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COMPACT MICROSTRIP LOWPASS FILTER WITH SHARP ROLL-OFF AND WIDE STOPBAND USING SEMICIRCLE ENDED STUB RESONATOR

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Abstract—In this paper, a semicircle ended stub resonator, cascaded to a modified radial patch to design a compact lowpass filter with sharp roll-off and wide stopband is proposed. This filter has 3 dB cutoff frequency at 1.54 GHz. The transition band is only 0.26 GHz from 1.54 GHz to 1.8 GHz with corresponding attenuation levels of −3 dB and −20 dB respectively. Maximum insertion loss is 0.1 dB in the passband, and the stopband bandwidth with the attenuation level better than −20 dB is extended from 1.8 GHz up to 13.93 GHz. So, a wide stopband is achieved. The proposed filter is designed, fabricated and measured, where there is a good agreement between the simulation and measurement results. The results show that a roll-off rate of 65.4 dB/GHz together with a relative stopband bandwidth of 154% with the suppression level of −20 dB is obtained while achieving a high figure of merit (FOM) of 23509.

1. INTRODUCTION

Planar filters, which apply printed circuit board (PCB) technologies, have got a lot of attention due to their easy fabrication, low cost, and convenient integration with other microwave circuits. Conventional microstrip lowpass filters utilize shunt stubs, and high impedance transmission lines have shown gradual cutoff frequency [1]. Moreover, compact size and good rejection in the stopband region for the lowpass filters are necessary in the modern microwave communication systems. Hence, different methods have been used to design lowpass filter with good characteristics. Lowpass filters with the coupled line in [2] have finite attenuation poles. Due to low capacitance of the coupled line,

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transmission zeros are not located near the cutoff frequency; therefore, the filter response is not sharp enough. Lately, LPFs with novel patch resonator in [3] and in [4] have been presented, while these filters have large circuit size. Defect ground structure (DGS) usages in the LPFs for a high out-band suppression and size reduction has been demonstrated [5–10]. However, the DGS for the microstrip lines brings the disadvantages such as complex fabrication and additional radiation. The wide stopband, low insertion loss, high return loss and sharp roll-off are the main factors in the design of the lowpass filters. In this paper, semicircle ended stub resonator, bended transmission line, and a modified radial patch have been used to reach the sharp response, compact size, low insertion loss, high return loss and wide stopband. In the proposed filter, the stop bandwidth is 12.13 GHz (from 1.8 GHz to 13.93 GHz). The proposed filter has been simulated, fabricated and measured. The measured results are in good agreement with the simulated results.

2. LOWPASS FILTER DESIGN

The design process is followed in the following steps.

2.1. Resonator Design

The proposed resonator consists of a semicircle ended stub structure. The dimensions and LC equivalent circuits of the proposed resonator are depicted in Figs. 1(a) and (b) [11] respectively. The high impedance lines act as series inductors and the low impedance lines act as shunt capacitors [12]. The $ABCD$ parameters of a two port network are given by:

$$A = \left.\frac{V_1}{V_2}\right|_{I_2=0} \qquad B = \left.\frac{V_1}{-I_2}\right|_{V_2=0} \tag{1}$$

$$C = \left.\frac{I_1}{V_2}\right|_{I_2=0} \qquad D = \left.\frac{I_1}{-I_2}\right|_{V_2=0} \tag{2}$$

The $ABCD$ parameters of the proposed resonator is obtained as:

$$A = \frac{\omega^2 L_{s1} C_r + \omega^2 L_r C_r - 1}{\omega^2 L_r C_r - 1} \tag{3}$$

$$B = \frac{j\omega^2 L_{s1}^2 C_r + 2j\omega^3 C_r L_{sr} L_r - 2j L_{s1}\omega}{1 - \omega^2 L_r C_r} \tag{4}$$

$$C = \frac{jC_r\omega}{1 - \omega^2 L_r C_r} \tag{5}$$

$$D = \frac{\omega^2 L_{s1} C_r + \omega^2 L_r C_r - 1}{\omega^2 L_r C_r - 1} \tag{6}$$

The relationship between S-parameters and $ABCD$ parameters is:

$$S_{11} = \frac{A + \frac{B}{Z_0} - \frac{C}{Z_0} - D}{A + \frac{B}{Z_0} + \frac{C}{Z_0} + D} \quad S_{12} = \frac{2(AD - BC)}{A + \frac{B}{Z_0} + \frac{C}{Z_0} + D} \tag{7}$$

$$S_{21} = \frac{2}{A + \frac{B}{Z_0} + \frac{C}{Z_0} + D} \quad S_{22} = \frac{-A + \frac{B}{Z_0} - \frac{C}{Z_0} + D}{A + \frac{B}{Z_0} + \frac{C}{Z_0} + D} \tag{8}$$

The S-parameters of the proposed resonator is:

$$S_{11}=S_{22} = \frac{j\omega^3 L_{s1} C_r (L_{s1}+2L_r) - j\omega(C_r+L_{s1})}{2Z_0(1-\omega^2 L_{s1} C_r - \omega^2 L_r C_r) + j\omega^3 L_{s1} C_r (1+2L_r) - j\omega(C_r+L_{S1})} \tag{9}$$

$$S_{12}=S_{21} = \frac{2Z_0\left(1-\omega^2 L_r C_r\right)}{2Z_0(1-\omega^2 L_{s1} C_r - \omega^2 L_r C_r) + j\omega^3 L_{s1} C_r (1+2L_r) - j\omega(C_r+L_{S1})} \tag{10}$$

Thus, we can control the S_{12} and S_{11} parameters by tuning C_r and L_r variables. Therefore, by adjusting C_r and L_r, the suppression of frequency response is obtained for the transmission zero at 1.98 GHz, which result in a sharp response. As shown in Figs. 1(a) and (b) the capacitor C_r and inductance L_r are functions of L, R, θ and W. Therefore, by varying these parameters, the resonator response is adjusted. The simulated S-parameters of the proposed resonator as a function of L, R, θ and W are shown in Figs. 1(c)–(f) respectively. As shown in Fig. 1(c), when the value of L decreases from 9 mm to 7 mm, the transmission zero at 1.98 GHz approaches to the upper frequencies. When the value of R decreases from 2.7 mm to 2.3 mm, the attenuation pole at 1.98 GHz approaches to the higher frequencies as similar as the Fig. 1(d) and when the value of θ decreases from 180 degrees to 140 degrees, the attenuation pole at 1.98 GHz approaches to the higher frequencies, as shown in Fig. 1(e). As shown in Fig. 1(f), when the value of W increases from 0.1 mm to 0.3 mm, the attenuation pole at 1.98 GHz approaches to the higher frequencies. So by changing the values of W, L, R and θ, we can control the location of the attenuation poles at 1.98 GHz and also the sharpness of the frequency response.

Figure 1(g) shows the slow-wave factor (SWF) of the proposed resonator versus frequency. It can be seen from the result that the uniform 50 Ohm microstrip line has SWF equal to 1.3 in the passband region, where the SWF of the proposed resonators increases and reaches 6.4 in the region close to 3 dB cutoff frequency. So we have 492% increment in SWF in comparison with the conventional

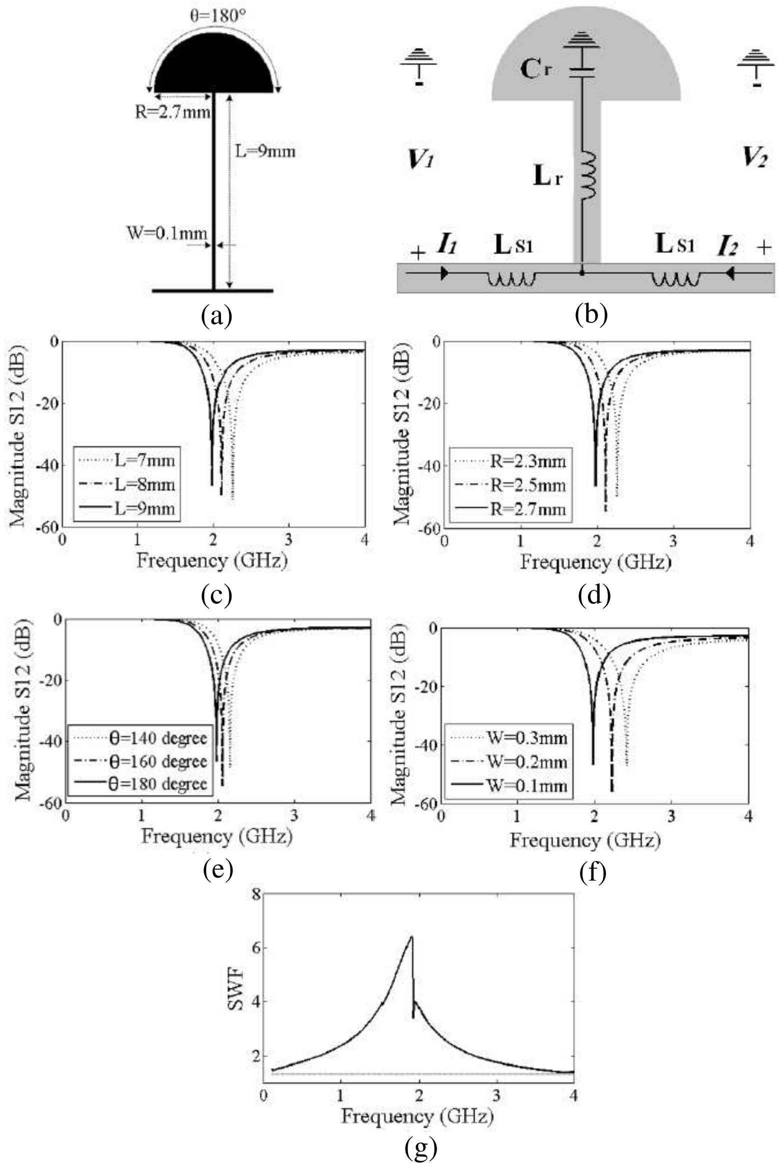
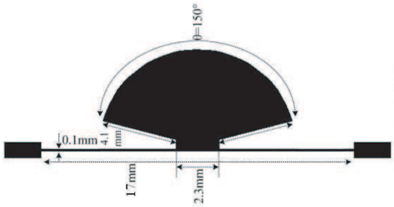


Figure 1. (a) Typical topology of proposed resonator. (b) LC equivalent circuit of the proposed resonator. (c) Simulated S_{21} parameter as function of L. (d) Simulated S_{21} parameter as function of R. (e) Simulated S_{21} parameter as function of θ. (f) Simulated S_{21} parameter as function of W. (g) The slow wave factor of the proposed resonator.



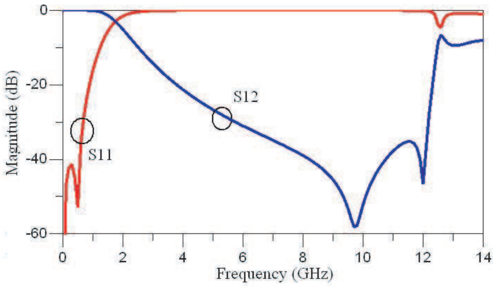


Figure 2. (a) The proposed suppressing cell. (b) The frequency response of the suppressing cell.

microstrip line. High SWF shows that we have obtained a resonator with the compact size.

2.2. 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 modified radial patch. The layout of the suppressing cell and its frequency response are shown in Figs. 2(a) and (b), respectively. As seen in Fig. 2(b), the suppression is achieved in frequency range of 3 to 12.5 GHz. The LC equivalent circuit of the suppressing cell is similar to the proposed resonator, which is shown in Fig. 1(b). Due to small value of the resonance inductance (L_r) of the suppressing cell, the transmission zeros appear in the high frequency, which results in a wide stopband.

To obtain a LPF with a wide stopband, sharp response and good passband performance, the proposed suppressing cell and the proposed resonator are combined. The main transmission line is bended, which result in size reduction. Fig. 3(a) shows the schematic of the proposed microstrip lowpass filter that consists of a semicircle ended stub resonator, which cascaded to a modified radial patch. By adding, modified radial patch to the proposed resonator, because of different cutoff frequency and attenuation poles in the stopband region, we can reach to a wide stopband. Fig. 3(b) shows the photograph of the proposed filter.

3. SIMULATION AND MEASUREMENT RESULT

The proposed filter is fabricated on a substrate with relative dielectric constant equal to 2.22, thickness of 10 mil and loss tangent equal to

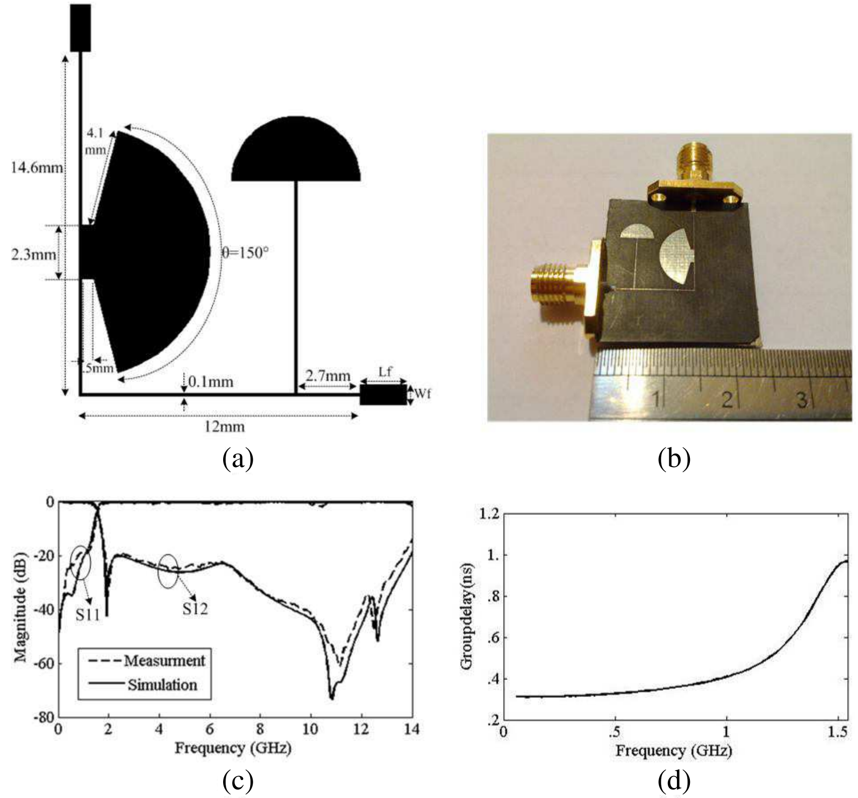


Figure 3. (a) Schematic of proposed lowpass filter. (b) Photograph of fabricated lowpass filter. (c) Simulation and measurement results of the designed lowpass filter. (d) Group delay of the proposed lowpass filter.

0.0009. Fig. 3(c) illustrates the simulated and measured results of the filter. Two microstrip stubs at the both sides of the filter, with width $W_f = 0.8$ mm and length $L_f = 2$ mm, are in order to match the impedance at input and output ports to 50 Ohm. The S-parameters are measured using the network analyzer N5230A, and the simulated results are achieved by the EM-simulator ADS based on the method of Momentum. The measured results are in good agreement with the simulated results. The designed filter has 3 dB cutoff frequency at 1.54 GHz and suppression level is greater than -20 dB from 1.8 GHz up to 13.93 GHz. The transition band is only 0.26 GHz from 1.54 GHz to 1.8 GHz with the attenuation level of -3 dB and -20 dB, respectively. The insertion loss in the passband is less than 0.1 dB and return loss

Table 1. Performance comparisons of this work with other filters.

Ref.	f_c (GHz)	RL	IL	ζ	RSB	SF	NCS	AF	FOM
[2]	2.5	14	0.45	34	1.15	2	0.07 × 0.28	1	3774
[3]	3.12	11.54	0.33	30.35	1.35	2	0.38 × 0.145	1	1487
[4]	2.4	13	0.2	0.2	1.335	2	0.351 × 0.106	1	6099
[13]	0.53	16.3	0.41	0.41	1.41	2	0.104 × 0.214	1	7978
[14]	1.18	32	0.6	0.6	1.323	1.5	0.079 × 0.079	1	8999
This work	**1.54**	**33.7**	**0.1**	**0.1**	**1.542**	**2**	**0.084 × 0.102**	**1**	**23509**

is better than 33.7 dB. The return loss in the stopband region is very close to 0 dB, which indicates small radiation loss. In addition, the flat group delay as shown in Fig. 3(d) is achieved with the maximum variation of 0.5 ns in the passband region. Excluding the input and output ports, the size of the filter is 12 mm × 14.6 mm.

Table 1 summarizes the filter performance such as, insertion loss (IL), return loss (RL), roll-off rate (ζ), relative stopband (RSB), suppression factor (SF), normalized circuit size (NCS), architecture factor (AF) and figure of merit (FOM) [14] and its comparison with the other works.

Parameters in the Table 1 are defined as follows:

Roll-off rate ξ is:

$$\xi = \frac{\alpha_{\max} - \alpha_{\min}}{f_s - f_c} \tag{11}$$

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 cutoff frequency.

The relative stopband width (RSB) is:

$$\mathrm{RSB} = \frac{\text{stopband}}{\text{stopband center frequency}} \tag{12}$$

The normalized circuit size (NCS) is:

$$\mathrm{NCS} = \frac{\text{physical size (length} \times \text{width)}}{\lambda_g^2} \tag{13}$$

The suppressing factor (SF) is based on the suppression in the stopband and is calculated as:

$$\mathrm{SF} = \frac{\text{rejection level}}{10} \tag{14}$$

For example, SF of stopbands with rejection levels of 10, 20, 30 and 33 dB are 1, 2, 3, and 3.3, respectively.

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:

$$\mathrm{FOM} = \frac{\zeta \times \mathrm{RSB} \times \mathrm{SF}}{\mathrm{NCS} \times \mathrm{AF}} \tag{15}$$

As seen in Table 1, the proposed filter has a good performance and figure of merit, i.e., 23509. The wide stopband, low insertion loss, high return loss and sharp roll-off are the main challenges in the design of the lowpass filters. All of these parameters in the proposed filter are better in comparison to other filters in the Table 1.

4. CONCLUSION

This paper presents a semicircle ended stub resonator, cascaded to a modified radial patch to design a compact lowpass filter with sharp roll-off and wide stopband. Results indicated that the filter has advantages of compact size, sharp roll-off, wide stopband and high figure of merit. Both simulations and measurements results have been presented and compared, and good agreement between them is achieved. The proposed filter with these features is a good candidate for the modern communication systems and applications where compact size, sharp response and wide stopband are the main factors.

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