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First order parallel coupled BPF with wideband rejection based on SRR and CSRR

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Abstract

In this paper a new approach for first order Chebyshev parallel coupled Bandpass filter resonant at 1 GHz is presented to obtain better results (wideband rejection, high selectivity and low bandpass insertion loss) compared to conventional design. The proposed filter (a tri-formation consisting of CSRR, SRR and stubs of stepped impedance are loaded microstrip resonator) can be configured, by laying split ring resonator (SRR) and complementary split ring resonator (CSRR) with 50 Ω microstrip lines, in addition to effect of loading two stubs of stepped impedance around center of midline microstrip with impedance line 55.36 Ω of parallel coupled. The proposed filter produces high selectivity from passband to stopband transition equals to 307.5 dB/GHz and an excellent wide stopband performance extend from 1.22 GHz to 5 GHz (harmonics repression till for 5 f_0); all are bellow -20 dB excepting one transmission zero of -19 dB, that can be eliminate the harmonic superior frequencies without using any external Bandstop filter. Also, enhancement low bandpass insertion loss level, where it reaches 0.25 dB at fundamental centered frequency ($f0$ = 0.96 GHz) with 21% bandwidth. The proposed filter is designed and simulated with computer aided of Ansoft HFSS software package which ordinarily used in microwave application.

Keywords: *bandpass filter, microstrip filters, MTMs filters, parallel coupled BPF, SBF based on SRR/CSRR*

1. Introduction

Microstrip bandpass filters (BPF) based on parallel coupled microstrip lines have been vastly used in microwave communication systems in order to allowing signal in required band of frequencies and rejecting all else. Parallel coupled microstrip line is the concerted one because of easy available employ method, planar structure, and readily designs procedures. But it's suffering from presence of superior frequencies nearby desired passband. This is fundamentally due to variance in even and odd mode phase velocities and disseminated impression of microstrip line. As well as harmonic frequencies, it has progressive cutoff response (low selectivity). To achieve a single desired passband with high selectivity response the superior frequencies should be suppression with achieving high selectivity characteristic.

Distinct techniques have been notified in literature to fix this issue. A coupled microstrip lines based on corrugated form are employed to balance even and odd mode phase velocities for achieving wide stopband in [1]. Established on methodology design (two method) for repressing spurious frequencies in dual band stopband filters, but it occupies a large area compare to a filter without using spurious frequencies repression [2]. Microstrip sections of Parallel coupled through a slotted ground plane are presented as structure blocks of PCML bandpass filters for spurious rejection in [3]. Design an open stub band stop filter (BSF) with asymmetrical double spurlines, used for repression first harmonic of parallel coupled bandpass filter in [4]. However, enhancement methods which reported above do increase over all structure size, principally in low frequencies operation. Therefore, it has been a growing regard for the use of metamaterial structures such as SRR or other structures [5], in the investment of compact microwave structures employing printed circuit bodies and MIMC techniques [6, 7]. Metamaterials (MTMs) are located as synthetic, operatively identical (moderate cell size very smaller than guided wavelength) and show highly extraordinary properties (effective values of ε_r and $\mu_r < 0$) [8]. Split ring resonator (SRRs) were one of the first chips suggested for metamaterial structure. Metallic metamaterial contains double SRRs to obtain magnetic

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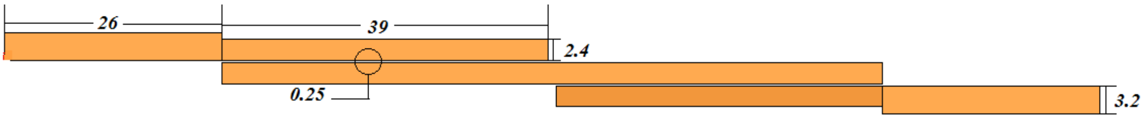
response at a concatenation of electromagnetic in microwaves [9, 10]. There are a lot of studies treated with metamaterial based BPFs over employing different constructions and different method, some of these papers are reviewed as fallows.

Explain possibility of sub-wavelength split ring resonator (SRR) and complimentary split ring resonator (CSRR) implications to construct microstrip stopband filter with band stop (4 to 5.8 GHz) [11]. SRR and CSRR resonators have been explained as a wherewithal for repression of spurious in microstrip and CPW techniques [12, 13]. A compact-BPF with second harmonic repression (S_{21} is 17.7 dB at frequency of 14.7 GHz) can be achieved employing triple-SRR is presented in [14]. In [15] a coupled metamaterial-based resonators (MBRs) combining with the defected ground structure (DGS) is introduced, this technique has been expanded wideband of bandpass filter, and revelation wide stopband repression till for 4 f_0 with S_{21} of 8~35 dB level. Bandpass filter with external recently proposed band stops filter (founded using three SBFs open stub, spurline, and CSRR) were connected in cascade way to realize wide stopband about to 5 f_0 with adequate selectivity is presented in [16]. Moreover, other filters are achieved by using of SRRs and CSRRs [17-19]. It is very important to take into consideration use of metamaterial SRRs in filter constructing, especially for low frequencies to avoiding increase the size of structure (SRRs mostly are positioned close to signal strip, it effects in increased area).

In this paper to repression unwanted superior frequencies, a rectangular SRR cell is placed in the center of microstrip line (output port of the filter) to obtain a rejection band filter. A wide band rejection as well as realize very high selectivity are achieved by placing a rectangular CSRR under 50Ω microstrip line (input port of the filter). Finally, to get zero transmission band, a two pairs of stepped impedance stubs loaded microstrip resonator (SISLM) are located in the center of parallel coupled microstrip line. The newly proposed bandpass filter (BPF), which constructed using SRR, CSRR and SISLM is established using finite elements based Ansoft HFSS software [20].

2. Evaluation the Performance of Conventional Parallel Coupled BPF

To characterize the major issue which intended to solve, a first order equal repel parallel coupled BPF has been designed here employing criterion design in [21, 22], centered at f_c=1 GHz with a fractional bandwidth (Δf) is 15% on FR4_epoxy 4.4 substrate with height 1.6 mm. The physical dimensions and layout parameters of conventional BPF are shown in Figure 1.



(a)

i	Z_{0e} Ω	Z_{0o} Ω	W_i (mm)	L_i (mm)	S_i (mm)
1	73.05	38.73	2.4	39	0.25

(b)

Figure 1. (a) BPF schematic layout, and (b) physical dimensions and layout parameters

Simulated scattering parameters (S_{11} and S_{21}) are shown in Figure 2. From the figure, the maximum insertion loss (S_{21}) is 1.17 dB, and the return loss (S_{11}) is better than 20 dB with 22% bandwidth at center frequency of 1 GHz. Also, it can be observed that the spurious frequencies (S_{21}) (f_{s1}, f_{s2} and f_{s3}) appear at doubles of fundamental frequency, as fallows; first harmonic f_{s1} is 5.9 dB at 2.15 GHz, while f_{s2} and f_{s3} are 3.8 and 5.1 GHz at 3 GHz and 4.2 respectively. These spurious frequencies retrograde the performance of BPF. Finally, to complete the whole description of simulated results it should be noted that the one of the influential parameters for BPF is selectivity (ξ) (see (1)) [23, 24].

$$\xi = \frac{\alpha(\min)-\alpha(max)}{fst-fc} \tag{1}$$

where α(min) and α(max) is 3 dB and 20 dB attenuation respectively, while f_{st} is 20 dB stop-band cutoff frequency and f_c is 3 dB cutoff frequency.

From results in Figure 2, it can be seen that the conventional BPF has no selectivity in stopband region (region of frequencies that > 1 GHz) according to criterions of (1). Now there are two essential dilemmas in this conventional BPF, the first dilemma is represented by existence of spurious frequencies in stopband region, and the second dilemma is performed by absence the selectivity. So, the proposed filter in this paper will solve this problem by embedding the suggested metamaterial that consisting of CSRR and SRR in input and output port of conventional filter to obtain a wide suppression bandwidth stopband filter as well as a high selectivity.

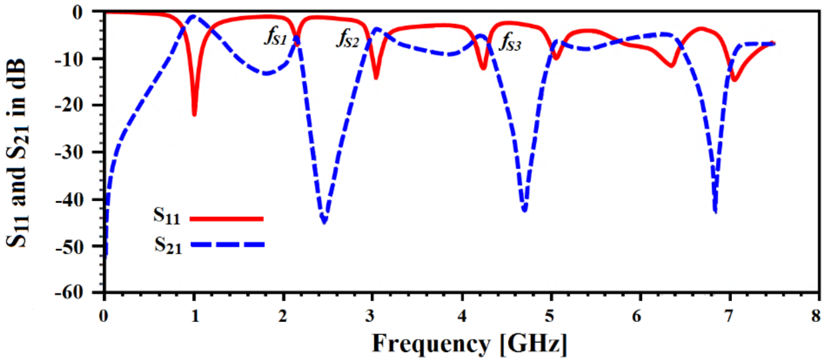
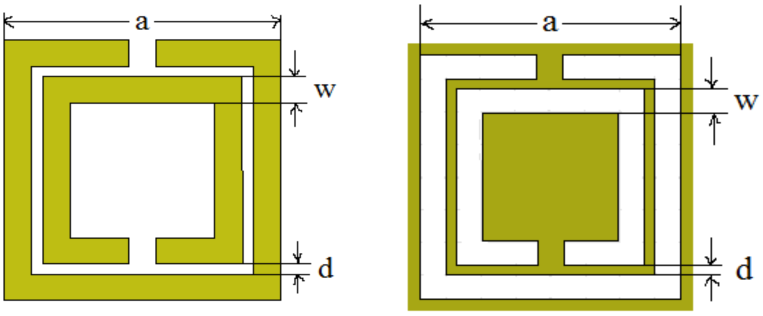


Figure 2. Simulated scattering parameters of conventional BPF

3. Design of Sharp Wide Band-stop using SRR and CSRR

Newly split ring resonator (SRRs) submitted by Pendry et al. [9] occasionally called Negative Refractive Index Materials [25]. SRRs are a couple of concentric velar rectangular rings with sections in them at adverse ends as shown in Figure 3 (a). a magnetic field (H) utilized vertical to the square ring flatten produces currents which, freedom on resonant royalties of the structure, turn out a magnetic field that may all counteract or foster the incident field. On other side, the complementary split ring resonator (CSRRs) is obtained by etching SRRs in the ground. This process construction with outlets is achieved as shown in Figure 3 (b).



(a) (b)

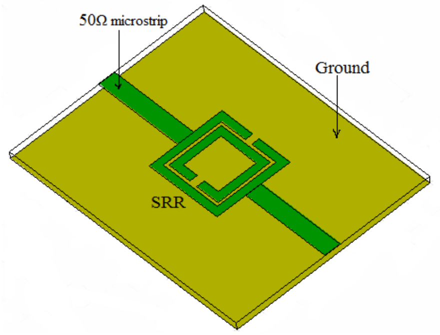
Figure 3. (a) Square split ring resonator and (b) complementary square split ring resonator

This paper picks feature of small electrical size of SRRs at resonance (~ $a=\frac{\lambda}{10}$ or less) to design two planar cells as microstrip stopband filter using two methods; first method is by placing SRR$_s$ as a loaded centered in microstrip line as shown in Figures 4, while a CSRR$_s$ etched in ground plane exactly below center of microstrip line is the second method as shown in Figure 5.

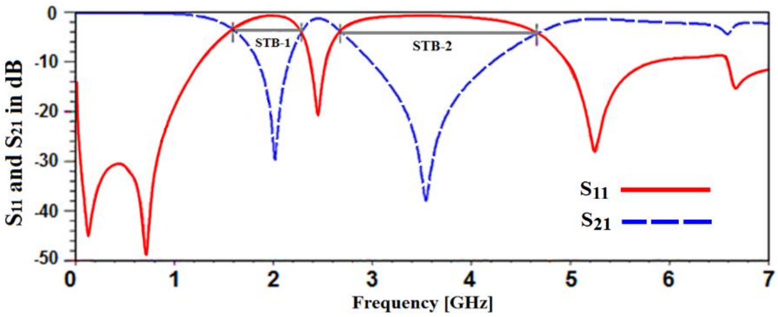
For all simulations, FR4-epoxy (ε_r = 4.4) substrate with height 1.6 mm is used. In order to obtain a wide band, stop harmonics rejection in conventional BPF, it must be taken into consideration bands region of superior frequencies, which are intended to repression. Figure 2 indicates two regions of spurious passband that upper than -20 dB; first region is (1.2-2.25 GHz) and second region is (2.8-4.47 GHz), however there are two regions of band stop are; (2.27-2.76 GHz) and (4.5-4.88 GHz). For this reason, the design resonance frequency in both two methods of SRR$_s$ and CSRR$_s$ stopband structures must be choose in order to realize required band stop, which reject all spurious frequencies in conventional BPF. This step can be obtained by tuning resonance frequency of SRR and CSRR with aid of system dimensions a, w and d [11].

Here it has been chosen the Proposed devise dimensions (a, w, and d) are equals for each of square SRR and CSRR, in which SRR resonant at 2 GHz and 3.58 GHz (as shown in Figure 4 (b), SRR producing two wide regions of stopband, which till for third spurious frequency f_{s3} of conventional BPF). In same time, Proposed dimensions progress of 1.3 GHz resonance frequency in CSRR type (producing a sharp rejection with narrow band to obtain high selectivity in addition to realizing a stopband in region less than 1.6 GHz as shown in Figure 5 (b)). And these dimensions are; a = 15 mm, w = 1.5 mm, and d = 0.6 mm (g = 1.5 mm, where g is a split gap in one ring as indicated in Figure 3 (a)).

Now, the concerted metamaterial cell that consists of SRR and CSRR shown in Figure 6 (a) will provide for achieving a wide stopband with sharp rejection. Figure 6 (b) indicate insertion loss (S_{21} with a 3 dB cutoff frequency of 1.25 GHz) parameter of combined metamaterial cell in Figure 6 (a), it can be seen that there are three regions of stopband, the first one is the result of effect of CSRR, while second and third are result of SRR effect, so the resultant is a wide rejection band, which represses more than third harmonic frequency f_{s3} of conventional BPF.

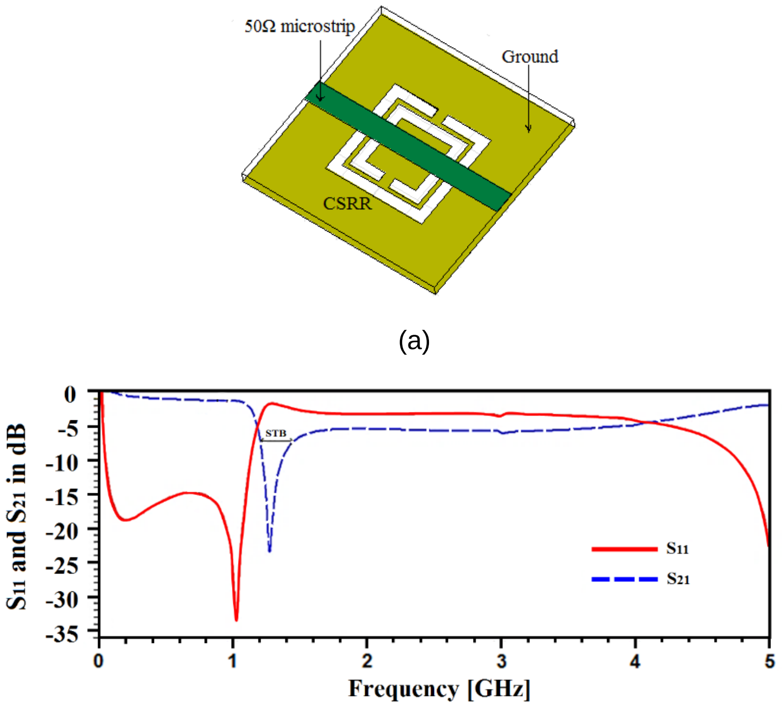


(a)



(b)

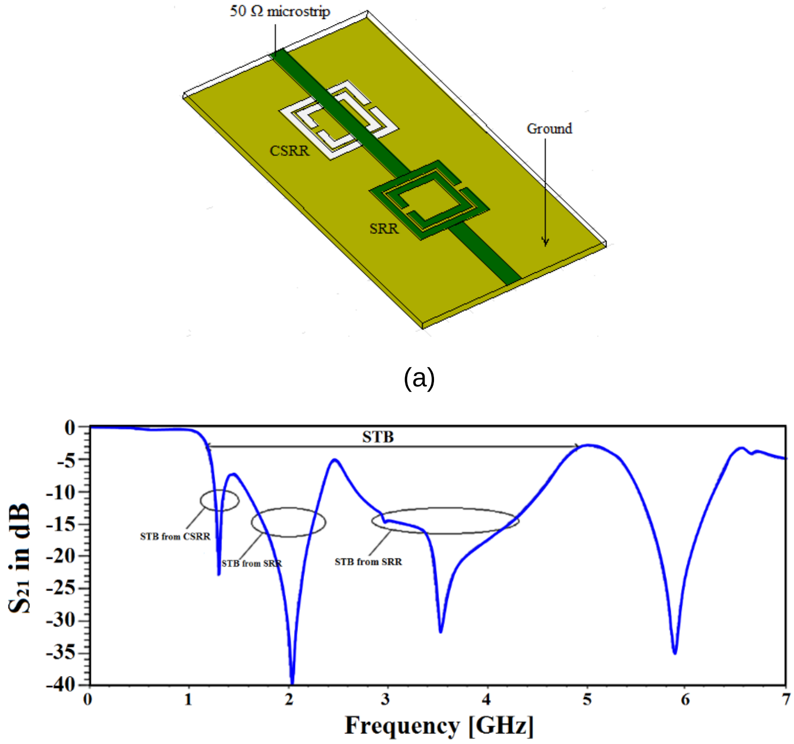
Figure 4. (a) Plane geometry of SRR loaded microstrip, and
(b) simulated scattering parameters of SRR geometry



(a)

(b)

Figure 5. (a) Plane geometry of CSRR loaded microstrip, and (b) simulated scattering parameters of CSRR geometry



(a)

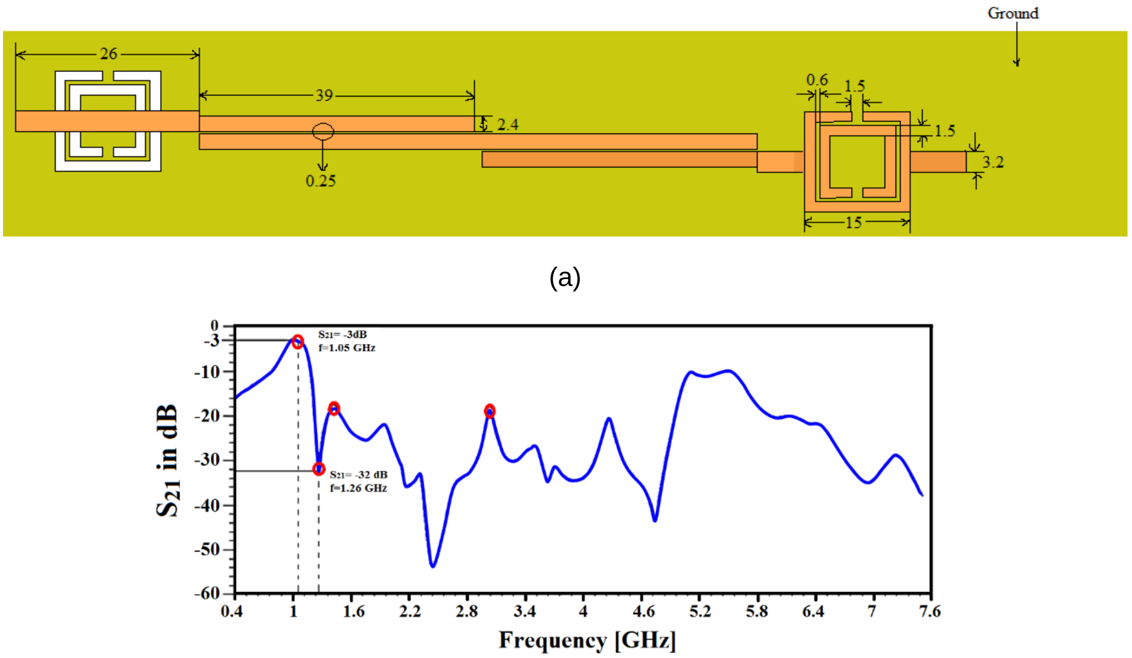
(b)

Figure 6. (a) Plane geometry of CSRR and SRR loaded microstrip, and (b) simulated scattering parameter of geometry

4. Spurious Frequencies Repression of Conventional BPF

In order to obtain a BPF with wide stopband and sharp rejection exactly as that achieved in combined metamaterial cell in Figure 6 (b), CSRR and SRR loaded must be redistributed in conventional BPF in way so as to ensure preservation of combined metamaterial cell performance, and this is done by etching a CSRR in ground plane exactly below center of microstrip line (input port of BPF), and placing SRR_s as a loaded centered in microstrip line (output port of BPF) as shown in Figure 7 (a).

To brief the effect of proposed technicality including CSRR and SRR, the performance of proposed filter is shown in Figure 7 (b), and it can be spotted that the design filter has a perfect stopband performance with a bandwidth is achieved from 1.22 GHz to the region of 5 GHz; all are bellow -20 dB excepting two transmission zeros -18.3 dB and 19 dB can be found at 1.4 GHz and 3 GHz respectively. As the result, the upper repudiation stopband becomes sharper than in conventional structure, it shows a bandpass characteristic with 3 dB cutoff frequency of 1.05 GHz. The insertion loss extends 32 dB at 1.26 GHz, so the selectivity is 138 dB/GHz, this illustrates the proposed filter much decliner than conventional filter. It can also be observed that there is one fundamental passband (at 3 dB cutoff frequency) from 0.96 GHz to 1.04 GHz with 0.06% bandwidth at center frequency of 1 GHz corresponds to 2.6 dB level of insertion loss. That's mean the proposed filter produced high insertion loss than conventional filter (1.17 dB insertion loss level). This explain that the employing of technicality including CSRR and SRR derived to perturbation in passband performance, for this reason the proposed filter resolved by loading two double section stubs of stepped impedance to the parallel coupled microstrip line of the proposed filter to improve passband performance.



(a)

(b)

Figure 7. (a) Proposed BPF schematic layout with physical dimensions (in mm), and (b) simulated scattering parameter of proposed filter

5. Realization of Modified Proposed BPF

The proposed filter designed in the previous section is moderated by introducing two symmetrical CSRR and SRR loaded, is succeeded in realizing a sharper rejection wide stopband, but has a perturbation in passband performance. In order to solve this imperfection, a two loaded of stepped impedance stub microstrip resonators are organized by loading around center of midline microstrip ($w = 2.4$ mm with impedance line 55.36 Ω) of parallel coupled in proposed first order filter with two symmetrical stubs of stepped impedance as shown in

Figure 8. In the modified proposed BPF filter, all the parameters of the initial proposed filter in Figure 7 (a) are kept unchanged while dimensions of the two stubs of stepped impedance are designed here employing criterion design in [16], as indicated in Figure 9. So, the high impedance line (series inductor) is set as (w = 0.5 mm with Z_{high} = 120 Ω) and the low impedance line (shunt capacitance) is set as (w = 12.25 mm with Z_{low} = 20 Ω).

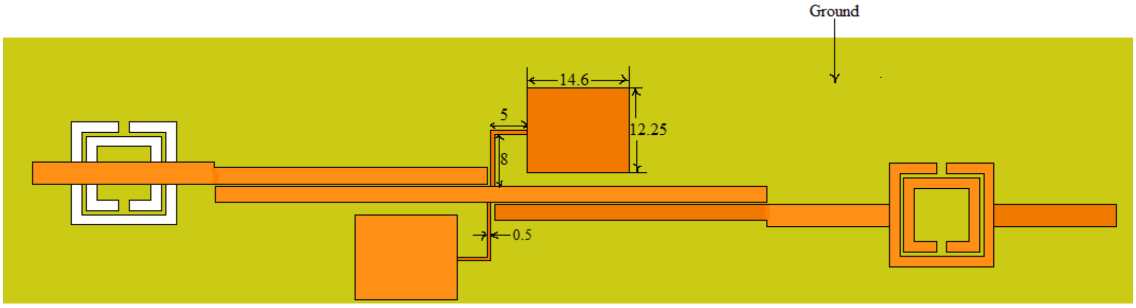


Figure 8. Modified proposed BPF schematic layout with physical dimensions for two symmetrical stubs (in mm)

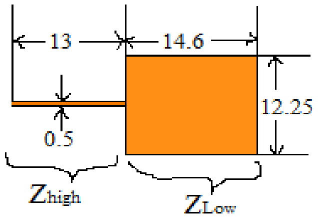


Figure 9. Physical dimensions for high and low impedance sections (in mm)

The performance of the modified proposed filter is shown in Figure 10, and it can be spotted that the design filter has a stopband performance with a bandwidth is achieved from 1.22 GHz to the region of 5 GHz; all are bellow -20 dB excepting one transmission zero of -19 dB can be found at 3.04 GHz, that's an excellent stopband is obtained. As the result, the upper repudiation stopband becomes sharper than in proposed structure, it shows a bandpass characteristic with 3 dB cutoff frequency of 1.03 GHz. The insertion loss extends 64.5 dB at 1.23 GHz, so the selectivity is 307.5 dB/GHz, this illustrates the modified filter much decliner than proposed filter. Finally, the most important part, which two stubs of stepped impedance microstrip resonators are designed for it, is to produce low insertion loss of fundamental bandpass than in proposed and conventional filters. Where it was achieving a fundamental passband (at 3 dB cutoff frequency) from 0.8 GHz to 1.03 GHz with 21% bandwidth at center frequency of 0.96 GHz corresponds to 0.25 dB level of insertion loss.

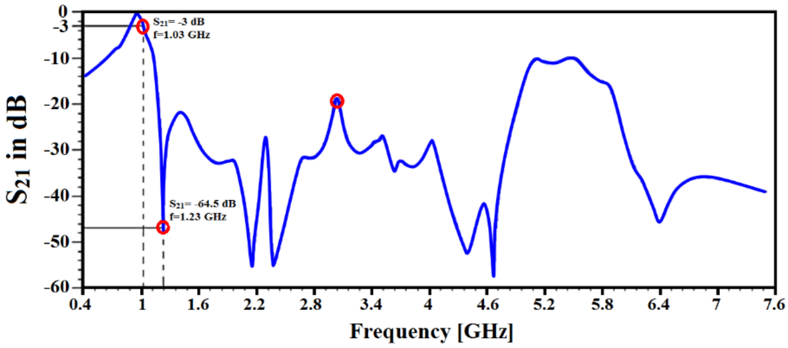


Figure 10. Simulated scattering parameter of modified proposed filter

After elicitation the optimized electrical parameters of modified proposed BPF, the group delay for conventional BPF and modified proposed BPF are plotted in Figures 11 and 12 respectively. For conventional BPF maximum group delay is 1.85 ns at passband center frequency of 1 GHz, while for modified proposed BPF maximum group delay is 3.5 ns at passband center frequency of 0.96 GHz. In general, it can be seen the variation of group delay for conventional is less than that for modified proposed filter, this is due to loading CSRR, SRR and two stubs of stepped impedance, which leads to increase of group delay than in conventional filter.

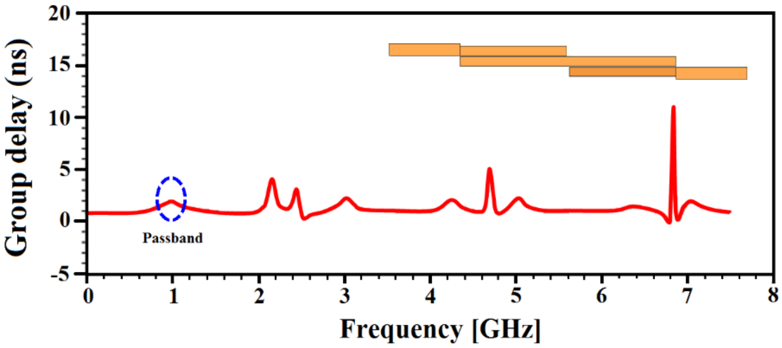


Figure 11. Simulated group delay of conventional filter

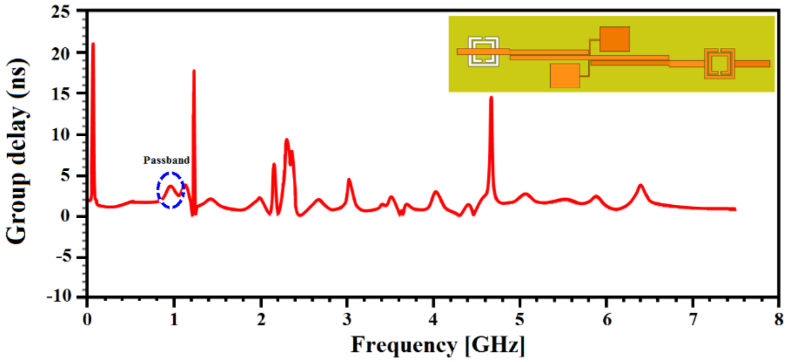


Figure 12. Simulated group delay of modified proposed filter

6. Conclusion

In this paper, the proposed filter has been devised in two stages, first stage by loading CSRR and SRR, while second stage can be obtained by adding two stepped impedance stubs to produce a tri-formation consisting of CSRR, SRR and stubs of stepped impedance are loaded microstrip resonator. The proposed bandpass filter illustrated above designed for achieving wideband rejection and high selectivity. It produces high selectivity from passband to stopband transition equals to 307.5 dB/GHz and wide stopband extend from 1.15 GHz to beyond 7 GHz; all are bellow -10 dB, while it produces an excellent wide stopband performance extend from 1.22 GHz to 5 GHz (harmonics repression till for 5 f_0); all are bellow -20 dB excepting one transmission zero of -19 dB. Also, enhancement bandpass insertion loss level, where it reaches 0.25 dB at fundamental centered frequency (21% bandwidth centered at f_0 = 0.96 GHz), while it was 1.17 dB in conventional filter (22% bandwidth centered at f_0 = 1 GHz). Finally, due to loading CSRR, SRR and two stubs of stepped impedance the maximum group delay for proposed filter is 3.5 ns at fundamental passband, while for conventional the maximum group delay is 1.85 ns at fundamental passband, and this is considered a slight variation.

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