Compact Tri-band Bandpass Filter Using Embedded Resonators With Multiple Transmission Zeros

MinhTan Doan[1,2], Quoc Trinh Do[1], Van Ha Tran[2]

1. Department of Radio Electronic Engineering Le Qui Don Technical University, Hanoi, Vietnam.
2. Department of Communication Engineering Nanjing University of Science & Technology 210094 Nanjing, China.

E-mail: doanminhtanhv@ yahoo.com

Abstract—**A compact microstrip tri-band bandpass filter (BPF) using the embedded open stubs loaded resonator is presented. The center frequencies of the first and the third passband can be conveniently controlled by tuning the dimensions of the short stub and open stubs, whereas the second passband frequency is fixed. Moreover, the filter has been implemented with multi-transmission zeros to improve the selectivity. To verify the proposed approach, a prototype of tri-band BPF centred at 2.4/3.5/5.2 GHz for WLAN/WiMAX applications is designed and fabricated. Measured results agree well with simulated ones.**

***Index Terms*—Tri-band bandpass filter, short stub loaded half-wavelength resonator, fractional bandwidth.**

I. INTRODUCTION

To meet the demand of multi-mode operation in modern wireless communication systems, tri-band bandpass filters (BPFs) has become one of the most important devices in the transmitters and receivers of microwave communication systems. Recent years, many approaches have been reported in the literature to designing tri-band BPFs [1-9]. In general, multi-band behaviour resonators or stubs loaded resonators were adopted widely to design tri-band filters. The tri-section stepped-impedance resonators (SIRs) is used to designed tri-band filter [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 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 stub loaded and half-wavelength resonator [6], open stub loaded and quarter-wavelength resonator [7]. Recently, a novel class of compact dual-mode triple-band bandpass filters based on a single microstrip ring resonator has been presented [8]. The square ring loaded resonator (SRLR) has been successfully proven in the design of a tri-band filter [9]. The SRLR can generate a tri-band response by tuning its geometric parameters and realize the high-order tri-band. However, for these structure difficult tuning of center frequencies and the selectivity needs to be improved.

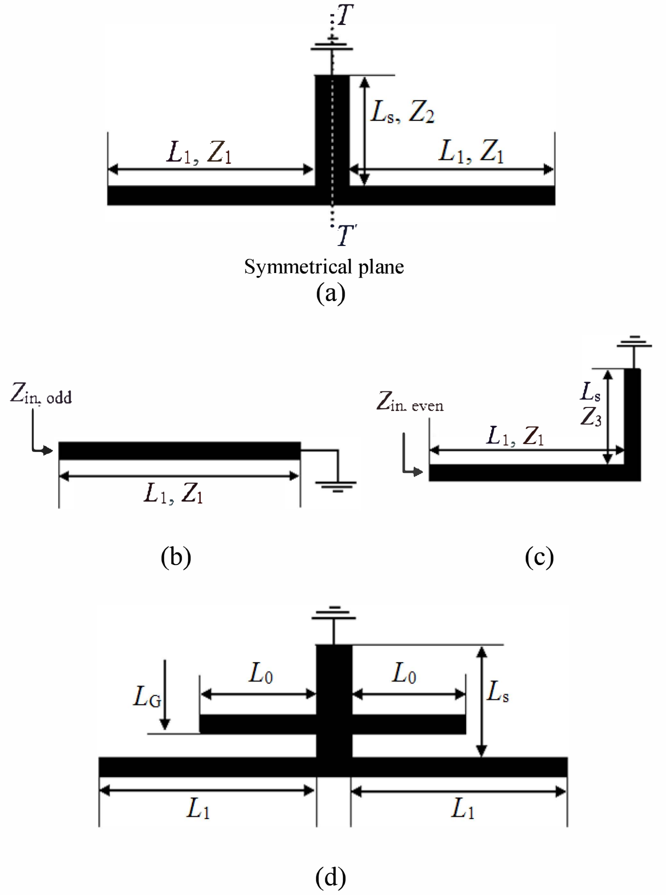


Fig. 1 Conventional SLHR and proposed embedded resonator
(a) Conventional SLHR. (b) Odd-mode equivalent circuit. (c) Even-mode equivalent circuit. (d) Embedded resonator.

The short stub loaded half-wavelength resonator (SLHR) has been successfully proven to design dual-band filters [10-11]. The center frequencies of the first and the second passbands can be conveniently controlled by tuning the dimensions of the short stub and hafl-wavelength resonator.

In this letter, the embedded two open stubs loaded resonator for designing a miniaturised tri-band bandpass filter is proposed. It is found that the embedded resonator can yield a new passband namely f_3. The third resonant frequency can be easily controlled by changing the open stub lengths. Moreover, the filter has been implemented with multiple transmission zeros, resulting in high selectivity.

978-1-4673-4352-7/12/$31.00 ©2012 IEEE

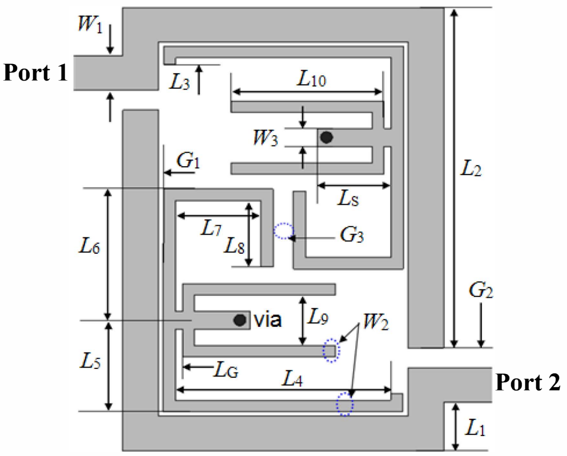


Fig. 2 Layout of proposed tri-band bandpass filter.

II. ANALYSIS AND DESIGN OF PROPOSED FILTER

Fig. 1(a) shows the layout of short stub loaded half-wavelength resonators consists of a common microstrip half-wavelength resonator and a short stub loaded. For odd-mode and even-mode excitation, the equivalent circuit are shown in Figs. 1(b) and (c). Meanwhile, the new embedded resonator is shown in Fig. 1(d). The layout of the proposed tri-band filter is shown in Fig. 2. In addition, to improve the selectivity of the filter, the skew-symmetrical 0^0 feeding structure [12] is introduced to realize input and output ports of the filter. Which could create extra transmission zeros at the adjacent three passbands, sharp passband skirts of the filter have been observed. This coupling structure makes a very compact circuit. The filter is constructed on a substrate with relative permittivity of 4.4 and thickness of $h = 0.8$ mm.

A. Characteristic of the SLHR Resonators

In addition, Z_1, L_1 and Z_2, L_s are the characteristic impedance and length of the half wavelength line and the short-circuited stub, respectively. The resonator is symmetrical and thus odd-and even-mode analysis can be used for characterization. Element values of Z_1, L_1 and Z_2, L_s in the prototype filter are determined by its passband specifications using the well-known formulas in [10-11]. The input impedance for even-mode and odd-mode can be expressed as

$$Z_{ine} = jZ_1 \frac{Z_1 \tan(\beta L_1) + 2Z_2 \tan(\beta L_s)}{Z_1 - 2Z_2 \tan(\beta L_1)\tan(\beta L_s)} \tag{1}$$

$$Z_{ino} = -jZ_1 \cot(\beta L_1) \tag{2}$$

Where β is the propagation constant, and it is equal for even-mode and odd-mode. The resonance condition is

$$Z_{ine} \to \infty, \ Z_{ino} \to \infty \tag{3}$$

The fundamental resonant frequencies of SLHR can be determined as follows:

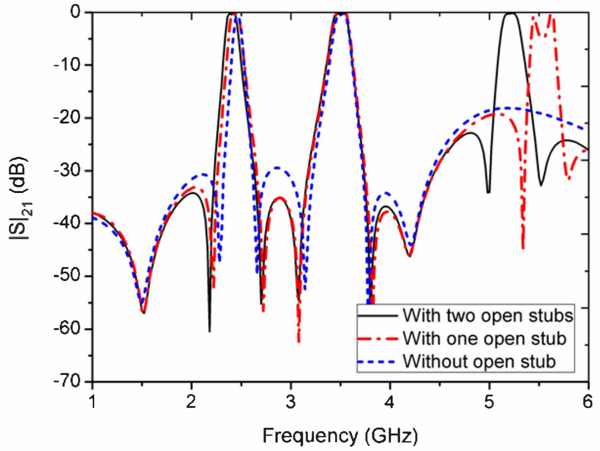
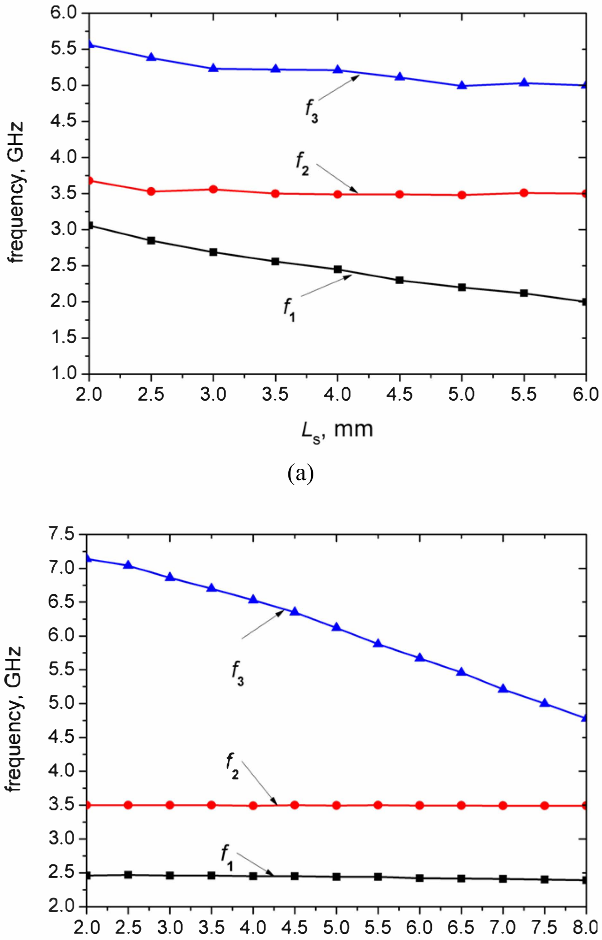


Fig. 3 Comparison of $|S_{21}|$ of the SLHR with and without embedded resonator.



(a)

(b)

Fig. 4 Three resonance frequencies of embedded resonator under the different length L_s (a) and L_0 (b).

$$f_{even} = \frac{c}{4(L_1 + L_s)\sqrt{\varepsilon_{eff}}} \tag{4}$$

$$f_{odd} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \tag{5}$$

While c is the light speed in free space, ε_{eff} the effective dielectric constant of the substrate.

Equation (4) is based on the special case: $Z_1 = 2Z_2 = Z_3$. From (4) and (5), indicating that two center frequencies can be easily adjusted to the desired value by tuning the length of short-stub and half-wavelength line, and its width is kept unchanged.

B. Characteristic of the Embedded Resonators

The innovation of this work is embedded two identical open stubs as shown in Fig. 1d to create the extra passband. The resonant frequency (named f_3) of this passband is mainly determined by the length of open stubs. The simulated insertion loss characteristics of the SLHR with and without embedded resonator are compared and depicted in Fig. 3. It is clearly seen that the filter using SLHR embedded resonator yields three passbands. To achieve better performance of the filter, we are embedded two identical open stubs. The frequency characteristic of the proposed resonator can be fully demonstrated as in Figs. 4(a) and (b), which illustrates the change of the first three resonant frequencies of the filter under the different short stub length L_s and open stub length L_0, while the other dimensions are fixed. From Fig. 4(a), it can be seen that f_1 is decreased from 3.18 to 2.1 GHz as L_s is increased from 2 to 6 mm, meanwhile f_3 varies a little and f_2 can be kept unchanged. In Fig. 4(b), the resonant frequency f_3 varies from 7.21 to 4.76 GHz by increasing the length of the open stub L_0 from 2 to 8 mm, while f_1 and f_2 are kept unchanged. So the design procedure of the tri-band bandpass filter using the proposed embedded resonator is as follows: first, select proper L_1 to obtain the resonant frequency f_2, then tune the length of the short stub L_s to obtain f_1, finally adjust the length of open stubs L_0 to obtain f_3.

C. Tri-band bandpass filter design

To verify the above-mentioned analysis, a tri-band bandpass filter is designed. The layout of the proposed tri-band filter is shown in Fig. 2. In addition, by using the skew-symmetrical 0^0 feeding structure [12], the filter was implemented with nine transmission zeros. Six transmission zeros near the edges of the three passbands are produced to achieve good selectivity. Meanwhile, good lower and upper stopband is achieved by another transmission zeros. When the width, length of the feed line and the coupling spacing G_1 and G_3 are fixed, the coupling degree between the feed line and the resonator at three passbands are determined only by G_2. Fig. 5 shows the simulated response of tri-band filter with respect to different values of source-load coupling space G_2. It is noted that all these transmission zeros will move close to their passbands with the decrease of G_2. Therefore, the selectivity is improved at the cost of stopband rejection level. Meanwhile, the bandwidth of passband still remains unchanged.

Finally, a compact tri-band BPF with center frequencies of passband at 2.4, 3.5 and 5.2 GHz is designed. After optimization using Ansoft HFSS 10.0, the dimensions for this filter are determined as: W_1 = 1.5mm, W_2 = 0.5mm, W_3 = 0.8mm, L_1 = 2.1mm, L_2 = 14.9mm, L_3 = 0.5mm, L_4 = 9mm, L_5 = 4mm, L_6 = 5.75mm, L_7 = 3.58mm, L_8 = 2.9mm, L_9 = 2.2mm, L_{10} = 6.37mm, L_s = 3.1mm, L_G = 0.3mm, G_1 = 0.2mm, G_2 = 0.9mm, G_3 = 0.84mm and via diameter is 0.5mm.

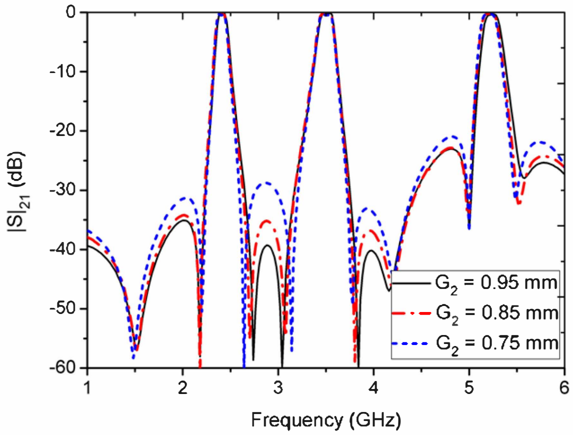


Fig. 5 Simulated frequency response S_{21} parameters of filter under different values of G_2.

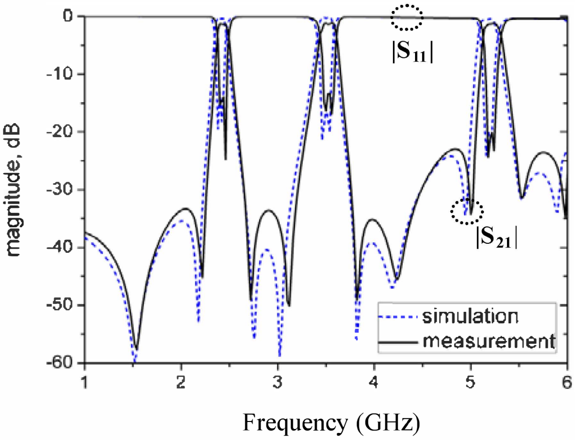


Fig. 6 Measured and simulated results of the tri-band bandpass filter.

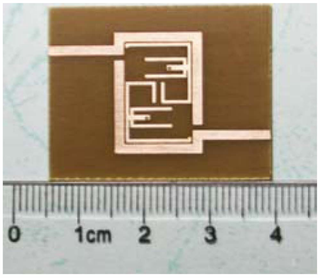


Fig. 7 Photograph of the fabricated tri-band bandpass filter.

III. MEASURED RESULTS AND DISCUSSIONS

A prototype is fabricated to demonstrate the design strategies, the photograph as shown in Fig. 7. The size of the tri-band bandpass filter is 19.4 mm * 13.4 mm (approximately

$0.28\lambda_g * 0.19\lambda_g$, λ_g is the guided wavelength on the substrate at the center frequency of the first passband), indicating quite compact design. The measurement is accomplished using Agilent 8753ES network analyzer. For comparison, the measured results and simulation results are shown together in Fig. 6. The measured 3-dB fractional bandwidth for the three passbands (2.4, 3.5 and 5.2 GHz) are found to be 4.7%, 3.8% and 3.7%, respectively. The measured minimum insertion losses including the loss from SMA connectors are 1.3, 1.2, and 1.4 dB, while the return losses are greater than 15, 13.5 and 21.5 dB, respectively. Six transmission zeros are generated near the passband edges, resulting in sharp roll-off rejection. Meanwhile, good stopband rejection is achieved by another transmission zeros.

IV. CONCLUSION

A novel compact tri-band bandpass filter using short stub loaded half-wavelength embedded resonators is proposed. Three passbands for WLAN and WiMAX applications are presented. The centre frequencies of the three passbands can be conveniently controlled to the desired values and nine transmission zeros are realised at the adjacent three passbands, resulting in very high selectivity. Good agreement is observed between the experiments and theoretical analysis, indicating the validity of the proposed design strategies.

REFERENCES

[1] C. H. Lee, C. I. G. Hsu, and H. K. Jhuang, "Design of a new tri-band microstrip BPF using combined quarter-wavelength SIRs," *IEEE Microw. Wirel. Compon. Lett.*, vol 16, no 11, pp 594-596, Nov 2006.

[2] Q. X. Chu and X. M. Lin, "Advanced triple-band bandpass filter using tri-section SIR," *Electron. Lett.*, vol 44, no 4, pp 295–296, Feb 2008.

[3] C. I. G. Hsu, C. H. Lee, and Y. H. Hsieh, "Tri-band bandpass filter with sharp passband skirts designed using tri-section SIRs," *IEEE Microw. Wirel. Compon. Lett.*, vol 18, no 1, pp 19-21, Jan 2008.

[4] F. C. Chen, Q. X. Chu, and Z. H. Tu, "Tri-band bandpass filter using stub loaded resonators," *Electron. Lett.*, vol 44, no 12, pp 747-749, Jun 2008.

[5] Q.X. Chu, F.C. Chen, Z.H. Tu and H.Wang, "A novel crossed resonator and its applications to bandpass filter," *IEEE Trans. Microw. Theory Tech.*, vol 57, no 7, pp 1753-1759, Jul 2009.

[6] X. Y. Zhang, Q. Xue, and B. J. Hu, "Planar tri-band bandpass filter with compact size," *IEEE Microw. Wirel. Compon. Lett.*, vol 20, no 5, pp 262-264, May 2010.

[7] M. T. Doan, W. Q. Che, K. Deng, and W. J. Feng, "Compact Tri-band bandpass filter using stub-loaded resonator and quarter-wavelength resonator," *In Proc. Int. Conf. Microw. China-Japan Joint*, pp 1-4, Apr 2011.

[8] S. Luo, L. Zhu, and S. Sun, "Compact dual-mode triple-band bandpass filters using three pairs of degenerate modes in a ring resonator," *IEEE Trans. Microw. Theory Tech.*, vol 59, pp 1222-1229. 2011.

[9] J. Z. Chen, N. Wang, Y. He, and C. H. Liang, "Fourth-order tri-band bandpass filter using square ring loaded resonators," *Electron. Lett.*, vol 47, no 15, pp 858-859, July 2011.

[10] Zhou, M. -Q., Tang, X. -H., and Xiao, F.: "Compact dual band bandpass filter using novel E type resonators with controllable bandwidths," *IEEE Microw. Wirel. Compon. Lett*, 2008, 18, (12), pp. 779-781.

[11] B. Lui, F. Wei and X. Shi, "Switchable bandpass filter with two-state frequency responses," *Electronics. Lett.,* vol. 47, no. 1, 6th January. 2011.

[12] C. M. Tsai, S. Y. Lee, and C. C. Tsai, "Performance of a planar filter using a 0^0 feed structure," *IEEE Trans. Microw. Theory Tech.*, vol 50, no 10, pp2362-2367. Oct 2002.