

Bandpass Filter with Four Transmission Zeros Using Dual-Mode Ring Resonator

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Abstract—A novel microstrip bandpass filter with four transmission zeros is proposed. Four transmission zeros close to the passband are realized to improve the selectivity for the passband. A sixth-order passband is realized with two shorted stubs and a dual-mode ring resonator. The transmission zeros near the passband can be adjusted conveniently by only changing the characteristic impedances of the coupled lines. For demonstration, a planar bandpass filter (3-dB bandwidth 21.9%) was designed and fabricated.

1. INTRODUCTION

Microwave dual-mode filter is a microwave filter with many attractive advantages such as high Q factor, compact size and sharp rejection skirt [1, 2]. Different ring resonators with open stubs and notches were used to design wideband bandpass filters with high selectivity [3–8]. Moreover, a dual-mode resonator using side-coupled lines was used to design bandpass filters without any perturbations [9, 10], and the bandwidth, transmission zeros frequencies of the dual-mode resonator can be simply controlled by changing the characteristic impedance of the coupled lines. However, cascaded ring resonators should be used to increase the passband-order, and number of the out-of-band transmission zeros cannot be increased.

In this paper, a novel bandpass filter loaded with shorted stubs using a dual-mode ring resonator is proposed. A sixth-order passband can be easily realized with only a ring resonator, and two open/shorted coupled lines are used to realize two additional transmission zeros close to the passband. The out-of-band transmission zeros can be adjusted conveniently by changing the even/odd-mode coupled line impedances. A prototype of the bandpass filter operating at 3.1 GHz is constructed on a dielectric substrate with $\varepsilon_r = 2.65$, $h = 1.0$ mm, and $\tan \delta = 0.003$.

2. ANALYSIS AND DESIGN OF PROPOSED BANDPASS FILTER

Figures 1(a)–(b) show the top view and transmission line circuit of the microstrip bandpass filter. A dual-mode ring resonator is attached to two quarter-wavelength side-coupled lines (electrical length θ , even/odd-mode characteristic impedance Z_{e1} , Z_{o1}). Two open coupled lines (Z_{e1} , Z_{o1} , θ) with shorted loaded stubs (Z_1 , θ) are located in the sides of the bandpass filter, and two open/shorted coupled lines (electrical length θ , even/odd-mode characteristic impedance Z_{e2} , Z_{o2}) are shunted across the input/output Ports 1, 2. Four microstrip lines with characteristic impedance $Z = 50 \Omega$ are connected to Ports 1, 2.

The $ABCD$ matrix of the bandpass filter circuit for Fig. 1(b) can be defined as $M_o \times M_{oc1} \times M_s \times M_t \times M_s \times M_{oc2} \times M_o$ (M_o -open/shorted coupled lines, M_{co1} and M_{co2} -coupled lines with shorted stubs,

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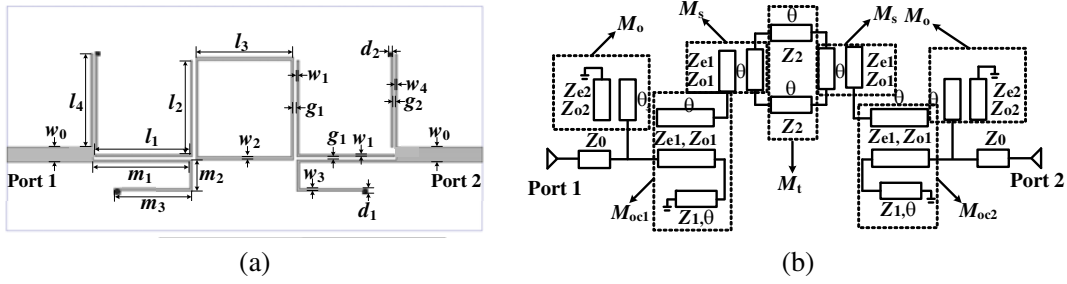


Figure 1. Structure and circuits of proposed microstrip filter. (a) Top view of the filter. (b) Transmission line circuit of the filter.

M_s -side-coupled lines, M_t -center two transmission lines), and the matrices of the coupled lines and stubs can be obtained from [11]. After $ABCD$ -, Y - and S -parameter conversions, when $S_{21} = 0$, four transmission zeros can be obtained:

$$\theta_{tz1} = \arccos \frac{Z_{e2} - Z_{o2}}{Z_{e2} + Z_{o2}}, \quad \theta_{tz2} = \pi - \theta_{tz1} \quad (1)$$

$$\theta_{tz3} = \arccos \sqrt{\frac{Z_{e1} + Z_{o1} - 2Z_2}{Z_{e1} + Z_{o1} + 2Z_2}}, \quad \theta_{tz4} = \pi - \theta_{tz3} \quad (2)$$

In addition, the transmission poles in the passband can be calculated when $S_{11} = 0$. When Z_0 is fixed, six roots for $S_{11} = 0$ can be found by properly choosing the relationships of Z_1 , Z_2 , Z_{e1} , Z_{o1} , Z_{e2} , Z_{o2} , and then six transmission poles in the passband can be achieved.

The simulated results of Fig. 1(b) are shown in Figs. 2(a), (b), (c). Compared with the bandpass filter circuit in [9], the two transmission zeros f_{tz1} , f_{tz2} can be used to further improve the passband selectivity, and the six transmission poles in the passband reflect that $S_{11} = 0$ has six real solutions, when Z_1 , Z_2 , Z_{e1} , Z_{o1} , Z_{e2} , and Z_{o2} are properly selected. In addition, the locations of two transmission zeros f_{tz1} , f_{tz2} do not change with Z_{e1} , and Z_{o1} , and the locations of two transmission zeros f_{tz3} , f_{tz4} do not change with Z_{e2} , and Z_{o2} . So, four transmission zeros close to the passband can be adjusted independently by this simple way. The 3-dB bandwidth is mainly determined by the characteristic impedance Z_{e1} , Z_{o1} , Z_2 (dual-mode ring resonator) [9]. The in-band balance of the filter can be adjusted by the characteristic impedance Z_1 (shorted stubs) [11].

To clarify the proposed filter design, the design procedures of the bandpass filter can be summarized as follows:

- (1) Based on Equations (1)–(2), choose the desired center frequency f_0 of the bandpass filter and determine the four transmission zeros locations close to the passband;
- (2) Adjust the shorted loaded stubs (Z_1) and transmission lines (Z_2) to realize a sixth-order passband for the bandpass filter and choose the desired bandwidth for the filter (3-dB bandwidth greater than 20%, ($|S_{11}| < -15$ dB) and out-of-band harmonic suppression ($|S_{21}| < -20$ dB);
- (3) Further optimize the values of Z_{e1} , Z_{o1} to realize better in-band and out-of-band transmission characteristics of the bandpass filter and carry out full-wave electromagnetic simulation and dimension optimization in the commercial software of HFSS.

Referring to the above discussions and the simulated results, the 3-dB bandwidth of the bandpass filter is chosen as 22.5%, and the final parameters for the filter circuit of Fig. 1(b) are listed as below: $Z_0 = 50 \Omega$, $Z_1 = 90 \Omega$, $Z_2 = 123 \Omega$, $Z_{e1} = 181 \Omega$, $Z_{o1} = 109 \Omega$, $Z_{e2} = 210 \Omega$, $Z_{o2} = 70 \Omega$. The structure parameters for Fig. 1(a) are: $l_1 = 17.2$ mm, $l_2 = 17$ mm, $l_3 = 17.1$ mm, $l_4 = 17$ mm, $m_1 = 17.2$ mm, $m_2 = 5.5$ mm, $m_3 = 12.4$ mm, $w_0 = 2.7$ mm, $w_1 = 0.2$ mm, $w_2 = 0.42$ mm, $w_3 = 0.47$ mm, $w_4 = 0.26$ mm, $g_1 = 0.57$ mm, $g_2 = 0.25$ mm, $d_1 = 0.7$ mm, $d_2 = 0.7$ mm, $\epsilon_r = 2.65$, $h = 1.0$ mm, $\tan \delta = 0.003$.

Figure 3 illustrates the simulated results of the bandpass filter with four transmission zeros. Five simulated transmission zeros are located at 2.2, 2.4, 3.6, 3.78, and 4.2 GHz, and the 3-dB bandwidth is 23.5% (2.74–3.47 GHz) with return loss greater than 15 dB (2.79–3.42 GHz).

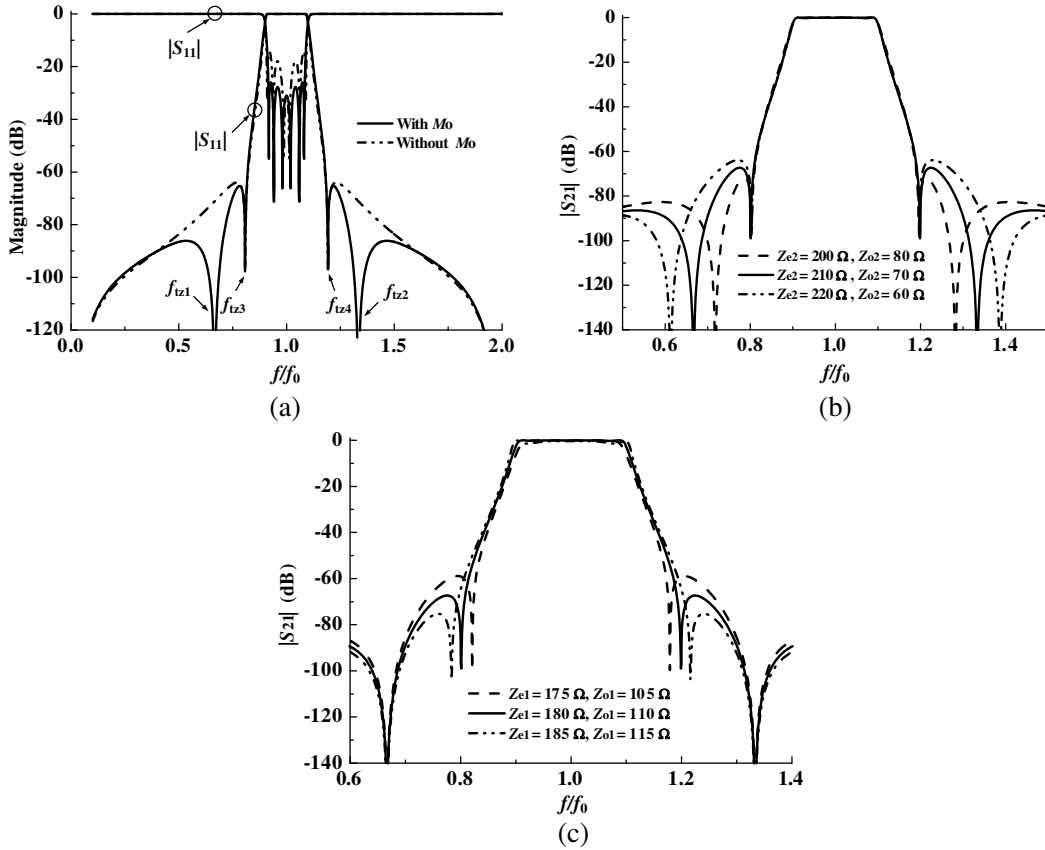


Figure 2. Simulated frequency responses of Fig. 1(b). (a) $|S_{21}|$ & $|S_{11}|$, $Z_0 = 50 \Omega$, $Z_1 = 90 \Omega$, $Z_2 = 120 \Omega$, $Z_{e1} = 180 \Omega$, $Z_{o1} = 110 \Omega$, $Z_{e2} = 200 \Omega$, $Z_{o2} = 70 \Omega$. (b) Versus Z_{e2} , Z_{o2} , $Z_1 = 90 \Omega$, $Z_2 = 120 \Omega$, $Z_{e1} = 180 \Omega$, $Z_{o1} = 110 \Omega$. (c) Versus Z_{e1} , Z_{o1} , $Z_1 = 90 \Omega$, $Z_2 = 120 \Omega$, $Z_{e2} = 200 \Omega$, $Z_{o2} = 70 \Omega$.

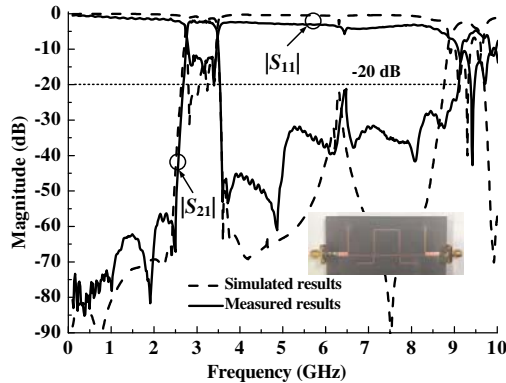


Figure 3. Photograph, measured, simulated results of the microstrip filter.

3. MEASURED RESULTS AND DISCUSSIONS

The measured results and a photograph of the bandpass filter are also illustrated in Fig. 3. Good agreement can be observed between the simulation and experiments. For the bandpass filter of Fig. 1(b), five transmission zeros are located at 1.91, 2.50, 3.58, 3.71, and 4.37 GHz. The 3-dB bandwidth is 21.9% (2.76–3.44 GHz) with return loss greater than 12.5 dB and insertions loss more than 20 dB from 3.54

to 9.11 GHz ($2.94f_0$). The second harmonic around 6.45 GHz is mainly due to the desynchronization between the quarter-wavelength lines in the resonator [9], and imperfect soldering skill of the shorted stubs and folded transmission line of the balanced filters also causes some slight frequency discrepancies of the measured passbands.

4. CONCLUSION

In this paper, a novel bandpass filter with high selectivity using a dual-mode ring resonator is proposed. Four transmission zeros close to the passband can be easily achieved, and the transmission zeros realized by the dual-mode ring resonator and open/shorted coupled lines can be adjusted independently. The proposed bandpass filter has the advantages of high selectivity, high passband-order and wideband harmonic suppression. Good agreement between simulated and measured responses of the filter is demonstrated.

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