A Novel Dual-Band Microstrip Bandpass Filter Design and Harmonic Suppression

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Abstract **─** This paper proposes a new dual-passband microstrip bandpass filter, which is composed of two asymmetric half-wavelength resonators and four shunt open stubs that provides four transmission zeros. Two short stubs are added to suppress the second harmonic. The relationship of the four transmission zeros and the dimensions of the filter are all provided. The dual-passband microstrip bandpass filter is fabricated with the first passband of 2.4 GHz corresponds to the bandwidth of 0.1 GHz and the second passband of 5.7 GHz corresponds to the bandwidth of 0.25 GHz. The insertion loss of the two passband is less than 1 dB and 3 dB, respectively and the return loss is more than 10 dB. The results of the measured and simulated data agree well.

Index Terms **─** Bandpass filter, dual-band, harmonic suppression, and transmission zeros.

I. INTRODUCTION

Recent development in wireless communication and radar systems has presented new challenges to design and produce high-quality miniature components with a dual-band operation. Therefore, as important component of wireless systems, the filter is required to have dual-band performance. To design the dual-band filter, the simplest way is combining two single-band filters at different passband frequencies [1-3]. But it requires an implementation area twice that of a single-band filter and additional external combining networks. Thus, an integrated filter with a dual-band response is more attractive. Step-impedance resonators (SIR) are utilized in [4-6] and the filters show high skirt selectivity. The method of defect ground structure and shunt open stubs technology are utilized wildly for filter size miniaturization and harmonic suppression [7]. In the filter design process, the shunt stubs are used to create transmission zeros in order to separate the passband and increase the stopband region [8-9].

This paper presents the new applications of shunt stubs for microstrip bandpass filters design. Primarily, the four shunt open stubs not only can be utilized to miniaturize the filter but also can be used to design the dual-band filter. Furthermore, the approach of the shunt short stubs is presented to suppress the harmonic and the harmonic is suppressed more than 10 dB. Finally, the designed filters with transmission zeros at finite frequencies give much improved selectivity. Above all, a dual-band filter with the first passband of 2.4 GHz and the second passband of 5.7 GHz is designed and the bandwidth is 0.1 GHz and 0.25 GHz for the first and second passbands, respectively. The insertion loss is less than 1 dB and 3 dB, respectively, and the return loss is more than 10 dB. The rejection between the two transmission bands is more than -17 dB from 2.7 GHz to 4.8 GHz. The results of the measured and simulated data agree well.

The rest of the paper is organized as follows: the theoretical analysis of the new dual-band filter with four transmission zeros by using two coupling half-wavelength resonators with four shunt open stubs is proposed in section II. The harmonic suppression structure with two short

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stubs is presented in section III. In section IV, a microstrip filter with a dual-passband response is fabricated. The conclusion is given in section V.

II. ANALYZING THE COUPLING OF ASYMMETRIC HALF-WAVELENGTH RESONATORS WITH TWO PARALLEL BRANCHES

Figure 1 shows the configuration of the filter using two asymmetric half-wavelength resonators with four shunt open stubs. The total length of the resonator is $l = 2l_3 + l_2 + l_2 = \lambda_0$, where λ_0 is the guided wavelength at the fundamental resonance. The l_4 connected to the resonator is the shunt open stub. The coupling between the two open ends of the resonators is simply expressed by the gap capacitance C_S [10-11].

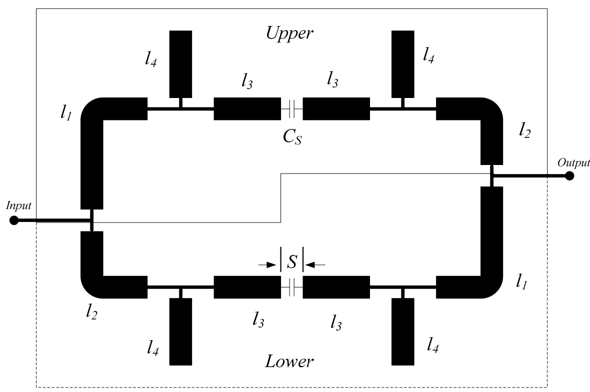


Fig. 1. Configuration of the filter using two asymmetric half-wavelength resonators with four shunt open stubs.

As shown in Fig. 1, the whole circuit represents a shunt circuit, which consists of upper and lower sections. Each section is composed of l_1, l_2, l_3, l_4, and C_S. The ABCD matrices for the upper and lower sections of the lossless shunt circuit are

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{upper} = M_1 M_4 M_3 M_C M_3 M_4 M_2 \,, \quad \text{(1a)}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{lower} = M_2 M_4 M_3 M_C M_3 M_4 M_1 \,, \quad \text{(1b)}$$

with

$$M_n = \begin{bmatrix} \cos\beta l_n & jZ_0 \sin\beta l_n \\ jY_0 \sin\beta l_n & \cos\beta l_n \end{bmatrix} \quad (n = 1,2,3)$$

$$M_C = \begin{bmatrix} 1 & \dfrac{1}{j\omega C_S} \\ 0 & 1 \end{bmatrix},$$

$$M_4 = \begin{bmatrix} 1 & 0 \\ jY_0 \tan\beta l_4 & 1 \end{bmatrix}.$$

Where β is the propagation constant, Z_0 is the characteristic impedance of the resonator, ω is the angular frequency and $Y_0 = 1/Z_0$. The Y-parameters for this circuit can be obtained by adding the upper and the lower section of the Y-parameters, which follow from equations (1a) and (1b), respectively. When the load is matching, S_{21} of the circuit can then be calculated from the total Y-parameters. Furthermore, the transmission zeros can be found by letting $S_{21} = 0$. For a small C_S, an approximate equation can be obtained as,

$$\begin{aligned}&\left[\cos\beta(l_2+l_3)\times\cos\beta(l_1+l_3)-\cos\beta(l_2+l_3)\right]\\ &\times\left[\sin\beta l_1\times\cos\beta l_3\times\tan\beta l_4-\cos\beta(l_1+l_3)\times\sin\beta l_2\times\cos\beta l_3\right]\\ &\times\left[\tan\beta l_4+\sin\beta l_1\times\sin\beta l_2\times\cos\beta l_3^{\,2}\times\tan\beta l_4^{\,2}\right]=0\end{aligned} \quad (2)$$

In generally, we assume $l_1<\lambda_0/4$, $l_2<\lambda_0/4$, $l_3<\lambda_0/4$, $l_4<\lambda_0/4$, where λ_0 is the guided wavelength at fundamental resonance. Thus, we can obtain $\sin\beta l_1\cos\beta l_3\tan\beta l_4 > 0$ and $\sin\beta l_2\cos\beta l_3\tan\beta l_4 > 0$. In addition, we assume $\sin\beta l_1\cos\beta l_3\tan\beta l_4 < 1$ and $\sin\beta l_2\cos\beta l_3\tan\beta l_4 < 1$. The four transmission zeros, f_1, f_2, f_3, and f_4, can be obtained as,

$$f_1 = \frac{c\times n\times \arccos(\sin\beta l_1\cos\beta l_3\tan\beta l_4)}{2\pi\sqrt{\varepsilon_{eff}}\,(l_1+l_3)} \quad \text{(3a)}$$

$$f_2 = \frac{c\times n\times \arccos(\sin\beta l_2\cos\beta l_3\tan\beta l_4)}{2\pi\sqrt{\varepsilon_{eff}}\,(l_2+l_3)}, \quad \text{(3b)}$$

$$f_3 = \frac{c\times n\times \arccos(-\cos\beta l_2\sin\beta l_3\sin\beta l_4)}{2\pi\sqrt{\varepsilon_{eff}}\,(l_1+l_3+l_4)}, \quad \text{(4a)}$$

$$f_4 = \frac{c\times n\times \arccos(-\cos\beta l_1\sin\beta l_3\sin\beta l_4)}{2\pi\sqrt{\varepsilon_{eff}}\,(l_2+l_3+l_4)}. \quad \text{(4b)}$$

Where ε_{eff} is the effective dielectric constant, n is the mode number, and c is the speed of light in free space. According to [12], the two transmission zeros, f_1' and f_2', in the case of without the stub-loaded resonator, can be written as,

$$f_1' = \frac{c \times n}{4(l_1 + l_3)\sqrt{\varepsilon_{eff}}} , \tag{5a}$$

$$f_2' = \frac{c \times n}{4(l_2 + l_3)\sqrt{\varepsilon_{eff}}} . \tag{5b}$$

Comparing equations (3), (4), and (5), the extra passband can be obtained by the shunt open stubs. For the first passband, the center frequency f_{centre} can be obtained as,

$$f_{center} \approx \frac{f_1 + f_2}{2} .$$

According to equation (5), the center frequency f'_{centre}, in the case of without the shunt open stubs, can be written as,

$$f'_{center} \approx \frac{f_1' + f_2'}{2} .$$

Obviously,

$$f_{center} < f'_{center} .$$

From the above analysis, the center frequency of the filter can be shifted to a low frequency by shunt open stubs. Therefore, the shunt open stubs can be used to implement the miniaturization of the half-wavelength resonators filter. However, the method will lead to reduced bandwidth after miniaturization. In the asymmetric half-wavelength resonators structure, the reduced bandwidth can be compensated to increase the distance of the two transmission zeros on the two side of the passband.

III. THE SUPPRESSION OF THE SECOND HARMONIC OF THE FIRST PASSBAND

The dual-band bandpass filter is designed with the first passband 2.4 GHz and the second passband 5.7 GHz, however, the second passband suffered from the effect of the second harmonic of the fundamental passband. To suppress the second harmonic of the fundamental passband, the shunt short stubs, as shown in Fig. 2, are designed. The harmonic suppression method of the shunt open stub is reported in [13], but the method of the shunt short stub can work more effective for a dual-band filter with the second passband of 5.7 GHz.

As shown in Fig. 2, there is a shunt short stub in the center of each half-wavelength resonator. The shunt short stub can make the second resonant frequency of the resonators deviated 2 f_0, where f_0 is the fundamental resonant frequency. Similar to [13], assuming $R = f_1/f_0$, where f_1 is the second resonant frequency and R is the ratio of the second resonant frequency and the fundamental frequency.

$$tanR\theta_s = -2tanR\frac{\theta_r}{2} , \tag{6}$$

where θ_r is the electrical lengths of the resonant and θ_s is the electrical lengths of the shunt short stub.

Equation (6) presents the relationship between the length of the shunt short stub and the second harmonic frequency. And the resonators with different second resonant frequency can make the harmonic suppression more effective [13]. The responses of the filter with and without the harmonic suppression structure are showed in Fig. 3. The second harmonic of the fundamental passband is suppressed more than 10 dB, as shown in Fig. 3 (b).

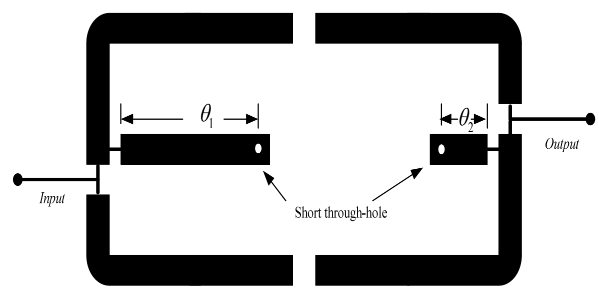
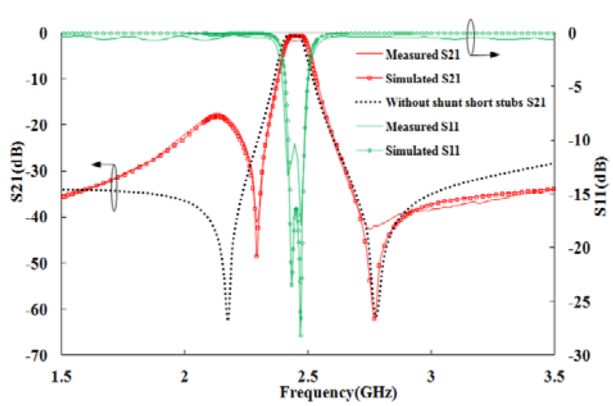
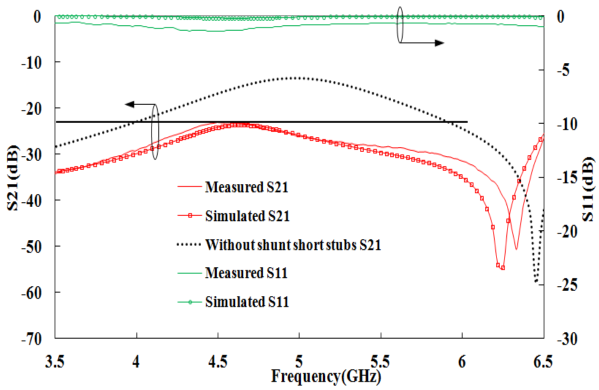


Fig. 2. The asymmetric half-wavelength resonators with shunt short stubs structure.



(a)



(b)

Fig. 3. The responses of the filter shown in Fig. 2 for, (a) the responses of the first passband and (b) the responses of the second harmonic.

IV. DUAL-BAND MICROSTRIP BANDPASS FILTER WITH FOUR TRANSMISSION ZEROS

Based on the theories presented above, a dual-band bandpass filter is designed with the first passband of 2.4 GHz and the second passband of 5.7 GHz. The Agilent technologies' Advanced Design System (ADS) is used for design and optimizing the filter and the commercial TLX dielectric substrate with a relative dielectric constant of 2.45 and a thickness of 0.79 mm is chosen for the filter design. The physical dimensions of the filter and its photograph are shown in Fig. 4.

The S-parameter simulation and measurement results for this filter are shown in Fig. 5. It can be seen that the first passband with center frequency of 2.45 GHz has less than 1dB insertion loss and greater than 10 dB return loss. The second passband with center frequency of 5.7 GHz has less than 3 dB insertion loss and greater than 10 dB return loss. The bandwidth is 0.1 GHz and 0.25 GHz for the first and second passbands, respectively. In addition, the better cutoff rate in the stopband is provided by four transmission zeros.

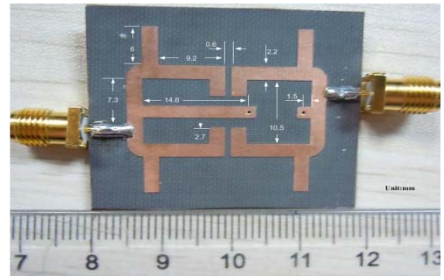


Fig. 4. The photograph of the proposed filter.

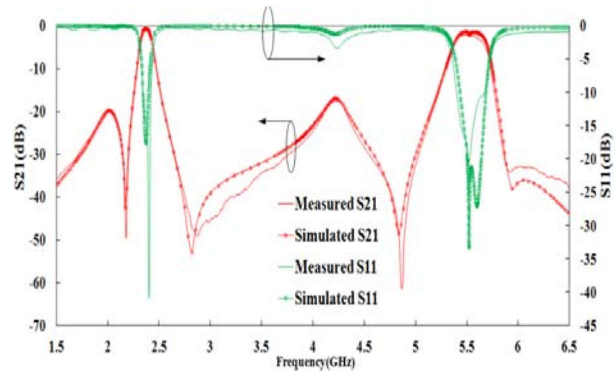


Fig. 5. The responses of the dual-band filter.

V. CONCLUSION

A theory of creating four transmission zeros is proposed by two coupling half-wavelength resonators with four shunt open stubs. Then, in order to suppress the harmonic, the approach of the shunt short stub is presented and the harmonic is suppressed more than 10 dB. Finally, based on the method presented above, a dual-band filter with the first passband of 2.4 GHz and the second passband of 5.7 GHz is designed and the bandwidth is 0.1 GHz and 0.25 GHz for the first and second passbands, respectively. The insertion loss is less than 1 dB and 3 dB, respectively, and the return loss is more than 10 dB. In addition, the designed filters with transmission zeros at finite frequencies give much improved selectivity. The rejection between two transmission bands is more than -17 dB from 2.7 GHz to 4.8 GHz.

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