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# Compact Microstrip Lowpass Filter with Ultra-Wide Stopband Performance Using Radial Stub Loaded Resonators

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**Abstract**—A new microstrip lowpass filter using radial stub loaded resonators is presented. A microstrip high impedance main transmission line loaded with five radial stub loaded resonators by five high impendence transmission lines is introduced in the design of the filter. Owing to the introduction of the radial stub structure, the filter achieves compact size and ultra-wide stopband. A demonstration filter with 3 dB cutoff frequency at 0.8 GHz has been designed, fabricated and measured. Results indicate that the proposed filter is able to suppress the 17th harmonic response referred to a suppression degree of 15 dB, together with a small size of $0.060\lambda_g \times 0.080\lambda_g$, where $\lambda_g$ is the guided wavelength at 0.8 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. 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 high performance simultaneously. Thus, techniques to achieve both size reduction and performance enhancement have been continually studied. Commonly, there are typical two methods to design a lowpass filter with compact size and wide stopband [3–10].

The first method is to form a lowpass filter by cascading multiple resonators [3–6]. With this method, Li et al. designed a lowpass filter by cascading multi-radial patch resonators [3]. Although sharp roll-off had been achieved, the size of the filter was relatively large, and only 6th harmonic response was suppressed. Cascading tapered microstrip resonant cells, a lowpass filter featured wide stopband and harmonic response was proposed in [4]. However, it is hard to achieve a compact size, and the stopband performance is not ideal. Based on the same method, a microstrip lowpass filter with low insertion loss and sharp roll-off was proposed by cascading modified semi-circle and semi-ellipse microstrip patch resonators [5]. However, the circuit size and passband performance still need improvement. Therefore, to further improve the stopband performance, Ma and Yeo proposed a lowpass filter by cascading LC resonant structures and transformed radial stubs. Although better than 13th harmonic suppression had been realized, this method also increased design complexity and circuit area [6].

The second method is to design a lowpass filter by using modified stepped impedance hairpin resonators [7–11]. Using a stepped impedance hairpin resonator with radial stubs, Wei et al. proposed a lowpass filter with 7th harmonic suppression performance [7]. Although compact design had been realized with this method, further improvement should be carried out in stopband bandwidth. The stopband performance should also be improved in [8], because the compact lowpass filter using a coupled-line hairpin unit, one spiral slot and two open stubs only achieve −10 dB attenuation up to 20 GHz of

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the stopband. A very wide stopband lowpass filter is achieved with a novel application of shunt open-stubs at the feed points of a center fed coupled-line hairpin resonator in [9], but the reflection loss is relatively large. In addition, using defected ground structure is also a popular and useful way. A lowpass filter composed of semicircle defected ground structures and semicircle stepped-impedance shunt stubs is proposed in [10, 11], but the circuit complexity and circuit size should be reduced.

The motivation of this paper is to design a new microstrip lowpass filter with both compact size and ultra-wide stopband. To achieve compact size and ultra-wide stopband rejection, five radial stub loaded resonators are loaded in the filter by five high impendence transmission lines. Measured results indicate that the designed filter has an ultra-wide stopband with better than 15 dB suppression degree up to 14.5 GHz. Furthermore, the size of the filter is only $11.6\times15.0\,\mathrm{mm}^2$, which corresponds to a compact electrical size of $0.060\lambda_g \times 0.080\lambda_g$, where $\lambda_g$ is the guided wavelength at 0.8 GHz.

## 2. CIRCUIT DESIGN

Figure 1 shows the layout of the proposed lowpass filter, which is composed of a high impedance microstrip main transmission line and five radial stub loaded resonators. Each radial stub resonator is composed of a high impedance transmission line and a radial stub patch, which are connected in series. To illustrate the design theory of the proposed filter, frequency responses caused by four rectangular radial stub loaded resonators and one isosceles radial stub resonator are studied. Fig. 2 shows the lumped-element equivalent circuit of the presented lowpass filter.

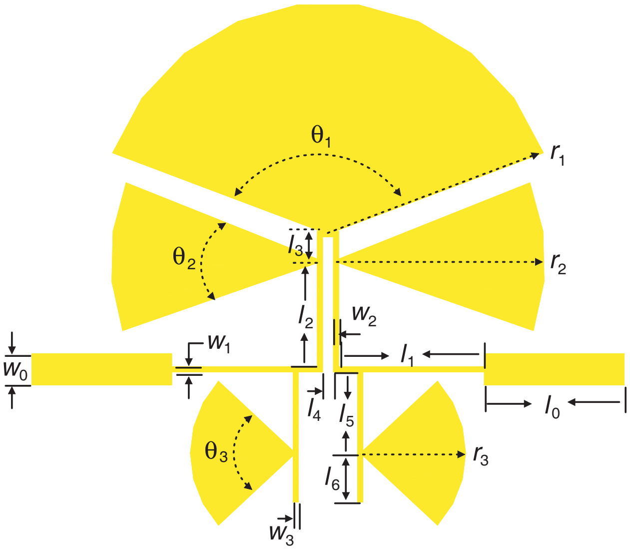

**Figure 1.** Layout of the proposed lowpass filter.

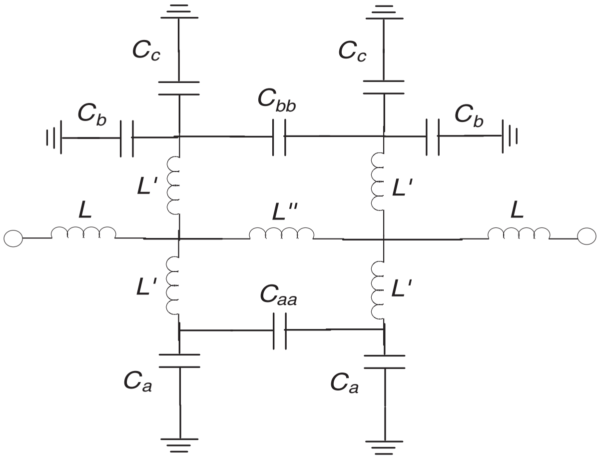

**Figure 2.** Lumped-element equivalent circuit of the proposed lowpass filter.

As can be seen from Fig. 3(a), the proposed filter with only two rectangular radial stub loaded resonators below the filter exhibits a wide stopband together with one transmission pole at 4.4 GHz. In order to suppress the undesired frequency response, other two rectangular radial stub loaded resonators are also introduced to the filter. Fig. 3(b) investigates the resonant properties of the radial stub loaded resonators. It can be seen that one transmission zero at 4.4 GHz in the stopband is achieved. This transmission zero is caused by the resonance of radial stub loaded resonators, and its frequency location can be controlled by the structure parameters of the radial stub loaded resonators.

Based on the investigation mentioned above, if we can properly combine the four rectangular radial stub loaded resonators in a filter, the mutual suppression of spurious passbands and thereby a better stopband performance is expected to achieve. Fig. 3(c) shows the frequency response of the filter with four rectangular radial stub loaded resonators. As expected, by locating the transmission zero in

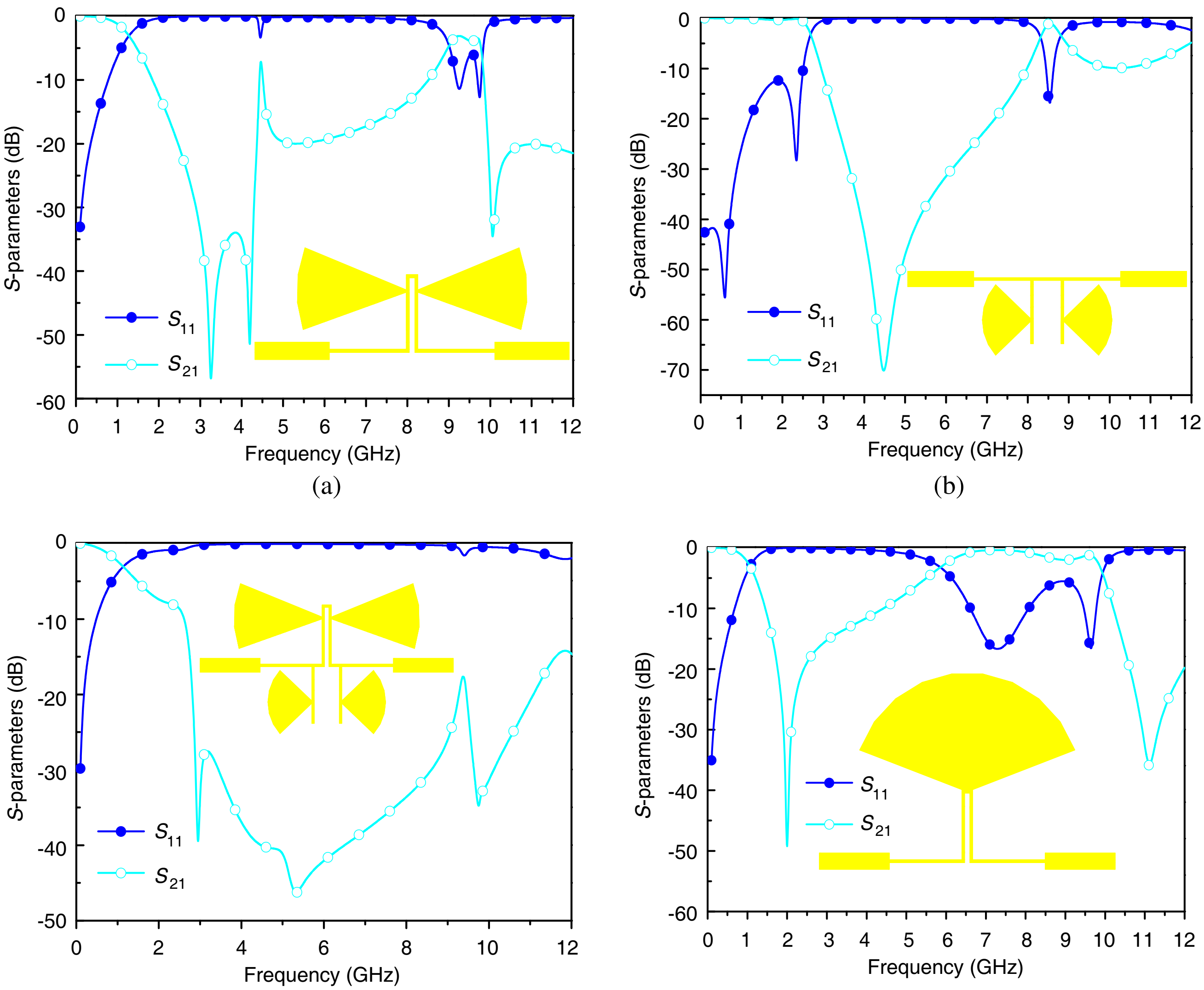

**Figure 3.** Simulated $S$-parameters of studied resonators. (a) Filter with only two radial stub loaded resonators below. (b) Filter with only two radial stub loaded resonators above. (c) Filter with four radial stub loaded resonators. (d) Filter with one isosceles radial stub resonator.

Fig. 3(b) around the position of spurious response appearing at about 4.4 GHz in Fig. 3(a), we finally achieve the new lowpass filter with an enhanced stopband performance. In order to achieve better roll-off rate, one isosceles radial stub resonator is introduced to the filter. It can be seen in Fig. 3(d) that the sharp roll-off rate of isosceles trapezoid resonator is achieved. Furthermore, we can properly combine the four rectangular radial stub loaded resonators and one isosceles radial stub resonator in the filter. As a result, a compact microstrip lowpass filter with ultra-wide stopband is designed.

The new lowpass filter is designed and fabricated based on the analysis mentioned above. The structure parameters are as follows: $l_0 = 5.2\,\text{mm}$, $l_1 = 5.4\,\text{mm}$, $l_2 = 3.9\,\text{mm}$, $l_3 = 1.1\,\text{mm}$, $l_4 = 0.4\,\text{mm}$, $l_5 = 2.9\,\text{mm}$, $l_6 = 1.9\,\text{mm}$, $w_0 = 1.16\,\text{mm}$, $w_1 = 0.2\,\text{mm}$, $w_2 = 0.2\,\text{mm}$, $w_3 = 0.2\,\text{mm}$, $r_1 = 5.0\,\text{mm}$, $r_2 = 4.0\,\text{mm}$, $r_3 = 3.1\,\text{mm}$, $\theta_1 = 140^\circ$, $\theta_2 = 42^\circ$, $\theta_3 = 86^\circ$. The substrate used here has a relative dielectric constant of 3.45 and thickness of 0.508 mm.

## 3. SIMULATION AND MEASUREMENT RESULTS

All simulations have been carried out using Ansoft HFSS 15.0 simulation software based on the finite element method (FEM). Measurement was accomplished on an Agilent N5244A network analyser. Fig. 4 shows the simulated and measured results, which are in good agreement. As can be observed from Fig. 4, the measured cutoff frequency $f_c$ is located at 0.8 GHz, as expected. Fig. 3 also shows that the spurious frequencies are suppressed from 2.08 up to 14.0 GHz with a suppression degree better than 10 dB. Thus, the proposed filter has a property of 17th harmonic suppression. Furthermore, the proposed filter exhibits a small electrical size of $0.060\lambda_g \times 0.080\lambda_g$, where $\lambda_g$ is the guided wavelength at 0.8 GHz. The deviations of the measurements from the simulations are attributed to the fabrication tolerance as well as SMA connectors. For comparison, Table 1 summarises the performance 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 shows a photograph of the fabricated filter.

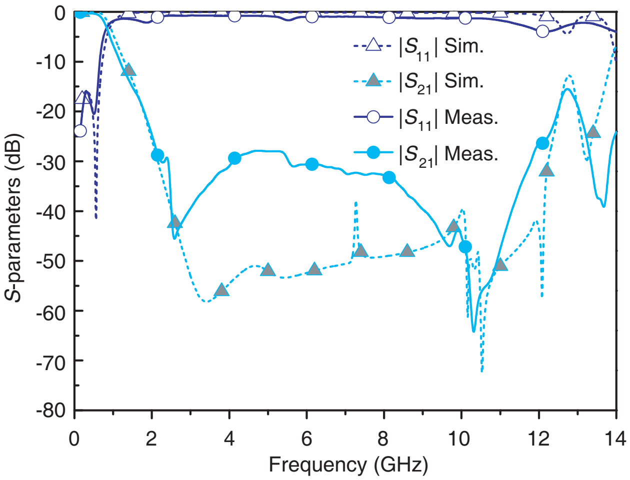

**Figure 4.** Simulated and measured performance of proposed filter.

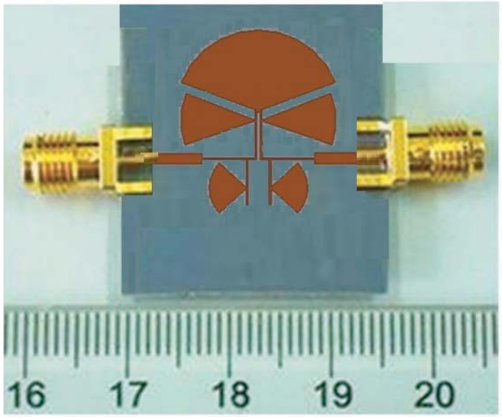

**Figure 5.** Photograph of the proposed lowpass filter.

**Table 1.** Performance 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] | 11th | 1.3 | $0.356\lambda_g \times 0.108\lambda_g$ | 2-D |
| [5] | 6th | 3.12 | $0.395\lambda_g \times 0.151\lambda_g$ | 2-D |
| [6] | 13th | 3 | $0.310\lambda_g \times 0.240\lambda_g$ | 2-D |
| [7] | 7th | 1.67 | $0.104\lambda_g \times 0.104\lambda_g$ | 2-D |
| [8] | 10th | 2 | $0.101\lambda_g \times 0.150\lambda_g$ | 2-D |
| [9] | 9th | 0.5 | $0.104\lambda_g \times 0.214\lambda_g$ | 2-D |
| [10] | 5th | 2.7 | $0.134\lambda_g \times 0.323\lambda_g$ | 3-D |
| [11] | 10th | 1.935 | $0.282\lambda_g \times 0.120\lambda_g$ | 3-D |
| This work | 17th | 0.8 | $0.060\lambda_g \times 0.080\lambda_g$ | 2-D |

## 4. CONCLUSION

A new microstrip lowpass filter is presented in this letter. One prototype filter with 3 dB cutoff frequency at 0.8 GHz has been demonstrated. Results indicate that the demonstrator has the properties of excellent performance. To summarise, the proposed lowpass filter is very useful for modern communication systems owing to its marked properties of simple topology, compact size, and ultra-wide stopband.

## ACKNOWLEDGMENT

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