Miniaturized Microstrip Lowpass Filter with Ultra-Wide Stopband

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Abstract **─** A new microstrip lowpass filter with compact size and ultra-wide stopband is presented. Using triangular patch resonators and butterfly resonator with four 45˚ radial "wing" patches, the introduced filter can successfully realize compact design and ultra-wide stopband. To further reduce the circuit size of the filter, the meander transmission lines are also adopted in the design. A demonstration filter with 3 dB cutoff frequency at 1.6 GHz has been designed, fabricated, and measured. Measured results show that the lowpass filter has an ultra-wide stopband bandwidth of 153.9 %, which is able to suppress the 11th harmonic response. Furthermore, it also has a small size of 14 × 15 mm^2, which corresponds to 0.114 λg × 0.122 λg, where λg is the guided wavelength at 1.6 GHz.

Index Terms **─** Lowpass filter and microstrip, ultra-wide stopband.

I. INTRODUCTION

Planar lowpass filters with compact size and high performance are frequently required in many microwave communication systems to suppress harmonics and spurious signals. Conventional method to realize microstrip lowpass filter is to utilize high-low impedance lines with shunt stubs and semi-lumped element for their remarkable characteristics. However, they provide a low stopband rejection and a relative flat roll-off characteristic together with a large size [1]. Therefore, techniques to reduce the filter size and enhance the performance have been widely studied in recent years [2-11].

One method to achieve good stopband performance is by cascading multi-resonators [2-5]. For example, in order to realize sharp roll-off and wide stopband suppression, Li *et al.* designed a lowpass filter by cascading multiple stepped impedance hairpin resonators in [2]. Although sharp roll-off had been achieved, this brings drawbacks in terms of large size and higher loss within the passband. By cascading multiple semi-circle and semi-ellipse patch resonators, Hayati *et al.* designed a lowpass filter with sharp roll-off and 6th harmonic response in [3]. But it is hard to get compact size and high performance simultaneously. Therefore, to further improve the stopband performance, Ma *et al.* proposed a lowpass filter by cascading LC resonant structure and transformed radial stubs in [4]. Although better than 13th harmonic suppression had been realized, this method always results in large circuit size and increases design complexity.

On the other hand, filters with good stopband performance can also be realized by using modified stepped impedance resonators. In [6], the conventional low-impedance stubs are replaced by the radial stubs, which have intrinsic wide stopband characteristic to realize a wide stopband rejection. Although compact design had been realized with this method, the roll-off performance is not ideal and further improvement should be

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carried out in stopband bandwidth. Recently, a compact ellipse function microstrip lowpass filter with ultra-wide stopband is proposed in [7]. The design is based on cascading high-impedance transmission lines and low-impedance butterfly resonators with two 55^0 radial "wing" patches to realize compact size and harmonic suppression. Furthermore, four triangle patch resonators are also utilized to achieve wide stopband. However, the transmission performance in the passband is not ideal due to the increasing of circuit discontinuity in the design. On the other hand, defected ground structure (DGS) and multilayer technique are also utilized to realize lowpass filter in [8-10]. Small size was realized, nevertheless, this method increases the complexity of circuit design.

The motivation of this paper is to design a new compact microstrip lowpass filter with ultra-wide stopband and good transmission performance. Both triangular patches and butterfly resonator with four 45^0 radial "wing" patches are used in the design to achieve compact size and ultra-wide band rejection. Meander transmission lines are also adopted in the design to further reduce the filter size. Results indicate that the proposed filter exhibits an ultra-wide stopband bandwidth from 2.37 GHz to 18.2 GHz with better than 17 dB suppression degree, a good passband performance with less than 0.3 dB passband insertion loss, and a compact electrical size of 0.114 λg × 0.122 λg, where λg is the guided wavelength at 1.6 GHz.

II. CIRCUIT DESIGN

Figure 1 shows the layout of the proposed lowpass filter. The dimensions of the presented lowpass filter are listed in Table 1. The substrate used here is Duroid 5870 with a relative dielectric constant of 2.33 and a thickness of 0.7874 mm. As can be seen from Fig. 1, the proposed filter consists of high–low impedance microstrip main transmission lines and two types of resonators, i.e., resonators 1 and 2. Resonator 1 is a triangular patch. Resonator 2 is composed of a high impedance transmission line and a butterfly resonator consists of four 45^0 radial "wing" patches, which are connected in series. Figure 2 shows the lumped-element equivalent circuit of the presented lowpass filter. In the circuit, C_a mainly represents the capacitance between the triangular patch and the ground plane while C_b mainly represent the capacitance between one of the "wing" patches of the middle butterfly resonator and the ground plane. C_{bb} mainly contains the coupling capacitance between the two "wing" patches of the butterfly resonator. The capacitance C_{ab} is formed by the capacitive coupling between the triangular patch and the middle butterfly resonator patch. The high impedance line is mainly represented by the inductance L and L'. It is obviously that the location of the 3 dB cutoff frequency and the stopband performance is mainly controlled by the values of L, C_a and C_b, which are determined by the structure parameters of W_2, l_1 and r. And the capacitors and inductors values of the lumped-element equivalent circuit of the proposed lowpass filter are given as follows: C_a = 1.1 PF, C_b = 1 PF, C_{ab} = 0.1 fF, C_{bb} = 0.1 fF, L = 8 nH, and L'= 0.1 fH.

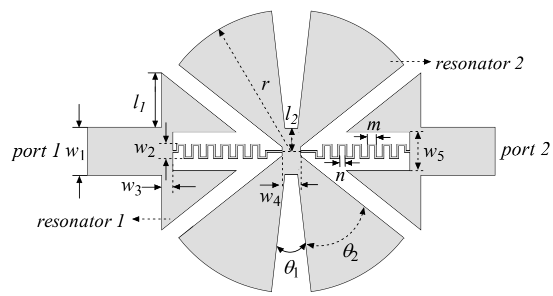


Fig. 1. Layout of the proposed lowpass filter.

Table 1: Structure parameters of the proposed lowpass filter.

l_1	l_2	w_1	w_2	w_3	w_4
3.9	1.1	2.6	1.2	0.6	1
w5	m	n	r	θ1(^{0})	θ2(^{0})
2.1	0.5	0.3	7.5	7	45

Unit: mm, unless specified.

To illustrate the design theory, frequency responses with the two types of resonators are primary studied. Figure 3 (a) shows the frequency response of the filter only with resonator 1. It can be seen that the filter exhibits a wide stopband with one transmission zero (TZ_1), which is caused by the resonance of the loaded triangular patches, and its frequency location can be controlled by the structure parameters of the triangular patch resonators. However, the roll-off performance is not ideal. Thus, butterfly resonator is also introduced to the filter to improve the roll-off and the stopband performance as shown in Fig. 3 (b). Since the loaded resonator 2 is not only enhanced by the shunt capacitance of the main transmission line but also by the couple with the neighboring triangular patches, i.e., resonator 1, and this will provide an extra finite transmission zero (TZ_2) inside the stopband. And the frequency location of the transmission zero (TZ_2) can be controlled by the structure parameters of the filter properly adjusted. Furthermore, the harmonic suppression responses of the proposed lowpass filter according to different parameter values are compared in Fig. 4. As can be seen from Fig. 4 (a), the length of the triangular patch, i.e., l_1, plays an important role in improving the stopband performance. Good stopband performance is obtained as l_1 is 3 mm. Fig. 4 (b) shows when θ_2 is different from 45^0, an undesired harmonic will be generated in the stopband and the increase of θ_2 will make the first zero (TZ_2) shift closer to the cutoff frequency. So, if we place it close to the fringe of the passband by choosing proper structure parameters, a lowpass filter with a sharp roll-off and wide stopband rejection can be achieved. On the other side, the loaded butterfly resonator can also result in high slow-wave effect as the increasing of shunt capacitance of the main transmission line. So the size of the proposed lowpass filter has been reduced compared with conventional lowpass filters.

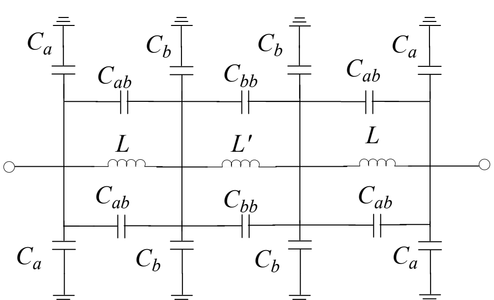
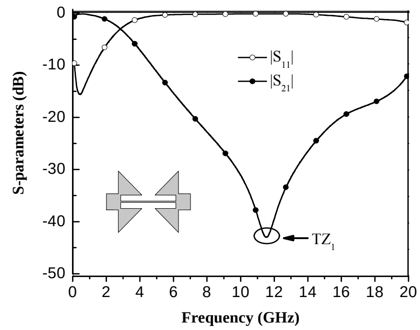
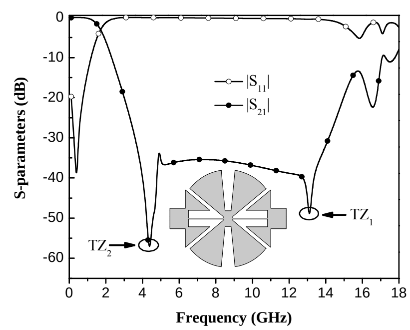


Fig. 2. Lumped-element equivalent circuit of the proposed lowpass filter.



(a)

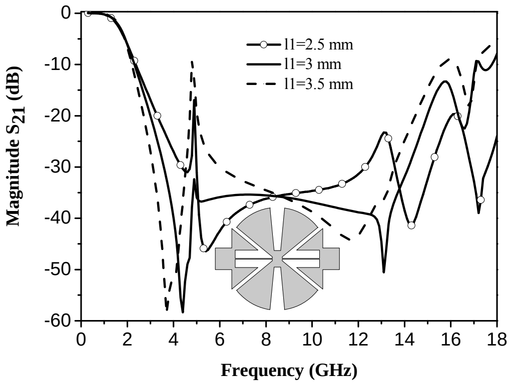


(b)

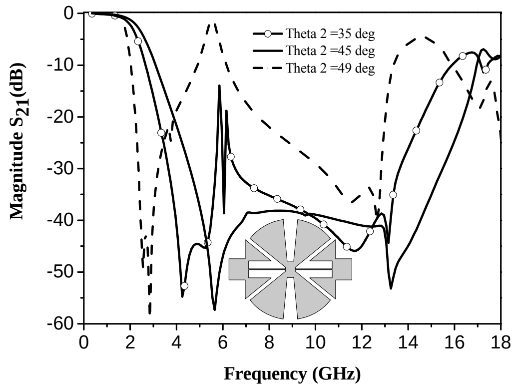
Fig. 3. Simulated S-parameters of studied resonator for the (a) filter with only resonator 1 and (b) the filter with resonators 1 and 2.

Figure 5 shows the simulated current distributions at different frequencies to display the signal trend in the passband and stopband. The current distribution in passband is shown in Fig. 5 (a). It can be seen that the signals at 0.5 GHz can be transferred from port 1 to port 2 along the high impedance meander lines. Figure 5 (b) shows another case of frequency at 10 GHz, which is in the stopband. It is found that the signals at 10 GHz are blocked by the high impedance lines.

To further reduce the size of the filter in our design, we also use the meander transmission line to replace the high-impedance section of the main transmission line. Therefore, combine the techniques mentioned above, a new microstrip lowpass filter with compact size and high stopband performance is realized. The proposed filter is designed based on the analysis mentioned above. Figure 6 is the photograph of the fabricated fiilter.



(a)

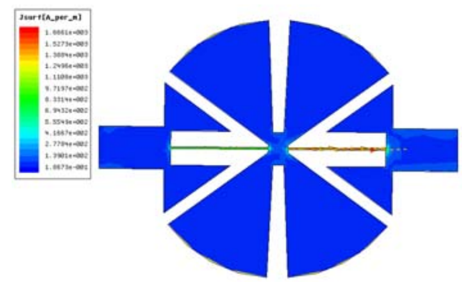


(b)

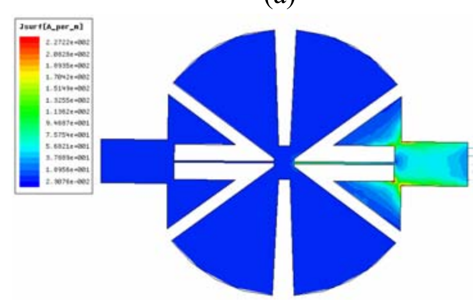
Fig. 4. Simulated S-parameters of the proposed filter: (a) simulated $|S_{21}|$ with different l and (b) simulated $|S_{21}|$ with different θ_2.

III. SIMULATION AND MEASUREMENT RESULTS

Simulation was accomplished using EM simulation software Ansoft HFSS 12. The comparisons between the circuit model EM simulated results and the equivalent lumped element circuit results are given in Fig. 7. Measurement was carried out on an Agilent 8722ES network analyzer. Figure 8 shows the simulated and measured results. As we can see from Fig. 8, the measured 3 dB cutoff frequency is at 1.6 GHz. Inside the passaband the insertion loss is less than 0.3 dB from DC to 1.05 GHz, which is to ensure the good transmission performance in the passband. In addition, the filter provides 11th harmonic suppression performance, as the spurious frequencies are suppressed from 2.37 GHz to 18.2 GHz with better than 17 dB suppression degree. The measured group delay in the passband is 0.23 ns – 0.5 ns, as shown in Fig. 9. Furthermore, the overall size of the fabricated filter is only 14 × 15 mm^2, which corresponds to a compact electrical size of 0.114 λg × 0.122 λg, where λg is the guided wavelength at 1.6 GHz. For comparison, Table 2 summarizes the performance of some recently published lowpass filters. As can be observed from the table, the presented filter has the properties of compact size, simple circuit topology, and ultra-wide stopband among the quoted filters.



(a)



(b)

Fig. 5. Simulated current distribution of the proposed lowpass filter: (a) simulated current distribution at 0.5 GHz and (b) simulated current distribution at 10 GHz.

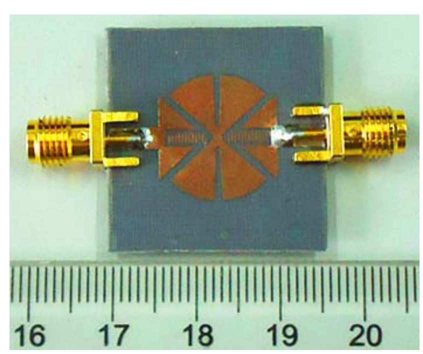


Fig. 6. Photograph of the proposed lowpass filter.

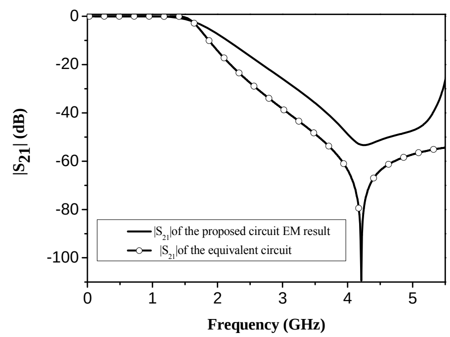


Fig. 7. Comparisons between the equivalent circuit model calculated results and EM simulates results.

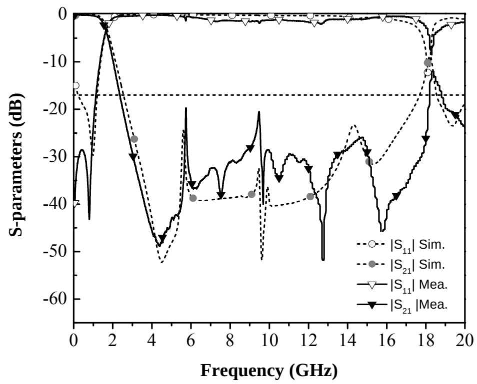


Fig. 8. Simulated and measured performance of proposed filter.

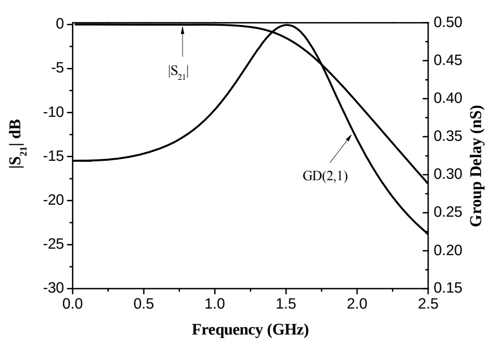


Fig. 9. Measured IL and group delay in the passband range of the proposed lowpass filter.

IV. CONCLUSION

A new microstrip lowpass filter is presented in this letter. One prototype filter with 3 dB cutoff frequency at 1.6 GHz has been demonstrated. Results indicate that the demonstrator exhibits the properties of compact size, good passband performance, and ultra-wide stopband. With all these good features, the proposed filter could be widely applied in microwave communication systems.

Table 2: Performance comparisons among published filters and the proposed one.

Ref.	Circuit size	Insertion loss	Harmonic suppression
2	0.114 λg × 0.105 λg	0.4 dB	6th
3	0.395 λg × 0.151 λg	0.33 dB	6th
4	0.31 λg × 0.24 λg	1 dB	13th
5	0.141 λg × 0.083 λg	0.5 dB	8th
6	0.104 λg × 0.104 λg	1.5 dB	7th
7	0.111 λg × 0.091 λg	0.4 dB	16th
11	0.104 λg × 0.123 λg	0.39 dB	10th
This work	0.114 λg × 0.122 λg	0.3 dB	11th

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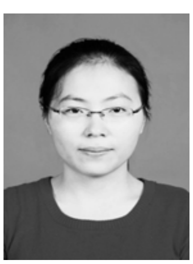

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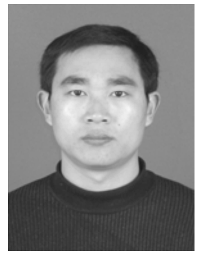

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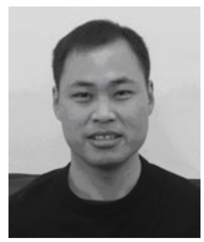

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