Tri-band Bandpass Filter Using Dual-mode Resonators

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Abstract—**This letter presents a compact tri-band bandpass filter (BPF) with controllable bandwidths. The proposed filter employs dual-mode resonators, i.e., crossed open-short stub loaded resonators and tri-section stepped impedance resonators. The center frequencies and bandwidths of the three passbands can be conveniently controlled by tuning the dimensions of two resonators. Moreover, on each side of each passband, there is at least one transmission zero, resulting in high skirt selectivity. To validate the design and analysis, a prototype of tri-band BPF is fabricated. Good agreement can be found between the measured and simulated results.**

***Index Terms*—Tri-band bandpass filter, Crossed open-short stub loaded resonators, Stepped impedance resonators.**

I. INTRODUCTION

Multi-band wireless communication systems have been gaining much interest in recent years. The 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 [1-3], although these structures are relatively complicated due to resonant frequencies of 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) [4-7]. The three desired frequencies can be conveniently controlled by tuning the lengths of half-wavelength resonator, open/short-stub [4] and [5], open-loaded/half-wavelength resonator [6], open-loaded/quarter-wavelength resonator [7]. Recently, a novel class of compact dual-mode triple-band BPFs based on a single microstrip ring resonator has been presented [8], the square ring loaded resonator (SRLR) [9]. The SRLR can generate a tri-band response by tuning its geometric

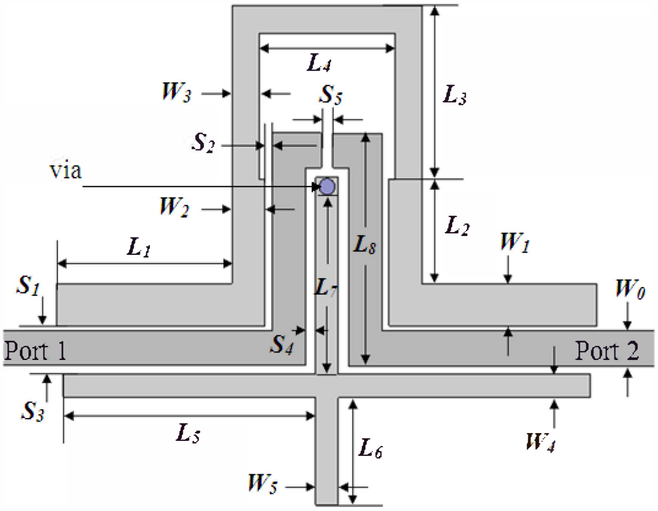

Fig. 1 layout of proposed tri-band filter

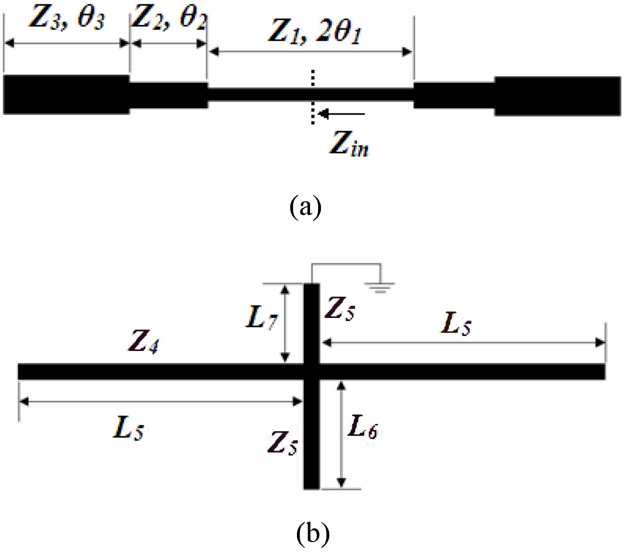

Fig. 2 (a) Geometry of the tri-section stepped-impedance resonators (resonator *a*)
(b) Geometry of the crossed open-short stub loaded resonators (resonator *b*)

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parameters and realize the high-order tri-band. However, for these structure difficult controllable bandwidths and the selectivity needs to be improved. In [10], the short-stub loaded half-wavelength resonator and stepped impedance resonator have been successfully proven in the design of two dual-band filter, and multiple transmission zeros are created to improve the selectivity of filter.

In this letter, dual-mode resonators, i.e., crossed open-short stub loaded resonators and tri-section stepped impedance resonators are used to design tri-band filter with controllable bandwidths. The passband frequencies and bandwidths can be tuned to desired values by controlling the corresponding resonator dimensions. Furthermore, multiple transmission zeros are created to improve the selectivity of the filter. Thus, sharp passband skirts of the BPF have been observed.

II. ANALYSIS AND DESIGN OF PROPOSED FILTER

A *Characteristic of the Resonators*

Figure 2(a) shows the geometry of the tri-section stepped-impedance resonators (SIR) (resonator *a*) considered in this letter. The SIR is symmetrical and has three different characteristic impedances Z_1, Z_2 and Z_3, while θ_1, θ_2 and θ_3 represent the corresponding electrical lengths. According to the three expression (1), (3) and (5) has given in [1] the first three resonant frequencies (namely f_{1a}, f_{2a}, and f_{3a},) can be obtained by properly determining the impedance ratio and electric lengths.

The geometry of the crossed open-short stub loaded resonators (resonator *b*) as shown in Figure 2(b). It comprises a common microstrip half-wavelength resonator, a short stub and an open stub, where Z_4 and Z_5 denote the characteristic impedances of the microstrip lines, and $2L_5$, L_6 and L_7 denote the lengths of half-wavelength resonator, open stub and short stub, respectively. From expression (1), (2), and (3), has given in [4], the first three resonant frequencies (namely f_{1b}, f_{2b}, and f_{3b},) can be obtained by tuning the dimensions of the half-wavelength, open-stub, and short-stub loaded resonator. In this design, the resonant frequencies in the first passband of the filter are f_{1a} and f_{1b}, in second passband are f_{2a} and f_{2b}, and in third passband are f_{3a} and f_{3b}, as shown in Figure 3.

B *Control of Bandwidths*

To achieve the required bandwidth for the three passbands, tuning of the coupling dimensions of the proposed filter is necessary. The bandwidth is determined by the coupling coefficients k_i (i=1, 2, 3) and external quality factor Q_{ei} (i=1, 2, 3). In this case, coupling coefficients k_i of the three passbands

can be determined by solving the following as:

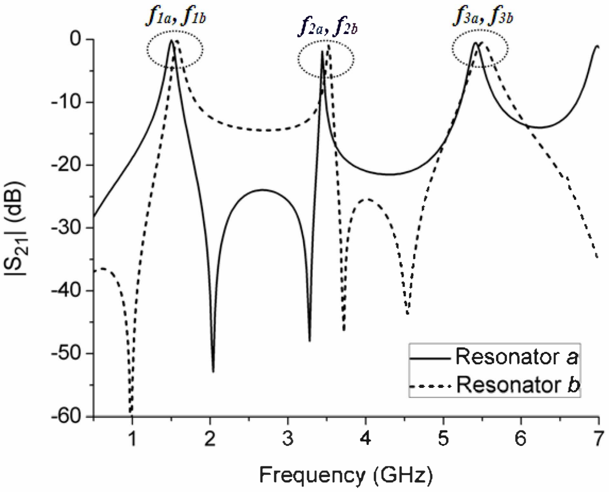

Fig. 3 Simulated insertion loss of dual-mode resonators under the weak coupling

$$k_1 = \left| \frac{f_{1a}^2 - f_{1b}^2}{f_{1a}^2 + f_{1b}^2} \right|, \quad f_1 = (f_{1a} + f_{1b})/2 \qquad (1)$$

$$k_2 = \left| \frac{f_{2a}^2 - f_{2b}^2}{f_{2a}^2 + f_{2b}^2} \right|, \quad f_2 = (f_{2a} + f_{2b})/2 \qquad (2)$$

$$k_3 = \left| \frac{f_{3a}^2 - f_{3b}^2}{f_{3a}^2 + f_{3b}^2} \right|, \quad f_3 = (f_{3a} + f_{3b})/2 \qquad (3)$$

Where f_1, f_2, and f_3 are the central frequencies of the first three passbands of this filter. From (1)-(3), we can see that the coupling coefficients of the three passbands can be controlled to desired values by tuning separately between the dual-mode resonators according to the previous six resonant frequencies, saying, Z_1, Z_2, Z_3, θ_1, θ_2, θ_3 (resonator *a*) and Z_4, Z_5, L_5, L_6, L_7 (resonator *b*) need to be optimized. Moreover, the resonant frequencies of each mode resonators can be independently controlled. Thus, the coupling coefficients of three passbands can be realized simultaneously.

When the dimensions of two resonators are fixed, and W_0 pre-selected to be 1.5 mm (which corresponds to 50 Ω), the external quality factors Q_{e1} at the first passband depend on the coupling space S_1, S_2, S_3, and S_4, while Q_{e2} and Q_{e3} at the second and third passband mainly depend on the coupling space S_1, S_2, and S_3. The variation of the coupling space S_4 only affects Q_{e1} but has no effect on Q_{e2} and Q_{e3} . This is because there is no energy in the short circuited stub when crossed open-short stub loaded resonators is resonating at frequency f_2, and f_3.

C Tri-band Filter Design

Based on the above analysis, the proposed new compact tri-band BPF with center frequencies of passband at 1.54, 3.5 and 5.4 GHz is designed on a substrate with ε_r = 4.4 and h = 0.8 mm. The layout of the proposed filter is shown in Figure 1; it consists of a crossed open-short stub loaded resonators and a tri-section stepped impedance resonators. In addition, to improve the selectivity of filter, the feeding structure [10], is introduced to achieve six transmission zeros in three passbands. The signal is coupled to two resonators at the same time, providing two main paths for the signal between the source and load, and no coupling between resonators is introduced. In each band, two resonators operate at an even and odd resonance, respectively. Thus, two transmission zeros at near the each passband edges occurs because of the cancellation of the transmitted signals going through two different paths [11]. Thus, the passband selectivity improvement.

After optimization using Ansoft HFSS 10.0, the design parameters are obtained as follows: W_0 = 1.5, W_1 = 1.82, W_2 = 1.45, W_3 = 1.21, W_4 = W_5 = 1, L_1 = 7.8, L_2 = 4.48, L_3 = 7.5, L_4 = 5.98, L_5 = 11.1, L_6 = 4.62, L_7 = 7.85, L_8 = 10, S_1 = 0.2, S_2 = 0.3, S_3 = 0.37, S_4 = 0.45, S_5 = 0.5, and via diameter is 0.5 (all in mm).

III. MEASURED RESULTS AND DISCUSSIONS

To verify the proposed approach, one prototype of tri-band BPF with sharp passband skirts is fabricated. The fabricated tri-band BPF with size is about $0.2\lambda_g$ x $0.23\lambda_g$, where λ_g is the guided wavelength of the microstrip line at the center frequency of first band. Thus, it is very compact. The prototype photograph is shown in Figure 4, and the measured and simulated results are illustrated in Figure 5. The measured 3-dB fractional bandwidth for the three passbands (1.56, 3.52 and 5.42 GHz) are found to be 120/141/140 MHz, respectively. The measured minimum insertion losses including the loss from SMA connectors are 1, 1.2, and 1.65 dB, while the return losses are greater than 20.5, 20 and 15.5 dB, respectively. Six transmission zeros with an attenuation level of more than 35 dB are created at 1.28, 1.72, 3.26, 3.71, 4.96 and 6.34 GHz. They are generated near the passband edges, resulting in sharp roll-off.

Fig. 4 Photograph of the proposed wideband BPF

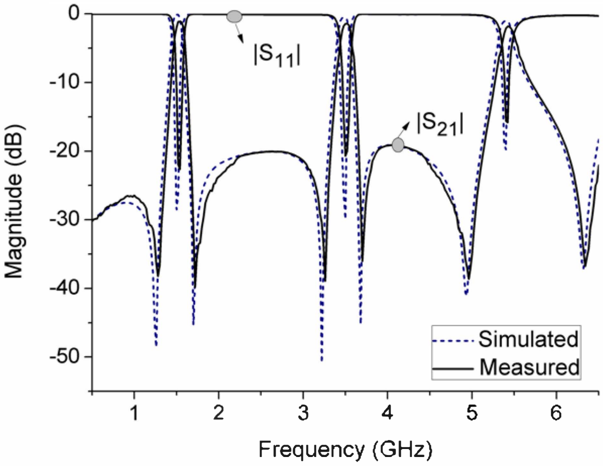

Fig. 5 Simulated and measured results of the proposed wideband BPF

IV. CONCLUSION

A new compact tri-band BPF using dual-mode resonators is proposed. The center frequencies and bandwidths of the three passbands can be conveniently controlled by tuning the dimensions of dual-mode resonators. Furthermore, the filter designed with six transmission zeros are realized 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 multi-band wireless communication systems.

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