Progress In Electromagnetics Research Letters, Vol. 41, 105–112, 2013

COMPACT STEP-IMPEDANCE RING RESONATOR FOR QUAD-BAND BAND-PASS FILTER

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Abstract—A compact quad-band microstrip band-pass filter (BPF) based on novel step-impedance ring resonator (SIRR) is investigated in this paper. The proposed BPF is composed of one ring resonator and input/output coupled structure. The novel resonator is studied and employed to generate four desired independent passbands. A compact quad-band BPF centered at 1.57, 2.45, 3.5 and 5.2 GHz is designed and fabricated. The predicted results are compared with measured data, and good agreement is reported.

1. INTRODUCTION

With the rapid development of modern wireless technologies, multi-service wireless communication systems have been gaining much attention, such as the applications of Wireless Local Area Network (WLAN), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) and global positioning system (GPS). Therefore, multi-band bandpass filters (BPFs) have been investigated aggressively to satisfy the newly developed multi-service system and the commercial products. Multi-mode ring resonators, step-impedance resonators (SIRs) and stub-loaded resonators (SLRs) are popular for the design of multi-band BPF [1–11]. However, most previous work mainly focused on the design of dual-band and tri-band BPFs. In [1, 2], dual-band BPFs are achieved based on folded SIR for WLAN application. In [3], SLRs are used to realize the dual-band performance. In [4], a pair of asymmetric SIRs with parallel coupling arrangement is obtained to realize the tri-band responses. Very recently, the quad-band BPF used as an essential component in the quad-band operation

Received 4 June 2013, Accepted 6 July 2013, Scheduled 10 July 2013
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system has received attention. Nevertheless, only few methods for quad-band BPFs have been explored and reported in the past few years. In general, the reported design methods for quad-band BPFs can be classified into four typical methods. The first method is to introduce transmission zeros to separate dual-band into quad-band [12], which is not applicable when the two passbands are far away. The second method is to combine multi resonators to fabricate a quad-band BPF [13, 14]. However, this method not only increased the device volume but also required additional matching circuits and feed structure. The third method is based on multi-layered structure, which reduces the circuit size effectively, while suffers from the design complexity and causes a complex integration in packaging [15]. The last method is based on single quad-mode resonator [16]. Among these design methods, the last method is simple and only introduces single type of resonator, which resulting in compact configuration. Therefore, the design method based on single resonator is worthy of investigating mostly.

Based on a novel ring resonator, a compact band-pass filter with quad-band characteristics is designed, fabricated, and measured in this paper. The proposed step-impedance ring resonator (SIRR) can introduce four desired passbands located at GPS (1.57 GHz), WLAN (2.45/5.2 GHz) and WiMAX (3.5 GHz) simultaneously. The good agreement between the simulated and measured results verifies the proposed design principle.

2. ANALYSIS AND DESIGN

2.1. Conventional Ring Resonator

Figure 1 shows the structure of the conventional ring resonator. For a single ring, when the circumference of the ring equals to an integral multiple of the guided wavelength, the resonance is established, as follows:

$$l = n\frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} = 2(a+b) \quad (\text{for mode } n = 1, 2, 3, \ldots) \tag{1}$$

where l is the circumference of the ring, λ_0 the wavelength in free space, and ε_{eff} the effective dielectric constant. Thus, the resonant frequencies can be represented as:

$$f_n = \frac{nc}{2\,(a+b)\,\sqrt{\varepsilon_{eff}}} \quad (\text{for mode } n = 1, 2, 3, \ldots) \tag{2}$$

where c is the velocity of light in free space.

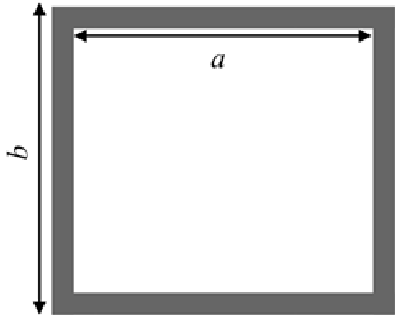


Figure 1. Geometry of conventional ring resonator.

2.2. Step-impedance Ring Resonator

Figure 2(a) shows the structure of the proposed step-impedance ring resonator (SIRR), which consists of a common ring resonator with two small rings on both sides. Since the ring resonator is symmetrical, the odd-even-mode method can be implemented. Under odd- or even-mode excitation at the two ports, the symmetrical plane T-T' becomes a perfect electricwall (E. W.) or magneticwall (M. W.). The even- and odd-mode equivalent circuit is shown in Figs. 2(b) and (c).

The transfer characteristics of the proposed SIRR with various dimensions are studied by HFSS 13.0, as shown in Fig. 3. It can

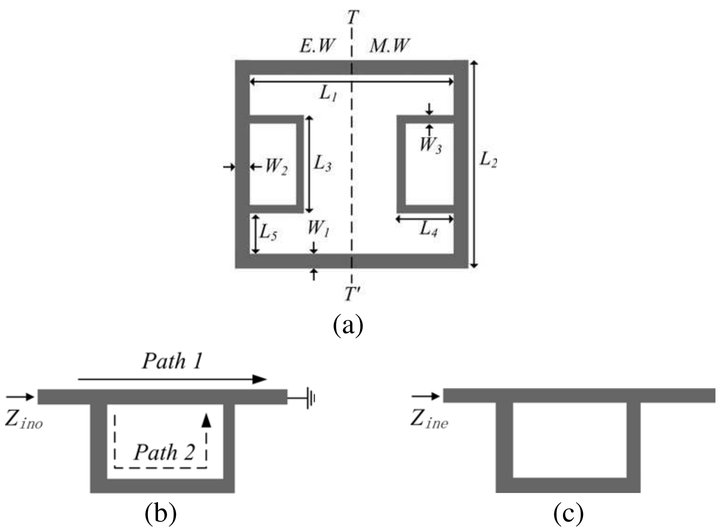


Figure 2. Geometry and equivalent circuit of the proposed SIRR. (a) Geometry. (b) Odd-mode equivalent circuit. (c) Even-mode equivalent circuit.

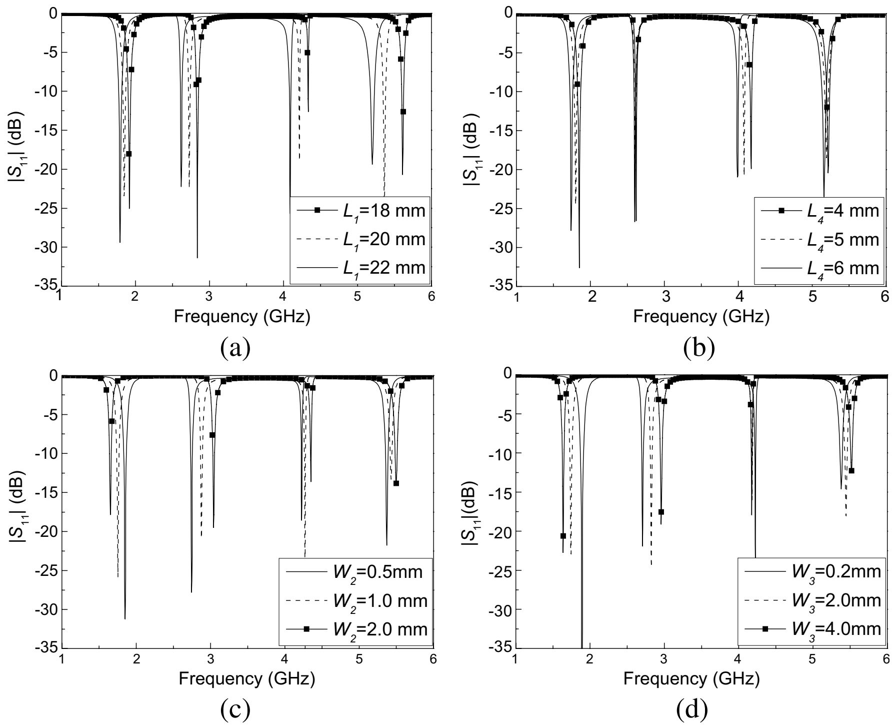


Figure 3. Simulated S-parameters of the proposed ring resonator for various dimensions. (a) L_1. (b) L_2. (c) L_3. (d) L_4.

be seen that the four resonant frequencies increase simultaneously as L_1 decreases. And the second and third resonant frequencies keep invariant as L_4 and W_3 decrease, respectively. But the change trend of first resonant frequency is opposite to that of other resonant frequencies as W_2 and W_3 change. Therefore, by appropriately adjusting the resonator dimensions, four desired resonant frequencies can be achieved.

2.3. Quad-band BPF

Figure 4 shows the geometry of the proposed quad-band BPF, which is composed of one SIRR and two coupled I/O ports. In order to reduce filter size, the SIRR is folded. Two rectangular DGSs are introduced to increase the coupling between the I/O port and ring resonator, which can improve passband performance. The substrate is RT/Duroid 5880 with the thickness of 1.0 mm and the dielectric constant of 2.2. All

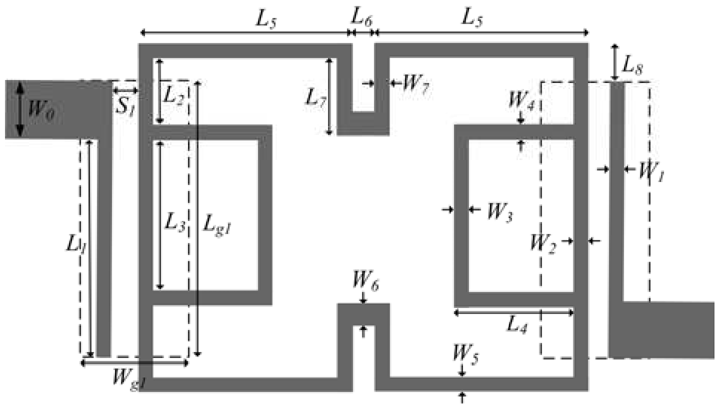
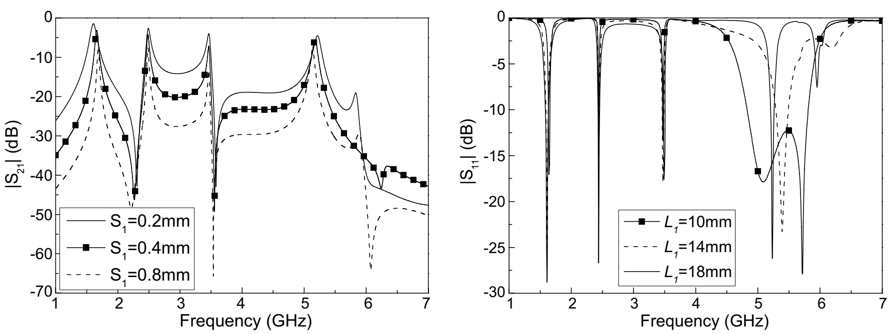


Figure 4. Configuration of the proposed quad-band BPF.



(a) (b)

Figure 5. Simulated bandwidth of the proposed SIRR for various dimensions.

the dimensions are selected as follows: $W_0 = 3.0\,\text{mm}$, $W_1 = W_4 = W_5 = W_7 = 0.5\,\text{mm}$, $W_2 = W_3 = 1.0\,\text{mm}$, $W_6 = 3.5\,\text{mm}$, $L_1 = 15\,\text{mm}$, $L_2 = 3.25\,\text{mm}$, $L_3 = 11.5\,\text{mm}$, $L_4 = 6.0\,\text{mm}$, $L_5 = 11.0\,\text{mm}$, $L_6 = 0.5\,\text{mm}$, $L_7 = 8.0\,\text{mm}$, $L_8 = 1.0\,\text{mm}$, $S_1 = 0.15\,\text{mm}$, $L_{g1} = 11.0\,\text{mm}$, $W_{g1} = 3.0\,\text{mm}$. As for bandwidth control, the external quality factor (Q_e) and coupling coefficient (k) should be considered. The Q_e and K are determined by the length of the feed lines and the gaps between the feed lines and resonator as shown in Fig. 5.

3. RESULTS AND DISCUSSION

Finally, the designed quad-band BPF is measured with an Agilent N5230A vector network analyzer. As shown in Fig. 6, the measured centre frequencies and 3 dB fractional bandwidths of the proposed filter are: 1.57 GHz (FBW = 6.9%), 2.45 GHz (FBW = 3.4%), 3.5 GHz (FBW = 2.9%), and 5.2 GHz (FBW = 4.7%), as expected. The measured minimum insertion losses are 0.78/1.45/2.3/1.42 dB, respectively, while the return losses of each passband are better than −12 dB. In addition, the proposed quad-band bandpass filter can generate transmission zeros with a better than 10 dB suppression degree on both sizes of the passbands, which give much improved selectivity. The overall filter size is about 26 mm × 38 mm, as shown in Fig. 7. The comparison with other reported quad-band BPFs is shown in Table 1, which depicts that the proposed BPF has good characteristics with compact size.

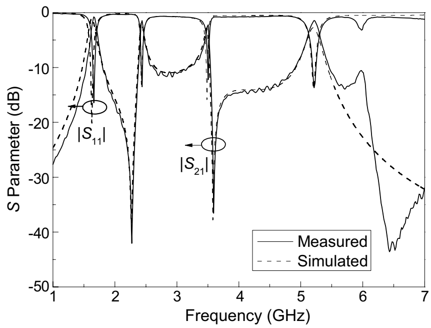


Figure 6. Simulated and measured S-parameters of the designed quad-band BPF.

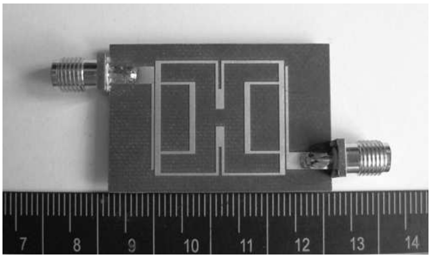


Figure 7. Photograph of the fabricated quad-band BPF.

Table 1. Comparison with some recently reported BPFs.

	Ref. [13]	Ref. [14]	Ref. [17]	Our work
Substrate Height (mm)/ε_r	1.0/27.9	0.787/2.2	0.508/3.55	1.0/2.2
Passbands (GHz)	1.57/2.45/ 3.5/5.2	2.4/3.5/ 5.2/6.8	1.5/2.5/ 3.6/4.6	1.57/2.45/ 3.5/5.2
Insertion loss (dB)	0.31/0.32/ 0.31/0.78	0.5/1.3/ 1.3/1.0	1.98/1.74/ 3.58/3.4	0.78/1.45/ 2.3/1.42
3-dB FBW (%)	9.55/31.84/ 11.1/15.96	6.4/9.4/ 3.8/4.9	5.5/12/ 11/4.3	6.9/3.4/ 2.9/4.7
size(mm^2)/ ($\lambda_g \times \lambda_g$)	260/ 0.5×0.2	480/ 0.3×0.3	2000/ 0.3×0.3	988/ 0.2×0.3

4. CONCLUSION

In this work, a compact quad-band BPF is proposed and investigated through the EM simulation and experiment. The predicted results are compared with measured data, and good agreement is reported. Due to its simple structure, compact size and good performance, the proposed BPF is attractive for GPS, WiMAX and IEEE 802.11a applications.

ACKNOWLEDGMENT

This work was supported by the fundamental research funds for the Central Universities (K50511020013), the National Natural Science Foundation of China under Grant 61101069 and the China Scholarship Council.

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