# Design of Tri-Band Bandpass Filter Based On Quad-Sections SIR Resonator for Wireless Applications

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*Abstract:* - In this article, a new tri-band bandpass filter, operating at 2-2.6 GHz, 3.5-4.5 GHz and 5-5.8 GHz for GSM, WiMAX and WLAN application is proposed. Two quad sections SIR resonators and corresponding feeding structures are introduced to enhance the tuneable range of operating frequencies. Using source/load coupling can realize two controllable transmission zeros around each operating band. The filter is analyzed and solved in terms of the transmission line model using finite element method (FEM) and results are refined by full-wave simulator CST Microwave Studio 2009 and SONNET Version.11. The comparison between magnitudes of s-parameters simulation results with SONNET and CST Microwave Studio simulators are also presented. The results show a good match between two simulation results with different commercial software for the proposed bandpass filter. The desired operating bands are covered by the response of the different software's.

*Key-Words:* - SIR resonator, microstrip bandpass filter, WLAN and WiMAX applications, tri-band filter, CST Microwave Studio, SONNET, Quad sections resonators.

## 1 Introduction

High-speed wireless Local Area Networks (LAN's) and other services such as global positioning systems (GPSs), Bluetooth, IEEE 203.16 worldwide interoperability for microwave access (WiMAX) systems and Industrial, Science and Medical (ISM) operate at frequencies between 2 GHz and 6 GHz with bandwidths up to hundreds of Megahertz. In order to accommodate this multi-band RF signal reception and transmission into a single RF transceiver, dual-band or multi-band components are needed to integrate circuits operating in different bands into a single unit so that size, cost and component count can be reduced. To meet the demand, much research has been carried out [1]-[7].

Step-impedance resonators (SIR's) are employed in the design of dual-band filters, due to their dual-band and tuneable harmonic properties. Cheng [8] describes a dual-band filter with half-wave step-impedance resonator in a classical comb-line configuration, which creates a strong transmission zero between the two pass-bands.

The basic method for designing multi-band bandpass filters consisted of using several resonators that were responsible for each resonant band. However, this method not only increased the device volume but also required additional matching circuits [9].

Bandpass filters designed with traditional microstrip parallel-coupled half-wavelength resonator has narrow stopband between the fundamental response and the first spurious response, so the stepped-impedance resonator (SIR) was presented in the past years not only to restrain the spurious responses, but also to shorten the resonator size. SIR also can be used to design tri-band even multi-band filters for tuning the higher-order resonant modes conveniently. The deficiency of this kind of resonator is its resonant frequencies are dependent, and transmission zeros are difficult to implement, especially for the fundamental SIR [10].

Stepped impedance resonators are widely used in filter designs to suppress the spurious response. To maximize the out-of-band attenuation, the stepped impedance ratio value used in the SIR is set to a small value. As a result, the quality factor of the SIR is reduced especially when narrow traces are used and the in-band insertion loss of the filter using this SIR becomes high [11, 12].

The conventional SIR, originally proposed in [13], consists of line sections having two different characteristic impedances. When these two-line sections are restricted to have the same electric length, the required impedance ratio of the SIR can be calculated using a simple formula for two arbitrarily specified resonant frequencies. In order to have a compact structure, a semi-loop SIR filter has been synthesized by modifying classic single SIR filters.

In this paper, a new tri-band BPF for wireless communications using quad-sections SIR microstrip line is proposed. The features of the scheme in comparison with proposed in literature [14, 15] are simple design, compact size, and low profile. Two different electromagnetic simulators are used to validate the results obtained for the return and the insertion loss responses.

## 2 Basics of Stepped Impedance Resonators

Stepped impedance resonator (SIR) is a TEM or quasi-TEM mode transmission line resonator that consists of two or more lines with different characteristic impedance. Fig.1 shows the two most popular SIR sections, short-circuited and open-circuited quarter wavelength resonators with the characteristic impedances Z1, $Z_2$ and electrical length $\theta_1$ and $\theta_2$ respectively [16].

The input admittance of $\lambda g$ /4 SIR, shown in Fig.1 (a) is equal to:

$$Y_{in} = jY_2\ (Y_2 tan\theta_1 . tan\theta_2 - Y_1)/(Y_2 tan\theta_1 + Y_1 tan\theta_2) \qquad (1)$$

Short-circuit quarter wavelength resonators behave like a parallel resonant circuit.

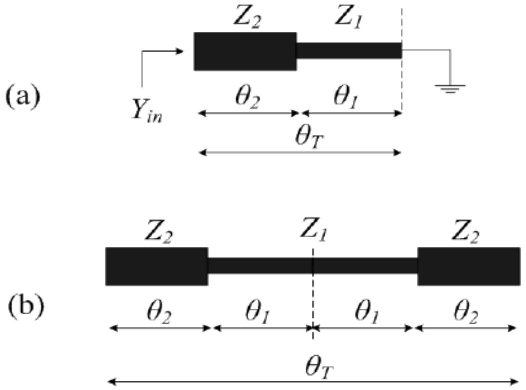


Fig.1: Stepped impedance resonators: (a) quarter-wavelength type; (b) half-wavelength type.

The parallel resonance condition $Y\ in$= 0 of the quarter - wavelength SIR will be:

$$tan\theta_1 . tan\theta_2 = Y_1/Y_2 = Z_2/Z_1 = K \qquad (2)$$

Impedance ratio $K$ and $\theta_1$, $\theta_2$ are determined the resonant condition of SIR. The total electrical length of resonator $\theta_T$ at resonant condition is given by:

$$\theta_T = \theta_1 + \theta_2 = \theta_1 + tan^{-1}\ (K/tan\theta_1) \qquad (3)$$

The total electrical length of the resonator has maximum value when $K \geq 1$ and minimum value when $K \leq 1$. The condition for these maximum and minimum values has been derived as [17]:

$$\theta_1 = \theta_2 = tan^{-1}\sqrt{K} \qquad (4)$$

The condition $\theta_1=\theta_2$ is a special condition which gives the maximum and minimum length of SIR which can be expressed as [18]:

$$\theta_{T\,min} = \theta_{T\,max} = tan^{-1}\left(2\sqrt{K}/(1-K)\right) \qquad (5)$$

Equation (5) provides the minimum value for $\theta_T$ when $0 < K < 1$ and $0 < \theta_T < \pi/2$, and maximum value for $\theta_T$ when $K > 1$ and $\pi/2 < \theta_T < \pi$.

The impedance ratio is given when follows to the ratio of the resonant frequency, $f_2/f_1$, and can be found as [19]

$$\begin{aligned} f_2/f_1 &< 2\, when\;\; K > 1 \\ f_2/f_1 &= 2\, when\;\; K = 1 \\ f_2/f_1 &> 2\, when\;\; K < 1 \end{aligned} \qquad (6)$$

The distinct feature of SIR comparing with UIR is that the resonators' length can be controlled using the impedance ratio $K$. This can be used to design SIRs which are shorter than their UIR counterparts resonating at the same fundamental resonance frequency.

In bandpass filter design, SIRs are employed to control the first spurious passband of filters. This is used to design bandpass filters with extended stopband, as well as to design dual-band bandpass filters [20].

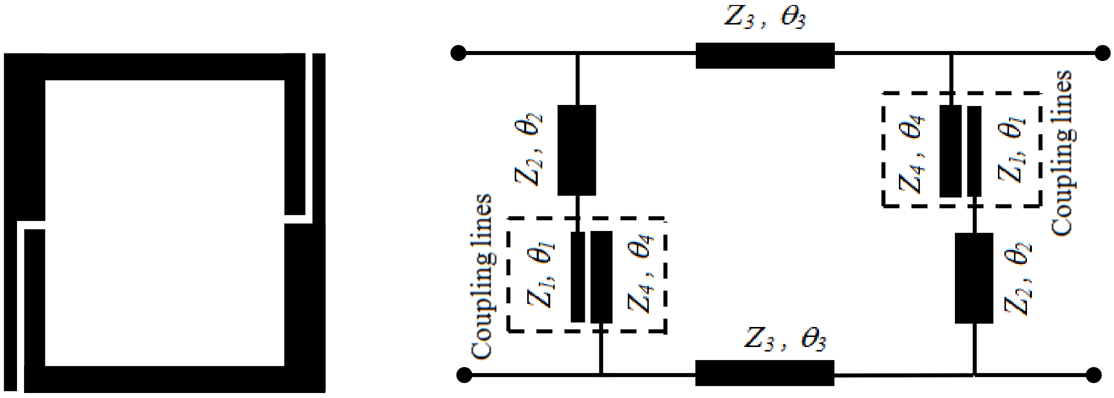
## 3 Proposed Quad-section SIR Resonators

The proposed quad-section SIR is shown in Fig. 2. The characteristic impedances of a quad-section SIR are Z1, Z2, Z3and Z4 and the corresponding electric lengths are $\theta_1$, $\theta_2$ ,$\theta_3$and $\theta_4$ respectively.

if $K_1 = Z_4/Z_3$, $K_2 = Z_3{=}Z_2$, $K_3{=}Z_2/Z_1$ and $\theta1{=}\theta2{=}\theta3{=}\theta4{=}\theta$, $\theta$ can be calculated as:

$$\theta = tan^{-1}\sqrt{\frac{K_1K_2K_3}{K_1+K_2+K_3+1}} \qquad (7)$$

and the total electric length can be got as



(a) (b)

Fig.2 Quad- section SIR Resonator and its equivalent circuit, (a) resonator structure and (b) its equivalent circuit

$$\theta_T = 8tan^{-1}\sqrt{\frac{K_1K_2K_3}{K_1+K_2+K_3+1}} \qquad (8)$$

For the split ring quad-section SIR, resonant condition can be got on the basis of transmission line theory and synthesizing the equivalent input impedance of each step as:

$$\begin{aligned} &1-\frac{Z_1}{Z_2}\,tan\theta_1.tan\theta_2-\frac{Z_1}{Z_3}\,tan\theta_1.tan\theta_3 \\ &-\frac{Z_2}{Z_3}\,tan\theta_2.tan\theta_3-\frac{Z_1}{Z_4}\,tan\theta_1.tan\theta_4 \\ &-\frac{Z_2}{Z_4}\,tan\theta_2.tan\theta_4-\frac{Z_3}{Z_4}\,tan\theta_3.tan \\ &+\frac{Z_1Z_3}{Z_2Z_4}\,tan\theta_1.tan\theta_2tan\theta_3.tan\theta_4 \\ &=0 \qquad (9) \end{aligned}$$

By properly selecting the relevant impedance or the strip width ratio, the tri-band filter using stepped-impedance resonators can be created. Here, simple and compact quad-section split ring SIR is used to get a tri-band operation.

Presented tri-band bandpass filter with quad-section split ring SIR is shown in Fig. 3, where, $W$=2.5 *mm*, $W_1$=8 *mm*, $W_2$=1.28 *mm*, $W_3$=2.68 *mm*, $W_4$=0.6 *mm*, $L$=19 *mm*, $L_1$=20.2 *mm*, $L_2$=11.2 *mm*, $L_3$=1.69 *mm*,

The filter is designed on a substrate with dielectric constant of 10.8 and a thickness of 0.768 *mm*, and I/O feed lines are microstrip lines with characteristic impedance of 50 ohms, and all gaps are 0.5 mm dimension. The filter has dimensions of 28*mm*× 60*mm*×0.768*mm.*

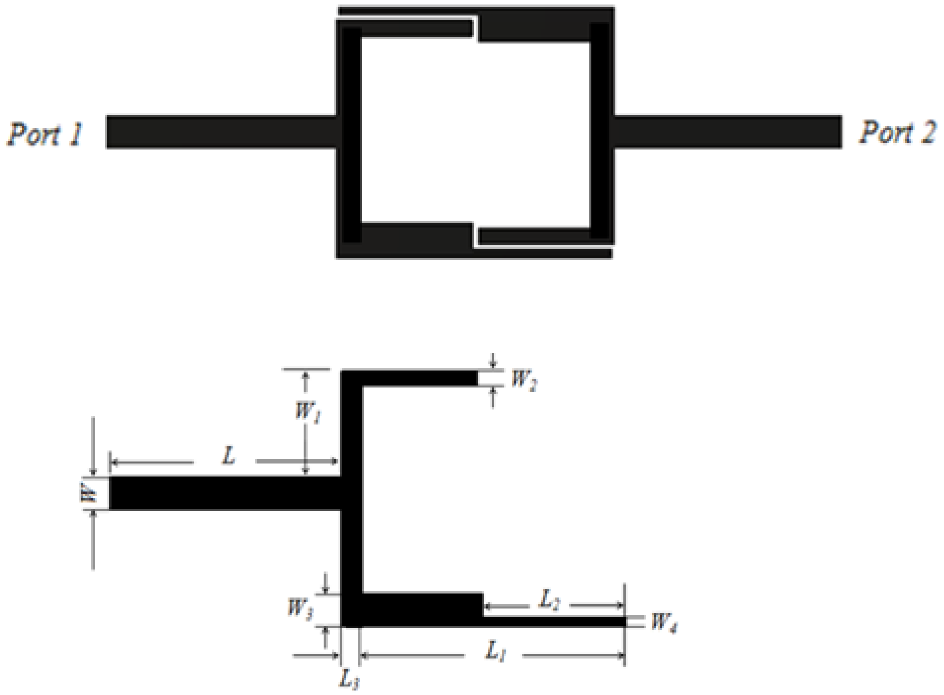


Fig.3 The proposed stepped impedance resonators (SIR), (a) bandpass filter structure, and (b) resonator dimensions.

## 4 Simulation Results and Performance Evaluation

Filter structure depicted in Fig.3 has been modelled and analyzed using the SONNET V.11 simulator [21]. Simulation results on return and insertion losses are depicted in Fig. 6. . This simulator performs electromagnetic analysis using the method of moments (MoM). By controlling the length of the resonators and the source-load coupling, up to three bands can be obtained, with a sharp skirt on the upper and lower sides of the pass-bands. The corresponding simulation results of return loss and transmission responses are shown in Fig.4.

In this figure, three bands with -10 dB return loss can be observed clearly. The first is from 2.1-2.6 GHz with two resonant frequencies of 2.117 GHz and 2.57 GHz with return losses of -13.2 dB and 30.45 dB respectively. The second one is from 3.5-4.5 GHz with two resonance frequencies at 3.6 GHz and 4.5 GHz with a return loss of -34.68dB and -26.53dB respectively. The third band is from 5-5.7 GHz with 5.1 and 5.61 GHz resonant frequencies and -31.93 and -31.85 dB return losses respectively. The transmission zeros are symmetrically located around the first band on 1.72 GHz and 2.92 GHz with -25.02 dB and -38.13 dB insertion loss, respectively. The upper transmission zero of the middle band is located at 4.7 GHz with insertion loss of -35.08 dB.

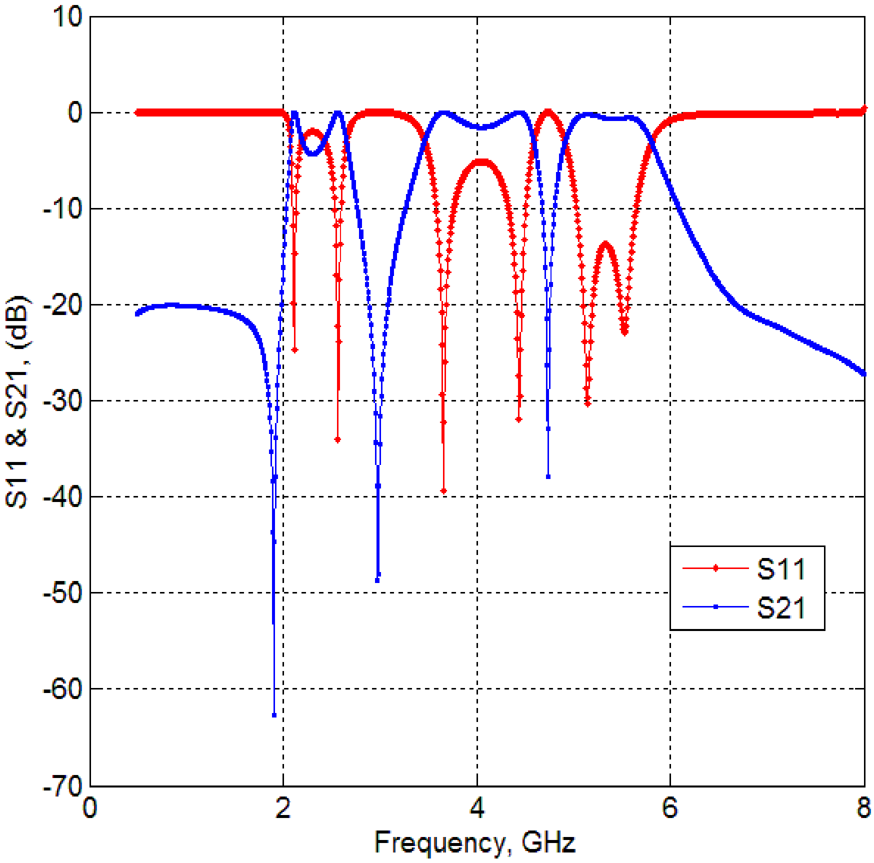
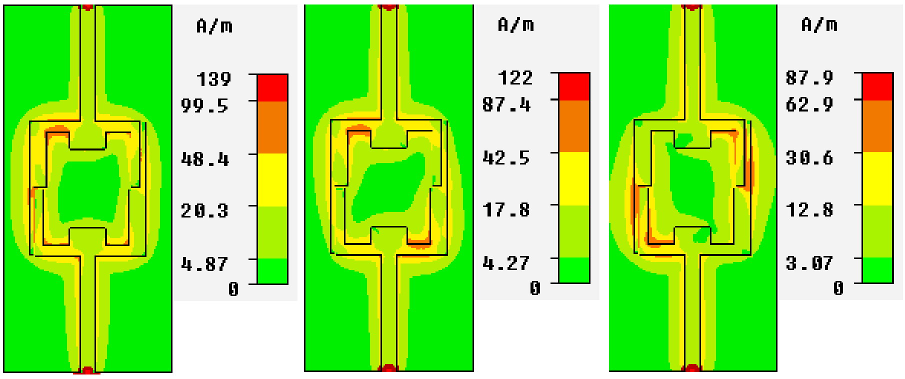


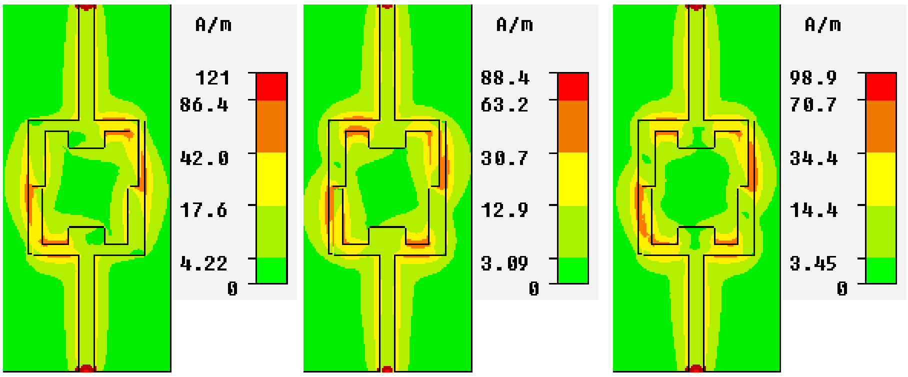
Fig.4 The return loss and transmission responses of the proposed filter using CST microwave studio.

The last transmission zero is located at 7.8 GHz with insertion loss of -27.69 dB. The out-of-bands rejection levels are less than -25 dB around upper and lower bands. The surface current distributions, at the resonant frequencies, using the electromagnetic simulator for the proposed bandpass filter are shown in Fig.5. It is clear from these distributions that the degenerate modes are well excited and coupled to each other at the designed frequencies. To validate the results obtained by CST Microwave Studio, the same design guidelines apply to the filter configuration introduced in Fig. 3 using SONNET V.11 simulator [22].

Simulation results on return and insertion losses are depicted in Fig. 6. Three bands are clearly observed and located from 2.2-2.55 GHz, 3.8-4.45 GHz and 5.1-5.5 GHz. The resonant frequencies within these bands are 2.26, 2.48, 3.9, 4.32, and 5.22 GHz, and the corresponding return losses are -26.12, -22.63, -27.84, -29.72, and -17.43 respectively. The out-of-band rejection observed are less than -50dB and -26 dB for lower and upper bands. The comparison between the magnitude of s-parameters simulation results with SONNET and CST Microwave Studio are shown in Fig. 7 and Fig. 8.



*f=2.1 GHz* *f=2.54 GHz* *f=3.6 GHz*



*f=4.5 GHz* *f=5.1 GHz* *f=5.7 GHz*

Fig.5 Surface current distributions at the pass-bands resonant frequencies.

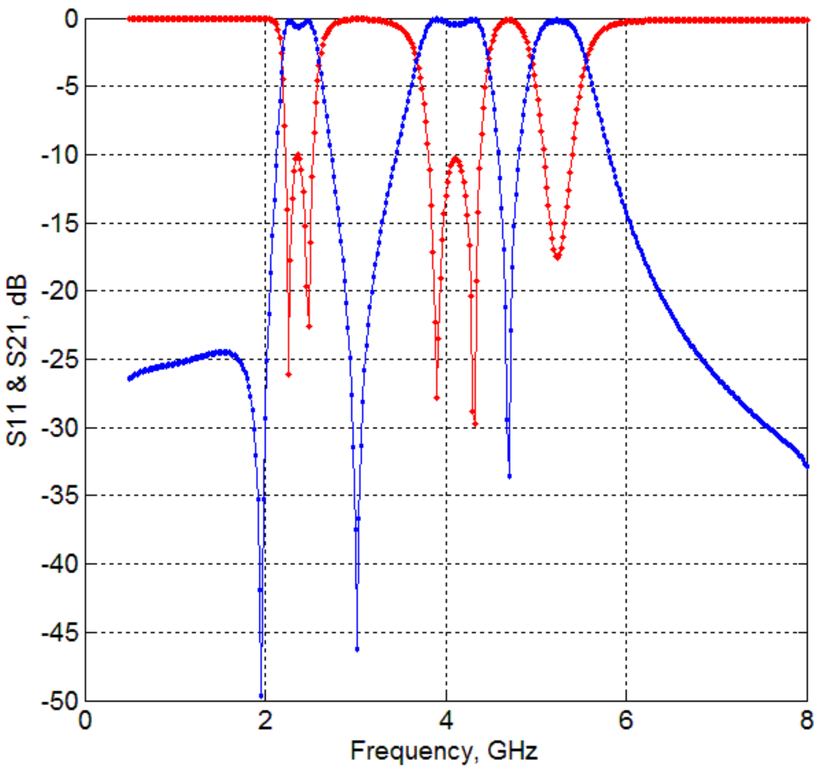


Fig.6 The return loss and transmission responses of the proposed filter using SONNET V.11.

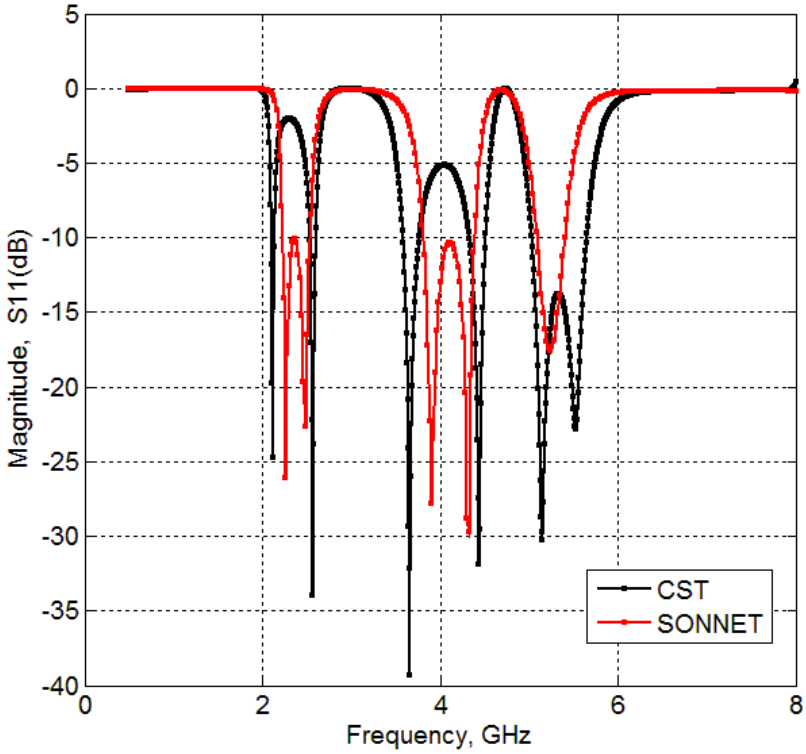


Fig. 7 Return loss responses of CST Microwave Studio and SONNET simulators for the proposed filter.

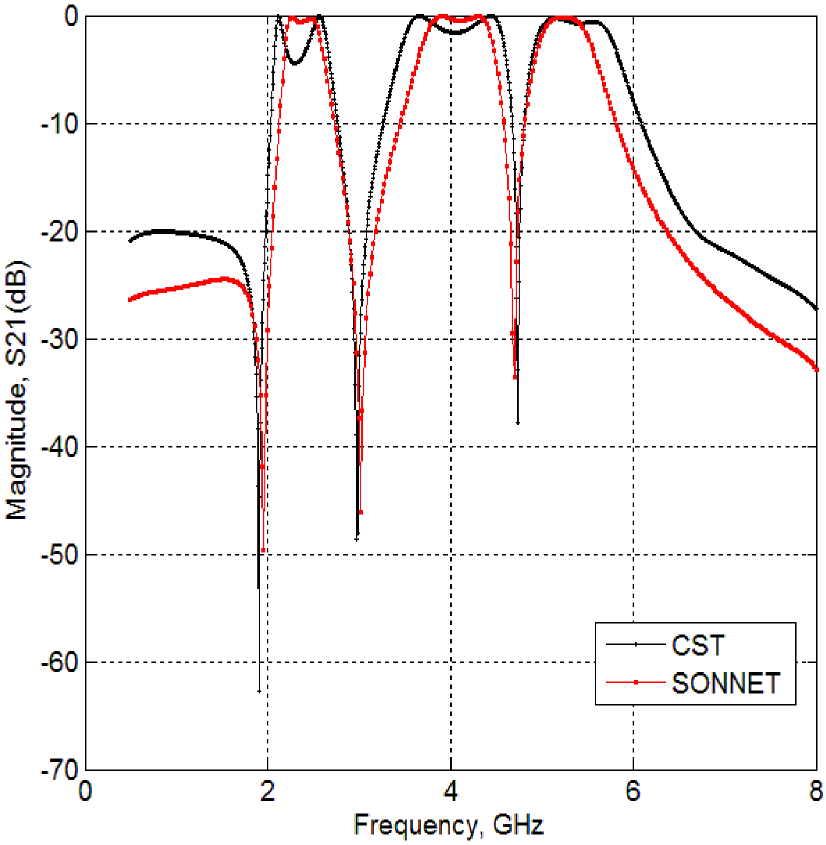


Fig. 8 Insertion loss responses of CST Microwave Studio and SONNET simulators for the proposed filter.

The plots show best match between two simulation results with different commercial software of proposed filter. The desired frequencies of 2.2, 2.4, and 5.2 GHz are covered within the responses of the CST and SONNET software, while 5.8 GHz are not covered by SONNET simulator.

The proposed filter results were compared with other reported tri-band SIR filters [14,15] as shown in Table 1. The results of the proposed filter in this work are comparative in insertion loss, selectivity as well as the filter structure has compact size, simple structure and low profile as compared with other design.

## 5 Conclusion

Design of new compact planar quad-sections SIR tri-band bandpass filter is presented. The core section is based on three resonances of a stepped impedance resonator and two tightly coupled microstrip lines.

The filter is designed, and its dimensions are optimized for small size and multi-band operation using CST Microwave Studio electromagnetic simulator. The transmission zeros at both sides of the passband of the proposed filter are generated by the resonator's arrangement. The filter shows a good

Table.1 Comparison between this work and other reported tri-band SIR filters

| | 1st/2nd/3rd passband (GHz) | Magnitude S21(dB) | Magnitude S11(dB) | Applications |
|---|---|---|---|---|
| Ref[14] | 1.5/2.4/5.78 | Not assigned | 10.6/15/18 | GPS<br>WLAN |
| Ref[15] | 1.8/2.7/3.3-4.8 | 2.2/2.1/2.3 | 14/13/9 | GSM<br>WiMAX<br>UWB |
| This work | 2.2-2.55/3.8-4.45/5.1-5.5 | Less than 0.9 within the bands | 19.11/23.71/16.33 | GSM<br>WiMAX<br>WLAN |

return and insertion losses within the operating bands. All performances are verified by two different EM packages, CST and SONNET electromagnetic simulation packages. Good agreement is found between the results obtained by these packages.

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