Novel Tri-band Microstrip Bandpass Filter Using Crossed Open Stubs with Different Lengths

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1. Introduction

In recent years, with the development and critical requirements on modern communication technology, more and more attentions have been paid to the multiband and multimode wireless communication systems. Tri-band microstrip bandpass filters (BPFs) play an important role in tri-band transceiver. Several tri-band BPFs have been implemented using stepped impedance resonators (SIR) due to their multi-band behaviors, simple structure and well-established design methodology [1]-[4]. However, the resonance frequencies of the SIRs are dependent, the filter design is quite complicated and it is not convenient to meet specific bandwidth requirement.

One of the most effective methods to realize high performance BPF is to create transmission zeros located at upper or lower side of the passband [5]-[7]. Some tri-band BPFs using dual behaviors resonators (DBRs) and crossed open/short stubs are proposed in [8]-[9]. In [8], each passband of the filters is separated by the transmission zeros produced by the resonance of the open stubs, however, multi-section open stubs with different impedances should be cascaded to realize different transmission zeros, thus causing large filter size.

To achieve simpler and more compact design for tri-band BPF, a new tri-band BPF operating at 2.45/5.25 GHz (WLAN bands) and 3.5 GHz (WiMAX) is proposed in this letter. Transmissions zeros created by the crossed open stubs are used to realize the passband and improve the performance of the passband, while ABCD matrix is used to determine the initial structure parameters. The filters are constructed on dielectric substrate with $\varepsilon_r = 2.65$ and $h = 1$ mm.

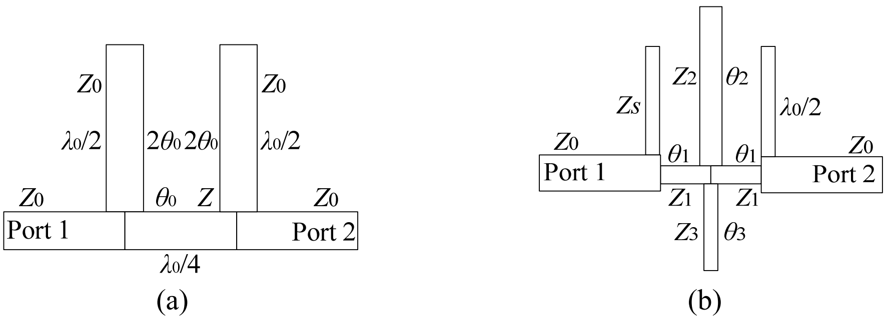


Fig. 1 (a) conventional half-wavelength open stub microstrip BPF; (b) proposed crossed open stubs tri-band microstrip BPF.

2. Analysis and Design of Proposed BPF

Fig.1 (a) shows the conventional half-wavelength open stub BPF (the central frequency of the BPF is f_0) separated by a quarter-wavelength (λ_0 /4) line. Fig. 1(b) gives the proposed crossed open stubs tri-band BPF, where the λ_0 /4 line in Fig.1 (a) is replaced by crossed open stubs with different lengths. Three passbands with sharp rejection can be realized by properly adjusting the locations of transmission zeros created by the crossed open stubs. Z_1, Z_2 and Z_3 represent respectively the characteristic impedances of the series and shunt sections of the crossed open stubs, while θ_1, θ_2 and θ_3 are their electrical lengths.

A. Design Equations of the Crossed Open Stubs

Here ABCD matrix formulation is introduced to find the equivalence between the crossed open stubs and the original $\lambda_0/4$ connection line. The ABCD matrix of the $\lambda_0/4$ connection line is given as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta_0 & jZ\sin\theta_0 \\ jY\sin\theta_0 & \cos\theta_0 \end{bmatrix} \tag{1}$$

The ABCD matrix of the crossed open stubs structure can be written as:

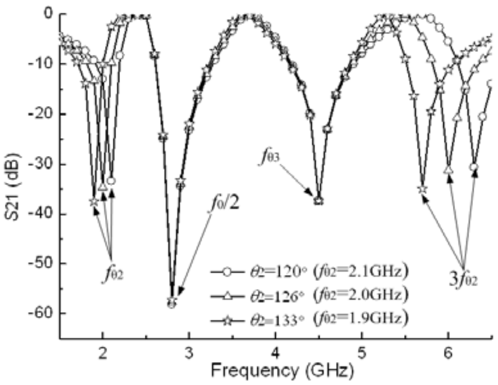
$$\begin{aligned} \begin{bmatrix} A_S & B_S \\ C_S & D_S \end{bmatrix} &= \begin{bmatrix} \cos\theta_1 & jZ_1\sin\theta_1 \\ j\sin\theta_1/Z_1 & \cos\theta_1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ j\tan\theta_2/Z_2 & 1 \end{bmatrix} \\ &\times \begin{bmatrix} 1 & 0 \\ j\tan\theta_3/Z_3 & 1 \end{bmatrix} \times \begin{bmatrix} \cos\theta_1 & jZ_1\sin\theta_1 \\ j\sin\theta_1/Z_1 & \cos\theta_1 \end{bmatrix} \end{aligned} \tag{2}$$

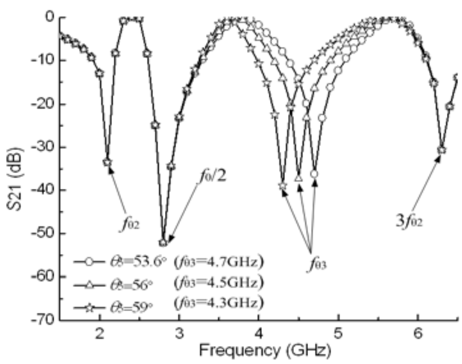
As stated above, the crossed open stubs are used to replace the $\lambda_0/4$ line, θ_0 is thus set to be 90°, and then we have:

$$\begin{bmatrix} A_S & B_S \\ C_S & D_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 0 & jZ \\ jY & 0 \end{bmatrix} \tag{3}$$

Z_1, Z_2 and Z_3 can thus be found as follows:

$$Z_1 = Z/\tan\theta_1, \quad \left|\tan\theta_2/Z_2+\tan\theta_3/Z_3\right| = (1-\tan^2\theta_1)/Z \tag{4}$$





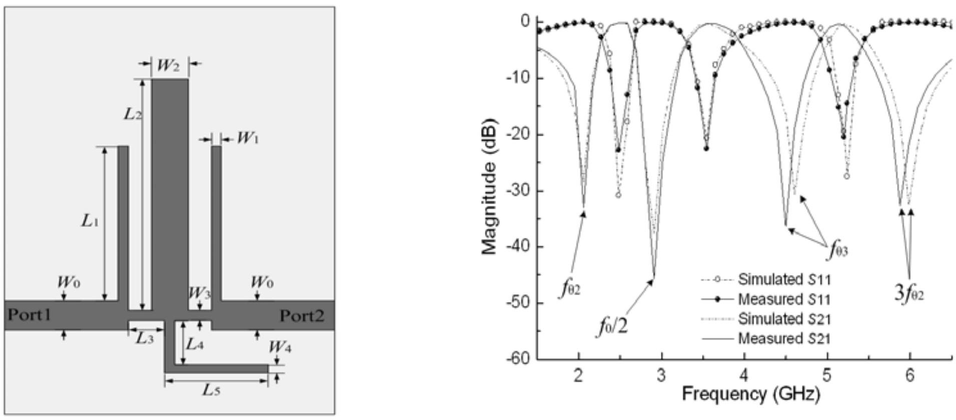
(a) (b)

Fig. 2 $S21$ response for proposed tri-band BPF versus θ_2 and θ_3. (a) θ_1 = 23°, θ_3 = 56°, Z_0 = 50 ohm, Z_s = 100 ohm, Z_1 = 90 ohm, Z_3 = 100 ohm; (b) θ_1 = 23°, θ_2 = 120°, Z_0 = 50 ohm, Z_s = 100 ohm, Z_1 = 90 ohm, Z_2 = 50 ohm.

B. Proposed Tri-band BPF with Crossed Open Stubs

Fig. 2 shows three different $S21$ responses versus θ_2 and θ_3 for the proposed tri-band BPF. From the simulated results in Fig. 2, we may note that, a low passband can be realized between $f_{\theta2}$ and $f_0/2$, a middle passband is achieved between $f_0/2$ and $f_{\theta3}$, while the upper passband is acquired between $f_{\theta3}$ and $3f_{\theta2}$. Obviously, the locations of the transmission zeros depend much on the electric length θ_2 and θ_3, the bandwidth for the passband can thus be tuned effectively by adjusting the length of the crossed open stubs. In addition, the impedance of the half-wavelength open stub Z_S can be also optimized to adjust the Q factor for the three passbands, saying the skirt selectivity of the filter.

In order to obtain approximately same performance for the three passbands locating at 2.45 GHz, 3.5 GHz and 5.25 GHz, θ_2 and θ_3 are finally chosen to be 120° and 56°, while the transmission zeros are set to be $f_{\theta 2} = 0.375f_0 = 2.1$ GHz, $f_{\theta 3} = 0.8f_0 = 4.5$ GHz ($f_0 = 5.6$ GHz). The calculated impedance of the connection line is $Z_1 = 90$ ohm, and the impedances for the crossed open stubs are $Z_2 = 50$ ohm and $Z_3 = 100$ ohm. In addition, the optimized impedance for the side crossed open stub is $Z_s = 100$ ohm. Fig. 3(a) illustrates the geometry of the tri-band BPF. The simulation results from Ansoft HFSS v10.0 are shown in Fig. 3(b). Obviously, three passbands are located separately around at 2.45 GHz (2.3-2.67 GHz), 3.5 GHz (3.3-3.74 GHz) and 5.25 GHz (5.05-5.45 GHz); while the transmission zeros created by the crossed open stubs can be observed to locate at 2.1 GHz, 4.5 GHz and 6.1 GHz, respectively, a tri-band BPF with sharp roll-off skirt selectivity is thus realized by the proposed crossed open stubs. In addition, further size reduction for the BPF can be achieved by using folded open stubs or SIR sections.



(a) (b)

Fig.3 (a) The geometry of proposed tri-band BPF (not in scale). $L_1 = 16.6$ mm, $L_2 = 23.9$ mm, $L_3 = 1.975$ mm, $L_4 = 4$ mm, $L_5 = 7.5$ mm, $W_0 = 2.7$ mm, $W_1 = 0.75$ mm, $W_2 = 2.7$ mm, $W_3 = 0.95$ mm, $W_4 = 0.75$ mm; (b) Measured and simulated results of the tri-band BPF.

3. Measured Results and Discussions

One prototype of the tri-band BPF with size of 25 mm× 37 mm is fabricated on substrate with $\varepsilon_r = 2.65$ and $h = 1$ mm. The photograph of the fabricated BPF is shown in Fig. 4. For comparison, the measured results are illustrated also in Fig. 3(b). We may note that, three transmission zeros are respectively at 2.1 GHz ($f_{\theta 2}$), 4.4 GHz ($f_{\theta 3}$) and 6 GHz ($3f_{\theta 2}$), while the three passbands are located centrally at 2.45 GHz, 3.5 GHz and 5.22 GHz, agreeing well with expected theoretical results. The measured insertion loss for the filter is less than 0.8 dB in the passband. The 3 dB fractional bandwidth for the three passbands is respectively 15.1% (2.28-2.65 GHz), 13.4% (3.32-3.78 GHz) and 7.6% (5-5.4 GHz). The slight frequency discrepancy may probably be caused by unexpected fabrication tolerance and measurement error.

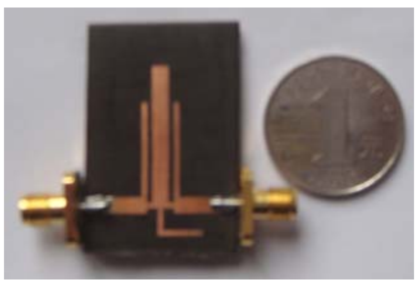


Fig. 4. Photograph of the fabricated tri-band BPF.

4. Conclusion

In this work, a new tri-band BPF is proposed and demonstrated, which is implemented with crossed open stubs with different lengths. To achieve more compact design, the quarter-wavelength line of conventional half-wavelength BPF is replaced with crossed open stubs. Three passbands for WLAN band and WiMAX can be realized between the transmission zeros created by the crossed open stubs. In addition, sharp out-of-band selectivity can also be realized obviously. Good agreement is observed between the experiments and theoretical analysis, indicating the validity of the proposed design strategies.

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References

[1] C.-F. Chen, T.-Y. Huang, and R.-B. Wu, "Design of dual- and triple-passband filters using alternately cascaded multiband resonators," *IEEE Trans. Microw. Theory Tech.*, vol. 54, no. 9, pp. 3550–3558, Sep. 2006.

[2] 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. Wireless Compon. Lett.*, vol. 16, no. 11, pp. 594–596, Nov. 2006.

[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. Wireless Compon. Lett.*, vol. 18, no. 1, pp. 19–21, Oct. 2008.

[4] Q. X. Chu, , F. C. Chen, Z. H. Tu and H. Wang, "A novel crossed resonator and its applications to bandpass filters," *IEEE Trans. Microw. Theory Tech.*, vol. 57, no. 7, pp.165–171, July 2009.

[5] C. Quendo, E. Rius and C.Person, "Narrow bandpass filter using dual-behavior resonators based on stepped-impedance stubs and different-length stubs," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 3, pp. 1034–1044, Mar. 2004.

[6] J.-R. Lee, J.-H. Cho, and S.-W. Yun, "New compact bandpass filter using microstrip $\lambda/4$ resonators with open stub inverter," *IEEE Microw. Guided Wave Lett.*, vol. 10, no. 12, pp. 526–527, Dec. 2000.

[7] H. Gan, D. W. Lou, and D. X. Yang, "Compact microstrip bandpass filter with sharp transition bands," *IEEE Microw. Wireless Compon. Lett.*, vol. 16, no. 3, pp. 107–109, May 2006.

[8] C. Quendo, E. Rius, A. Manchec, Y. Clavet, B. Potelon, J.-F. Favennec, and C. Person, "Planar tri-band filter based on dual behavior resonator," *European Microwave Conference*, vol.1, pp. 269–272, Oct. 2005.

[9] 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.