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BANDWIDTH ENHANCEMENT AND FURTHER SIZE REDUCTION OF A CLASS OF ELLIPTIC-FUNCTION LOW-PASS FILTER USING MODIFIED HAIRPIN RESONATORS

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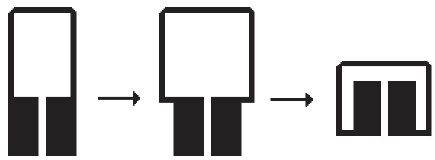
Abstract—A compact elliptic-function low pass filter using microstrip stepped-impedance modified-hairpin resonators is developed and a multiple cascaded filter using semi-hairpin resonators is designed, analyzed and tested. Sharpness of cut off frequency, low insertion-loss, enhancement of bandwidth and very compact size are the features of the proposed low-pass filter. Size reduction of this filter is reported about 62% with 13% enhancement of bandwidth respects to the conventional filter with comparable performance. The measurement results are in good agreement with the theoretical ones.

1. INTRODUCTION

The design of microwave filters with compact size and high-performance is a subject of interest in communication systems. Three of the most important features of a desirable low-pass filter, which are highly demanded in these systems are wide rejection bandwidth, sharp cut-off frequency response and wide-band band-pass. Low-pass filters with these features are strongly required in communication systems to suppress harmonics and unwanted frequencies. Formerly different classes of the low-pass filters using microstrip transmission-lines were devised [1–4]. There are different methods for size reduction of low-pass filters in these studies, but the return-loss is not good in some of them and the harmonics suppression has been badly achieved in the other studies. A wide-band elliptic-function low-pass filter has been already designed and introduced in [5]. It provides a wide-band pass-band, but a narrow stop-band. Moreover, several studies have tried to achieve the feature of the wide rejection bandwidth of low-pass filters [6, 7].

Recently in [8] a low-pass filter has been developed using stepped-impedance hairpin resonators. This filter provides a wide stop band with a sharp cut-off frequency. The configuration of a conventional stepped-impedance hairpin resonator is shown in Figure 1(a), this structure consists of a single transmission line and a symmetric capacitance-load parallel coupled lines.



(a) (b) (c)

Figure 1. The derivation method of the proposed model from its conventional model.

In [8], the prototype filters have been synthesized from the equivalent-circuit model and to optimize the performance of this filter; an electromagnetic simulator (Advanced Design System software) has been used. In this paper a simple model of stepped-impedance modified-hairpin resonator is presented to lead considerable size reduction more than the conventional ones. In order to reduce the size of this layout and have a very compact size, the unused space in the structure of the usual stepped-impedance hairpin resonator in Figure 1(a) is used so that a highly miniaturized low-pass filter can be designed with mentioned desirable features. A miniaturized elliptic-function low-pass filter is designed at 2.25 GHz and fabricated on a 25-mil-thick RF-35 PTEE/Woven substrate with a relative dielectric constant $\varepsilon_r = 10.2$. In this LPF, not only the overall size is dramatically reduced, but also its band-pass width is increased in analogy with the other conventional ones which have been classified in this class. Furthermore, the simulated and measurement results of the proposed multiple cascaded low-pass filter are presented.

2. THE STEPPED-IMPEDANCE MODIFIED-HAIRPIN RESONATOR

To make use of vacant space in the conventional model, the two capacitance-load parallel coupled lines of the conventional stepped-impedance hairpin resonator in Figure 1(a) can be easily mirrored into its unused space. The derivation method of the proposed model from its conventional model is shown stage by stage in Figure 1.

In new state, the obtained structure consists of a single transmission line and a symmetric capacitance-load parallel coupled lines similar to previous ones whereas miniature. Similar to [8], the equivalent π-network circuit of the two parts of the proposed model can be obtained, which are shown in Figures 1(a) and (b) and the equivalent-circuit of the stepped-impedance modified-hairpin in terms of lumped element is shown in Figure 2(c).

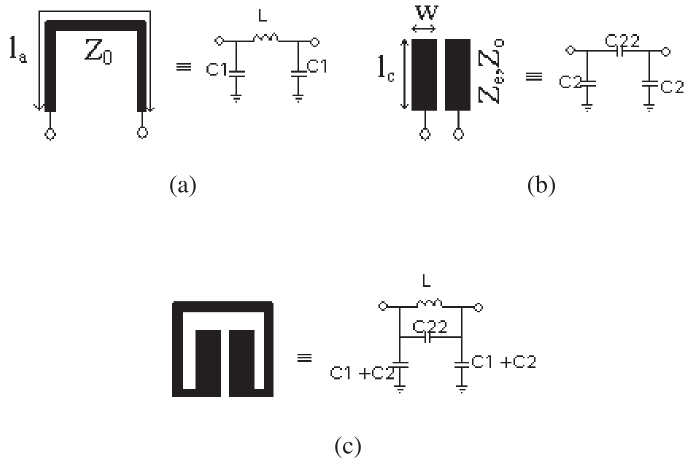


Figure 2. The equivalent-circuit of (a) a single, (b) a coupled, (c) the proposed model transmission-line.

The relationships between lumped and distributed elements can be derived using $ABCD$ matrix and their equivalent-circuit models. Equations (1)–(4) show these relationships.

$$C_{22} = \frac{Z_e - Z_o}{2\omega Z_e Z_o \cot(\beta_c l_c)} \tag{1}$$

$$C_2 = \frac{1}{\omega Z_e \cot(\beta_c l_c)} \tag{2}$$

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

$$C_1 = \frac{1 - \cos(\beta_a l_a)}{\omega Z_0 \sin(\beta_a l_a)} \tag{4}$$

From (1)–(4), it is observed that C_{22}, C_2, L and C_1 are depended on l_a, Z_0, W and l_c and the resonance frequency of stepped-impedance semi-hairpin is a function of them, so it can tune these parameters for a special resonance frequency. Figure 3 shows the different microstrip low-pass filters using different stepped-impedance semi-hairpin resonators which are designed at 3-dB cut-off frequencies f_1, f_2 and f_3 GHz, respectively.

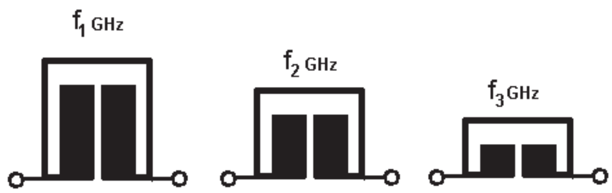


Figure 3. The different low-pass filter designed for different resonance frequency.

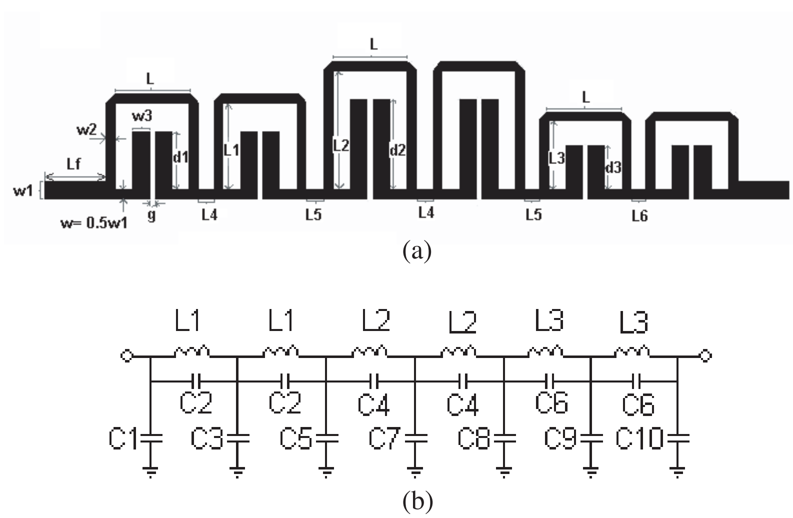
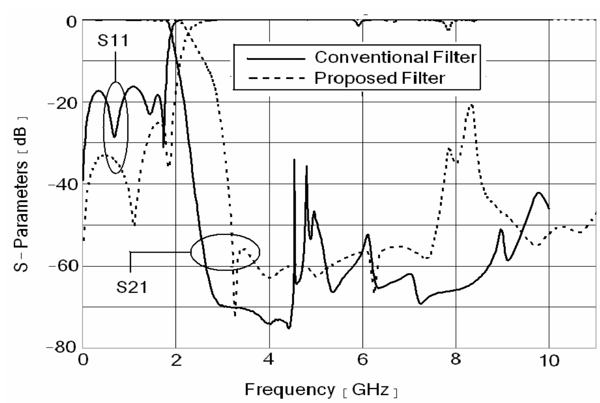


Figure 4. (a) The proposed compact multiple cascaded low-pass filter with Lf = 2 mm, L = 2.5 mm, L1 = 2.97 mm, L2 = 4.42 mm, L3 = 2.72 mm, L4 = 0.5 mm, L5 = 0.6 mm, L6 = 0.43 mm, d1 = 1.97 mm, d2 = 3.47 mm, d3 = 1.87 mm, w1 = 0.54 mm, w2 = 0.3 mm, w3 = 0.55 mm, g = 0.2 mm, (b) its equivalent-circuit model.

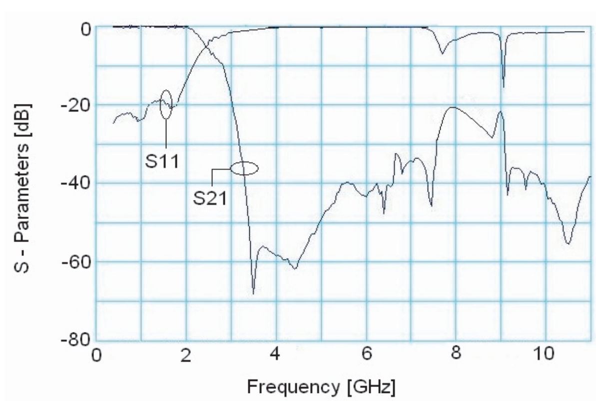
3. MULTIPLE CASCADED LOW-PASS FILTER

Initially, the conventional LPF in [8] is followed. It has been designed for a 1.94 GHz cut-off frequency using 6 cascaded hairpin resonators. This one has a high performance; however, its boarding size is still rather large. In this article, by following this LPF, a novel compact low-pass filter with high size reduction is designed and introduced. As the equality of the proposed and conventional stepped-impedance hairpin resonators using their equivalent-circuits was shown in previous section, a very compact low-pass filter using multiple cascaded stepped-impedance modified-hairpin resonators can be designed. Figure 4 shows its layout and equivalent-circuit model of this low pass filter.

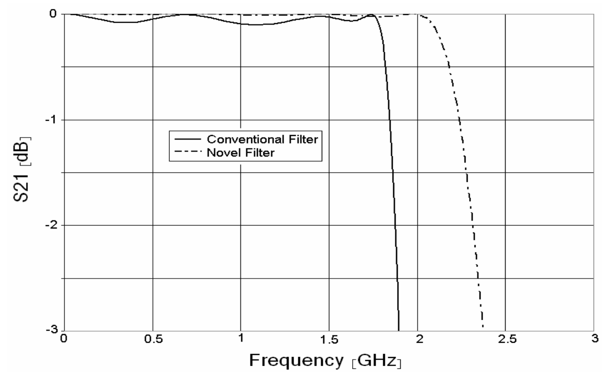
To optimize the performance of the prototype filter, an electromagnetic simulation (ADS) is used to tune its dimensions and afterward, a miniaturized multiple cascaded low-pass filter is designed for a 3-dB cut-off frequency of 2.25 GHz on a 25-mil-thick substrate with relative dielectric constant $\varepsilon_r = 10.2$. To optimize the dimensions of the filter, electromagnetic (EM) simulator tool (ADS) has been used. To compare the performance of the proposed filter with the



(a)



(b)



(c)

Figure 5. (a) The simulated frequency of the conventional and the proposed low-pass filters; (b) Measured; and (c) S_{21} within 3-dB bandwidth.

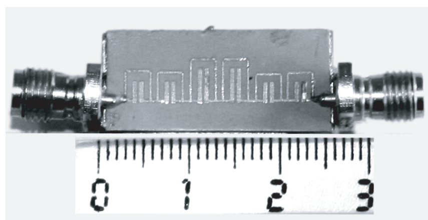


Figure 6. The fabricated of the proposed compact multiple cascaded low-pass filter.

conventional one, their simulated frequency responses are shown in Figure 5. The proposed elliptic low-pass filter has a 3-dB pass band from dc to 2.25 GHz. The insertion-loss is less than 0.1 dB and the return-loss is better than 19 dB and the rejection greater than 40 dB from 3.2 to 6.7 GHz and 20 dB to 10 GHz within stop band. In comparison with the conventional one, as it is observed in Figure 5, the proposed one has a frequency performance better than the performance of the conventional one. The scattering parameter measurement is performed using an Agilent 8722ES network analyzer over the frequency range from 0.5 to 11 GHz. Figure 5(b) gives the measured frequency responses of the elliptic low pass filter. As it can be seen in Fig. 5, the simulated and measured responses are in good agreement except the return loss from dc to 2 GHz. This discrepancy can be attributed to the sensitivity of the length of the port line Lf (fig.4), and it is mainly caused by the junction discontinuities and the tolerance in fabrications.

4. CONCLUSION

To reduce the size of the conventional stepped-impedance hairpin resonator, a novel model of this resonator has been proposed. Using this proposed model a low-pass elliptic-function filter using multiple cascaded semi-hairpin resonators has been designed. It provides a sharp cut-off frequency response and low insertion loss with a very compact size. The results are verified by measurements. It has been shown that the new elliptic low-pass filter works as well as a conventional one, though with a size reduction of about 62% and 13% enhancement of bandwidth.

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