter.

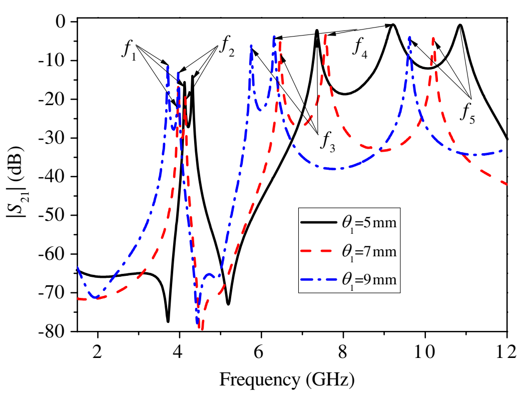


Figure 2: Simulation transmission response of the dual-band filter with weak coupling.

2.2. Characteristics of Parallel-coupled Feed Line

Figure 3(a) shows the layout of circular ring dual-band BPF which fed by the parallel-coupled feed lines. (L_1, w_1) and (L_2, w_2) are the electrical length and the width of the parallel-coupled feed line connecting with input/output port and the loaded open stub on the circular ring resonator, respectively.

To examine the characteristics of the parallel-coupled lines, only the parallel-coupled feed lines shown in Fig. 3(b) with three different length of L_1 are simulated. These three kinds of simulated results are shown in Fig. 4(a) when $L_1 = L_2$, $w_1 = w_2$, the transmission zeroes of the parallel-coupled lines are distributed in the stopband. According to the curves in Fig. 4(b), the transmission zero f'_{Tz2} can be changed widely by altering the length of parallel-coupled feed line of L_1 while the length of L_2 remain unchanged, and transmission zero f'_{Tz1} varies slightly. The effect of these overlaps can be displayed when the circular ring resonator and the parallel-coupled lines are used together. Fig. 5 shows the simulated results of the circular ring fed by the parallel-coupled lines shown in Fig. 3(b) with three different length of L_1. The overlap of zeroes shown in Fig. 5 result in the fifth resonant frequency suppression in Fig. 2, cause sharper rejections at cutoff regions, and wider stopband.

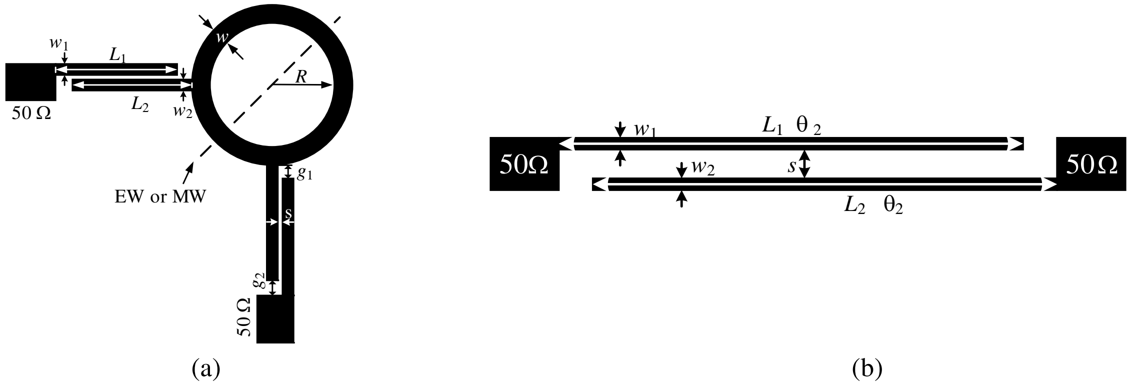


Figure 3: (a) Circular ring resonator fed by parallel-coupled lines; (b) Parallel-coupled feed line used in Fig. 3(a).

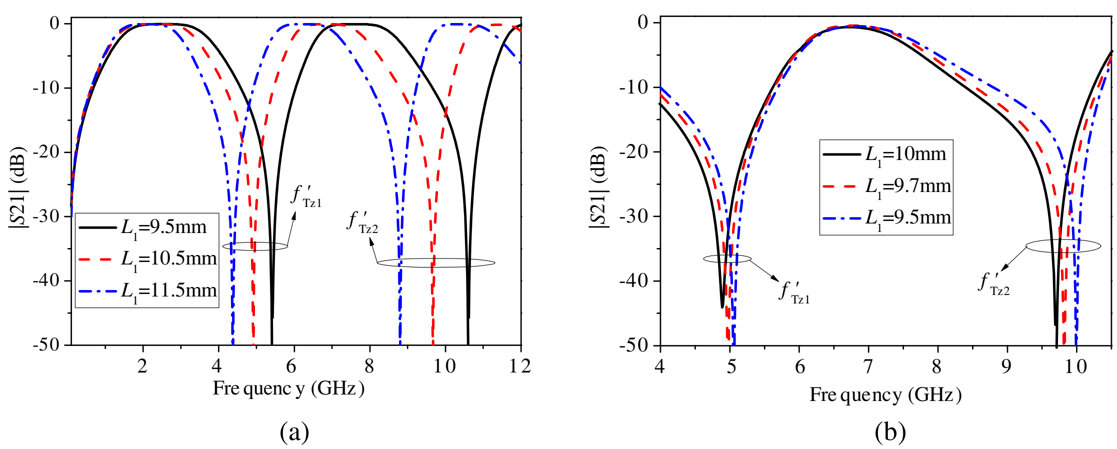


Figure 4: (a) Simulated results for the parallel-coupled feed line using three kinds of L_1 in the case of $L_1 = L_2$; (b) Variation of the transmission zeroes versus the length of L_1.

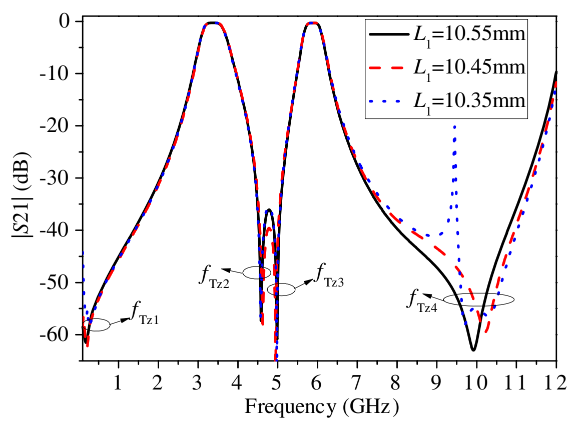
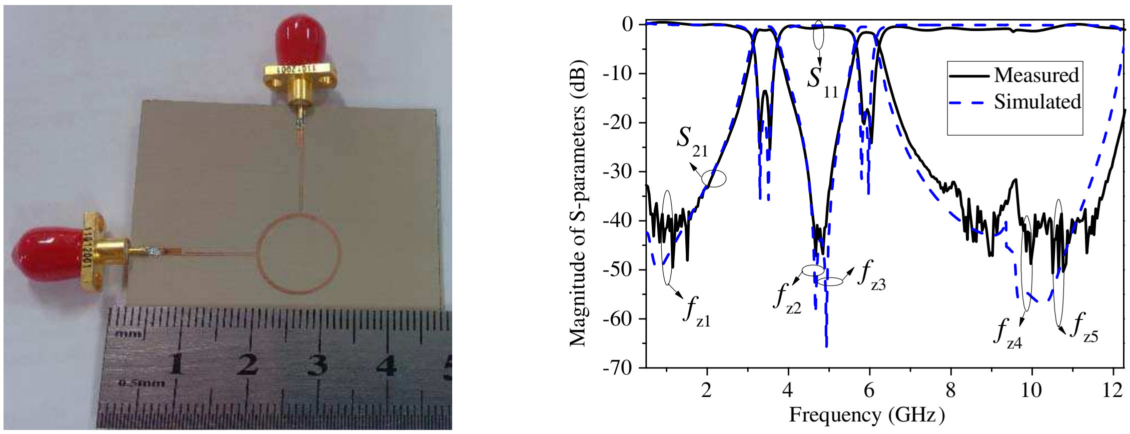


Figure 5: Simulated results of the circular ring resonator fed by the parallel feed line versus the length of L_1.

3. EXPERIMENTAL RESULTS

Based on the circular ring quadruple-mode resonator, a dual-band BPF has been designed and fabricated on *Taconic* RF-35 substrate with relative dielectric constant of $\varepsilon_r = 3.5$ and thickness of $h = 0.508$ mm. The geometry of the proposed filter is shown in Fig. 3(a). The dimensions are obtained as: $L_1 = 10.41$ mm, $L_2 = 10.55$ mm, $w_1 = 0.13$ mm, $w_2 = 0.16$ mm, $w = 0.6$ mm, $g_1 = 0.3$ mm, $g_2 = 0.44$ mm, $s = 0.21$ mm, $R = 6.5$ mm.

The photograph of the fabricated filter is presented in Fig. 6(a). The simulated and measured frequency responses are compared in Fig. 6(b). Dotted lines and solid lines indicate the simulated and measured results, respectively. A good agreement is achieved between the simulated and the measured results. The measured minimum insertion loss achieves 1.0 dB in the first passband and 1.6 dB in the second passband. The 3-dB fractional bandwidth of the proposed filter is 18% and 8%, respectively. Its passband return loss is larger than 15.6 dB. Three transmission zeroes are generated at 1.01, 4.62, 4.85, 9.85 and 10.32 GHz, respectively. With the help of an additional transmission zero provided by the coupled-line section, the fifth resonance which located in the upper stopband can be fully suppressed. In the measured upper-stopband responses, a 20 dB rejection in the frequency range of 6.78 to 12.25 GHz is obtained.



(a) (b)

Figure 6: (a) Photograph of the fabricated dual-band bandpass filter; (b) Simulated and measured results of dual-band BPF.

4. CONCLUSION

A dual-band BPF using a single circular ring resonator has been presented. The two transmission poles are generated in each passband after installing two parallel-coupled-line sections at two excitation ports. Meanwhile, two transmission zeroes are placed between the two passbands and three transmission zeroes are created in the stopband which resulted in a good selectivity and wide upper stopband. The spurious frequency caused by the fifth resonance of the resonator has been suppressed by an additional zero brought by the parallel-coupled-line section, thus widening the upper stopband.

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