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Balanced Triple-Mode Microstrip Bandpass Filter Based on Double-Sided Parallel-Strip Line

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Abstract—This letter proposes a novel balanced triple-mode microstrip bandpass filter based on a double-sided parallel-strip line resonator for the first time. The triple-mode resonator is realized by a stub-loaded structure. Stripline-like structure is employed to excite the triple-mode resonator under differential mode operation. Meanwhile, good common mode suppression can be achieved. For the demonstration, a balanced triple-mode microstrip filter was designed, fabricated, and measured.

1. INTRODUCTION

Balanced microstrip bandpass filters (BPFs) have the advantages of compact size, light weight, and low cost [1–7], which have been widely researched. The balanced single-band filters can be designed by single-mode and dual-mode microstrip resonators. Because the symmetry plane of an open-end single-mode microstrip resonator can be equivalent to an electric wall, the single-mode resonator can be easily employed to implement balanced filter with high-performance differential mode (DM) responses and good common mode (CM) suppression [4]. However, their sizes are large. In [7], a compact balanced single-band filter was designed using a dual-mode loop resonator. However, the rejection level of CM suppression and stopband of DM response are not good enough. In [8, 9], balanced single-band microstrip filters were designed based on dual-mode resonators combined with single-mode resonators. High-performance DM and CM responses of balanced microstrip filters can be realized, but their sizes are large. Balanced dual-band microstrip filters can be designed based on dual-mode resonators [10, 11]. Besides, balanced microstrip filters can also be realized by the double-sided parallel-strip line (DSPSL) [10, 12, 13]. However, their sizes are also large because single-mode resonators are employed.

On the other hand, triple-mode microstrip resonators are widely researched to design compact unbalanced single-band filters [14–16]. Triple-mode microstrip resonators are mainly realized by stub-loaded half-wavelength line resonators. Triple-mode stub-loaded microstrip resonator can be realized by a half-wavelength transmission line resonator with a pair of tap-connected open-ended stubs, one short- and one open-stub lines, or two stepped-impedance open-stub lines. And corresponding unbalanced triple-mode filters were designed. To our best knowledge, no literature reports the balanced microstrip filter based on a triple-mode microstrip resonator. It should be noted that balanced wideband filters can be realized using triple- and multiple-mode slotline resonators [17–20].

This letter proposes a balanced microstrip bandpass filter (BPF) based on a triple-mode DSPSL resonator for the first time. The triple-mode resonator is realized by a half-wavelength transmission line resonator with one short-stub line and one stepped-impedance open-stub line. The triple-mode

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resonator is excited by a stripline-like structure. Compact size and high performance of CM suppression as well as DM response can be available at the same time. For the demonstration, a balanced triple-mode microstrip filter was designed, fabricated, and measured to verify the proposed design method. Measured results agree well with the simulated ones.

2. THE PROPOSED BALANCED TRIPLE-MODE MICROSTRIP FILTER

3D view of the proposed balanced triple-mode microstrip BPF is shown in Fig. 1(a). It is composed of a triple-mode DSPSL resonator and two pairs of balanced input and output (IO) ports. The corresponding coupling scheme under DM operation is shown in Fig. 1(b). The proposed balanced structure has two substrate layers and three metal layers. The middle metal layer is considered as the ground plane. Layouts of the upper and lower metal layers are the same. In order to facilitate the manufacture of the filter, thicknesses of the two substrate layers are fixed by 0.254 mm. Substrate material of Roger 5880 with its relative permittivity of 2.2 has been used for the design.

As shown in Fig. 1(c), the triple-mode DSPSL resonator is realized by a half-wavelength transmission line resonator with one short-stub line and one stepped-impedance open-stub line. The DSPSL resonator can realize three resonance modes (denoted by modes 1, 2, and 3, respectively), and the corresponding electric-field distributions are shown in Fig. 2(a), Fig. 2(b), and Fig. 2(c), respectively. The electric-field distribution of mode 2 is out-of-phase at the input and output ports, which can realize one negative main coupling path as shown in Fig. 1(b).

Stripline-like structures are employed to feed the triple-mode resonator with DM operation and CM suppression. As shown in Fig. 1(a), a pair of balanced input ports is denoted by S_1 and S_2; a

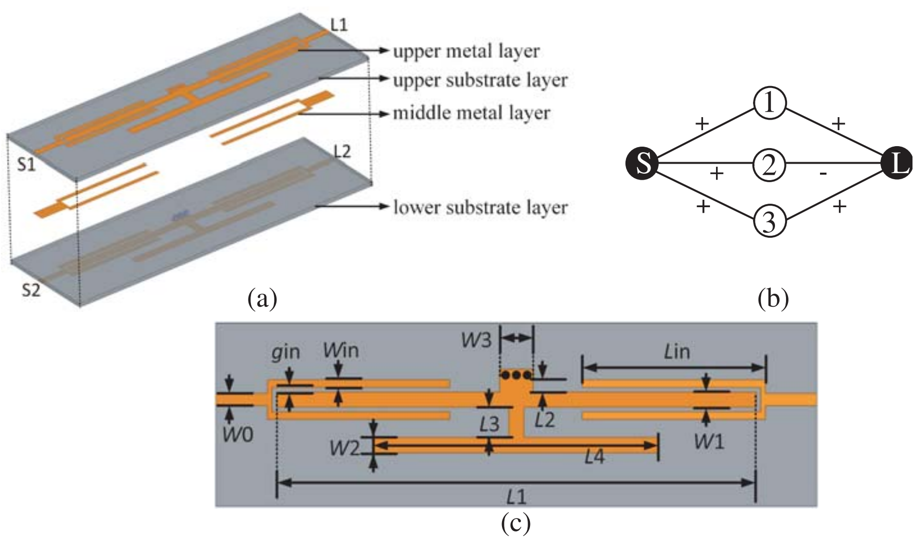

Figure 1. Layout of the proposed balanced triple-mode microstrip filter and its corresponding coupling scheme under DM operation. (a) 3D view, (b) corresponding coupling scheme under DM operation, (c) top view.

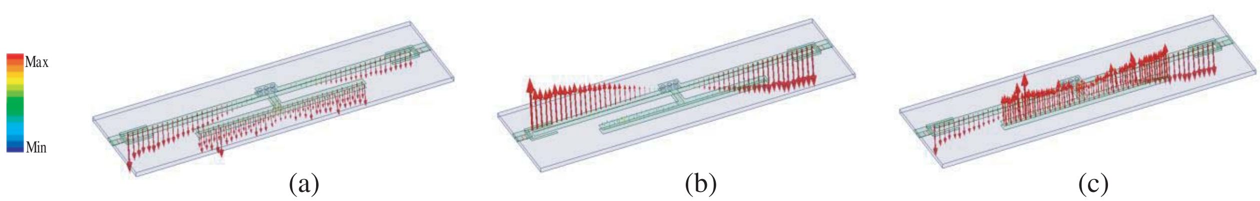

Figure 2. Electric-field distributions (a) mode 1, (b) mode 2, (c) mode 3.

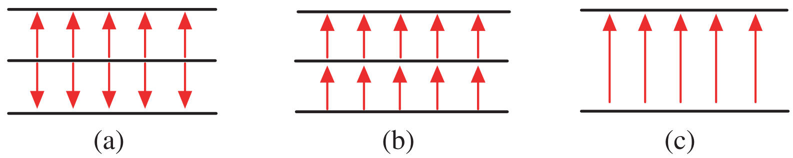

Figure 3. Electric-field distributions on the responding cross sections (a) CM of balanced feed lines, (b) DM of balanced feed lines, (c) operation mode of the triple-mode resonator.

pair of balanced output ports is denoted by L_1 and L_2. To clearly illustrate the working principle of the balanced triple-mode filter, the electric-field distributions of DM and CM signals as well as the operation mode of triple-mode resonator on the corresponding cross sections are shown in Fig. 3.

Under CM operation, the exciting signals of balanced input ports on the cross section are shown in Fig. 3(a). Since the effects of the two CM exciting signals cancel each other out, the electric field in Fig. 3(c) cannot be excited. Thus, CM signals cannot pass through the proposed filter. Under the DM operation, the exciting signals of balanced input ports on the cross section are shown in Fig. 3(b), which can excite the electric field in Fig. 3(c) because the effects of the two DM exciting signals are the same. Thus, the proposed balanced triple-mode filter has the intrinsic features of DM operation and CM suppression.

As shown in Fig. 1(c), IO feeding lines with parameters W_{in}, g_{in}, and L_{in} are mainly employed to vary the external quality factors (Q_e) of the triple-mode resonator. The single port structure is used to extract Q_e, which can be calculated [X]:

$$Q_e = \frac{\omega_0}{\Delta\omega_{\pm 90^\circ}} \tag{1}$$

where ω_0 is the resonance, and $\Delta\omega_{\pm 90^\circ}$ is determined from the resonance at which the phase shift $\pm 90^\circ$ with respect to the absolute phase at ω_0. Extracted external quality factors against g_{in} and L_{in} are shown in Fig. 4(a) and Fig. 4(b), respectively. The relationship between external quality factors (Q_{e1}, Q_{e2}, and Q_{e3}) and external coupling coefficients (M_{S1}, M_{S2}, and M_{S3}) can be expressed as Eq. (2):

$$Q_{ei} = \frac{1}{M_{Si}^2 \cdot \mathrm{FBW}} \tag{2}$$

where FBW is the fractional bandwidth of a filter.

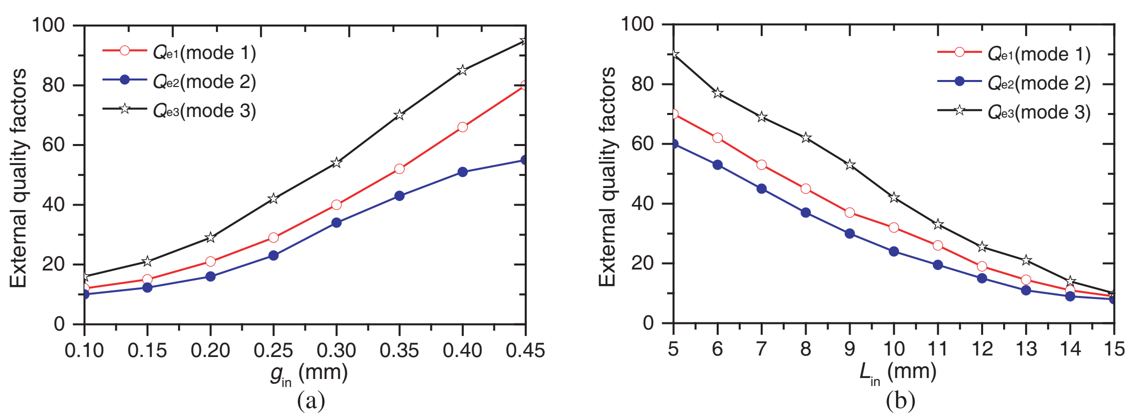

Figure 4. Extracted external quality factors (a) changing g_{in}, (b) changing L_{in}.

The three resonances of the triple-mode resonator can be controlled well. As shown in Fig. 2, parameter L_1 can affect all the resonances because the electric-fields distributions of the three modes are all on the microstrip line denoted by L_1. When L_1 is increased, the three resonances will be decreased, and the simulated DM responses are not presented here. When the length of the stepped-impedance

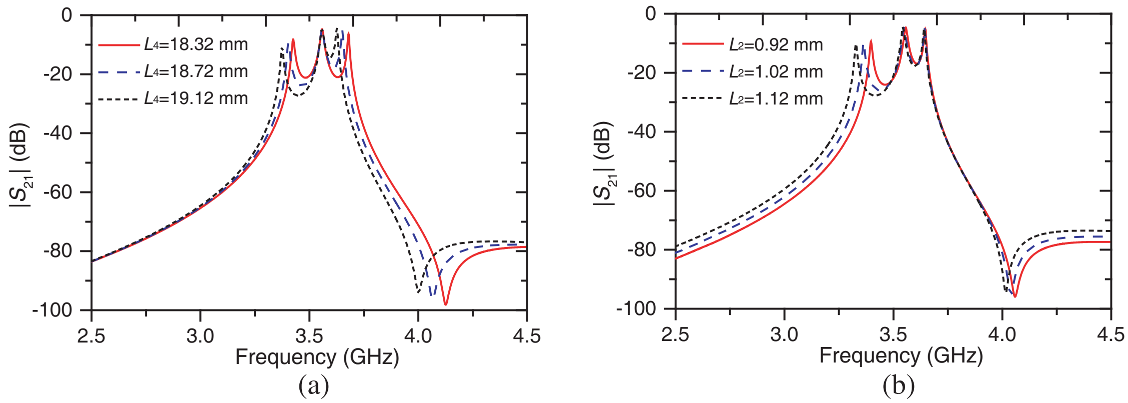

Figure 5. Simulated DM responses under weak IO coupling (a) changing g_{in}, (b) changing L_{in}.

open-stub line is increased (i.e., L_4 is increased), the resonances of modes 1 and 3 are decreased while the resonance of mode 2 is constant, and corresponding simulated DM responses are shown in Fig. 5(a). When the length of the short-sub microstrip line is increased (i.e., L_2 is increased), the resonance of mode 1 is decreased while other two resonances are constant, and corresponding simulated DM responses are shown in Fig. 5(b). Thus, the bandwidth of the proposed triple-mode bandpass filter can be controlled well because the three resonances can be controlled flexibly.

3. SIMULATED AND MEASURED RESULTS

Based on the proposed balanced triple-mode microstrip filter in Fig. 1, a balanced filter with the DM center frequency (f_{0d}) of 3.5 GHz and bandwidth of 200 MHz is designed for the demonstration. The structure parameters of the designed filter are given as follows: $W_0 = 0.76$, $W_{in} = 0.3$, $L_{in} = 12$, $g_{in} = 0.18$, $W_1 = 0.7$, $W_2 = 1$, $W_3 = 2.2$, $L_1 = 31.52$, $L_2 = 0.17$, $L_3 = 2$, $L_3 = 18.72$ (all units: mm).

To verify the designed triple-mode filter, the prototype was fabricated and measured. The comparisons between the simulated and measured responses are presented in Fig. 6. For the DM responses, as shown in Fig. 6(a), the measured f_{0d}, insertion loss (IL), minimum return loss (RL), and 3-dB bandwidth are 3.53 GHz, 1.18 dB, 17.04 dB, and 225 MHz (6.37%), respectively. A transmission

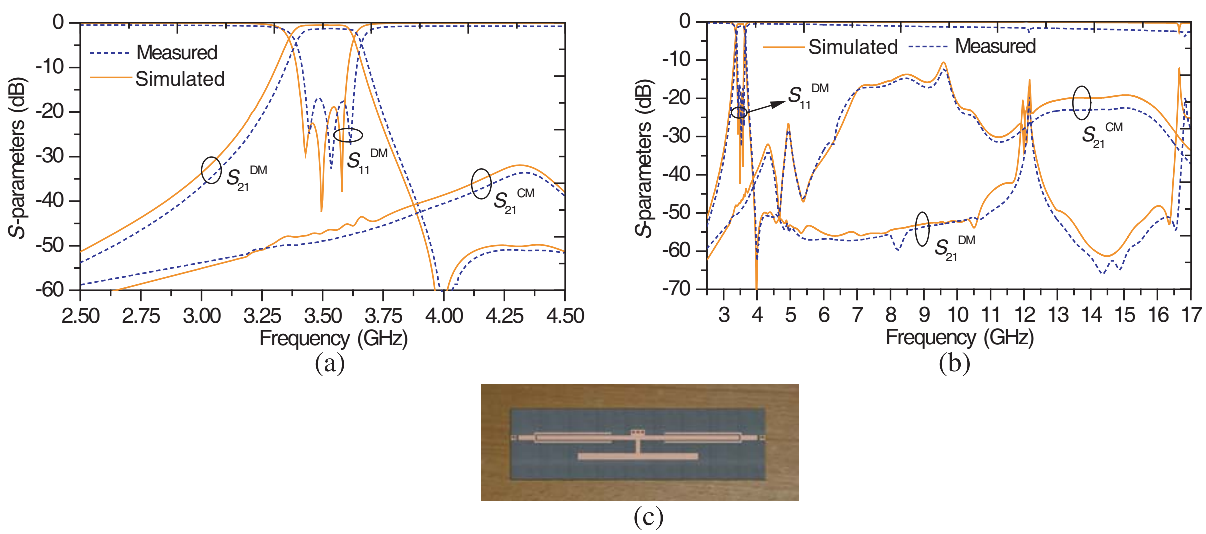

Figure 6. Measured and simulated responses of the proposed balanced BPF (a) DM and CM operation, (b) wideband of DM and CM operation, (c) photograph of the fabricated filter.

zero at 4.01 GHz can be clearly observed as expected. Wideband responses are shown in Fig. 6(b). Rejection level over 20 dB is better than 16.85 GHz, which indicates that the proposed filter has a wide stopband of DM response. For the CM responses, as shown in Fig. 6(a), there is a 49 dB CM suppression level in the passband. Moreover, rejection level over 20 dB is better than 6.76 GHz, which indicates that the proposed filter has a good CM suppression. The size of the designed filter is about 35 mm × 7 mm ($0.56\lambda_g \times 0.11\lambda_g$), where λ_g is the guided wavelength at f_{0d}. A photograph of the fabricated filter is shown in Fig. 6(c).

Table 1 provides detailed comparisons with other reported balanced microstrip filters. The proposed balanced triple-mode filter can realize compact size and high performance of CM suppression as well as DM response. Moreover, the design method in this letter can be extended to design single-/dual-/multiple-band filters using other dual-/triple-/multiple-mode microstrip resonators with double-sided parallel-strip line and stripline-like feeding structure.

Table 1. Compared with other recently reported balanced microstrip filters.

Ref.	f_{0d} (GHz)	m	Size ($\lambda_g \times \lambda_g$)	CM@f_{0d}/dB	Upper stopbands ($S_{21}^{DM} < -20$ dB/ $S_{21}^{CM} < -20$ dB)	Technique
[6]	5.2	3	0.14 × 0.45	41	$3.26f_{0d}/3.26f_{0d}$	T1
[7]	2.39	2	0.21 × 0.21	24.4	$2.72f_{0d}/2.1f_{0d}$	dual mode loop
[8]	3.1	3	0.75 × 0.65	45	$2.92f_{0d}/5.1f_{0d}$	T2
[9]–I	2.4	4	0.63 × 0.63	42.8	$1.94f_{0d}/1.78f_{0d}$	T2
[9]–II	2.4	4	0.63 × 0.63	48	$4.9f_{0d}/3.99f_{0d}$	T2
[12]	2.9	5	0.72 × 1.02	20	$2.34f_{0d}/2.12f_{0d}$	DSPSL
This work	3.53	3	0.56 × 0.11	49	$4.86f_{0d}/1.8f_{0d}$	triple-mode DSPSL

m: number of transmission poles in DM response, T1: single-mode short- and open-end resonators, T2: single-mode and dual-mode resonators, DSPSL: double-sided parallel-strip line resonator.

4. CONCLUSION

In this letter, a novel balanced microstrip BPF using a triple-mode DSPSL resonator with stripline-like feeding structures is proposed. For the demonstration, a balanced triple-mode microstrip filter was designed, fabricated, and measured. Both the simulated and measured results indicate that the proposed technique should become a competitive candidate for the development of RF/microwave circuits and systems.

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