Progress In Electromagnetics Research Letters, Vol. 7, 87–95, 2009

A COMPACT COMPOSITE BROAD STOP-BAND ELLIPTIC-FUNCTION LOW-PASS FILTER FOR ULTRA WIDE-BAND APPLICATIONS USING INTERDIGITAL CAPACITORS

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Abstract—A compact composite ultra wide-band elliptic-function low-pass filter is introduced by combining in cascade a microstrip stepped-impedance resonator using interdigital capacitor and an admittance inverter. A triple cascade low-pass filter is designed, analyzed and tested with this technique accompanied by its equivalent circuit model. This composition acts similar to a composite filter with desired attenuation and matching properties in order to obtain wide bandwidth and broad stop-band. The proposed low-pass filter features the sharpness of cut off frequency, low insertion loss, enhancement of bandwidth up to X-band frequencies and very compact size.

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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. Different types of small size low-pass filters have been investigated 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 the other studies, several small-size filters have been introduced using microstrip stepped-impedance hairpin resonators [2, 3]. They feature compact size and wide width stop-band, but not a wide-band pass-band.

Formerly, a wide rejection band low pass filter using microstrip transmission lines has been proposed [4]. To increase the width of pass-band, improve the performance and reduce the size, several types of elliptic-function low pass filters using modified hairpin resonators have been designed and proposed in recent years [5–7]. In some of these papers the pass-band has been increased and in others, the authors have focused on one size reduction.

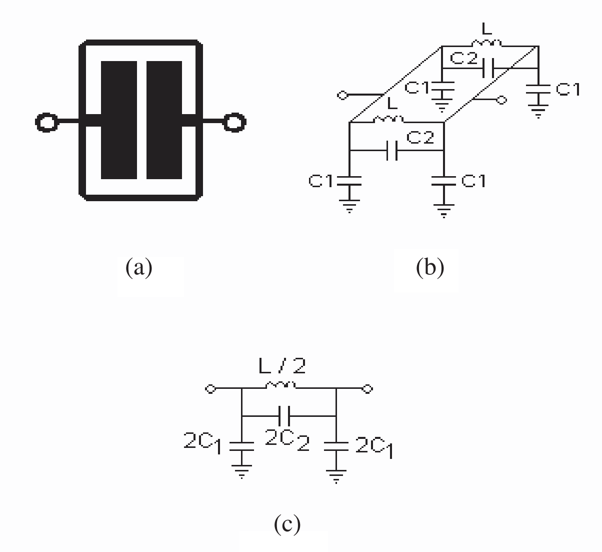
In this paper, a wide band pass-band low-pass filter is demonstrated by combining in cascade an admittance inverter with a microstrip stepped-impedance resonator accomplished by interdigital capacitor up to X-band with a wide rejection band, desired return and insertion losses, compact size and excellent sharpness of cut-off frequency.

Due to the fact that those favorable features are not easily achieved with conventional models, the method with which this proposed LPF has been designed can be a promising technique.

Initially, the equivalent circuit model of the proposed layout is analyzed and presented and at the next stage, its equality is shown by a stage of composite filter. Following, a triple cascade wide-band low-pass filter is designed for a 3-dB cutoff frequency of 10 GHz and fabricated on a 25-mill-thick PTEE/Woven substrate with a relative dielectric constant $\varepsilon_r = 10.2$. The exact dimensions of the filter are optimized by electromagnetic (EM) simulation (ADS).

2. EQUIVALENT-CIRCUIT MODEL FOR THE PROPOSED STRUCTURE

Initially, the structure of the conventional microstrip stepped-impedance resonator in [2] is followed. This structure consists of two



(a) (b)

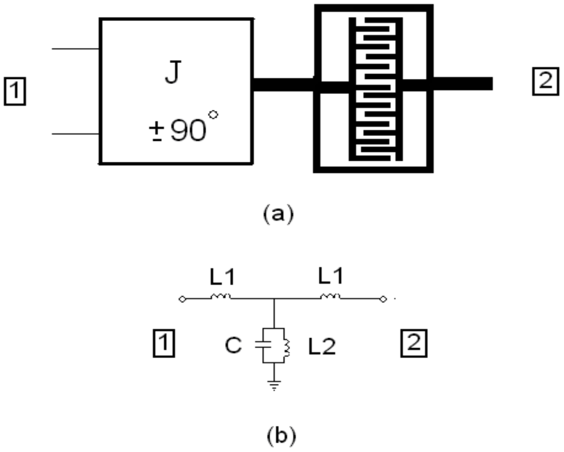
(c)

Figure 1. (a) The proposed modified microstrip stepped-impedance hairpin resonator, (b) and (c) its *L*-*C* equivalent circuit.

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 which is shown in Fig. 1(a) can be realized.

Referring to the equivalent-circuit of the proposed model, it is observed that two inductors are parallel to each other and all of the capacitances also are parallel together. Considering to the simple primary impedance equations for an inductor and a capacitor it is obvious that the more inductance reduces, thereby its band-width increases, the more capacitor increases, thereby the harmonics suppression improves. By taking this fact into consideration, a wide bandwidth by combining in cascade this model by an admittance inverter to reduce inductors and increase capacitors dramatically can be realized. Fig. 2(a) shows the layout of the proposed microstrip low-pass filter in which a modified microstrip stepped-impedance hairpin resonator and an admittance inverter are combined in cascade.

The equivalent circuit of the conventional stepped-impedance hairpin resonator in terms of lumped elements L and C and necessary equations have been derived in [5] and [6]. In this paper, similarly, *L*-*C* values for proposed composite filter in Fig. 2(a) can be obtained using its equivalent circuit in terms of the *L*-*C* values which are shown in Fig. 2(b). Furthermore, it can be shown that combining the proposed



(a)

(b)

Figure 2. (a) The combination of the modified microstrip stepped-impedance hairpin resonator and an admittance inverter, (b) its equivalent circuit model.

stepped-impedance hairpin resonator and an admittance inverter is equal to a composite filter as shown in Fig. 3(a) for impedance matching and wide band property. The relationships between L-C values in the conventional and proposed layout are found using equivalent circuit analysis and their $ABCD$ matrixes as

$$CL_1L_2 = J^2 2L(C_1 + C_2) \tag{1}$$

$$CL_1^2L_2 = 4C_1L(C_1 + 2C_2) \tag{2}$$

$$L_1 + L_2 = 2J^2 \tag{3}$$

$$L_1(L_1 + 2L_2) = 8C_1 \tag{4}$$

where L, C_1 and C_2 refer to the structure in Fig. 1 and L_1, L_2 and C refer to Fig. 2.

3. COMPACT WIDE-BAND ELLIPTIC-FUNCTION LOW-PASS FILTER

Using above obtained equations, a broad stop-band elliptic-function low-pass filter can be designed and analyzed. To design and simulate this filter, the J invertors can, in the simplest form, be constructed using quarter-wave transmission lines. The proposed low-pass filter is designed for a 3-dB pass-band from dc to 10 GHz on a 25-mil-thick substrate with relative dielectric constant $\varepsilon_r = 10.2$. To optimize the performance of this filter, electromagnetic simulation is used to tune the dimensions of the prototype filter and optimized dimensions are given in Table 1. In theory, the insertion- and return-losses are less than 0.3 dB and better than 17 dB respectively and the rejection greater than 45 dB from 10 to 21 GHz.

Table 1. The optimized demensions of the proposed low-pass filter.

Parameter	L (mm)	L_1 (mm)	L_2 (mm)	L_3 (mm)
Opt. Value	1.2	1.62	1.1	0.59
Parameter	W_1 (mm)	W_3 (mm)	$W = W_2$ (mm)	S (mm)
Opt. Value	0.3	0.09	0.12	0.01

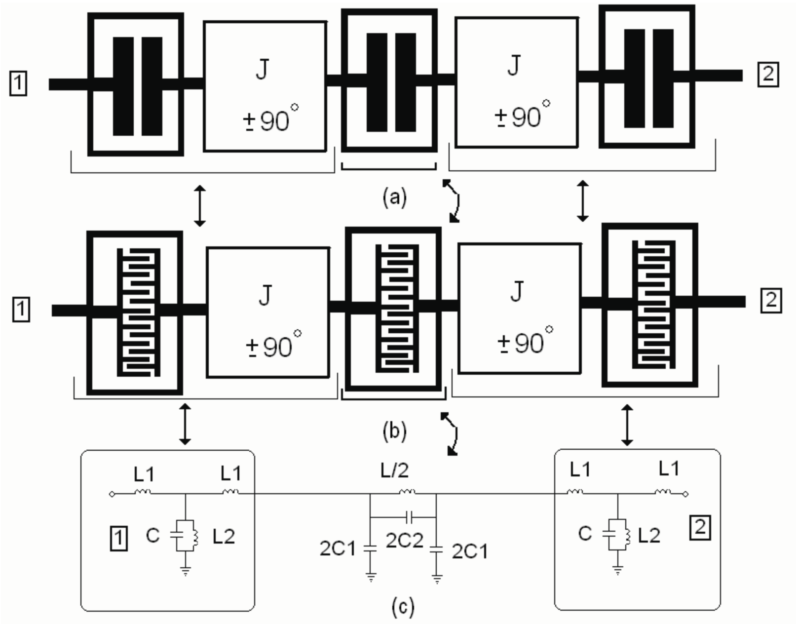


Figure 3. The low-pass filter using cascade resonators. (a) Layout, (b) equivalent circuit.

4. IMPLEMENTATION OF THE PROPOSED WIDE-BAND LPF

Due to the fact that the distance S (0.01 mm) in the Fig. 2 between two coupled lines is very small, this filter therefore practicably requires advanced equipments and a high cost for fabrication. To design this filter somehow to be practical, the coupled lines are replaced by Interdigital capacitor by appropriate distances among its coupled lines.

The parameters of the interdigital capacitor are tuned using EM simulator to make its performance equal to the two coupled lines in

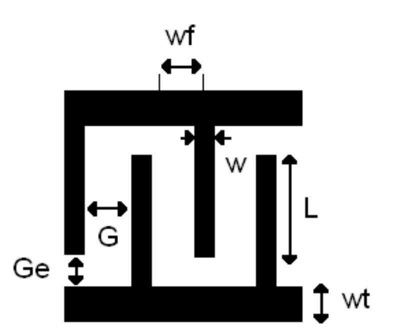
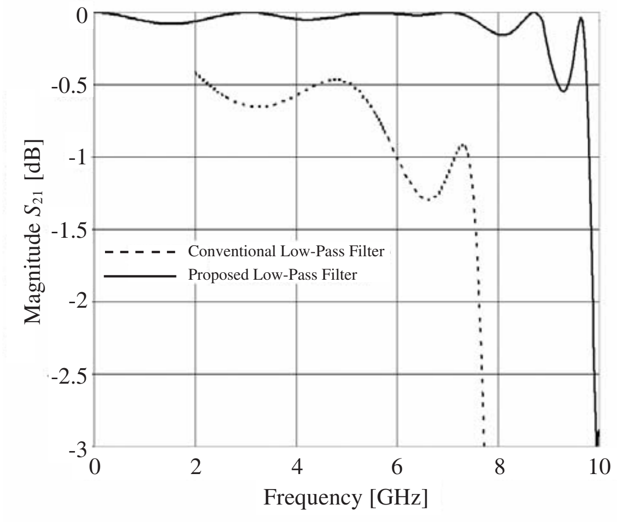
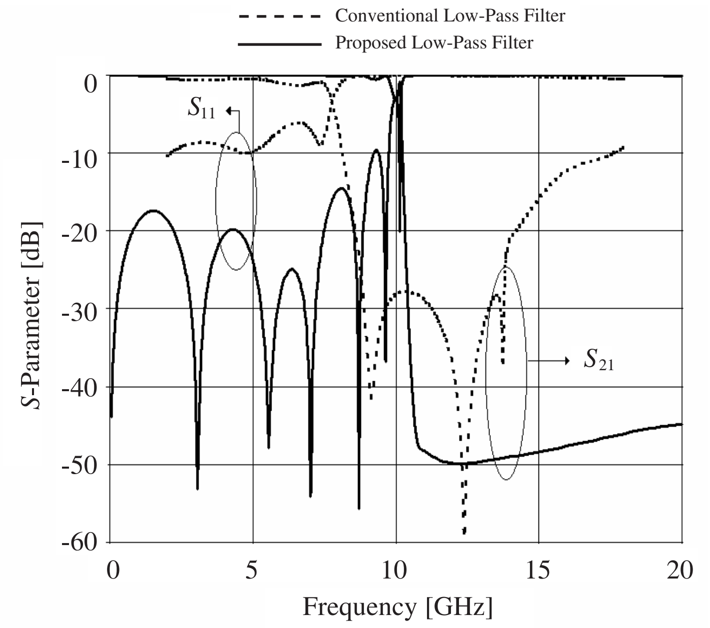


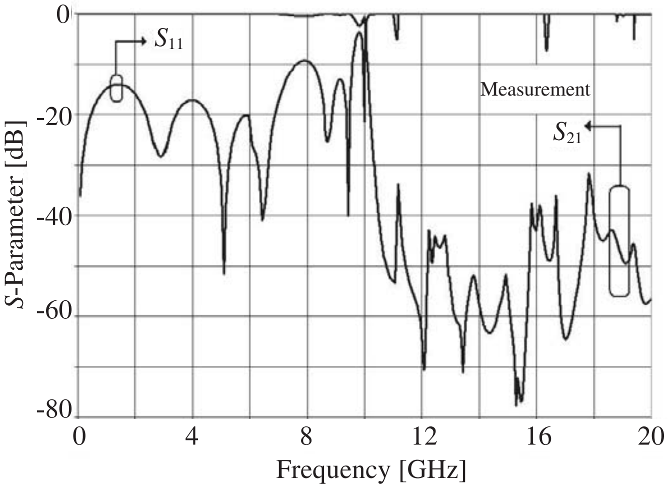
Figure 4. The interdigital capacitor using in the design of proposed LPF with $Ge = G = 0.05\,\mathrm{mm}, w = 0.1\,\mathrm{mm}, L = 0.1\,\mathrm{mm}, wt = 0.05\,\mathrm{mm}, wf = 0.3\,\mathrm{mm}$ and $Np = 8$.



(a)


Conventional Low-Pass Filter
Proposed Low-Pass Filter
S_{11}
S_{21}
S-Parameter [dB]
0
-10
-20
-30
-40
-50
-60
0
5
10
15
20
Frequency [GHz]

(b)


S_{11}
Measurement
S_{21}
S-Parameter [dB]
0
-20
-40
-60
-80
0
4
8
12
16
20
Frequency [GHz]

(c)

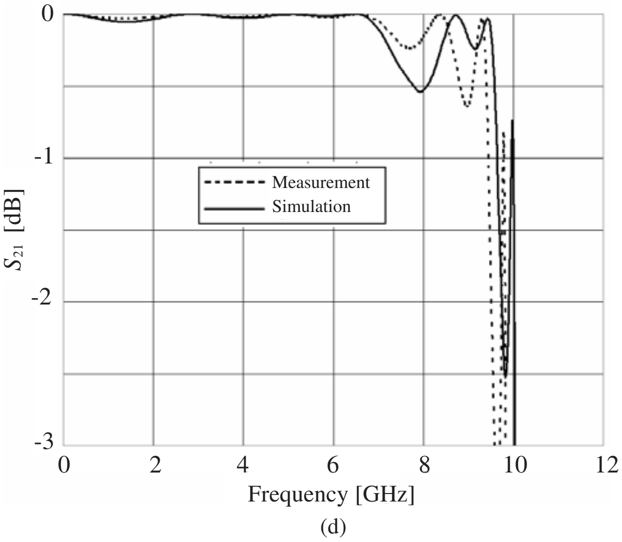


Figure 5. Simulated (a) frequency responses of the conventional and proposed low-pass filter, (b) S_{21} within the 3-dB bandwidth, without interdigital capacitor, (c) measurement and simulation of the proposed LPF using interdigital capacitor, (d) measurement within the 3-dB.

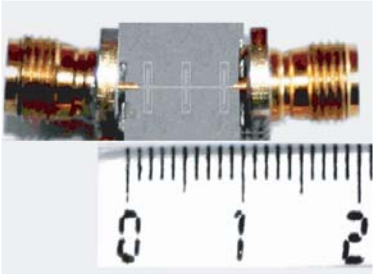


Figure 6. The fabricated of the proposed LPF.

the proposed layout. The layout and the dimensions of this Interdigital capacitor are given in Fig. 4.

In order to compare the performance of the proposed low-pass filter with and without interdigital capacitor with the conventional one in [1], their frequency responses are shown in Fig. 5. Referring to Fig. 5, in the proposed filter, all of the features such as the return loss, harmonics suppression, width of rejection band and insertion loss are much better than those of the conventional one.

5. CONCLUSION

To improve the performance of the conventional low pass filers using microstrip lines, a novel model has been introduced. Compact multiple cascaded elliptic-function low pass filters have been analyzed, designed, and tested by this technique. This filter has shown an excellent sharp cutoff frequency response, a wide rejection band, a good return loss, a desire insertion loss and finally a wide pass band up to X-band frequencies using matching impedance properties.

ACKNOWLEDGMENT

The author would like to thank N. Behdad, Center School of Florida for his constructive discussion and R. Khosravi, Iran Telecommunication Center, for his assistance of measurement setup.

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