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Design of wide stopband lowpass filter with sharp roll-off

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Abstract: In this paper, a modified semi-circle patch and a semi-circle stepped impedance resonator are cascaded to design a compact lowpass filter with sharp response and wide stopband. This filter has 3-dB cutoff frequency at 1.55 GHZ. The transition band is only 0.29 GHZ from 1.55 to 1.84 GHZ with -3 dB and -20 dB respectively. Maximum insertion loss is 0.4 dB in the passband and stop bandwidth with attenuation level better than -20 dB extends from 1.84 GHZ up to 12.5 GHZ and up to 15 GHZ is greater than -10 dB, hence wide stopband is achieved. Simulation and measurement results are presented and good agreement between them is achieved. Results show that we have obtained a high Figure-of-Merit (FOM) of 30433.

Keywords: microstrip, lowpass filter, delta stub structure, sharp response and wide stopband.

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Compact size lowpass filters with superior rejection are essential in developing the modern microwave communication systems. The general configuration of microstrip lowpass filter is stepped impedance and Kuroda identity Stub that only provide Butterworth and Chebyshev response. To reach sharp response, we have to use multiple cells; these increments enlarge the dimension and insertion loss in the passband region of the filter in [1]. In [2] a lowpass filter with interdigital capacitors has mostly discussed the location of the attenuation poles and little information is available about other parameters of the filter. Another method is to use complementary split ring resonators [3], that present small size and sharp response but this structure due to its 3D configuration is difficult to fabricate. Lowpass filters with coupled line in [4] and [5] have finite transmission poles. Because of low capacitance of the coupled line, transmission zeros are not located near the cutoff frequency; consequently the filter response is not sharp enough. Recently LPFs with novel patch resonator in [6] and in [7] have been reported, while these filters have drawback of large circuit size. Efforts to reduce size of filter while achieving wide stopband are being extended. In this paper a compact lowpass filter with wide stopband and sharp roll off using a cascaded modified semi-circle, which is loaded by delta stub, and semi circle stepped impedance section is proposed. The stop bandwidth is 10.66 GHZ (from 1.84 to 12.5 GHZ). The filter is simulated, fabricated and measured. Simulated and measured results are presented and compared; also good agreement between them is achieved.

2 Lowpass filter design and results

The proposed resonator consists of a semi circle that is loaded by delta stub structures. Fig. 1 (a) and Fig. 1 (b) illustrates the layout and equivalent circuit of the delta stub unit. It’s smaller than an open circuited transmission line and is modeled by “n” number of transmission lines of length Ld in [8]. When we create the delta stub, transition from passband to stopband becomes steep and a lower cutoff frequency is reached.

The dimensions of the resonator are depicted in Fig. 1 (c). The effect of the delta stub on the frequency response is shown in Fig. 2 (a). It can be seen that the cutoff frequency is affected by the delta stub structures. The simulated S-parameters of the proposed resonator as a function of W0 and L0 are depicted in Fig. 2 (b) and 2 (c), respectively. When the value of W0 increases from 0.2 to 0.4 mm with step 0.1 mm, attenuation pole in 2 GHZ

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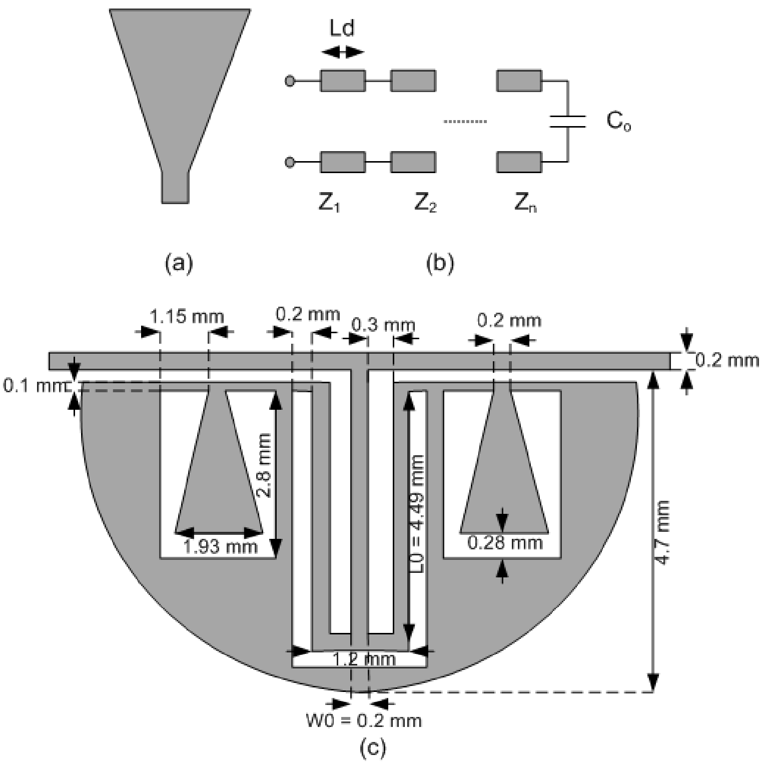

Fig. 1. (a) Geometry of delta stub [6]. (b) Equivalent circuit of deltastub [6]. (c) Typical topology of proposed LPF.

approach to higher frequencies. As shown in Fig. 2 (c) when the value of L0 decreases from 4.49 to 2.67 mm with step of 0.91 mm, transmission zero in 2 GHZ as similar as Fig. 2 (b) will approach to upper frequency range. So by changing the values of W0 and L0 we can control the location of transmission pole at 2 GHZ and also sharpness of the frequency response. Assuming the structure is loss-less, its phase velocity is given by:

$$v_p = \frac{1}{\sqrt{lc}} \tag{1}$$

where l and c refer to the equivalent inductance and capacitance per unit length, respectively. Also, the dimension of the filter is proportional to the guided wavelength at the cutoff frequency. On the other hand, λ_g is proportional to phase velocity, so with reducing v_p we get slow-wave propagation. Good slow-wave factor can lead to the size reduction. The slow-wave factor (SWF) is given by:

$$SWF = \frac{\lambda_0 \Delta\theta}{360L} + \sqrt{\varepsilon_{eff}} \tag{2}$$

where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-0.5} \tag{3}$$

Where L is a physical length of microstrip line, λ_0 is the guided wavelength; $\triangle\theta$ is the phase difference in term of degree between the conventional microstrip and the proposed resonator and ε_{eff} is the effective microstrip permittivity. Fig. 2 (d) shows the slow-wave factor of the proposed resonator

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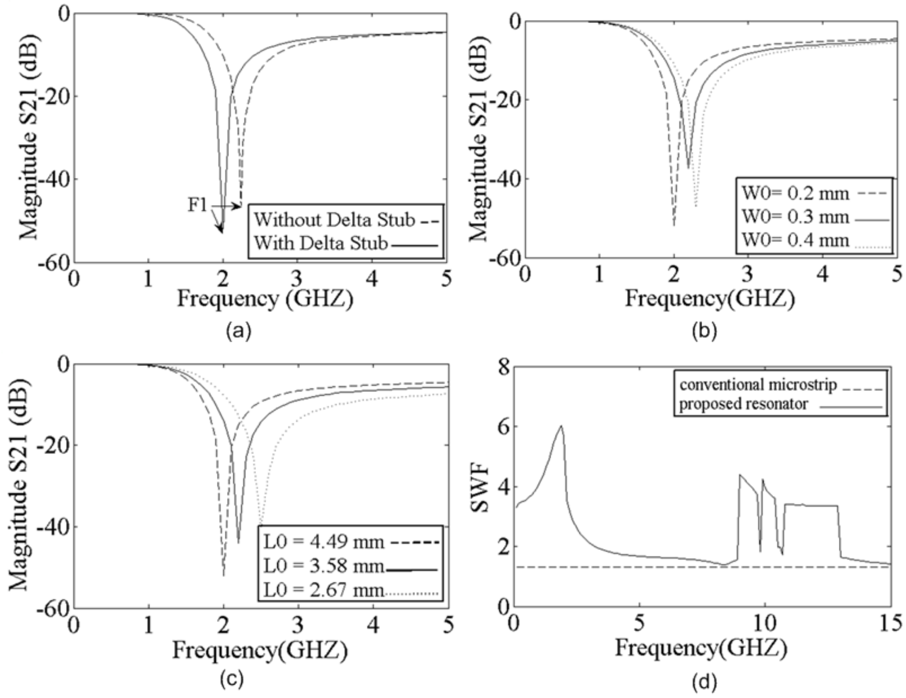

Fig. 2. (a) The frequency response of resonator with and without delta stub structures. (b) Simulated S21 parameter as function of W0. (c) Simulated S21 parameter as function of L0. (d) The slow wave factor of the proposed resonator.

versus frequency. It can be seen from the result that the uniform 50 ohm microstrip line has SWF equal to 1.37 in the passband region, where the SWF of the proposed resonators increases and reaches 6.05 in the region close to 3 dB cutoff frequency. So we have 441% increases in SWF around cutoff frequency in comparison with the conventional microstrip line. High SWF shows that we obtained a resonator with compact size.

Fig. 3 (a) and Fig. 3 (b) show the layout and photograph of the microstrip lowpass filter that consists of semi circle stepped impedance section in series with proposed resonator. By adding, semi circle stepped impedance resonator to the proposed resonstor, because of different cutoff frequency and attenuation poles in the stopband region, we can reach to wide stopband. On the other hand, to have good suppression of harmonics we can add open stubs to the structure of filter (between semi-circle and designed resonator). Filter structure, discussed above, is designed on a substrate with dielectic constant equal to 2.2, thickness of 10 mil and loss tangent equal to 0.0009. Fig. 3 (c) illustrates the simulated and measured results of the filter. Two open microstrip stubs are placed at the both sides of the filter, with width Wf = 0.83 mm and length Lf = 1.7 mm, are in order to match the impedance at input and output ports to 50 ohm. The S-parameters are measured using network analyzer N5230A and the simulated results are achieved by the EM-simulator ADS based on the method of momentum. The measured results are consistent with the simulated results. The designed filter has 3-dB cutoff

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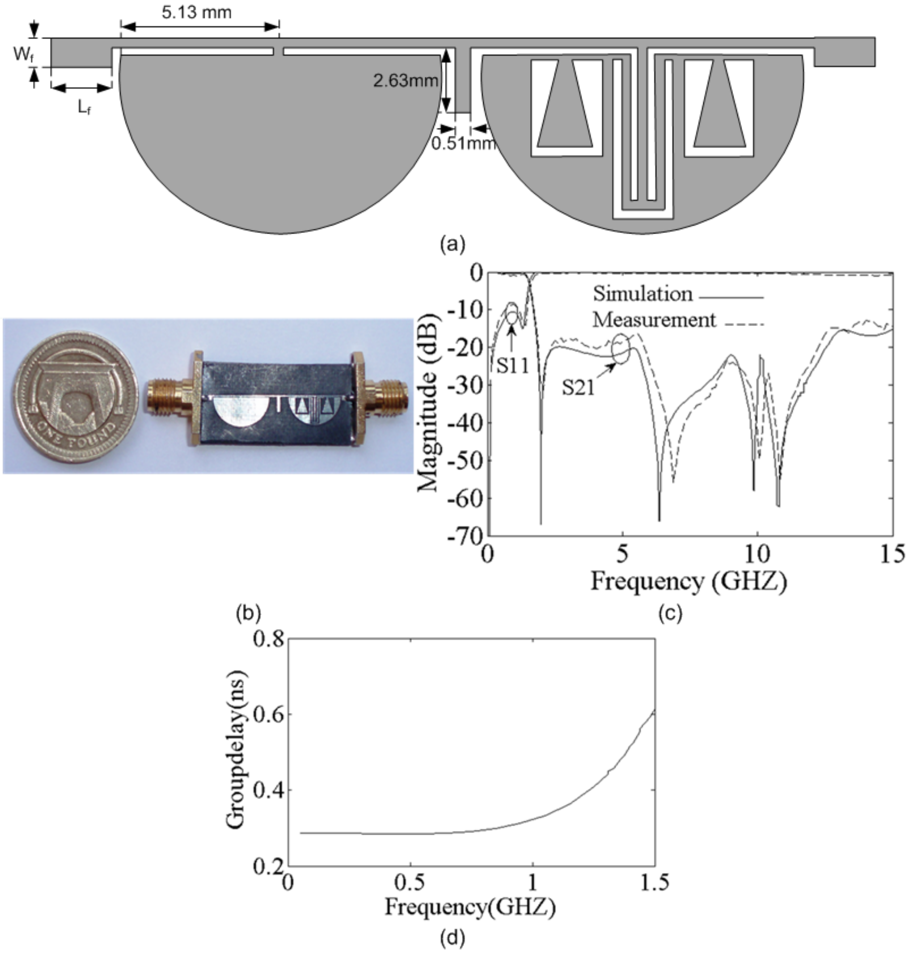

Fig. 3. (a) Geometry of proposed LPF. (b) photograph of fabricated LPF. (c) Measured and simulated results of designed lowpass filter. (d) The group delay of the proposed lowpass filter.

frequency at 1.55 GHz and suppression level is greater than −20 dB from 1.84 up to 12.5 GHz and up to 15 GHz suppression level is better than −10 dB. The transition band from 1.55 to 1.84 GHz with −3 and −20 dB, respectively, is 0.29 GHz. The insertion loss in the passband is less than 0.4 dB and return loss is better than 10.5 dB from DC to 1.31 GHz. The return loss in the stopband region is very close to 0 dB, which indicates small radiation loss. In addition the flat group delay in Fig. 3 (d) is achieved in the passband region with the maximum variation of 0.5 ns in the passband region. Excluding the input and output ports, the size of the filter is 23.3 mm × 5 mm.

Table I summarizes some lowpass filters performance. Among them, the roll-off rate (ζ) is used to evaluate the roll-off sharpness which is defined as:

$$\zeta = \frac{\alpha_{max} - \alpha_{min}}{f_s - f_c} \tag{4}$$

where α_{max} is the 20 dB attenuation point; α_{min} is the 3 dB attenuation point; f_s is the 20 dB stopband frequency; and f_c is the 3 dB cutoff frequency.

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The Relative Stopband Bandwidth (RSB) is given by:

$$RSB = \frac{stopband\ bandwidth}{stopband\ centre\ frequency} \tag{5}$$

The Suppression Factor (SF) is based on the stopband suppression. A higher suppression degree in the stopband leads to a greater SF. For instance, if the stopband bandwidth is calculated under 20 dB restriction, then the SF is considered as 2. The Normalised Circuit Size (NCS) is given by:

$$NCS = \frac{physical\ size(length \times width)}{\lambda_g^2} \tag{6}$$

This is applied to measure the degree of miniaturization of diverse filters, where λ_g is the guided wavelength at 3 dB cutoff frequency. The Architecture Factor (AF) can be recognised as the circuit complexity factor, which is signed as 1 when the design is 2D and as 2 when the design is 3D. Finally, the Figure Of Merit (FOM) is defined as:

$$FOM = \frac{\zeta \times RSB \times SF}{NCS \times AF} \tag{7}$$

Through this table, we can see that the proposed filter exhibits good performance and also a high Figure Of Merit (30433) among the quoted filters.

Table I. Comparison of our work with other filters.

ref.	ζ	RSB	SF	NCS	AF	FOM
[2]	56.56	1.13	2	0.3×0.086	1	4963
[3]	150.44	1.03	2	0.23×0.09	2	7485
[4]	8.5	1	2	0.11×0.094	1	1644
[5]	34	1.15	2	0.074×0.28	1	3774
[6]	30.35	1.35	2	0.38×0.145	1	1487
[7]	56.66	1.335	3	0.351×0.106	1	6099
Our Work	58.62	1.49	2	0.164×0.035	1	30433

3 Conclusion

This paper presents a compact microstrip lowpass filter by cascading modified semi circle resonator, which is loaded by delta stub structure, and semi circle stepped impedance resonator. Results indicated that the filter has advantages of compact size, sharp response, wide stopband and high Figure Of Merit of 30433. Good agreement between measured and simulated results is achieved in both passband and stopband regions. This filter is of interest in applications where small size and wide stopband as well as sharp roll off are the main factors.

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