# Compact Microstrip Lowpass Filter with Wide Stopband and Sharp Roll-off using Triple Radial Stubs Resonator

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***Abstract*** **─** A novel microstrip lowpass filter with good specifications such as sharp cutoff, wide stopband, low insertion loss, and high return loss is proposed. The proposed lowpass filter is realized using triple radial stubs resonator, i.e., three $60^{o}$ radial stubs and harmonic attenuator, i.e., T shaped cell loaded by the semicircle. The cutoff frequency of the proposed filter is adjusted to 1.39 GHz. The transition band is approximately 0.21 GHZ from 1.39 GHz to 1.6 GHz with corresponding attenuation levels of -3 dB and -20 dB. The stopband with better than -20 dB rejection is from 1.6 GHz to 12.36 GHz, insertion loss in the passband is less than 0.1 dB, return loss is less than -25 dB and the overall size of the filter is 0.0074 $\lambda g^2$ ( $15 \times 12.3$ mm$^2$ ). The proposed filter is fabricated and measured. The simulation and measurement results are in good agreement.

***Index Terms*** **─** Lowpass filter, microstrip, radial stub, sharp roll-off, and wide stopband.

## I. INTRODUCTION

Due to increasing constraint of reduction in size with optimum performance such as sharp cut-off, wide stopband, low insertion loss, and high return loss designs of lowpass filters are done with different methods. The sharp cut-off shows a sharper transition band, which indicates the higher selectivity; wide stopband shows the band with more than -20 dB harmonic suppression; low insertion loss shows high passing signals in the passband and high return loss refer to low return signals in the passband.

The conventional filter design method is normally not used, due to inherited deficiencies like the slow roll-off, poor frequency response in the passband and narrow stopband [1]. The Radial patches are presented in [2], which has good specification such as sharp roll-off and wide stopband, but the return loss in the pass band and the size of the filter is not satisfactory. A compact LPF using front coupled tapered compact microstrip resonator cell (FCTCMRC) is presented in [3], which despite the small size, neither the passband performance nor the stopband widths are good. Another method is to use complementary split ring resonators [4], which present sharp response and compact size, but fabrication of this structure because of its 3D configuration is difficult. A LPF with wide stopband using coupled line hairpin unit is demonstrated in [5]. In this filter, the insertion loss and return loss in the passband and the attenuation level in the stopband is not adequate. Later, LPF with novel patch resonator in [6] has been presented, while this filter has large circuit size. New ultra wide stopband LPF using transformed radial stubs (TRS) is introduced and investigated in [7], which has bad return loss in both passband and stopband, and the insertion loss in the passband is not good. A new compact defected ground structure (DGS) lowpass filter using a crescent shape structure etched in the ground plan is introduced in [8]. This filter has a gradual roll-off and narrow stopband.

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In this paper, a microstrip LPF having compact size, sharp roll-off, wide stopband, low insertion loss, and high return loss in the passband is presented.

## II. FILTER DESIGN

The design process for the proposed filter is as follows:

1- Design of the proposed three 60° radial stub resonator to achieve sharp roll-off response and to eliminate harmonics that appear near the cutoff frequency.
2- Suppressing Cells design and its addition to the proposed resonator in order to extend the stopband.
3- Combination of the proposed resonator and suppressing the cell to have a LPF with a wide stopband, sharp response, and good passband performance.

A detailed description of these steps is presented.

### A. Proposed resonator

The 180° radial stub resonator and its LC equivalent circuit are shown in Figs. 1 and 2, respectively. The capacitance of Cr in Fig.2 would be lumped capacitor or other circuit's capacitance like straight or radial stubs.

Fig. 1. The 180° radial stub resonator.

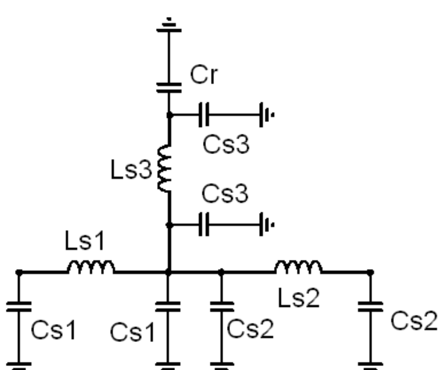


Fig. 2. LC equivalent circuit of the 180° radial stub resonator.

Figure 3 shows two types of capacitive elements, i.e., radial and straight stubs and their equivalent circuit. The parameter of the distributed stub section, which includes radial and the straight stubs of Fig. 3, can be modeled approximately as a lumped element.

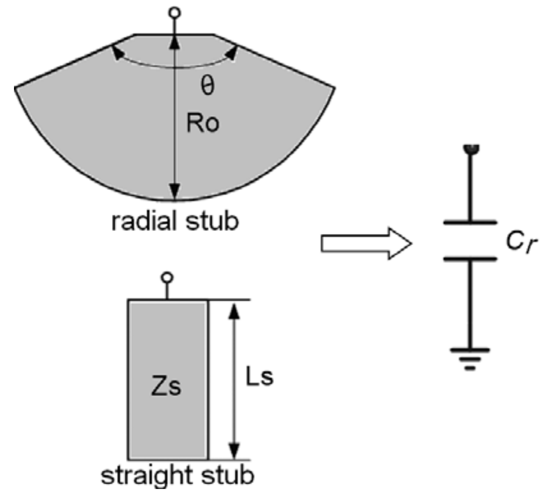


Fig. 3. Two types of capacitive elements and their model.

A distributed transmission line, when the effective electric length is less than a quarter wavelength, can be modeled as a lumped elements. The proposed three 60° radial stub is shown in Fig. 4. The simulated S-parameters of the proposed resonator with different dimension of W, L and, R are illustrated in Figs. 5, 6, and 7, respectively. As seen in Fig. 5, by increasing W from 0.1 mm to 0.5 mm with steps of 0.2 mm, the inductance of the resonator will be decreased, which makes the transmission zero move away from the lower frequency. Similarly, as shown in Fig. 6, when L increases from 10.5 mm to 12.5 mm with step of 1 mm, the inductance of the resonator will be increased, which result in moving the transmission zero to the lower frequency. As shown in Fig. 7, when R decreases from 3 mm to 2.2 mm with steps of 0.4 mm, the capacitance of the proposed resonator decreases so the cutoff frequency move to the higher frequency.

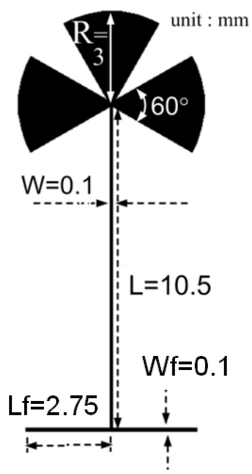


Fig. 4. The proposed three 60° radial stub resonator.

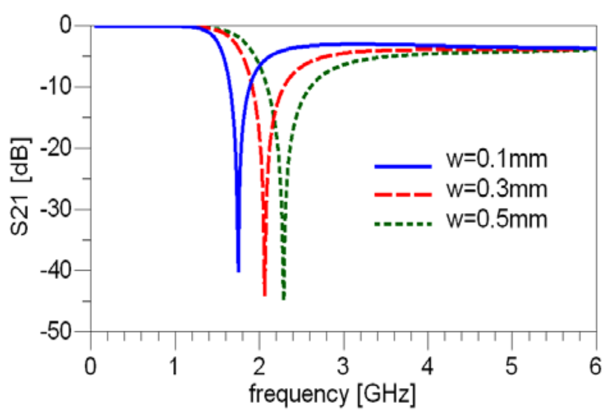


Fig. 5. Frequency response of the proposed resonator with different dimensions of W.

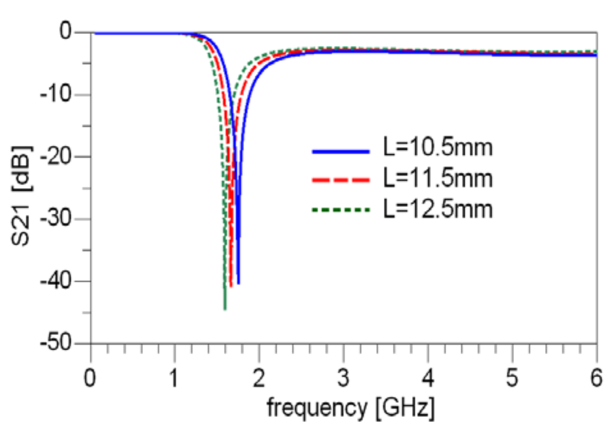


Fig. 6. Frequency response of the proposed resonator with different dimensions of L.

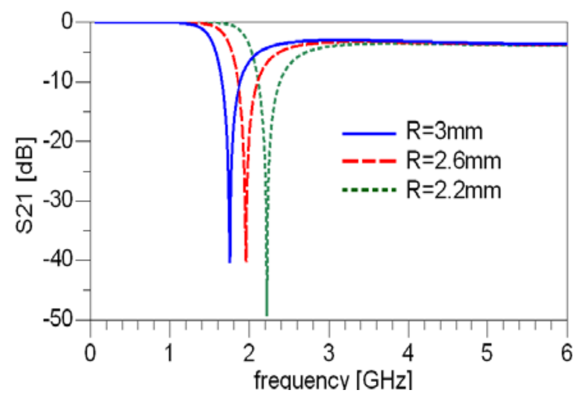


Fig. 7. Frequency response of the proposed resonator with different dimensions of R.

Frequency response of the proposed resonator with different dimensions of Lf is shown in Fig. 8. As it is seen, when Lf increases the suppression level increases without change in the location of the transmission zero. But increment of Lf result in the size increment. The decrement of Wf increment the inductance of the transmission line, which result in the increment of suppressing level as shown in Fig. 9. Therefore, the optimum value for Wf and Lf with respect to suppression level and filter size are selected.

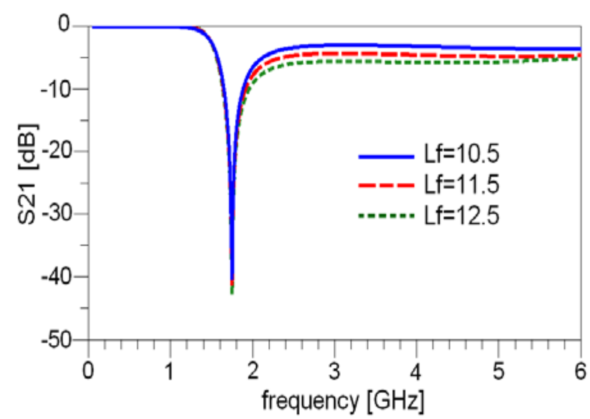


Fig. 8. Frequency response of the proposed resonator with different dimensions of Lf.

As seen in Fig. 10 the cut-off frequency of the proposed resonator is adjusted to 1.49 GHz and the transition band is approximately 0.2 GHz from 1.5 GHz to 1.7 GHz with corresponding attenuation levels of -3 dB and -20 dB. The dimensions of the proposed resonator are as follows: R = 3 mm, W = 0.1 mm, L = 10.5 mm, Lf = 2.75 mm, Wf = 0.1 mm.

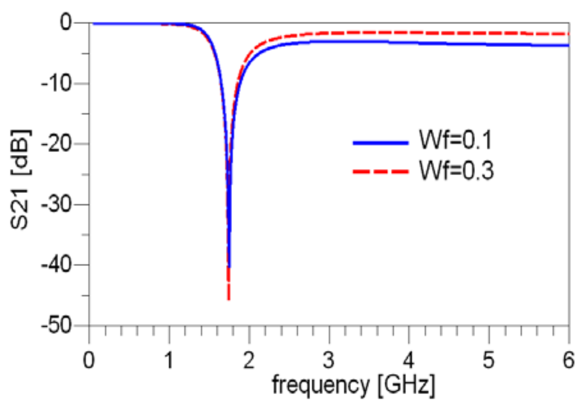


Fig. 9. Frequency response of the proposed resonator with different dimensions of Wf.

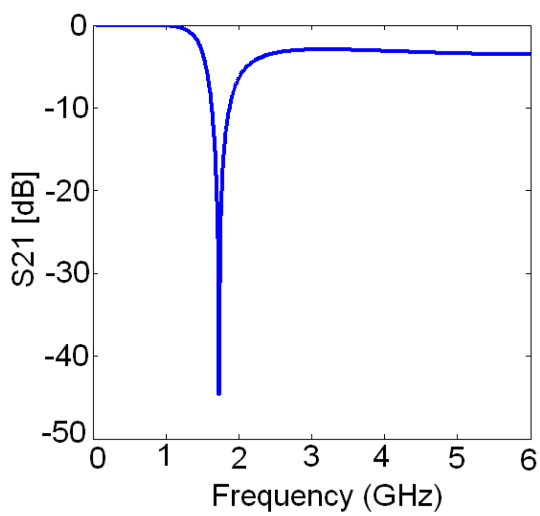


Fig. 10. The frequency response of the proposed three 60° radial stub resonator.

### B. Suppressing cell design

To obtain a LPF with wide stopband, a suppressing cell to suppress the harmonics in the stopband is required. It is realized by a T shaped cell that is loaded by the semicircle. Figure 11 shows the single T shaped cell and T shaped cell loaded by the semicircle. Their frequency response is shown in Fig. 12. As it is seen from Fig. 12, when T shaped cell is loaded by the semicircle, the suppression level in the stopband is increased.

### C. Proposed filter

To have a LPF with a wide stopband, sharp response and good passband performance, the proposed suppressing cell and the proposed resonator are combined. The proposed filter and its frequency response are shown in Figs. 13 and 14, respectively.

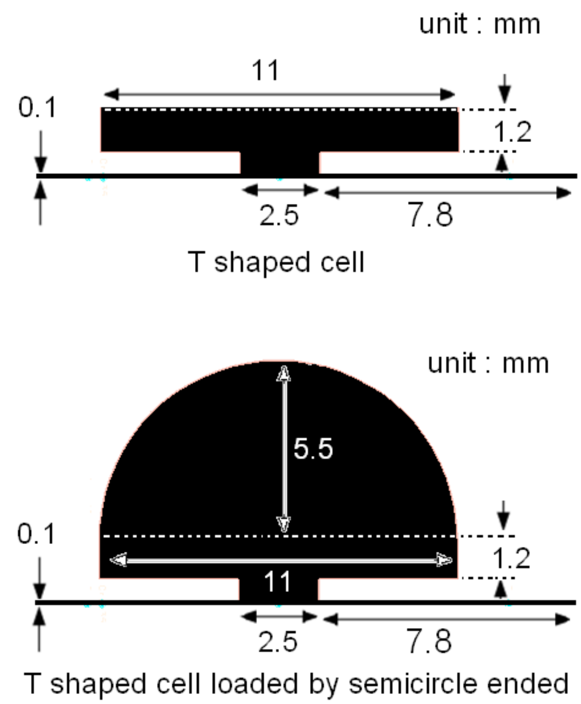


Fig. 11. The single T shaped cell and T shaped cell loaded by semicircle.

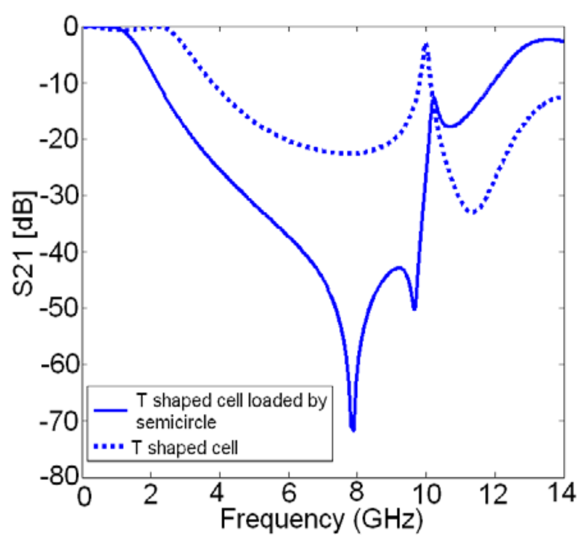


Fig. 12. Frequency response of the single T shaped cell and T shaped cell loaded by semicircle.

As shown in Fig. 15 when Lt is increased from 10.95 mm to 19.95 mm with steps of 3 mm, the stopband will be increased but the return loss and the insertion loss performance is decreased. Therefore, the optimum value for Lt with respect to its passband and stopband performance is selected.

The main transmission line in the proposed filter is bended, which results in size reduction. This work increases the inductance effect in the main transmission line, so the rejection level in the stopband is increased. Bending the transmission line has reduced the overall filter size by 52 % and increased the suppression level in the stopband. The proposed LPF with bended transmission line and its frequency response are shown in Figs. 16 and 17, respectively.

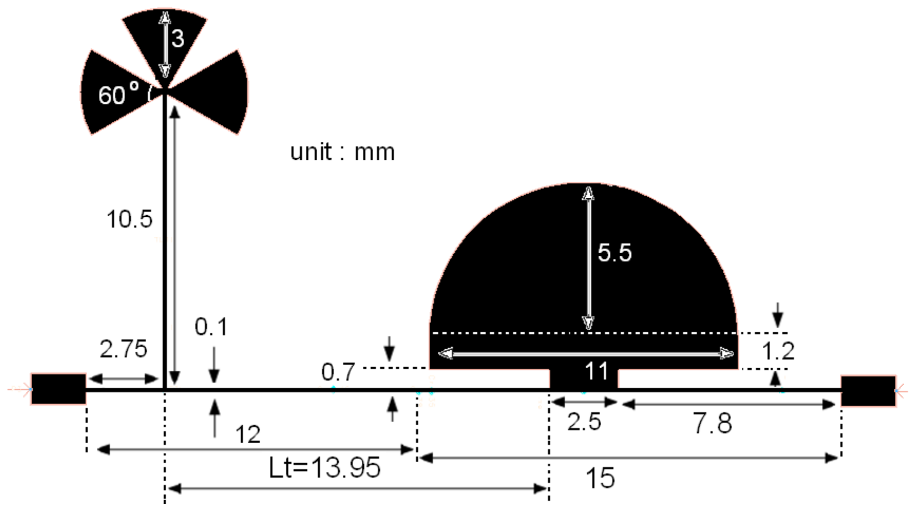


Fig. 13. The proposed filter in the straight form.

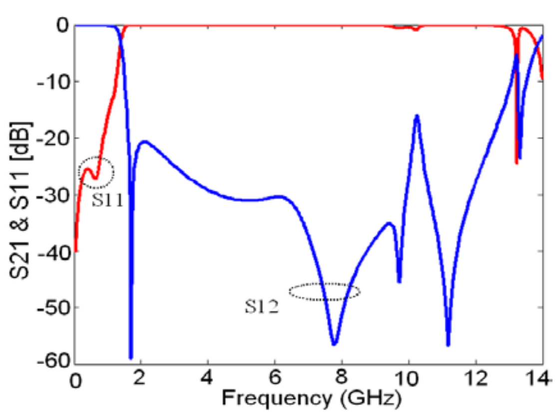


Fig. 14. Frequency response of the proposed filter in the straight form.

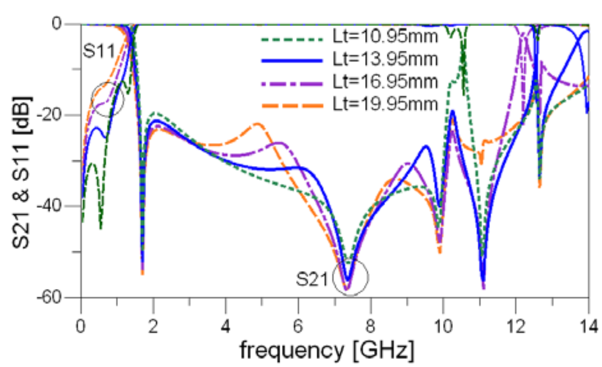


Fig. 15. Frequency response of the proposed filter in the straight form with different dimensions of Lt.

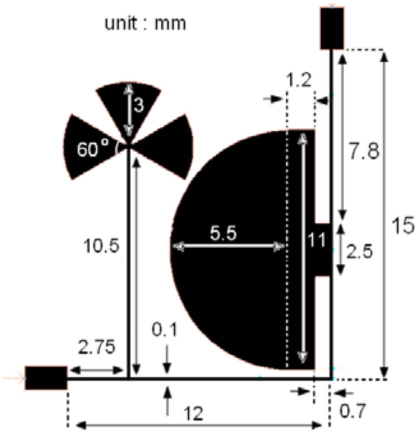


Fig. 16. The proposed filter in the bended form.

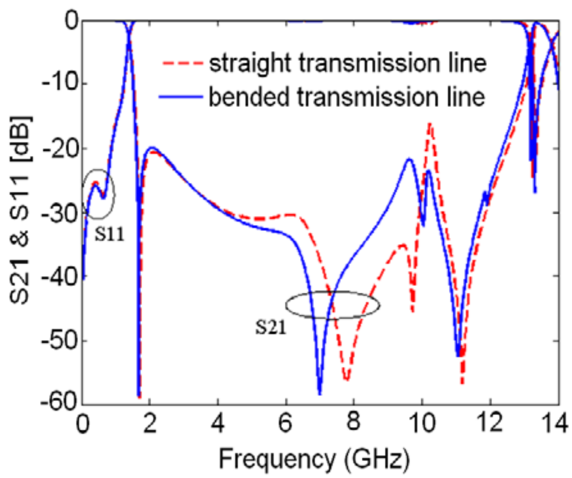


Fig. 17. Frequency response of the proposed filter in the both straight and bended form.

## III. SIMULATION AND MEASUREMENT

The proposed LPF is designed and optimized using EM-simulator of ADS. The main transmission line has been bended, which results in size reduction. The microstrip LPF is fabricated on a substrate with dielectric constant of $\varepsilon_r = 2.2$, thickness of $h = 15$ mil and loss tangent equal to 0.0009. The source and the load of the structure have characteristic impedance of $Z_0$ equal to 50 Ω with width of 1.1 mm. The photograph and the simulated and measured results of the proposed filter are illustrated in Figs. 18 and 19, respectively. It is seen that the attenuation level in the stopband is higher than -20 dB, which is achieved from 1.6 GHz to 12.36 GHz and present the wide stopband. The proposed filter has low insertion loss of less than 0.1 dB and return loss of more than 25 dB in the passband. The frequency response of the filter is very sharp with the transition band equal to 0.21 GHz from 1.39 GHz to 1.6 GHz with corresponding attenuation levels of -3 dB and -20 dB.

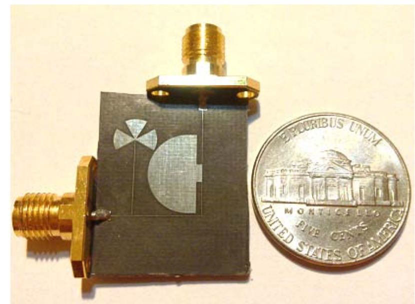

Fig. 18. The photograph of the proposed filter.

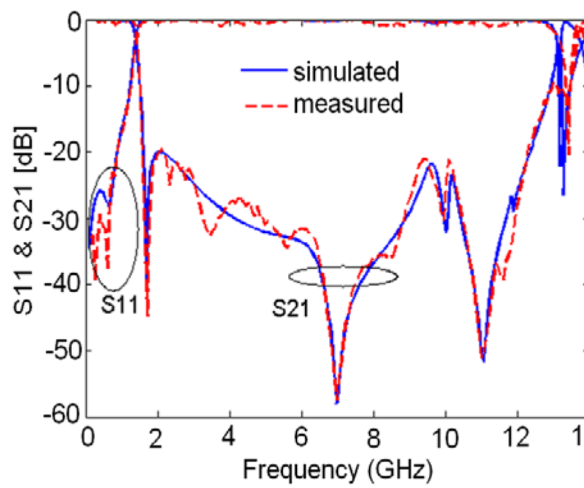


Fig. 19. The simulated and measured results of the proposed filter.

The performance comparison between the proposed LPF and other works is presented in Table 1, where ξ, RSB, NCS, SF, AF, FOM, RL, and IL correspond to the Roll-off rate, relative stopband width, normalized circuit size, suppressing factor, architecture factor, figure of merit, return loss, and insertion loss, respectively. These parameters are defined as follows:

Roll-off rate ξ is

$$\xi = \frac{\alpha_{max} - \alpha_{min}}{f_s - f_c}, \tag{1}$$

where $\alpha_{max}$ is the -20 dB attenuation point; $\alpha_{min}$ is the -3 dB attenuation point; $f_s$ is the -20 dB stopband frequency, and $f_c$ is the -3 dB cut-off frequency. Therefore, the high roll off rate shows a sharper transition band, which indicates the higher selectivity.

The relative stopband width (RSB) is

$$\mathrm{RSB} = \frac{\text{stopband} \ \ (-20\text{dB})}{\text{stopband} \ \ \text{center} \ \ \text{frequency}}, \tag{2}$$

where the high RSB shows the high stopband that is the band with more than -20 dB harmonic suppression.

The normalized circuit size (NCS) is

$$\mathrm{NCS} = \frac{\text{physical} \ \ \text{size (lenght} \times \text{width)}}{\lambda_g^2}, \tag{3}$$

where the lower NCS indicates the size of the filter is compact. The suppressing factor (SF) is based on the suppression in the stopband and is calculated as,

$$\mathrm{SF} = \frac{\text{rejection} \ \ \text{level}}{10}. \tag{4}$$

The architecture factor (AF) for a planar and 3-D structure is defined as 1 and 2, respectively. Finally, the figure of merit (FOM) is defined as,

$$\mathrm{FOM} = \frac{\xi \times \mathrm{RSB} \times \mathrm{SF}}{\mathrm{NCS} \times \mathrm{AF}}. \tag{5}$$

The FOM shows the overall performance of a LPF, where the filter with compact size, sharp transition band, high suppression level, and high stopband leads to a high FOM.

Table 1: Performance comparison between the proposed LPF and other works.

| **Ref.** | **ξ** | **RSB** | **NCS** | **SF** | **AF** | **FOM** | **RL (dB)** | **IL (dB)** |
|---|---|---|---|---|---|---|---|---|
| [2] | 56.66 | 1.355 | 0.037 | 3 | 1 | 6099 | 11 | 0.1 |
| [3] | 35.5 | 0.71 | 0.028 | 2 | 1 | 1800 | 12 | 1 |
| [5] | 62.06 | 1.42 | 0.022 | 2 | 1 | 7978 | 16.3 | 0.5 |
| [6] | 30.35 | 1.35 | 0.055 | 2 | 1 | 1487 | 11.54 | 0.33 |
| [7] | 72 | 1.71 | 0.074 | 2.5 | 1 | 4159 | 12 | 1.5 |
| **Proposed filter** | **80.95** | **1.59** | **0.0074** | **2** | **1** | **34550** | **25** | **0.1** |

In the structure of the proposed filter, the three $60^0$ radial stub resonator is used to control the transition band, which result in increasing roll-off rate (ξ) i.e., equal to 80.95. The stopband is extended to 12.36 GHz using T shaped cell loaded by semicircle as suppressing cell, so the RSB is increased. By bending the transmission lines the overall size of the filter is reduced to about 52 % that makes NCS to have a lower value among the referred filters. Finally, the comparison shows that the proposed filter has the best figure of merit (FOM), ξ, NCS, return loss (RL), and insertion loss (IL) among the referred filters.

## IV. CONCLUSION

A microstrip LPF with good specifications such as sharp roll-off, wide stopband, low insertion loss, and high return loss is designed and optimized. The three $60^o$ radial stubs resonator added to the T shaped cell loaded by the semicircle, results in sharp cutoff and wide stopband. The measurement results are in good agreement with the simulation results, and the proposed filter has very high FOM in comparison with the other works that is presented in recent years. This Filter with such features is a good candidate for modern communication system.

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