Research Article



Compact Microstrip Lowpass Filter with Ultra-wide Stopband and Sharp Rolloff based on Modified Hairpin Resonator

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Abstract

Keywords:

lowpass filter(LPF) ultra-wide stopband sharp roll-off modified hairpinresonator In this paper, a new microstrip lowpass filter featuring ultra-wide stopband, compact size and sharp roll-off is reported. This lowpass filter is composed of modified hairpin structures. To have an ultra-wide stopband two pairs of semicircular patch resonators are loaded. Accordingly, the proposed filter with 3 dB Cut-off frequency at 1.77 GHz has been designed, fabricated and measured. Results indicate that the designed LPF achieves an ultra-wide stopband of 14.28 times the Cut-off frequency with overall better than 20 dB attenuation level and a sharp roll-off of 185 dB/GHz. The dimension of this filter is 0.094 $\lambda g \times 0.228 \lambda g$, which was: λg is the guide wavelength at the Cut-off frequency. It was concluded that the measurment results are in good agreement with simulations.

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1. Introduction

Microwave filters have an important role in communication systems [1-2]. Lowpass filters (LPFs), with high performance such as ultra-wide stopband rejection and sharp roll-off, are a branch of these studies. LPFs are very desirable in numerous wireless communication systems to decrease spurious signals. It is the motivation for researchers to put the stress in this domain. Recently, comprehensive studies on sharp roll-off and ultra-wide band filters have been done and several LPFs have been suggested to achieve this performance. One of the common methods to implement LPFs is using hairpin shape resonators. A wide stopband LPF using stub-loaded coupled-line hairpin unit is proposed in [3], but its return loss in stopband region has some ripple. A microstrip LPF with ultra-wide stopband and sharp rejection is presented in [4], which is used both closed loop stepped impedance (CLSI) and U-shape resonators to achieve sharp frequency response and ultra-wide

stopband. In [5], a sharp response microstrip LPF with high selectivity and wide stopband using folded stepped impedance open stubs is proposed that comprises two lateral folded open stubs and a central mirrored semicircle ended suppressing cell. A compact LPF using T-shaped resonator with a wide stopband is presented in [6]. In this paper, a new microstrip LPF with compact size, sharp roll-off and ultra-wide stopband based on modified hairpin resonator is presented and implemented. The proposed filter with 3 dB Cut-off frequency at 1.77 GHz has been designed, fabricated and measured. Results indicate that the designed LPF achieves an ultra-wide stopband with overall better than 20 dB attenuation level and a sharp roll-off of 185 dB/GHz.

2. Filter Design

2.1. Main resonator and its characteristics

The layout of the proposed main resonator is demonstrated in Figure 1, which is composed of three types of resonators, i.e. resonators 1, 2 and 3. To describe the design theory of the proposed main resonator, the frequency response and proposed LC model of each part has been studied one by one.



Fig. 1: Schematic diagram of the proposed main resonator.

Figure 2(a) depicts the layout of the resonator 1. As seen; this resonator has a hairpin shape structure and is composed of two main parts: low and high impedance. Parameters of the resonator 1 are as follows: d1 = 6.29 mm, d2 = 7.64 mm, d3 = 8.14 mm, d4 = 4.86 mm, d5 = 4.80 mm, d6 = 4.41 mm, d7 = 1.05 mm, d8 = 2.20 mm, d9 = 0.22 mm, d10 = 0.15 mm, d11 = 0.10 mm. This resonator can create one deep transmission zero at 4.22 GHz with 73.85 dB attenuation which is the first transmission zero as seen in Figure 2(b).

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Fig. 2: The resonator 1, (a) Schematic diagram. (b) Simulated S-parameters.

The proposed LC model of the resonator 1 is depicted in Figure 3(a), [4]. Due to symmetry of the resonator's structure, the half circuit LC analysis is used. In this model the parameters: (L4, L5 and C5), (L2, L3 and C3) and (L1 and C1) are the central transmission lines LC model, C2 and C4 are the capacitance effects of the bends. Moreover, C6 is the capacitance effect of the open subs with the width of d8. L6, also denotes inductance of the stubs with the width of d7 and C7 is the gap's capacitance effect which is shown by d9.



Fig. 3: The resonator 1, (a) Proposed LC model (b) EM and circuit simulation results.

Figure 3(b) demonstrates the EM and circuit simulation results of the resonator 1. As seen these results are in good agreement. The values of the circuit elements that are used in the circuit simulation are as follows: L1 = 2.7 nH, L2 = 1.5 nH L3 = 1.83 nH, L4 = 2.56 nH, L5 = 2.89 nH, L6 = 0.73 nH, C1 = C2 = 0.13 pF, C3 = 0.07 pF, C4 = 0.13 pF, C5 = 0.11 pF, C6 = 1.25 pF, C7 = 0.03 pF.

In this research, the circuit elements values are calculated and then in order to better matching the circuit and EM simulated results, tuning techniques are used with 5% tolerance.

The structure using just one microstrip hairpin resonator has not a suitable frequency response so the designer has a few options to design. To have a sharper frequency response and better using of the circuit's space and reducing the circuit size, the secondary resonator is added. Figure 4(a) depicts the layout of the resonator 2 in combination with resonator 1.

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Fig. 4: The resonator 2 in combination with resonator 1, (a) Schematic diagram. (b) Simulated S-parameters.

As seen in Figure 4(b), this structure can create one deep transmission zero at 2.13 GHz and the transition band characteristics improved.

The proposed LC model of this structure is demonstrated in Figure 5(a). As seen, L7 and L8 are inductances of the stubs with the length of *n* and *p*. L9 is presents inductance of the stubs with the length of *a1*, C8 and C9 are capacitance effects of the open subs with the length of *a4* and *z*. The values of the circuit elements are as follows: C8 = 0.28 pF, C9 = 0.21 pF, L7 = 0.54 nH, L8 = 3.08 nH, L9 = 0.11 nH. Figure 5(b) depicts the circuit and EM simulation results of this structure; these results are in good agreement too.



Fig. 5: The resonator 2 in combination with resonator 1, (a) Proposed LC model. (b) EM and circuit simulation results.

As seen in Figure 6(a), the main resonator design is completed by adding resonator 3 which is composed of some open stubs. This structure can enhance the stopband band width (SBW) of the main resonator which is demonstrated in Figure 6(b).

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Fig. 6: The main resonator, (a) Schematic diagram. (b) Simulated S-parameters.

The proposed LC model of this structure is illustrated in Figure 7(a). In this model L10 and L11 are inductances of the stubs with the length of *u* and *w10*. C10 and C11 are capacitance effects of the open subs with the length of *a12* and *q*. Moreover, L3 is divided to L3' and L3". The values of the circuit elements are as follows: C10 = 0.71 pF, C11 = 1.01 pF, L3' = 1.69 nH, L3" = 0.14 nH, L10 = 1.33 nH, L11 = 0.91 nH.



Fig. 7: The main resonator, (a) Proposed LC model. (b) EM and circuit simulation results.

Figure 7(b) demonstrates the circuit and EM simulation results of the main resonator. As simulations are shown in Figures 3(b), 5(b) and 7(b), the differences between the circuit and EM responses in each plot are most obvious in higher frequency because of modeling the transmission lines by LC elements approximately and assuming them lossless.

After describing the behavior of the main resonator, due to the high dimensions variability of it, we are going to study the effects of general scaling on the frequency response of the main resonator. In this method all of the main resonator's dimensions are simultaneously scaled with a certain scaling factor to achieve a similar structure with different sizes and frequency response characteristics. By this

method changing the Cut-off frequency and transition band in order to reach a desirable frequency response will be possible. Table 1 shows the results of the main resonator's Cut-off frequency and transition band as a function of several scaling factors.

Scale Factor	0.25	0.5	0.75	1	1.25	1.5	1.75	2
fc	6.95	3.33	2.25	1.70	1.36	1.12	0.09	0.08
Transition Band 3dB to 20 dB	0.51	0.35	0.20	0.13	0.10	0.09	0.08	0.07

Table1: Main resonator's Cut-off frequency and Transition band results as a function of scale factor.

2.2. High Frequency Attenuator Units

Although the main resonator has created an acceptable sharp roll-off frequency response, it has not a wide stopband. In order to extend the SBW, undesirable harmonics should be suppressed by adapting some suitable suppressing cells. Thus the semi-circular patch resonator is used to increase the SBW. The LPF prototype has a semi-circular patch resonator in one side, which provide good SBW, but it founded that the return loss and insertion loss in stopband region have undesirable high ripples. In order to have a symmetrical design and also to have an ultra-wide stopband and more decrease in undesirable ripples, another semi-circular patch resonator is adopted to the other side of the main resonator. Figure 8, presents the layout of the proposed LPF. To have a more decrease in undesirable high frequency harmonics, instead of using right angeles, curved angeles are used in a corner of the low impedance parts. Parameters of the filter are as follows: a1 = 0.45 mm, a3 = 0.21 mm, a4 = 4.07, a5 = 0.35 mm, a6 = 7.20 mm, a2 = a7 = a8 = t = 0.15 mm, a9 = 0.29 mm, a10 = 0.15 mm, a11 = 0.90 mm, a12 = 3.77 mm, a13 = 8.44 mm, w1 = 0.96 mm, w2 = 1.02 mm, w3 = w5 = 0.10 mm, x = w4 = w7 = 0.30 mm, w8 = 0.60 mm, w9 = d7 = 1.05 mm, w10 = 0.77 mm, w11 = 0.29 mm, w12 = 0.30, q = 4.85 mm, y = 0.70 mm, z = 5.56 mm, u = n = 1 mm, m = 0.30 mm, R = 2.15 mm, r1 = r2 = 1 mm, r3 = 0.50 mm, p = 5.85 mm.

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Fig. 8: Schematic diagram of the proposed LPF.

3. Simulation and measurement Results

The proposed LPF has been fabricated on a substrate with a relative dielectric constant of 3.38, thickness of 20 mil, and loss tangent of 0.0021. The photograph and S-parameters of the fabricated LPF are depicted in Figures 9(a) and (b), respectively.



Fig. 9: The fabricated LPF, (a) Photograph. (b) S-parameters.

This LPF has 3 dB Cut-off frequency around 1.77 GHz. The return loss is better than -10 dB. The SBW is achieved from 1.91 to 27.19 GHz which shows an ultra-wide stopband with the suppression **118** | P a g e

level better than 20 dB. The transition band is 0.14 GHz from -3 dB to -20 dB. The size of the LPF is $9.76 \times 23.71 \text{ mm}^2$. Table 2 exhibits the comparison between the performances of the proposed filter with some other LPFs.

In this Table, the roll-off rate ξ is defined as:

$$\xi = \frac{\alpha_{max} - \alpha_{min}}{fs - fc} \frac{dB}{GHz}$$
(1)

Where α_{max} is the 40 dB attenuation point, α_{min} is the 3 dB attenuation point, f_s is the 40 dB stopband frequency, and f_c represents the 3 dB Cut-off frequency. The relative stopband bandwidth (RSB) is given by:

$$RSB = \frac{stopband \ bandwidth}{stopband \ center \ frequency}$$
(2)

The suppression factor (SF) is based on the SBW; for example, when the SBW is referred to 20 dB suppression, the corresponding SF is defined as 2. The normalized circuit size (NCS) can be derived as below:

$$NCS = \frac{physical size (length \times width)}{\lambda_g^2}$$
(3)

Finally, the Figure of merit (FOM), the overall index of a proposed filter, is given by:

$$FOM = \frac{\xi \times RSB \times SF}{NCS \times AF}$$
(4)

Ref.	Roll-off rate ξ	Relative stopband bandwidth (RSB)	SF	NCS	FOM
[3]	95	1.40	2	0.104 × 0.214	11952
[4]	80.43	1.64	2.3	0.330 × 0.180	5108
[5]	121.42	1.44	2	0.136 × 0.245	10495
[6]	46	1.37	2	0.220 × 0.137	4182
This work	185	1.73	2	0.094 × 0.228	29800

Table 2: Comparison of LPFs performance.

4. Conclusions

A lowpass filter with 1.77 GHz Cut-off frequency using modified hairpin resonator has been designed, fabricated and measured. Results indicate that the designed LPF achieves an ultrawide stopband of 14.28 times the Cut-off frequency with overall better than 20 dB attenuation level. Considering all these good features, the proposed filter is applicable for modern communication systems.

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