A Lowpass Filter with Sharp Roll-off and High Relative Stopband Bandwidth using Asymmetric High-Low Impedance Patches

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Abstract. *In this letter, a microstrip lowpass filter with −3 dB cut-off frequency at 1.286 GHz is proposed. By using two main resonators which are placed symmetrically around (Y) axis a sharp roll-off rate (250 dB/GHz) is obtained. The proposed resonators are consisted of two asymmetric high-low impedance patches. To achieve a high relative stopband bandwidth (1.82) four high-low impedance resonators and four radial stubs as suppressing cells are employed. Furthermore, a flat insertion loss in the passband and a low return loss in the stopband can prove desired in-band and out-band frequency response. The proposed lowpass filter has a high figure of merit about 63483.*

Keywords

High-low impedance patches, lowpass filter, resonator, radial stub

1. Introduction

Microstrip lowpass filters (LPFs) as key microwave components are in high demand in wireless communication systems. In order to improve in-band and out-band performances of LPFs, many efforts have been done in recent years. For instance in [1], a stub-loaded coupled-line hairpin unit has been utilized to design a LPF with sharp cut-off and wide stopband. To design a LPF with an ultra-wide stopband rejection, both triangular and polygonal patch resonators are used [2], but this structure does not have a sharp transition band. In [3], a LPF by using transformed radial stubs is designed and an ultra-wide stopband is obtained. To design a quasi-elliptic LPF with wide stopband symmetrically loaded radial shape patches and meandered main transmission line are employed [4], but it suffers from a low level of suppression in the stopband. To achieve an ultra-wide stopband both triangular and radial patch resonators have been applied to the structure of the proposed LPF, in [5]. However, this circuit has a gradual cut-off frequency. Another way to expand the stopband region is using hairpin resonator [6], [7]. By employing this cell in [6], the stopband has been broadened. However, the overall circuit size has become relatively large and also the skirt performance is not desired. A method of using stepped impedance hairpin resonator with radial stubs has been done in [7] to propose a LPF with wide stopband, but this design has not been able to achieve a sharp transition band. In [8], to present a LPF rat-race directional couplers have been utilized to perform as bandstop transversal filtering sections (TFSs). Nonetheless, by adopting this method the overall circuit size has been significantly increased and also the rejection band has not been adequately widened. In [9], a quasi-π-slot resonator and open stubs have been employed and a LPF with sharp cut-off has been proposed, but the occupied area is large. In this letter, a microstrip LPF with −3 dB operating frequency of 1.286 GHz is proposed. Sharp roll-off and ultra-wide stopband have been obtained by using two main resonators and two different suppressing cells, respectively. The frequency responses of the fabricated and designed LPF show a good correlation between measurements and simulations.

2. Lowpass Filter Design

The configuration of the implemented LPF is illustrated in Fig. 1. As it can be seen, the designed circuit is composed of two main resonators and two different suppressing cells. Each of these resonators and suppressing cells are employed to improve a special range of the final frequency response.

In the first step, a low pass resonator with −3 dB cut-off frequency of 1.28 GHz by utilizing high-low impedance resonator to create a great capacitance has been designed.

Fig. 1. The configuration of the implemented LPF.

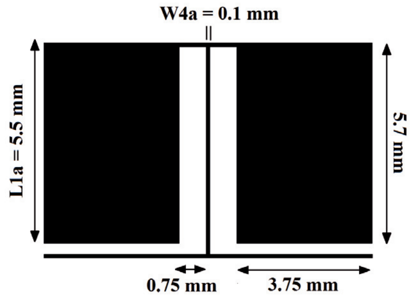

Fig. 2a. The primary resonator.

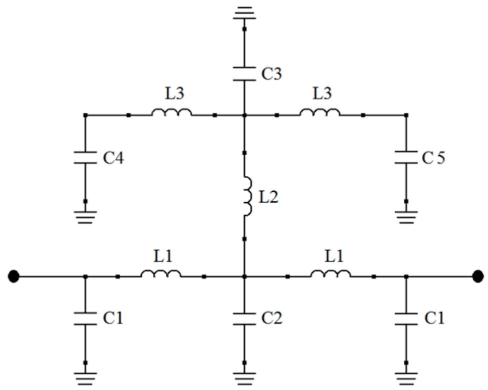

Fig. 2b. Its equivalent LC circuit.

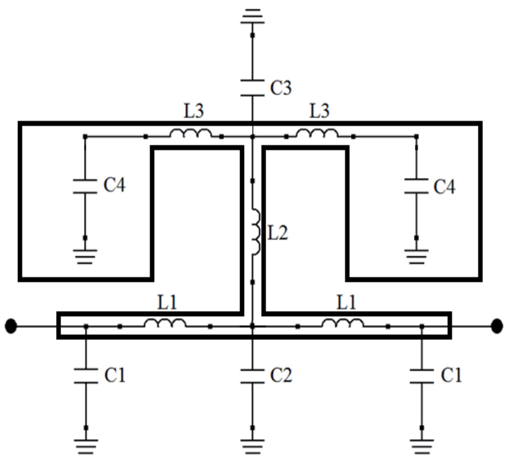

Fig. 2c. Combination of microstrip structure and its LC circuit.

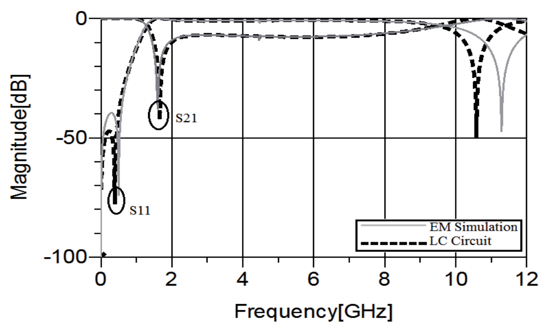

Fig. 3. The EM simulation result and frequency response of LC circuit of the primary structure shown in Fig. 2.

In Figs. 2a and b, the primary proposed resonator and its equivalent LC circuit are shown. Each high-low impedance patches in both sides of the proposed resonator creates an inductor connected to a capacitance in series. As it is seen from Fig. 2c, low impedance transmission line (TL) can be modeled by a capacitance (C4) and high impedance TL creates an inductor (L3). L1 and L2 account for the transmission lines determined by La and Lb in Fig. 2a, respectively. C1, C2 and C3 model the capacitance between the microstrip structure and the ground. The calculated values of the lumped elements of the proposed resonator are optimized as follows [10]: L1 = 3.23 nH, C1 = 58 fF , L2 = 4.16 nH , C2 = 192 fF, L3 = 54 nH, C3 = 84.7 fF, C4 = 1.006 fF. The lumped-element values without using any transfer function and based on the characteristic impedance and the electrical length of each employed transmission line have been obtained [10]. Therefore, the cut-off frequency of the structure can be controlled by the electrical lengths. Note that the values of inductors and capacitances have been calculated based on a substrate with a thickness of 0.508 mm, the permittivity of 2.2 and the loss tangent of 0.0009.

Figure 3 shows the EM simulation and the frequency response of LC circuit which are in good agreement. According to the EM simulation, the proposed resonator has a –3 dB operating frequency of 1.28 GHz. In the pass band region, the insertion loss is close to zero and the return loss is better than −39.6 dB. Moreover, the designed resonator has a transmission zero at 1.6 GHz with corresponding attenuation level of −38.13 dB leading to having a desired transition band. As can be seen, this single resonator suffers from a narrow stopband with a low level of suppression, though. In order to clarify how the values of dimensions can affect the frequency response, several full-wave simulations versus La1 and W4a have been plotted in Fig. 4 and Fig. 5, respectively. In both cases the remaining parameters in Fig. 2a have been kept constant. It is important to note that in order to minimize the occupied area, the dimensions on Fig. 2a have been optimized in the final design (see Fig. 10).

Figure 4 shows the behavior of the proposed primary resonator against changing the value of La1. By increasing the value of La1 from 3.5 to 5.5 mm with steps of 1, the transition zero at 1.97 GHz will move to lower frequencies causing a sharper transition band.

Similarly, in Fig. 5, when W4a enhances from 0.1 to 0.5 mm with steps of 0.2 mm, transmission zero will

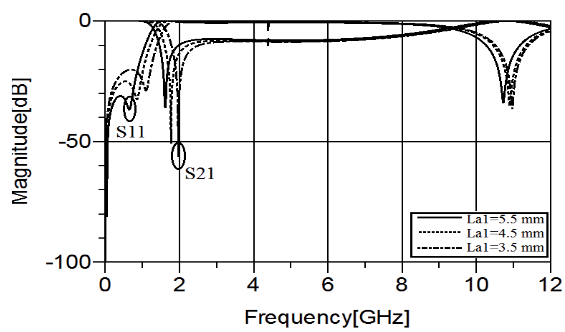

Fig. 4. The behavior of the proposed primary resonator against changing the value of La1.

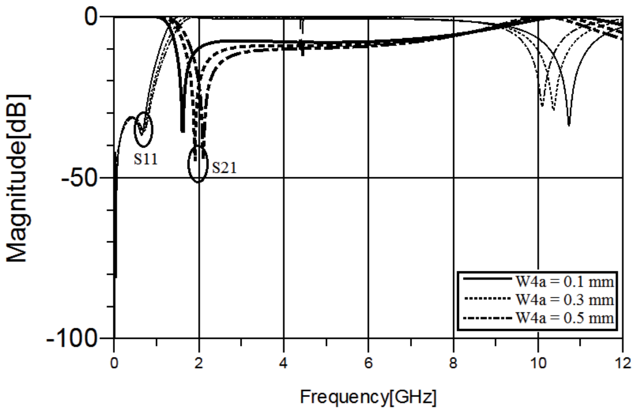

Fig. 5. The behavior of the proposed primary resonator against changing the value of W4a.

approach the upper frequencies, which means that it makes the sharpness performance worse.

According to the shown frequency response of the primary resonator in Fig. 3, it does not have a sharp roll-off rate and also suffers from a low level of suppression in the stopband. Connecting two out of primary resonators in series leads to creating transition zeros (TZs). More TZs results in expanding the stopband with an improved suppression level.

Figures 6a, b and c illustrate the configuration of the connected resonators in series, its equivalent LC circuit and the frequency responses of both of them. As it is observed from the EM simulation result, the insertion loss and return loss in whole pass band are less than 0.1 dB and −16.5 dB, respectively. The −3 dB operating frequency has partially gotten affected and shifted to 1.265 GHz which is trivial in comparison to the cut-off frequency of the primary case. The structure and the values of capacitances and inductors of LC circuits are remained without any changes in analogy with that shown in Fig. 2b. The only difference is appeared in the coupling capacitance of Cg which is 75 fF. Using the connected resonators and making some changes on their structures the final LPF can be obtained. To justify the reasons of employing each of resonators and the effects of them on the frequency response, separately, the performance description bellow have been done. Figure 7 shows the procedure of designing the proposed LPF, step by step.

In Fig. 7a, two main resonators are placed symmetrically around (Y) axis, which lead to a sharp transition band about 0.243 GHz from −3 to −60 dB. These resonators create two transition zeros (TZ1 and TZ2) at 1.49 and 1.65 GHz with corresponding attenuation levels of −56.58 dB and −57.34 dB, respectively. Since, TZ1 and the −3 dB cut-off frequency of 1.28 GHz are located close to each other, a sharp transition band can be achieved. However, the stopband bandwidth is not wide enough.

Notice that the utilized patches of each resonator are not the same size. In order to improve the stopband region the first suppressing cell using four radial stub patches has been designed. As shown in Fig. 7b, the first suppressing cell can reject spurious frequencies in the regions of a, b, c

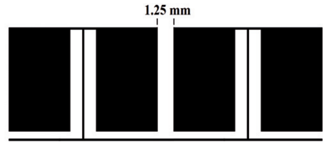

Fig. 6a. The configuration of the connected two out of the primary resonators in series.

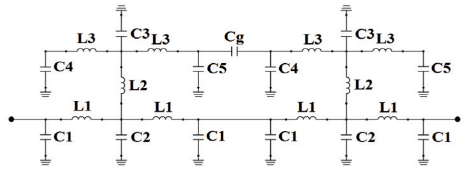

Fig. 6b. Its equivalent LC circuit.

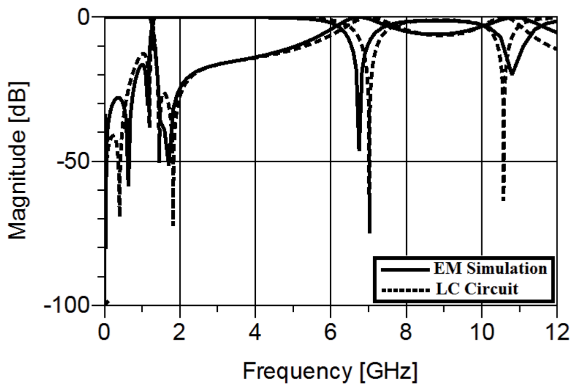

Fig. 6c. The frequency responses of microstrip and LC circuits.

and d better than −20 dB (F1 = 8.68 GHz, F2 = 11.67 GHz, F3 = 11.84 GHz, F4 = 22.77 GHz, F5 = 22.95 GHz, F6 = 26.17 GHz, F7 = 26.76 GHz, F8 = 28.99 GHz).

The used radial stubs are not able to suppress unwanted frequencies out of the mentioned regions, i.e. a, b, c and d, though. In order to reject the spurious frequencies in remained regions, four high-low impedance resonators as second suppressing cell are employed. Figure 7c shows the frequency response of the second suppressing cell. As can be seen, the used high-low impedance resonators can suppress the spurious frequencies in the regions of e, f, g and h with corresponding attenuation levels more than −20 dB (F9 = 2.93 GHz, F10 = 9.28 GHz, F11 = 12.88 GHz,

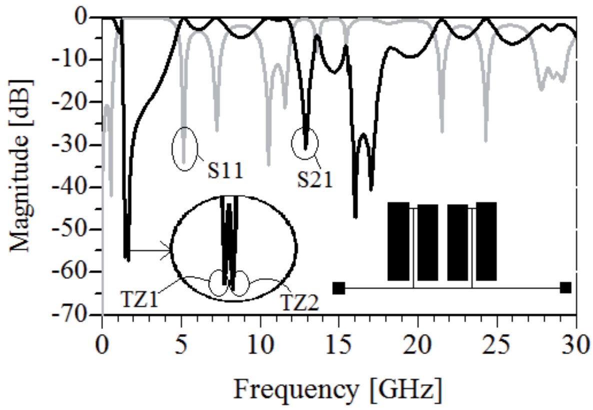

Fig. 7a. Simulation result of the main resonators.

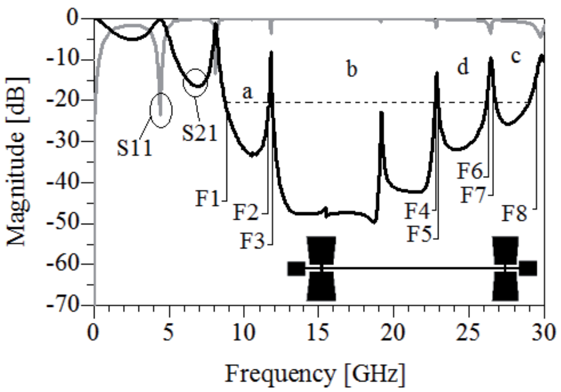

Fig. 7b. Simulation result of the first suppressing cell.

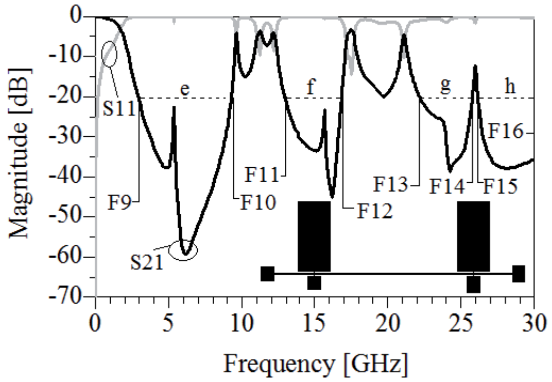

Fig. 7c. Simulation result of the second suppressing cell.

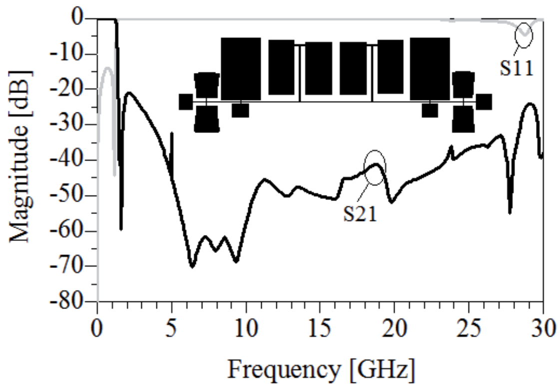

Fig. 7d. Simulation result of the proposed LPF.

F12 = 16.9 GHz, F13 = 22.14 GHz, F14 = 25.77 GHz, F15 = 26 GHz, F16 = 39.26 GHz). Finally, by combining both main resonators and the two designed suppressing cells a LPF with −3 dB cut-off frequency of 1.28 GHz has been proposed. The scattering parameters of the designed LPF with sharp cut-off and ultra-wide stopband are shown in Fig. 7d. As can be seen, the implemented LPF has a transition zero at 1.44 GHz with corresponding attenuation level of −40.765 dB, which leads to a sharp transition band.

3. Simulation and Measured Results

The simulated and measured scattering parameters are carried out using Agilent's ADS Electromagnetic simulator (EM Simulator) software and HP 8720B vector network analyzer, respectively. The proposed LPF with −3 dB cut-off frequency of f_c = 1.286 GHz is fabricated on a substrate with the thickness of 0.508 mm, a dielectric constant of 3.38 and the loss tangent of 0.0027. The results of both measurements and simulations are illustrated in Fig. 8.

As it is depicted, the implemented lowpass filter has an insertion loss better than −0.25 dB from DC to 1.1 GHz and a return loss less than −14.35 dB in whole passband. The measured results indicate that, the proposed LPF has a sharp transition band from 1.286 to 1.434 GHz with corresponding attenuation levels of −3 and −40 dB, respectively. The corresponded roll-off rate (250 dB/GHz) indicates a good skirt performance.

The stopband of the designed LPF can cover a frequency range from 1.413 up to 30 GHz (22.23 f_c) with a rejection level of −22 dB. The calculated relative stop-

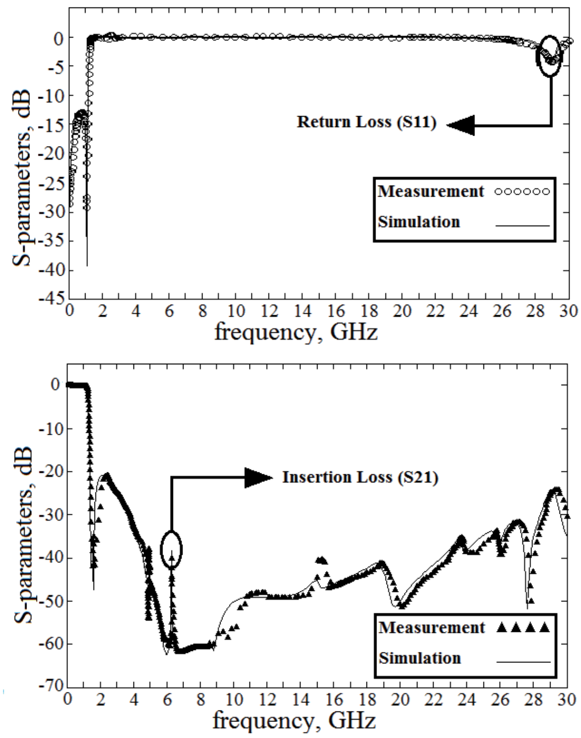

Fig. 8. The results of both measurements and simulations of the final LPF.

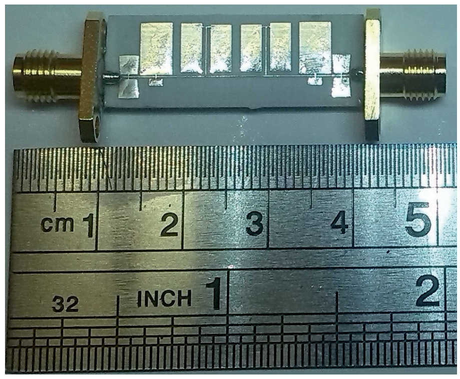

Fig. 9. The photograph of the proposed LPF.

Ref.	Roll-off Rate (-3 to -40 dB)	Relative stopband bandwidth (RSB)	Suppression Factor (SF)	Normalized circuit size (NCS)	Architecture Factor (AF)	Figure of merit (FOM)
[1]	95	1.4	2	0.104×0.214	1	11951
[2]	22	1.55	1.5	0.810×0.089	1	7095
[3]	62	1.72	3	0.310×0.240	1	4430
[4]	36	1.32	1.5	0.079×0.079	1	11543
[5]	37	1.65	1.5	0.091×0.111	1	9065
[6]	37	1.15	2	0.280×0.076	1	3999
[7]	30	1.25	1.5	0.080×0.080	1	8789
[8]	200	1.36	2	0.801×0.374	1	1815.9
[9]	82	1.28	2.5	0.110×0.220	1	10842
This work	250	1.82	2.2	0.219×0.072	1	63483

Tab. 1. Comparison between the performance of the proposed Lowpass Filter and previous work.

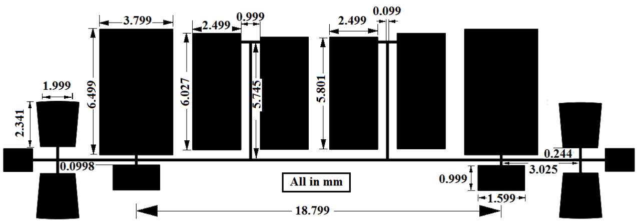

Fig. 10. The dimensions of the proposed LPF.

band width equal to 1.82 verifies a desired rejection band performance. Figures 9 and 10 illustrate the fabrication and dimensions of the proposed LPF.

Table 1 indicates a comparison between the published LPFs and this work.

4. Conclusion

A microstrip lowpass filter with −3 dB cut-off frequency of 1.286 GHz has been designed and fabricated. Sharp cut-off and ultra-wide stopband are achieved by using two main resonators and two different suppressing cells, respectively. The insertion loss less than 0.25 dB and return loss better than −14.35 dB exhibit a good in-band performance.

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