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Miniaturized Microstrip Lowpass Filter with Ultra-Wide Stopband Performance Using Trapezoid Patch Resonators

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Abstract—A new miniaturized microstrip lowpass filter with ultra-wide stopband performance using trapezoid patch resonators is investigated. To achieve compact design and ultra-wide band rejection, trapezoid patch resonators are employed in the filter. To further reduce the circuit size of the filter, a meander transmission line is also introduced in the design. A demonstration filter with 3 dB cutoff frequency at 0.50 GHz has been designed, fabricated, and measured. Results indicate that the proposed filter is able to suppress the 26$^{\text{th}}$ harmonic response referred to a suppression degree of 15 dB. Furthermore, the proposed filter exhibits a small size of $0.122\lambda_g \times 0.109\lambda_g$, where λ_g is the guided wavelength at 0.50 GHz.

1. INTRODUCTION

Planar lowpass filters with compact size and high performance are in great demand for wireless communication systems to suppress harmonics and spurious signals because of their easy fabrication, low cost, and easy integration with other microwave circuits. Conventional lowpass filters using shunt stubs or high-low impedance transmission lines have been widely used in microwave systems for their remarkable characteristics [1]. However, it is hard to achieve compact size and high performance simultaneously. Thus, techniques to achieve both size reduction and performance enhancement have been studied in recent years [2–11].

The usual approach to design a compact lowpass filter with ultra-wide stopband performance and compact size is to form a lowpass filter by cascading multiple resonators [3–11]. A lowpass filter was designed by cascading multi-radial patch resonators in [3], but the size of the filter was relatively large. A lowpass filter featured harmonic response was achieved based on cascading tapered resonant cells in [4], but it is hard to achieve a compact size and stopband performance. Therefore, to further improve the stopband performance, a lowpass filter was proposed by cascading LC resonant structures and transformed radial stubs. Although better than 13$^{\text{th}}$ harmonic suppression had been realized, this method also increased design complexity and circuit area in [5]. A lowpass filter with low insertion loss and sharp roll-off was proposed by cascading modified microstrip patch resonators consisting of semi-circles and semi-ellipses in [6]. However, the compact size and stopband bandwidth still need to be improved. A lowpass filter with 7$^{\text{th}}$ harmonic suppression performance was reported using stepped impedance hairpin resonator in [7]. Although compact design had been realized with this method, further improvement should be carried out in stopband bandwidth. On the other hand, filter design is not restricted in the 2-D level. Using defected ground structure is also a popular and useful way, but it increases the circuit complexity in [8].

Based on the previous works [9], a new miniaturized microstrip lowpass filter with ultra-wide stopband performance is proposed and implemented in this paper. Trapezoid patch resonators are used

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in the filter to achieve compact size and ultra-wide band rejection. To further reduce the circuit size, a meander transmission line is adopted in the filter design. Measured results indicate that the designed filter has a harmonic suppression rejection better than 15 dB from 1.12 to 13.28 GHz, together with less than 0.3 dB insertion loss in the passband. Furthermore, the size of the filter is only 16.7 mm × 15.2 mm, which corresponds to a compact electrical size of $0.122\lambda_g \times 0.109\lambda_g$, where λ_g is the guided wavelength at 0.50 GHz.

2. FILTER DESIGN

Figure 1 shows the schematic layout of the presented lowpass filter, which is composed of a high-low impedance microstrip main transmission line and two types of resonators, i.e., resonator *Ra* and resonator *Rb*. Resonator *Ra* is composed of a low impedance transmission line and a trapezoid patch, which are connected in series. Resonator *Rb* is composed of a high impedance transmission line and a trapezoid patch, which are connected in series. To illustrate the design concept of the proposed filter, frequency response caused by the resonator *Ra* has been studied. As can be seen from Fig. 2(a), the proposed filter with only resonator *Ra* exhibits a wide stopband together with one transmission zero inside the stopband. Fig. 2(b) shows the resonant properties of the filter with resonator *Ra* and resonator *Rb*. Since the loaded resonator *Rb* is coupled with adjacent trapezoid patches, i.e., resonator *Ra*, this will not only enhance the shunt capacitance of the main transmission line but also provides extra finite transmission zeros inside the stopband. Therefore, the proposed lowpass filter has a low cutoff frequency and harmonic suppression. Furthermore, to achieve miniaturized circuit design, one meander transmission line is also introduced to replace the internal high-impedance line of the filter. Thus, the size of the proposed lowpass filter can be further reduced.

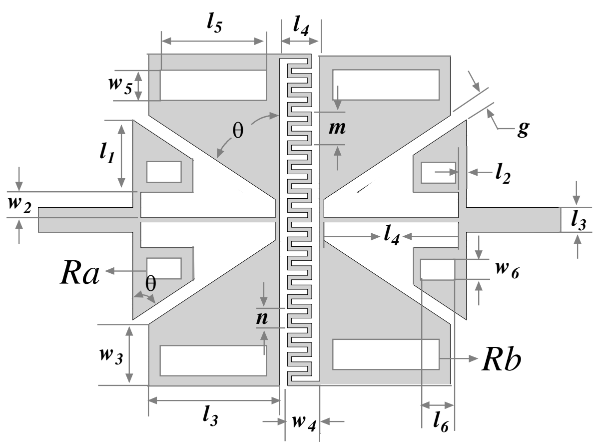

Figure 1. Schematic layout of proposed lowpass filter.

Figure 3 shows the lumped-element equivalent circuit of the proposed lowpass filter. As shown in Fig. 3, C_a mainly represents the capacitance between the trapezoid patch and the ground plane. C_b mainly represents the capacitance between the trapezoid patch and the ground plane. C_{ab} represents the coupled capacitance between the trapezoid patch and the trapezoid patch. Clearly, the location of the 3 dB cutoff frequency and stopband performance is mainly controlled by the values of L_a, L_b, L_{ab}, and C_b. On the other hand, the frequency locations of the transmission zeros inside the stopband can be controlled by the values of C_a and C_{ab}. Moreover, both C_{ab} and L can increase capacitance and inductance of the circuit. As the above-mentioned properties are valuable for our design, a lowpass filter with enhanced stopband performance and compact size can be realized. The capacitors and inductors values of the lumped-element equivalent circuit of the proposed lowpass filter are given as follows: $C_a = 1.1\,\text{pF}$, $C_b = 1.0\,\text{pF}$, $C_{ab} = 0.1\,\text{fF}$, $L_{ab} = 92.0\,\text{nH}$, $L_a = 0.5\,\text{fH}$, $L_b = 56.0\,\text{nH}$, $L_{bb} = 62.0\,\text{nH}$.

The new lowpass filter is designed and fabricated based on the analyses mentioned above. The structure parameters are as follows: $l_1 = 2.52\,\text{mm}$, $l_2 = 0.48\,\text{mm}$, $l_3 = 1.12\,\text{mm}$, $l_4 = 1.44\,\text{mm}$,

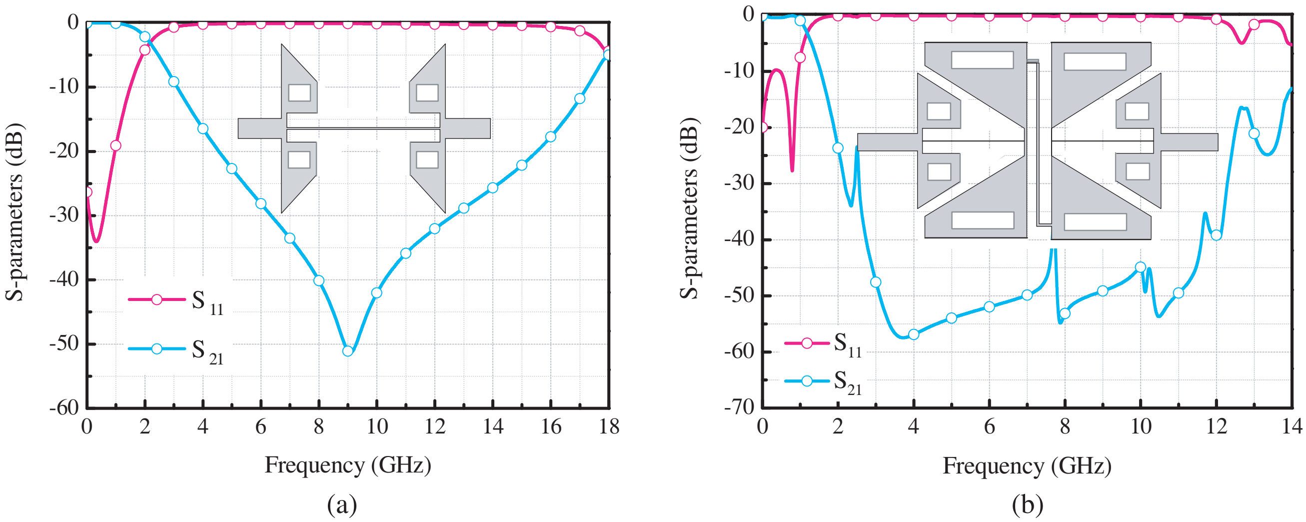

Figure 2. Simulated S-parameters of studied resonator. (a) Filter with only resonator Ra. (b) Filter with resonator Ra and resonator Rb.

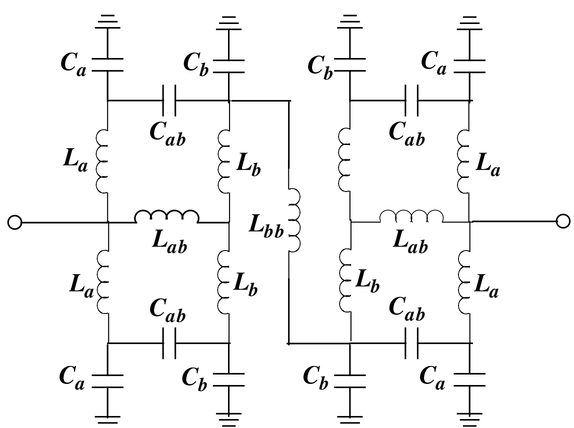

Figure 3. Lumped-element equivalent circuit of the proposed lowpass filter.

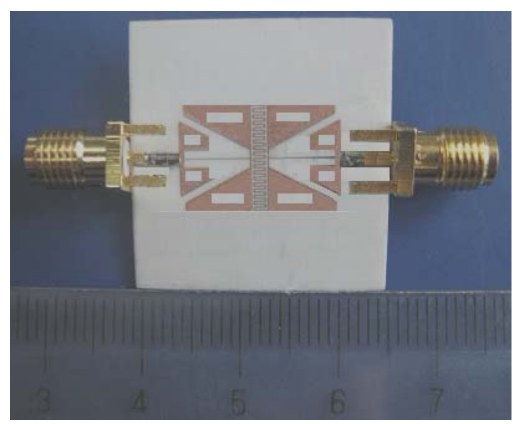

Figure 4. Photograph of the proposed lowpass filter.

$l_5 = 3.83$ mm, $l_6 = 1.16$ mm, $l_7 = 4.84$ mm, $w_2 = 1.13$ mm, $w_3 = 2.17$ mm, $w_4 = 1.33$ mm, $w_5 = 1.17$ mm, $g = 0.68$ mm, $m = 1.18$ mm, $n = 0.68$ mm, $\theta = 62°$. The substrate used here has a relative dielectric constant of 3.45 and thickness of 0.508 mm. Fig. 4 shows a photograph of the proposed lowpass filter.

3. EXPERIMENTAL RESULTS

All simulations have been carried out using Ansoft HFSS 15.0 simulation software based on the finite element method. Measurement is completed on an Agilent N5244A network analyser. Fig. 5 shows the simulated and measured results, which are in good agreement. As shown in Fig. 5, the measured cutoff frequency f_c is around 0.50 GHz, as expected. The insertion loss inside the passband is less than 0.3 dB, which indicates a good passband performance. The voltage standing wave ratio (VSWR) corresponding to the passband is less than 1.7. Fig. 5 also shows that the spurious frequencies are suppressed from 1.12 up to 13.28 GHz with a suppression degree better than 15 dB. Thus, the proposed filter has a property of 26^{th} harmonic suppression. Furthermore, the size of the lowpass filter is only 16.7 mm $\times$ 15.2 mm, which corresponds to an electrical size of $0.122\lambda_g \times 0.109\lambda_g$, where λ_g is the waveguide length at 0.50 GHz. For comparison, Table 1 summarizes the performance of other reported

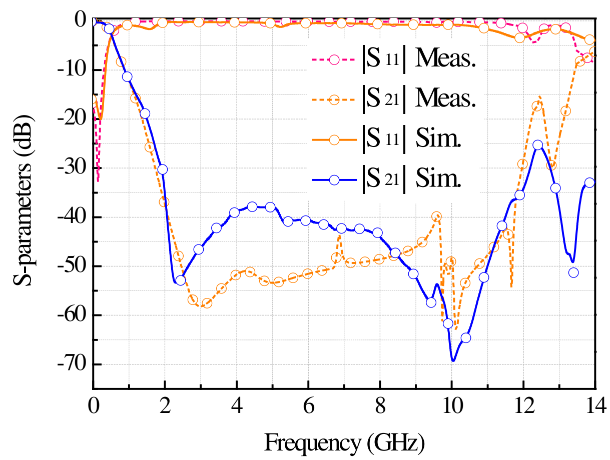

Figure 5. Simulated and measured performance of proposed filter.

Table 1. Performance comparisons among published filters and proposed one.

Ref.	Harmonic suppression	Maximum passband insertion loss (dB)	Circuit size
[3]	6th	0.5	$0.351\lambda_g \times 0.106\lambda_g$
[4]	11th	1.0	$0.356\lambda_g \times 0.108\lambda_g$
[5]	13th	1.5	$0.310\lambda_g \times 0.240\lambda_g$
[6]	6th	0.3	$0.395\lambda_g \times 0.151\lambda_g$
[7]	7th	0.5	$0.104\lambda_g \times 0.104\lambda_g$
[8]	6th	1.2	$0.273\lambda_g \times 0.237\lambda_g$
This work	26th	0.3	$0.122\lambda_g \times 0.109\lambda_g$

lowpass filters. As can be seen from the table, our proposed filter has the properties of miniaturized circuit size, low passband insertion loss, and good harmonic suppression among the quoted filters.

4. CONCLUSION

A new miniaturized microstrip lowpass filter with ultra-wide stopband performance using trapezoid patch resonators is investigated in this paper. One prototype filter with 3 dB cutoff frequency at 0.50 GHz has been demonstrated. Results indicate that the proposed filter demonstrates many attractive features with compact circuit size, low passband insertion loss, and ultra-wide stopband. With all these good features, the proposed filter is applicable to modern communication systems.

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