# Design of Balanced Dual-Band Bandpass Filter with Self-Feedback Structure

Xinwei Chen, Guorui Han, Runbo Ma, Jiangrui Gao, and Wenmei Zhang

*ABSTRACT—A balanced dual-band bandpass filter based on λ/2 stepped-impedance resonators and open-loop resonators is proposed in this letter. By employing a type of self-feedback structure, an extra transmission zero is introduced near the common-mode resonance frequency, and the common-mode signal is suppressed. The measured results indicate that the filter can operate in 2.46 GHz and 5.6 GHz bands, and the insertion loss is 1.85 dB and 1.9 dB, respectively. Also, better common-mode suppression is achieved.*

*Keywords—Balanced, dual-band, SIR, open-loop resonator, common-mode suppression.*

## I. Introduction

The rapid development of wireless communication is creating extraordinary demand for dual-band radio frequency (RF) front-end solutions. Various dual-band filters have recently been proposed. In [1], transmission zeros are introduced in the middle of a wide bandpass filter to enforce the emergence of two separate passbands. Also, some dual-band filters and tri-band filters have been designed using stepped impedance resonators (SIRs) [2]-[4]. Balanced circuits are still essential for a front-end. Recently, a few balanced single-band filters have been investigated [5], [6].

In this letter, a balanced dual-band bandpass filter based on λ/2 SIRs and open-loop resonators is presented. The dual-band operation can be realized by adjusting the length ratio and the impedance ratio of the SIRs. To improve the insertion loss, open-loop resonators are used. Also, by employing a type of self-feedback structure, an extra transmission zero is introduced near the common-mode resonance frequency, and the common-mode signal is suppressed.

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## II. Design Theory of the Filter

Figure 1 shows the proposed balanced dual-band filter, which consists of two λ/2 SIRs (resonators 1 and 4) and two open-loop resonators (resonators 2 and 3). Under differential-mode operation, resonators 1 and 4 resonate at the center frequency of the first and second bands, while resonators 2 and

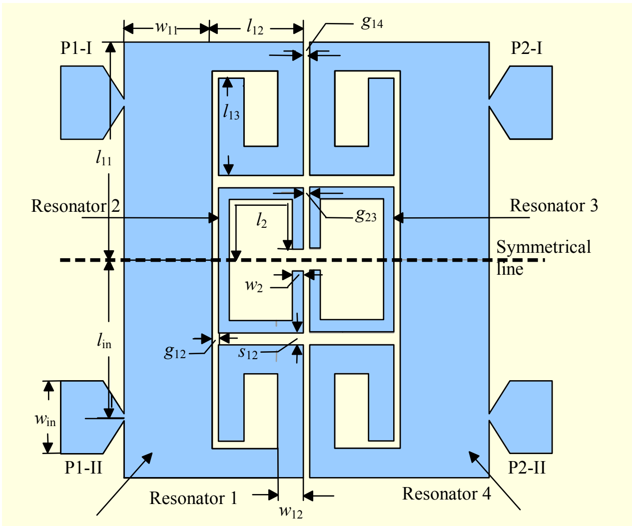


Fig. 1. Structure of the proposed filter ($l_{11}$ = 9 mm, $l_{12}$ = 4.3 mm, $l_{13}$ = 4 mm, $w_{11}$ = 4.2 mm, $w_{12}$ = 1.2 mm, $l_2$ = 8.5 mm, $w_2$ = 0.5 mm, $w_{in}$ = 3 mm, $g_{12}$ = 0.3 mm, $s_{12}$ = 0.5 mm, $g_{23}$ = 0.3 mm, $g_{14}$ = 0.3 mm, $l_{in}$ = 5.5 mm).

  

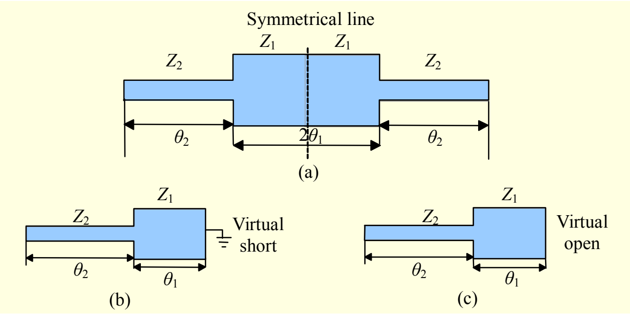


Fig. 2. SIR structure: (a) basic SIR structure, (b) differential-mode equivalent-half-circuit, and (c) common-mode equivalent-half-circuit.

3 resonate at the center frequency of the second band.

Figure 2 shows the basic structure of a λ/2 SIR. It consists of two microstrip lines with characteristic impedances $Z_1$ and $Z_2$ and electrical lengths $\theta_1$ and $\theta_2$. The impedance ratio is defined as $R_Z=Z_2/Z_1$ and the length ratio is defined as $U=\theta_2/(\theta_1+\theta_2)$.

Due to the symmetric structure, under differential-mode excitation, a perfect electric conductor (PEC) wall appears along the symmetric line. Therefore, resonators 1 and 4 can be treated as shorted λ/4 SIRs as shown in Fig. 2(b). In addition, under common-mode excitation, a perfect magnetic conductor (PMC) wall appears along the symmetric-line. Therefore, resonators 1 and 4 may be treated as λ/2 resonators as shown in Fig. 2(c) [6].

Neglecting the effects of discontinuities and open end, the input impedance seen from the open end of Fig. 2(b) can be expressed as

$$Z_{\text{in\_dif}} = jZ_2 \frac{Z_1 \tan\theta_1 + Z_2 \tan\theta_2}{Z_2 - Z_1 \tan\theta_1 \tan\theta_2}. \quad (1)$$

The parallel resonance occurs when $Y_{\text{in\_dif}}=1/Z_{\text{in\_dif}}=0$. We can deduce the differential-mode resonance condition as

$$R_Z = \tan\theta_1 \tan\theta_2 . \quad (2)$$

In addition, one can express the input impedance seen from the open end of Fig. 2(c) as

$$Z_{\text{in\_com}} = -jZ_2 \frac{Z_1 \cot\theta_1 - Z_2 \tan\theta_2}{Z_2 + Z_1 \cot\theta_1 \tan\theta_2}. \quad (3)$$

Then the common-mode resonance condition can be deduced as

$$R_Z = -\cot\theta_1 \tan\theta_2 . \quad (4)$$

According to (2) and (4), the $f_{d2}/f_{d1}$, $f_{c1}/f_{d1}$ for different $R_Z$ and $U$ are plotted in Fig. 3, where $f_{d1}$, $f_{d2}$, and $f_{c1}$ are the differential-mode first, second, and common-mode first-resonance frequencies, respectively. As seen in Fig. 3, resonators 1 and 4 can resonate at $f_{d1}$ and $f_{d2}$ when $R_Z$ and $U$ are properly selected. In addition, $f_{c1}/f_{d1}$ is smaller than $f_{d2}/f_{d1}$ for a given value of $R_Z$ and $U$. In other words, $f_{c1}$ will appear between $f_{d1}$ and $f_{d2}$ and

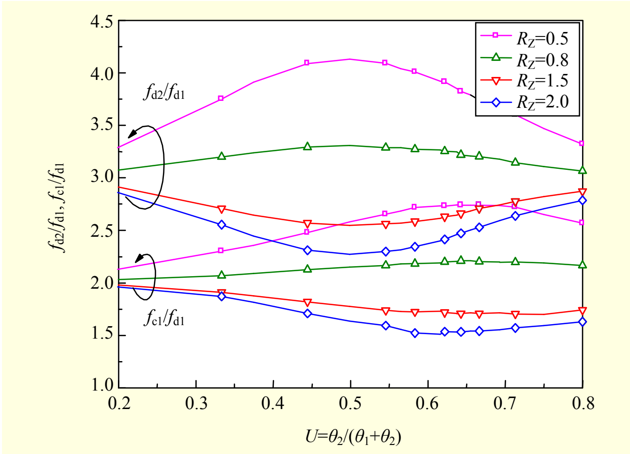


Fig. 3. The $f_{d2}/f_{d1}$ and $f_{c1}/f_{d1}$ for various $R_Z$ and $U$.

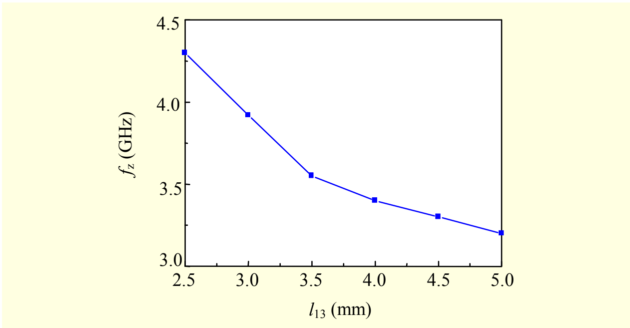


Fig. 4. Relationship between $f_z$ and $l_{13}$.

cause poor common-mode suppression. To suppress the common-mode signal, a type of self-feedback is formed by employing the folded SIR so that an extra transmission zero is introduced near $f_{c1}$. The transmission zero ($f_z$) can be determined by the coupled length of $l_{13}$. The relationship between $f_z$ and $l_{13}$ is shown in Fig. 4. It can be seen that the $f_z$ decreases as $l_{13}$ increases.

## III. Simulated and Measured Results

A balanced dual-band filter with Butterworth and quasi-elliptic frequency responses for the first and second band is designed with the following specifications:

$f_{d1}$=2.4 GHz, FBW$_1$ (relative bandwidth)=12.5%,

$f_{d2}$=5.6 GHz, FBW$_2$=25%.

The design procedure for the filter can be summarized as follows. First, select the structure parameters. Resonators 1 and 4 operate at 2.4 GHz and 5.6 GHz. Hence, $R_Z$=2 and $U$=0.58 are chosen. Resonators 2 and 3 have to operate at 5.6 GHz. Therefore, $f_{c1}$=3.6 GHz; thus, $f_{c1}/f_{d1}$=1.5, and $l_{13}$ can be obtained as 4 mm as seen in Fig. 4. Then, determine the design parameters of the filter, namely, the coupling coefficients and external quality factors. The parameters of the designed filter

Table 1. Design parameters of filter.

| Band | Element of low-pass prototype | Design parameters |
|---|---|---|
| 1 | $g_0=g_3=1$, $g_1=g_2=1.4142$ | $M_{14}=0.085$, $Q_{ei}=Q_{eo}=11.78$ |
| 2 | $g_1=0.94982$, $g_2=1.35473$, $J_1=-0.12333$, $J_2=1.0181$ | $M_{12}=0.220$, $M_{23}=0.220$, $M_{14}=-0.032$, $Q_{ei}=Q_{eo}=3.799$ |

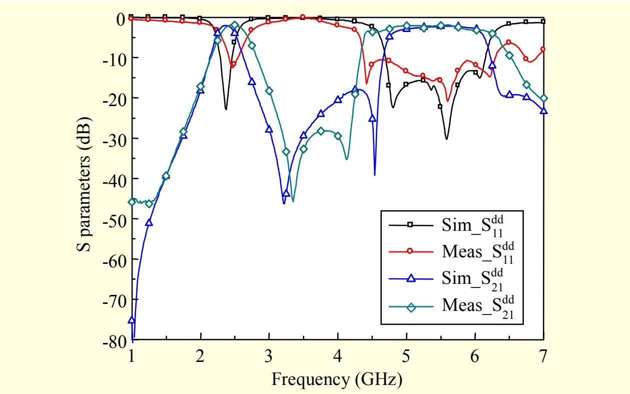


Fig. 5. Differential-mode response of the proposed filter.

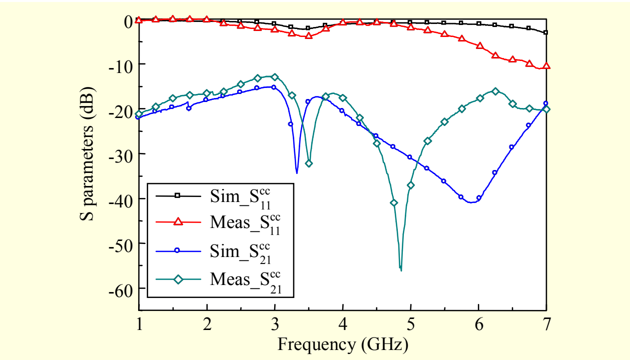


Fig. 6. Common-mode response of the proposed filter.

are listed in Table 1. To obtain $g_{12}$, $s_{12}$, $g_{23}$, and $g_{14}$, the full-wave simulator was used. The filter was fabricated on an FR4 substrate ($\varepsilon_r$=4.4, $h$=1.6 mm, tan$\delta$=0.02), and the circuit size of the filter is 17.3 mm×18 mm (equal to $0.24\lambda_g \times 0.25\lambda_g$, where $\lambda_g$ is the guided wavelength at $f_{d1}$).

The standard four-port S parameters were measured with the network analyzer. The two-port differential-mode and common-mode S parameters can be extracted from standard four-port S parameters [5]. The simulated and measured differential-mode and common-mode responses of the realized filter are shown in Figs. 5 and 6.

Figure 5 shows the differential-mode response of the proposed filter. It indicates that the center frequency of the first passband is at 2.46 GHz, with an insertion loss of less than 1.85 dB and a 3 dB-FBW of 16% (2.27 GHz to 2.67 GHz), and the center frequency of the second passband is at 5.6 GHz, with an insertion loss of less than 1.9 dB and a 3 dB-FBW of 34% (4.38 GHz to 6.27 GHz). Figure 6 shows the common-mode response of the proposed filter. The common-mode signal is suppressed to the levels of -15 dB and -22 dB at 2.46 GHz and 5.6 GHz, respectively. Moreover, the common-mode signal is suppressed below -13 dB from 1 GHz to 7 GHz because the common-mode transmission zero at 3.5 GHz is introduced. Compared with the simulated results, the passbands are widened and the common-mode transmission zero is slightly shifted. The differences are mainly caused by fabrication error of the line spacing and the electric constant deviation of the fabricated FR4.

## IV. Conclusion

This letter proposed a balanced dual-band band-pass filter which consists of symmetric SIRs and open-loop resonators. By properly adjusting the impedance ratio and length ratio of the SIRs and the length of the open-loop resonators, the designed filter can operate at 2.46 GHz and 5.6 GHz, with the insertion loss of 1.85 dB and 1.9 dB, respectively. Furthermore, the filter achieves acceptable common-mode suppression at the two passbands. Good agreement between measured and simulated results was achieved.

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