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COMPACT DUAL-MODE TRI-BAND MICROSTRIP BPF WITH THREE SETS OF RESONATORS

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Abstract—In this letter, a novel compact dual-mode tri-band microstrip bandpass filter (BPF) is proposed using three sets of dual-mode resonators, i.e., the quarter-wavelength resonator (QWR) which is designed for the first passband, and two sets of stub loaded resonators (SLR) for the second and third passband, respectively. The center frequencies and bandwidths of three passbands can be flexibly tuned and designed. Multiple transmission zeros can be generated to improve the selectivity. Meanwhile, the BPF can obtain more compact size by adopting the folded resonators and extended feed lines. Finally, a tri-band microstrip BPF prototype with fractional bandwidths 18.3% at 1.8 GHz, 5.5% at 3.6 GHz and 12.2% at 5.25 GHz is designed. The measured results are in good agreement with the full-wave simulation results.

1. INTRODUCTION

Multi-band multi-standard modern wireless communication systems have been gaining much attention in recent years [1–4]. These systems prefer multi-band transceivers to several single-band ones. In tri-band transceivers, tri-band BPFs are important building blocks and thus heavily demanded. In response to this need, much research has been conducted and various design approaches have been proposed [5–11]. In [5], tri-band filters with the Chebyshev and quasi-elliptic responses can be realised by the synthesis and design techniques. Another method to design tri-band filters is to use transmission zeros to split a single passband to three passbands. By adjusting

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the coupling matrix, two pairs of transmission zeros are introduced into the passband, thereby splitting the original single passband into three [6]. Nevertheless, this method calls for significant computational efforts, and the band assignment is limited in adjacent regions. For a typical design, two different resonators are used to realize the desired three passbands, such as the SIR and SLR, applying their multiband behaviours. The first and third passbands are generated by the first and second resonant modes of the stepped-impedance resonator (SIR) [7] or stub-loaded resonators (SLR) [8], and the second passband is created by the first resonant mode of an additional resonator. To reduce the circuit size, the tri-band BPF with good in-band and high selectivity can be designed using only one set of resonator [9]. However, the center frequencies and bandwidths of three passbands [7–9] could not be simultaneously conveniently adjusted. The tri-band microstrip BPFs [10, 11] with independently controlled center frequencies and bandwidths were designed by utilizing three sets of resonators. In [10], tri-band BPF using two $\lambda/4$ hairpin resonators designed to resonate at the first and second passband and one $\lambda/2$ hairpin resonator which resonates at the third passband. The specification of the triple passbands can be individually met, but it took too much space owing to its parallel-cascade structure. In [11], the feed structure of compact tri-band BPF realized independently by using three sets of resonators is combination of conventional parallel coupled-line feed and tap coupled-line feed. So, the total size was reduced compared with the BPF [10] using three sets of resonators.

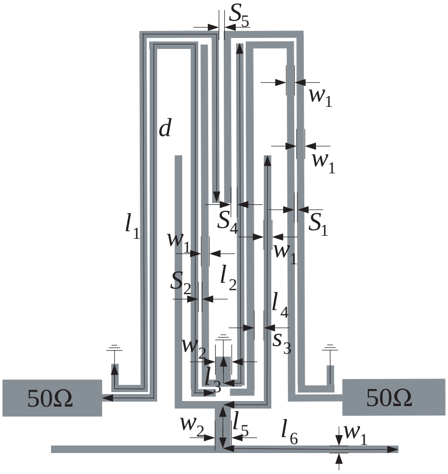


Figure 1. Configuration of the dual-mode tri-band microstrip BPF.

In this letter, a dual-mode tri-band microstrip BPF with compact size and high selectivity, as shown in Fig. 1, is proposed using three sets of dual-mode resonators, i.e., one QWR and two SLRs. The QWR is designed to resonate at the first passband, while the second and third passbands are generated by the short SLR and open SLR, respectively. Three passband performances can be easily adjusted by changing the dimensions of the corresponding resonators. Due to the intrinsic characteristics of the resonators, parasitic coupling and extended feed lines, multiple transmission zeros can be created to improve the selectivity. A tri-band BPF which can obtain more compact size by adopting the folded structure is designed at 1.8, 3.6 and 5.25 GHz. The measured results agree well with the simulated predictions.

2. COMPACT DUAL-MODE TRI-BAND MICROSTRIP BPF

As shown in Fig. 1, the proposed dual-mode tri-band microstrip BPF is composed of three sets of dual-mode resonators, i.e., one QWR and two SLRs, which are coupled to 50 Ω input/output extended coupling feed lines with length d and width w_1. The QWR in Fig. 2(a) is made up of two identical intercoupling short transmission lines with length l_1 and w_1. The short and open SLRs shown in Figs. 2(b) and (c) are formed by adding the short stub (l_3, w_2) and T-shape stub with two sections

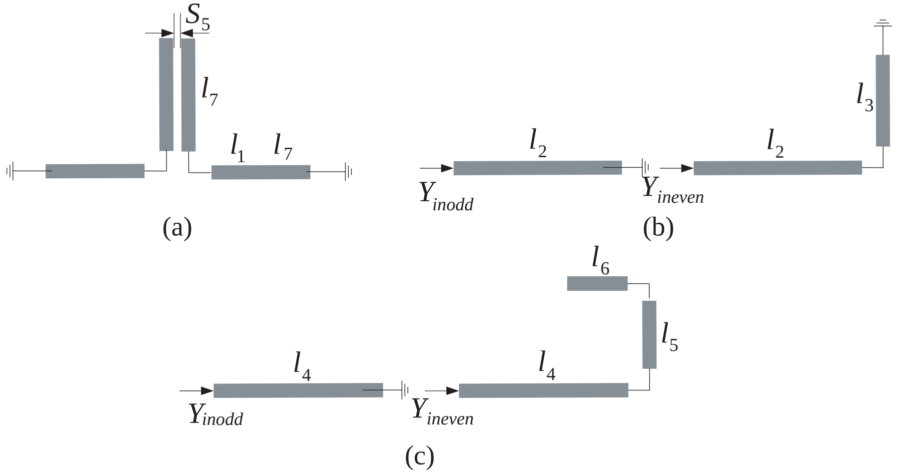


Figure 2. Schematic of three resonators: (a) QWR; (b) Short SLR; (c) Open SLR.

(l_5, w_2) and ($2l_6$, w_1) at the centre plane to the transmission lines with $2l_2$ and $2l_4$, respectively. The first and second passbands are obtained by the QWR and short SLR, respectively, while the third passband is independently generated by the open SLR. As explained in [12], the bandwidth of the filter with the QWR can mainly be adjusted by the coupling section (S_5, l_7). The centre frequency f_{01} can be expressed as:

$$f_{01} = c/(4\sqrt{\varepsilon_e} l_1) \tag{1}$$

where c is the speed of light and ε_e denotes the effective dielectric constant of the substrate.

Since the short and open SLR are symmetric, the analysis can be done based on the odd-even-mode method. The bandwidths of the filter with short and open SLRs can be flexibly tuned by the lengths l_3 and l_6, respectively. And the centre frequencies f_{02} and f_{03} can be

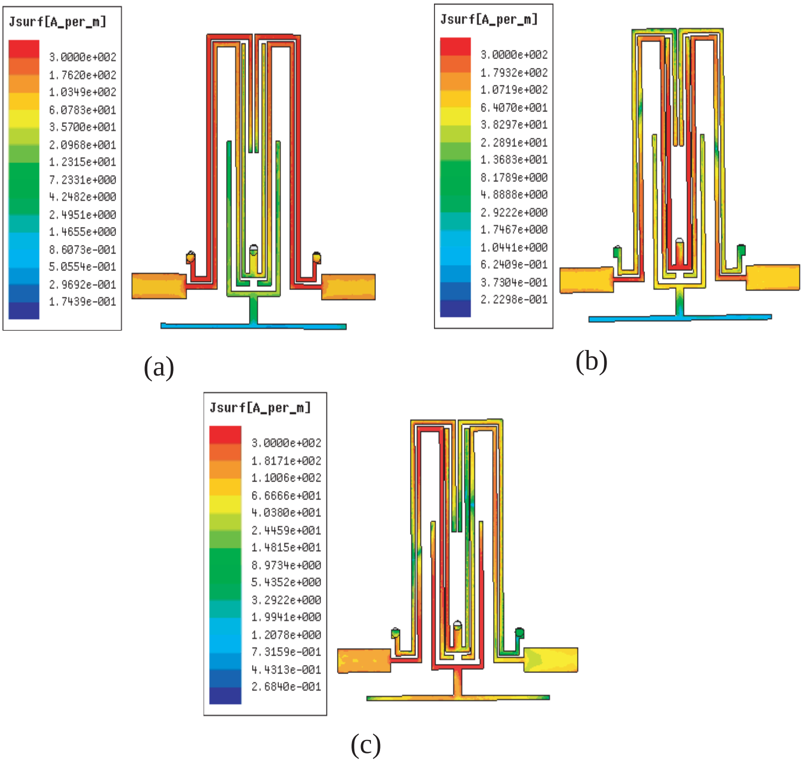


Figure 3. Current distributions of the tri-band filter with three resonators: (a) 1.8 GHz; (b) 3.6 GHz; (c) 5.25 GHz.

expressed as:

$$f_{2odd} = c/(4\sqrt{\varepsilon_e} l_2); \quad f_{2even} = c/(4\sqrt{\varepsilon_e}(l_2 + l_3)) \tag{2}$$

$$f_{02} = (f_{2odd} + f_{2even}) \tag{3}$$

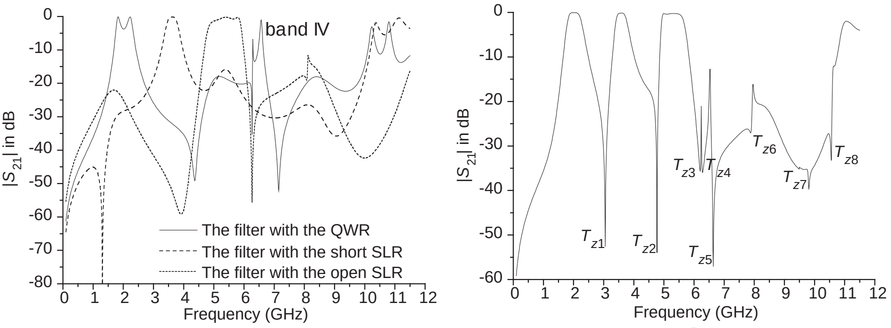
$$f_{3odd} = c/(4\sqrt{\varepsilon_e} l_4); \quad f_{3even} = c/(2\sqrt{\varepsilon_e}(l_4 + l_5 + l_6)) \tag{4}$$

$$f_{03} = (f_{3odd} + f_{3even}) \tag{5}$$

where f_{2odd} and f_{2even} are odd and even mode resonant frequencies of the short SLR; f_{3odd} and f_{3even} are odd and even ones of the open SLR.

The proposed tri-band BPF is to be designed on the RT/Duroid 5880 substrate with relative dielectric of 2.2 and thickness of 0.508 mm. Three passband centre frequencies are chosen to be at 1.8 GHz (f_{01}), 3.6 GHz (f_{02}) and 5.25 GHz (f_{03}), respectively, which are commercially practical in modern wireless communications application. Fig. 3 gives the current distributions at 1.8, 3.6 and 5.25 GHz of the tri-band filter with three resonators. Though the plots, we can see that the current at 1.8, 3.6 and 5.25 GHz mainly distributes at the QWR, short SLR and open SLR, respectively. So it can further be verified that the EM waves are transmitted in the filter from port 1 to port 2 and each passband can basically be implemented individually.

Under the feed lines in Fig. 1 unchanged, the filter with one resonator is simulated without two other resonators. From the Fig. 4(a), the first spurious band (band IV) of the QWR appears at $3.28 f_{01}$, the presented BPF can be applied to design tri-band location with f_{03}/f_{01} less than 3. Fig. 4(b) gives the $|S_{21}|$ in dB of the filter with three resonators. The simulated 3 dB fractional bandwidths of the



(a) (b)

Figure 4. (a) The $|S_{21}|$ in dB of the filters with the QWR, short SLR and open SLR, respectively; (b) The $|S_{21}|$ in dB of the filter with three resonators.

first and second passbands can be broadened for the mutual coupling between the QWR and short SLR strengthen the coupling between the resonators and feed lines. Based on the odd-even-mode method, the transmission zeros T_{z1} and T_{z7} can be generated by Resonator II due to f_{even} lower than f_{odd}. For f_{odd} lower than f_{even}, the transmission zero T_{z5} can be generated by Resonator III. As explained in [12, 13], the transmission zeros T_{z2} and T_{z6} can be generated by the long feed lines. The transmission zeros T_{z3} and T_{z8} can be generated by the coupling between two transmission lines of Resonator I. An additional transmission zero T_{z4} is excited by the parasitic coupling between Resonator I and Resonator II. As can be seen from the Fig. 4(b), the band IV can be suppressed by the transmission zeros T_{z3}, T_{z4} and T_{z5}. The transmission zeros T_{z1} and T_{z2} can be designed to isolate the first and second passbands and the second and third passbands, respectively. The transmission zeros T_{z6}, T_{z7} and T_{z8} can be used to deepen the upper-stopband. Meanwhile, more compact units can be obtained by the folded resonators and feed lines in Fig. 1.

3. EXPERIMENTAL RESULTS

The previously designed dual-mode tri-band microstrip BPF at 1.8, 3.6 and 5.25 GHz is fabricated on the same substrate as mentioned in the above section, and its photograph is shown in Fig. 5. After simulation and optimization by HFSS, the dimensions of the tri-band BPF are listed in Table 1. The simulated and measured responses are compared in Fig. 6 and both of them are found to be in very reasonable agreement with each other. In the triple passbands, the measured 3 dB fractional

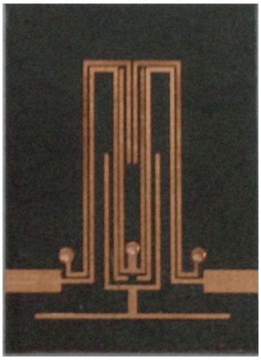


Figure 5. Photograph of the implemented tri-band microstrip BPF.

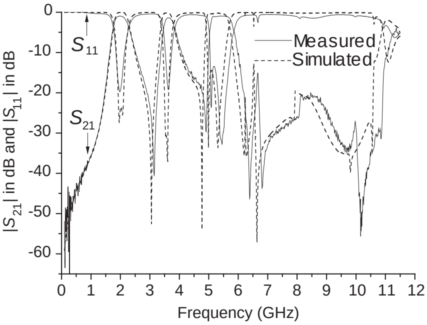


Figure 6. Simulated and measured frequency responses of the tri-band microstrip BPF.

Table 1. Dimensions of fabricated prototype (UNIT: mm).

Parameter	l_1	l_2	l_3	l_4	l_5	l_6
Value	28.37	15.3	1.5	11.45	2.0	6.85
Parameter	l_7	w_1	w_2	s_1	s_2	s_3
Value	7.0	0.3	0.6	0.15	0.1	0.35
Parameter	s_4	s_5	d			
Value	0.22	0.16	34.5			

bandwidths are about 18.3% at 1.8 GHz, 5.5% at 3.6 GHz and 12.2% at 5.25 GHz, with measured minimum insertion losses are −3 dB and the passband return loss better than −10.1 dB. Two transmission zeros T_{z1}, T_{z2} are located at 3.15 GHz and 4.91 GHz resulting in high isolation between adjacent bands, with an attenuation level of less than −30 dB. The insertion loss of the upper stopband in the great mass of range from 6.7 to 10.91 GHz is better than 20 dB. In addition, the total size is only $0.171\lambda_g \times 0.231\lambda_g$ in which λ_g is the guided wavelength of 50 Ω microstrip line at 1.8 GHz.

4. CONCLUSION

A compact dual-mode tri-band microstrip BPF has been proposed in this letter. The tri-band performance is realized independently by using three sets of dual-mode resonators. Multiple transmission zeros can be generated to improve the selectivity. The design methodology has been described and a demonstration BPF has been implemented with fractional bandwidths 18.3%, 5.5% and 12.2% at 1.8, 3.6 and 5.25 GHz. The total size is only $0.171\lambda_g \times 0.231\lambda_g$ in which λ_g is the guided wavelength of 50 Ω microstrip line at 1.8 GHz. The good performance and compact structure make it attractive for multi-band applications in future communication systems.

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