

Compact Microstrip Lowpass Filter with Ultra-Wide Stopband Characteristic Using Square Ring Loaded Resonators

Zhiqiang Li^{1, *} and Sung-Jin Ho^{1, 2}

Abstract—A novel compact microstrip lowpass filter with ultra-wide stopband characteristic using square ring loaded resonators is proposed. A microstrip high impedance main transmission line loaded with five square ring loaded resonators is adopted in the design of the filter. Owing to the adoption of the square ring structure, the filter achieves compact size and ultra-wide stopband. A demonstration filter with 3 dB cutoff frequency at 0.72 GHz has been designed, fabricated, and measured. Results indicate that the proposed filter is able to suppress the 19th harmonic response referred to a suppression degree of 15 dB, together with a small size of $0.054\lambda_g \times 0.070\lambda_g$, where λ_g is the guided wavelength at 0.72 GHz.

1. INTRODUCTION

Miniaturised lowpass filters with high performance are in great demand for communication systems to suppress harmonics and spurious signals. Filters fabricated by printed circuit board technology are generally preferable for their easy realisation and low cost as well as 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, 2]. However, it is hard to get compact size and broad stopband simultaneously. Thus, techniques to achieve both size reduction and characteristic enhancement are continually being studied. Commonly, there are typically two methods to design a lowpass filter with compact size and wide stopband [3–8].

The first method is to achieve a lowpass filter by cascading multiple resonators [3, 4]. A compact lowpass filter was designed by cascading radial patch resonators in [3]. However, the size of the filter was relatively large and only 6th harmonic response was suppressed. A microstrip lowpass filter was proposed by cascading LC resonant structures and transformed radial stubs in [4]. However, this method also increased design complexity and circuit area.

The second method is to get a lowpass filter by using modified stepped impedance hairpin resonators [5–8]. A compact lowpass filter was proposed with improved harmonic suppression characteristic [5, 6]. However, further improvement should be carried out in stopband bandwidth. A compact lowpass filter was proposed using defected ground structures in [7, 8], which though increases the circuit complexity and circuit size should be reduced.

The goal of this communication is to design a new compact microstrip lowpass filter with ultra-wide stopband. To obtain compact size and ultra-wide stopband rejection, five square ring loaded resonators are introduced in the filter. Measured results indicate that the designed filter has an ultra-wide stopband with better than 15 dB suppression degree up to 14.0 GHz. Furthermore, the size of the filter is only $11.6 \times 12.4 \text{ mm}^2$, which corresponds to a compact electrical size of $0.054\lambda_g \times 0.070\lambda_g$, where λ_g is the guided wavelength at 0.72 GHz.

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2. CIRCUIT DESIGN

Figure 1 shows the configuration of the proposed lowpass filter, which is composed of a high impedance microstrip main transmission line and five square ring loaded resonators. Each square ring resonator is comprised of a high impedance transmission line and a square ring structure, which are connected in series. To illustrate the design concept of the presented lowpass filter, frequency responses caused by four square ring loaded resonators and one isosceles square ring resonator have been studied. Fig. 2 shows the lumped-element equivalent circuit of the proposed filter.

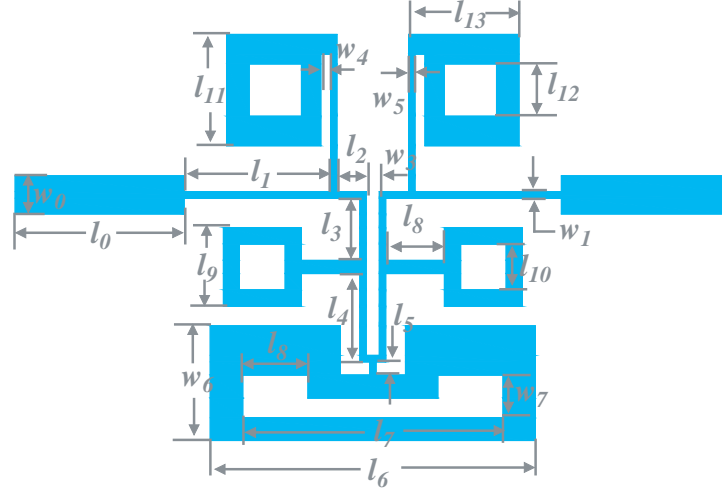


Figure 1. Configuration of the proposed lowpass filter.

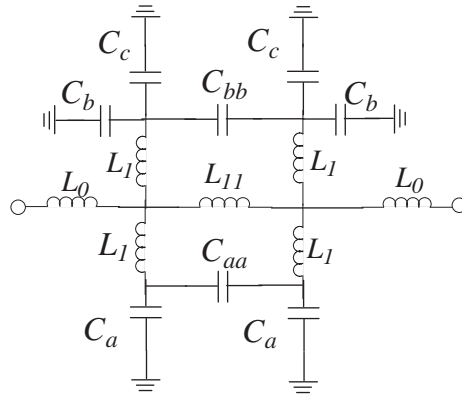


Figure 2. Lumped-element equivalent circuit of the proposed lowpass filter.

As can be seen from Fig. 3(a), the proposed filter with only two square ring loaded resonators below the filter exhibits a wide stopband together with one transmission poles at 4.5 GHz. In order to suppress the undesired frequency response, other two square ring loaded resonators are also introduced to the filter. Fig. 3(b) investigates the resonant properties of the square ring loaded resonators. It can be seen that one transmission zero at 4.5 GHz in the stopband is achieved. This transmission zero is caused by the resonance of square ring loaded resonators and its frequency location can be controlled by the structure parameters of the square ring loaded resonators.

According to the investigation mentioned above, if we can properly combine the four square ring loaded resonators in a filter [9], the mutual suppression of spurious passbands and thereby a better stopband characteristic is expected to achieve. Fig. 3(c) shows the frequency response of the filter with four square ring loaded resonators. As expected, by locating the transmission zero in Fig. 3(b) around

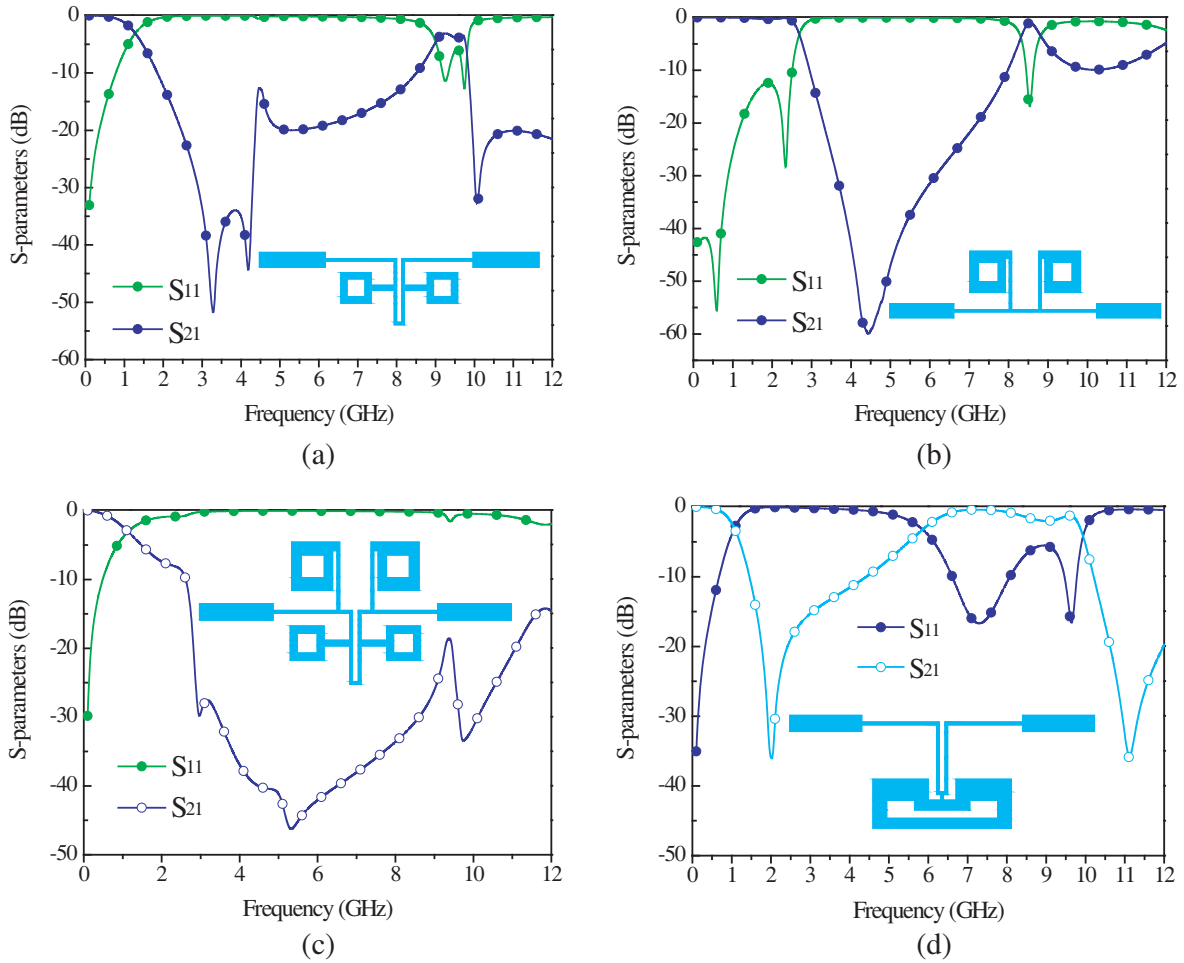


Figure 3. Simulated S -parameters of studied resonators. (a) Filter with only two square ring loaded resonators below. (b) Filter with only two square ring loaded resonators above. (c) Filter with four square ring loaded resonators. (d) Filter with one isosceles square ring loaded resonator.

the position of spurious response appeared at about 4.5 GHz in Fig. 3(a), we finally achieve the new lowpass filter with an enhanced stopband characteristic. In order to achieve better roll-off rate, one isosceles radial stub resonator is adopted to the filter. As can be seen in Fig. 3(d), the sharp roll-off rate of isosceles square ring resonator is achieved. Moreover, we can properly combine the four square ring loaded resonators and one isosceles square ring resonator in the filter. In consequence, a compact microstrip lowpass filter with ultra-wide stopband is designed.

The new lowpass filter is designed, fabricated in virtue of the analysis mentioned above. The structure parameters are as follows: $l_0 = 5.2$ mm, $l_1 = 4.5$ mm, $l_2 = 0.9$ mm, $l_3 = 1.9$ mm, $l_4 = 2.4$ mm, $l_5 = 0.4$ mm, $l_6 = 10.0$ mm, $l_7 = 8.0$ mm, $l_8 = 2.0$ mm, $l_9 = 2.4$ mm, $l_{10} = 1.4$ mm, $l_{11} = 3.4$ mm, $l_{12} = 1.6$ mm, $l_{13} = 3.4$ mm, $w_0 = 1.16$ mm, $w_1 = 0.2$ mm, $w_2 = 0.2$ mm, $w_3 = 0.4$ mm, $w_4 = 0.3$ mm, $w_5 = 0.2$ mm, $w_6 = 3.4$ mm, $w_7 = 1.3$ mm. The substrate used in the proposed lowpass filter has a relative dielectric constant of 3.48 and a thickness of 0.508 mm.

3. SIMULATION AND MEASUREMENT RESULTS

All simulations have been carried out using HFSS 14.0 simulation software based on the finite element method. Measurement was accomplished on an Agilent 8566B network analyser. Fig. 4 shows the simulated and measured results, which are in good agreement. As can be observed from Fig. 4, the

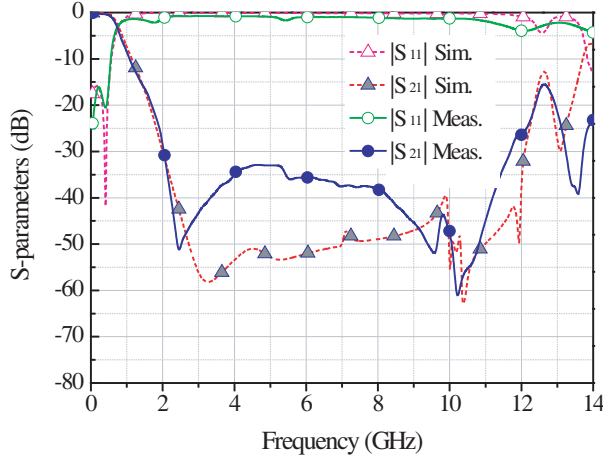


Figure 4. Simulated and measured characteristic of proposed filter.

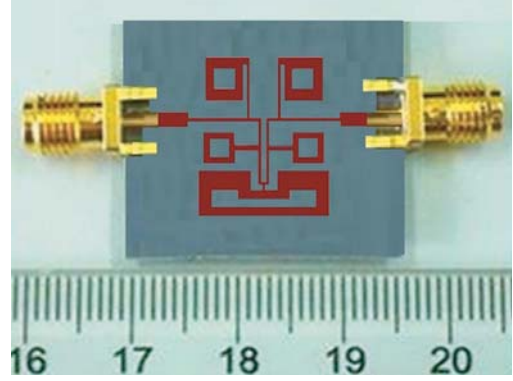


Figure 5. Photograph of the proposed lowpass filter.

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

Ref.	Harmonic suppression	Cutoff frequency (GHz)	Circuit size	Circuit dimension
[2]	6th	1.69	$0.140\lambda_g \times 0.076\lambda_g$	2-D
[3]	6th	2.4	$0.351\lambda_g \times 0.106\lambda_g$	2-D
[4]	13th	3.0	$0.310\lambda_g \times 0.240\lambda_g$	2-D
[5]	7th	1.67	$0.104\lambda_g \times 0.104\lambda_g$	2-D
[6]	9th	0.5	$0.104\lambda_g \times 0.214\lambda_g$	2-D
[7]	5th	2.7	$0.134\lambda_g \times 0.323\lambda_g$	3-D
[8]	10th	1.935	$0.282\lambda_g \times 0.120\lambda_g$	3-D
[9]	9th	1.5	$0.108\lambda_g \times 0.145\lambda_g$	2-D
This work	19th	0.72	$0.054\lambda_g \times 0.070\lambda_g$	2-D

measured cutoff frequency f_c is located at 0.72 GHz, as expected. Fig. 3 also shows that the spurious frequencies are suppressed from 1.12 up to 14.0 GHz with a suppression degree better than 10 dB. Thus, the proposed filter has a property of 19th harmonic suppression. Furthermore, the proposed filter exhibits a small electrical size of $0.054\lambda_g \times 0.070\lambda_g$, where λ_g is the guided wavelength at 0.72 GHz. The deviations of the measurements from the simulations are expected mainly due to the reflections from the SMA connectors and the finite substrate. For comparison, Table 1 summarises the characteristic of some published lowpass filters. As can be seen from the table, our proposed filter has the properties of compact size, simple circuit topology, and ultra-wide stopband among the quoted filters. Fig. 5 is the photograph of the fabricated filter.

4. CONCLUSION

A novel compact microstrip lowpass filter is proposed in this communication. One prototype filter with 3 dB cutoff frequency at 0.72 GHz has been studied. Results indicate that the proposed filter demonstrates many attractive features with compact size, simple structure, and ultra-wide stopband. With all these good features, the proposed filter is applicable to modern wireless communication systems.

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