A Novel Compact Tri-band Filter Based on a Single Substrate Integrated Waveguide Cavity

Rui-Sen Chen, Yejun He*, Jie-En Xie, Long Zhang, Sai-Wai Wong
Guangdong Engineering Research Center of Base Station Antennas
Shenzhen Key Laboratory of Antennas and Propagation
College of Electronics and Information Engineering, Shenzhen University, 518060, China
Email: crs13763378709@163.com, heyejun@126.com*, 995896732@qq.com, longzhang717@163.com, wongsaiwai@ieee.org

***Abstract*—A compact tri-band bandpass filter (BPF) using a single substrate integrated waveguide (SIW) cavity with offset feed-line is proposed in this paper. Firstly, a single SIW cavity fed by microstrip-line and L-shape slots with rectangular slot is applied to construct a tri-band BPF. The offset feed-line is used to excite the three resonant modes to achieve the three passbands. The rectangular slot in the SIW is applied to improve the filtering performance. This filter has a very compact configuration, which still remains a good filtering performance. Then, a second order tri-band filter based on the first order tri-band filter is designed and analyzed. Finally, the proposed second order tri-band filter is fabricated and verified by simulations and experiments.**

***Index Terms*—tri-band, substrate integrated waveguide (SIW), offset feed-line, bandpass filter (BPF).**

I. INTRODUCTION

Due to the coexistence of different communication systems, multiple-band filters with high performance have attracted extensive attention to cover the multiple-band services. Stepped-impedance resonators (SIRs) and stub loaded resonator (SLR) are widely used to design multiple-band filters [1]- [7]. A second-order tri-band band-pass filter (BPF) was designed using tri-section stepped-impedance resonators (TSSIRs) [2], and a tri-band bandpass filter (BPF) using square ring short stub loaded resonators (SRSLR) is presented in [4]. The work [8] presents a new class of tri-band bandpass filters in a single metal cavity containing triple identical sets of metal-post pairs with low insertion loss. In work [9], the complementary split-ring resonators (CSRRs) is proposed and demonstrated on the basis of SIW technology to design miniaturized multi-band filters with the advantages of compact size and easy integration.

II. DESIGN OF PROPOSED FILTERS

The configurations of the proposed tri-band bandpass filters (BPFs) are shown in Fig. 1, including first order BPF and second order BPF. As shown in Fig. 1 (a), the filter is composed of a single SIW cavity, microsrtip line, a pair of L-shape slots and a rectangular slot. The offset microstrip line and L-shape slots are combined to form the feed-line. The Fig. 1 (b) shows the proposed second-order tri-band filter, which is simply cascade connection of two circuits in Fig. 1 (a).

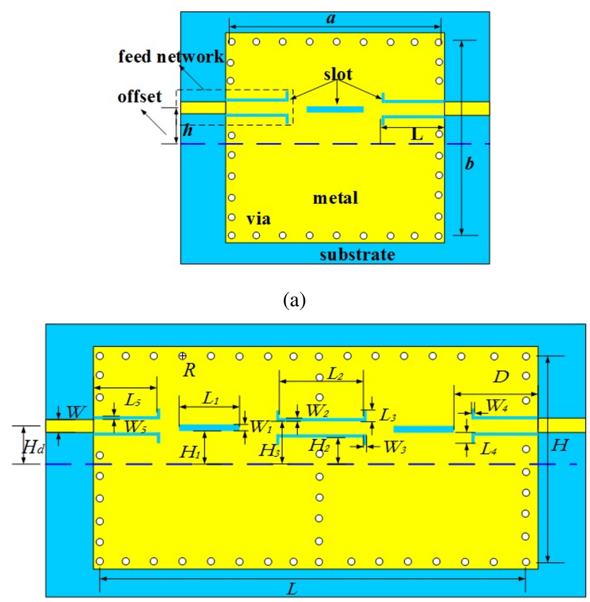


Fig. 1. Geometry of the proposed tri-band filters: (a) first order and (b) second order.

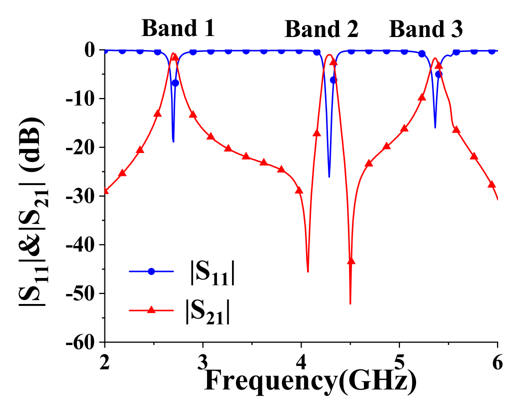
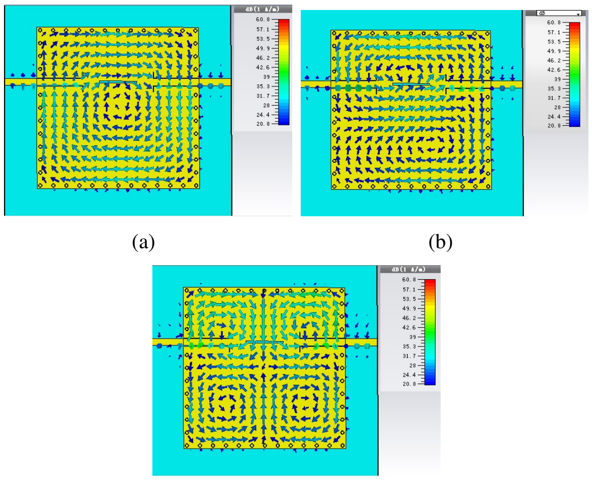


Fig. 2. Simulated S-parameters of the first order tri-band BPF.

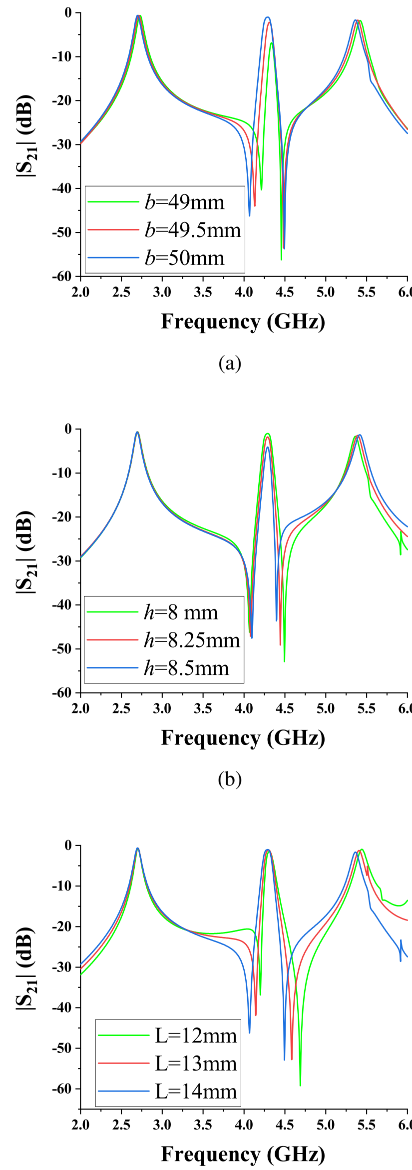


(a) (b) (c)

Fig. 3. Magnetic field distributions of the three resonant modes: (a) 2.71 GHz, (b) 4.31 GHz and (c) 5.38 GHz.

A. Design and analysis of first order tri-band BPF

As shown in Fig. 1 (a), the microstrip-line and a pair of L-shape slots are used to constitute the feeding network, which is a common feeding method in SIW applications. The offset feed-line is used to generate three resonant modes with the frequency not closing to each other. Also, it can produce transmission zeroes between each two resonant modes. Thus, the presented model can construct a tri-band filter. The rectangular slot inside the SIW cavity is applied to improve the filtering performance. The simulated S-parameters are presented in Fig. 2, where it can be seen that the filter has three passbands with the center frequency respectively at 2.71 GHz, 4.31 GHz and 5.38 GH, namely f_1, f_2, and f_3. The insertion losses (ILs) of the three passbands are 1.1 dB, 1.0 dB and 2.0 dB, respectively. The return losses (RLs) of the three passbands are all better than 15 dB. Compared to the tri-band filters shown in [1-9], the proposed filter has more compact configuration, which still remains a good filtering performance. To further analyze the mechanism of the tri-band filter, the magnetic field distributions of the three resonant modes are given in the Fig. 3 (a), (b) and (c), respectively. The mode f_1 is the fundamental mode TE101 of the SIW cavity. The mode f_2 is TE102 mode with diagonal-symmetry magnetic field. The mode f_3 is the TE202 mode, but the field is not completely symmetry, and the field in the feed-line part is stronger, leading to the frequency shift when comparing to typical TE202 mode in SIW cavity. Fig. 4 (a), (b) and (c) show the frequency tuning by b (the height of the cavity), h (the offset of the feed-line) and L (length of the L-shape slots), respectively. From Fig. 4 (a), it can be seen that the increasing b causes all the three resonant modes to shift to the low frequency, the reason is that when b becomes larger, the SIW cavity also becomes larger, and then resulting in the frequency decrease of all the resonant modes. As the first resonant mode f_1 is only controlled by the size of the SIW cavity, so the varying L and h has no effect on



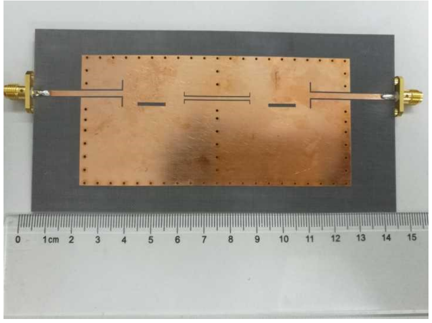
(a) (b) (c)

Fig. 4. $|S_{21}|$ against: (a) height of cavity, b; (b) offset of feed-line, h and (c) length of L-shape slots, L.

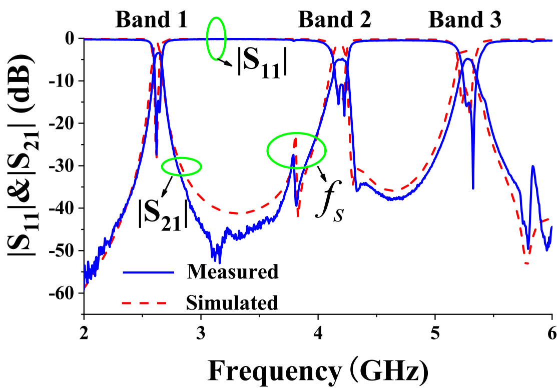
f_1, as shown in Fig.4 (b) and (c). Fig. 4 (b) indicates that the increasing h results in the increase of mode f_3, while f_1 and f_2 remain unchanged. It can be concluded from Fig. 4 (c) that the varying length of the L-shape slot only cause the shift of f_2 and f_3. Thus, all the three modes can be shifted to a desire position within a certain frequency range by modifying the parameters b, L, and h.

B. Design of second order tri-band BPF

In order to achieve a wide passband and sharp selective skirt, a second order tri-band BPF based on the first order filter introduced previously is designed. The geometry is shown in Fig.1 (b) with the marked dimensions. The simulated S-parameter



(a)



(b)

Fig. 5. (a) Photograph of the proposed filter; (b) Simulated and measured S-parameters of proposed second order tri-band BPF.

of the proposed filter is shown in Fig. 5 (b) with dotted line. The filter has three passbands with the center frequencies 2.62 GHz, 4.21 GHz and 5.25 GHz. Each passband has two transmission poles. Also, we can see that it has a parasitic mode at the frequency f_s, which is produced by the pair of U-shape slots. It is essential to make a trade-off between the performance of the three passbands and suppression of parasitic mode. After the optimization, the final dimensions of the proposed filter are given in Table I. The ILs are 1.08 dB, 1.55 dB and 2.91 dB, and the RLs are 23 dB, 13.3 dB and 11.6 dB, respectively, and the suppression of parasitic mode is 20 dB. Then, the filter is fabricated on a substrate with dielectric constant of 2.55 and thickness of 0.8 mm, as shown in Fig. 5 (a). Fig.5 (b) provides the simulated and measured S-parameters of the proposed filter. The measured results show that the proposed filter has three passbands, and all the measured RLs are better than 11 dB. Both of them have a good agreement with the simulated results. However, the measured ILs of the three bands are 3.48 dB, 4.82 dB and 4.88 dB, respectively, which are much higher than the simulated results, as shown in Fig.5 (b). The main reason is that the fabricated PCB board has a larger dielectric loss tangent, leading to higher energy loss and a higher IL.

III. Conclusion

A compact first order tri-band BPF using a single SIW cavity is firstly presented and analyzed. The offset feed-line consists of microstrip lines and L-shape slots is applied to achieve the expected tri-band BPF. Then, a second order tri-band BPF based on the first order tri-band filter is proposed and designed to improve the passband selectivity. The proposed filters have very compact configuration and high selectivity, which can be applied to the multiband communication systems.

TABLE I

Dimensions of the Proposed Tri-Band BPF(Unit: mm)

W	W_1	W_2	W_3	W_4	W_5	H	D
2.2	1.2	0.35	0.2	0.46	0.46	48	19.75
L	L_1	L_2	L_3	L_4	L_5	R	H_d
100	10.5	25	1.7	4	15.7	0.5	10.1

Acknowledgment

This work is supported in part by the National Natural Science Foundation of China under Grant 61372077, Grant 61801299, and Grant 61871433, in part by Shenzhen University Research Startup Project of New Staff (20188082), in part by the NTUT-SZU Joint Research Program (2018009), in part by the Fundamental Research Funds for the Central Universities (2017ZD044), in part by the Natural Science Foundation of Guangdong Province (2018A030313481), in part by the Shenzhen Science and Technology Programs (JCYJ 20180207154824493, JCYJ 20170302150411789, JCYJ 20170302142515949, GCZX 2017040715180580, GJHZ 20180418190529516), and in part by Guangzhou Municipal Science and Technology Program (201707010490).

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] 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.

[3] F. Wei, P. Y. Qin, Y. J. Guo and X. W. Shi, "Design of multi-band bandpass filters based on stub loaded stepped-impedance resonator with defected microstrip structure," *IET Microw. Antennas Propag.*, vol. 10, no. 2, pp. 230-236, 2016.

[4] M. T. Doan, W. Q. Che, W. J. Feng, "Tri-band bandpass filter using square ring short stub loaded resonators," *Eletron. Lett.*, vol. 48, no. 2, pp. 106-107, Jan. 2012.

[5] X. M. Lin and Q. X. Chu, "Design of triple-band bandpas filter using tri-section stepped-impedance resonators," *in Proc. Int. Conf. Microw. Millimeter Wave Tech.*, Guilin, China, Apr. 2007, pp. 1-3.

[6] Y.-C. Chen, Y.-H. Shieh, C.-H. Her, and C.-I. G. Hsu, "Tri-band microstrip BPF design using tri-section SIRs," *in Proc. IEEE AP-S Int. Symp. Dig.*, Jun. 2007, pp. 3113-3116.

[7] H. W. Wu, G. S. Chen and Y. W. Chen, "New Compact Triple-Passband Bandpass Filter Using Multipath-Embedded Stepped Impedance Resonators," *IEEE Microw. Wirel. Compon. Lett.*, vol. 24, no. 3, pp. 158-160, Mar. 2014.

[8] S. W. Wong, F. Deng, Y. M. Wu, L. Zhu, Q. X. Chu and Y. Yang, "Individually Frequency Tunable Dual- and Triple-band Filters in a Single Cavity," *IEEE Access*, vol. 5, pp. 11615-11625, 2017.

[9] Y. Dong, C. -T. M. Wu and T. Itoh, Miniaturised multi-band substrate integrated waveguide filters using complementary split-ring resonators," *IET Microw. Antennas Propag.*, vol. 6, no. 6, pp. 611-620, 2012.