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Compact lowpass filter with wide stopband using open stubs loaded tapered compact microstrip resonator cell

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Abstract: we have proposed an open stubs loaded tapered compact microstrip resonator cell (OSL-TCMRC) for designing of the lowpass filter with wide stopband and low insertion loss. By optimization of this structure and insertion of open stubs, undesirable response and harmonics will be suppressed. In order to validate the proposed design, a lowpass filter with low insertion loss in passband and wide stopband is designed, fabricated and measured. Simulation results are compared to the experimental results and good agreement between them was achieved.

Keywords: lowpass filter, open stubs loaded TCMRC, wide stopband, low insertion loss, photonic band gap (PBG)

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Microstrip lowpass filter (LPF) is a cardinal part in microwave circuits. In order to access the modern microwave communication system requirements, compact microstrip LPF with a low insertion loss and a wide stopband are in high demand. Due to the compact size and easy fabrication of planar resonators, they have increasingly been taken into consideration to be employed in LPF design.

A technique for the synthesis of microstrip LPF is to use a one dimensional (1-D) photonic band gap (PBG) structure with a microstrip transmission line. The PBG structure shows characteristics of the bandstop, which can be used to reject unwanted signals within stopband frequencies, and a slow-wave effect, which can reduce the dimension of the microstrip circuit.

A one-dimensional (1-D) compact microstrip resonance cell (CMRC) has been proposed in [1], and a spiral compact microstrip resonance cell (SCMRC) has been proposed in [2, 3]. A lowpass filter using tapered compact microstrip resonator cell (TCMRC) with a non-uniform cell dimension has been proposed in [4], and a rectangular patch CMRC (RPCMRC) with a defected ground structure has been proposed in [5]. All of these use the photonic band gap to get a decrement of the harmonics in the stopband with a compact size. However, in these proposed filters, the insertion loss in the passband and a spurious response suppression in the stopband remain as main challenges. To improve the rejection band, defected ground structures (DGS) for designing Low-Pass filters are used in [6] and [7]. This structure is not applicable on metal surfaces and cannot give a robust mechanical endurance against strain, because of the etching in ground plane.

Some other techniques have been proposed to synthesize microstrip lowpass filters such as miniaturized stepped impedance [8], open loop resonators [9] and triangular patch resonators with fractal defection [10]. However, the wide stopband and suppress suppression in the stopband re-

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main as drawbacks of proposed filters. Cascading several CMRCs in a series form is the first way to extend the stopband, but this method increases the circuit size and transmission loss, so it is not suitable for modern microwave applications.

This paper presents a lowpass filter with a wide stopband and a compact size using OSL-TCMRC. By tuning the open stubs and tapered lengths, and spacing between them, the stopband performance can be extended. The simulation of the designed structure is conducted by an EM-Simulator (ADS), and then it is fabricated. The proposed lowpass filter has been validated by simulation and experiment, both of which will be presented below.

2 Design of the filter structure

The structure of the proposed OSL-TCMRC is illustrated in Fig. 1 (a). As it can be seen from this figure, the compact microstrip resonator cell consists of four horizontal open stubs with different lengths and two tapered cells. In addition, in order to increase the capacitance between tapered and vertical transmission lines, we have added slits to the tapered junctions in the structure. Hence the open stubs loaded tapered compact microstrip resonator cell (OSL-TCMRC) is obtained. It can clearly be observed that the structure increases capacitance by using a gap between the central narrow line and open stubs, so it can give an attenuation pole in the stopband, and consequently it will have a wide stopband. The L-C equivalent circuit of the proposed filter is obtained by using the transmission line model as shown in Fig. 1 (b), which is described as follows: L_1, L_2 are inductance of the central line, L_{t1}, L_{t2} are inductance of the tapered, L_{s1} is inductance of the open stub, L_{f1} is inductance of the feed line, $C_1 \ldots C_8$ are capacitance between the tapered and the open stubs to ground, C_{t1} and C_{t2} are capacitance between the tapered and the central lines, $C_{i1} \ldots C_{i4}$ are capacitance of the gap between the open stubs and the central line, C_{o1} is capacitance of the open stub, and C_{f1} is the capacitance between the feed line and the open stub. The demonstrated resonator is implemented on (RT/Duriod 5880) substrate with relative permittivity, height and a loss tangent equal to 2.2, 10 mil and 0.0009. The simulated s-parameters of the proposed resonator as functions of W_{t1}, W_{t2} and L_1 are shown in Fig. 1 (c), Fig. 1 (d), Fig. 1 (e) respectively. As seen in Fig. 1 (c), when W_{t1} increases from 0.3 mm to 0.5 mm, the transmission zero in 16.1 GHz will approach the lower frequency. Similarly, in Fig. 1 (d) by decreasing W_{t2} from 0.9 mm to 0.5 mm, transmission zero in 15.3 GHz will move away from the lower frequency. In Fig. 1 (e) by decreasing L_1 from 1.6 to 1.2 mm due to decrements of the effective series inductance, transmission zero in 6.0 GHz will move away from the lower frequency. Hence, the location of transmission zero can be controlled by a parallel capacitance with a series inductance as the attenuation zero location becomes lower, which is due to the increment of the series inductance and the decrement of the resonant frequency of the equivalent LC circuit as shown in Fig. 1 (b).

The open stubs are used to provide the additional capacitance and in-

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ductance to reduce the cutoff frequency, while the tapered cells are used to control harmonic and spurious suppression. If the dimensions of the internal open stubs are arbitrarily selected, the harmonics and the spurious will not be suppressed well, and only a narrow rejection bandwidth will be obtained. Therefore, the internal open stubs need to be optimized. The stepped lines are added on both sides of the resonator to enhance the cou-

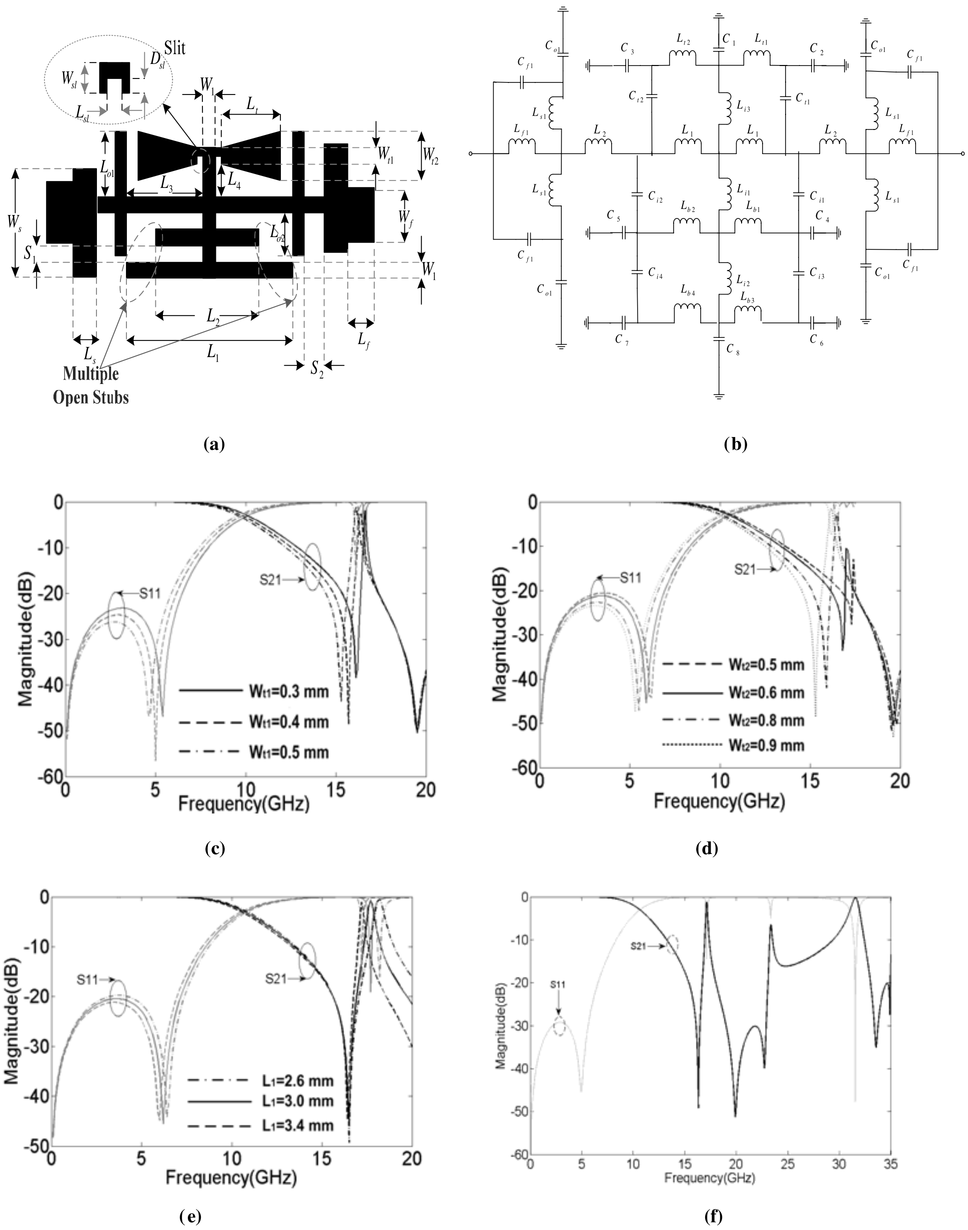

Fig. 1. (a) Schematic diagram of the proposed OSL-TCMRC. (b) Equivalent circuit (c) S-parameter simulation of the proposed resonator as a function of W_{t1}. (d) S-parameter simulation of the proposed resonator as a function of W_{t2}. (e) S-parameter simulation of the proposed resonator as a function of L_1. (f) S-parameter simulation of the proposed resonator.

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pling line effects. It should be noted that if the width of the coupled line, Ws, is reduced to the feed line width, Wf, the insertion loss of the directly connected OSL-TCMRC will be high. Therefore, the stepped in the near and far ends of the proposed structure with an asymmetrical length in top and bottom sections result in a low insertion loss in the passband for the designed lowpass filter. The dimensions of our proposed structure shown in Fig. 1 (a) are as follows: L_1=3.8, L_2=3.2, L_3=1.8, L_4=0.4, L_t=1.6, W_1=0.2, W_{t1}=0.2, W_{t2}=0.7, L_{o1}=0.9, L_{o2}=0.5, S_1=0.2, S_2=0.2, L_s=0.5, W_s=1.4, L_f=0.5, W_f=0.8, W_{sl}=0.2, D_{sl}=0.1, L_{sl}=0.1, all in mm. The S-parameter simulation of the proposed resonator with above the dimensions is illustrated in Fig. 1 (f). From this figure, it can be seen that its insertion loss from DC to 9.16 GHz is less than −1 dB, and its in-band return loss is always better than −20 dB. The S_{21} is −20 dB in 15.39 GHz. The return loss in the stopband is about 0 dB, which indicates that the small radiation loss is negligible. The proposed structure has a transmission pole in 4.96 GHz with −45.36 dB in the passband, and a transmission zero in 16.32 GHz with −49.20 dB in the stopband near the passband.

3 Simulation and measurement

To obtain a filter with a wide stopband, a resonator with different dimensions is needed. The wide stopband is obtained because of the resonators with multi cutoff frequencies. For more attenuation of the harmonics in the stopband, the open stubs with non-equal lengths, vertically connected to the central microstrip line, play the main roll. The EM-simulator (ADS) is used for optimization of the dimensions of the resonator to obtain the LPF as shown in Fig. 1 (a) with desired characteristics.

As shown in Fig. 2 (b), by increasing W_{t2} from 0.5 mm to 0.8 mm, the transmission zero in 17.4 GHZ has been moved to a lower frequency, and a similar case has happened in Fig. 2 (c) in which S_1 has increased from 0.3 to 0.5 mm. Consequently, the transmission zeros in the stopband can be easily controlled by the dimensions of the proposed resonator. The dimensions of obtained LPF according to Fig. 2 (a) are as follows: L_{o3}=0.6, L_5=3.44, L_6=2.4, L_7=2.2, all in mm.

The proposed LPF using the obtained OSL-TCMRC structure with the above dimensions has been fabricated with microelectronic technology in accordance with the pattern, shown in Fig. 2 (a). In addition, a photograph of the fabricated filter is shown in Fig. 3 (a). The measurements of the proposed LPF are carried out using an HP8757A network analyzer. Fig. 3 (b) shows simulated and measured S-parameters of the lowpass filter using the proposed structure, where S_{11} and S_{21} are in dB. As seen in Fig. 3 (b), the insertion loss in the passband is less than −1.0 dB from DC to 9.11 GHz, the S_{21} is equals −3.0 dB and −20.00 dB for 9.51 GHz and 11.43 GHz respectively, and has a transmission zero in 16.42 GHz with −60.94 dB. By optimization of the open stubs and tapered dimensions, the harmonics in the stopband are more attenuated and the stopband is observed from 10.31 GHz

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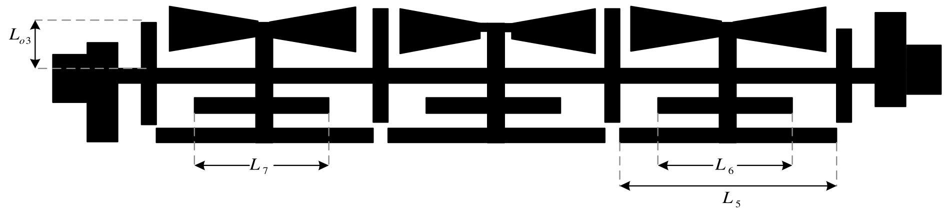
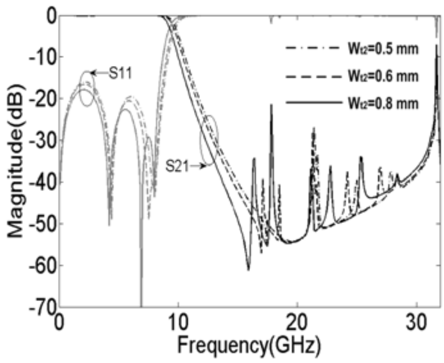
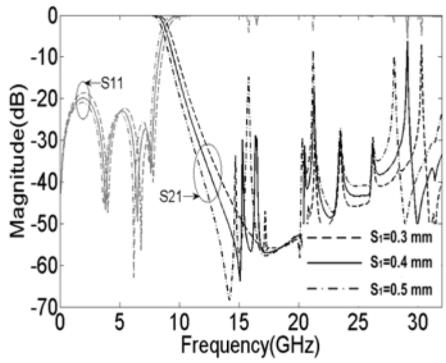


(a)

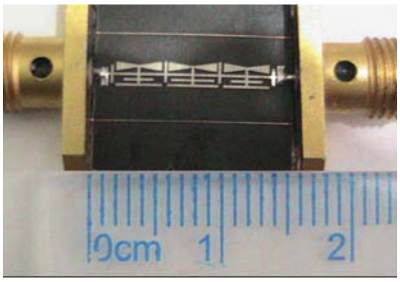


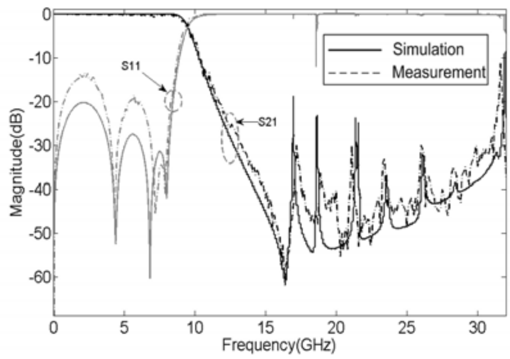
(b)



(c)

Fig. 2. (a) Schematic diagram of the designed LPF. (b) Simulated S-parameter of the designed LPF as a function of W_{t2}. (c) Simulated S-parameter of the designed LPF as a function of S_{11}.





(a) **(b)**

Fig. 3. (a) A photograph of the fabricated filter. (b) Simulated and measured S-parameters of the proposed LPF.

to 31.94 GHz with better than −10 dB that gives a 21.63 GHz reject band; therefore, the designed filter has a wide stopband. The return loss is better than −20.30 dB in the passband and the obtained three transmission poles as follows: 4.14 GHz with −52.45 dB, 6.84 GHz with −60.32 dB and 8.03 GHz with −41.77 dB. The size of the lowpass filter is 14.6 mm × 1.9 mm.

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4 Conclusion

In this paper, an improved microstrip resonator using an open stubs loaded tapered compact microstrip resonator cell is designed. The proposed resonator is applied to obtain a lowpass filter with a low insertion loss, a wide stopband and a high return loss. A compact wide stopband lowpass filter is designed, and implemented by connecting three proposed OSL-TCMRC cascading in a series form. The radiation and scattering effects are maintained at low levels. The slow-wave effect is enhanced by increasing the inductance and capacitance, which results in a reduction in the circuit size. Tapered and open stubs, which are coupled to the main line, allow the designer to control the stopband location and reduce the number of harmonics.

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