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Compact microstrip lowpass filter with ultra-sharp roll-off and ultra-wide stopband using stepped impedance Hairpin resonator

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ABSTRACT

A novel microstrip lowpass filter (LPF) with very sharp roll-off, compact size and ultra-wide stopband is presented in this paper. The structure consists of modified stepped impedance Hairpin resonator and a circular patch as a suppressor. The proposed LPF has the cut-off frequency of 1.07 GHz. The simulation results indicated that the transition-band of the proposed LPF is 0.09 GHz from −3 to −20 dB. Maximum insertion-loss at about 80% of the passband is 0.1 dB. The proposed LPF has been designed, fabricated and measured. From the measurements, good agreements with the simulated results are obtained. Also, an ultra-wide stopband was achieved. Proposed LPF has an ultra high figure-of-merit (FOM) of 151,523, which shows its strong efficiency.

1. Introduction

The most important challenge of a filter design in microwave field is that of the optimization of the device parameters [1]. Lowpass filters (LPFs) are crucial components in microwave applications, which can be used to block unwanted high frequency harmonics and to reject the spurious responses. To meet the size requirements of modern microwave communication systems, compact microwave LPFs with low insertion-loss, sharp transition-band and wide stopband width are highly desirable in RF front-end researches. In [2], a compact LPF with sharp roll-off is presented but the structure suffers from a low return-loss in the passband, low attenuation level in the stopband and complex structure because of using DGS technique. In [3], an LPF with compact size, low insertion-loss and high return-loss in the passband is presented but the filter has a gradual roll-off. In [4], an LPF with sharp roll-off and high attenuation level in stopband is presented. The weaknesses of the presented structure are its high insertion-loss (almost 2 dB) and low return-loss (near to 11 dB) in passband. In [5], a compact lowpass filter using triangular-shaped patches is presented. Although the filter has a sharp roll-off, but the stopband is narrow and the value of FOM shows its inefficiency. An LPF with extended stopband and compact size using M-shaped units is presented in [6]. The structure has a high suppression level in the stopband but the roll-off is not so sharp and the value of relative stopband is not so high. In [7], a compact lowpass filter with extended stopband is presented but the filter has a gradual roll-off and it also has complex structure.

In this paper, a compact lowpass filter with very sharp roll-off and ultra-wide stopband width and ultra-high FOM is presented. The presented LPF is designed, simulated and fabricated. There is an acceptable agreement between the simulation and measurement results.

2. Filter design

Fig. 1 shows the structure of conventional Hairpin resonator. The equivalent LC model of the structure and also its theoretical analysis are discussed in [8], but they are presented briefly in this paper.

As it is clear in Fig. 1, the structure consists of a high-impedance inductive line and also low-impedance coupled lines. The ABCD matrix of the inductive line and coupled lines are shown in Fig. 2.

In Fig. 2, β is the phase constant of the single transmission line, Zoe and Zoo are the even-mode and odd-mode impedances of the coupled lines and θ_{eff} is the arithmetic-averaged electrical length the even-mode length of the parallel coupled lines.

The equivalent LC model of the single transmission line and also parallel coupled lines are shown in Fig. 3.

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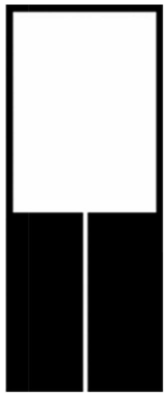
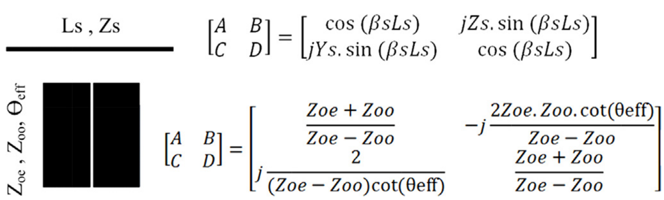


Fig. 1. Structure of the conventional Hairpin resonator.



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(\beta sLs) & jZs.\sin(\beta sLs) \\ jYs.\sin(\beta sLs) & \cos(\beta sLs) \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \dfrac{Zoe + Zoo}{Zoe - Zoo} & -j\dfrac{2Zoe.Zoo.\cot(\theta eff)}{Zoe - Zoo} \\ j\dfrac{2}{(Zoe - Zoo)\cot(\theta eff)} & \dfrac{Zoe + Zoo}{Zoe - Zoo} \end{bmatrix}$$

Fig. 2. The ABCD matrix of single transmission line and parallel coupled lines.

The value of the elements in the LC circuit model can be calculated using the ABCD matrices as below:

$$L = \frac{1}{\omega} \times Zs \times \sin\left(\frac{2\pi}{\lambda_g} l\right) \tag{1}$$

$$Cs = \frac{1}{\omega} \times \frac{1}{Zs} \times \tan\left(\frac{\pi}{\lambda_g} l\right) \tag{2}$$

$$Cc = \frac{-Im(Y21)}{\omega c} \tag{3}$$

$$Cp = \frac{Im(Y11 + Y21)}{\omega c} \tag{4}$$

In this work, the conventional Hairpin structure is modified in order to enhance the performance and also reduction of the size. Fig. 4 shows the proposed resonator. As it is clear in Fig. 4, the proposed structure is achieved by bending the low-impedance part of the conventional Hairpin resonator.

The EM-simulation results of the proposed resonator are shown in Fig. 5.

All the simulations in this paper are done using ADS software by choosing the substrate with dielectric constant of 2.22, thickness of 20 mil (0.508 mm) and loss-tangent of 0.0009.

Fig. 6 shows the LC circuit model of the designed resonator.

The values of the LC elements in Fig. 6 are shown in Table 1.

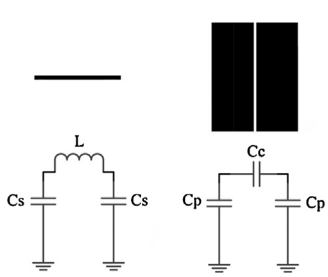


Fig. 3. The equivalent LC model of the single transmission line and parallel coupled lines.

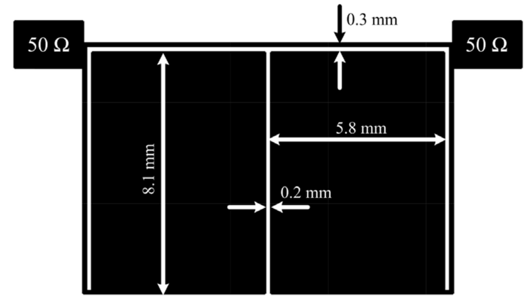


Fig. 4. Proposed modified Hairpin resonator.

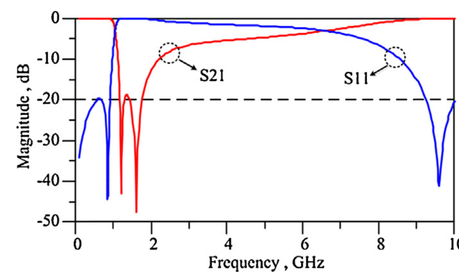


Fig. 5. EM-simulation results of the proposed resonator.

A comparison between the EM-simulation and LC circuit results of the designed resonator are shown in Fig. 7 and as it is clear, there is a good agreement between the results.

As can be seen in Fig. 5, the proposed resonator has some strong points such as: very sharp roll-off skirt, very low insertion-loss and

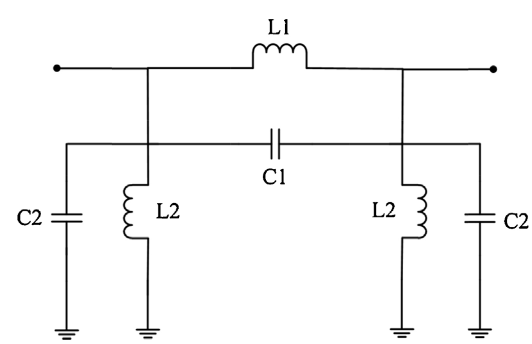


Fig. 6. LC circuit model for the designed resonator.

Table 1
The values of the LC elements.

Element	L1	L2	C1	C2
Value	9 nH	4.8 nH	4.7 pF	1.5 pF

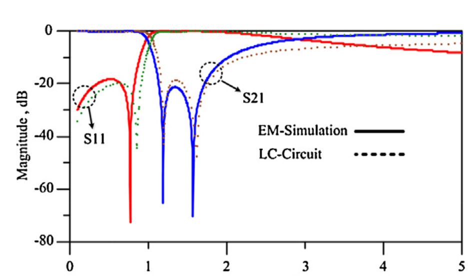


Fig. 7. Comparison between the EM-simulation and LC circuit results of the designed resonator.