LETTER
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Compact microstrip stepped-impedance lowpass filter with wide stopband using SICMRC

Mohsen Hayati[1,2a)] **and Hamed Abbasi**[1]
[1] *Electrical and Electronics Engineering Department, Razi University Tagh-E-Bostan, Kermanshah-67149, Iran*
[2] *Computational Intelligence Research Center, Faculty of Engineering, Razi University. Tagh-E-Bostan, Kermanshah-67149, Iran*
a) *mohsen_hayati@yahoo.com*

Abstract: This paper presents the design of a lowpass filter (LPF) with high and ultra wide rejection in the stopband using stepped-impedance compact microstrip resonator cell (SICMRC). The proposed filter consists of a prototype stepped-impedance LPF, which is modified to form a double arrow shaped microstrip cell (DASMC) with a wide stopband. Then, SICMRC is embedded in the structure of the DASMC to obtain a sharp response. The attenuation level in the stopband is better than −20 dB that is achieved from 6.6 to 41.7 GHz. The proposed filter has low insertion loss less than 0.1 dB and high return loss more than 26 dB in the passband. The transition band is approximately 0.74 GHZ from 5.86 to 6.6 GHz with corresponding attenuation levels of −3 and −20 dB. The cut-off frequency of the prototype filter is 5.8 GHz. It has a simple shape and a compact size of 14.2 mm × 8.2 mm. The proposed filter has been designed, fabricated and measured. The Comparison between the simulation and experimental results shows that they are in good agreement.

Keywords: lowpass filter, microstrip, stepped impedance
Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Microwave lowpass filters are in high demand in modern communication systems in order to suppress the unwanted harmonics and environmental noises. So far, different methods have been proposed to design the high performance lowpass filters [1]. A very compact size filter using hairpin resonators is introduced in [2], although the rejection-bandwidth needs to be improved. The symmetrically loaded resonant patches and meander transmission lines are adopted in [3] and have resulted in a very wide stopband and high passband performance, but the level of rejection is not very high, and they have a relatively large size. A filter with an embedded bandstop structure is designed in [4] in which, despite the small size, neither the passband performance nor the stopband width is good. More recently, stub-loaded coupled-line hairpin unit has been utilized [5] and has gained high performance, particularly in terms of compactness. In [6], a 1-D photonic bandgap transmission line is proposed. Photonic bandgap (PBG) has been used in the LPFs for size reduction. The PBG for the microstrip lines brings the disadvantages such as complex fabrication and additional radiation. The filter in [6] has a bad return loss and insertion loss and narrow stopband. In [7], design of improved CMRC structure used in terahertz sub harmonic pumped mixer is presented. In the filter in [7], the return loss and stopband up to cut-off frequency fc is low. In [8], a miniaturized microstrip lowpass filter with broad stopband and sharp roll-off is presented, while the suppression level in the stopband is low. Also the return loss and the insertion loss are not adequate.
In this letter, the design of a compact lowpass filter with high and ultra-wide rejection in the stopband using stepped impedance compact microstrip resonator cell is presented. The proposed filter has advantages such as compact size, ultra-wide stopband and low insertion loss in the passband.

2 Filter design

The design procedure for the proposed LPF is as follows: At first, we design a classic stepped-impedance LPF. This type of lowpass filter can be served

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as a prototype to design lots of practical filters with frequency and element transformations. Fig. 1 (a) shows the structure of the proposed prototype stepped-impedance lowpass filter. It utilizes a cascaded structure of alternative $Z_{0L} = 154$, $Z_{0C1} = 27$ and $Z_{0C2} = 10\,\Omega$, which represents the impedance transmission lines with width of the 0.1, 2.7 and 8.1 mm respectively. The Guided wavelength of the transmission lines are $\lambda_{gL} = 40$, $\lambda_{gC1} = 39$ and $\lambda_{gC2} = 36$ mm. When width of the low impedance transmission line is much larger than the length, Z_{0C2} in Fig. 1 (a) for example, it can be taken as a pair of shunt open stubs. The equivalent circuit is the same as Fig. 1 (b). The source and the load of the structure have characteristic impedance of equal to 50 Ω. The high-impedance lines act as series inductors (L1, L2) and the low impedance lines or shunt open stubs act as shunt capacitors (C1, C2). The equivalent LC circuit of the prototype filter is shown in Fig. 1 (b). The cut-off frequency of the prototype filter is 5.8 GHz. The microstrip LPF is fabricated on a substrate with dielectric constant of, thickness of and loss tangent equal to 0.0009.

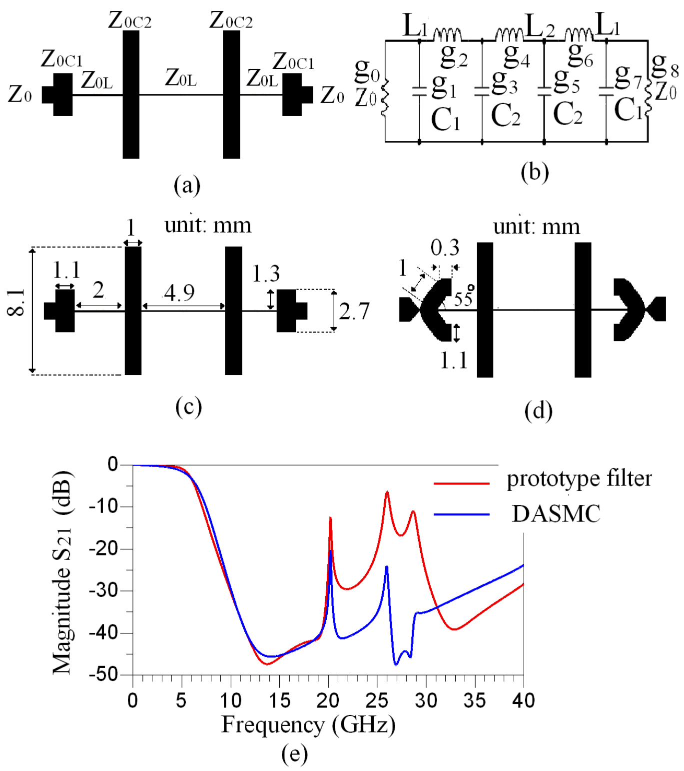

Fig. 1. (a) General structure, (b) Approximated LC ladder model and (c) The layout and dimension of the prototype filter. (d) The layout and (e) The frequency response of the DASMC and prototype filter.

To design a lowpass prototype filter, Chebyshev function response is chosen. Element values for Chebyshev LPF with a passband ripple equal to L_{Ar} dB are computed using the following formulas:

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$$g_0 = 1; g_{n+1} = 1; g_1 = \frac{2}{\gamma} sin\left(\frac{\pi}{2n}\right); \tag{1}$$

$$g_i = \frac{1}{g_{i-1}} \frac{4sin\left(\frac{(2i-1)\pi}{2n}\right) sin\left(\frac{(2i-3)\pi}{2n}\right)}{\gamma^2 + sin^2\left(\frac{(i-1)\pi}{n}\right)} \tag{2}$$

where

$$\gamma = sinh\left(\frac{\beta}{2n}\right); \beta = ln\left[coth\left(\frac{L_{AR}(dB)}{17.37}\right)\right] \tag{3}$$

Element values for a seven-pole (n=7) LPF with Chebyshev response and very low passband ripple (less than 0.05) are calculated as follows: $g_0 = g_8 = 1$, $g_1 = g_7 = 0.32$, $g_2 = g_6 = 0.92$, $g_3 = g_5 = 1.06$, $g_4 = 1.3$. By using the following equations:

$$L_i = \frac{Z_0}{g_0} \frac{g_i}{2\pi fc}; C_i = \frac{g_0}{Z_0} \frac{g_i}{2\pi fc} \tag{4}$$

$$l_{L_i} = \frac{\lambda_{gLi}}{2\pi} sin^{-1}\left(\frac{\omega_c L_i}{Z_{0L}}\right); l_{C_i} = \frac{\lambda_{gCi}}{2\pi} sin^{-1}\left(\omega_c C_i Z_{0C}\right) \tag{5}$$

The parameters of the transmission line as well as the physical lengths of the low and high impedance lines, which are shown in Fig. 1 (b), are obtained as follows: L1 = 1.26 nH, L2 = 1.8 nH, C1 = 0.17 pF and C2 = 0.55 pF, lL1 = 1.92 mm, lL2 = 2.8 mm and lC1 = 1.04 mm, lC2 = 1.15 mm. To achieve a good response for the proposed filter, the final results are optimized by an electromagnetic (EM) simulator of ADS as follows: lL1 = 2 mm, lL2 = 4.9 mm, lC1 = 1.1 mm and lC2 = 1 mm. The proposed prototype filter with its dimensions and the scattering parameter S21 is demonstrated in Fig. 1 (c) and 1(e) respectively. It can be seen clearly that the cut-off frequency of the prototype filter is adjusted to 5.8 GHz with Chebyshev response. To extend the stopband, we have proposed DASMC, where its structure and simulated S21 are demonstrated in Fig. 1 (d) and 1(e) respectively. As shown in Fig. 1 (d), by bending the open stubs the capacitances that appear between the open stubs and transmission line, increases the attenuation level above −20 dB over a wide frequency range in the proposed DASMC, which is illustrated in Fig. 1 (e). Consequently, wide and high rejection can be achieved without any variation of size by bending the open stubs that are placed at the both sides of the prototype filter. The angle between the crumpled arms and the transmission line of the DASMC is 55 deg. Fig. 1 (e) shows that the response has gradual roll-off. To obtain a sharper rate of cut-off and achieve elliptic function response, SICMRC is embedded in the structure of the DASMC.

To design SICMRC with cut-off frequency of 5.8 GHz, the structure of the elliptic function prototype lowpass filter is proposed and illustrated in Fig. 2 (a). The characteristic impedances for microstrip lines with the width 0.1 and 4.5 mm are 154 and 27 Ω, respectively. An elliptic function, lumped model for the lowpass filter is illustrated in Fig. 2 (b).

The element values for the prototype filter are obtained from [1] in which, passband ripple of 0.1 dB and minimum stopband attenuation of 24 dB are

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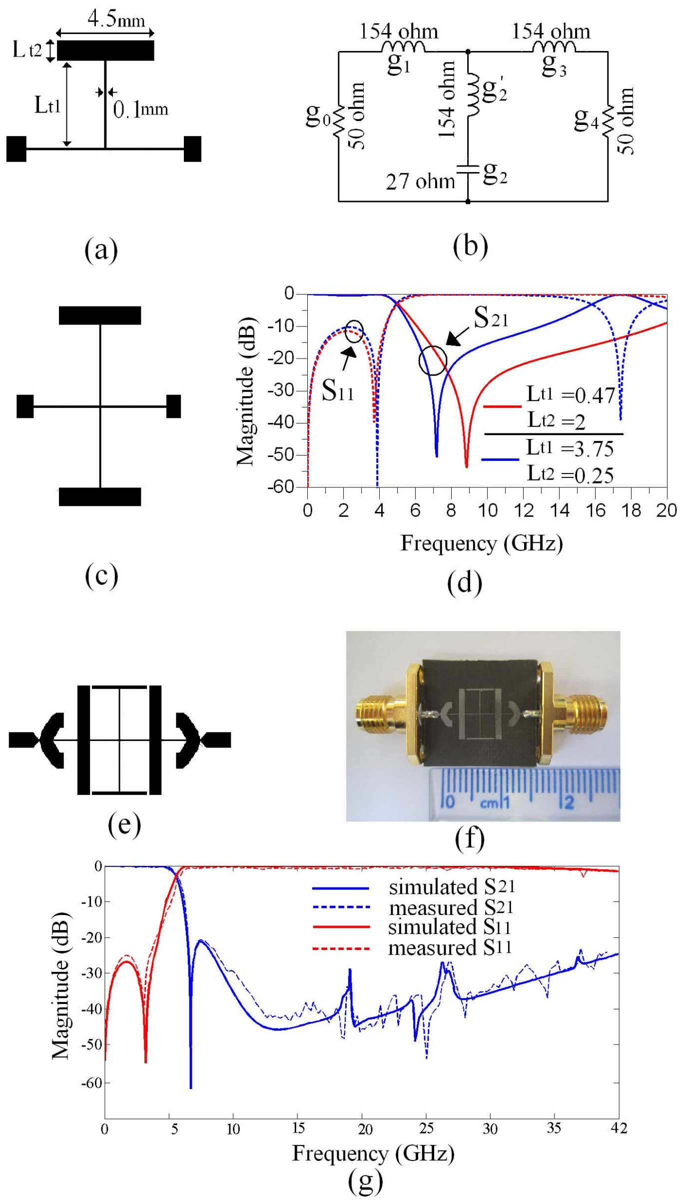

Fig. 2. (a) layout, (b) Equivalent lumped Model and (c) symmetrical structure of the Elliptic function prototype filter. (d) The comparison of simulated S21 of the elliptic function prototype filter for different values of Lt1 and Lt2. (e) The final layout and (f) Photo of realization of the proposed filter. (g) measurement and simulated of the proposed LPF.

considered in the design so that: $g_0 = g_4 = 1$, $g_1 = g_3 = 0.8949$, $g_2 = 0.9375$, $g_2' = 0.2070$. In a similar way, using equations (5) and (6), the actual dimensions of the lines are determined as follows: Lt1 = 0.47 mm and Lt2 = 2 mm. By adjusting Lt2 and Lt1 i.e., dividing Lt2 to 8 and multiplying Lt1 by 8, the finite attenuation pole has got closer to the passband without causing a considerable change to the cutoff frequency. Consequently, frequency response of the prototype filter has become sharper. The problem of the declined pass-

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band performance that is caused by this adjustment can be solved by using the prototype filter in a symmetrical form that is illustrated in Fig. 2 (c). The comparison of the simulated S21 of the elliptic function prototype filter for the different values of Lt1 and Lt2 is demonstrated in Fig. 2 (d).

The final layout and photograph of the fabricated filter are shown in Fig. 2 (e) and (f) respectively. As seen, this structure consists of the elliptic and Chebyshev function prototype LPFs that are embedded in one structure. The simulated and measured results of the proposed filter are illustrated in Fig. 2 (g). It is seen that the reduction level in the stopband is better than −20 dB, which is achieved from 6.6 to 41.7 GHz. The proposed filter has low insertion loss less than 0.1 dB and high return loss more than 26 dB in the passband. The transmission band is approximately 0.74 GHZ from 5.86 to 6.6 GHz with corresponding attenuation levels of −3 and −20 dB. The proposed filter's advantages are better return loss and insertion loss, wider stopband and simple fabrication, in comparison to the reference [6], better return loss, sharper roll-off and larger stopband up to cut-off frequency, in comparison to the reference [7] and wider stopband, highest suppression level in the stopband, smaller size, as well as better the return loss and insertion loss, in comparison to the reference [8].

Table I. performance comparisons of this work with other filters.

Ref.	stopband up to f_c	$RL(dB)$	$IL(dB)$	$size(\lambda_g^2)$	$size(mm^2)$
[2]	4.8	15	1	0.14	180
[3]	7	38	0.1	0.08	209
[4]	2.7	10.5	0.5	0.02	237
[5]	5	16.3	0.5	0.02	2456
This Work	7.1	26	less than 0.1	0.07	116

The comparison between the proposed filter with the other filters is shown in Table I. The comparison shows that the proposed filter has a good performance.

3 Conclusion

A compact microstrip lowpass filter with a high and ultra wide rejection-band using stepped impedance CMRC is presented. The DASMC and T-shaped microstrip cell resonators are embedded in one layout to present a wide and a sharp rejection. The results show that the stopband with −20 dB has become very wide from 6.6 up to 41.7 GHz. Furthermore, the Proposed filter has low insertion loss in the passband, sharp response, simple shape and compact size of only 14.2 mm × 8.2 mm. A good agreement between the simulated and experimental results has been achieved.

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