Microstrip Balanced Filter with Common-Mode Transmission Zero

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1. Introduction

Balanced bandpass filter has become the basic component of the balanced systems, because it can provide the differential-mode bandpass and suppress the common-mode noise at the same time. Therefore, a well-designed balanced filter should possess high common-mode suppression, excellent out-of-band rejection and high selectivity. However, previous reported works [1-3] of the balanced filters are rather limited. One may only achieve a balanced filter with either an extended stopband [2] or common-mode suppression [3]. In [4], using multisection resonator, the stopband is extended up to the fifth harmonic. At the same time, the common-mode rejection ration (CMRR) achieves 46 dB. However, the previous methods can only suppress the common-mode signal outside of the differential-mode passband. As far as we know that no way has been used to reduce the common-mode signal inside the differential-mode passband.

In this paper, the common-mode transmission zero is proposed to improve the common-mode suppression inside the differential-mode passband. It is realized by the source-load coupling. A two-order balanced bandpass filter demonstrates the controllability of the common-mode transmission zero. To extend the stopband while keeping the high common-mode suppression, resistor-loaded resonator is adopted to absorb the common-mode signal outside of the differential-mode passband. Therefore, a four-order filter using two resistor-loaded SIRs and two resistor-loaded UIRs is designed and fabricated. As a result, a balanced filter with high common-mode suppression, wide differential-and common-mode stopbands and good selectivity may be realized.

2. Two-Order Balanced Filter

Fig. 1 shows the proposed balanced two-order bandpass filter. It consists of two SIRs and four input/output couplings. In differential-mode operation, the center points of the SIRs are equivalent to virtual-short, while in common-mode operation, they become into virtual-open. The source and load feeding lines are folded to realize the source-load coupling. In single-ended filter, the source-load coupling is used to provide transmission zero to enhance the selectivity of the filter [5]. Here, the source-load coupling provides both differential- and common-mode transmission zeros. The differential-mode one can enhance the selectivity of the differential-mode passband, while the common-mode one can greatly improve the common-mode suppression inside the differential-mode passband, if the position of the common-mode transmission zero is controllable. Fig. 2(a) shows that the position of the common-mode transmission zero can be controlled by changing the distance d. And the position of common-mode transmission zero can be moved inside the differential-mode passband. At the same time, when d is changed, the differential-mode transmission zero also moves, however, the differential-mode passband is almost not changed.

In differential-mode operation, the center frequency of the passband is decided by the dimensions of the SIR. Since the input/output coupled line was inserted into the low impedance line of the SIR, the resonant frequencies will be different from that of the conventional SIR. But the characteristic of the resonator is similar to the conventional SIR. It still can be used to increase the frequencies of the harmonics to extend the stopband of a filter. For external quality factor, it is decided by the length of the input/output coupled line ($l_2 + l_3$). The gap g_1 can control the coupling coefficient. After optimization, the dimensions of this filter can be obtained as follows: $W = 1.2$ mm, $W_1 = 7.8$ mm, $W_2 = 0.435$ mm, $W_3 = 0.3$ mm, $l_1 = 14.8$ mm, $l_2 = 9.35$ mm, $l_3 = 5.55$ mm, $l_4 = 2$ mm, $l_5 = 11.5$ mm, $g_1 = 0.45$ mm, $g_2 = 0.3$ mm, $g_3 = g_4 = 0.15$ mm, $g_4 = 0.3$ mm, $d = 4.42$ mm, $d_1 = 0.3$ mm and $d_2 = 5.35$ mm. Fig. 2(b) shows the simulated and measured response of the proposed two-order filter. The differential-mode passband is located at 0.99 GHz with 17.2% relative bandwidth. The minimum insertion loss (inclusive of SMA connectors) is 1.18 dB. With a transmission zero located inside the differential-mode passband, the CMRR in 3-dB differential-mode passband is larger than 47 dB, which demonstrates that the common-mode transmission zero generated by source-load coupling can get high CMRR inside the passband.

3. Four-Order Balanced Filter

To widen the common-mode stopband and improve the selectivity of the differential-mode passband while keeping the high common-mode suppression, a four-order balanced bandpass filter using two resistor-loaded SIRs and two resistor-loaded UIRs is designed as shown in Fig. 3. It still has source-load coupling. Similar to the two-order filter, the length of input/output coupled line ($l_3 + l_4 + l_5$) and the gaps (g_1, g_2) decided the external quality factor and coupling coefficients, respectively.

By careful simulation and optimization, the dimensions are given as follows: $W = 1.2$ mm, $W_1 = 7.8$ mm, $W_2 = 0.435$ mm, $W_3 = 0.5$ mm, $W_4 = 0.3$ mm, $l_1 = 16$ mm, $l_2 = 16.4$ mm, $l_3 = 5.55$ mm, $l_4 = 8.55$ mm, $l_5 = 5.185$ mm, $l_6 = 2.5$ mm, $l_7 = 17.3$ mm, $l_8 = 1.8$ mm, $g_1 = 0.25$ mm, $g_2 = 0.34$ mm, $g_3 = 0.3$ mm, $g_4 = g_5 = g_6 = 0.15$ mm, $d = 9.7$ mm, $d_1 = 1.5$ mm, $d_2 = 1.44$ mm, $d_3 = 5.21$ mm, $R_1 = R_2 = 82\Omega$ and $R_3 = R_4 = 22\Omega$. Fig. 4 shows the simulated and measured results. It can be seen that the selectivity of the differential-mode passband is better than that of the two-order one. And the CMMR inside the passband is greatly improved because of the common-mode transmission zero. Moreover, by adding the resistors on respective resonators, some common-mode signals can be absorbed by the resistors [3]. In differential-mode operation, the passband is located at 0.91 GHz with 15.4% relative bandwidth. The minimum insertion loss (inclusive of SMA connector) is 1.91 dB. The 35 dB stopband is up to $4.5 f_0^d$. The common-mode suppression is always larger than 35 dB. The CMRR inside the 3-dB passband is larger than 66 dB. The measurement results agree well with the simulation results. From above results, the demonstrated balanced filter gives a better performance of good CMRR, high selectivity, and wide rejection bandwidth.

4. Conclusion

This paper presents the novel balanced bandpass filter using source-load coupling to generate common-mode transmission zero, which can greatly improve the common-mode suppression inside the passband. An improved design using resistor-loaded UIRs and SIRs extends the stopband and improves the selectivity, while keeping the high common-mode suppression. The experimental results agree well to the theoretical predictions.

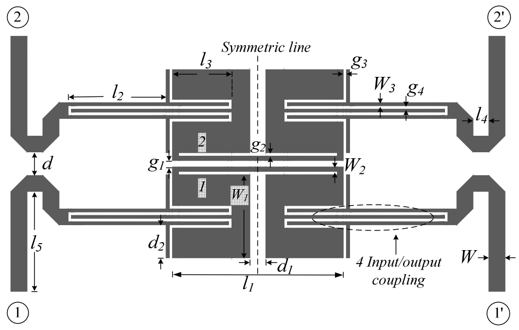
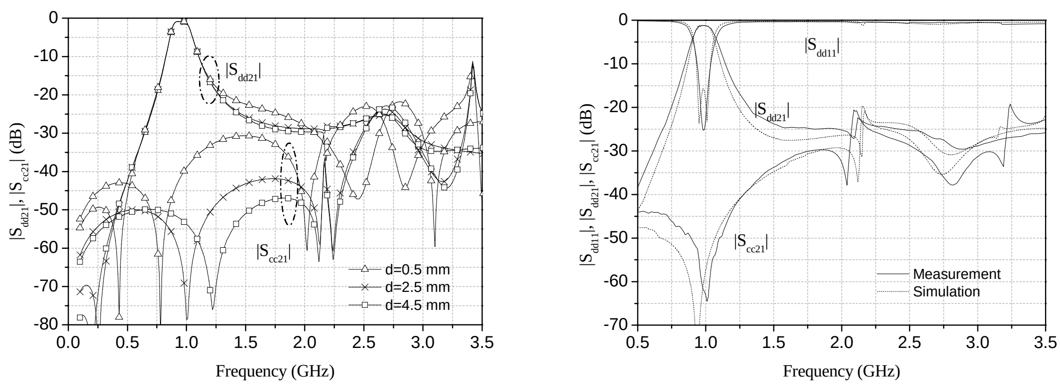


Figure 1: Configuration of the proposed two-order balanced bandpass filter.



(a) (b)

Figure 2: Response of the two-order balanced filter. (a) Differential- and common-mode response versus distance d . (b) Measured and simulated response of the proposed two-order balanced bandpass filter.

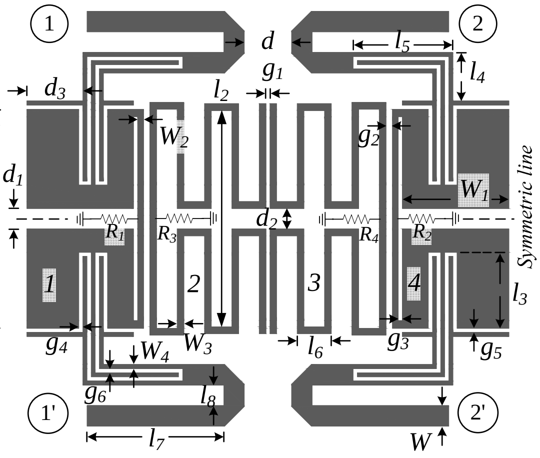
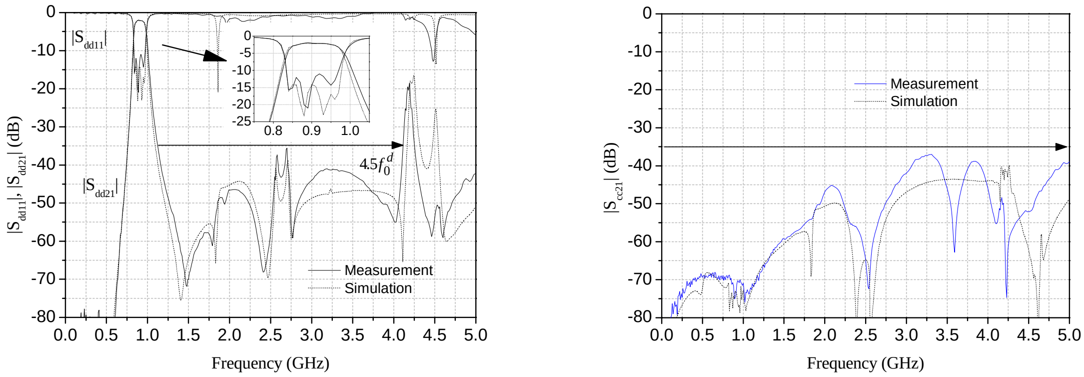


Figure 3: Configuration of the proposed four-order balanced bandpass filter.



(a) (b)

Figure 4: Simulated and measured response of the proposed four-order balanced bandpass filter. (a) Differential-mode response. (b) Common-mode response.

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