Dual-mode dual-band microstrip bandpass filter based on stepped impedance resonator (SIR) for wireless communication applications

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In this letter, a dual-mode dual-band microstrip bandpass filter (BPF) based on stepped impedance resonator (SIR) for wireless communication applications is introduced. By choosing a proper impedance ratio, a BPF operating at 2.4/5.2 GHz is designed and analyzed. By adjusting the perturbation size, two degenerate modes are excited and coupled within the first passband. Two transmission zeros which further improve the performance of the BPF locate on both sides of the first passband. The fractional bandwidth (FBW) of the two passbands are 8% and 6%, respectively. The maximum insertion loss (IL) is better than 0.9dB and the return loss is better than -20dB.

Keywords: Dual-Mode; Dual-Band; Stepped Impedance Resonator (SIR); Bandpass Filter (BPF); Wireless Communication.

1. Introduction

Microstrip bandpass filters (BPFs) have been widely applied in the front-ends of various modern wireless communication systems due to their low loss, low cost, compact size and easy fabrication. What's more, microstrip BPFs are mainly used to filter out the signals within specific frequency bands and suppress the spurious signals outside the bands, which can simplify the system complexity and improve the system stability to a certain extent. With the rapid development of wireless communication technology, microstrip BPFs with excellent performance and compact structure are imperatively needed.

In recent years, dual-mode microstrip filters have been used to meet these demands. The most attractive point for a dual-mode resonator is that it can be used as a doubly tuned circuit, therefore, the number of resonators required for a given degree of filter is reduced by half and the structure of the whole filter will be correspondingly smaller [1]. Dual-mode resonators are introduced by Wolff for the first time [2]. Since then, a lot of research on dual-mode resonators has been carried out by academicians. Meander loop resonator has been developed for miniaturization of high selectivity narrowband microwave bandpass filter [3]. Using slow-wave transmission line ring resonator and square-patch element, a novel compact dual-mode microstrip bandpass filter with 3% bandwidth is developed [4]. A pair of crossed slots with unequal widths is embedded in a $\lambda/2$ patch resonator, a miniaturized dual-mode bandpass filter with two transmission zeros and low insertion-loss is developed and designed [5].

In this paper, a compact dual-mode dual-band microstrip bandpass filter (BPF) based on stepped impedance resonator is presented for wireless communication applications. Recent advances in wireless communication have created a need for dual-band operation for RF devices, and it's known that a uniform microstrip resonator has resonance frequencies at multiples of its fundamental resonance. So it is not suitable for constructing a dual-band filter of which the center frequency of the second passband is not twice the first one [6]. In order to meet the need for dual-band operation, the stepped impedance resonator (SIR) is applied to design dual-band filter because of its tunable harmonic frequencies. The proposed filter operates at 2.4 and 5.2 GHz. By changing the perturbation element, two degenerate modes are excited and coupled in the first passband. The existence of the two transmission zeros (TZs) improves the frequency selectivity.

2. Resonant Characteristics of an SIR

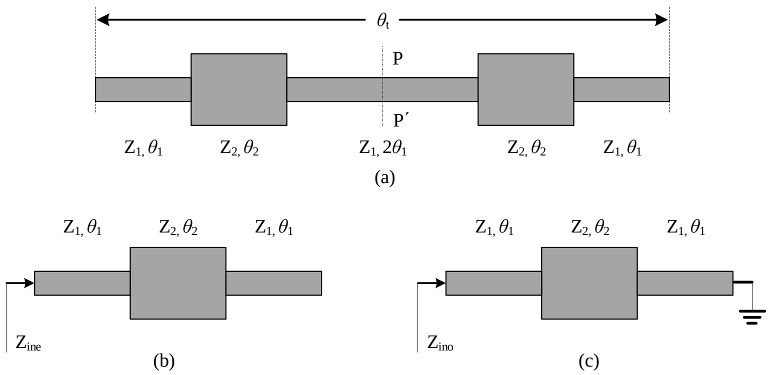

Fig. 1 Configuration of the proposed stepped impedance resonance (a) geometrical diagram of the SIR, (b) equivalent circuit for even mode, (c) equivalent circuit for even mode.

The resonator structure to be considered here is shown in Figure 1(a). It is obvious that the SIR resonator is constructed by cascading a microstrip section with characteristic impedance Z_1 in the center accompanied with the two microstrip sections with characteristic impedance Z_2 in the two sides, and two microstrip sections with characteristic impedance Z_1 are located in the two terminals. The SIR has total electric length $\theta_t = 4\theta_1 + 2\theta_2$, and θ_1 and θ_2 are electrical lengths of the microstrip sections with characteristic impedances Z_1 and Z_2, respectively, and $K = Z_2/Z_1$ is the impedance ratio. For practical application all segments are generally considered of equal electrical length for ease of design calculation, so $\theta_1 = \theta_2 = \theta$ and the total electrical length is $\theta_t = 6\theta$.

Different from the analytical approaches mentioned in [7], the SIR can be analyzed using even-/odd-mode analysis because of its symmetry. By setting the plane of symmetry to be open- and short- circuited for the even and odd resonances, respectively, as shown in Figure 1 (b) and Figure 1 (c), the expressions for the even and odd input impedances can be obtained as follows:

$$\begin{aligned} Z_{ine} &= jZ_1 \frac{\left(K^2 + K + 1\right)\tan^2\theta - K}{\left(2K + 1 - K^2\tan^2\theta\right)\tan\theta} \\ Z_{ino} &= jZ_1 \frac{\left(2K + K^2 - \tan^2\theta\right)\tan\theta}{K - \left(K^2 + K + 1\right)\tan^2\theta} \end{aligned} \tag{1}$$

According to the resonant condition $1/Z_{in} = 0$, we can derive:

$$\begin{aligned} &\tan^2\theta = \frac{K}{K^2 + K + 1}, \tan\theta = 0 \quad \text{(even– mode)} \\ &\tan^2\theta = \frac{2K + 1}{K^2}, \tan\theta \to \infty \quad \text{(odd– mode)} \end{aligned} \tag{2}$$

By solving the Eq. (2), the nununiformly spaced resonant frequencies can be obtained. The ratios of the resonant frequencies can be derived as follows:

$$\begin{aligned} \frac{f_{s1}}{f_0} &= \frac{\theta_{s1}}{\theta_0} = \frac{\tan^{-1}\sqrt{(2K+1)/K^2}}{\tan^{-1}\sqrt{K/\left(K^2+K+1\right)}} \\ \frac{f_{s2}}{f_0} &= \frac{\theta_{s2}}{\theta_0} = \frac{\pi}{2\tan^{-1}\sqrt{K/\left(K^2+K+1\right)}} \\ \frac{f_{s3}}{f_0} &= \frac{\theta_{s3}}{\theta_0} = \frac{\pi - \tan^{-1}\sqrt{(2K+1)/K^2}}{\tan^{-1}\sqrt{K/\left(K^2+K+1\right)}} \end{aligned} \tag{3}$$

Where f_0 and $f_{sn}(\mathrm{n}=1,2,3)$ are the resonant frequencies of the fundamental mode and higher orders, respectively, while, θ_0 and $\theta_{sn}(\mathrm{n}=1,2,3)$ are the corresponding electrical lengths.

The above results are shown in Figure 2. It has provided that the ratio of f_{sn}/f_0 can be realized by changing the impendence ratio. In this paper, we mainly focus on the f_{s1}/f_0. Fig. 2 clearly shows that, the smaller K is, the larger the ratio of f_{s1}/f_0 is. If $f_{s1} \geq 2f_0$ is required, $K \leq 1$ should be chosen, and vice versa. It should be mentioned that $f_{s1}/f_0 = 2$ for $K = 1$, which is expected since SIR is a conventional $\lambda/2$ resonator.

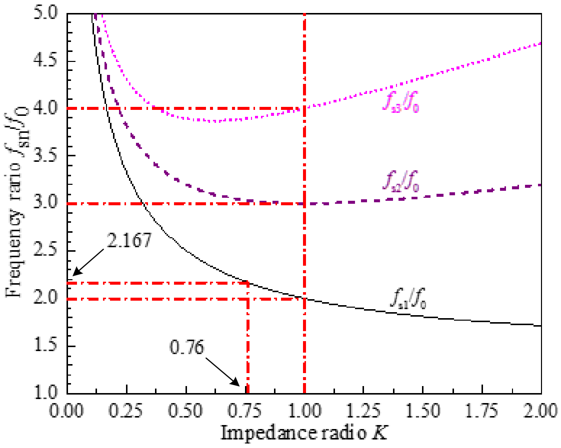

Fig. 2 Frequency ratio (f_{sn}/f_0) with respect to the impedance ratio K.

3. Filter Design

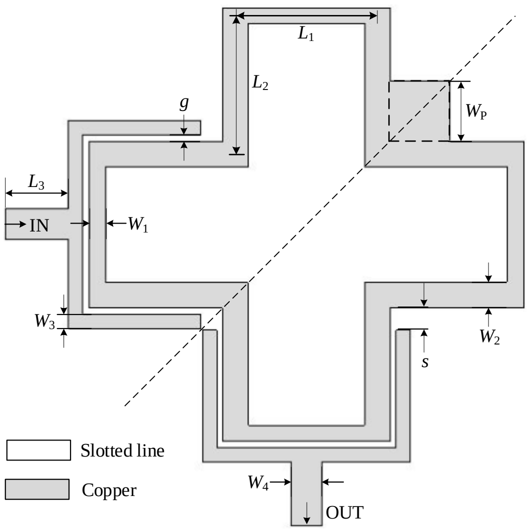

Fig. 3 Schematic of the dual-mode BPF based on the proposed SIR

In order to validate the above property, a dual-mode dual-band microstrip BPF based on the proposed SIR is introduced. The schematic of the proposed dual-mode BPF is shown in Figure 3. The centre frequencies of the two passbands are considered to be 2.4 and 5.2 GHz, respectively, i.e. the frequency ratio is $f_{s1}/f_0 = 2.167$. As shown in Figure 2, the corresponding impedance ratio is calculated as $K = 0.76$. So the high impedance microstrip segment is chosen to have 70Ω with a line width (W_1) of 0.5mm, and the low impedance microstrip segment is chosen to have 53.2Ω with a line width (W_2) of 1mm.

By connecting the two ends of a one-wavelength transmission line in a ring-like formation, a resonator is formed. The resonator is fed by a pair of orthogonal feed lines and each feed line is connected to a U-shaped coupling arm. The gap size between the resonator and coupling stubs is $g = 0.2$ mm which is selected in consideration of strong coupling and etching tolerance. Additionally, a small square patch is attached to a corner of the loop which is 135° offset from both input and output ports for exciting and coupling a pair of degenerate modes.

The proposed BPF is analyzed and optimized by using CST Microwave Studio 2014 and it's assumed that the filter is designed on a substrate with a relative dielectric constant of 10.8 and a dielectric thickness of 1.27mm. The geometrical dimensions are decided as: $W_1 = 0.5$ mm, $W_2 = 1$ mm, $W_3 = 0.45$ mm, $W_4 = 0.98$ mm, $W_P = 1.9$ mm, $L_1 = 4.55$ mm, $L_2 = 4.55$ mm, $L_3 = 2$ mm, $g = 0.2$ mm, $s = 0.7$ mm. The total area of the proposed BPF is $16.3 \times 16.3\,\text{mm}^2$, which corresponds to a size of $0.3\lambda_g \times 0.3\lambda_g$, where λ_g is the guided wavelength at the fundamental frequency $f_0 = 2.4$ GHz.

4. Performance Evaluation

Figure 4 shows the frequency responses of the proposed BPF. It is clearly observed that two passbands with central frequencies locate at 2.4 GHz and 5.2 GHz, separately. At the first passband, the maximum IL is 0.51 dB, the FBW is 8% and the return loss is better than -28 dB from 2.37 GHz to 2.44 GHz. The two transmission zeros are -48 dB and -70 dB at the frequencies of 2.142 GHz and 2.81 GHz, respectively. The maximum IL is 0.92 dB and the FBW is 6% at the second passband. It should be mentioned that two degenerate modes are located at 2.384 GHz and 2.425 GHz separately.

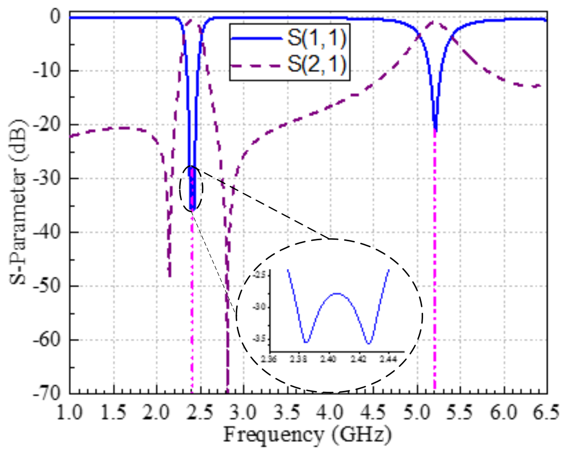

Fig. 4 Simulated frequency responses of the proposed BPF

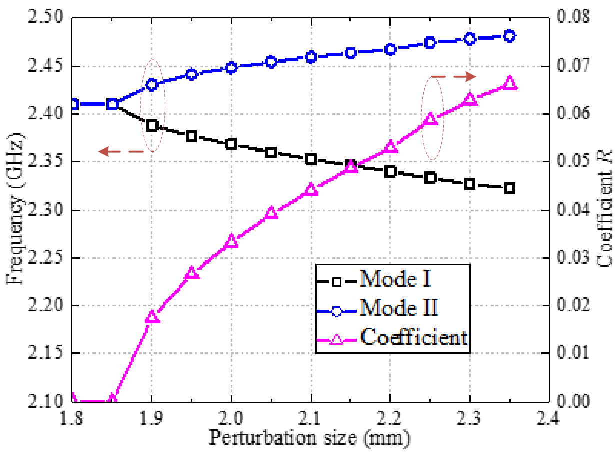

Fig. 5 Resonant frequencies and coupling coefficient versus the perturbation size

Figure 5 shows the resonant frequencies of two degenerate modes and corresponding coupling coefficient versus the perturbation size which is changing from 1.8 mm to 2.35 mm. It is apparent that the degenerate modes appear when $W_P > 1.85$ mm and with the increasing of the perturbation size, the distance between the two resonant frequencies becomes larger and accordingly the bandwidth expands. Meanwhile, the coupling coefficient also increases with the increasing of the perturbation size.

5. Conclusion

In this paper, a dual-mode microstrip BPF based on SIR has been analyzed. The simulated results show that the BPF operates at 2.4 GHz and 5.2 GHz. There are two TZs on both sides of the first passband. The existence of the two TZs improves the frequency selectivity of the BPF as well as the stopband rejection. Therefore, the BPF can reduce the interferences from other systems and it can be used for wireless communication applications in terms of the performance. Additionally, the mode splitting characteristic and the impact of the perturbation size on the performance of the BPF are investigated.

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