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COMPACT BANDSTOP FILTER WITH MULTIPLE REJECTION ZEROS

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Abstract—This paper presents a compact band stop filter (BSF) based on the dual metal plane configuration with multiple rejection zeros (RZs). Quasi-lumped technique with novel patch-via-spiral dual mode resonator is applied to the design of the proposed filter. Multiple rejection zeros are introduced by open-end stubs for high selectivity. Design equations are obtained by using a lossless transmission line model. The calculated results show that the lower and upper rejection zeros can be easily tuned by the coupling capacitor and the open-end stubs respectively. By using the Microstrip-Coplanar-Waveguide (CPW) structure, the size of the proposed filter can be reduced to $12.8\,\text{mm} \times 9\,\text{mm}$ (i.e., $0.24\lambda_g \times 0.17\lambda_g$), where λ_g denotes the guided wavelength at center frequency.

1. INTRODUCTION

Bandstop Filters (BSFs) are used to suppress the noise and useless signal. The performance of the filter directly influences the quality of the modern communication system. Lots of researches have been made to enhance the performance of the filter [1–6]. In [1–4], open-end stubs are applied to introduce multiple rejection zeros near the stopband or located far from the stopband for sharp rejection and high selectivity respectively. By using coupling microstrip lines, multiple rejection zeros can also be obtained for good selectivity [5, 6]. However, the large size of these filters do restrict their application. Compact

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structure with high performance becomes increasingly important in modern filter design. Due to the consideration of compact size, Spiral structure and Step Impedance Resonator (SIR) [7–10] are widely used in cases which are sensitive to the size of the filter. Microstrip Coplanar Waveguide (CPW) structure [11, 12] and Defected Ground Structure (DGS) [13–15] are also highly effective ways for reducing the size of filters in their multilayer design technique.

In this paper, bandstop filter with improved frequency selectivity and compact size has been studied. Quasi-lumped technique with novel patch-via-spiral structure is applied to the design of the proposed filter. Lower and Upper rejection zeros are introduced by coupling capacitor and open-end stubs respectively. Due to the symmetrical structure, the even-odd mode analysis technique can be applied to achieve the transmission function to analyze the rejection zeros.

2. COMPACT BANDSTOP STRUCTURE DESIGN

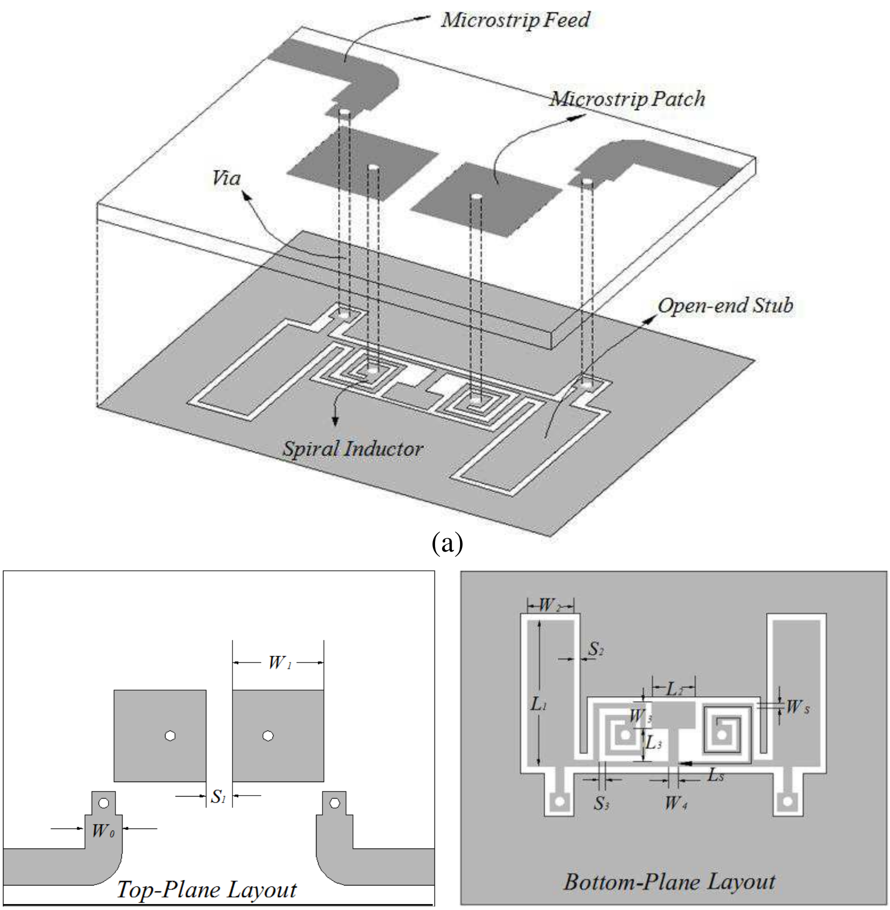
2.1. Wide Stopband Design

Quasi-lumped-circuit design technique is applied in this paper in order to achieve the stop band. The three-dimensional geometry is shown in Figure 1(a). The newly proposed filter is mainly composed of four elements, the microstrip patch on the top plane, the connecting via through the substrate, the grounded spiral resonator on the bottom plane, and three open-end stubs connected to the spiral inductor. The proposed filter is fabricated by using a Rogers RO4350(tm) substrate with relative dielectric constant 3.66 and has a compact size of 12.8 mm × 9 mm, which corresponds to a size of $0.24\lambda_g \times 0.17\lambda_g$.

Note that the capacitor formed by the microstrip patch, CPW spiral conductor and the ground, the equivalent circuit of the proposed filter is shown in Figure 2(a), in which L_1 represents the spiral conductor, C_4 denotes the coupling capacitor between the spiral structure and microstrip patch, C_2 represents the capacitor between the microstrip patch and the ground. C_1 denotes the coupling capacitor between the CPW open-ends and the ground, C_3 stands for the coupling capacitor of the two patch, $\theta_i\,(i = 1, 2, 3)$, $Z_i\,(i = 1, 2, 3)$ denote the electric length and the characteristic resistance of the CPW microstrip line respectively. Due to its symmetrical geometry, the even-odd mode equivalent circuit is shown in Figure 2(b).

The even-mode input admittance without open-end stubs can be calculated as:

$$Y_{ineven1} = \frac{Z_2 + jZ_{L_2}\tan\theta_2}{Z_2(Z_{L_2} + jZ_2\tan\theta_2)} + \frac{\left(1 - \omega^2 L_1 C_4\right) j\omega C_2}{1 - \omega^2 L_1 C_4 - \omega^2 L_1 C_2} \tag{1}$$



(b)

Figure 1. Proposed bandstop filter with multiple rejection zeros. (a) Three-dimensional geometry. (b) Top-bottom plane layout.

where

$$Z_{L_2} = -j2Z_3 \cot\theta_3 \tag{2}$$

The same as the calculation above, the odd-mode input admittance without open-end stubs is:

$$Y_{inodd1} = \frac{\left(1-\omega^2 L_1 C_4\right)\left(j\omega C_2 + j\omega C_3\right) + j\omega L_1}{j\omega L_1 (j\omega L_2 + j\omega C_3)} - j\frac{1}{Z_2}\cot\theta_2 \tag{3}$$

So the transmission function of the equivalent circuit can be given as

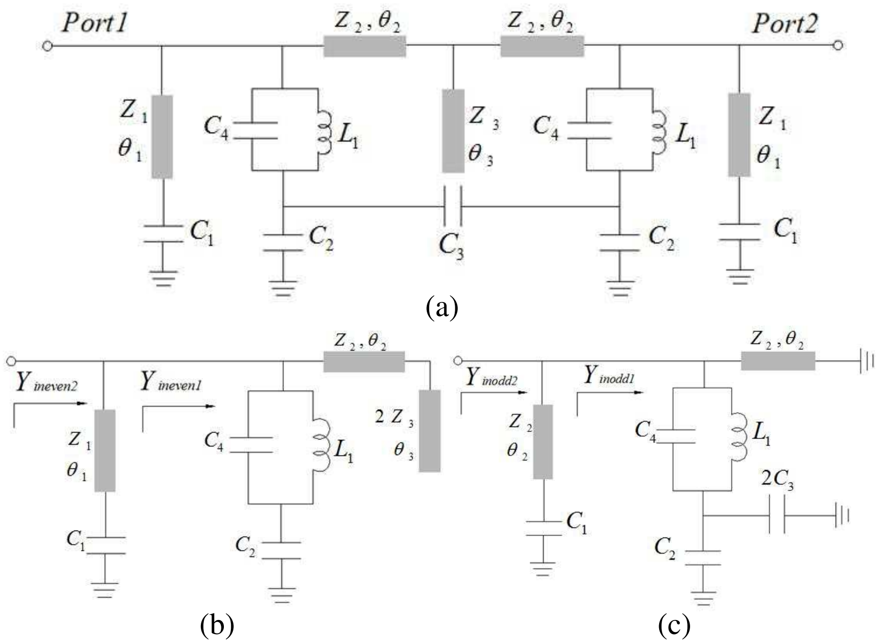


Figure 2. (a) Equivalent circuit of the proposed filter. (b) Even-odd mode equivalent circuit.

below:

$$S_{11} = \left(Y_0^2 - Y_{inodd1}Y_{ineven1}\right)/[(Y_0 + Y_{inodd1})(Y_0 + Y_{ineven1})] \tag{4}$$

So the influence of the spiral resonator to the stopband can be easily calculated, which is shown in Figure 3. The operating stopband shifts to the higher frequency as the spiral inductor decreases.

In the proposed bandstop filter, the $L_1 = 1.508\,\text{nH}$ is chosen, letting $n = 2$, $w = 0.2\,\text{mm}$, $h = 0.508\,\text{mm}$, so the inner and outer diameter of the spiral structure can be roughly calculated as $D_{out} = 1\,\text{mm}$ and $D_{in} = 0.3\,\text{mm}$ from the equations given below [16], therefore the length of the spiral structure can be easily calculated as about $L_s = 5.0\,\text{mm}$.

$$L(\text{nH}) = 0.03937\frac{a^2n^2}{8a+11c} \cdot K_g \quad \text{for} \quad a, c \text{ in } \mu\text{m} \tag{5}$$

$$a = \frac{D_{out} + D_{in}}{4} \qquad c = \frac{D_{out} - D_{in}}{2} \tag{6}$$

$$K_g = 0.57 - 0.145\ln\frac{w}{h} \tag{7}$$

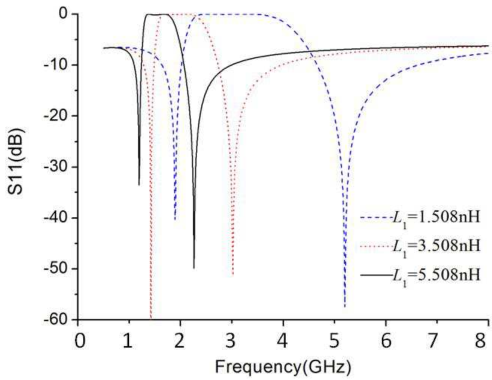


Figure 3. The influence of the spiral inductor to the stopband.

where D_{out}, D_{in} represent the outer and inner diameter respectively, w is the width of the spiral line, h denotes the thickness of the substrate.

On the other hand, there can be only one condition that $Y_{inodd1}Y_{ineven1}/Y_0^2 \to 1$ where $S_{11} \to 0$. The corresponding parameter is $L_1 = 1.508\,\text{nH}$, $C_1 = 0.644\,\text{pF}$, $C_2 = 1.557\,\text{pF}$, $C_3 = 0.16\,\text{pF}$, $C_4 = 0.25\,\text{pF}$, $\theta_1 = 0.104$, $\theta_2 = 0.174$, $\theta_3 = 1.318$, $Z_2 = 122\,\Omega$, $Z_3 = 96\,\Omega$. The result without the two open-end stubs is given in Figure 4. We can easily achieve two rejection zeros in the frequency about 2 GHz and 4.5 GHz which located in the lower and upper band respectively by proper designing of the parameter. The lower rejection zero shifts closer to the operating band as C_3 decreases while the upper rejection zero remains almost unmoved; θ_3 denotes the electric length of the open end transmission line between the two spiral inductor. We can find out the upper rejection zeros shifts closer to the operating band as the θ_3 increases while the lower rejection zeros remains almost stable.

2.2. High Selectivity Design

In order to improve the character of the stop band and achieve high selectivity, an additional reflection zero in the upper band is introduced by the two symmetrical open-end stubs cascaded to the spiral inductor. The even-odd mode analysis technique can also be applied to the new structure for its symmetrical structure.

The even-mode input admittance with open-end stubs is:

$$Y_{ineven2} = \frac{Z_1 + jZ_{L_1}\tan\theta_1}{Z_1(Z_{L_1} + jZ_1\tan\theta_1)} + \frac{Z_2 + jZ_{L_2}\tan\theta_2}{Z_2(Z_{L_2} + jZ_2\tan\theta_2)}$$

$$+\frac{\left(1-\omega^2 L_1 C_4\right) j\omega C_2}{1-\omega^2 L_1 C_4-\omega^2 L_1 C_2} \tag{8}$$

where

$$Z_{L_1}=\frac{1}{j\omega C_1} \tag{9}$$

The odd-mode input admittance is:

$$Y_{inodd2}=\frac{Z_1+jZ_{L_1}\tan\theta_1}{Z_1(Z_{L_1}+jZ_1\tan\theta_1)}+\frac{\left(1-\omega^2 L_1 C_4\right)\left(j\omega C_2+j\omega C_3\right)+j\omega L_1}{j\omega L_1\left(j\omega L_2+j\omega C_3\right)} -j\frac{1}{Z_2}\cot\theta_2 \tag{10}$$

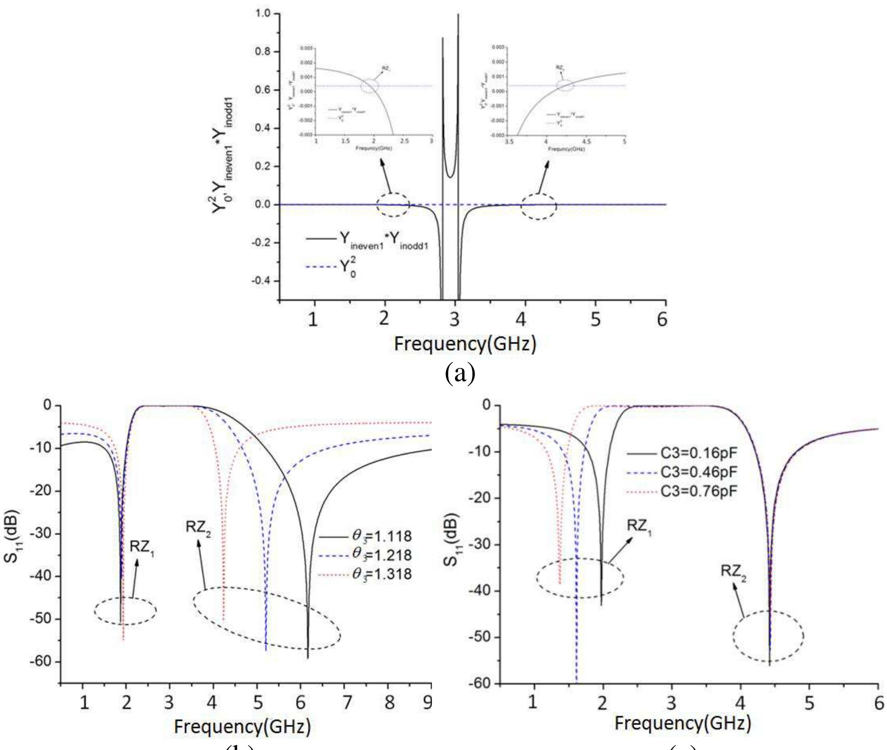
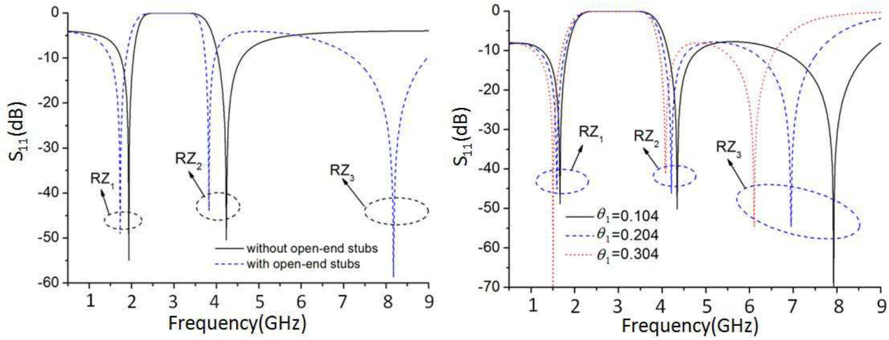


Figure 4. Calculated results of the equivalent circuit without two symmetrical open-end stubs. (a) The introduced two rejection zeros. (b) Influence of the middle open-end stub to the upper rejection zero. (c) Influence of the coupling capacitor in the top layer to the lower rejection zero.



(a) (b)

Figure 5. Calculated results of the equivalent circuit with two symmetrical open-end stubs. (a) The RZ_3 introduced by the two symmetrical open-end stubs. (b) Influence of the open-end stubs to the RZ_3.

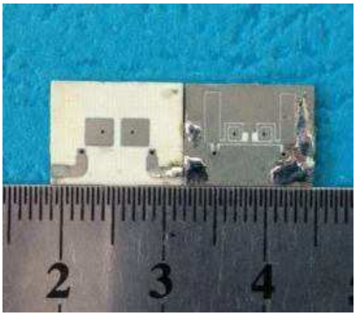
The transmission function of the equivalent circuit can be given as below:

$$S_{11} = (Y_0^2 - Y_{inodd2}Y_{ineven2})/[(Y_0 + Y_{inodd2})(Y_0 + Y_{ineven2})] \qquad (11)$$

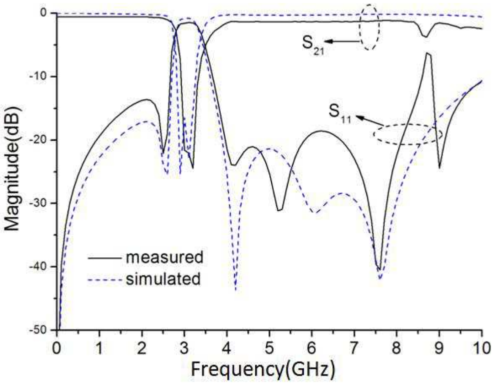
The result calculated with two open-end stubs is given in Figure 5, another rejection zero can be obtained by the open-end stubs, we can easily find that as the electric length of the open-end stubs θ_1 cascaded to the spiral inductor increases, the third rejection zero shifts closer to the operating band.

3. SIMULATED AND MEASURED RESULT

The proposed filter is fabricated by using a Rogers RO4350(tm) substrate with relative dielectric constant 3.66 and thickness of 0.508 mm. The final geometrical dimensions are optimized by the electromagnetic simulation software and decided as: $W_0 = 1.1$ mm, $W_1 = 2.7$ mm, $W_2 = 1.5$ mm, $W_3 = 0.8$ mm, $W_4 = 0.3$ mm, $L_1 = 4.2$ mm, $L_2 = 1.3$ mm, $L_3 = 1.0$ mm, $L_S = 8.7$ mm, $S_1 = 0.77$ mm, $S_2 = 0.2$ mm, $S_3 = 0.2$ mm. The photograph of the fabricated bandstop filter (BSF) with multiple rejection zeros is shown in Figure 6(a), the open-end stub between the two spiral inductors is replaced by a step impedance resonator (SIR) for the consideration of compact size. Simulated and measured responses are also depicted in Figure 6(b), which are found in good agreement with each other, showing a stop band from 2.7 GHz to 3.7 GHz and three rejection zeros



(a)



(b)

Figure 6. Fabricated BSF and responses. (a) Top and bottom layout of the fabricated filter. (b) Measured and simulated results.

located at 2.5 GHz, 4 GHz, 7.5 GHz respectively which improves the suppression out of the stop band to more than −20 dB till 8.5 GHz.

4. CONCLUSION

A compact band stop filter with multiple rejection zeros is presented in this paper. Three rejection zeros are introduced in the lower and upper band to improve the frequency selectivity and suppression out of the stopband. It has been verified by simulation and measurement. The new BSF exhibits favorable frequency selectivity and wide upper pass band performance and occupies a size of only $0.24\lambda_g \times 0.17\lambda_g$.

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