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COMPACT AND HARMONIC SUPPRESSION OPEN-LOOP RESONATOR BANDPASS FILTER WITH TRI-SECTION SIR

J. Zhang, J.-Z. Gu, B. Cui, and X. W. Sun †

Shanghai Institute of Microsystem & Information Technology
CAS
Shanghai 200050, China

Abstract—A compact open-loop resonator bandpass filter with suppression of the second and the third harmonics is demonstrated in this paper. This novel filter is based on a Tri-Section SIR to achieve size minimization and suppressed spurious response. The simulations and measurements of a 0.9 GHz prototype bandpass filter are presented. The measured results agree well with simulation and calculation.

1. INTRODUCTION

As one of the key components in RF front-ends, bandpass filters with compact size, good performance, and low cost are highly demanded. The open-loop resonator bandpass filter which was first proposed by J.-S. Hong in 1995 [1, 2] has been widely used in many microwave and wireless systems due to its planar structure, narrow realizable bandwidth and easy fabrication process.

In order to suppress spurious response, a number of technologies have been investigated. Stepped impedance resonators (SIR) [3, 4], DGS(defected ground structure) [5, 6], complementary split ring resonators (CSRRs) [7, 8] are widely used in filter design. In the previous work [9], an open-loop resonator structure with capacitive termination has been proposed. The filters constructed using the prototype is compact in size and provide very good in-band and out-band characteristics. However, there are no theoretical formulae to support the design procedure and it takes times of simulation to attain suitable parameters.

† The first three authors are also with Graduate School of the Chinese Academy of Sciences.

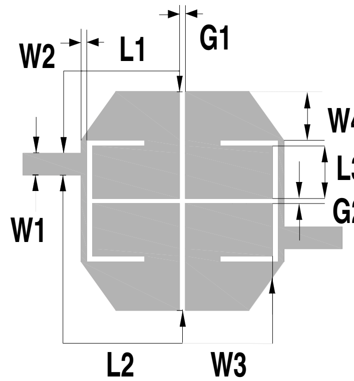

Figure 1. Layout of the proposed open-loop resonator bandpass filter with Tri-section SIR.

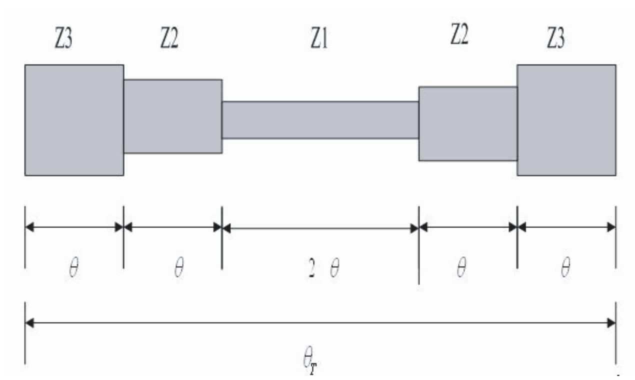

Figure 2. Tri-section stepped impedance resonator.

In this letter, a novel open-loop resonator filter is introduced. This filter is constructed with a Tri-Section SIR. Compared with the conventional SIR, it can offer more design flexibility and exhibit better characteristics with simple design process.

2. CIRCUIT DESIGN

The schematic diagram of the proposed bandpass filter is shown in Figure 1, consists of a Tri-section SIR. The feature of the high order spurious response suppression originates from multiple resonances of the stepped-impedance resonator as shown in Figure 2, where the Tri-section SIR has the total electric length $\theta_T = 6\theta$ and impedance ratio

$K_1 = Z_3/Z_2$, $K_2 = Z_2/Z_1$. It has been proven that resonances occurs under the conditions given below [10].

$$\theta = \tan^{-1}\left(\sqrt{\frac{K_1 K_2}{K_1 + K_2 + 1}}\right) \tag{1}$$

$$\theta_T = 6\tan^{-1}\left(\sqrt{\frac{K_1 K_2}{K_1 + K_2 + 1}}\right) \tag{2}$$

the first spurious "f_{s1}" occurs at

$$f_{s1} = \frac{\theta_{s1}}{\theta_0} f_0 \tag{3}$$

where

$$\theta_{s1} = \tan^{-1}\sqrt{\frac{(K_1+1)^2(K_2+1) + K_2^2 K_1}{K_2^2 + K_1 K_2 + K_2}} \tag{4}$$

It implies that by properly determining the impedance ratio k_1, k_2, the relative resonance frequency ratio can be easily attained.

As a demonstration example, a bandpass filter for 900M application was designed. The initial circuit dimensions calculated from the formulae (1)–(4) which are $k_1 = 0.5$, $k_2 = 0.295$, $\theta = 25.9°$, were optimized by a 2.5D EM simulator, ADS Momentum, to include the effects of layout discontinuities, unequal odd- and even-mode velocities, and parasitic coupling among non-adjacent microstrip lines. The optimized circuit parameters are $Z_3 = 13.2\,\Omega$, $Z_2 = 28.2\,\Omega$,

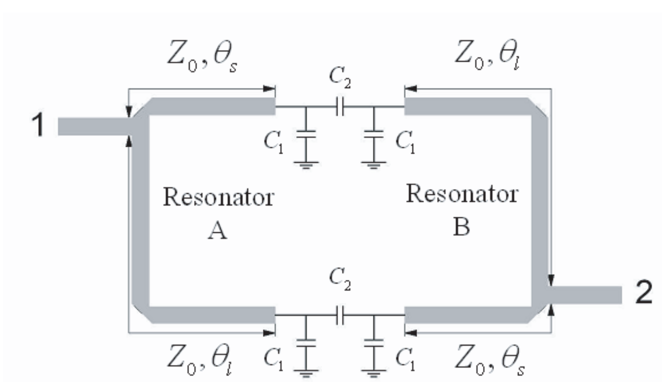

Figure 3. Equivalent circuit model of electrical coupling for a skew-symmetric feed structure.

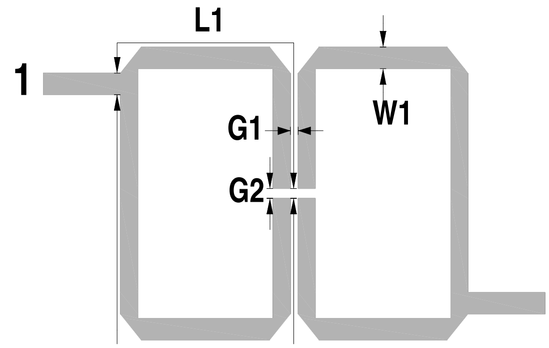

Figure 4. Layout of open-loop resonator bandpass filter.

$Z_1 = 89\,\Omega$ ($k_1 = 0.47$, $k_2 = 0.316$), $\theta_1 = 49.5°$, $\theta_2 = 26.3°$, $\theta_3 = 13°$. Clearly, the optimized circuit parameters $k_1, k_2, \theta_1, \theta_2$ agree with the theoretical calculation result well, while θ_3 deflects quite a lot. The deflection is due to the inner coupling [9]. The coupling gap between the two Z_3 stubs are modeled as a π-network with C_1 and C_2 shown in Figure 3. The value of C_1 is usually small and neglected in the analysis, but its value increases in the proposed structure.

3. SIMULATED AND MEASURED RESULT

For comparison, an open-loop resonator bandpass filter and a proposed one with a Tri-Section SIR are both designed and fabricated on the substrate of $\varepsilon_r = 2.65$, thickness $h = 1000\,\mu$m and loss tangent of 0.003. The S-parameters were measured using an Agilent E8358A PNA including two SMA connectors.

Fig. 1 shows the layout of the proposed filter, where $L1 = 20.08$ mm, $L2 = 30.08$ mm, $L3 = 6.5$ mm, $W1 = 2.7$ mm, $W2 = 1$ mm, $W3 = 15$ mm, $W4 = 6$ mm, $G1 = 0.3$ mm, $G2 = 0.6$ mm (G1 and G2 can be deduced by calculating the coupling coefficient of the coupling microstrip), total size is $926.1\,\text{mm}^2$.

Fig. 4 shows the configuration of a skew-symmetric feeding open-loop resonator bandpass filter with electrical coupling, where $L1 = 40.25$ mm, $L2 = 67.55$ mm, $W1 = 2.7$ mm, $G1 = 0.3$ mm, $G2 = 0.3$ mm, total size is $1939.3\,\text{mm}^2$.

Fig. 5 illustrates the measured and simulated S-parameters of the skew-symmetric feeding open-loop resonator bandpass filter. The centre frequency is 0.9 GHz. The figure shows that the insertion and return loss are better than 1.4 dB and 10.1 dB, respectively. The 2nd harmonic suppression is as bad as 3.6 dB only.

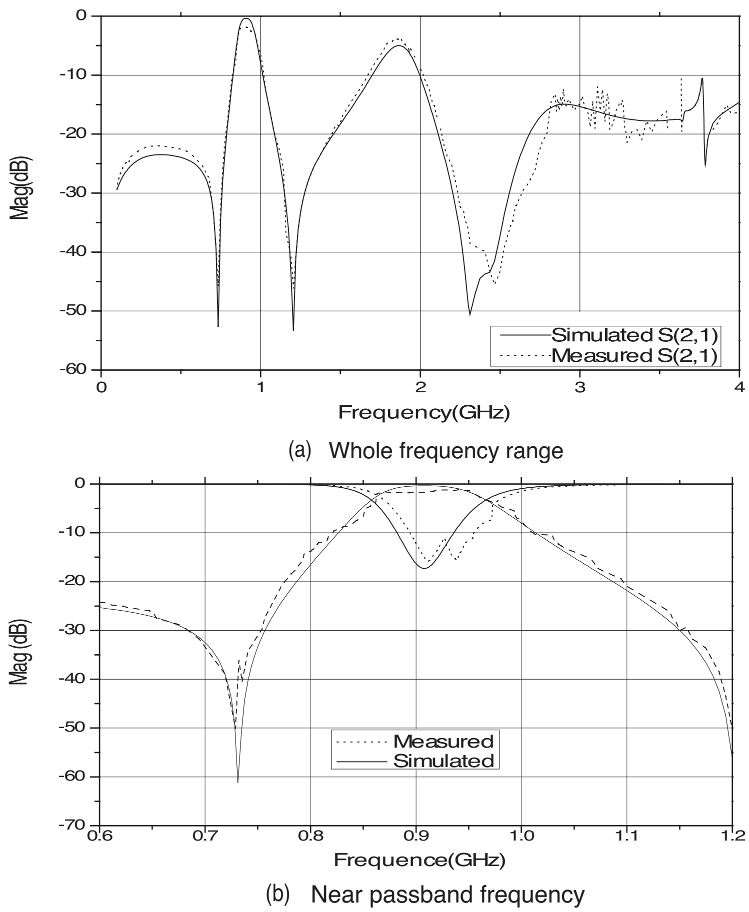

Figure 5. Simulated and measured S parameter of conventional open-loop resonator bandpass filter (a) whole frequency range (b) near passband frequency.

Table 1. Comparison of two filters transmission performance.

Filter Type	Insert Loss	Return Loss	Stopband (Lower)	Stopband (Upper)
Conventional	1.4dB	10.1dB	21.2dB	3.6 dB
Proposed	2.5dB	11 dB	24.8dB	30.8dB

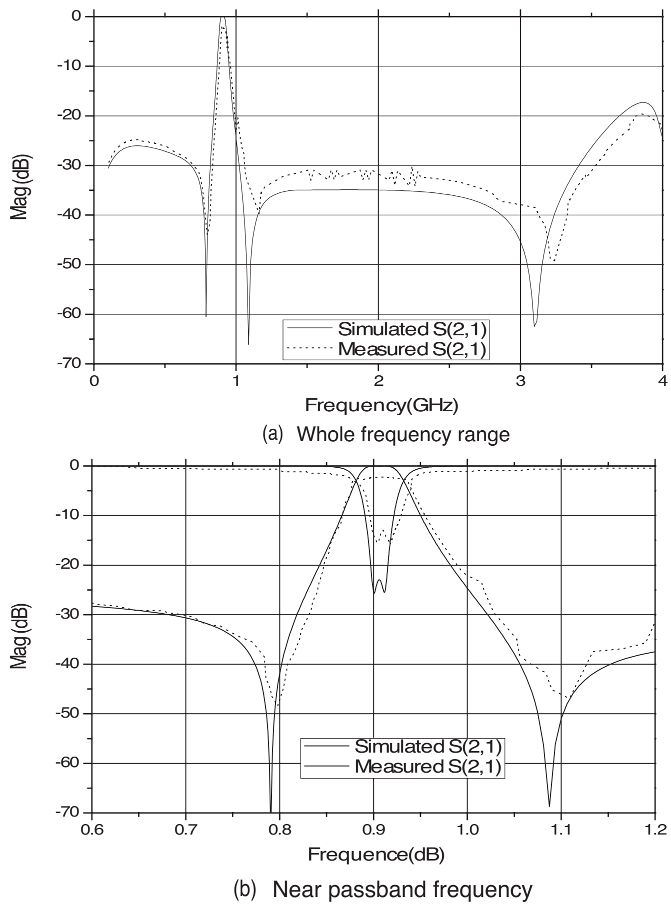

Figure 6. Simulated and measured S parameter of proposed open-loop resonator bandpass filter with Tri-section Sir (a) whole frequency range (b) near passband frequency.

Fig. 6 shows the measured and simulated S-parameters of the proposed open-loop resonator bandpass filter with Tri-section SIR. For comparison, the centre frequency is set in 0.9 GHz too. From the figure, it can be clearly found that the proposed filter shows a much better stopband rejection performance than the one above. The suppression of stopband rejection below 3 GHz is as high as 30 dB; there is more than 26 dB improvement from 3.6 dB to 30 dB in 2nd harmonic suppression due to the Tri-section SIR. Table 1 shows the details transmission performance comparison of two filters.

4. CONCLUSION

A novel open-loop resonator bandpass filter with Tri-section SIR has been presented in the paper. In order to demonstrate its potential, a conventional open-loop resonator filter and the proposed one with Tri-section SIR have both been designed and fabricated for comparison. The filter proposed in the paper not only shows a superior harmonic suppression in stop-band, but also saves as much as 60% circuit size compared with the conventional one.

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