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COMPACT MICROSTRIP BANDPASS FILTER WITH MULTISPURIOUS SUPPRESSION

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Abstract—A compact microstrip bandpass filter (BPF) with multispurious suppression is presented. The filter consists of two coupled half-wavelength stepped impedance resonators (SIRs) and tapped input/output (I/O) lines. With tuning the impedance ratio (K) and length ratio (α) of SIRs, a very wide stopband can be easily achieved. The filter is designed at 2.4 GHz (f_0) with a wide stopband to 20 GHz ($8.16f_0$) and an average rejection level better than 25 dB. This study provides a simple and effective method to achieve a filter with very wide stopband and compact circuit size simultaneously. Good agreement between the full-wave electromagnetic (EM) simulation and measurement is compared.

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1. INTRODUCTION

Planar bandpass filters (BPFs) having compact size and a very wide stopband are very popular to implement the radio frequency (RF) front end in microwave communication systems [1]. Common planar filters suffer from the existence of spurious frequencies at multiples of fundamental resonant frequencies, which may seriously degrade the RF performance of the active circuits. Since the spurious frequencies of the stepped impedance resonator (SIR) can be easily controlled by its impedance ratio and length ratio, the SIR-based spurious-suppressed filters and dual-band filters are popularly utilized in advanced planar filters design [2, 3].

Recently, various methods for wide stopband filters have been reported [4–10]. Makimoto et al. proposed the filter using parallel coupled stripline SIR to control spurious response and insertion loss [4]. Zhang et al. proposed the compact open-loop resonator bandpass filter with suppression of the second and the third harmonics [5]. The filter is based on a Tri-Section SIR to achieve size minimization and suppressed spurious response. Chin et al. proposed a novel spurious suppressed bandpass filter with triangular stepped impedance resonators [6]. The proposed resonators are folded for a triangular schematic, which creates two transmission zeros. Chen et al. proposed the filter employing an array of SIRs with tapped-transformer coupling at I/O ports to provide a wider stopband range [7]. Lin et al. proposed the filter using both half- and quarter-wavelength SIRs to improve the stopband from $1.14f_0$ to $5.2f_0$ [8]. C Tang et al. proposed the filter using parallel-coupled stacked SIRs and the open-loop resonators for spurious suppression [9]. Wang et al. proposed a bandpass filter with wide stop-band. The wide stop-band is achieved by introducing tri-section stepped-impedance resonator [10]. The results exhibit the two transmission zeros to provide a high out-of-band rejection. These works can effectively achieve spurious suppression or shifting the harmonics in the design of planar microstrip bandpass filters.

In this paper, we propose a compact bandpass filter with multispurious suppression. This study provides a simple and effective method to achieve a compact bandpass filter with very wide stopband. The two bended half-wavelength SIRs are employed to realize the compact bandpass filter. By tuning the impedance ratio and physical length of SIRs, good multispurious suppression is well achieved at upper stopband. Predicted frequency response is confirmed by experiment of a fabricated filter.

2. CIRCUIT DESIGN

Figure 1 shows the configuration of the proposed filter. The filter consists of two bended half-wavelength SIRs and tapped I/O lines. Size of the filter by adopting bended SIRs can be easily miniaturized. In addition, the arrangement of the tapped I/O lines can be further miniaturized the circuit size [10].

Figure 2 shows the structure of the stepped impedance resonator

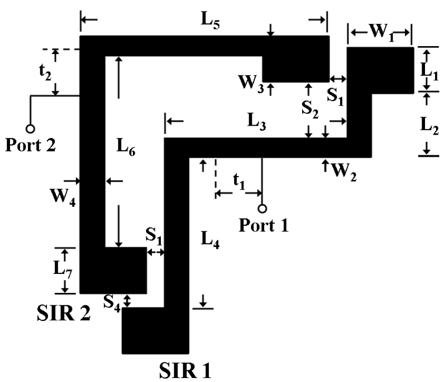

Figure 1. Configuration of the proposed filter. (t_1 and t_2 are measured from the center of the resonator.)

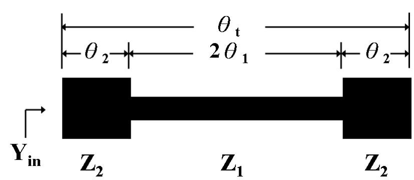

Figure 2. Structure of the stepped impedance resonator (SIR) with impedance ratio $K < 1$.

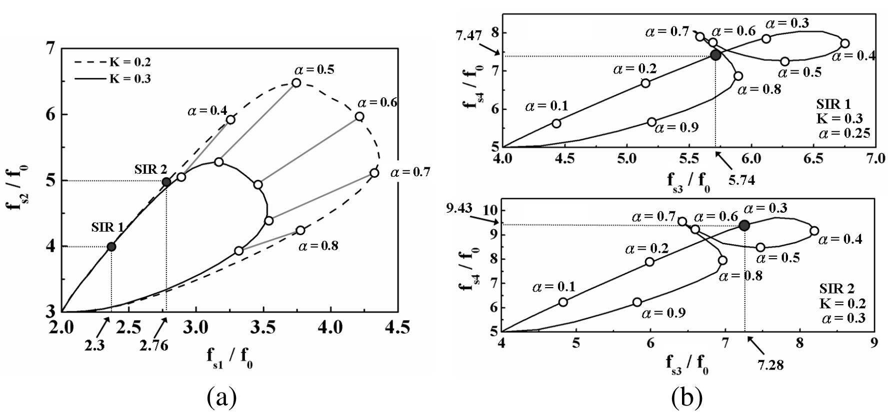

Figure 3. Normalized ratios of (a) f_{s1}/f_0 vs. f_{s2}/f_0 and (b) f_{s3}/f_0 vs. f_{s4}/f_0 for an SIR with $K = 0.2$ and 0.3.

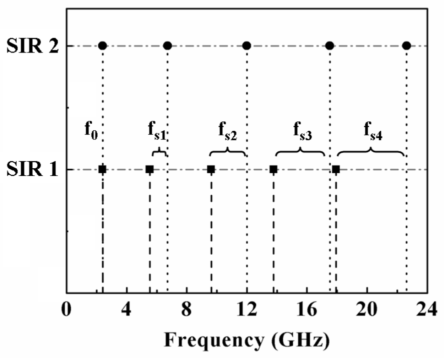

Figure 4. Fundamental and spurious frequencies of each SIR for the filter.

(SIR) with impedance ratio $K < 1$, where K is defined as $K = Z_2/Z_1$. The input admittance Y_{in} of the proposed SIR is derived in the following equation [4]:

$$Y_{in} = jY_2 \frac{2(K\tan\theta_1 + \tan\theta_2)(K - \tan\theta_1 \tan\theta_2)}{K(1-\tan^2\theta_1)(1-\tan^2\theta_2) - 2(1+K^2)\tan\theta_1 \tan\theta_2} \tag{1}$$

The resonant frequencies of SIR occurs while $Y_{in} = 0$. The resonance conditions are well known and determined by one of the following equations [6]:

$$\tan\theta_1 = K\cot\theta_2 \quad \text{(Odd resonances)} \tag{2}$$

$$-\cot\theta_1 = K\cot\theta_2 \quad \text{(Even resonances)} \tag{3}$$

To achieve the widely tunable resonant frequencies of SIR, the length ratio of SIR is defined as

$$\alpha = \frac{\theta_2}{(\theta_1+\theta_2)} = \frac{2\theta_2}{\theta_t} \quad \theta_1 = \frac{(1-\alpha)\theta_t}{2} \quad \theta_2 = \frac{\alpha\theta_t}{2} \tag{4}$$

Substituting (4) into (2) and (3), there are several solutions for θ_t, which are dependent on the choice of K and α To provide a very wide stopband, both of the SIRs need to design at the same fundamental frequency (f_0) and place the higher resonant frequencies (spurious frequencies, f_{si}) at the different frequency positions. Fig. 3 shows the normalized ratios of the higher resonant frequencies (f_{si}, $i = 1$ to 4) to the fundamental frequency (f_0) for an SIR with impedance ratio $K = 0.2$ and 0.3. In Fig. 3(a), $f_{s1}/f_0 = 2.3$ and $f_{s2}/f_0 = 4$ for SIR 1 and $f_{s1}/f_0 = 2.76$ and $f_{s2}/f_0 = 5$ for SIR 2 can be observed. $f_{s3}/f_0 = 5.74$ and $f_{s4}/f_0 = 7.47$ for SIR 1 and $f_{s3}/f_0 = 7.28$ and

$f_{s4}/f_0 = 9.43$ for SIR 2 are also shown in Fig. 3(b). Marked red points are the chosen characteristics of the SIRs.

By using this simple method to determine the resonant frequencies of SIR, a bandpass filter having the wide stopband or the multi-passband can be easily achieved. Fig. 4 shows the fundamental and spurious frequencies of each SIR for the filter. In this work, the filter is designed at $f_0 = 2.4\,\text{GHz}$ and has a very wide stopband. The SIR 1 with $K = 0.3$ and $\alpha = 0.25$ and the SIR 2 with $K = 0.2$ and $\alpha = 0.3$ are utilized in this design. The fundamental frequency of SIR 1 and SIR 2 is located at 2.4 GHz, where the spurious frequencies can be blocked by controlling the dimension of SIRs.

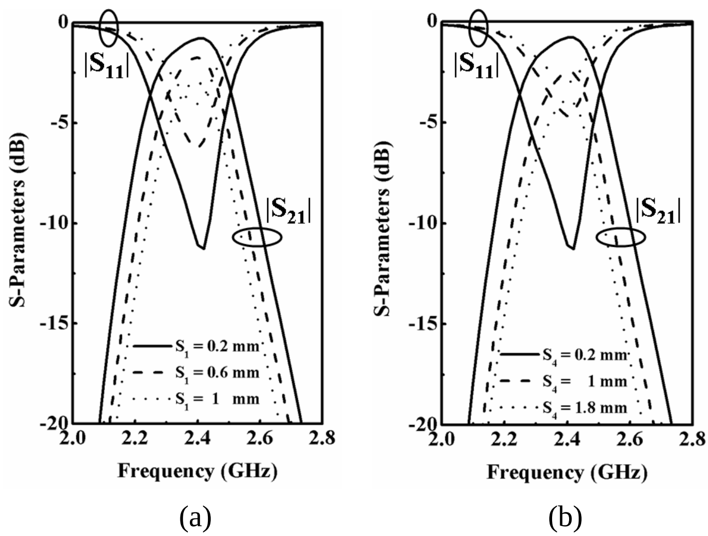

Figure 5. Simulated frequency response of the filter under different coupling spacing (a) S_1 ($S_2 = 2\,\text{mm}$ and $S_4 = 0.2\,\text{mm}$) and (b) S_4 ($S_1 = 0.2\,\text{mm}$) between the two SIRs. ($\theta_1 = 42°$, $\theta_2 = 14°$ and $\alpha = 0.25$ for SIR 1 and $\theta_1 = 35°$, $\theta_2 = 16°$ and $\alpha = 0.3$ for SIR 2).

Figure 5 shows the simulated frequency response of the filter under different coupling spacing S_1 and S_4 between the two SIRs. The coupled spacing (S_1 and S_4) is tuned to effectively yield the good inter-coupling degree and improve the return loss ($|S_{11}|$) in the passband. From Fig. 5(a), $|S_{11}|$ increases when increasing S_1 from 0.2 to 1 mm (all the other dimensions are held constant), meanwhile, the insertion loss ($|S_{21}|$) decreased due to the reduced inter-coupling degree. When increasing the S_4 from 0.2 to 1.8 mm (the same with S_2 from 2 to 3.6 mm), the $|S_{11}|$ becomes poor, as shown in Fig. 5(b). It implies that

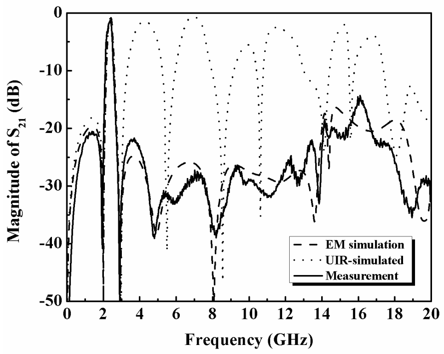

Figure 6. Simulated and measured insertion loss $|S_{21}|$ of the filter. ("UIR-simulated" curve indicates the frequency response of the proposed structure using the uniform impedance resonators (UIRs).)

S_1 and S_4 dominate the inter-coupling degree in the passband.

Figure 6 shows simulated and measured insertion loss $|S_{21}|$ of the filter. The $|S_{21}|$ curve labeled "UIR-simulated" is the simulation for filter with uniform impedance resonators (UIRs), of which the spurious frequencies from 4 to 20 GHz seriously deteriorate the filter rejection at upper stopband. The $|S_{21}|$ curves labeled with "measurement" and "EM simulation" for filter with the SIR structure, and they are in good agreement.

3. RESULTS

In order to provide verification on the predicted frequency response, the compact bandpass filter with multispurious suppression is fabricated on the Duroid 5880 substrate with relative dielectric constant $\varepsilon_r = 2.2$, loss tangent $\tan\delta = 0.0009$ and thickness $h = 0.787$ mm. We choose $\alpha = 0.25$ and $K = 0.3$ with $Z_1 = 100\,\Omega$ and $Z_2 = 30\,\Omega$ for SIR 1 and $\alpha = 0.3$ and $K = 0.2$ with $Z_1 = 100\,\Omega$ and $Z_2 = 20\,\Omega$ for SIR 2 Size of the fabricated filter is $15.5 \times 19.6\,\text{mm}^2$, approximately $0.18\lambda_g \times 0.23\lambda_g$, where λ_g means the guided wavelength at center frequency. To improve the selectivity of the passband, the position of the tapped I/O lines ($t_1 = 3$ mm and $t_2 = 4.2$ mm) with $50\,\Omega$-line is well designed for the optimum external quality factor ($Q_e = f_0/\delta_{3\text{-dB}}$, where f_0 and $\delta_{3\text{-dB}}$ express the center frequency and the 3-dB bandwidth of the passband) by using the full-wave electromagnetic (EM) simulation [11], as shown in Fig. 7.

Photograph of the fabricated BPF is shown in Fig. 8(a). Measured frequency responses of the filter are characterized in an HP 8510C network analyzer Fig. 8(b) shows the comparison between the simulated and measured frequency responses of insertion loss $|S_{21}|$ and return loss $|S_{11}|$. Measured results of the filter have $|S_{11}|$ of 25 dB, $|S_{21}|$ of 0.5 dB and FBW (3-dB fractional bandwidth) of 0.12 at 2.4 GHz. The transmission zeros near the skirts of passband can be obtained by properly tuning the inter-coupling degree (S_1 and S_4). The rejection level of spurious suppression at 16 GHz ($6.7f_0$) is around

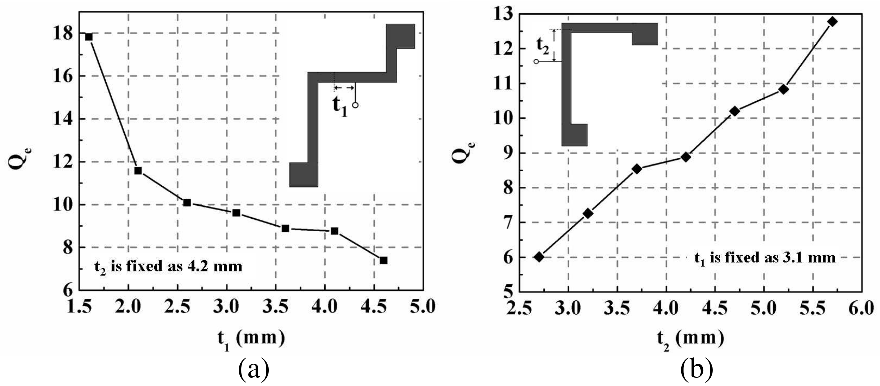

Figure 7. Simulated external quality factor Q_e versus the tap positions of (a) SIR 1 and (b) SIR 2.

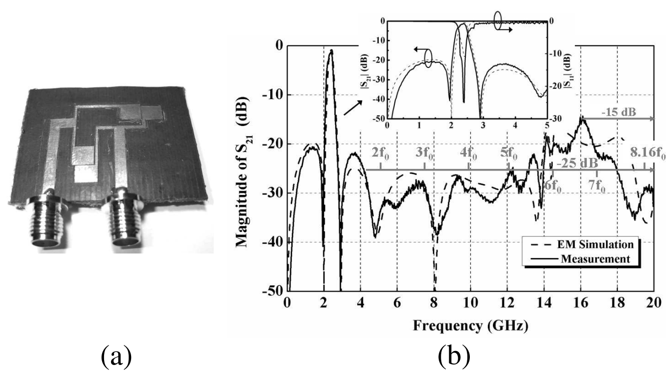

Figure 8. (a) Photograph and (b) simulated and measured frequency responses of the fabricated filter. ($W_1 = 4.7$, $W_2 = 0.6$, $W_3 = 4.3$, $W_4 = 0.43$, $S_1 = S_4 = 0.2$, $S_2 = 2$, $L_1 = 3.8$, $t_1 = 3$, $t_2 = 4.2$, $L_2 = 2.6$, $L_3 = 10.55$, $L_4 = 8.9$, $L_5 = 15.2$, $L_6 = 10.8$ and $L_7 = 4.3$. All are in mm.)

Table 1. Comparisons of the past literatures.

	Ref. [6]	Ref. [10]	Ref. [12]	**Proposed filter**
Center frequency f_0 (GHz)	1.5	1.6	4	**2.4**
$\lvert S_{11}\rvert/\lvert S_{21}\rvert$ (dB)	20/1	20/1.1	15/1.5	**25/0.5**
3-dB FBW (%)	8.1	1.5	120	**12**
Circuit size (mm^2)	675 (45×15)	177 (13×13)	200 (10×20)	**115 (13.4×8.6)**
Wide stopband range	$5.6f_0$	$2.4f_0$	$5.1f_0$	**8.16 f_0**
Average S_{21}-magnitude of stopband (dB)	20	30	20	**25**

$|S_{21}| = 15\,\mathrm{dB}$, which is acceptable for the design of a filter with very wide stopband [10]. Slightly mismatch between the simulated and measured results might be due to the fabrication errors or the variation of material properties. Moreover, the multispurious suppression level under $|S_{21}| = 25\,\mathrm{dB}$ to 20 GHz ($8.16f_0$) is good to extent against the previous literatures, as summarized in Table 1.

4. CONCLUSION

In this paper, a compact microstrip bandpass filter with multispurious suppression has been proposed, which has good rejection level around 25 dB up from $2f_0$ to $8.16f_0$. By changing the impedance ratio and length ratio of the SIRs, the higher order spurious frequencies can be tuned to achieve a very wide stopband. Design procedure and analysis for the filter are well introduced. Finally, this study provides a simple and effective method to achieve a bandpass filter with very wide stopband. The superior features indicate that the proposed filter has a potential to be utilized in modern mobile wireless communication systems.

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