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Design of Triple-Bandpass Filters Using an Asymmetric Stepped-Impedance Ring Resonator

Wensong Wang[1], You Li[2], Qunsheng Cao[2, *], Shuhui Yang[3], and Yinchao Chen[4]

Abstract—An asymmetric stepped-impedance ring resonator (ASIRR) is proposed for the design of a triple-bandpass filter. This resonator is applied to create the former two passbands by utilizing a stepped-impedance circular ring and the third passband by introducing two asymmetric coupling structures. It is found that the S-parameter performance can be improved by adding a pair of shorted and open stubs, and the second passband and the stopbands on both sides of the third passband can be tuned by adjusting the length of open stubs. A prototype filter operating at 1.04, 3.52 and 5.57 GHz is designed, fabricated, and measured with the corresponding fractional bandwidths of 23.1%, 7.4%, and 4.1%. Good agreements between the simulated and measured results are achieved for the ASIRR filter. Also, four transmission zeros are generated.

1. INTRODUCTION

Triple-band bandpass filters (BPFs) play an important role in multi-band multi-standard wireless communication systems and are investigated for various RF circuit applications [1–7]. As an essential component of a triple-band transceiver, a BPF is allowed to transmit three frequency band signals and filter out any unwanted ones. So various approaches have been proposed to design triple-band BPFs as follows: (i) the combination of three single-band resonators to share the same input and output ports [8–11], but the overall size is large; (ii) the combination of one dual-band resonator and the other single-band one [12]; (iii) only one set of resonator, which employs the second and third harmonics, such as stub-loaded resonators [13]; (iv) splitting single passband to three passbands by transmission zeros, which are generated by stubs or cross-coupling [14], but it is not applicable to the case of widely spaced passbands. Normally, a stepped-impedance resonator (SIR) filter circuit has a simple structure by using a well-established design method, and its resonant frequencies can be easily tuneable by adjusting different geometry dimensions, although it may be difficult to retain a satisfactory bandwidth at each passband [15].

In this article, an asymmetric stepped-impedance ring resonator (ASIRR) filter is proposed with a pair of stubs. The resonator employs two parts: one is a stepped-impedance circular ring, and the other is two asymmetric coupling structures. The former is resonated at the first and second passbands, and the latter works at the third passband. By adding a pair of shorted and open stubs, the filter can be tuned to achieve the desired passbands and bandwidths. The triple-band ASIRR filter is fabricated and measured to validate the design concept.

2. DESIGN CONCEPT

The top view of the proposed ASIRR is shown in Fig. 1(a). It consists of a symmetric stepped-impedance circular ring and two outer asymmetric microstrip arcs with input/output ports. Different

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* Corresponding author: Qunsheng Cao (qunsheng@nuaa.edu.cn).

[1] Nanyang Technological University, Singapore. [2] Nanjing University of Aeronautics and Astronautics, China. [3] Communication University of China, China. [4] University of South Carolina, USA.

from a traditional stepped-impedance ring resonator [15], this resonator introduces two segments of uniform microstrip lines which couple on the stepped-impedance circular ring. Due to symmetries of the axes of x-x' and y-y' as shown in Fig. 1(a), the stepped-impedance circular ring is equivalent to a multi-mode stepped-impedance transmission-line model as shown in Fig. 1(b). Herein, Z_i and θ_i ($i = 1$, 2, 3, 4, and 5) are respectively the characteristic impedance and electrical length of line section i. Fig. 1(c) shows the approximate one of two sets of asymmetric coupling structures. Each coupling structure consists of a stepped-impedance line and a uniform microstrip line, and is asymmetric about axis x-x'. Fig. 1(d) shows the S-parameters of the ASIRR with $\varphi_1 < \varphi_2$, and the ASIRR has five resonant frequencies f_j ($j = 1$, 2, 3, 4, and 5). The resonant conditions for a multi-mode model can be formulated by the transmission-line theory [16]. In this case, the first mode is utilized to generate the first resonant frequency f_1, while the second and third modes can create the second and third ones, f_2 and f_3, respectively. The latter two resonant frequencies, f_4 and f_5, may be contributed by

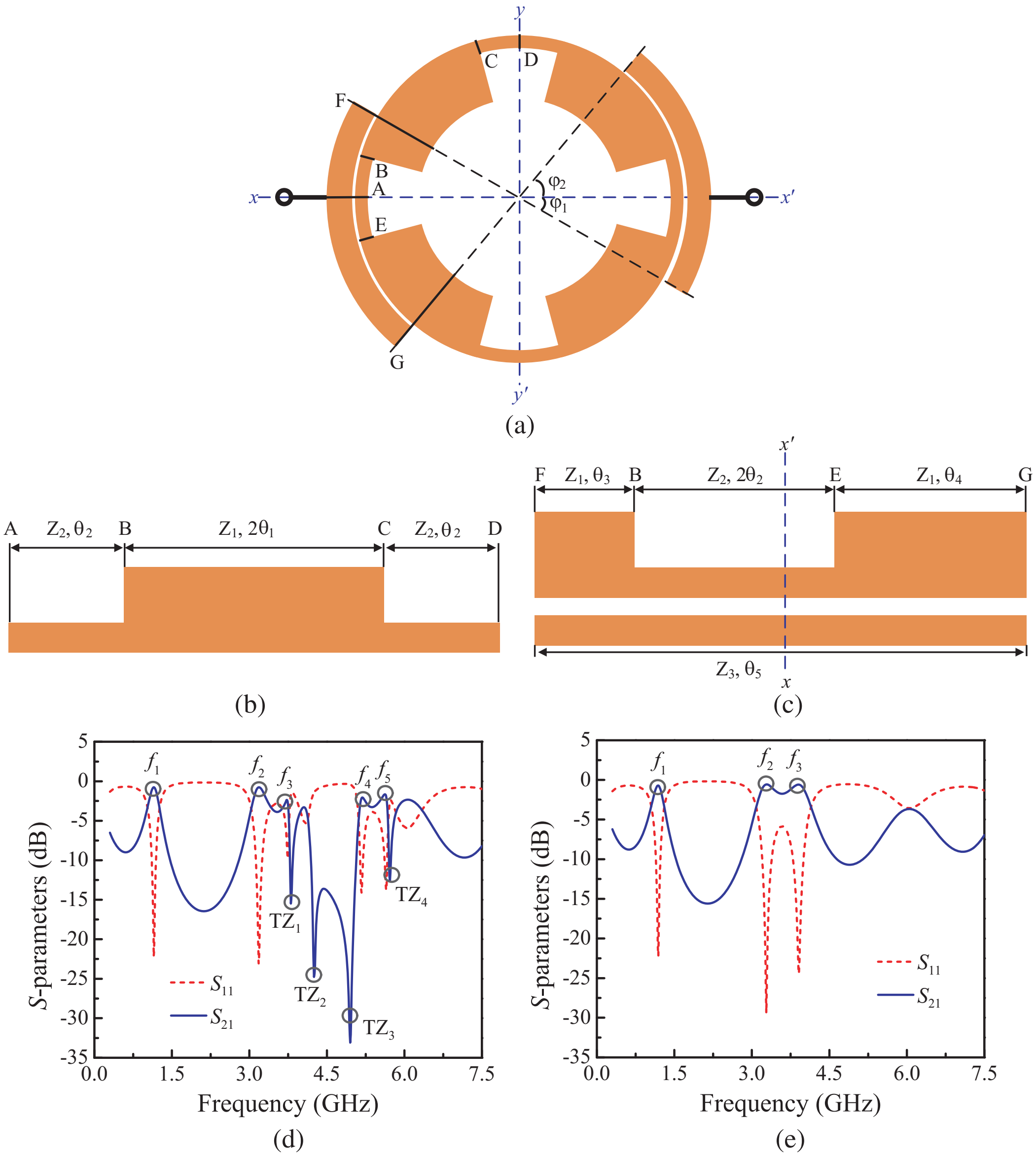

Figure 1. Top view of the proposed ASIRR, and its corresponding transmission-line model. (a) Top view of the proposed ASIRR; (b) Multi-mode model; (c) Approximate asymmetric coupling structure; (d) S-parameters of the ASIRR with $\varphi_1 < \varphi_2$; (e) S-parameters of the ASIRR with $\varphi_1 = \varphi_2$.

two asymmetric coupling structures. But if the coupling structure is symmetric about axis x-x', i.e., $\varphi_1 = \varphi_2$, and f_4 and f_5 are not activated in the S-parameters shown in Fig. 1(e). In the ASIRR case, f_1 is utilized to generate the first passband, and f_2 and f_3 can create the second passband, while f_4 and f_5 can form the third passband. In addition, four transmission zeros (TZ$_1$, TZ$_2$, TZ$_3$, and TZ$_4$) are produced and presented on both sides of the third passband, where the first three transmission zeros are located between the third and fourth resonant frequencies, f_3 and f_4. They can improve the skirt selectivity. This is mainly due to the asymmetry and coupling properties of the introduced structures.

The defined impedance ratio $K = Z_1/Z_2$ and electrical length ratio $\alpha = \theta_1/\theta_2$ are used to analyze the features of the stepped-impedance circular ring [15]. Fig. 2 shows the calculated frequency ratios (f_i/f_1, $i = 2$ and 3) versus K for different values of α. It is found that when α is unchanged, as the value of K increases, f_2/f_1 is almost constant, and f_3/f_1 becomes smaller; when K is unchanged, as the value of α increases, f_2/f_1 has a little change, while f_3/f_1 becomes smaller. The presented relations in Fig. 2 indicate a moving trend of resonant frequencies, which is helpful to tuning the stepped-impedance circular ring working in the bands of interest.

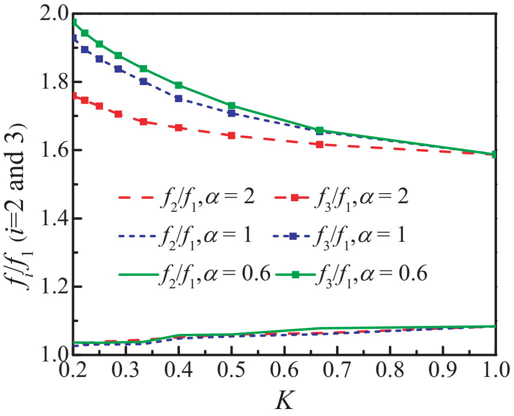

Figure 2. f_i/f_1 ($i = 2$ and 3) versus K for different values of α.

Figures 3(a) and (b) show the proposed asymmetric stepped-impedance ring resonator for two cases of only shorted stubs (L_1 and L_2) and shorted and open stubs together (L_1, L_2, L_3, and L_4), respectively. Figs. 3(c) and (d) plot the corresponding S-parameters, respectively. Compared with Fig. 1(d), S_{21} can be improved in Fig. 3(c), where the second and third passbands present a better performance, because the resonant frequencies f_2 and f_3 become closer, and f_4 tends to f_5. In the meantime, S_{21} becomes smaller between the first and second transmission zeros, and it improves the stopband performance from the second to the third passband.

It is found that by adjusting the length (m) of open stubs (L_3 and L_4) from 1 mm, 5.8 mm to 10 mm, as shown in Fig. 3(b), the centre frequency for the second passband can be tuned, and the high- and low-frequency stopbands on either side of the third passband also changes in Fig. 3(d).

3. ASIRR FILTER DESIGN

The proposed filter is designed and fabricated with the substrate of Rogers RO4350(tm), which has the thickness of 0.508 mm, relative dielectric constant of 3.66, and loss tangent of 0.004. The copper layer is printed on a substrate with thickness of 0.017 mm and conductivity of 5.8×10^7 S/m. $K = 0.35$ and $\alpha = 3.7$ are considered for the triple-band design with centre frequencies of 1.02, 3.52, and 5.58 GHz. As seen in Fig. 4, the low-impedance Z_1 is estimated to be 15.49 Ω with line width ($a + b$) of 5.3 mm, and the high-impedance Z_2 is about 44.79 Ω with line width (b) of 1.3 mm. The other parameters are designed with $d = 0.2$, $e = 0.5$, $u = 1.8$, $v = 1$, $m = 9.5$, $n = 1$, $g = 0.21$, $w = 2$, and $r = 12.5$, all in mm, in addition to $\varphi_1 = 30°$, $\varphi_2 = 49.5°$, $\varphi_3 = 35.5°$, and $\varphi_4 = 9.5°$. Compared with the input/output ports of a traditional ring filter, which are typically spatial-separated by 90°, the input/output ports of

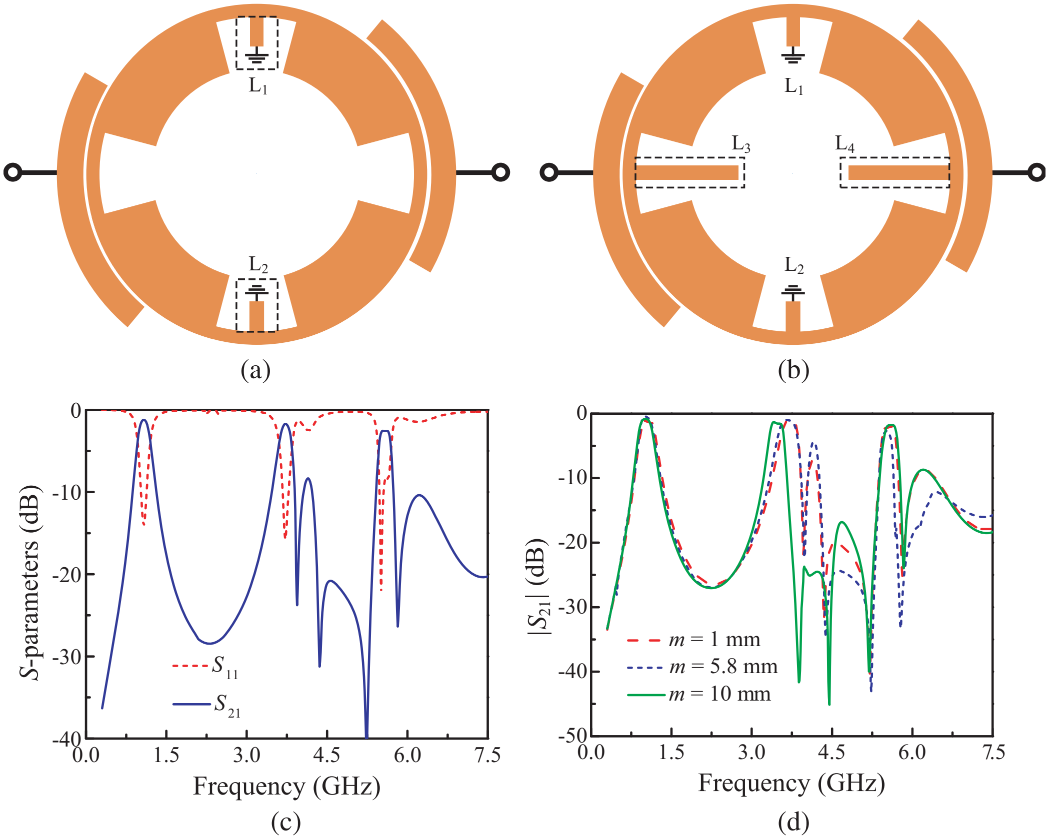

Figure 3. ASIRR with a pair of shorted and open stubs, and the corresponding S-parameters. (a) ASIRR with shorted stubs L_1 and L_2; (b) ASIRR with shorted stubs L_1 and L_2, and open stubs L_3 and L_4; (c) S-parameters for Fig. 3(a); (d) S-parameters for Fig. 3(b).

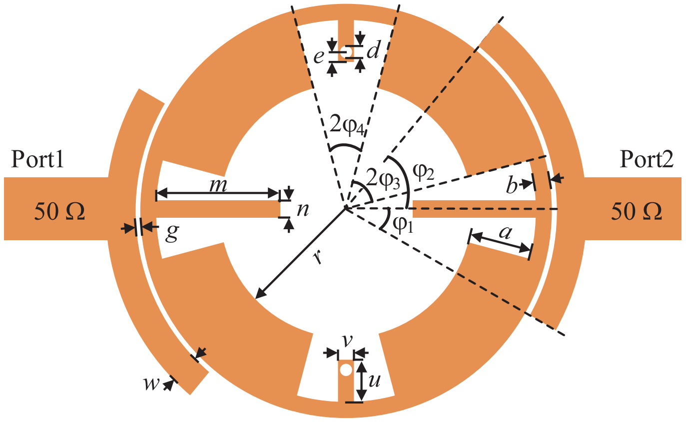

Figure 4. Top view of the proposed triple-band BPF.

this design are in a straight line and connected to ASIRR by 50 Ω microstrip lines. The simulation is accomplished in the HFSS environment.

The fabricated filter is shown in Fig. 5. Fig. 6 shows the simulated and measured S-parameters of the triple-band filter, which are in good agreements. The measurement is performed by an R&S ZVA67 vector network analyzer. As seen in Fig. 6, the measurement curves are selected from many sets of measured results for different fabricated filters. They seem to be better than the simulations,

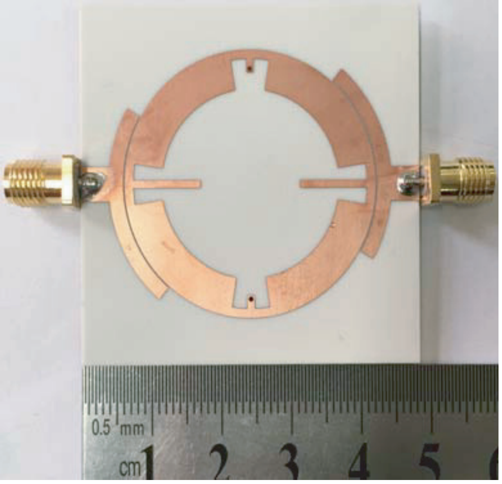

Figure 5. Photograph of the fabricated filter.

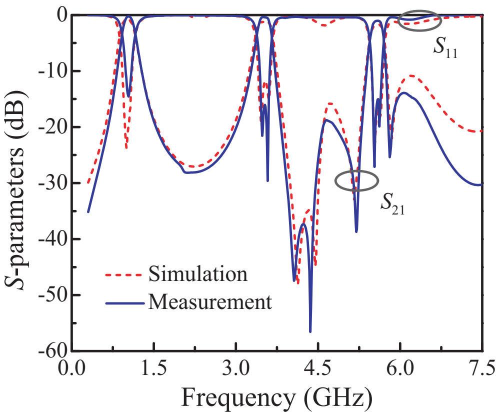

Figure 6. Simulated and measured S-parameters of the triple-band BPF.

due to the unpredictable errors of fabrication process. The simulated 3-dB fractional bandwidths are about 26.6%, 8.5%, and 3.9% at centre frequencies of 1.02, 3.52, and 5.58 GHz, while the measured bandwidths are 23.1%, 7.4%, and 4.1% at centre frequencies of 1.04, 3.52, and 5.57 GHz, respectively. The measured insertion/return losses at the corresponding centre frequencies are 0.24/14.56, 0.39/16.31, and 1.05/16.16, all in dB, respectively. The measured rejection band at the level of −20 dB from the first to second passbands is across 1.53 through 3.01 GHz, and the −18 dB rejection band between the second and third passbands ranges from 3.8 to 5.31 GHz. The high-frequency stopband starts at 5.75 GHz with an insertion loss of greater than 11.5 dB.

4. CONCLUSION

In this article, a novel resonator is presented to develop a triple-band BPF by applying a stepped-impedance circular ring and asymmetric coupling structures. The prototype filter is fabricated with a compact size of $0.27\lambda g \times 0.21\lambda g$, where λg is the guided wave-length of 50 Ω microstrip line at the centre frequency of 1.04 GHz of the first passband. The measured and simulated results are shown with good agreements, and four transmission zeros are also generated. The S-parameters can be improved by adding a pair of shorted and open stubs. Also, the second passband and stopbands can be tuned by adjusting the length of the open stubs.

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