High-selectivity Dual-band Bandpass Filter By Utilizing Asymmetrical Stepped-impedance Resonator

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ABSTRACT

This paper proposed a high cutoff rejection of dual-band bandpass filter by utilizing an asymmetrical stepped-impedance resonator. The dual-band bandpass filter with high-selectivity is introduced the controllable transmission zeros (TZs) with good cutoff signal rejection to improve the signal responses. The transmission zeros are present between the first resonant filter and the second passband filter to combine a good cutoff signal rejection. The TZs are located at both side passbands of both filters to suppress harmonic signals and achieve a reasonable cutoff rate in the out-off band. The first filter is operated at the operational resonance of 1.8 GHz, and another one is designed at 2.45 GHz. The coupled feed lines filters can combine two passband filters that enable an easy dual-band structure. Both minimum passband's insertion losses are 1.35 dB, and the harmonic signal suppression between the first and the second passband is less than 20 dB of the frequency range 1.9 to 2.3 GHz. A high-selectivity performance with an asymmetrical stepped-impedance resonator can be applied in many wireless communications.

Keywords: dual-band, asymmetrical stepped-impedance resonator, high-selectivity

1. INTRODUCTION

In RF/Microwave communication systems, filter plays an essential and significant component in the RF front ends of both the receiving and transmitting channel. This filter can be fabricated on a variety of material types. Mainly, filter structures are familiar to planar filter circuits, which are easily fabricated by this technology. The commercial applications also used used these suitable materials due to their compactness, lightweight, and low fabrication process cost [1]. A multiband bandpass filter (BPF) is a significant device in modern multi-services, such as a dual-band filter. This kind of filter has been used widely as a vital circuit component in dual-band wireless communications as in [2-7]. Lately, many research papers have been represented to improve the bandpass filter response for multiband communications [8-14], which compact size, lightweight, and high signal performance of filter design are essential factors in modern communications.

However, most planar bandpass filters are fabricated by using half-wavelength resonators, which have a harmonic signal at the multiples of mid-band frequency. This inherent problem of harmonic frequencies is unwanted for a highly responsive receiver. A wide suppress harmonic is necessary to get rid of the coming signals into the channel signal path. Some research works [15–18] are proposed the slow-wave effect of stepped-impedance

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resonator filters to suppress these harmonic signals from the desired frequencies to improve the wider stopband. Based on an asymmetric open-loop stepped-impedance resonator such as in [19], a small-size cross-coupled resonator filter reducing the upper side frequency harmonic was presented. This kind of filter configuration is introduced as a size diminution.

Therefore, the asymmetric resonator filter with a high cutoff rejection technique is challenging to create a dual-band filter out of the passband response. A simple and practical method for filter design is challenging in recent years. The significantly attenuated signal of the out of signal rejection is also demanded to isolate the first and second resonant frequency band's closeness. Controllable transmission zeros (TZs) can be used to achieve this kind of required attenuation.

This paper presents a straightforward configuration of a dual-band bandpass filter by utilizing asymmetrical stepped-impedance resonators. The dual-band bandpass filter made suitable compactness and low complexed-structure of asymmetrical stepped-impedance. Two bandpass filters are designed independently and combined using the input/output coupled feeder, which is easily used to excite the frequency signal in a dual-band bandpass filter. The closeness attenuation between the first resonant frequency and the second resonant frequency can be controlled using this coupled feed structure.

2. MATERIALS AND METHODS

2.1ASYMMETRICAL STEPPED-IMPEDANCE RESONATOR

The proposed open loop asymmetrical stepped-impedance resonator is divided into two sections, as shown in Figure 1.

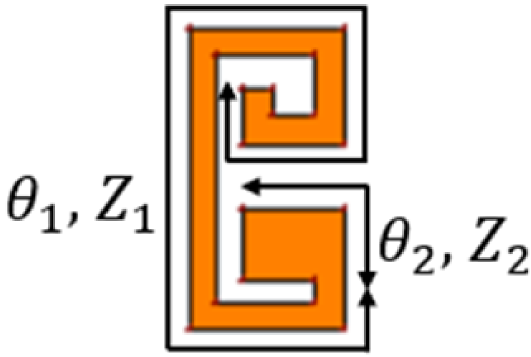


Figure 1. Resonator filter by using an asymmetric half-wavelength structure

The characteristic impedance (Z_1 and Z_2) refers to the different characteristic impedance of a transmission line with the electrical lengths (θ_1 and θ_2), respectively. The stepped discontinuity between the two sections has no influences which assume that the opened-gap of the asymmetric resonator is referred to the input admittance (Y_i), which can be explained in [19]

$$Y_i = jY_1 \frac{\tan\theta_1 + R_Z \tan\theta_2}{1 - R_Z \tan\theta_1 \tan\theta_2} \quad (1)$$

Where

$$R_Z = Y_2/Y_1 = Z_1/Z_2$$

For during resonant mode, the required condition can be expressed as

$$\tan\theta_1 + R_Z \tan\theta_2 = 0 \quad (2)$$

As calculated in equation (2), it can be mentioned that the resonant condition of asymmetric stepped-impedance resonator not only considers the impedance ratio R_Z but also considers the length of the line (L_n). The normal length of impedance resonator can be calculated by

$$L_n = (\theta_1 + \theta_2)/\pi$$
$$= \left(\theta_1 + tan^{-1}\left(-\frac{\tan\theta_1}{R_Z}\right)\right)/\pi \quad (3)$$

For $R_Z = 1$, the resonator's normal length is one that agrees with the case of a standard uniform impedance resonator. When $R_Z > 1$, in this case, the value of resonator length is less than one. It means that the resonator length is shorter than the standard length of a normal resonator. Therefore, the reduced size of the resonator is presented in this case.

2.2 BANDPASS FILTER UTILIZING ASYMMETRICAL STEPPED-IMPEDANCE RESONATOR

The asymmetrical stepped-impedance resonator filter can be designed independently at its operating frequency. First step: the first filter is designed at the center frequency of 1.8 GHz with 50 MHz bandwidth (fractional bandwidth, FBW=4.4%). The second step: The second resonant frequency filter is designed at resonant frequency 2.45 GHz with 50 MHz bandwidth (FBW=3.5%).

Using asymmetrical resonator structure as shown in Fig. 1, the represented half-wavelength microstrip resonator filters are asymmetrical open-loop resonators. looks alike. The resonator filters were optimized by using IE3D full-wave EM simulators. A capacitively coupled port stimulates the asymmetrical resonator via ports 1 and 2. For example, in this design, a second-degree Chebyshev microstrip bandpass filter was simulated and fabricated using a microstrip resonator technology. A printed circuit board (PCB), Rogers RO3006 dielectric substrate h = 1.27 mm, the permittivity e_r= 6.15, and the loss tangent value (0.0027) is selected for the filter design. The schematic structure of the asymmetrical stepped-impedance resonator filter is shown in Figure 2. Herein, the asymmetrical half-wavelength uniform stepped-impedance resonator filters are selected to fabricate the BPF resonator for compact size and straightforward structure. The distributed coupling technique is employed to feed the input/output load. This coupling-feed of the loading effect is minimal, and the independent filter design for two passbands can be designed using this efficient method. Thus, it is very flexible to control the passband for the proposed dual-band resonator filter. The coupling coefficient factor and the external quality factor are used to determine the physical dimensions of the BPF [20]. When the fractional bandwidth (FBW) and center frequency are given, the coupling coefficients factors and external quality factors which are necessary to calculate then can be achieved by

$$K_{ij} = \frac{FBW}{\sqrt{g_1 g_2}} \qquad (4)$$

$$Q_e = \frac{g_0 g_1}{FBW} \qquad (5)$$

Where the normalized g-value elements are the values of the lumped lowpass prototype circuit. The value g_0 and g_2 are 1.0, and g_1 is 1.4142 for Chebyshev response. The coupling-coefficients can be obtained from the two dominant resonant modes when the coupled resonators are synchronously tuned nearby, i.e., f_{p1} and f_{p2}. The coupling coefficient can then be obtained by

$$K_{ij} = \frac{f_{p2}^2 - f_{p1}^2}{f_{p2}^2 + f_{p1}^2} \qquad (6)$$

where K_{ij} is the coupling coefficient between two resonators, i and j. Furthermore, the external quality factor can then be expressed in the below equation.

$$Q_e = \frac{f_0}{\Delta f_{3-dB}} \qquad (7)$$

Where f_0 and $\Delta f_{3\text{-dB}}$ represent the resonant mode and the 3dB bandwidth of the input/output resonator response, respectively, the prototypes of asymmetrical resonator filters are designed for the fundamental resonant frequencies at 1.8 GHz and 2.45 GHz with the fractional bandwidth (FBW=4.4% at 1800 MHz and 3.5% at 2450 MHz), respectively. The external coupling gap (g) and the internal coupling space (s) can be excited, as in Figure 2. The corresponding external quality factors (Q_e) are 31.85 for the first band and 48.49 for the second band. The coupling coefficient (K_{12}) is 0.037 for the fundamental resonant frequency f_1 = 1.8 GHz, and K_{12} is 0.029 at 2.45 GHz, respectively.

The coupling coefficients factor and external quality factors of the asymmetric resonator are portrayed in Figure 3(a) and (b), respectively. Therefore, the physical dimensions of the BPF resonator filter can be easily analyzed by these plotted curves.

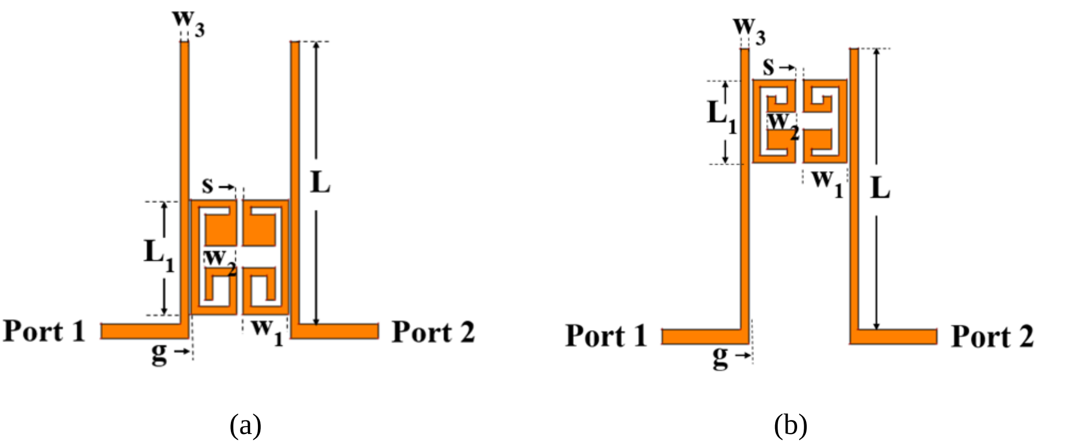


Figure 2. The layout of asymmetric half-wavelength stepped-impedance resonator filter (a) at the operating frequency 1.8 GHz (b) at the operating frequency 2.45 GHz

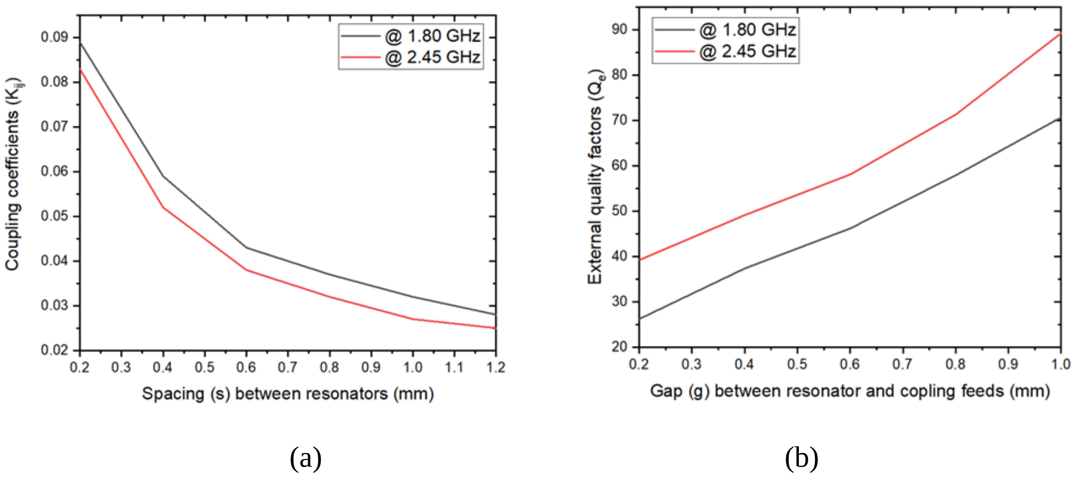


Figure 3. (a) Coupling coefficient curves and (b) External quality factors

Table 1 Dimensions of dual-band resonator filter using an asymmetrical stepped-impedance resonator

Dimensions	f_1=1.8 GHz	f_2=2.45 GHz
Resonator length (w_1)	5.8 mm	5.5 mm
Resonator length (w_2)	4 mm	3.5 mm
Coupling-feed width (w_3)	1 mm	1 mm
Space between coupling-feed and resonator (g)	0.26 mm	0.49 mm
Spacing between resonators (s)	0.77 mm	1.06 mm
Resonator length (L_1)	14.4 mm	10.6 mm
Resonator length (L)	37 mm	37 mm
Distance (D) between two resonant frequencies	5 mm	5 mm

The IE3D simulator is used to distribute the current flows of the proposed asymmetrical resonator filters. Figure 4(a) shows the current flows of the filter designed at the operating frequency at 1.8 GHz, and figure 4(b) displays the EM simulation of S-parameters at a resonant frequency of 1.8 GHz. Figure 4(c) illustrates the current flows of the second filter operating frequency at 2.45 GHz, and figure 4(d) shows the EM simulation of S-parameters at a resonant frequency of 2.45 GHz. It can be observed that two bandpass filters (the first and second bandpass filters) exhibit reasonable TZs at both sides of center frequencies.

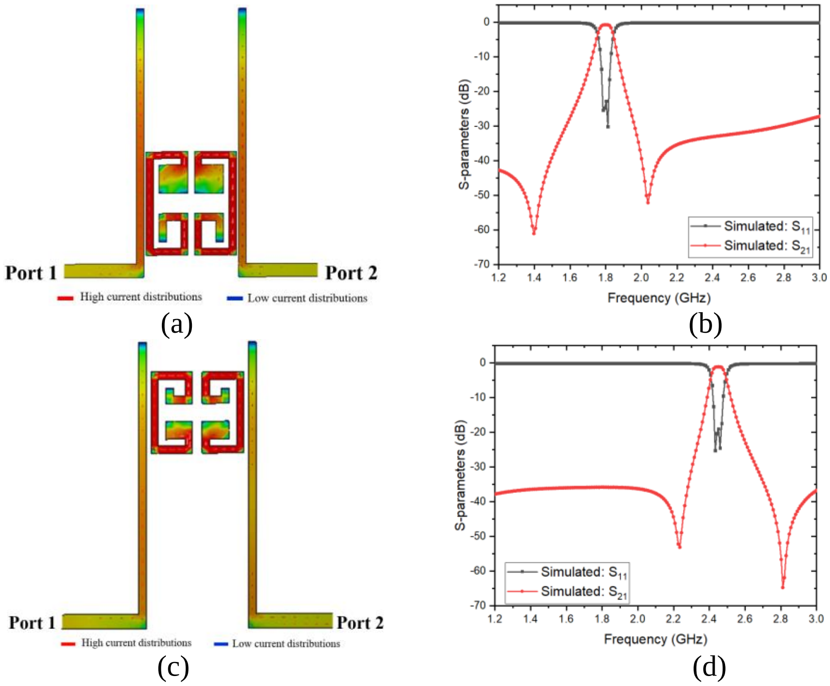


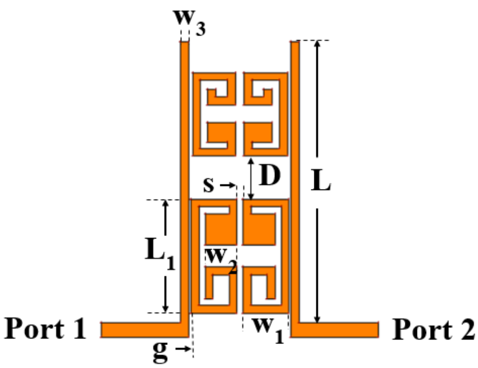
Figure 4. Simulated results of the proposed resonator filters (a) Flows of current distribution at the center frequency of 1.8 GHz (b) S-parameters at 1.8 GHz (c) Distributed current flows at 2.45 GHz (d) S-parameters at 2. 45 GHz

3. RESULTS AND DISCUSSION

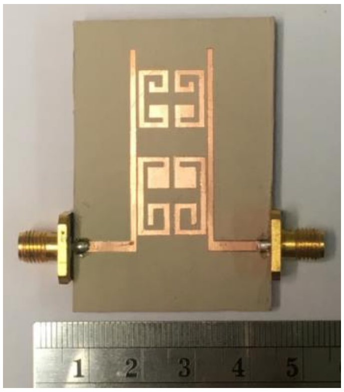
3.1 DUAL-BAND BANDPASS FILTER By UTILIZING ASYMMETRICAL STEPPED-IMPEDANCE RESONATOR

Two different asymmetrical stepped-impedance resonator filters must be placed between two transmission coupled-lines terminated by an open end to excite dual passbands. The input/output (I/O) microstrip coupled-feed structure is represented as the feeding line. Typically, the coupling degree between two resonators and the low insertion loss can be achieved by a small coupling-gap, narrow coupled-line, and the long coupled-line lengths of the feeders. Because the coupled-gap, width of a line, and length of a line can be optimized appropriately to receive the proper input/output coupling values.

The proposed dual-band structure is presented in Figure 5(a). The matching coupled-feed line of the input feed 50 Ω line is used to appropriately couple the two filters. Figure 5(b) shows a photograph of the fabricated dual-band filter prototype. Figures 5(c) and 5(d) show the flow of distributed current at the resonant frequency of 1.8 GHz and 2.45 GHz, respectively. Agilent Vector Network Analyzer is used to carry out the Measurement results. The realizable physical sizes of the BPF are listed in Table 1. Figure 5(e), the controllable TZs can be adjusted by changing the distance of two resonator filters. From Figure 5(f), the dual-band by using asymmetric resonator filter exhibits the insertion losses (|S_{21}|) less than 1.15 dB and 1.35 dB, and the return losses (|S_{11}|) better than 20 dB in both frequencies. The excess losses in the measured results are mainly from the loss of conductor, SMA connection port between the input/output port, and fabrication errors from the milling machine, making the prototype.

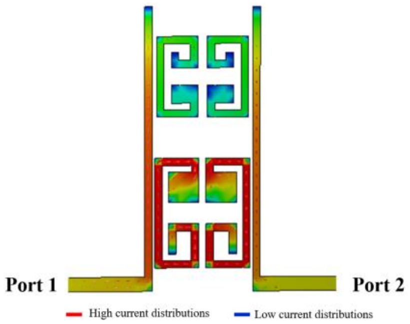


(a)

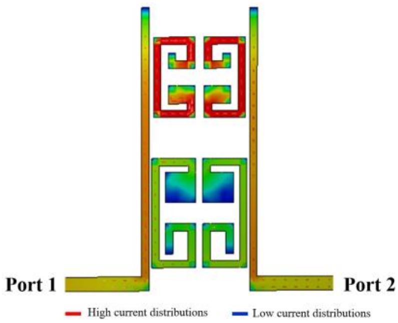


(b)

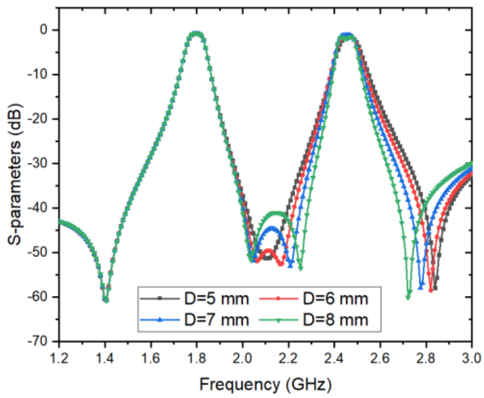
Figure 5. (a) Schematic structure (b) Photograph of real configuration (c) Distributed current flows at 1.8 GHz (d) Distributed current flows at 2.45 GHz (e) Simulated controllable TZs and (f) Simulated and measured responses at 1.8 GHz and 2.45 GHz



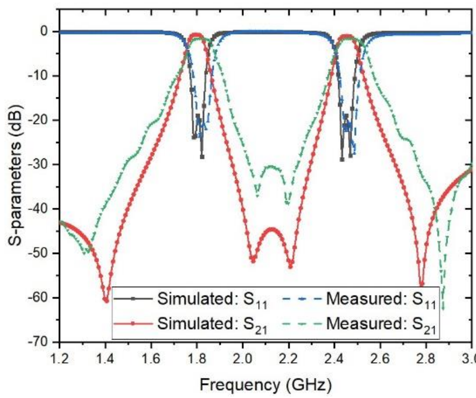
(c)



(d)



(e)



(f)

Figure 5. (Continue) (a) Schematic structure (b) Photograph of real configuration (c) Distributed current flows at 1.8 GHz (d) Distributed current flows at 2.45 GHz (e) Simulated controllable TZs and (f) Simulated and measured responses at 1.8 GHz and 2.45 GHz

A dual-band with an easy and efficient design method is an alternative technique to design by controlling TZ's location. This technique is introduced to improve the dual-band frequency response in which two proximity passbands are close to each other. Controllable transmission zeros (TZs) are achieved by the high-selectivity dual-band bandpass filter response that exhibits the transmission zeros between two passbands with a reasonable cutoff rate.

4. CONCLUSIONS

This research paper presents a dual-band bandpass filter by utilizing an asymmetrical stepped-impedance dual-band filter. Simultaneous size reduction and controllable transmission zeros for the dual-band filter can be achieved in this resonator configuration. A dual-band configuration with controllable transmission zeros location is easily improved with two proximity frequency bands. The places of the TZs are located beside passbands of the filters to suppress the undesired signal. This technique obtains good cutoff rejection in the stopband to improve bandpass signal selectivity and stop the unwanted signal for the dual-band bandpass filter. The 1.8 GHz and 2.45 GHz of an asymmetrical stepped-impedance dual-band filters are demonstrated and measured. The out-of-band signal suppression is better than 20 dB between two passbands, and the insertion loss in each band is less than 1.35 dB. The simulated result accords with the measured result agreement.

5. ACKNOWLEDGMENTS

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