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DESIGN OF COMPACT MICROSTRIP LOW-PASS FILTER WITH ULTRA-WIDE STOPBAND USING SIRS

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Abstract—A novel low-pass filter (LPF) is designed and fabricated based on stepped-impedance resonator (SIR). Semi-circles are used to reduce the size of the filter. The open-circuited stubs are used in the filter, and its simplified equivalent circuit is also proposed. The measured 3 dB cutoff frequency is 5.2 GHz with no more than 0.3 dB ripple level in the pass-band. From 5.5 to 14 GHz, the investigated LPF has a rejection level better than 20 dB. Measured results show good agreement with simulated ones.

1. INTRODUCTION

A compact and good performance low-pass filter (LPF) is highly demanded in modern microwave communication systems, especially in wireless and mobile communications in order to suppress harmonics and spurious signals. There are several general requirements for a LPF, such as low loss, wide rejection band, and small size in some specific applications [1]. In microwave filters design, harmonic suppression is very important. Some methods such as defected ground structure (DGS) [2–5] and electromagnetic band-gap (EBG) [6–8] have been known as providing rejection of certain frequency bands, and cascaded low-pass unit-cells, the harmonic passbands, can be suppressed. There are some design parameters, which have an effect on the band-gap property, such as the number of lattice, lattice shapes, lattice spacing, and relative volume fraction. Another difficulty in using this DGS circuit is caused by the radiation from the periodic etched defects [9–11]. Still, there are many new structures that have been proposed recently. A compact LPF consisted of ring resonator and two open stubs [12]. The filter had a sharp attenuation performance, but did

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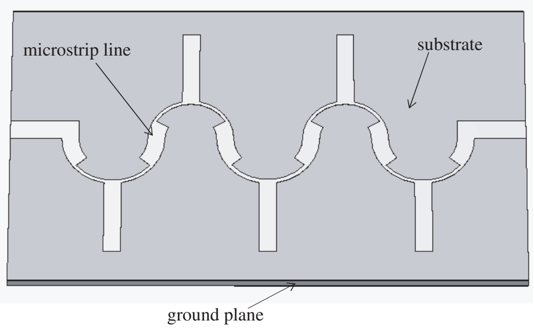


Figure 1. 3-D view of the proposed LPF.

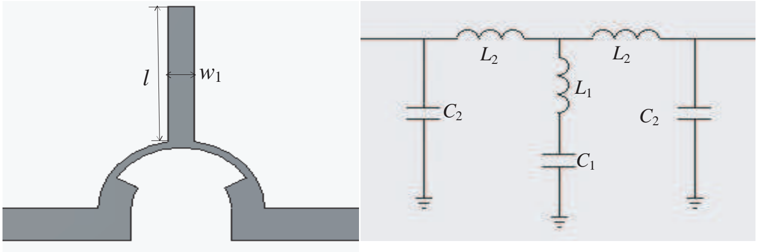
not have a wide stop-band. SSL was used in a low-pass filter [13], and another new LPF was presented by using triangular and trapezoidal patch resonators with fractal defection [14]. These filters had good wide-band performance but did not have good transmission zeroes performance. Due to the frequency-distributed behavior of finite-extended transmission lines these filters always suffer from poor stop-band performance beyond the cutoff frequency.

In this paper, a new compact low-pass filter consisting of SIRs and open-circuited stubs is proposed as well as the simplified equivalent circuit. The 3-D view of the filter is shown in Figure 1. The effects of physical dimensions of the proposed LPF on these equivalent-circuit parameters are described. It is the purpose of this paper to show a potential for applying the proposed LPF to practical circuits. Compared to conventional structure, the new structure has an advantage of minimized size because the semi-circles are used and also has good selectivity in the pass-band by adjusting the size of open-circuited stubs [15]. The proposed filter has been fabricated and measured. The measured results are in good agreement with the simulation ones.

2. FILTER DESIGN

Figure 2 shows the unit used in the LPF design and its equivalent circuit. The cell of the filter is composed of high-impedance and low-impedance transmission lines. These are much shorter than the associated guided-wavelength, so as to act as semi-lumped elements. The high-impedance lines act as series inductors, and the low-impedance lines act as shunt capacitors. Open-circuited stubs are used in the filter, and they are approximate quarter guided-wavelength. So the open-circuited stubs will act as shunt series-LC circuit, and the effective inductance L_1 and capacitance C_1 are determined by the size of the stub with dimensions l and w_1. Therefore, the structure shown in Figure 2(a) is directly realized through the LC ladder type of low-pass filters of Figure 2(b).

S-parameters of the filter cell and its equivalent circuit are depicted as well after we calculate the value of the capacities and inductances. The comparison between the simulation results of the layout unit structure and its equivalent circuit is shown in Figure 3. Parameters $L_1 = 0.56\,\text{nH}$, $L_2 = 2\,\text{nH}$, $C_1 = 0.7\,\text{pF}$, $C_2 = 0.34\,\text{pF}$. The substrate used for simulation is FR4 0.635 mm thick with dielectric constant 4.4. The relationship between the physical size of the structure and the values of the equivalent circuit parameters is evaluated from the circuit modeling. As shown in Figure 3, the equivalent circuit simulation results show good agreement with that of the EM simulation.



(a) (b)

Figure 2. The LPF unit and its equivalent circuit. (a) Proposed compact LPF unit. (b) Equivalent circuit of the LPF unit shown in (a).

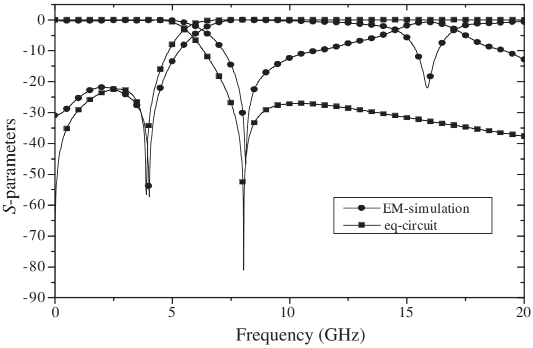


Figure 3. Comparison between EM-simulation and circuit simulation results of the proposed filter unit.

From the results shown in Figure 3, we can see that the filter unit cannot meet the requirement. A schematic diagram of the LPF is shown in Figure 4. It is composed of several cascaded unit resonators. It is well-known that cascaded resonators, as in the case of classical LPFs, may extend the stop-band. If these resonators are cascaded using certain schemes, a very wide reject band can be obtained. However, the cutoff frequency of the overall filter may change. In order to keep the same cutoff frequency, a new method is developed shown in Figure 4.

The results with different units are shown in Figure 5, and the number is varied from 1 to 3 and 5. In all cases, the resultant cutoff frequency is 5.2 GHz. Increasing the number of the unit results in more steep descent at cutoff frequency as expected. Return loss in the pass-band becomes lower, and 5 units are used at last.

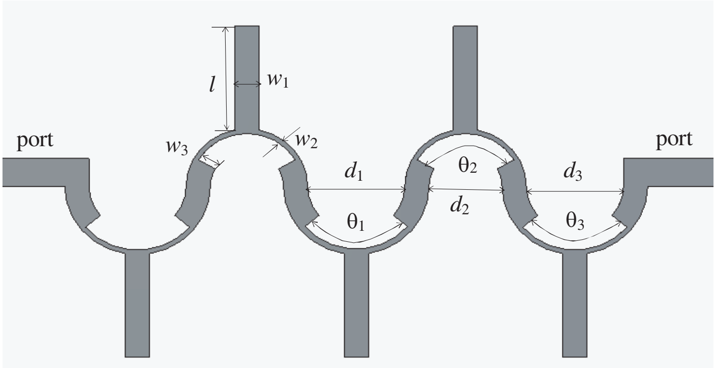


Figure 4. The schematic diagram of proposed LPF structure.

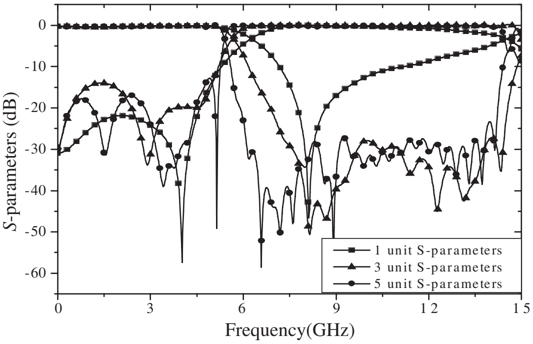
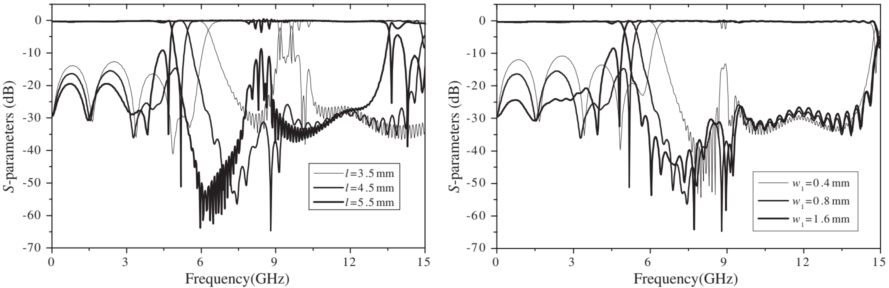


Figure 5. Impact of increasing number of units.



(a) Impact of parameter l changes (b) Impact of parameter w_1 changes

Figure 6. Simulation results with different open-circuited stub size.

Referring to Figure 4, open-circuited stub approximate quarter guided-wavelength can be equivalent to shunt series-LC circuit, and the effective inductance L_1 and capacitance C_1 are determined by size of the stub with dimensions l and w_1. During the design, CST-MWS EM-simulation was performed on the proposed structure in order to optimize some of the parameters. Figure 6 shows how length l and width w_1 determine cutoff frequency of the filter while other parameters are fixed. Simulations have shown that cutoff frequency and return loss in the pass-band can be shifted by changing length l and width w_1.

3. RESULTS

According to the optimized results using EM-simulation, the dimensions of the proposed LPF are as follows: $d_1 = 4\,\text{mm}$, $d_2 = 3\,\text{mm}$, $d_3 = 4\,\text{mm}$, $w_1 = 1\,\text{mm}$, $w_2 = 0.25\,\text{mm}$, $w_3 = 0.75\,\text{mm}$, $l = 4.5\,\text{mm}$ and $\theta_1 = \theta_2 = \theta_3 = 120°$. The width of the feed-line is designed as 1.2 mm, corresponding to 50-ohm characteristic impedance. The substrate with a dielectric constant of 4.4, loss tangent 0.003 and thickness 0.635 mm is used. Figure 6 shows photograph of the fabricated LPF. The dimension of LPF is $24\,\text{mm} * 14.7\,\text{mm}$ as can be seen in Figure 7.

The measurement of the proposed LPF is done by an Agilent N5230A network analyzer to measure the return loss and insertion loss, and the results are shown in Figure 8. The measured 3 dB cutoff frequency is 5.2 GHz with no more than 0.3 dB ripple level in the pass-band. From 5.5 to 14 GHz, the investigated LPF has a rejection level better than 20 dB. The measurements show good consistency with the simulated ones in the performance of both insertion loss and return loss.

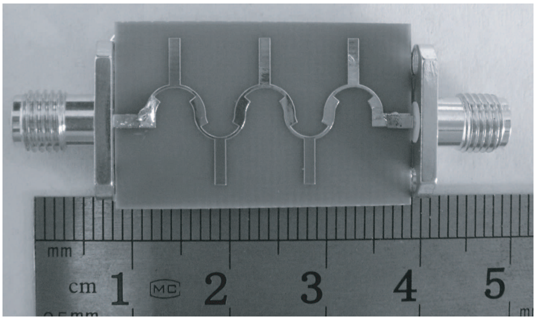


Figure 7. Photograph of the proposed LPF.

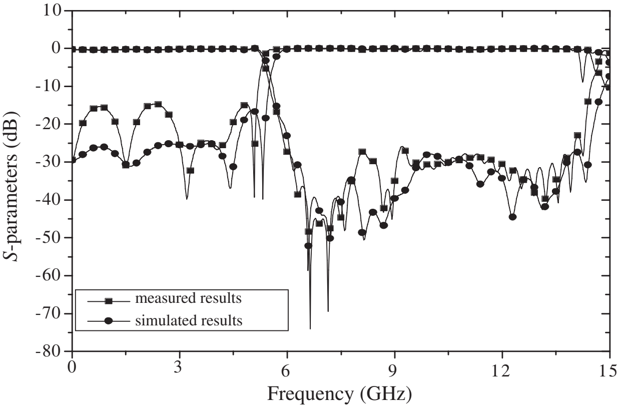


Figure 8. Measured and simulated S-parameters of proposed LPF.

4. CONCLUSIONS

A compact LPF using SIRs and open-stubs has been proposed. To verify the performance, the filter is simulated and measured. The measured 3 dB cutoff frequency is 5.2 GHz with no more than 0.3 dB ripple level in the pass-band. From 5.5 to 14 GHz, the investigated LPF has a rejection level better than 20 dB. The measurements show good consistency with the simulated ones in the performance of both insertion loss and return loss. With the advantages of minimized size, low insertion loss in the passband and wide rejection band, the LPF has been fabricated to meet the requirements of high performance for the modern wireless communication systems.

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