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High Selective and Wide-Stopband Bandpass Filter Using Simple Uniform Impedance Resonators

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Abstract—A fifth-order bandpass filter with high selectivity and wide-stopband using quarter- and half-wavelength uniform impedance resonators (UIRs) is presented in this letter. The use of a terminated coupled line provides controllable transmission zeros that can suppress the parasitic passbands. A pair of transmission zeros is generated on both sides of the passband by introducing cross-coupling. As a result, high selectivity and wide stopband can be achieved simultaneously. The method of controlling transmission zeros using a coupled line and an open/short-circuited stub is analyzed, and the method of improving passband selectivity using cross-coupling is given in details. The concept is experimentally tested in a microstrip bandpass filter with center frequency 1 GHz. The measured attenuation is better than 24 dB up to 18 GHz.

1. INTRODUCTION

Microwave bandpass filters with high selectivity and spurious passband suppression are essential components that have a major influence on the performance of communication systems. There have been many attempts to design wide stopband filters [1–6]. Wide stopband microstrip bandpass filters can be achieved by using quarter-wavelength stepped impedance resonators in [1, 2]. In [3], a method of using a SIR resonator is proposed to suppress the harmonic. In [4–6], the combination of a parallel coupled transmission line and an open-circuited stub is used to generate transmission zeros to suppress the parasitic passband. Appropriate introduction of transmission zeros can achieve high selectivity and wide stopband. However, in these examples, the selectivity of the bandpass filter needs to be improved. The transmission zeros are generated near the passband by dividing the input/output port of the filter into two paths in [7] and by introducing cross-coupling in [8] to improve the selectivity. Few methods mention how to design a filter with both high selectivity and wide stopband. Those methods only consider how to achieve a wide stopband but neglect high selectivity, or achieve high selectivity but neglect wide stopband. In [9], meander coupled lines are used to design a highly selective bandpass filter, but the stopband is not very wide, only up to 8.75 times of the center frequency.

In this letter, a fifth-order bandpass filter with high selectivity and wide stopband is designed by combined half- and quarter-wavelength UIRs. The microstrip filter operating at 1 GHz is shown in Fig. 1, which consists of two half-wavelength UIR and three quarter-wavelength UIRs. By properly choosing the lengths of the parallel coupled transmission line and open/short-circuited stub, a group of transmission zeros can be generated and controlled flexibly to suppress the spurious passband. Cross coupling is introduced so that the selectivity of the passband is improved by extra transmission zeros. Therefore, a band-pass filter with high selectivity and a wide stopband is achieved.

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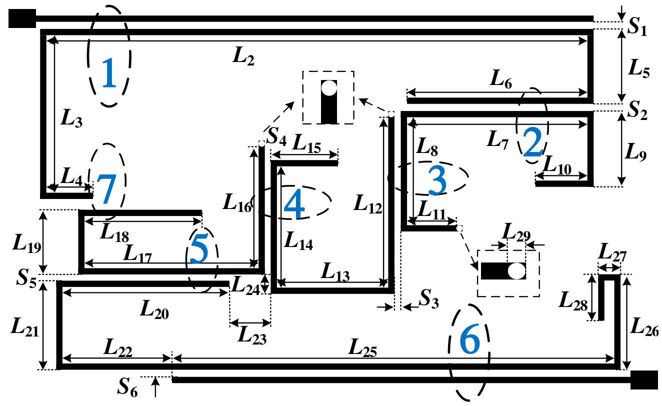


Figure 1. Configuration of the fifth-order microstrip filter.

2. FILTER STRUCTURE ANALYSIS

A microstrip fifth-order bandpass filter operating at 1 GHz, which consists of six adjacent coupled Sections 1–6 and one cross coupled Section 7, is shown in Fig. 1. Aiming to reduce the filter size, the fifth-order filter consists of two half-wavelength UIRs and three quarter-wavelength UIRs. Short circuits at the end of the resonators are provided by metalized via holes with diameter 0.5 mm. The mechanism of the transmission zeros will be detailed below.

2.1. Terminated Coupled Lines

In Fig. 1, different types of terminated coupled lines are used to obtain the couplings between resonators, including open-circuited (Fig. 2(a)) and short-circuited (Fig. 2(b)) loaded coupled lines. The fourth coupled section is different from the structure in Figs. 2(a) or (b), which is not considered here. A method of generating controllable transmission zeroes using the structure in Fig. 2(a) is introduced in [6]. After similar analysis, the structure in Fig. 2(b), which consists of a coupled line and short-circuited stub, has homologous characteristics in homogeneous mediums.

A microstrip coupled line loaded with a short-circuited stub is shown in Fig. 2(c). The substrate

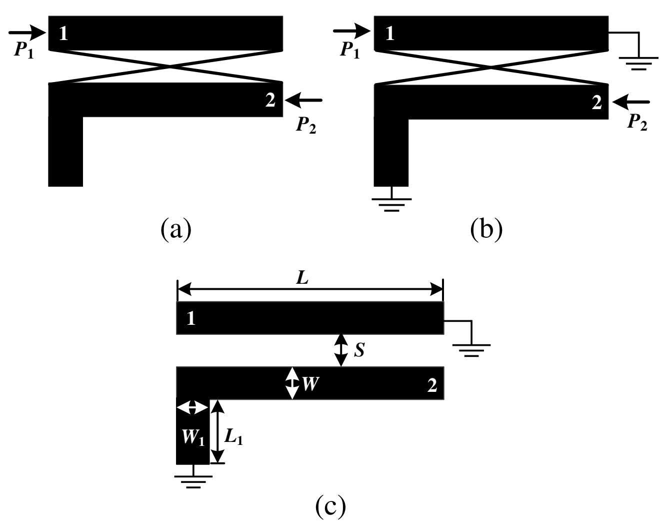
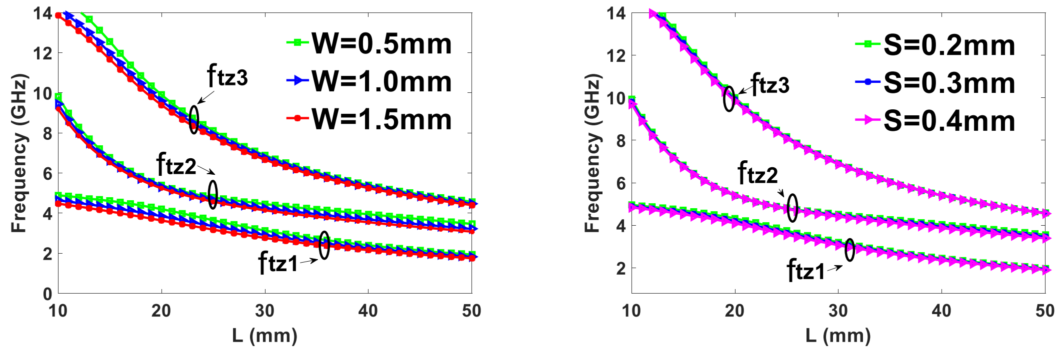


Figure 2. Terminated coupled line. (a) Coupled line connected with open-circuited stub in [6]. (b) Coupled line connected with short-circuited stub. (c) Microstrip terminated coupled line.



(a) (b)

Figure 3. Distribution of transmission zeros at different W and S. (a) W. (b) S.

with dielectric constant $\varepsilon_r = 2.55$, loss tangent $\delta = 0.0029$, and thickness $h = 0.8\,\text{mm}$ is used. Fig. 3 shows the position of the first three transmission zeros under different W and S in the case of fixed L_1 ($L_1 = 10\,\text{mm}$). When the impedances are changed, the transmission zeros distribution changes little. Namely, the effects of changes in W and S on the position of transmission zero is small. Based on these conclusions, the structures in Figs.2(a) and (b) can be both used to generate two controllable transmission zeros. Table 1 shows a group of L and L_1 lengths (Fig. 2(c)) determined by the expected transmission zeros. The f_{tzn} plot is the nth zero generated by the structure in Fig. 2(c). The position of the transmission zeros generated by each coupling section in Fig. 1 is listed in Table 2.

Table 1. Solution of the transmission zeros distribution ($f_0 = 1\,\text{GHz}$, $Z_{oe} = 138.26\,\Omega$, $Z_{oo} = 72.69\,\Omega$, $Z_o = 106.16\,\Omega$).

		f_{tzn}							
		$3f_0$	$4f_0$	$5f_0$	$6f_0$	$7f_0$	$8f_0$	$9f_0$	$10f_0$
f_{tz1}	$2f_0$	47.3	48.9	39.2	27.0	30.2	25.1	33.2	39.5
		14.3	2.2	22.2	24.3	23.8	24.5	23.4	22.1
	$3f_0$		30.6	32.0	32.6	32.2	32.4	17.6	22.2
			11.8	7.7	0.8	6.7	4.2	16.2	15.6
	$4f_0$				16.9	14.2	12.3	10.8	19.5
					11.6	12	12.3	12.5	11.0
	$5f_0$					14.7	12.6	11.0	9.8
						9.0	9.4	9.6	9.8
	$6f_0$						15.3	11.2	10.0
							5.9	7.7	7.9
	$7f_0$							12.0	10.2
								5.9	6.5

xx.x Coupled line length, mm   Stub length, mm   No solution

2.2. Cross-Coupling

Figure 4 shows the approximate coupling diagram of the fifth-order bandpass filter in Fig. 1. Electric cross-coupling is introduced. Using the phase rules in [10], the phase shifts can be found for two possible signal paths. Path 1-2-3-4-5 is the primary path, and path 1-4-5 is the secondary path that follows the cross-coupling. Since resonators 1, 4 and 5 are commonly included in the primary path and secondary path, the contribution of the coupling between resonators 4 and 5 and the contribution of the phase shift of resonators 1, 4 and 5 can be ignored when calculating the phase. Table 1 shows the phase calculation results for both paths. As can be seen from the results in Table 3, the transmission zeros are generated above and below the passband.

Table 2. Distribution of transmission zeros ($f_0 = 1\,\text{GHz}$).

Coupled Section	Transmission Zeros (Controlled)	Transmission Zeros (Uncontrolled)
1	$f_{tz1} = 2f_0,\ f_{tz2} = 3f_0$	$f_{tz3} = 4.2f_0,\ f_{tz4} = 5.8f_0,$ $f_{tz5} = 7.3f_0,\ f_{tz6} = 8.4f_0 \ldots$
2	$f_{tz1} = 4f_0,\ f_{tz2} = 6f_0$	$f_{tz3} = 10.7f_0,\ f_{tz4} = 13f_0 \ldots$
3	$f_{tz1} = 7f_0,\ f_{tz2} = 9f_0$	$f_{tz3} = 15.2f_0 \ldots$
5	$f_{tz1} = 3f_0,\ f_{tz3} = 9f_0$	$f_{tz2} = 6.6f_0,\ f_{tz4} = 12.6f_0,$ $f_{tz5} = 14.8f_0 \ldots$
6	$f_{tz3} = 5f_0,\ f_{tz4} = 7f_0$	$f_{tz1} = 2.4f_0,\ f_{tz2} = 3.8f_0,$ $f_{tz5} = 9f_0,\ f_{tz6} = 10.5f_0 \ldots$

Table 3. Total phase shifs for the filter.

	Below Resonance	Above Resonance
Path 1-2-3-4	$+90° + 90° - 90° + 90°\ +90° = +270°$	$+90° - 90° - 90° - 90° + 90° = -90°$
Path 1-4	$+90° = +90°$	$+90° = +90°$
Result	Out of phase	Out of phase

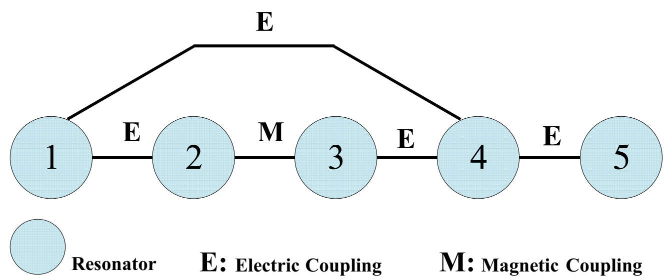


Figure 4. Coupling diagram for the proposed filter.

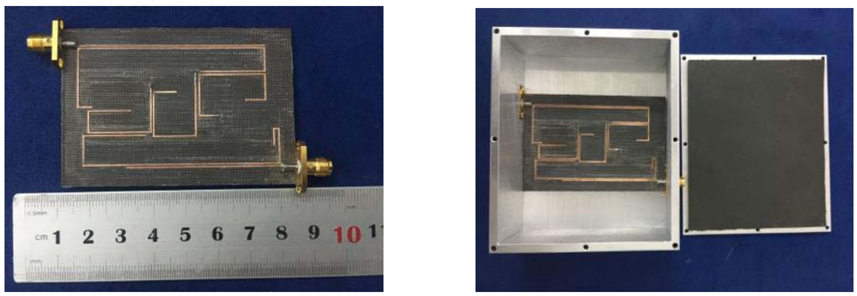
3. RESULTS

The microstrip bandpass filter is designed and fabricated for verification. The center frequency of the filter is taken to be 1 GHz with a fractional bandwidth of 10%. The ripple level is designed to be 0.04321 dB. According to the specification, the coupling matrix of the bandpass filter can be obtained as [11]

$$M = \begin{pmatrix} 0 & 0.89 & 0 & 0.07 & 0 \\ 0.89 & 0 & -0.65 & 0 & 0 \\ 0 & -0.65 & 0 & 0.65 & 0 \\ 0.07 & 0 & 0.65 & 0 & 0.89 \\ 0 & 0 & 0 & 0.89 & 0 \end{pmatrix} \tag{1}$$

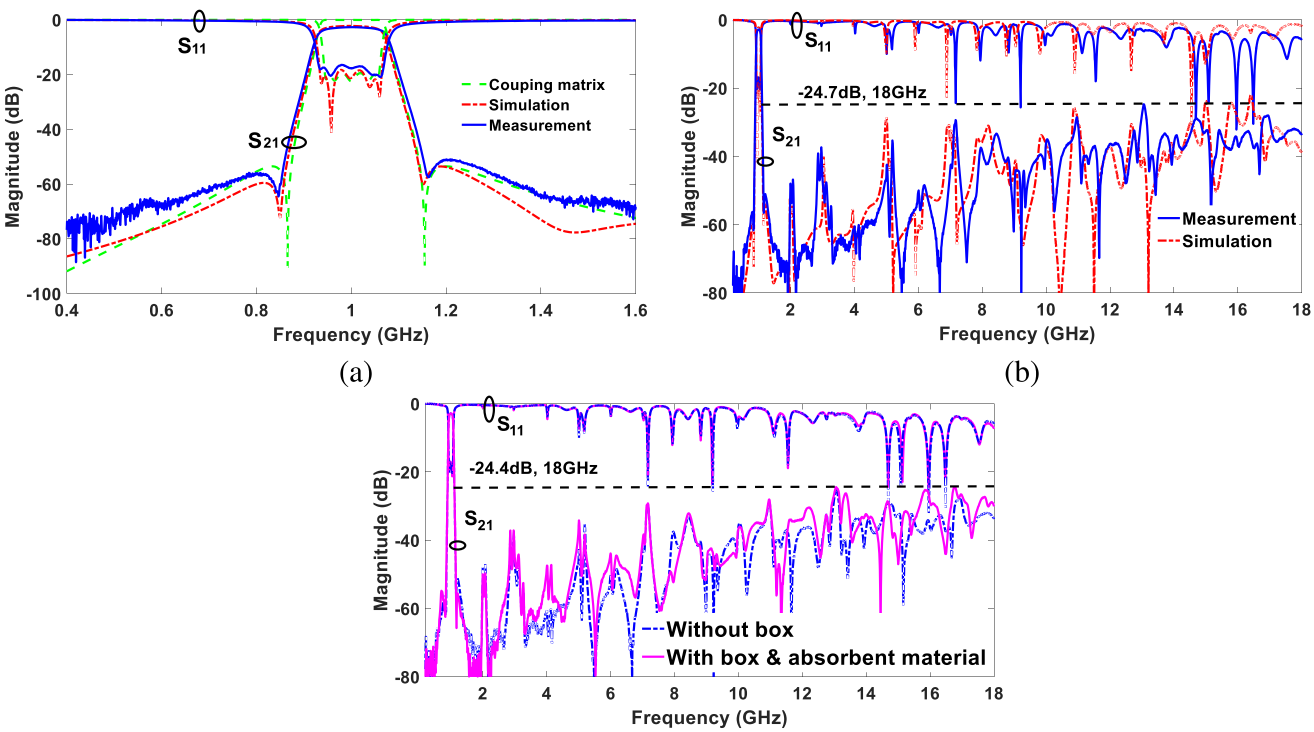
Optimized parameters (mm) of the lengths in Fig. 1 are listed as follows: $L_2 = 58.3$, $L_3 = 18.12$, $L_4 = 4.09$, $L_5 = 8.06$, $L_6 = 20.4$, $L_7 = 20.4$, $L_8 = 12.6$, $L_9 = 8.7$, $L_{10} = 6.1$, $L_{11} = 5.55$, $L_{12} = 18.95$, $L_{13} = 12.72$, $L_{14} = 13.45$, $L_{15} = 7.5$, $L_{16} = 14.1$, $L_{17} = 18.92$, $L_{18} = 13$, $L_{19} = 7.3$, $L_{20} = 19.03$, $L_{21} = 9.73$, $L_{22} = 13$, $L_{23} = 2.21$, $L_{24} = 1.35$, $L_{25} = 47.5$, $L_{26} = 11.3$, $L_{27} = 2.1$, $L_{28} = 5.5$, $L_{29} = 0.5$, $S_1 = 0.2$, $S_2 = 0.43$, $S_3 = 0.72$, $S_4 = 0.32$, $S_5 = 0.4$, $S_6 = 0.3$, and the width of microstrip line is 0.5 mm.

Fig. 5(a) shows a photograph of the fabricated filter, and its total size is about 65 mm × 39 mm, which is much smaller than that of the fourth-order filter (96 mm × 52 mm) using half-wavelength resonators [6]. The filter is loaded in a 30 mm high metal box with absorbent material, which is shown in Fig. 5(b). Simulated and measured results of the filter are in good agreement, as shown in Fig. 6. In the passband, the measured insertion loss is less than 2.4 dB and the return loss better than 16.4 dB. At the same time, two transmission zeros are generated at 0.845 GHz and 1.165 GHz, which improve the passband selectivity. In addition, the stopband rejection is better than 24.7 dB up to more than 18 GHz. Fig. 6(c) shows the measured results under the metal box and absorbent material, and > 24.4 dB attenuation up to 18 GHz has been achieved. Compared with the previous works, the proposed filter shows ultra-wide stopband and high selectivity simultaneously, as listed in Table 4.



(a) (b)

Figure 5. Fabricated filter. (a) Without metal box. (b) With metal box and absorbent material.



(a) (b) (c)

Figure 6. *S*-parameters of the fifth-order filter. (a) Narrowband responses. (b) Wideband responses (without metal box). (c) Measured results of the filter with metal box and absorbent material.

Table 4.

Ref.	N	f_0 (GHz)	FBW (%)	IL (dB)	RL (dB)	SRR	HS
[1]	4	1.5	10	2.35	14.85	$8.25f_0$ (32.49 dB)	×
[2]	4	2	7	2.6	21	$11.4f_0$ (27.5 dB)	×
[4]	3	1	7	2	18	$8.7f_0$ (25 dB)	×
[5]	3	1	1	0.4	17	$17f_0$ (32 dB)	×
[6]	4	1	1	1.9	17.2	$14.9f_0$ (28 dB)	×
[7]	4	8.7	18.4	2.4	16.5	$4.1f_0$ (15 dB)	√
[9]	4	0.38	48.5	0.43	17.5	$8.7f_0$ (25 dB)	√
This work	**5**	**1**	**10**	**2.4**	**16.4**	$> \mathbf{18f_0}$ **(24.7 dB)**	√

N: Filter order; SRR: Stopband Rejection Range; HS: High Selectivity.

4. CONCLUSION

In this letter, a simple and effective method to design a microstrip bandpass filter with high selectivity and wide stopbands has been proposed. The coupled line terminated with a stub is used to suppress the parasitic passband, and the cross coupling is introduced to improve passband selectivity. By using a combination of an open-circuited stub and a short-circuited stub, not only can the transmission zeros be conveniently controlled, but the size of the filter can be reduced. The bandpass filter has been fabricated for verification. The measured result shows that the stopband rejection is better than 24.7 dB up to more than 18 GHz ($18f_0$), and two transmission zeros are generated at 0.845 GHz and 1.165 GHz, which has quite promising performance.

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