Square Dual-Mode Quasi-Elliptic Bandpass Filter with Wide Upper Stopband

Y. Ma [1,2], W. Che [1], W. Feng [1], and J.-X. Chen[3]

[1] Department of Communication Engineering, Nanjing University of Science and Technology, Nanjing 210094, China
yeeren_che@163.com

[2] Faculty of Mathematics and Physics, Huaiyin Institute of Technology, Huai'an 223003, China

[3] School of Electronics and Information, Nantong University, Nantong 226019, China

Abstract ─ A square dual-mode quasi-elliptic bandpass filter (BPF) with a wide stopband is proposed. To realize the quasi-elliptic response and harmonic suppression for the filter, the inductive source-load coupling is introduced. To achieve wider stopband suppression, the open-circuited stubs are adopted. A demonstration filter with 3-dB fractional bandwidth (2.84 GHz – 3.28 GHz) about 14.3 % has been designed, fabricated, and measured. Simulated and measured results indicate that the proposed filter can effectively suppress 6th harmonic response referred to a suppression degree of 16.5 dB.

Index Terms ─ Bandpass filter, dual-mode, quasi-elliptic, and wide upper stopband.

I. INTRODUCTION

To meet the requirements of modern microwave communication systems, compact microwave BPFs with wide stopband suppression and low cost are highly required. The dual-mode microstrip resonators are attractive because each resonator can be used as a doubly tuned circuit, therefore, the number of resonators required for a given degree of filter is reduced by half, resulting in a compact design [1]. Open stub loaded dual-mode filters have an inherent transmission zero [2]. The dual-mode filters with two transmission zeros were obtained by introducing capacitive and inductive source-load coupling in [3] and [4], respectively. A hexagonal dual-mode inductance-load filter with four transmission zeros was presented in [5]. Harmonic suppression is not considered in [3-5]. Generally, designing bandpass filters with wideband harmonic suppression is a challenge [6-10]. Dual-mode filters with harmonic suppression were realized by source-load coupling in [6-7]. The stopband is extent to $3f_0$ (f_0: passband center frequency) in [6], but there is only one transmission zero and the selectivity is not good. The BPF with a short-stub-loaded odd-even mode open loop stepped impedance resonator achieving 60 % size reduction is presented in [7], but the first spurious passband occurs at $3f_0$. Another miniaturized dual-mode BPF with 67 % size reduction in [8] is realized using odd-even mode loop resonator. A coupling and routing scheme is presented to suppress the first harmonic response, yet the stopband is only extended up to $2.72f_0$.

In this letter, a square dual-mode quasi-elliptic BPF using the short-circuited and open-circuited stubs with a wide stopband is proposed. The inductive source-load coupling introduces another transmission zero at lower stopband edge to realize quasi-elliptic response and harmonic suppression partly. The stopband is extended to $6.4f_0$ by employing the open-circuited stubs. The theoretical design, simulation, and experimental results are given and discussed.

II. ANALYSIS AND DESIGN OF PROPOSED BPF

The circuit of the proposed square dual-mode resonator under weak coupling is shown in Fig. 1 (a), consisting of a half- wavelength resonator with

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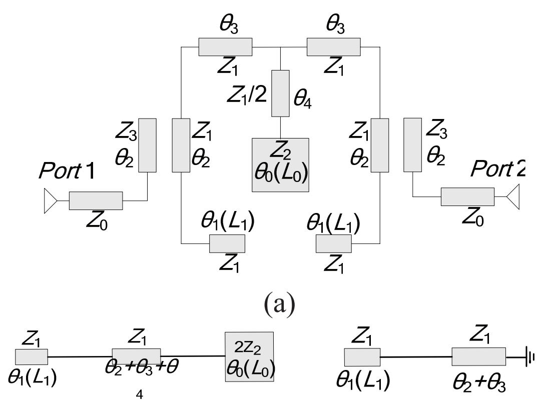
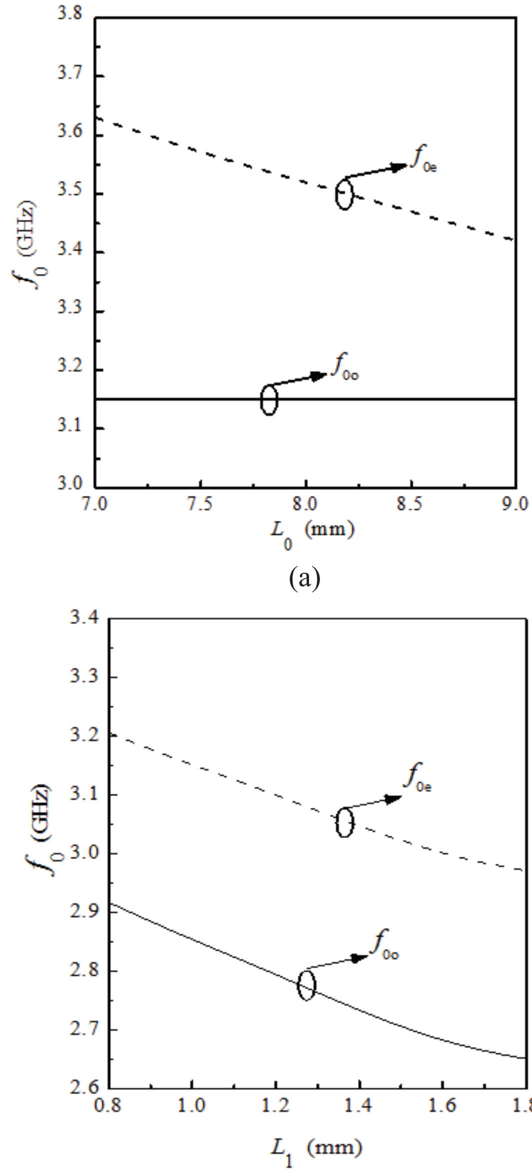
a shunt open stub. Z_1 is the characteristic impedance of the half-wavelength resonator with the electrical length $\theta_1 + \theta_2 + \theta_3 = 90°$, $Z_1/2$ and Z_2 are the characteristic impedance of the open stubs with the electrical length θ_4 and θ_0, respectively. Two microstrip lines with characteristic impedance $Z_0 = 50\ \Omega$ are connected to ports 1 and 2. The even-odd mode equivalent circuits of the proposed filter are shown in Figs. 1 (b) and (c). The frequency responses of the resonator under weak coupling are shown in Fig. 2 (a) and (b) for the case of different L_0 and L_1. It is easy to see that L_0 only controls the even-mode resonant frequency while the even-odd mode resonant frequencies are controlled by L_1. Thus, the required central frequency and passband can be achieved by controlling L_0 and L_1 with the proper characteristic impedance.



(a) (b) (c)

Fig. 1. (a) Circuit of proposed dual-mode resonator, (b) even-mode circuit, and (c) odd-mode circuit.

The layout of the proposed filter is shown in Fig. 3. The via holes are used to realize the required inductance. A transmission zero caused by the inductive cross-coupling between source and load is introduced at lower stopband for improving the selectivity, which can be controlled by tuning the coupling gap (S_3). As shown in Fig. 4 (a), when S_3 decreases from 1.5 mm to 0.5 mm, the lower transmission zero moves towards the passband edge while the upper inherent transmission zero changes barely. The quasi-elliptic response of the filter is realized with the two transmission zeros. It may be seen that the stopband is affected by S_3. In order to achieve the narrower roll-off skirts and wider stopband suppression, S_3 is designed as 1 mm. The stopband may be further broadened by introducing two quarter-wavelength open-circuited stubs [10].

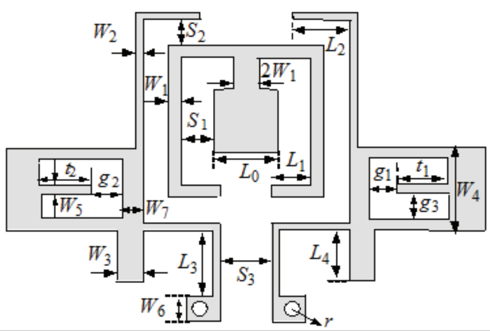


(a) (b)

Fig. 2. (a) Simulated even-odd mode frequency responses under different L_0 and (b) simulated even-odd mode frequency responses under different L_1.

Figure 4 (b) shows the simulated frequency responses of the proposed filter with two same quarter-wavelength open-circuited stubs under the optimized values of W_3 and L_4 (as shown in Fig. 3).

With the introduction of the two different embedded open-circuited stubs (EOCS) wider stopband can be realized. The two open-circuited stubs acts as bandstop way [11] to generate two more transmission zeros in the upper stopband as be seen in Fig. 4 (b) for harmonic suppression. Figure 4 (b) shows the simulated frequency responses of the proposed filter with the two EOCS s under the optimized values of g_1, g_2, g_3, t_1, t_2, and W_5 (as shown in Fig. 3). In this way, a square dual-mode quasi-elliptic BPF with a wide stopband using the short-circuited and open-circuited stubs can be realized.



parameters	W_1	W_2	W_3	W_4	W_5	W_6	W_7	L_0	L_1	L_2	L_3
values (mm)	0.8	0.4	1	1.9	0.6	1.4	0.7	8.2	1.4	1.8	6.2
parameters	L_4	S_1	S_2	S_3	g_1	g_2	g_3	t_1	t_2	r	
values (mm)	3.2	0.5	0.4	1.0	0.3	0.4	0.2	3.0	2.6	0.3	

Fig. 3. Layout and parameters of proposed filter.

III. MEASURED RESULTS AND DISCUSSIONS

One prototype of the proposed dual-mode quasi-elliptic BPF with a wide stopband is designed and fabricated on an RO4003c substrate with ε_r = 3.38 and h = 0.8 mm. The structure parameters of the filter are shown in Fig. 3. The size of the filter is 19.3 mm × 20.0 mm, which corresponds to an electrical size of $0.33\lambda_g \times 0.34\lambda_g$, where λ_g is the guided wavelength at the center frequency of the passband. Figure 5 shows the photograph of the fabricated filter. The measured S-parameters are illustrated in Fig. 6. As can be seen from this figure, the measured 3-dB fractional bandwidth is about 14.3 % (2.84 GHz – 3.28 GHz), with the minimum insertion loss less than 1 dB. Inside the passband, the return loss is better than 15.3 dB. Two transmission zeros (at 1.87 GHz and 3.84 GHz) are near the edges of the passband, realizing the quasi-elliptic response. Furthermore, the proposed filter also exhibits a wide stopband performance of 6th harmonic suppression referred to a 16.5 dB suppression degree. Table I shows the performance comparison of the proposed design with several previous designs. Hence, the advantages of the proposed filter can be clearly observed.

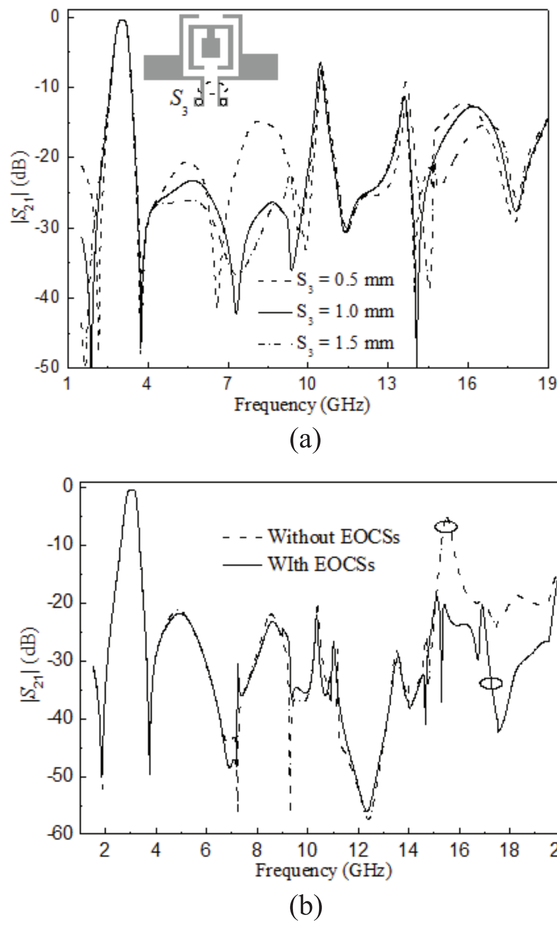


Fig. 4. (a) Frequency responses of the BPF with S-L coupling under different S_3 and (b) frequency responses of the BPF with/without EOCSs.

Table I: Performance comparison of filters.

Ref.	Harmonic suppression
[2]	No
[3]	No
[4]	No
[5]	No
[6]	2nd
[7]	3rd
[8]	2nd
This work	6th

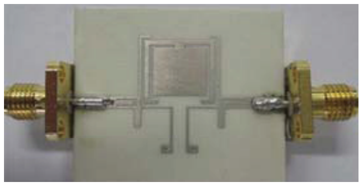


Fig. 5. Photograph of the proposed dual-mode BPF.

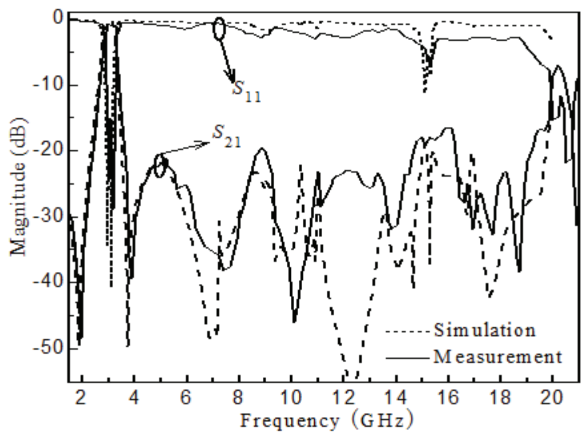


Fig. 6. Simulated and measured results of the dual-mode BPF.

IV. CONCLUSION

A square dual-mode quasi-elliptic BPF with a wide stopband is proposed. Both wide stopband and the quasi-elliptic response can be obtained by employing the open-circuited and short-circuited stubs. Simulated and measured results show that the proposed BPF has the properties of low insertion loss, wider stopband, and high selectivity. With all these good performances the proposed filter could be applicable for modern wireless communication system.

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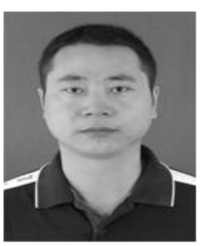
Yalin Ma received the M. Sc. degree from UESTC, Chengdu, China, in 2006. He is currently working toward the Ph.D. degree in Electromagnetic Field and Microwave Technology in NJUST. His research interest is the design of tunable circuits, differential network, etc.

Wenquan Che received the M.Sc. degree from NUST, Nanjing, China, in 1995, and the Ph.D. degree from the City University of Hong Kong (CITYU), Kowloon, Hong Kong, in 2003. She is currently a Professor with NUST, Nanjing, China. Her research interests include electromagnetic computation, planar/coplanar circuits and subsystems in RF/microwave frequency, microwave monolithic integrated circuits (MMICs) and medical application of microwave technology. Dr. Che was the recipient of the 2007 Humboldt Research Fellowship presented by the Alexander von Humboldt Foundation of Germany, the 5th China Young Female Scientists Award in 2008 and the recipient of Distinguished Young Scientist awarded by the National Natural Science Foundation Committee (NSFC) of China in 2012.

Wenjie Feng received the M. Sc. degree from NUST, Nanjing, China, in 2010, and is currently working toward the Ph.D. degree in Electromagnetic Field and Microwave Technology in NJUST. His research interests include ultra-wideband (UWB) circuits and technologies, etc.



Jian-Xin Chen received the M.S. degree from UESTC, Chengdu, China, in 2004, and the Ph.D. degree from CITYU, Kowloon, Hong Kong, in 2008. He is currently a Professor with Nantong University, Jiangsu Province, China. His research interests include RF/microwave active and passive circuit designs.