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COMPACT DUAL-BAND BANDPASS FILTER USING IMPROVED SPLIT RING RESONATORS BASED ON STEPPED IMPEDANCE RESONATOR

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Abstract—In this letter, a compact planer dual-band bandpass filter (BPF) using novel split-ring resonators (SRRs) is proposed. Compared with conventional SRRs, the stepped impedance split ring resonator (SIR-SRR) has better performance on miniaturization. To verify good characteristics of the novel structure, a new resonator-embedded cross-coupled filter, constructed by a pair of new resonators, is designed. This new filter has good characteristics of compact size and high selectivity. The improved SRR unit cell has a size of $0.108\lambda_g \times 0.108\lambda_g$ (where λ_g is the guided wavelength) at central frequency (2.25 GHz) of upper passband. Simulated results show that two central frequencies of the filter locate at 1.90 and 2.25 GHz with 3-dB fractional bandwidths of 1.0% and 7.7%, respectively. The lower passband band is generated by inner resonator with a via hole to gound plane, while the upper passband is created by outer resonator. Moreover, a good out-band performance is shown in this letter. Its stop-bands are extended 0–1.85 GHz at lower band and 2.4–5.8 GHz at upper band with a rejection level of about 20-dB. The measured and simulated results are well complied with each other.

1. INTRODUCTION

With the rapid development of wireless communication systems, there have been increasing demands for dual-band radio frequency devices. Dual-band bandpass filters are essential components in RF front-end of both the receiver and transmitter. Compact size, low losses, high selectivity, low cost and high performance BPFs are the goals for

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modern wireless communication applications, especially in compact size and high selectivity. In 1999, Pendry et al. [1] proposed an artificial negative magnetic permeability medium (NMPM), which is composed of a regular array of electrically small resonant particles referred as split ring resonators (SRRs). SRRs have attracted great interest among researchers in electromagnetic and microwave community due to their characteristics of electrically small resonant. From a duality argument,complementary split-ring resonators (CSRRs) [2] were introduced by Falcone et al. in 2004. Their applications to planar miniaturized microwave filters were proposed and investigated in [3–5].

In order to achieve better performance of the filter, a novel improved SRR structure is proposed to reduce the circuit size in this letter. In addition, a 0 degree feed structure of a two-pole cross-coupled filter is also used to design the filter. Compared with those filters designed with a 180 degree feed structure [6, 7], the filter with a 0 degree feed topology has two extra zeros near its passband. Therefore, steeper rejection can be obtained in the filter. As previously mentioned, a novel dual-band BPF with four transmission zeros is proposed, which has good characteristics of high selectivity and expanded stopband. The new design has been verified by experiment results.

2. FILTER DESIGN

The models of SRRs and SIR-SRRs are plotted in Fig. 1. The conventional SRRs can be viewed as a pair of curved uniform

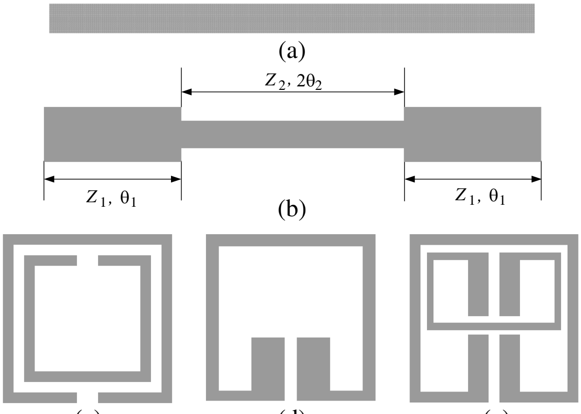

Figure 1. In each row of this figure represents the top view of a resonant magnetic particle. (a) UIR. (b) SIR. (c) SRRs. (d) SIR-SRR. (e) SIR-SRRs.

impedance resonators (UIRs), while SIR-SRRs are made from the SIR. Therefore, we just need to analyze the characteristics of SIR replacing SIR-SRRs. SIR-SRRs inherit some excellent features of SIR, the resonator length and corresponding spurious frequency response can be tuned by changing the impedance ratio. It adds an extra degree of freedom for filter design. For SIR, the fundamental mode is the first odd mode and the lowest spurious mode is the first even mode [8]. Analyzing the fundamental mode and the lowest spurious mode is a very important process to design the filter. The equations for SIR can be written as:

$$\tan\theta_1 = \frac{Z_2}{Z_1}\cot\theta_2, \tag{1}$$

and

$$\cot\theta_1 = -\frac{Z_2}{Z_1}\cot\theta_2, \tag{2}$$

where Equation (1) is for the odd modes and Equation (2) is for the even modes. At the same time, Equation (1) is the same as fundamental resonant equation given by [8], while Equation (2) is different from the first higher order resonant equation. We can utilize those two formulas to calculate the central frequencies of the fundamental mode and the first higher mode.

As aforementioned above, using SIR-SRR structure including SIR-SRR and SIR-SRRs can suppress higher harmonics. The geometry of the BPF with SIR-SRR is shown in Fig. 2. The filter is designed on a thin dielectric substrate with low relative permittivity of 2.2. Fig. 3 shows the simulated S-parameters for the BPF with SIR-SRR and the conventional SRRs. The filter with SIR-SRR structure has a lower central frequency than conventional SRRs. It is also observed that the result is in good performance on harmonic suppression as SIR-SRR unit cells are used. Some advantages for the proposed SIR-SRR are as follows: its abilities to control spurious response by changing impedance ratio. Compared with conventional SRRs, the first spurious-mode resonant frequency corresponding to SIR-SRR will shift to the higher frequency. The two transmission zeros

Figure 2. Geometry of the BPF with SIR-SRR.

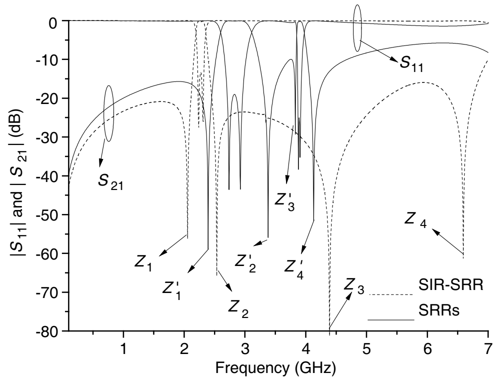

Figure 3. Comparison of the simulated S-parameters of the BPF with SIR-SRR and the conventional SRRs.

corresponding to the first spurious-mode resonant frequency will also shift to the higher frequency. The coupling of two resonators can be tuned by controlling parameter g_1. Coupling between two fundamental resonators altering not only suppress the spurious response but also maintain the same position of the two transmission zeros. Therefore, a stopband expanded BPF with four transmission zeros is obtained, which has high frequency selectivity.

In order to fulfill the requirements for dual-band BPFs, two SIR-SRRs unit cells are implemented in this letter. SIR-SRRs is composed of outer resonator and inner resonator. It also can be viewed as two resonators due to its structure, which is composed of a pair of folded SIRs nested in each other. The inner resonator is considered as a $\lambda/4$-type folded short-stub, while the outer resonator is viewed as a $\lambda/2$-type folded SIR. The coupling between inner SIR and outer SIR will be reduced when the impedance ratio is increased. As the impedance ratio is greatly increased, the two independent resonance modes will be created. The upper passband is excited by two outer resonators, and the bandwidth can be controlled by tuning the distance of them. The lower passband is excited by the inner SIRs, and the bandwidth can be adjusted by tuning the dimensions of the resonators. So we can adjust the lower passband to the required frequency while keeping the upper band fixed. Then a novel dual-band BPFs can be achieved. The configuration of the proposed dual-band filter is shown in Fig. 4. Fig. 5 shows the simulated $|S_{21}|$ with varied S_{slit1} and S_{slit2} Bandwidth can be controlled on both the bands by tuning S_{slit1} and S_{slit2}. The bandwidth of lower passband will expand when S_{slit1} and S_{slit2} increase from 0.6 to 0.7 mm, while the bandwidth of upper one will reduce.

3. RESULTS AND DISCUSSION

The filter is designed and fabricated on a thin dielectric substrate with low relative permittivity of 2.2, loss $\tan\theta$ of 0.0009 and thickness of 0.508 mm. The 50 ohm feed line is terminated with a standard SMA connector to facilitate the measurement and connect with other standard microwave modules. As shown in Fig. 4, by using the optimized parameters of the filter, the dimensions of the proposed filter are selected as follows: $a_1 = 10\,\text{mm}$, $w_s = 0.45\,\text{mm}$, $w_{s1} = 3\,\text{mm}$, $g_1 = 0.2\,\text{mm}$, $s_{slit1} = 0.45\,\text{mm}$, $s_{slit2} = 0.45\,\text{mm}$, $W_f = 1.57\,\text{mm}$.

A photograph of the fabricated microstrip filter is shown in Fig. 6. The S-parameters are measured using an N5230A network analyzer, and are plotted in Fig. 7 together with simulated results. Simulated results show that the lower passband and upper passband, which are centered at 1.9 and 2.25 GHz, have insertion loss of < 1.2 and < 0.2 dB, with 3-dB fractional bandwidths of 1.0% and 7.7%, respectively. The measured and simulated results are complied with each other. The slight shift of frequency might be due to the

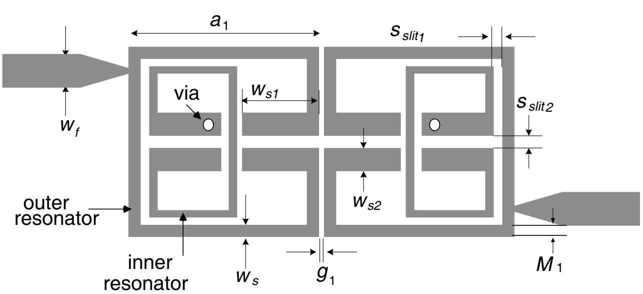

Figure 4. Configuration of proposed filter.

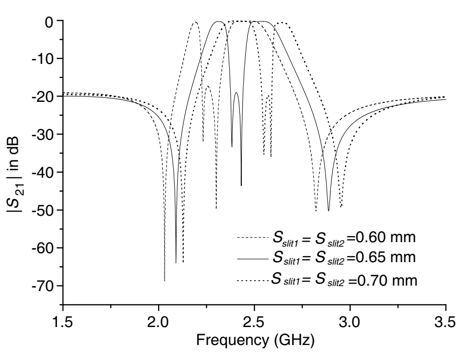

Figure 5. Simulated $|S_{21}|$ of the proposed filter with varied S_{slit1} and S_{slit2}.

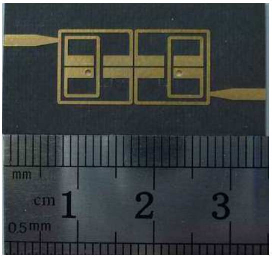

Figure 6. A photograph of the proposed filter.

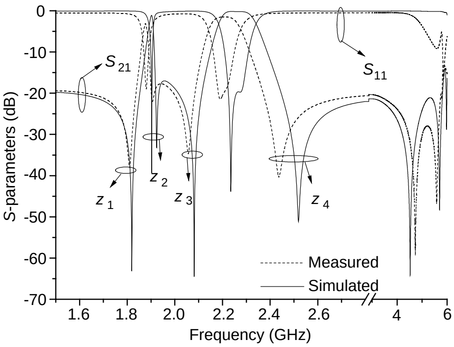

Figure 7. Simulated and measured S-parameters of the proposed filter.

unexpected tolerance of fabrication. Additionally, the filter has a good out-of-band performance. Two transmission zeros are created on both sides of each passband (upper passband and lower passband).

4. CONCLUSION

In conclusion, a novel structure of SIR-SRRs is introduced in filter design. Compared with conventional SRRs, the proposed resonator presents a better performance on miniaturization. Cross-coupled filters are used to realize elliptic or quasi-elliptic response. The combination of the improved SRRs structure and cross-coupled filters technique can be applied to design a miniaturized dual-band BPF. The lower and upper passband is created by inner and outer resonators, respectively, while the inner resonator is equal to a parallel $\lambda/4$-type folded short-stub. The passband can be conveniently tuned by controlling the corresponding resonator dimensions and the location of via hole. Two transmission zeros Z_1 and Z_2 are created beside the lower frequency, while Z_3 and Z_4 are created beside the upper frequency. They are near the passbands edges and enhance the rate of roll-off. The new design has been verified by experiment results. In summary, as a type of appropriate resonator, SIR-SRRs is a good candidate in filters design.

ACKNOWLEDGMENT

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