Wide-Stopband Microstrip Bandpass Filters Using Quarter-Wavelength Stepped-Impedance Resonators and Bandstop Embedded Resonators

Tsung-Nan Kuo, Wei-Chiang Li, Chi-Hsueh Wang, and Chun Hsiung Chen, *Fellow, IEEE*

***Abstract*—Novel compact microstrip bandpass filters (BPFs) with extended stopband are proposed using both quarter-wavelength $(\lambda/4)$ stepped-impedance resonators and bandstop embedded resonators. First, by properly designing the impedance and length ratios of the stepped-impedance resonators, the developed filter may be made compact and its spurious harmonics may be pushed to the higher frequency region. Next, by suitably designing the bandstop structure so as to suppress the lower spurious harmonics of stepped-impedance resonators and then embedding the bandstop structure into the $\lambda/4$ resonators, one may realize the BPFs with wideband spurious suppression. In particular, by connecting the bandstop embedded resonators to the input/output ports, a compact fourth-order BPF of dimension 0.089 $\lambda_g \times 0.27\lambda_g$ is implemented and its stopband is extended up to 8.25 f_0 with an adequate rejection of greater than 32.49 dB, where f_0 is the passband center frequency and λ_g is the microstrip guided wavelength at f_0.**

***Index Terms*—Bandstop embedded resonator, microstrip bandpass filter (BPF), quarter-wavelength $(\lambda/4)$ resonator, spurious suppression.**

I. Introduction

COMPACT size bandpass filters (BPFs) with superior out-of-band rejection are essential in developing the modern microwave communication systems. To suppress the unwanted interference or noise, the BPFs with wide-stopband characteristics are usually required. A direct method for wideband spurious suppression is to cascade the lowpass structures at input and output ports [1], [2]. However, the extra lowpass structures may degrade the insertion loss and increase the circuit area. In [3], [4], the lowpass structures were integrated into the BPFs, but only the second harmonic frequency was suppressed. In [5], by using capacitive coupling, several open stubs were created to establish adjustable multiple transmission zeros. These transmission zeros may suppress several unwanted spurious passbands, but it demands long tuning time to design the open stubs.

In [6], [7], the concepts of equalizing the phase velocities of eigenmodes were proposed to suppress the unwanted spurious passbands. However, these parallel coupled-line filters have the drawback of large circuit size and require a long tuning period for achieving multi-harmonic suppression. In [8], the coplanar waveguide electromagnetic bandgap resonators were adopted for spurious suppression, but only the second and third harmonics were eliminated. Recently, the idea of using dissimilar resonators [9], [10] was employed to stagger the harmonic frequencies of each resonator. However, by arranging these dissimilar resonators, it would destroy the symmetry of the filters and cost a lot of simulation time.

In this study, novel compact microstrip BPFs with wide stopband are proposed. The proposed filters are composed of $\lambda/4$ stepped-impedance resonators and properly designed bandstop embedded resonators. The $\lambda/4$ stepped-impedance resonators are used to push the spurious harmonics to the higher frequency region and the bandstop embedded resonators are designed to suppress the lower spurious harmonics, so that a BPF with wide stopband may be accomplished. Moreover, both $\lambda/4$ stepped-impedance resonators and bandstop embedded resonators are smaller in size, thus the implemented filters possess not only wide stopband but also compact circuit sizes.

II. λ/4 Stepped-Impedance Resonators and Bandstop Structure

The adopted $\lambda/4$ stepped-impedance resonator has been well characterized and its resonant frequencies may be evaluated and adjusted as in [11]. In this study, the $\lambda/4$ stepped-impedance resonators with impedance ratio of 0.38 and length ratio of 0.36 are chosen so that the second and third harmonic frequencies may be pushed to $4f_0$ and $7f_0$.

Fig. 1(a) shows the physical layout of microstrip bandstop structure, which is composed of a series high-impedance line and two low-impedance shunt stubs. It should be noted that an edge coupling between two low-impedance shunt stubs has been introduced to create an extra transmission zero so as to give better selectivity and wider stopband. Moreover, due to the capacitive loading effect of two low-impedance shunt stubs, the bandstop structure shows the slow-wave characteristic to reduce the circuit size.

As shown in Fig. 1 (b), the frequency responses of this bandstop structure exhibit a stopband ranging from 4.8 to 12.74 GHz with a rejection level better than 10 dB. As a result, a bandstop embedded resonator may be formed by embedding the bandstop structure into a $\lambda/4$ resonator. With the rejection band of

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The authors are with the Department of Electrical Engineering and Graduate Institute of Communication Engineering, National Taiwan University, Taipei 106, Taiwan, R.O.C. (e-mail: chchen@ew.ee.ntu.edu.tw).

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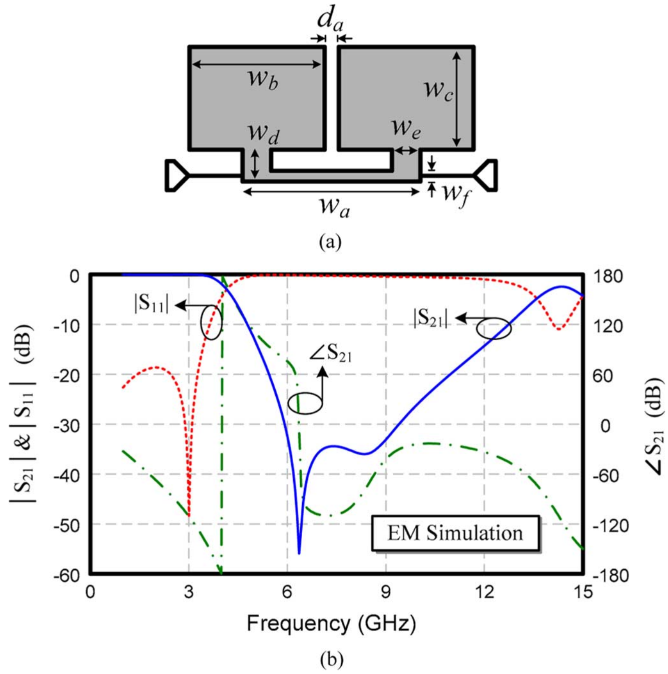

Fig. 1. Proposed microstrip bandstop structure. (a) Physical layout. (w_a = 6.35 mm, w_b = 3.683 mm, w_c = 4.826 mm, w_d = 1.143 mm, w_e = 1.016 mm, w_f = 0.381 mm, d_a = 0.508 mm). (b) Fullwave simulated frequency responses.

bandstop structure adjusted to suppress the lower spurious harmonics of $\lambda/4$ stepped-impedance resonator, one may implement a compact BPF with its stopband widely extended.

III. Fourth-Order Filter With Stepped-Impedance Resonators Connected to Input/Output

The circuit configuration of the first proposed fourth-order microstrip filter is shown in Fig. 2, which is fabricated on the Rogers RO4003C substrate with $\varepsilon_r = 3.38$, $\tan\delta = 0.0022$, and thickness $h = 0.813$ mm. Specifically, the first and fourth resonators are composed of the $\lambda/4$ stepped-impedance resonators while the second and third resonators are of the $\lambda/4$ bandstop embedded resonators. Each resonator is folded to achieve required couplings and to make the size compact. It should be mentioned that extra stepped-impedance lines have also been introduced and connected to the bandstop structure so as to establish the second and third $\lambda/4$ bandstop embedded resonators as shown in Fig. 2.

The proposed fourth-order filter is designed using the coupled-resonator procedures [12]. The design parameters of this fourth-order filter are determined for the Butterworth response with the center frequency f_0 at 1.5 GHz and a fractional bandwidth of 10%. The external quality factor Q_e and coupling coefficients M_{ij} associated with the specifications are

$$Q_{\text{ei}} = Q_{\text{eo}} = 11.09, M_{12} = M_{34} = 0.083, M_{23} = 0.067.$$

To determine the physical dimensions of the filter, the fullwave simulator ADS Momentum is employed to establish the required design curves for external quality factor Q_e and coupling coefficients.

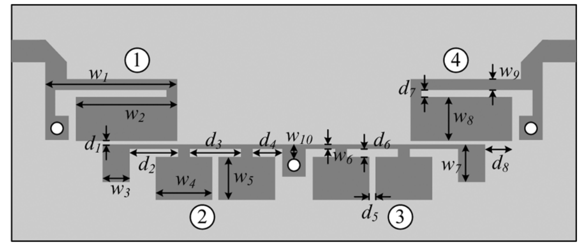

Fig. 2. Circuit layout of the proposed fourth-order microstrip filter with stepped-impedance resonators connected to input/output. (Via diameter = 1 mm, w_1 = 11.3 mm, w_2 = 8.636 mm, w_3 = 2.286 mm, w_4 = 4.826 mm, w_5 = 3.683 mm, w_6 = 0.381 mm, w_7 = 3.302 mm, w_8 = 3.81 mm, w_9 = 0.889 mm, w_{10} = 1.27 mm, d_1 = 0.254 mm, d_2 = 4.191 mm, d_3 = 4.318 mm, d_4 = 2.54 mm, d_5 = 0.508 mm, d_6 = 0.762 mm, d_7 = 0.635 mm, and d_8 = 2.286 mm).

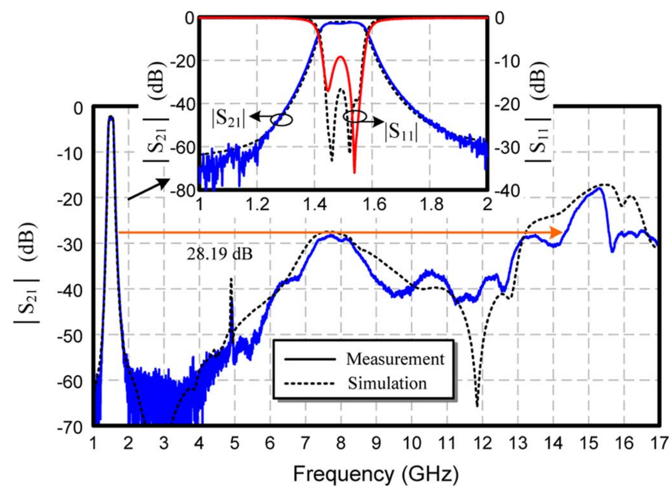

Fig. 3. Simulated and measured frequency responses of the proposed fourth-order microstrip filter (Fig. 2) with stepped-impedance resonators connected to input/output.

Fig. 3 shows the measured and simulated responses of the first fourth-order filter with stepped-impedance resonators connected to input and output (see Fig. 2). The measured center frequency is at 1.5 GHz and the measured 3 dB fractional bandwidth is 10.3%. The implemented filter has an insertion loss lower than 2.424 dB and a minimum return loss of 9.2 dB within the passband. As can be seen from the wideband responses, this filter has a wide stopband up to 14.3 GHz (9.53 f_0) with a rejection level over 28.19 dB. Note that a peak around 4.9 GHz with a quite low level of 38 dB is observed to associate with the first harmonic frequency of the bandstop embedded resonators as depicted in Fig. 3, however its effect is not significant. The circuit size of this fabricated fourth-order filter is 10.414 mm × 42.672 mm, which is approximately 0.085 λ_g × 0.349λ_g, where λ_g is the microstrip guided wavelength on the substrate at center frequency.

IV. Compact Fourth-Order Filter With Bandstop Embedded Resonators Connected to Input/Output

To save the circuit size, another compact fourth-order microstrip filter is implemented by exchanging the positions of

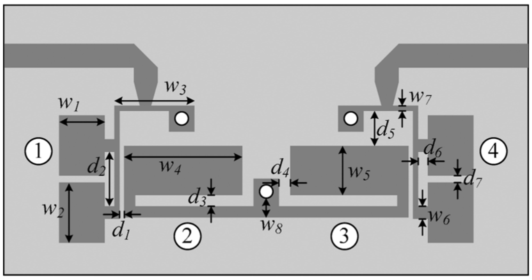

Fig. 4. Circuit layout of the proposed compact fourth-order microstrip filter with bandstop embedded resonators connected to input/output. (Via $\text{diameter} = 1$ mm, $w_1 = 3.683$ mm, $w_2 = 4.826$ mm, $w_3 = 6.35$ mm, $w_4 = 9.398$ mm, $w_5 = 3.937$ mm, $w_6 = 1.016$ mm, $w_7 = 0.381$ mm, $w_8 = 1.524$ mm, $d_1 = 0.381$ mm, $d_2 = 4.318$ mm, $d_3 = 0.889$ mm, $d_4 = 0.889$ mm, $d_5 = 2.794$ mm, $d_6 = 0.762$ mm, and $d_7 = 0.508$ mm).

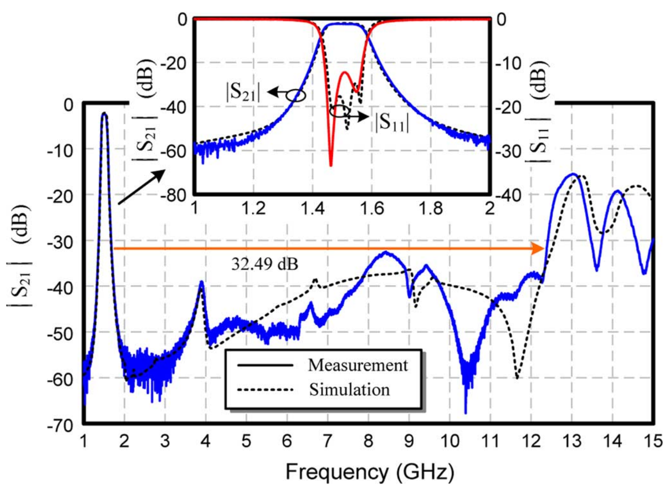

Fig. 5. Simulated and measured frequency responses of the proposed fourth-order microstrip filter (Fig. 4) with bandstop embedded resonators connected to input/output.

the $\lambda/4$ stepped-impedance resonators and the bandstop embedded resonators. Fig. 4 shows the circuit layout of the proposed compact fourth-order filter, which is also designed for the Butterworth response with the center frequency at 1.5 GHz and a fractional bandwidth of 10%. Specifically, although the feeding method associated with these bandstop embedded resonators is different from that of Fig. 1(a), the first and fourth resonators still have the bandstop behavior.

The measured and simulated responses of the proposed compact fourth-order filter (see Fig. 4) are shown in Fig. 5. The implemented compact fourth-order filter has the measured center frequency at 1.508 GHz, a measured 3 dB fractional bandwidth of 10%, a minimum insertion loss of 2.35 dB, and a return loss of 14.85 dB. Its stopband is extended up to 12.38 GHz (8.25 f_0) with an adequate rejection greater than 32.49 dB. This fabricated fourth-order filter has a compact dimension of 10.922 mm $\times$ 33.02 mm, which is approximately 0.089 $\lambda_g \times 0.27\lambda_g$.

V. Conclusion

In this letter, two novel fourth-order microstrip filters using $\lambda/4$ stepped-impedance resonators and bandstop embedded resonators have been realized and carefully examined. By combining the advantages of stepped-impedance resonators and bandstop structures, that is, pushing the spurious harmonics higher and providing a certain rejection band, two BPFs with wide-stopband feature and without any extra component are achieved. Moreover, since both $\lambda/4$ stepped-impedance resonators and bandstop embedded resonators are smaller in sizes, the proposed filters have compact circuit dimensions. The implemented compact fourth-order filter (Fig. 4) has the merits of compact size and good performance when compared with the previously fabricated wide-stopband filters.

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