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A NOVEL MINIATURIZED WIDE-BAND ELLIPTIC-FUNCTION LOW-PASS FILTER USING MICROSTRIP OPEN-LOOP AND SEMI-HAIRPIN RESONATORS

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Abstract—A highly miniaturized low-pass filter using microstrip open-loop and semi-hairpin resonators is designed and analyzed to enhance the bandwidth and further size reduction of this kind of elements. Initially, two microstrip open ring resonators and separately, two semi-hairpin resonators are arranged and attached back-to-back to each other respectively. A compact LPF is designed and simulated using these modified resonators. The size reduction of this proposed filter is reported about 65% with 190% enhancement of bandwidth in analogy with the conventional low-pass filters.

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1. INTRODUCTION

Microwave elliptic-function low-pass filters using microstrip stepped-impedance are highly demanded due to their compact size, low fabricated cost, high performance and easy fabrication.

Wide rejection bandwidth, sharp cut-off frequency and wide-band band-pass are the most important features of a desirable low-pass filter which is recently a subject of interest in new communication systems. To realize this kind of LPF, several types of small size low-pass filters have been widely reported in several recent researches.

In [1], a wide band elliptic-function low-pass filter using elementary structure has been proposed. This filter provides a wide-band pass-band with a sharp cut-off frequency response, but a narrow stop-band. In other studies, several small-size filters have been introduced using microstrip stepped-impedance hairpin resonators [2, 3]. These have been realized in miniature accompanied by wide width stop-band, but not wide-band pass-band.

Moreover, a low pass filter with wide rejection band has been proposed using microstrip transmission lines [4]. To increase the width of pass-band, improve the performance and reduce the size, several types of elliptic-function low pass filters have been designed and proposed using modified hairpin resonators in recent years [5, 6]. In some of these papers, the pass-band has been increased and in other ones, the authors have mainly focused on the size reduction.

Furthermore, a compact composite ultra wide-band elliptic-function low-pass filter has been recently proposed in [7]. This LPF provides a wide rejection band and wide pass-band with a compact size.

In this paper, a wide band pass-band low-pass filter is demonstrated by combining in cascade microstrip open-loop and semi-hairpin resonators with a wide rejection band, compact size and excellent sharpness of cut-off frequency.

Due to the fact that the mentioned favorable features are not easily achieved with conventional models, the method used in this LPF can be a promising technique to enhance the bandwidth and reduce the size.

Initially, the equivalent circuit model of the proposed layout is analyzed and presented, and at the next stage, a wide-band low-pass filter is designed for a 3-dB cutoff frequency of 5.9 GHz and simulated on a 25-mill-thick substrate with a relative dielectric constant $\varepsilon_r = 10.2$. The exact dimensions of the filter are optimized by electromagnetic (EM) simulation (ADS).

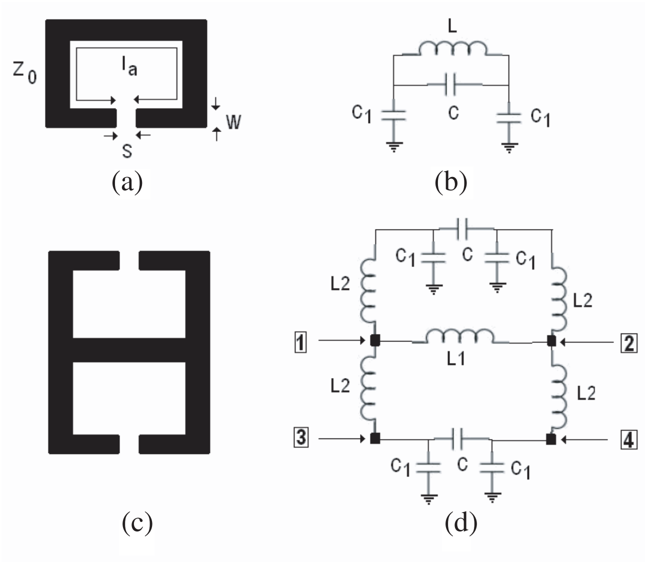


Figure 1. (a) and (b) the conventional microstrip open-loop resonator and its equivalent circuit model, (c) and (d) the proposed resonator and its equivalent circuit model.

2. DESIGN PROCEDURE

2.1. The Modified Microstrip Open-loop Resonator

Figure 1(a) shows the layout of the conventional microstrip open-loop resonator [8]. As discussed in this study, for the frequencies near its resonant frequency, its equivalent lumped-element circuit model can be derived as shown in Fig. 1(b).

This structure consists of a simple transmission line and a gap which can be approximated as a series and two shunt capacitors shown in Fig. 1(b). To increase the band-width and reduce the size, this layout can be modified, and the structure shown in Fig. 1(c) can be realized as discussed in [6].

To follow the procedure, the conventional microstrip open-loop resonator is mirrored to have a modified resonator shown in Fig. 1(c). Referring to this structure, if the points 1 and 2, as shown in Fig. 1(d), are selected for the input/output ports, it is observed that two inductors are parallel to each other and all of the capacitances also are parallel together. Considering the simple primary impedance equations for an inductor and a capacitor it is obvious that the more inductance reduces, thereby its band-width increases and, the more capacitor increases, thereby the harmonics suppression improves.

In another way, if the input/output ports are changed to the pair of points 3 and 4, the structure will have a asymmetrical structure, and it can be shown by EM simulation tools that in the new case, the filter has a much wider pass-band and reject band than those of the first symmetrical structure with the same parameters.

By taking this fact into consideration, a wide bandwidth can be realized by combining in cascade this model with another resonators.

The relationships between lumped and distributed elements can be obtained using derived equations in [9] as follows:

$$C_1 = \frac{2\varepsilon_r\varepsilon_0 W}{b-s} \ \text{Fd/m} \tag{1}$$

$$C = \frac{\varepsilon_r\varepsilon_0 W}{S} \ \text{Fd/m} \tag{2}$$

$$L = \frac{Z_0 \sin(\beta_a l_a)}{\omega} \tag{3}$$

where ε_r and b are the relative dielectric constant and thickness of the substrate; β_a and ω are the phase constant and angular frequency, respectively; other parameters have been shown in Fig. 1(a).

To have a simple design and reduce the number of unknown

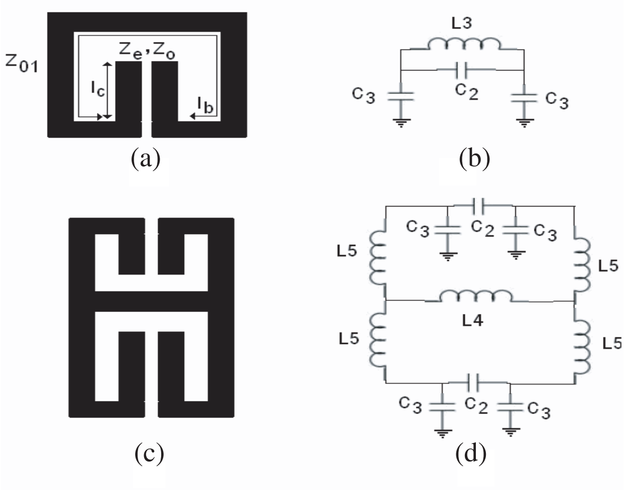


Figure 2. (a) and (b) the conventional microstrip semi-hairpin resonator and its equivalent circuit model, (c) and (d) the proposed resonator and its equivalent circuit model.

variables, another equation can be added to these as follows:

$$L = L_1 + 2L_2 \tag{4}$$

where L, L_1 and L_2 are the inductors shown in Fig. 1.

2.2. The Proposed Semi-hairpin Resonator

To introduce the other resonator, initially, the structure of the conventional microstrip stepped-impedance semi-hairpin resonator in [6] is followed. This structure, as shown in Fig. 2(a), consists of two parallel simple transmission lines and a symmetric capacitance-load parallel coupled lines. To increase the band-width and reduce the size, this layout can be modified, and the structure shown in Fig. 2(c) can be realized.

Similarly, the relationships between lumped and distributed elements can be obtained using derived equations in [6] as follows:

$$L_3 = \frac{Z_{01}\sin(\beta_b l_b)}{\omega} \tag{5}$$

$$C_2 = \frac{Z_e - Z_o}{2\omega Z_e Z_o \cot(\beta_c l_c)} \tag{6}$$

$$C_3 = \frac{1}{\omega Z_e \cot(\beta_c l_c)} + \frac{1-\cos(\beta_b l_b)}{\omega Z_0 \sin(\beta_b l_b)} \tag{7}$$

where β_b, β_c and ω are the phase constant and the angular frequency of the given transmission lines, respectively, and other parameters are given in Fig. 2(a).

Similarly, to reduce the number of unknown variables, another equation can be added as follows:

$$L_3 = L_4 + 2L_5 \tag{8}$$

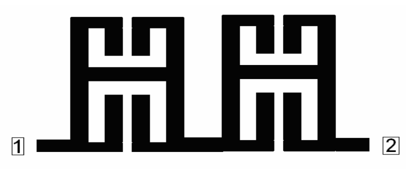
where L_3, L_4 and L_5 are the inductors indicated in Fig. 2.

2.3. Compact Elliptic-function Low-pass Filter

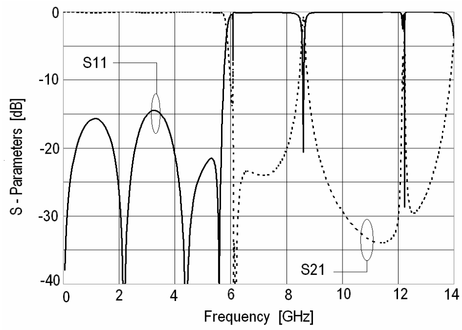
From (1)–(8), it is observed that both kinds of resonators in terms of lumped elements depend on l_a, l_b, l_c, Z_0, Z_{01} and other parameters, and their resonance frequencies are a function of them. These parameters can therefore be tuned for a special resonance frequencies.

Initially, a low-pass filter is realized using two proposed semi-hairpin resonators in cascade. Fig. 3 shows the geometry of this LPF and its frequency response.

Observing the frequency response of the low-pass filter in Fig. 3, the stop-band bandwidth is limited by harmonics, especially for the

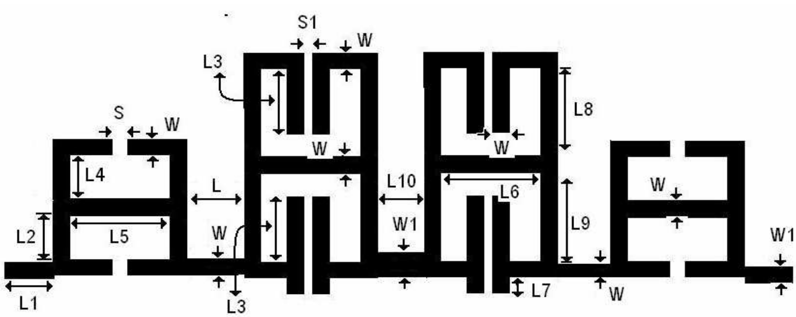


(a)

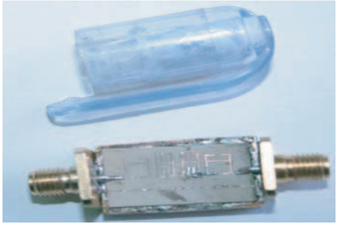


(b)

Figure 3. (a) the proposed LPF (b) its frequency response.



(a)



(b)

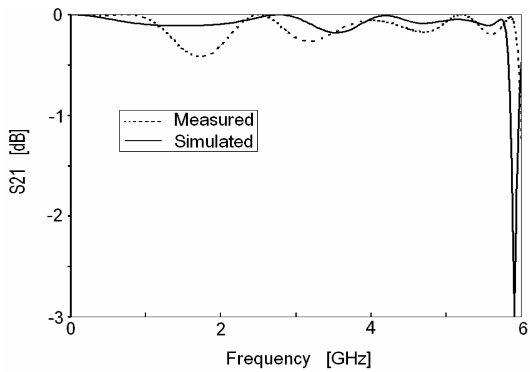
Figure 4. The layout of the proposed cascaded LPF with $L = 0.88\,\text{mm}$, $L_1 = 2.2\,\text{mm}$, $L_2 = 2.5\,\text{mm}$, $L_3 = 1.5\,\text{mm}$, $L_4 = 1\,\text{mm}$, $L_5 = 3.2\,\text{mm}$, $L_6 = 1.98\,\text{mm}$, $L_7 = 0.5\,\text{mm}$, $L_8 = 1.8\,\text{mm}$, $L_9 = 2.5\,\text{mm}$, $L_10 = 1.1\,\text{mm}$, $W = 0.3\,\text{mm}$, $W_1 = 0.69\,\text{mm}$, $S = 0.7\,\text{mm}$, and $S_1 = 0.38\,\text{mm}$, (b) the fabricated of the proposed LPF.

second and third harmonics. In order to extend the stop-band bandwidth, additional attenuation poles, similar to [2], at the second and third harmonics can be added. The attenuation poles are implemented by using the other proposed open-loop resonator with a higher 3-dB cut-off frequency and attenuation at the second and third harmonics.

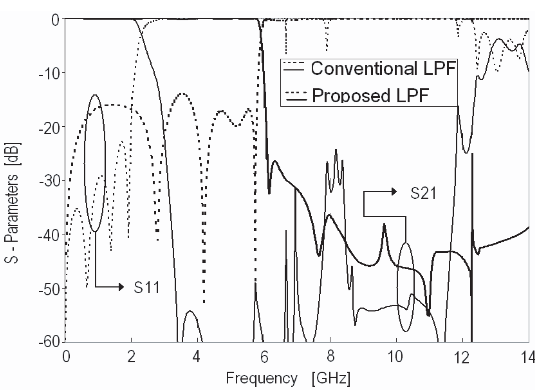
To have a desirable performance and attenuate the two harmonics, at the next stage, the proposed low-pass filter in Fig. 3(a) is sandwiched between two poles designed by open-loop resonator as shown in Fig. 4.

The performance of the cascaded low-pass filter is optimized by an electromagnetic simulation tool (ADS) to tune its dimensions. It is simulated on a 25-mil-thick substrate with a relative dielectric constant $\varepsilon_r = 10.2$ for a cut-off frequency of 5.9 GHz.

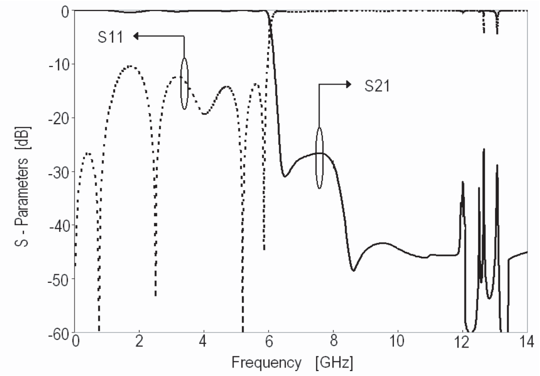
Figure 5 shows the frequency response of the introduced low-pass filter in comparison with the one proposed in [6]. As observed, in the new one, the pass-band and stop-band bandwidth both have been



(a)



(b)



(c)

Figure 5. a) S_{21} within the 3-dB bandwidth for the proposed LPF (b) its simulated frequency response (c) measured results.

dramatically increased. However, the main drawback of the new design is its relatively high return loss as compared with the conventional one.

As observed from Fig. 5, the proposed elliptic-function low-pass filter has a 3-dB pass band from dc to 5.9 GHz. The insertion loss is better than 0.5 dB; the return loss is better than −11 dB; the rejection loss is greater than −25 dB within stop-band. There is a discrepancy between simulated and measured results, especially in return loss and rejection loss around 12 GHz and frequencies higher than it which can be mainly attributed to the junction discontinuities and tolerance in fabrication.

3. CONCLUSION

To enhance the bandwidth and further size reduction of the conventional microstrip stepped-impedance hairpin elliptic-function low-pass filter, two models of compact microstrip open-loop and semi-hairpin resonators have been introduced and analyzed. A compact elliptic-function low-pass filter is designed and simulated using these proposed resonators. The size reduction of this proposed filter is reported about 65% with 190% enhancement of bandwidth in analogy with the conventional low-pass filter in [2].

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