Tri-band bandpass filter using square ring short stub loaded resonators

M.T. Doan, W.Q. Che and W.J. Feng

A tri-band bandpass filter (BPF) using square ring short stub loaded resonators (SRSLR) is presented. The characteristics of the triple-mode resonator are investigated by using even/odd mode analysis. The centre frequencies of the first three passbands can be independently controlled by tuning the dimensions of the SRSLR. Moreover, the filter has been implemented with eight transmission zeros to improve the selectivity. A prototype of a tri-band BPF centred at 2.4, 3.5 and 5.2 GHz has been designed and fabricated. Good agreement can be found between the measured and simulated results.

Introduction: Tri-band bandpass filters (BPFs) with high performance are essential in the design of transmitters and receivers for microwave communication systems. In response to this need, various design approaches have been proposed. The tri-band BPFs can be constructed using tri-section stepped-impedance resonators (SIRs), such as the ones in [1, 2]. Although these structures are relatively complicated because the resonant frequencies of an SIR are dependent, the three passbands at any desired frequencies can be obtained. Another widely used method to design tri-band filters is the stub loaded resonator (SLR) [3, 4]. The three desired frequencies can be conveniently controlled by tuning the lengths of half-wavelength resonator, open/short-stub [3], open-loaded and half-wavelength resonators [4]. Recently, the square ring loaded resonator (SRLR) has been successfully proven in the design of a tri-band filter [5]. The SRLR can generate a tri-band response by tuning its geometric parameters and realise the high-order tri-band. However, for this structure difficult tuning of centre frequencies and the selectivity needs to be improved. In this Letter, a new SRSLR is introduced for the design of tri-band filters. The passband frequencies can be conveniently tuned to the desired values by controlling the corresponding resonator dimensions. Furthermore, a new coupling structure is introduced to produce eight transmission zeros at the adjacent three passbands and sharp passband skirts of the BPF have been observed.

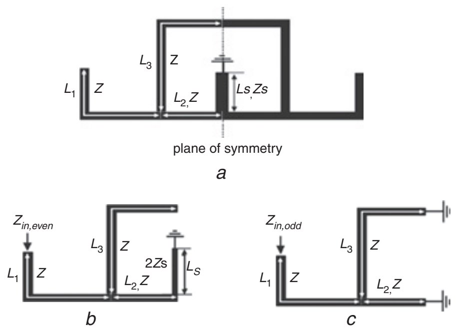

Fig. 1 *Layout of square ring short stub loaded resonators*

a SRSLR
b Even-mode equivalent circuit
c Odd-mode equivalent circuit

Proposed square ring short stub loaded resonator: Fig. 1*a* shows the layout of the proposed SRSLR. It consists of two open folders, a square ring and a short-stub, where (L_1, Z), ($2(L_2 + L_3)$, Z) and (L_s, Z_s) are the lengths and the characteristic impedances of the open folder, square ring and short-stub, respectively. The resonator is symmetrical and thus even- and odd-mode analysis can be used. From the resonance condition ($Y_{in} = 0$), when the even-mode (Fig. 1*b*) is excited, two resonant frequencies can be obtained as follows:

$$f_{even1} = \frac{c}{4(L_1 + L_2 + L_s)\sqrt{\varepsilon_e}}, \quad f_{even2} = \frac{c}{2(L_1 + L_3)\sqrt{\varepsilon_e}} \tag{1}$$

where c is the light speed in free space, and ε_e denotes the effective dielectric constant of the substrate. For odd-mode (Fig. 1*c*), the resonant frequency can be obtained as:

$$f_{odd1} = \frac{c}{4(L_1 + L_2)\sqrt{\varepsilon_e}} \tag{2}$$

Equation (1) is based on the special case of $Z = 2Z_s$. From (1) and (2), when $L_s > 0$ and $L_3 < L_1 + 2L_2$, we can obtain $f_{even1} < f_{odd1} < f_{even2}$. Thus, the first three resonant frequencies of the proposed SRSLR could be controlled by tuning L_1, L_2, L_3 and L_s. Fig. 2 shows the EM simulated frequency responses of the SRSLR. In Fig. 2*a*, by changing the short-stub length L_s, the first passband frequency f_{even1} can be shifted within a wide range, when the f_{odd1} is fixed, meanwhile f_{even2} varies a little. Fig. 2*b* shows the simulated insertion loss of the filter for cases of different length L_3, the third passband f_{even2} can be shifted within a wide range, when f_{even1} and f_{odd1} are fixed. According to (1) and (2), the first resonant frequency is determined by L_1, L_2, and L_s, the second resonator frequency is determined by L_1 and L_2, and the third resonant frequency is determined by L_1 and L_3. So in the filter design, to obtain the desired passband frequencies, f_{odd1} can be determined by adjusting the length of L_1 and L_2 then f_{even1} can be controlled simply by tuning the length of L_s, and f_{even2} can be determined by adjusting the length of L_3.

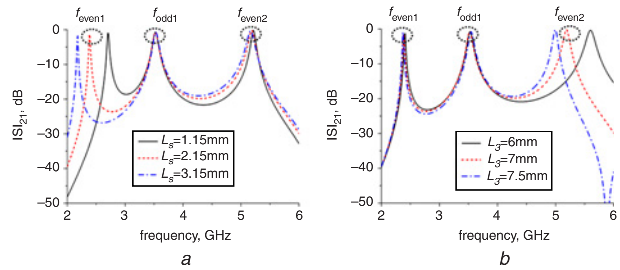

Fig. 2 *Simulated insertion loss of SRSLR under weak coupling with different L_s and L_3*

a L_s
b L_3

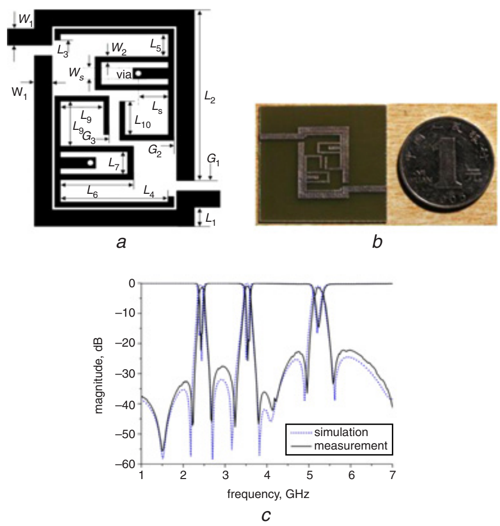

Fig. 3 *Layout of tri-band BPF (Fig. 3a), photograph of tri-band BPF (Fig. 3b) and simulated and measured results of tri-band BPF*

$W_1 = 1.5$, $W_2 = 0.5$, $W_s = 1$, $L_1 = 1.7$, $L_2 = 15.3$, $L_3 = 0.5$, $L_4 = 9$, $L_5 = 2$, $L_6 = 6.1$, $L_7 = 2$, $L_8 = 4$, $L_9 = 3.6$, $L_{10} = 3.1$, $G_1 = 0.9$, $G_2 = 0.2$, $G_3 = 0.9$, and via diameter is 0.5 (all in mm)

Tri-band bandpass filter design and result: Based on the SRSLR, a tri-band BPF has been designed on a substrate with $\varepsilon_r = 4.4$ and $h = 0.8$ mm. The layout of the proposed filter is shown in Fig. 3*a*; it consists of two SRSLR, and an *L*-shaped feed structure is used. In addition, to improve the selectivity of the filter, the skew-symmetrical 0° feeding structure [6] is introduced to achieve extra transmission zeros in the stopband. To verify the proposed approach, one prototype of tri-band BPF at 2.4, 3.5 and 5.2 GHz has been fabricated. The prototype photograph is shown in Fig. 3*b*, and the measured and simulated results are illustrated in Fig. 3*c*. The measured 3 dB fractional bandwidths for the three passbands (2.4, 3.5 and 5.2 GHz) are found to be 5%, 3.7% and 4.2%, respectively. The measured minimum insertion losses including the loss from SMA connectors are 1.2, 1.1, and 1.5 dB, while the return losses are greater than 16.5, 18 and 14.5 dB, respectively. Eight transmission zeros are created at 1.51, 2.21, 2.69, 3.2, 3.79, 4.15, 4.94 and 5.58 GHz. Six transmission zeros are generated near the passband edges, resulting in sharp roll-off. Meanwhile, good stopband rejection is achieved by another two transmission zeros.

Conclusions: A compact tri-band BPF (2.4, 3.5 and 5.2 GHz) using new SRSLR is proposed. The centre frequencies of the three passbands can be independently controlled and eight transmission zeros are realised at the adjacent three passbands, resulting in very high selectivity. The simple topology, compact size and high selectivity make the proposed tri-band filter attractive for multiband wireless communication systems.

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One or more of the Figures in this Letter are available in colour online.

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