Tri-band Bandpass Filter Using Two Short Stubs and An Open Stub Loaded Resonator

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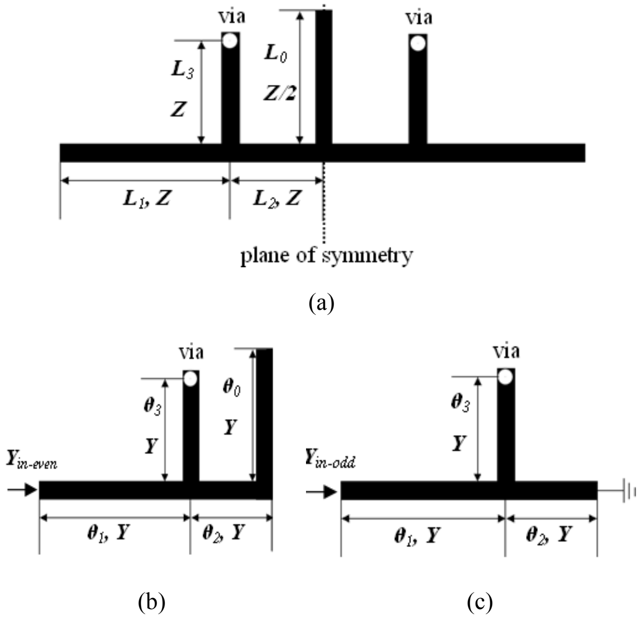
***Abstract*—A tri-band bandpass filter (BPF) using two short stubs and an open stub loaded resonators is presented. The classical even-/odd-mode method is applied to analyze the characteristics of the proposed resonator, which shows that it has two pairs of symmetrical resonant modes. The center frequencies of the first and the third passband can be flexibly controlled by tuning the dimensions of two short stubs and an open stub, whereas the second passband frequency is fixed. To verify the proposed approach, a prototype of tri-band BPF centered at 1.57, 2.4 and 3.95 GHz is designed and fabricated. Measured results agree well with simulated ones.**

Index Terms—Tri-band bandpass filter, open stub and short stub loaded resonator.

I. INTRODUCTION

Multi-band wireless communication systems have been gaining much interest in recent years. The tri-band bandpass filters (BPFs) has become one of the most important in the design of transmitters and receivers for microwave communication systems. Many different methods on designing tri-band BPFs have been explored and reported. A widely used method to design tri-band filters is to utilise the tri-section stepped-impedance resonators (SIRs) [1]-[3]. Although these structures are relatively complicated because resonant frequencies of SIR are dependent, the three passbands at any desired frequencies can be obtained. Another used method to design tri-band filters is the stub loaded resonator (SLR), and employs two sets of resonators. The three desired frequencies can be conveniently controlled by tuning the lengths of half-wavelength resonator, open/short-stub [4], open-loaded and half-wavelength resonator [5]. Recently, the square ring loaded resonator (SRLR) [6] and square ring short stub loaded resonator (SRSLR) [7-8] have been successfully proven in the design of the tri-band filters. The SRLR can generate a tri-band response by tuning its geometric parameters. However, for this structure difficult tuning of center frequencies. By embedded a short stub loaded, the center frequencies of the first three passbands can be independently controlled by tuning the dimensions of SRSLR.

In this paper, a new resonator using two short stubs and an open stub loaded is introduced to design tri-band filter. The passband frequencies can be conveniently tuned to desired values by controlling the dimensions of two short stubs and an open stub. The theoretical design, simulation and experimental results are given and discussed.



(a)

(b) (c)

Fig. 1 (a) Layout of new resonator. (b) Even-mode equivalent circuit. (c) Odd-mode equivalent circuit.

This paper is organized as follows. Section II investigates the characteristics of the two short stubs and an open stub loaded resonator. In Section III, IV a tri-band BPF using two short stubs and an open stub loaded resonator is designed, simulated, and fabricated. Finally, a conclusion is given in Section V.

II. ANALYSIS OF PROPOSED NEW RESONATOR

Fig. 1(a) shows the layout of proposed new resonator. It consists of a common microstrip half-wavelength resonator, two short stubs and an open stub, where ($2(L_1 + L_2)$, Z), (L_3, Z), and (L_0, $Z/2$) are the lengths and the characteristic impedances of half-wavelength resonator, the short stub and an open stub, $Y=1/Z$ denotes characteristic admittance of the microstrip resonator, and $\theta_1+\theta_2$,θ_3 and θ_0 denote the electrical lengths of half-wavelength resonator, short-stub and open-stub, respectively. The resonator is symmetrical and thus even- and odd-mode equivalent circuits are given in Figs. 1(b) and (c), respectively. Its one-port input admittance can then be found as [10], [11]

$$Y_{in-even} = jY \frac{\tan\frac{\theta_0+\theta_2}{2} + \tan\theta_1 - \cot\theta_3}{2 - \tan\frac{\theta_0+\theta_2}{2}\tan\theta_1} \tag{1}$$

$$Y_{in-odd} = jY \frac{-\cot\frac{\theta_2}{2} + \tan\theta_1 - \cot\theta_3}{2 + \cot\frac{\theta_2}{2}\tan\theta_1} \tag{2}$$

At the resonance frequencies, the input admittance of each mode will be equal to zero, which indicates $Y_{\text{in-even}} = 0$ for even mode and $Y_{\text{in-odd}} = 0$ for odd mode. Fig. 2 plots the simulated frequency response under the weak coupling with physical dimensions: L_1 = 16.55mm, L_2 = 1.15mm, L_3 = 8.85mm, L_0 = 8.2mm, Z = 87 ohm, three resonant frequencies can be observed at f_1 = 1.59 GHz, f_2 = 2.45 GHz and f_3 = 4.1 GHz, respectively.

III. TRI BAND BANDPASS FILTER DESIGN

To demonstrate the proposed concept, a tri-band BPF is designed on a substrate with $\varepsilon_r = 4.4$ and $h = 0.8$ mm. Fig. 3 shows the layout of proposed tri-band bandpass filter using new resonator with pseudo-interdigital resonators structure. In Fig. 4, shows the EM simulated frequency responses of the filter under the different short stub length L_6, the first passband frequency $f_{\text{even1}} - f_1$ can be shifted within a wide range, when the $f_{\text{odd1}} - f_2$ is fixed, meanwhile the $f_{\text{even2}} - f_3$ varies a little. In addition, Fig. 5 shows the simulated insertion loss of the filter in cases of different length L_5, the third passband f_{even2} can be shifted within a wide range, when f_{even1} and f_{odd1} are fixed. So in the filter design, to obtain desired passband frequencies, f_{odd1} can be determined by adjusting the length of the L_1 and L_2 then f_{even1} can be controlled simply by tuning the length of L_6, and f_{even2} can be determined by adjusting the length of L_5.

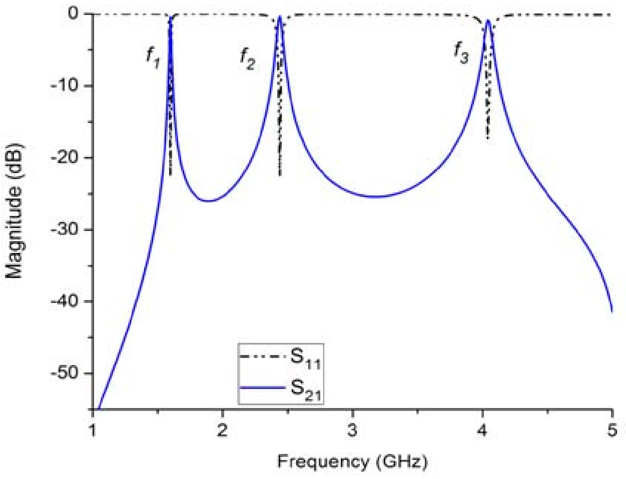


Fig. 2 The S parameter under weak coupling

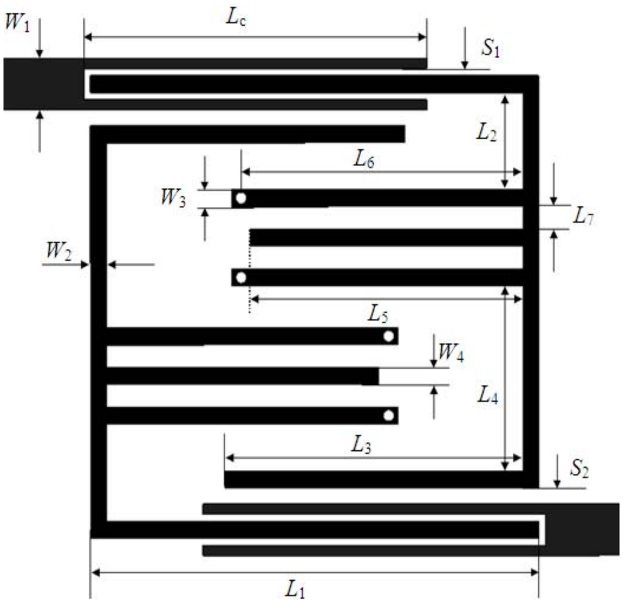


Fig. 3 Layout of the proposed tri-band BPF

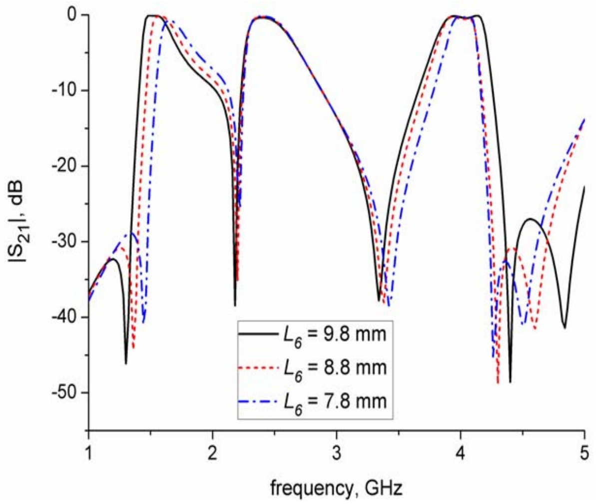


Fig. 4 Simulated insertion loss of filter with different L_6

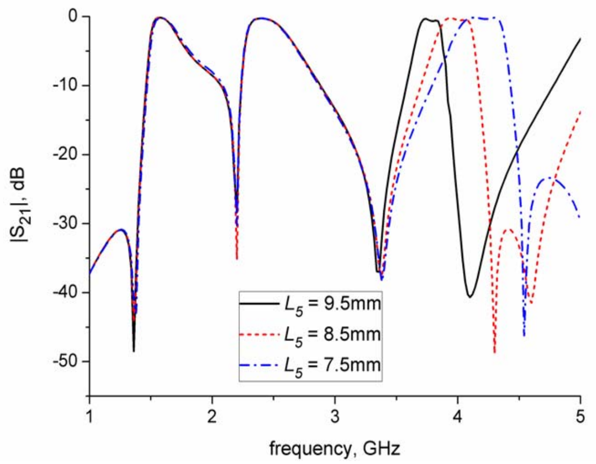


Fig. 5 Simulated insertion loss of filter with different L_5

Finally, a tri-band BPF with resonance frequencies at 1.57 GHz, 2.4 GHz, and 3.95 GHz, with independently controlled center frequencies is designed. After optimization using Ansoft HFSS 11.0, the dimensions for this filter are determined as: W_1 = 1.5mm, $W_2 = W_3 = W_4$ = 0.8mm, L_1 = 14mm, L_2 = 2.8mm, L_3 =9.3mm, L_4 =5.35mm, L_5 = 8.5mm, L_6 = 8.8mm, L_7 = 0.65mm, L_c = 10.7mm, S_1 = 0.2mm, S_2 = 0.45mm, and via diameter is 0.4mm.

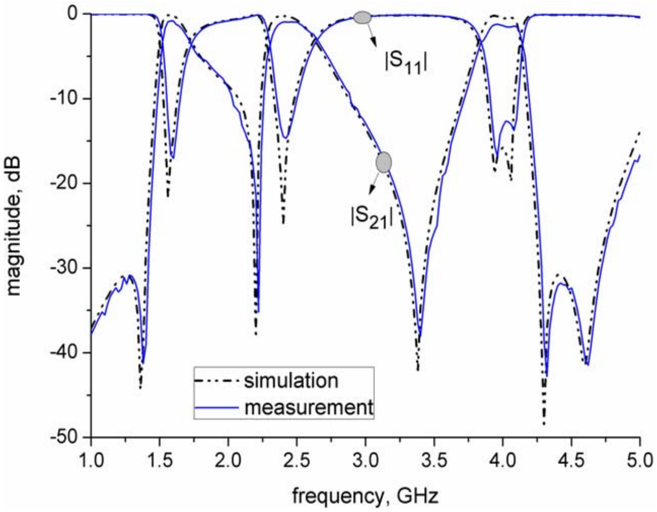


Figure 6. Simulated and measured responses of tri-band BPF.

IV. MEASURED RESULTS AND DISCUSSIONS

The measured and simulated results are illustrated in Fig. 6. The measured 3-dB fractional bandwidth for the three passbands (1.58, 2.41 and 3.97 GHz) are found to be 13.1, 13 and 7.4%, respectively. The measured minimum insertion losses including the loss from SMA connectors are 1.1, 1.2, and 1.4 dB, while the return losses are greater than 16, 15 and 13.5 dB, respectively. In addition, to improve the selectivity of the filter, the pseudo-interdigital resonators structure proposed in [9] is introduced to achieve extra transmission zeros in the each passband edges. Five transmission zeros are created at 1.36, 2.2, 3.38, 4.3 and 4.65 GHz. Four transmission zeros are generated near the passband edges, resulting in sharp roll-off. Meanwhile, good stopband rejection is achieved by another transmission zero.

A slight frequency discrepancy can be found between the measured and simulated results; the reasons may be explained below. In the practical prototype of the proposed tri-band BPF, two shorting via holes were soldered with the microstrip ground, the imperfect soldering skill actually affects the equivalent wavelength of the shorted lines. In addition, the limited fabrication precision, also contributes a little error to the measurement results.

V. CONCLUSION

A compact tri-band BPF using new resonator is proposed. The center frequencies of the three passbands can be independently controlled. The center frequencies of the first and the third passband can be flexibly controlled by tuning the dimensions of two short stubs and an open stub, whereas the second passband frequency is fixed. Moreover, the filter has been implemented with five transmission zeros are realized at the adjacent three passbands, which give much improved selectivity. The simulated results are finally verified by our experiment of the fabricated filter.

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