A Wide Stopband Filter with Source-load Coupling Technique

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Abstract— In this paper, a wide stopband bandpass filter using source-load coupling technique is proposed. With the source-load coupling structure, multiple transmission zeros are generated to suppress the harmonic responses in the stopband. By adjusting the gap space between the input/output feed lines, the locations transmission zeros can be controlled. Moreover, the open stub of the input/output feed lines are also used to generate transmission zeros in the stopband. In this design, stepped-impedance resonators (SIR) are utilized to minimize the overall circuit size and control the harmonic frequencies. The impedance and length ratios of the SIR are determined to move its first harmonic to a higher frequency. The center frequency of the filter is 2.45 GHz, and the stopband rejection is higher than 30 dB from 2.9 GHz to 13.36 GHz.

1. INTRODUCTION

Bandpass filter with small size and high performance is demanded in modern wireless communication systems. A second-order bandpass filter is a good candidate for low-loss applications, because the resonators are few in number. But the steepness of the skirts near the passband is not satisfied due to its low-order response. Moreover, the distributed resonators result in spurious responses in the stopband. In [1], a defected ground structure (DGS) is proposed to improve the stopband response, but it needs additional backside fabrication process and occupies large area. Cross-coupled technique is used to generate tunable transmission zeros to improve the stopband responses [2]. Source-load coupling technique is used generate transmission zero near the passband to improve the skirt-selectivity of the filter in [3].

The proposed filter is realized by two coupled stepped-impedance resonators (SIRs) with source-load coupling. The source-load coupling formed by the input/output feed lines can generate multiple controllable transmission zeros. By adjust the I/O coupling gap, the transmission zeros can be adjusted to suppress the harmonic response. Furthermore, the upper and lower arm of the I/O feed lines can also generate transmission zeros to improve the stopband performance. The circuit features small circuit size and wide stopband rejection. The center frequency of the filter is 2.45 GHz with stopband rejection higher than 30 dB from 2.9 GHz to 13.36 GHz.

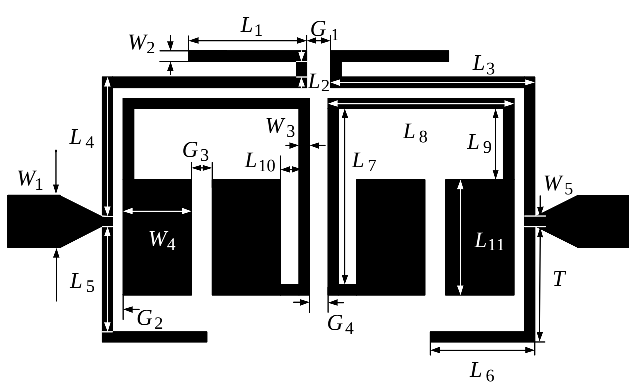

Figure 1: Layout of the bandpass filter with source-load coupling. $L_1 = 4.5$, $L_2 = 0.6$, $L_3 = 7.8$, $L_4 = 4.9$, $L_5 = 4$, $L_6 = 4$, $L_7 = 6.7$, $L_8 = 7.1$, $L_9 = 2.7$, $L_{10} = 0.7$, $L_{11} = 4.4$, $W_1 = 1.8$, $W_2 = 0.4$, $W_3 = 0.4$, $W_4 = 2.6$, $W_5 = 0.4$, $G_1 = 0.9$, $G_2 = 0.4$, $G_3 = 0.8$, $G_4 = 0.7$, $T = 4.4$ (unit: mm).

2. CIRCUIT DESIGN

Figure 1 is the circuit schematic of the proposed bandpass filter, which is composed by two SIRs with a feed structure having line width W_2 and space G_2. Especially, the input and output feed lines are bent to form a small coupling gap G_1 to realize the source-load coupling. Stepped-impedance resonators (SIR) have the advantages of controlling the harmonic resonance frequencies [4]. In this design, the impedance ratio and the length ratio of the SIR are determined to have its second and third harmonic resonances located at $2.6f_0$ and $4.1f_0$, respectively, where f_0 is the fundamental frequency of the SIR. This bandpass filter is designed to have a second-order Butterworth response with a center frequency of $f_0 = 2.45\,\text{GHz}$ and a fractional bandwidth (FBW) of 5.5%. The lumped circuit element values of the low-pass prototype filter are $g_0 = 1$, $g_1 = 1.4142$, $g_2 = 1.4142$, and $g_3 = 1$. The corresponding quality factor Q_e and coupling coefficient M_{12} can be obtained by

$$Q_e = \frac{g_1}{FBW} = 25.7$$
$$M_{12} = \frac{FBW}{\sqrt{g_1 g_2}} = 0.038 \tag{1}$$

where M_{12} represents the coupling coefficient between the two coupled SIRs, and Q_e is the external quality factor associated with the I/O coupling. Figure 2(a) shows the trend of quality factor Q_e versus tapping position T under different values of G_2. According to this figure, $T = 4.4\,\text{mm}$ and $G_2 = 0.4\,\text{mm}$ are chosen to have $Q_e = 26$. Figure 2(b) is the simulated coupling coefficient M_{12} versus the space G_4. These results are extracted by the EM software Sonnet.

Figure 3 is the simulation result of the filter in Figure 1. It can be observed that total ten transmission zeros (TZ_1-TZ_{10}) are generated. It is known that coupled lines with capacitive and inductive loads at one end can produce controllable transmission zeros [6, 7]. In this circuit, TZ_1 and TZ_8 are resulted by the coupled line section L_7 loaded with the open stub L_{11}. The low-frequency zero TZ_1 is generated when the loaded open stub is capacitive, and the transmission zero condition of TZ_8 is satisfied while the loaded open stub is inductive at a higher frequency. The equivalent circuit of gap space G_1 that forms source-load coupling in Figure 1 can be modeled as a capacitance C_g [3]. The locations of the transmission zeros generated by the source-load coupling

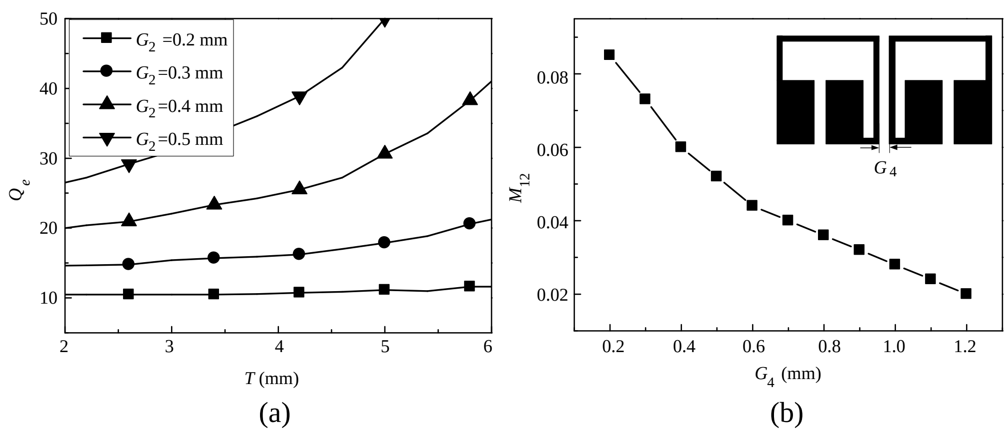

Figure 2: (a) Simulated Q_e versus tapping position T, and (b) M_{12} versus gap space G_4 at 2.45 GHz.

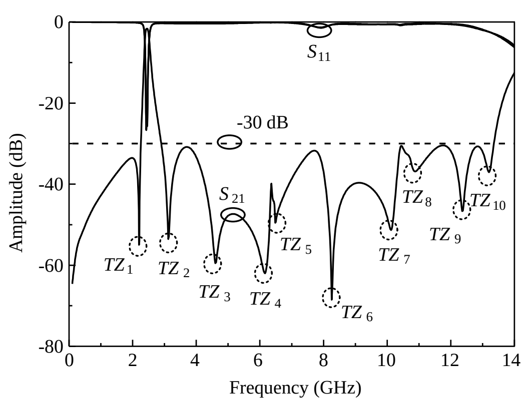

Figure 3: Simulation result of the proposed filter.

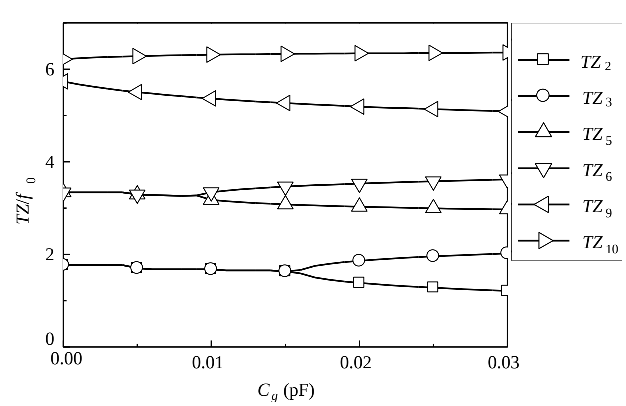

Figure 4: Transmission-zero frequencies versus gap capacitance C_g.

can be controlled by adjusting the gap space G_1. Figure 4 shows the relations of the locations of the transmission zeros versus different values of C_g. It it seen that the three transmission zero pairs TZ_2-TZ_3, TZ_5-TZ_6, and TZ_9-TZ_{10} split away from each other as C_g increases. Figures 5(a) and (b) show the transmission zeros resulted by the upper and lower arms of the I/O feed lines. The upper arm is composed by line sections of $L_1 + L_2 + L_3 + L_4$, and the lower arm is composed by $L_5 + L_6$. The zeros occur at the frequencies when the length equals to $(2n + 1)\lambda/4$. Thus, these zeros can be moved to lower frequencies by increasing their lengths. It is noted that once you change the line lengths of the I/O feed lines, the external quality factor Q_e will be slightly changed, and some iterations might be needed in the design process.

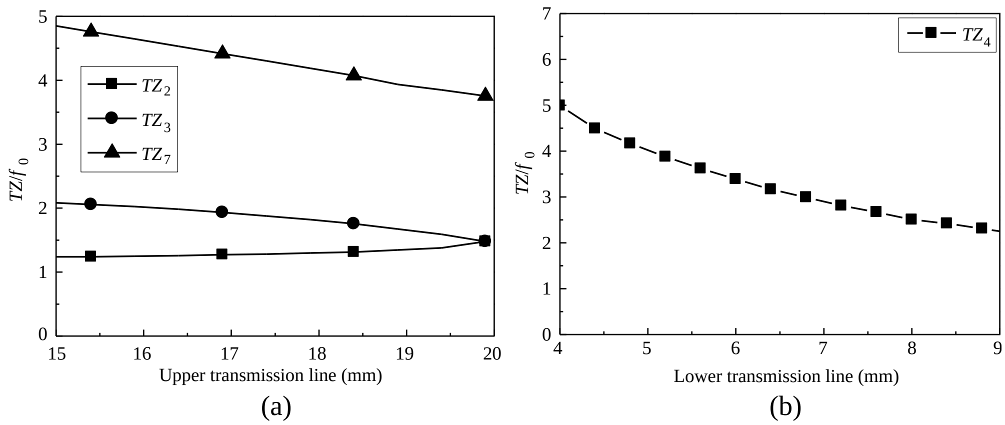

Figure 5: Transmission-zero frequencies versus the length of the input/output coupling line. (a) Upper arm and (b) lower arm.

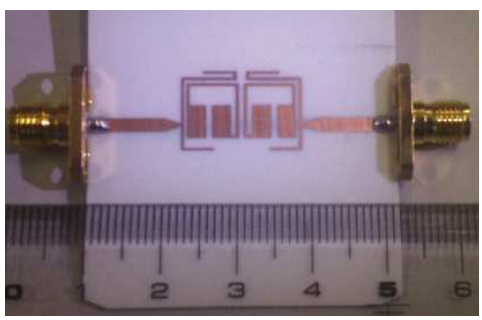

Figure 6: Photograph of the fabricated filter.

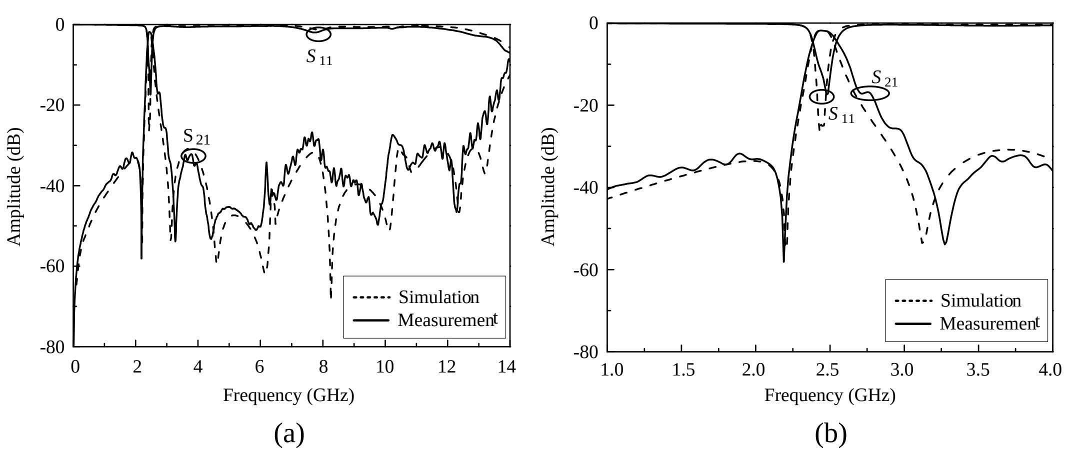

Figure 7: Measured and simulated results of the filter. (a) Wideband response and (b) narrow-band response.

3. SIMULATION AND MEASUREMENT RESULT

The filter is fabricated on the RO4003C substrate with $\epsilon_r = 3.41$, $h = 0.8\,\text{mm}$, and $\tan\delta = 0.0027$. Figure 6 is the photograph of the fabricated filter. It occupies a circuit area of $0.15\lambda_g \times 0.22\lambda_g$, where λ_g is the guided wavelength of the center frequency. The measured and simulation results is shown in Figure 7. The measured center frequency is 2.45 GHz with a FBW of 5.67%, an insertion loss of 1.63 dB, and the stopband rejection better than 30dB from 2.91 GHz to 13.36 GHz.

4. CONCLUSION

In this paper, a wide stopband bandpass filter with source-load coupling is realized. The filter is composed by two coupled SIRs with coupled-line coupling structure. Transmission zeros are created by the input/output source-load coupling, the capacitive/inductive loaded coupled line, and the quarter-wavelength open stub. The center frequency of the filter is 2.45 GHz, and the stopband rejection is higher than 30 dB from 2.9 GHz to 13.36 GHz. The circuit area is $0.15\lambda_g \times 0.22\lambda_g$.

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