On the Design of Close and Open Loop Hexagonal Multiplexer for Communication System

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ABSTRACT
In this paper, close and open loop hexagonal resonator filter, multiplexer of high selectively and compact size are presented. The tri-band multiplexer topology is based on the hexagonal close loop resonators of different size which capacitive coupled from a single input. The filter and multiplexer have been designed on substrate dielectric constant $\varepsilon_r = 10.2$ and thickness = 0.635 mm. The hexagonal multiplexer offers the tri-band of bandwidth 60MHz with centre frequencies f_1=4.45GHz and f_2=5.3GHz, and 85MHz at f_3=5.85GHz. The new filter offers the rejection around better than 35 dB. In tri-band multiplexer, the rejection has been observed better in first band in comparison the third band. The open loop hexagonal for multiband rejection is also studied. The close and open loop hexagonal multiplexer structure have been simulated using IE3D software and HFSS. These close loop tri-band hexagonal multiplexer and open loop band rejection are compact in size and useful for communication system.

Keywords: Close loop Hexagonal resonator, Open loop hexagonal resonator, Band pass filter, multiplexer, microstrip line, capacitive coupling.

1. INTRODUCTION
Modern mobile communication systems require high performance narrow-band RF/Microwave band pass and band rejection filters having high selectivity and low insertion low. It is also important to reduce filter's size and weight in order to integrate with other components as a single chip system. Latest development of the high performance filter is either by active MMIC filter or passive planar filter [1-5]. Among passive filters, quasi-elliptic cross-coupled filter based on open loop resonators recently becomes a successful candidate for developing high performance RF/ Microwave band pass and band rejection filter. Many researchers have proposed various configurations for filters [2]-[4]. Various designs of dual-mode microstrip loop resonator filters have been proposed in the past [6-11]. These filter design include the square, triangular and circular geometries. In spite of the thorough literature available in these geometries, the hexagonal geometry remains unexplored and unstudied. Hexagonal geometry promises better confinement in the microstrip circuits due to their large interior angles (as compared to rectangle and square counterparts).

Recently, planar dual-band filters have been extensively proposed as a key component in dual-band wireless communication systems. They were first implemented by the combination of two filters at different frequencies, with the inherent disadvantage of increased overall size [12]. Also, they were realized by using a cascade connection of a wideband bandpass filter and a bandstop filter [12]. However, the resultant circuit topology is also large in size. To reduce the size an open loop hexagonal topology has been used.

In this paper, close and open loop hexagonal resonator filters and tri-band multiplexer of compact size proposed. The hexagonal open loop filters are presented for multiband rejection. The planar filters and multiplexer are easy to fabricated and integrate with MC/MMICs circuits. The detail parametric study of tri-band multiplexer has been done with respect to various parameters using commercial software based on method of Moment.

2. SINGLE CLOSE LOOP HEXAGONAL FILTER CONFIGURATION
Figure 1 shows the hexagonal loop resonator filter which is capacitive coupled at input and output. The each side length of hexagonal resonator has been taken 5 mm. The width of hexagonal loop resonator is 0.3 mm. The filter has been designed on substrate dielectric constant $\varepsilon_r = 10.2$ and thickness = 0.635 mm. The filter has been simulated using commercial software based on Method of Moment (MOM). The optimized response of the filter is shown in Figure 2. The optimized coupled gap is 0.2 mm. The port probe thickness for 50 Ω has been taken 0.25 mm.

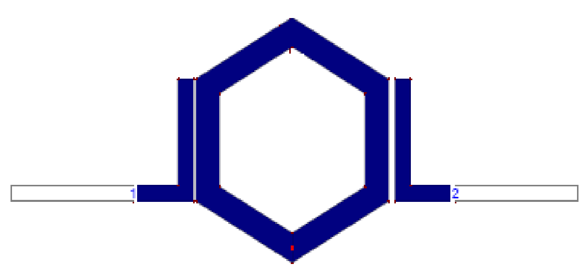

Figure 1. Simple hexagonal loop resonator filter

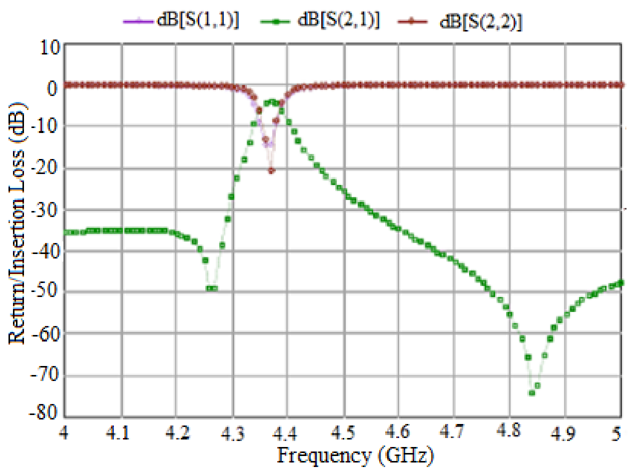

Figure 2. Simulated frequency response S21 and S11 (in dB)

3. CLOSE LOOP HEXAGONAL FILTER WITH PERTURBATION

Hexagonal filter with perturbation filter is made from loop resonator as shown in Figure 3. Various filter parameters consist of the following dimensions: side length of hexagonal (S), perturbation size (*P*), input and output port thickness (*t*), port tap thickness (*T*) and coupling distance (*c*). *P* is the side of the square patch perturbation introduced at an angle of 120° with respect to input port. *t* is the thickness of the input port coupling line-strip. *T* is the side of square tap used to connect input port to the coupling line, whereas *c* is capacitive coupling distance between port and the hexagonal loop resonator side.

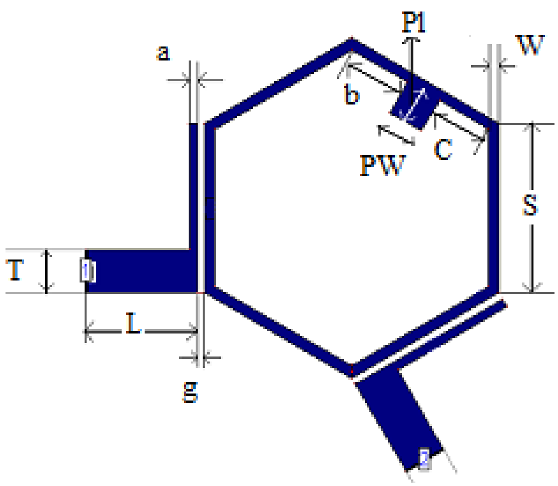

Figure 3. Hexagonal loop resonator filter with perturbation

The filter with notation is shown in Figure 3. The filter has been designed on substrate dielectric constant $\varepsilon_r = 10.2$ and thickness = 0.635 mm This filter is simulated using IE3D simulator. Optimum value of each parameter has been tabulated in table 1.

The output parameters S_{21} and S_{11} are shown in Figure 4. The bandwidth of the hexagonal loop resonator with perturbation has been observed more in comparison of unperturbed hexagonal loop resonator filter. It is clear from Figure 2 and Figure 4.

Table 1 Dimension of Optimized Close loop hexagonal filter with perturbation

Patch Perturbation Width (PW)	1.1 mm
Patch Perturbation Length (PL)	1.0 mm
Coupling Gap (g)	0.2 mm
Tap Edge (T)	1.15 mm
Patch Thickness (a)	0.25 mm
Loop Width (W)	0.3 mm

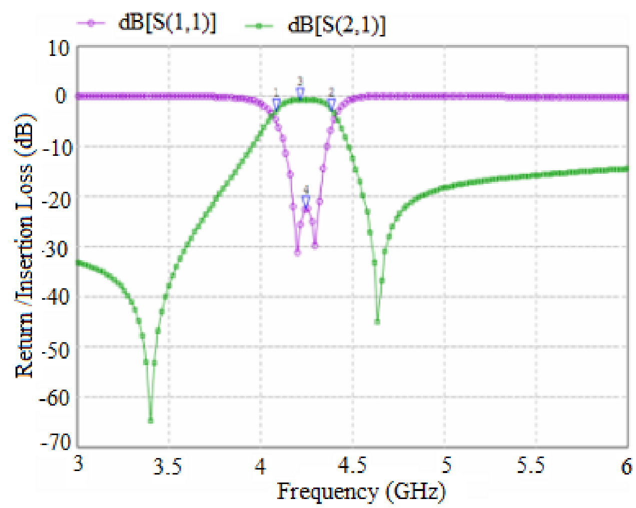

Figure 4, Simulated frequency response S21 and S11 (in dB).

4. TRI-BAND CLOSE LOOP HEXAGONAL MULTIPLEXER

The tri-band multiplexer is shown in Figure 5. Proposed multiplexer is made from loop resonator of hexagonal geometry as shown in Figure 1. Various loop hexagonal filters parameters consist: side length of hexagonal (S), input and output port thickness (*t*), port tap thickness (*T*), coupling distance (c_{mn}) and intergap distance (gap_{mn}). *T* is the side of square tap used to connect input port to the coupling line, whereas *c* is capacitive coupling distance between port and the hexagonal side. The loop length of hexagonal resonator has been calculated at center frequency 4.0 GHz, 4.6 GHz and 5.1 GHz. The loop length of the resonator must be integral multiple of the wavelength at the center frequency of the pass band. In this case, 1st harmonic of the resonant frequency has been utilized to obtain the pass-band which means that total loop length must be equal to the center wavelength. In order to find the required loop length, effective permittivity was estimated from IE3d for microstrip from which effective guided wavelength was calculated using following relation. For given characteristic impedance, *Zo*, of microstrip-line the ratio W/h of the strip-line is given by following expression

$$\frac{W}{h} = \begin{cases} 8\dfrac{e^{\lambda}}{e^{2\lambda}-2} & .when \quad W/_h < 2 \\ \dfrac{2}{\pi}\left[B - 1\ln(2B-1) + \dfrac{\mathcal{E}_r - 1}{\mathcal{E}_r + 1}\left\{ \ln(B-1) + 0.39 - \dfrac{0.62}{\mathcal{E}_r} \right\} \right] & .when \quad W/_h > 2 \end{cases} \tag{1}$$

$$A = \frac{Z_0}{60}\left(\sqrt{\frac{\mathcal{E}_r+1}{2}}\right) + \frac{\mathcal{E}_r-1}{\mathcal{E}_r+1}\left(0.23 + \frac{0.11}{\mathcal{E}_r}\right) \tag{2}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\mathcal{E}_r}} \tag{3}$$

When $\left(\frac{W}{H}\right) < 1$

$$E_e = \frac{E_r+1}{2} + \frac{E_r-1}{2}\left[\left(1+12\left(\frac{W}{H}\right)\right)^{-1/2} + 0.04\left(1-\left(\frac{W}{H}\right)\right)^2\right]$$

When $\left(\frac{W}{H}\right) \geq 1$

$$\mathcal{E}_e = \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-1}{2}\left(1 + 12\left(\frac{W}{H}\right)\right)^{-1/2} \tag{4}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\mathcal{E}_{eff}}} \tag{5}$$

The hexagonal loop resonator lengths at frequency 4.0 GHz , 4.6 GHz and 5.1 GHz are 4.94 mm, 4.25 mm and 3.95 mm respectively. The intergap between each hexagonal loop resonator has been optimized using EM simulator. After studying the effect of all individual parameters, the optimized has been applied to achieve to get optimum response of tri-band multiplexer.

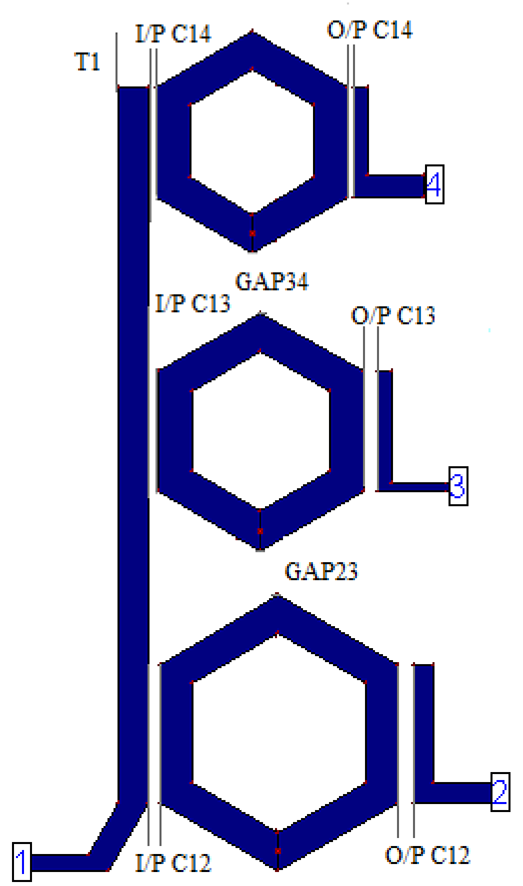

Figure 5 Hexagonal loop resonator tri-band multiplexer

4.1 Effect of variation in input coupling distance (C_{nm})

The input Coupling distance is the capacitive coupling between the input port and the each hexagonal loop resonator filter. The coupling distance between input and first, second, third filter are C_{12}, C_{13}, C_{14} respectively. Lesser the coupling gap, better coupling has been observed. This means that on decreasing the gap, pass band insertion of the filter response decreases and bandwidth increases [8-9]. If this gap is large between the input port and the filter (as well as output port and filter) is inhibited, increases the pass band insertion loss of the filter, which is undesirable [10]. Figure 6 shows the simulated effect of changing the coupling gap on the output parameter S_{21}, S_{31}, S_{41} .From the graph, it is clear that, the filter response deteriorates as the value of C_{mn} is increased. Other parameters in this simulation were kept constant as mentioned in the figure caption. Hence in our case, minimum possible coupling gap is needed. The hexagonal loop resonator multiplexer has been optimized for input coupling distance. The figure 6, figure 7 and figure 8 show the tri-band multiplexer simulated results with respect to optimized input coupling distance. The optimum coupling distance between input and first, second and third hexagonal are C_{12} = 0.42 mm, C_{13} = 0.36 mm and C_{14} = 0.33 mm respectively.

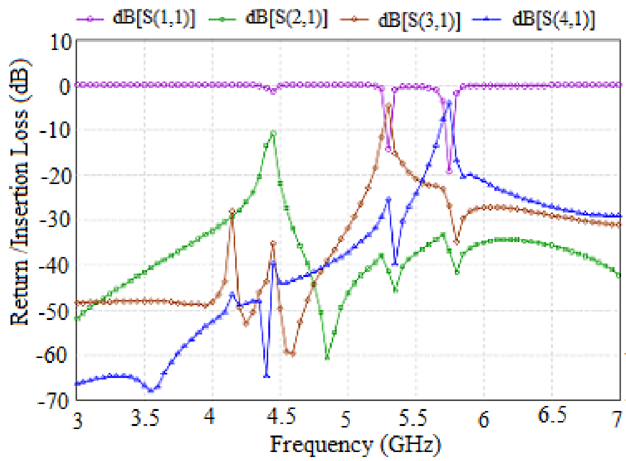

Figure 6. Hexagonal loop resonator multiplexer for first Input coupling gap C_{12} = 1.0 mm, C_{13} = 0.36 mm, C_{14} = 0.33 mm,

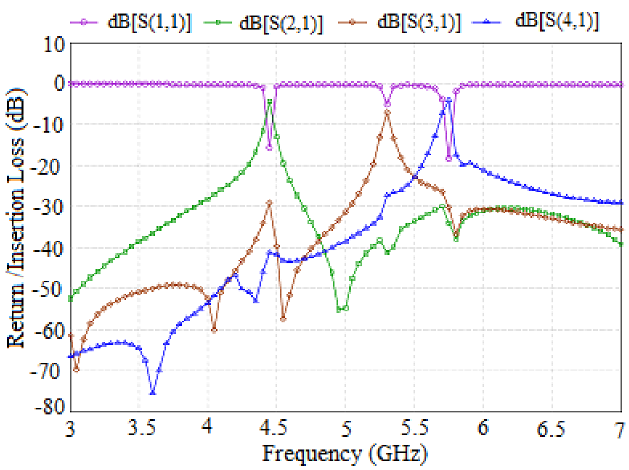

Figure 7. Hexagonal loop resonator multiplexer for first Input coupling gap C_{12} = 0.42 mm, C_{13} = 0.86 mm, C_{14} = 0.33 mm,

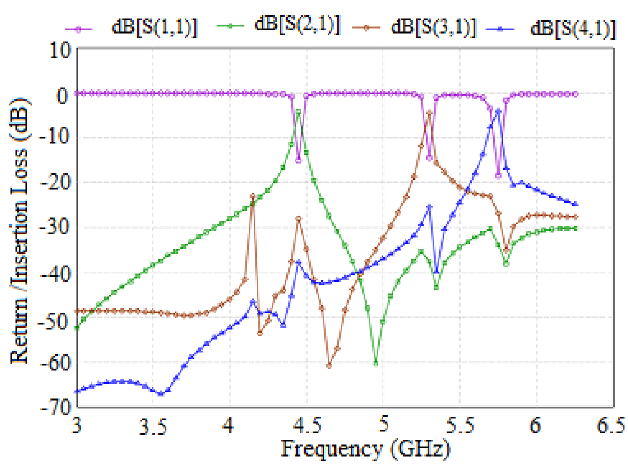

Figure 8. Hexagonal loop resonator multiplexer for first Input coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.85 mm

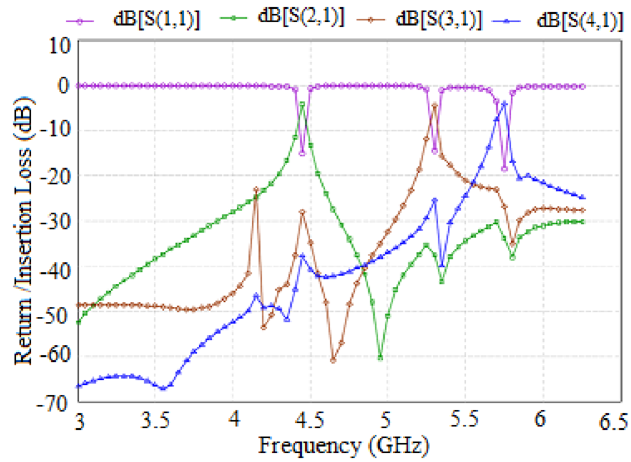

Figure 9. Hexagonal loop resonator multiplexer for first Input coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.33 mm

4.2 Effect of variation in output coupling distance

As the output coupling gap increases the capacitive effect i.e. the capacitance involved in coupling decreases [5-7]. Capacitance is inversely proportional to the distance and hence the response gets poorer at the port 2 output without much affecting the other ports output as shown in Figure 10 for C_{12} = 0.53 mm. Similarly simulated results for C_{13} = 0.51 mm in Figure 11 and simulated results for C_{14} = 0.23 mm is figure 12 are shown respectively. Effect of output coupling gap due to C_{13} = 0.51, C_{14} have been shown in Figure 11 for second filter and Figure 12 for third filter respectively.

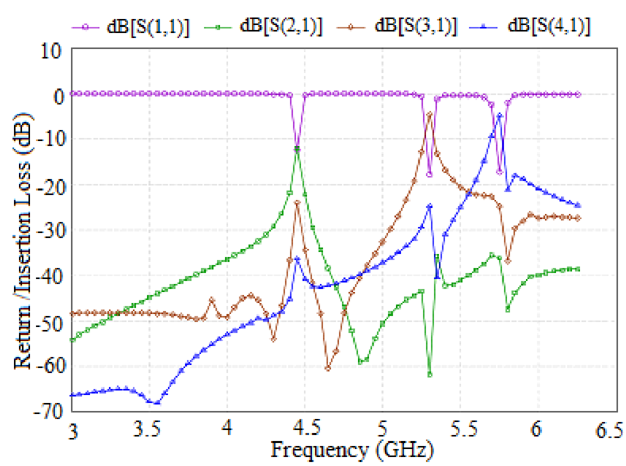

Figure 10, Hexagonal loop resonator multiplexer for first I/P coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.33 and O/P Coupling C_{12} = 1.0 mm, C_{13} = 0.51 mm, C_{14} = 0.23 mm

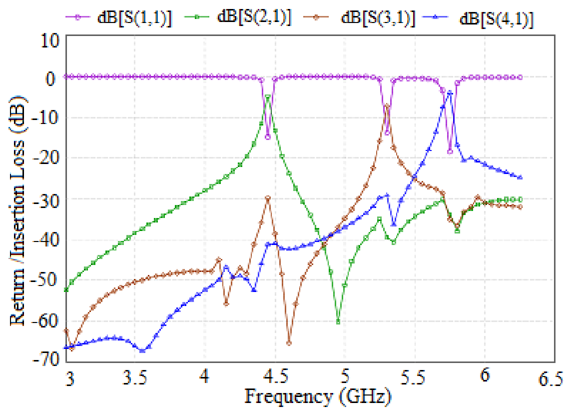

Figure 11, Hexagonal loop resonator multiplexer for first I/P coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.33 mm and O/p Coupling C_{12} = 0.53 mm, C_{13} = 1.0 mm, C_{14} = 0.23 mm

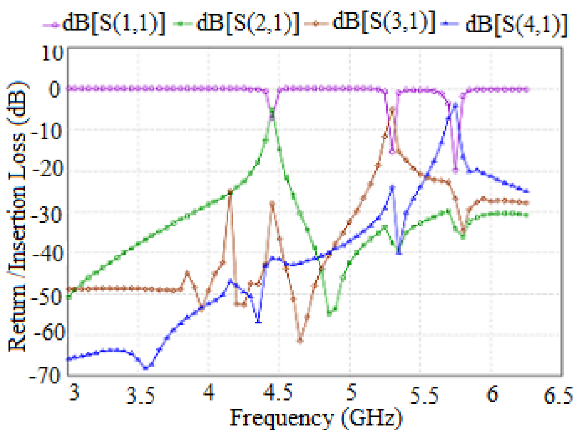

Figure 12, Hexagonal loop resonator multiplexer for Input coupling gap C_{12} = 0.42mm, C_{13} = 0.36mm, C_{14} = 0.33mm and O/P Coupling gap C_{12} = 0.53 mm, C_{13} = 0.51mm, C_{14} = 0.23 mm

4.3 Effect of variation in inter gap distance

As the inter gap distance between hexagonal loop resonator of multiplexer number 2 and 3 increases, the capacitive effect i.e. the capacitance involved in coupling decreases [3-4]. Capacitance is inversely proportional to the distance and hence the response gets poorer at the port 2 output without much affecting the other ports output. The inter gap distance between the filters of multiplexer have been optimized. The optimized inter distance coupling between 1 and 2 filters Gap_{23} = 1.58 mm and between 2 and 3 filters is Gap_{34} = 2.15 mm. The simulated results of these inter gap distance are shown in Figure 13, Figure 14 and Figure 15 respectively. The effect between the inter distance coupling between the filter first and filter second changes the response of filter first as shown in Figure 13. Figure 14 shows the effect of inter distance coupling between filter 2 and filter 3. It effects the response of second filter as visible in Figure 14. Figure 15 shows the response of optimized inter distance between the filters. In Figure 15, all the optimized parameters like input coupling gap, output coupling gap and inter distance are also given. The total size of the tri-band multiplexer design on RT/Duriod substrate is 27 mm x 17 mm. The conductor thickness has been taken ½ oz and substrate dielectric constant 10.5 with substrate thickness of 0.635 mm.

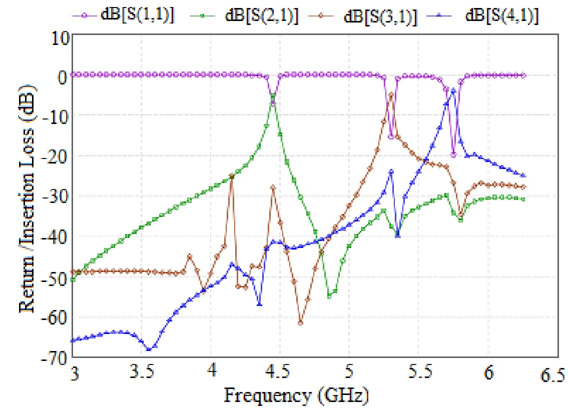

Figure 13, Hexagonal loop resonator multiplexer for first Input coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.33 mm and output Coupling C_{12} = 0.53 mm, C_{13} = 0.51 mm, C_{14} = 0.23 mm, Inter Gap distance Gap_{23} = 2.0 mm, Gap_{34} = 2.15 mm

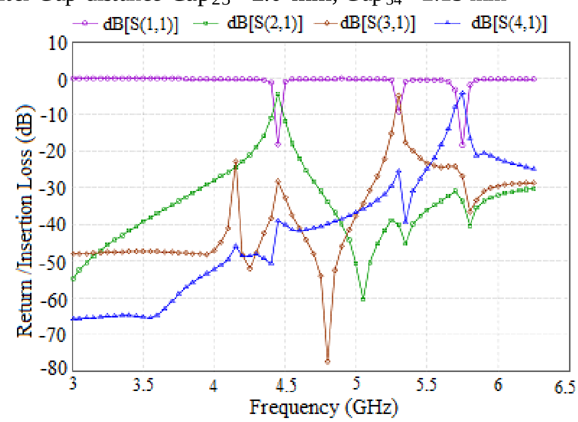

Figure 14, Hexagonal loop resonator multiplexer for first Input coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.33 mm and output Coupling C_{12} = 0.53 mm, C_{13} = 0.51 mm, C_{14} = 0.23 mm, Inter Gap distance Gap_{23} = 0.23 mm Gap_{34} = 1.65 mm

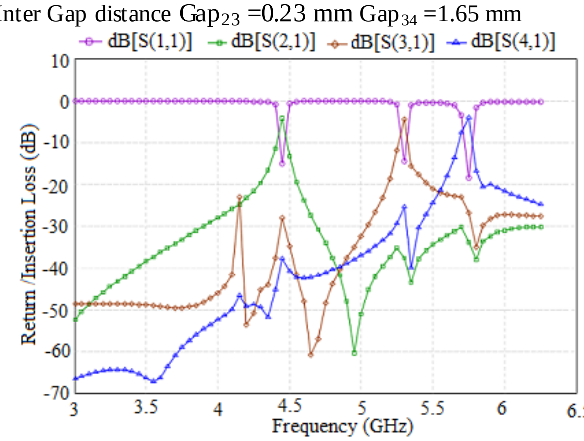

Figure 15, Hexagonal loop resonator multiplexer for first I/p coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} = 0.33 mm and O/p Coupling C_{12} = 0.53 mm, C_{13} = 0.51 mm, C_{14} = 0.23 mm, Inter Gap distance Gap_{23} = 1.58 mm Gap_{34} = 2.15 mm

5. OPEN LOOP HEXAGONAL FILTER AND MULTIPLEXER

The using open loop hexagonal resonator, a simply multi-armed open-loop resonator with the input/output ports directly coupled to the resonator is shown in Figure 16. The idea of utilizing the open-loop hexagonal resonator as a compact bandstop filter was inspired using the dual-mode bandstop filter. Utilizing a multi-armed resonator guarantees a multireject band response. This response is anticipated as each pair of the resonator arms creates a reject band in the transmission response. Meanwhile, properly adjusting these multireject bands will create appropriate multitransmission bands. The number of these transmission bands depends on the used number of hexagonal resonator arm pairs (N +1 arm pairs will create N bandpass transmission bands). It is worth mentioning also that the direct feed of the structure guarantees a lowpass transmission band which facilitates the design of combined lowpass bandpass filters. The single hexagonal open loop resonator has been simulated and optimized. The simulated response i.e insertion loss and return loss versus frequency is shown in Figure 17. It has the low band pass response from DC to 3.5 GHz and band stop response is from 3.5 GHz to 6.5 GHz. Similarly two arm hexagonal open loop resonator are simulated as shown in Figure 18. The simulated results exhibits the two wide stop band as shown Figure 19 from 3 GHz to 5 GHz and 5.25 GHz to 6.5 GHz.
The smallest open loop gap of hexagonal decides the higher band reject while largest open loop hexagonal decides the lower band rejection. The spacing between the hexagonal and side length decide the bandwidth of band pass filter. The length L decided the center frequency of filter.

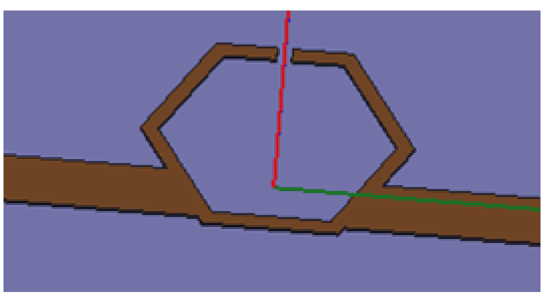

Figure 16, Open loop hexagonal filter

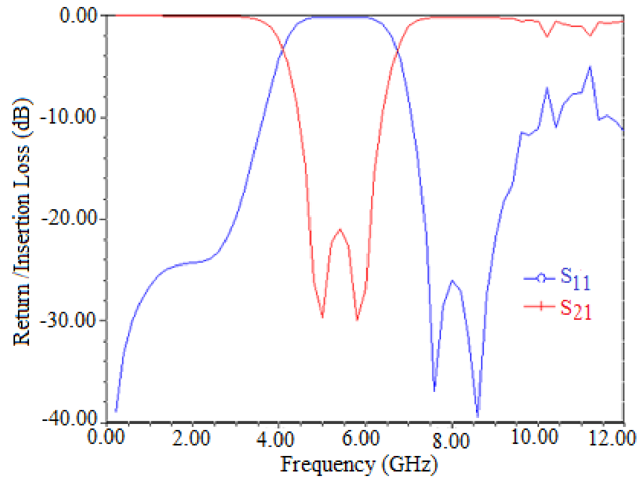

Figure 17, Open loop hexagonal low pass and Band rejection filter

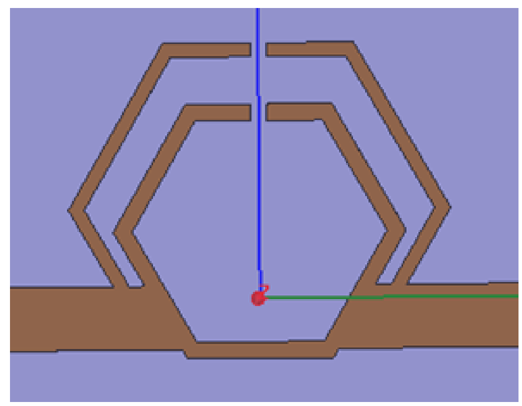

Figure 18, Two Open loop hexagonal filter

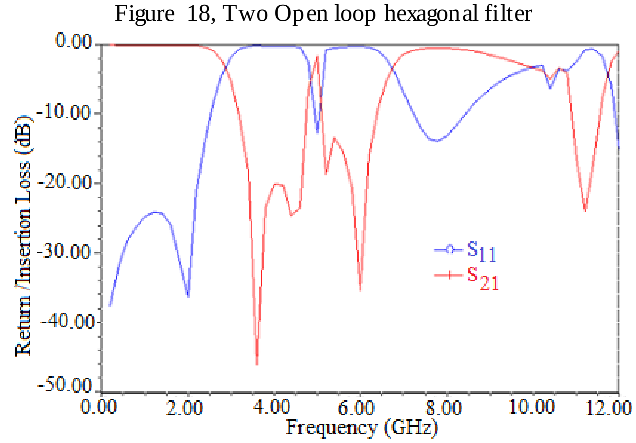

Figure 19, Two open loop hexagonal low pass and Band rejection filter

6. RESULTS AND DISCUSSION

In order to study the proposed hexagonal filter with, without perturbation and tri-band multiplexer, these microstrip filters and multiplexer are simulated using IE3D electromagnetic simulator based on MOM (Method of Moment) numerical method. All filters circuits are designed on RT/Duriod substrate with relative dielectric constant of 10.5 and thickness 0.635 mm. The hexagonal loop resonator filter with and without perturbation and multiplexer, a extensive parametric effect of multiplexer has been done using 3D-EM simulators. It has been observed that parameter change in one filter changes the response of other filters. Inter gap distance between the filter is also the critical parameters. The inter gap distance between first and second (Gap_{23}) effect the response of first and second filter and inter gap distance between second and third filter Gap_{34} =2.15 effect the response of second and third filter. The inter gap distance have been optimized. The optimum values are Gap_{23} =1.58 mm Gap_{34} =2.15 mm. The Input coupling gap of first filter effects the response of first and second filter but no effect on the response of third filter. Similarly, inter gap of second and third filter effects the response of second filter and third one. It can be concluded that the effect of inter coupling gap is on the filter and its adjacent filter. All the inter coupling gap have been optimized. The optimum values are C_{12} = 0.42 mm, C_{13} = 0.36 mm and C_{14} = 0.33 mm. Similarly output coupling gap of individual filter has been optimized. In this, it has been observed that the variation of gap effects the filter response of individual filter. Very less effect in the adjacent filter has been observed. All the three output coupling gap have been optimized. The optimum output coupling gap values are C_{12} = 0.53 mm, C_{13} = 0.51 mm, C_{14} = 0.23 mm. All the dimension of the tri-band multiplexer have been shown in Figure 20. The optimum simulated result of multiplexer is shown in Figure 21. It has been observed from the simulated results that hexagonal multiplexer offers the tri-band of bandwidth 60MHz with centre frequencies f_1=4.45GHz and f_2=5.3GHz and 85MHz at f_3=5.85GHz. The return loss of first and second band is around -18 dB and the return loss of the third filter is around -34 dB. It has also been observed that selectivity of these filter is good. The selectivity of first filter is better than the selectivity of third filter.

Triple open loop hexagonal with directly coupled input and output is shown in Figure 22. This triple open loop hexagonal has been designed of FR4 substrate of thickness 1.53 mm. The three hexagonal open loop arm offer the three band rejection with low pass band as shown in Figure 23. This type of filter can be used for Ultra wideband system application which is a modern wireless technology. The output simulated response S_{21} and S_{11} are shown in Figure 17 with optimization.

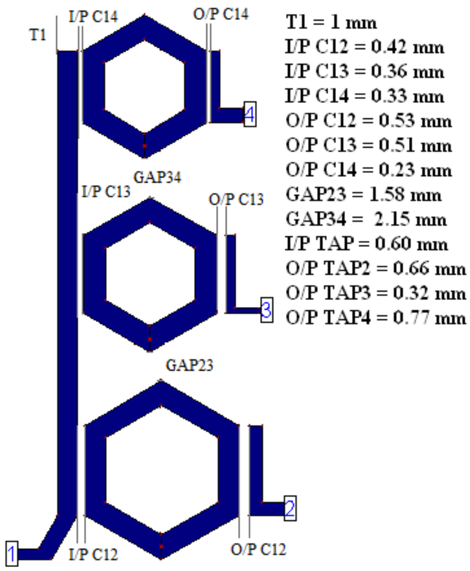

Figure 20, Schematic diagram of the hexagonal loop resonator tri-band multiplexer with optimized parameter values.

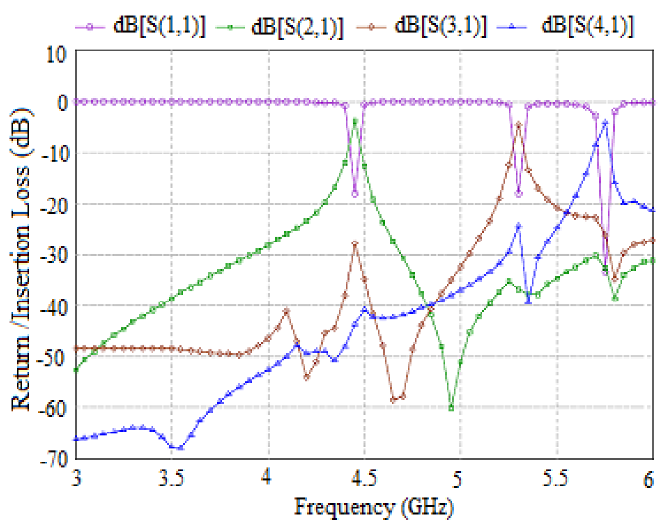

Figure 21. Simulated frequency response S_{11}, S_{21}, S_{31} & S_{41} (in dB) for Input coupling gap C_{12} = 0.42 mm, C_{13} = 0.36 mm, C_{14} =0.33 mm and output Coupling C_{12} = 0.53 mm, C_{13} = 0.51 mm, C_{14} = 0.23 mm, Inter Gap distance Gap_{23} =1.58 mm Gap_{34} =2.15 mm

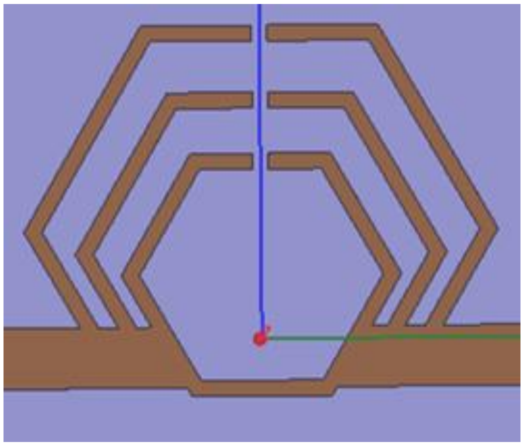

Figure 22, Three Open loop hexagonal filter/multiplexer

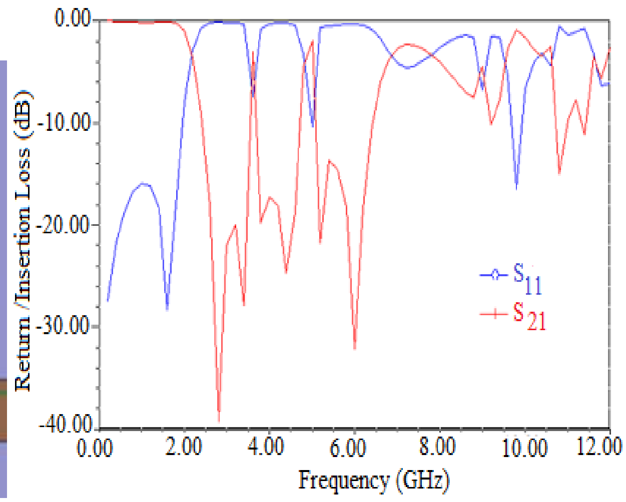

Figure 23, Simulated results three open loop hexagonal filter/multiplexer

6. CONCLUSIONS

A compact close and open loop hexagonal resonator filter with and without perturbation has been designed. The bandwidth of filter with perturbation has been observed better. Using three hexagonal close loop resonators, a tri-band has been constructed with full parametric study. The optimization of the critical parameters of the multiplexer filter is accomplished the desired response. The center frequency of the first, second and third filters decided by size of loop resonators. Three open loop hexagonal filter have also designed for low pass and band rejection. This triplet filter has been optimized with respect to critical design parameters. The proposed filter and multiplexer are compact, easy to fabricate and easy to integrate with MIC/MMIC microwave circuits. Such type of circuits is useful for communication system.

7. ACKNOWLEDGEMENTS

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