Compact Dual-Wideband Bandpass Filter with Multimode Resonator

Haiwen Liu, Shen Li, Xuehui Guan, Baoping Ren, Jiuhuai Lei, and Yan Wang

A microstrip dual-wideband bandpass filter using a multimode resonator (MMR) is proposed in this letter. The proposed MMR loaded with a T-shaped open-ended stub and a short-ended stub exhibits triple mode characteristics, and a synthesis method is developed to illustrate the wide passband with independently controllable center frequencies and bandwidths. To verify this design methodology, a dual-wideband filter with fractional bandwidths of 19.1% and 27.9% is designed and fabricated. The measured results agree with the simulations.

Keywords: Wideband, dual-band, bandpass filter, BPF, multimode resonator, MMR.

I. Introduction

The microwave dual-band bandpass filter (BPF) is a critical component in multiband mobile communication systems. Many methods have been proposed for dual-band BPFs. In [1], [2], ring resonators were proposed to realize the dual-band characteristic with advantages of a high Q factor and low radiation loss. The stepped-impedance resonator (SIR) is another popular choice for dual-band BPF designs [3], [4]. The locations of two passbands can be tuned by properly selecting the impedance ratio and physical length ratio of two sections. In addition, a compact dual-band BPF with three poles in each passband is designed by using a cascaded SIR and a uniform-impedance resonator [5]. The skew-symmetrical feeding structure and cross coupling can control the isolation between two passbands, while it is inconvenient to regulate the dual-band performance. Nevertheless, a more flexible design in terms of the choice of band allocation and tuning the central frequencies of two passbands independently is needed. Moreover, it is noted that most dual-band BPFs using just an open stub-loaded half-wavelength resonator are applied to the narrow band (usually less than 10%) design [6]. Instead of conventional single-band quarter-wavelength shorted stubs, short-circuited SIRs have been utilized for dual-wideband BPF design to meet the challenge of designing a dual-band filter with a wide bandwidth, a controllable central frequency and bandwidth, and a compact size [7].

In this letter, a novel triple mode resonator with a T-shaped open-ended stub and a short-ended stub is introduced. The proposed resonator can generate three resonant modes, which are explained by even and odd mode analysis. Then, a compact multimode resonator (MMR) composed by the proposed triple mode resonators with a common short-ended via is given. The MMR can provide dual-wideband bandpass characteristics, which are applied to the dual-band BPF design with a wide bandwidth and controllable central frequency. Finally, this dual-wideband filter is analyzed, fabricated, and measured.

II. Analysis of Triple Mode Resonator

Figure 1 depicts a layout of the proposed triple mode resonator with a T-shaped open-ended stub and a short-ended stub along the central plane, where Z_1, Z_2, Z_3, and Z_4 and θ_1, θ_2, θ_3, and θ_4 denote the characteristic impedances and electrical lengths of the resonator, respectively.

Since the proposed triple mode resonator is symmetrical to the *A*-*A′* plane, even and odd mode theory is adopted to analyze the resonator structure. The corresponding odd mode and even mode equivalent circuits are shown in Fig. 2(a) and 2(b),

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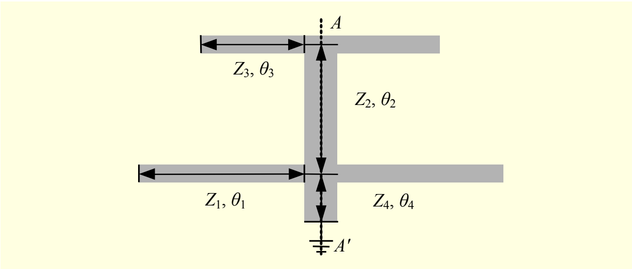

Fig. 1. Structure of proposed triple mode resonator.

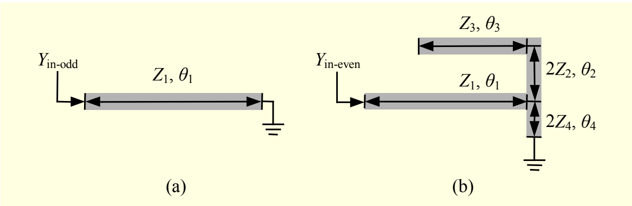

Fig. 2. Equivalent circuits: (a) even mode; (b) odd mode.

respectively. As shown in Fig. 2(a), the odd mode resonance condition can be derived by setting $Y_{in\text{-}odd} = 0$, and the odd mode frequency f_o can be deduced as

$$\theta_1 = \frac{\pi}{2} \qquad (\text{at } f{=}f_o). \qquad (1)$$

From (1), it can be observed that the odd mode resonant frequency is only controlled by electrical length θ_1 and has no relationship with this short-ended stub.

As shown in Fig. 2(b), the even mode resonance condition can be determined by setting $Y_{in\text{-}even} = 0$. Two even mode frequencies, f_{e1} and f_{e2}, can be excited by the resonator with electrical lengths $\theta_1+\theta_2+\theta_3$ for the open-end condition and the other resonator with electrical lengths $\theta_1+\theta_4$ for the short-end condition. For simplicity, $Z_3 = 2Z_2 = 2Z_4$ is assumed. Thus, the even mode frequencies can be derived as

$$\cot\theta_4 - \tan(\theta_2+\theta_3) = \frac{2}{K}\tan\theta_1 \qquad (\text{at } f{=}f_{e1} \text{ and } f{=}f_{e2}), \qquad (2)$$

where $K = Z_4 / Z_1$ is the impedance ratio of the resonator.

From (2), a design graph of the proposed triple mode resonator is described in Fig. 3. Frequency ratios f_{e1} / f_o and f_{e2} / f_o are plotted with open-ended stub length $\theta_2+\theta_3$ and short-ended stub length θ_4. As shown in Fig. 3, it is found that the wide band with three resonant frequencies can be formed and located at f_o when the ratio values of f_{e2} / f_o and f_{e1} / f_o both approach 1. So, to obtain the physical dimensions of the proposed triple mode resonator, a design procedure is listed as follows:

a) θ_1 can be determined by (1) with a given f_o.

b) From Fig. 3, adjust the short-ended stub length, θ_4, to 1° and make a reach for $f_{e1} / f_o \approx 1$.

c) From Fig. 3, adjust the open-ended stub length, $\theta_2+\theta_3$, to

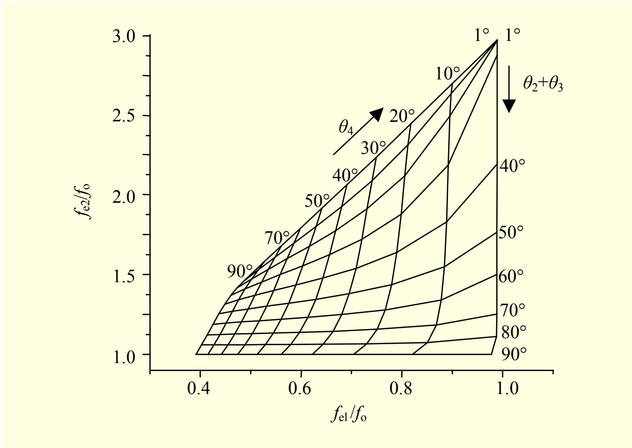

Fig. 3. Design graph of proposed triple mode resonator with K=2.

90° and make a reach for $f_{e2} / f_o \approx 1$.

d) Based on steps b) and c), f_o, f_{e1} and f_{e2} can be allocated at adjacent frequencies of a single passband. Furthermore, the two bandwidths can be tuned by the choice of the frequency ratio between the maximum and minimum values among f_o, f_{e1}, and f_{e2}.

III. Dual-Wideband BPF Design

To verify the above analysis, a dual-wideband BPF filter is designed to operate at 1.57-GHz and 2.4-GHz applications. It is fabricated on a Taconic RF-35A2 substrate with a relative dielectric of 3.5 and thickness of 0.76 mm. The proposed filter is composed of two triple mode resonators, as shown in Fig. 4.

Also, the two triple mode resonators are connected by a common short-ended via, in which each resonator generates a passband. Note that the two resonators in the respective passband can be tuned separately. Once the central frequency of each passband is fixed, the odd mode frequency can be obtained by choosing the corresponding electrical length, θ_1, from (1). Additionally, two even mode frequencies can be adjusted independently by choosing the corresponding electrical lengths, ($\theta_2+\theta_3$) and θ_4, from Fig. 3 to meet the required bandwidth.

For the sake of a compact size, the proposed triple mode resonator is folded into a meandering structure. The dimensions of this filter are optimized, and the detailed information is listed in Table 1. Compared with the MMR filter with single Resonator I or Resonator II, Fig. 5 shows the simulated and measured results of the proposed filter. The measured center frequencies of the two passbands are 1.57 GHz and 2.4 GHz, which is for GPS and WLAN applications, respectively. Within the two passbands, the fractional bandwidths are 19.1% and 27.9%. The measured minimum insertion loss in the 1.57-GHz band and the 2.4-GHz-band is

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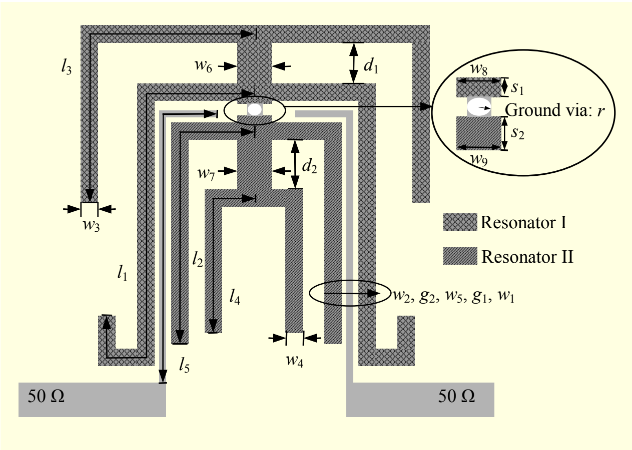

Fig. 4. Configuration of proposed dual-band BPF.

Table 1. Dimension of fabricated filter (unit: mm).

l_1	29.1	w_3	0.9	d_1	3.7	w_8	1.8
w_1	0.9	l_4	13.5	w_6	1.8	s_2	0.3
l_2	19.8	w_4	0.9	d_2	2.8	w_9	1.8
w_2	0.9	l_5	20.9	w_7	1.8	g_1	0.2
l_3	22.5	w_5	0.5	s_1	0.2	g_2	0.2

0.5 dB and 0.8 dB, respectively, with the passband return loss better than 15 dB. Each resonator (Resonator I and Resonator II) acts as a cascaded triplet section [8], which can lead to one or two transmission zeros (TZs) at the upper skirt, shown in Fig. 5(b). Thus, three TZs are produced and clearly observed at 1.86 GHz, 3 GHz, and 3.54 GHz, which result in high selectivity. A photograph of the fabricated dual-wideband BPF is inserted in Fig. 5(c). The size of the filter is approximately 22.6 mm × 21.5 mm, that is, approximately $0.12\lambda_0 \times 0.11\lambda_0$ (λ_0 is the guided wavelength in the free space at the central frequency of the first passband). Figure 5(c) illustrates the group delays of the dual-wideband filter. The maximum group delay is 2.8 ns at the 1.57-GHz band and 1.5 ns at the 2.4-GHz band. The measured group delay is 2.5 ns at the 1.57-GHz band and 1.5 ns at the 2.4-GHz band, which is in agreement with the simulation. In this study, the circuit is simulated by Ansys HFSS 10 and measured by CETC AV3629.

Table 2 summarizes the comparison of the proposed filter with those reported in previous works. The presented dual-BPF has the following advantages: a compact size, independent control of passband bandwidths, and a wide band.

IV. Conclusion

In this letter, a triple mode resonator loaded with a T-shaped open-ended stub and a short-ended stub was introduced. Considering even and odd mode analysis, a synthesis method was developed to explain its triple mode characteristics. Based on the resonator, a compact dual-wideband BPF was designed and fabricated. The fractional bandwidths of two bands were

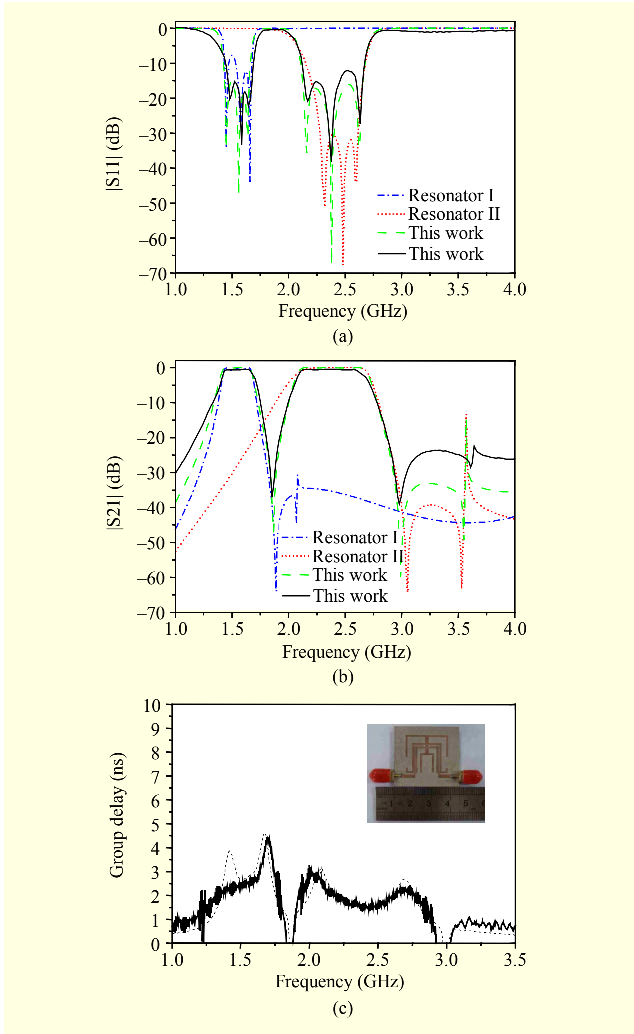

Fig. 5. Responses of designed dual-wideband BPF for (a) |S11|, (b) |S21|, and (c) group delays (simulation: dished line; measurement: solid line).

Table 2. Comparison between proposed filter and referenced filters.

Filter	1st/2nd passbands (GHz)	3-dB FBW (%)	A*	Circuit size ($\lambda_0 \times \lambda_0$)
[3]	1.0/1.2	4.2/4.5	No	0.13×0.14
[4]	1.575/2.4	6.0/3.8	No	0.16×0.11
[5]	2.0/3.1	5.3/5.7	No	0.45×0.48
[6]	1.68/2.81	8.1/6.8	No	0.13×0.10
This work	1.57/2.4	19.1/27.9	Yes	0.12×0.11

* independent control of passband bandwidth of 1st and 2nd passbands

19.1% for the first band (1.57 GHz) and 27.9% for the second band (2.4 GHz). The circuit possessed two wide passbands with controllable center frequencies and bandwidths. Three TZs were created to improve the selectivity and upper stopband performances. Agreement between the simulated and measured results demonstrated the validity of the proposed structure.

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