Design and Analysis of Stub Loaded Resonator

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***Abstract---** Microwave filters are an important component in front end receiver of microwave communication system. They are used for passing frequency components within a particular pass band and to reject the interfering signal outside of that operating frequency band. Their functionality also includes to reject the unwanted product from the output of the mixers and amplifiers, and to set the IF bandwidth of the IF receiver. Important parameters include cutoff frequency, insertion loss, out of the band attenuation rate measured in dB per decade of the frequency. Filters with sharper cutoff frequency provide more rejection for out of the band signals. Insertion loss, measured in dB, is the amount of attenuation seen by signal through the pass band of the filter. Size requirement for most of the Personal Communication Systems require filters to be compact in size and wideband. This work presents design of Microwave filters in Global System for Mobile and Wireless Local Area Network Bands. Afterwards, a detailed analysis for designing filters with these requirements in presented. First, a Conventional T Shape Bandpass Filter is presented. Consequently, A Modification in T Shape MicrostripBandpass Filter is presented with considerable size reduction.*

I. BRIEF REVIEW OF LITERATURE

L. Bousbia.*et al*, (2013) investigated Study and Modeling of T and L shaped resonators for UWB Band Pass Filter. His research of T and L shaped resonators are considered for the design of UWB band pass filter which operates at the center frequency of 5 GHz. Unlike any earlier work, he propose a novel analytical performance study of T and L shaped resonators that investigates the relationship between the input admittance of both resonators and the electrical lengths. In this work, bandstop filter loaded with two T, L and mixed open stubs, are proposed to design compact UWB band pass filter. Three topology of UWB bandpass filter and their comparison study between the performances of these structures was discussed.**Bin You**.*et al*, (2014) proposed a High-Selectivity Tunable Dual-BandBandpass Filter Using Stub-LoadedStepped-Impedance Resonators.Compared with the traditional tunablefilter, the source-load coupling and T-shape stub-loaded lines are employed in his design. The proposed BPF architecture hasthe advantages of high selectivity and less control voltages. Inthe overall tuning range, the proposed filter is designed with5–6 transmission zeros and more than 30 dB rejection betweenthe two passbands. Meanwhile, only one control voltage is neededfor each passband. A prototype of this filter is fabricated andmeasured. The measurement results show great agreement withsimulated results, which show that the first passband can betuned in a frequency range from 0.8 to 1.02 GHz, and the secondpassband varies from 2.02 to 2.48 GHz

Leila. *et al*, (2011) proposed an ultra-wideband (UWB) bandpass filter using loop resonators. They delivers excellent scattering parameters with magnitude of insertion loss, S21 lower than 0.09dB and return loss found better than 20 dB. The demonstrated bandpass filter has 3-dB fractional bandwidth of 65% of center frequency (5.46 GHz), in the range of 3.7 GHz to 7.22GHz. The filter is constructed by ring resonator and T-shaped stub loaded at the line center.**ReungyotLerdwanittip**.*et al*, (2011) proposed a Bandpass Filters using T-shape Stepped Impedance Resonators for Wide Harmonics Suppression and their Application for a Diplexer. The T-shape stepped impedance resonators are adopted for the design of microstripbandpass filters for wide harmonics suppression. The proposed filters are operated at the center frequency of 2.44 GHz and 5.20 GHz, respectively. These bandpass filters have been also applied for a high performance diplexer. The insertion losses at the center frequencies of 2.44 and 5.20 GHz are 1.23 and 1.18, respectively. The applicable return losses for both frequency bands and a wide stopband better than 17 dB up to 20 GHz have been obtained.

Kuan Deng.*et al*, (2012) proposed a compact dual-band bandpass filter using asymmetric T-shaped resonators. Two compact dual-band bandpass filters withT-shaped resonators are used. The demonstrated filters are four-stage design composed by four T-shaped resonators in conjunction with the microstrip lines in the I/O ports. The location of the two passbands can be adjusted by suitably changing the impedance ratio and the length of the T-shaped resonators. For comparison, two different feeding structures are employed, saying, coupled-line feeding and tapped-line feeding patterns. For better energy input in the second pattern, the two resonators connected with the tapped-lines are asymmetric. For demonstration, one dual-band filter was designed at 2.45 GHz and 5.8GHz. **Andres Li Shen**. *et al*, (2014) proposed a novel dual-band bandpass Filter using asymmetric stub-loaded Stepped-Impedance Resonators at frequencies of 1 and 2.6 GHz. Each resonator is first designed and simulated to operate at the given frequencies. Then, they are coupled together while applying suitable coupling configurations at the input and output to improve the filter's performance. The filter's input reflection coefficients (S11) are -11.2 and -12.9 dB and insertion loss (S21) are -0.44 and -1.2 dB at the two design frequencies respectively.

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Y.-C. Chiou.*et al*, (2011) proposedplanar multiband bandpass filter with multimode stepped-impedance resonators. Planar multiband bandpass filters are implemented based on the versatile multimode stepped-impedance resonators (SIRs). The author discuss about resonant spectrum of a SIR can be calculated as functions of the length ratios for various impedance ratios of the high- and low-impedance sections. Thus, by properly selecting the geometric parameters and designing the input/output coupling structure, the SIRs are feasible to realize multiband multimode filters. Using a single SIR, a dual-mode dual-band, a dual-mode triple-band or a hybrid dual-/triple-mode dual-band bandpass filter can be realized. Emphasis is also placed on designing specified ratios of center frequencies and fractional bandwidths of the passbands. To extend the design flexibility, extra shunt open stubs are used to adjust the ratio of the passband frequencies. In addition, sharpness of the transition bands is improved by designing the input/output stages. Simulation results are validated by the measured responses of experimental circuits**. Zhang**.*et al*, (2010) proposed a novel planar multimode bandpass filters with radial-line stubs. This novel approach for designing planar multimode wideband bandpass filters with good selectivity. The multimode resonator is composed of an open-ended microstrip line with length of half-wavelength ($\lambda/2$) and several radial-line stubs. By using different kinds of radial-line stub-loaded, different kinds of responses including three-pole and four-pole bandpass filters can be realized. Depending on electric field distribution and equivalent circuit model, the characteristics of the filter are analyzed. To verify the proposed method, two filters are implemented. The measured results exhibit good agreement with the simulation.**Fu-Chang Chen.et al, (2009)** proposed design of Compact Tri-Band Bandpass Filters using assembled resonators. Author discusseda novel approach for designing tri-band bandpass filter with independently controllable center frequencies and improved stopband rejection characteristic. The assembled resonator constructed by a stepped impedance resonator and a common half-wavelength resonator is employed to obtain tri-band response. The stepped impedance resonator is designed to operate at the first and third passbands and the other resonator is designed to operate at the second passband. Two kinds of filter configurations with cascaded and pseudointerdigital formats are proposed. Based on lossless lumped-element equivalent circuit, it is found that both filter structures can introduce transmission zeros between passbands. To verify this approach, two filter are designed and fabricated; the measured results exhibit tri-band bandpass responses with high selectivity.

Leila Bousbia. et al,(2014) proposed a new compact UWB Filter using open-stubs.Open resonator is employed and loaded with Tor L shaped open stub to achieve the UWB bandpass filter topology. The best performances filter are obtained by UWB filter based on T-open stubs compared to the other ones realized by UWB filter based on L-open stubs. 53% fractional bandwidth and 0.7dB insertion loss are gained experimentally. The proposed band-pass filter exhibiting with a wide pass-band from 5.4 to 9.4 GHz has been simulated and experimentally confirmed. The occupied size of studied filter is only 10×10 mm^2 without connectors.

II. DESIGN OF BAND PASS FILTER

As with any other transmission line structure, the analysis methods for a microstrip line are aimed at determining the characteristic impedance and propagation constant (phase velocity and attenuation constant). The various methods of microstrip analysis may be divided into two main groups as shown in figure 4. In the first group, which comprises quasi-static methods, the nature of the mode of propagation is considered to be pure TEM and the microstrip characteristics are calculated. From the electrostatic capacitance of the structure, it is founded that this analysis is adequate for designing circuit at lower frequencies (below X-band) where the strip width and the substrate thickness are much smaller than the wavelength in the dielectric material. The methods in the second group take into account the hybrid nature of the mode of propagation.The techniques followed for fullwave analysis are more rigorous and analytically complex. An important outcome of the fullwave analysis is information about dispersive nature of the microstrip line.

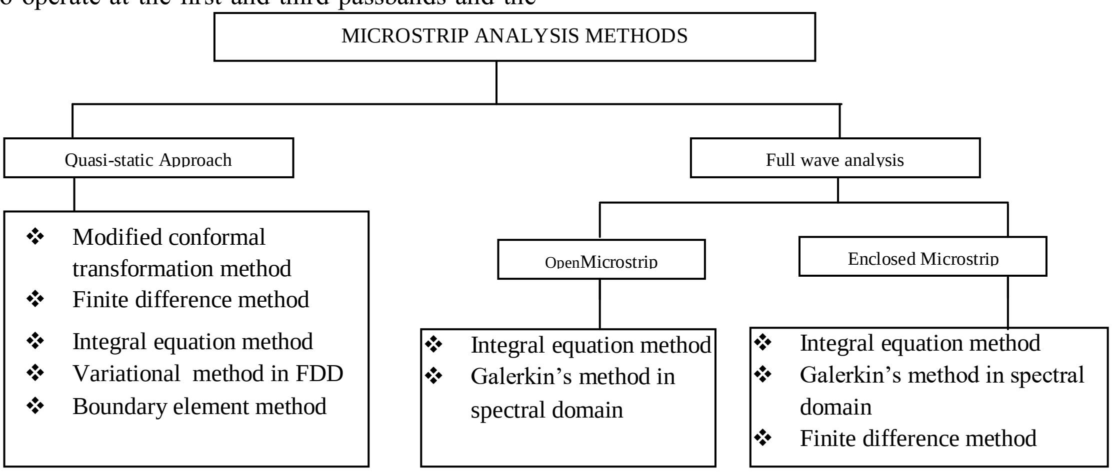

Figure 1: Various methods of microstrip analysis

This includes variation of characteristic impedance Z_0, and phase velocity (or effective dielectric constant ε_{re}) with frequency. As a fullwave analysis becomes fairly complicated, several quasi-empirical methods known as "dispersion models" have been developed for finding variations of Z_0 and ε_{re} with frequency.

III. DESIGN OF BPF USING STUB LOADED RESONATOR

In this section, the filter design process is presented. Discuss the implementation setup, conventional T-shaped bandpass filter and their even-odd mode analysis technique. In order to achieve a better performance of the filter, investigate various structure of stub loaded type bandpass filter.

IV. IMPLEMENTATION SETUP

The filter design is begins with choosing a suitable substrate. Initial study based on T- shaped stub loaded resonator. From that we analyzing about quarter-wavelength open-circuited stubs filter and short circuited stub connected in series to the filter (i.e. T shape resonator). The main reasons why we choose this type of microstrip filters are their response in passband has less insertion loss, planar structure filter, easy to design and cheap in fabrication. The simulation work was carried out using HFSS and the fabricated design was tested using vector network analyzer.

V. CONVENTIONAL BPF USING SLR

Based on the characteristic analysis of tri-section SLR, we can get three passband frequency in T shaped BPF. The convention filter has symmetry property so it has even and odd mode characteristics. Basically even-odd mode analysis method follows two principles. That is superposition and circuit symmetry. A conventional and proposed filter follows circuit symmetry property. Stub loaded resonator uses quarter wavelength microstrip line.

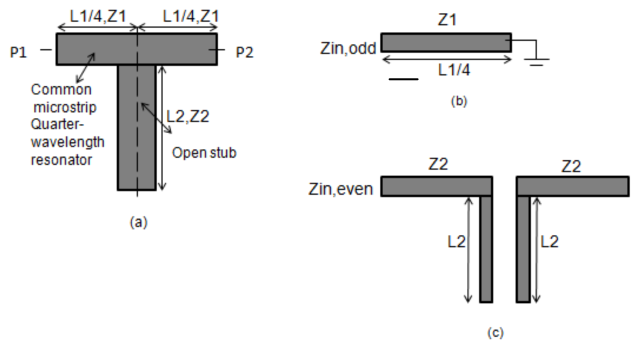

Figure 2: (a) Conventional T shaped resonator (b) Odd mode equivalent circuit (c) Even mode equivalent circuit

If both ports are excited simultaneously with equal signal amplitudes and matching phase, there can be no currents crossing from one side of the symmetry plane to the other. This is called the *even-mode.*

If the two ports are excited with equal amplitudes but 180º out of phase, then all nodes that lie on the symmetry plane must have zero potential with respect to ground. This is called the *odd-mode.* Odd mode equivalent circuit is virtually grounded.

Resonance Condition

The design is based on odd and even mode technique. At the resonance condition of $Y_{in,odd} = 0$, the first odd-mode resonant frequency can be expressed as:

$$f_{01} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \quad (5.1)$$

$$f_{e1} = \frac{c}{4(L_1 + L_2)\sqrt{\varepsilon_{eff}}} \quad (5.2)$$

$$f_{e2} = \frac{c}{4(L_1 + L_3)\sqrt{\varepsilon_{eff}}} \quad (5.3)$$

Where, c = speed of light in free space.

ε_{eff} = effective dielectric constant of the substrate.

These are under the condition of $Z_1 = Z_2$ (Z_1 is the characteristic impedance of the transmission line), it act as purely resistive network because impedance get cancel each other. The proposed stub loaded resonator could be controlled by tuning the width of the transmission line and stubs.

The electrical length of a transmission line is defined as follows,

$$\theta = \beta l = \frac{2\pi f\sqrt{\varepsilon_r}}{c} l \quad (5.4)$$

Wherefis the resonant frequency, ε_r is the effective relative permittivity, c is the velocity of light in vacuum and *l* is the length of the resonator line.

Table 1: Fabrication specification

SPECIFICATION	
Substrate material	FR4 epoxy
Dielectric constant	4.4
Substrate thickness(mm)	1.6
Loss tangent	0.02
Dimension (mm)	31.25 x 31.25

The electrical length of the resonator line decreases with the increasing of the loaded capacitance.Specifications for the designed filters and substrates used are given in the tables 1. Cost of the circuit is less due to FR 4 substrate. High dielectric constant material is used. Thickness of the material is related to loss of the filter.

(a) Front view (b) Back view

Figure 3: Photograph of T-shaped resonator

The lower and the higher transmission poles occur at the even-mode resonant frequencies of the T-shaped stub. The two zeros contribute to the sharp cut-off response of a bandpass filter design. The second transmission pole is of odd-mode resonance and not affected by the T-shaped stub.

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The odd-mode frequencies vary with different L1. The first and the third transmission poles occur due to the even-mode resonance. The even-mode frequencies vary with different L2 and L3. By adjusting the dimensions of the resonator, it provides flexibility in determining the frequencies of transmission poles and zeros. This is useful for bandpass filter designs with different specifications.

VI. SIMULATION RESULT

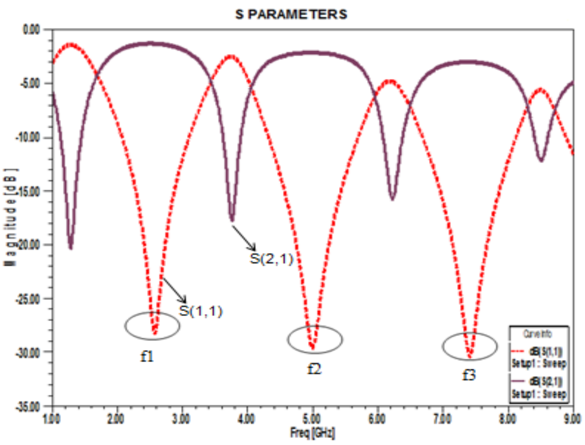


Figure 4 : Frequency versus magnitude graph(T shape filter)

Simulation result shows that, the tri-band bandpass filter at 2.5, 4.87 and 7.4 GHz was designed and fabricated. The open stub is act as capacitor, and total size is 31.25 × 31.25 mm^2. The measured 3 dB fractional bandwidths for the three passbandscentred at 2.5, 4.87 and 7.4 GHz are found to be 84.49%, 43.71% and 27.22% respectively. The minimum insertion losses measured for the three passbands in the same sequence are 1, 2 and 3 dB, and the return losseswithin the three passbands are below 27.72 dB.

Table 2: Parameters of the filter

Center Freq(GHz)	FBW (%)	IL (dB)	RL (dB)
f1(2.5)	84.49	1	27.72
f2(4.87)	43.71	2	29.54
f3(7.4)	27.22	3	30.28

Table 2 indicates that first resonant frequency f_1 used for GSM application and the second resonant frequency f_2 suitable for WLAN application.

VII. EXPERIMENTAL RESULTS

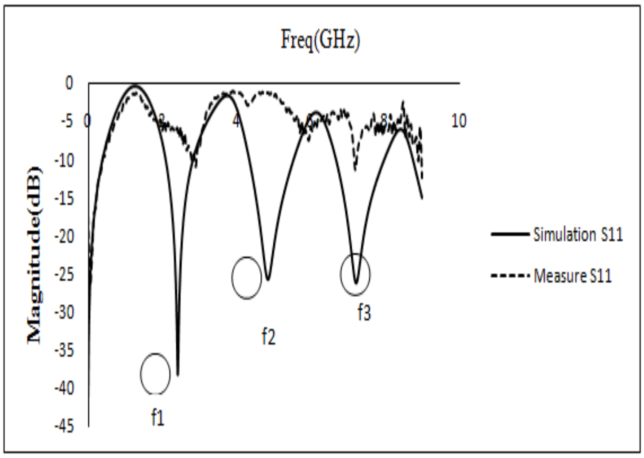


Figure 5: (a)S_{11} Simulated and Measured result of conventional T shaped BPF

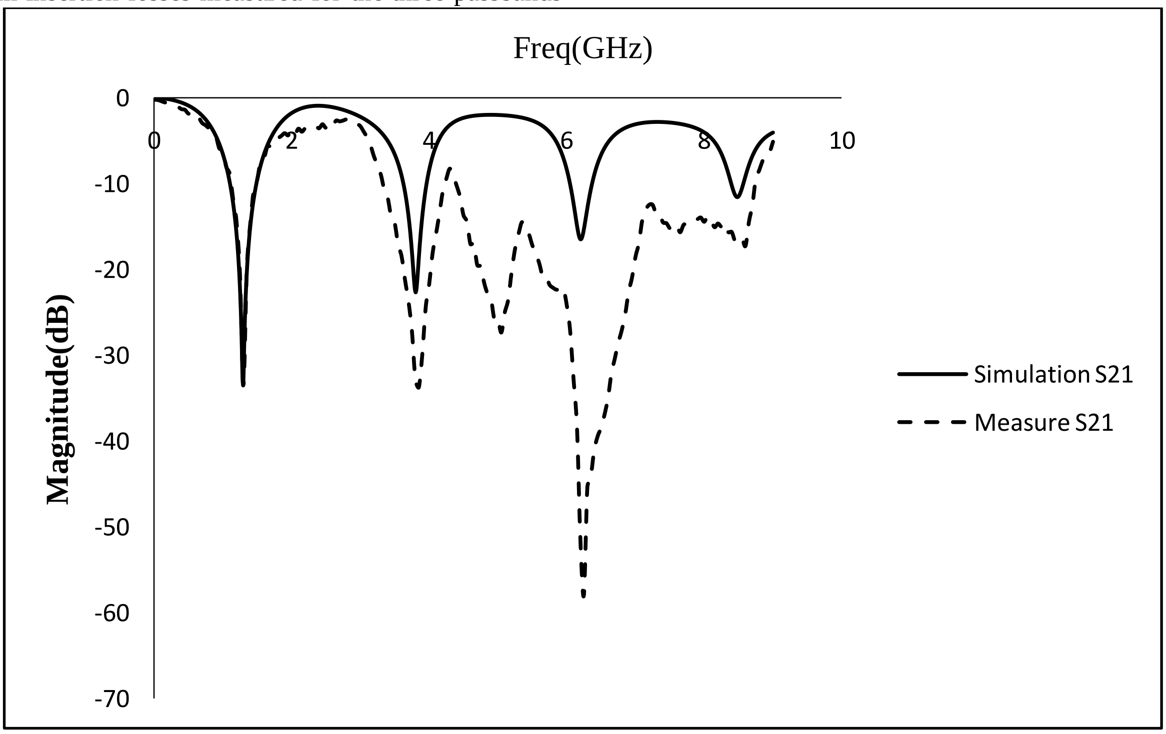


Figure 5: (b)S_{21} Simulated and Measured result of conventional T shaped BPF

Simulated and measured results shows T shaped BPF has Tri band nature with broad range of desired frequencies. T shaped resonator used for wireless local area network application. Three passbands were obtained between 1 to 9 GHz frequency ranges. High selectivity of the passbands was obtained greater than 25dB. Insertion loss of are not more than 3dB.

VIII. PROPOSED FILTER DESIGNS

A compact multi-band bandpass filter was designed, which uses direct coupledline technology to achieve high selectivity of the filter. According to the design principle of SLR filter, basic resonator is designed with low cost substrate.

In this design quarter wavelength stub is used to meet multi-band BPF gives broad range of frequencies. Based on stub length, filter introduce single, dual, quad and penta band respectively. Furthermore, the multi-band resonator with open stubs in series and parallel is presented. The effect of microstrip open end on each stub has been taken into account. The design techniques for multi-band filters based on a single filter circuit. However it still challenging to the designer, because it is difficult to design a single bandpass filter to achieve multi-bands with reduction in size. The proposed filter has great degree of freedom flexibility.

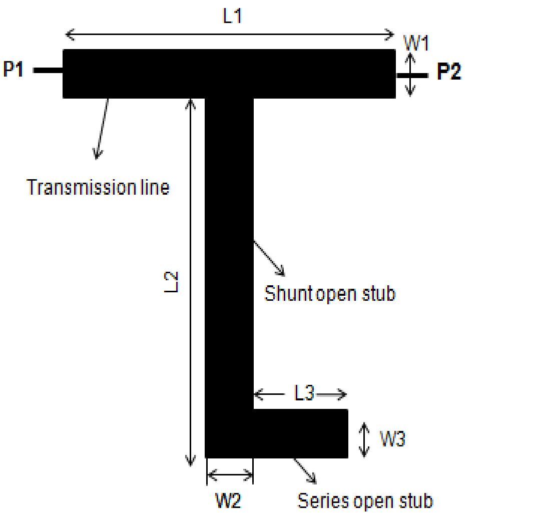


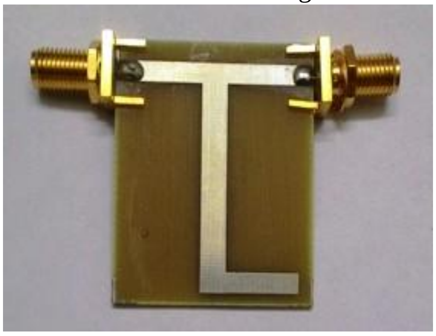
Figure 6: Proposed bandpass filter design using SLR

The designed BPF consists of two open stub loaded resonators placed in L shape at the mid of transmission line. This structure introduces multiple passband along with wide stopband signals. In each passband single transmission zero is presented.Meander line structure used in L shape improves the performance of the BPF of the input and output, and the stub loaded resonator helps for size reduction.

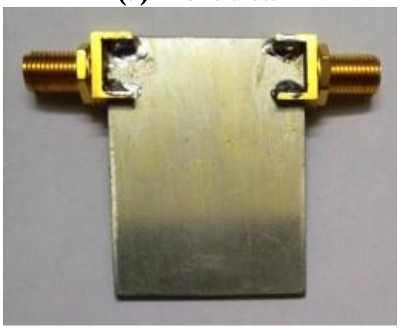
Table 3: Specification of the filter

SPECIFICATION	
Substrate material	FR4 epoxy
Dielectric constant	4.4
Substrate thickness(mm)	1.6
Loss tangent	0.02
Size of the filter(mm²)	31.25×31.25

Specification of the proposed filter was listed above. Thickness of the material is directly proportional to the loss of the filter. This means that when thickness of the substrate material is less, insertion loss of the filter is also less. If it is high, insertion loss of the filter also high.



(a) Front view



(b) Back view

Figure 7:Photograph of BPF using SLR

IX. SIMULATION RESULTS

The proposed filter consists of bend at the T-shape arranged stub-loaded resonators, and has a significantly widened passband.

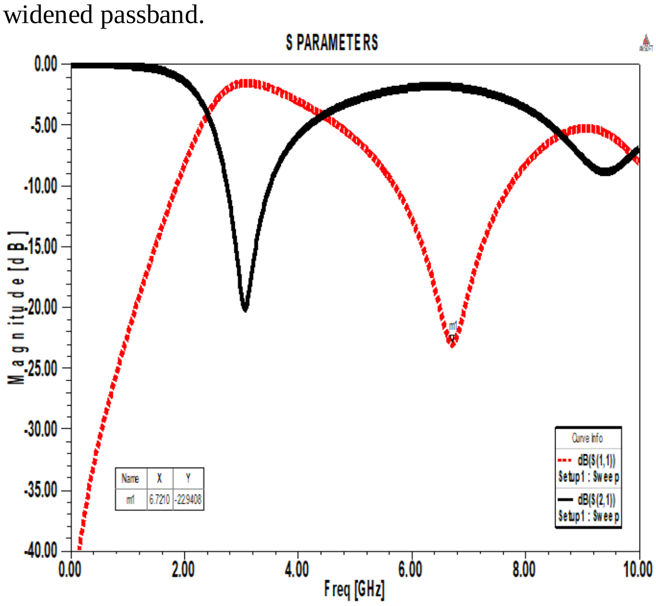


Figure 8: (a)Simulation result of single band filter

The filter has a passband covering 3.5-9.3 GHz, Center frequency at 6.7 GHz which used for ultra wideband (UWB) application. The overall size of the filter of single band filter is 10×10 mm², the structure of the filter is same as figure 6.

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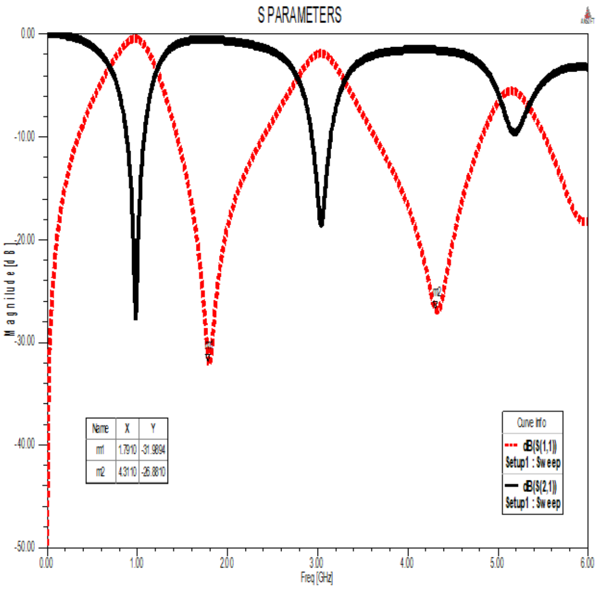

Figure 8 :(b) Simulation result of Dual-band filter

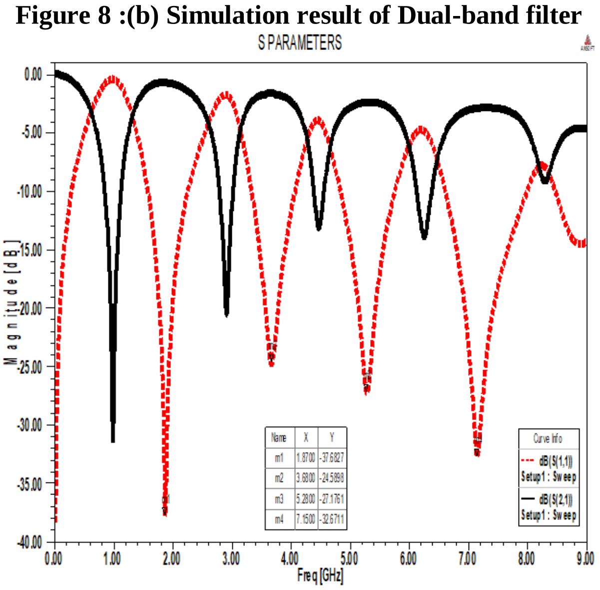

Figure 8 :(c) Simulation result of Quad-band filter

For the same structure with dimension of 31.25× 31.25mm² has Dual/quad and penta band, only the electrical length of the filter should change. From the simulation results it can be noted that the proposed filter has multiband nature with wide stopband signals.

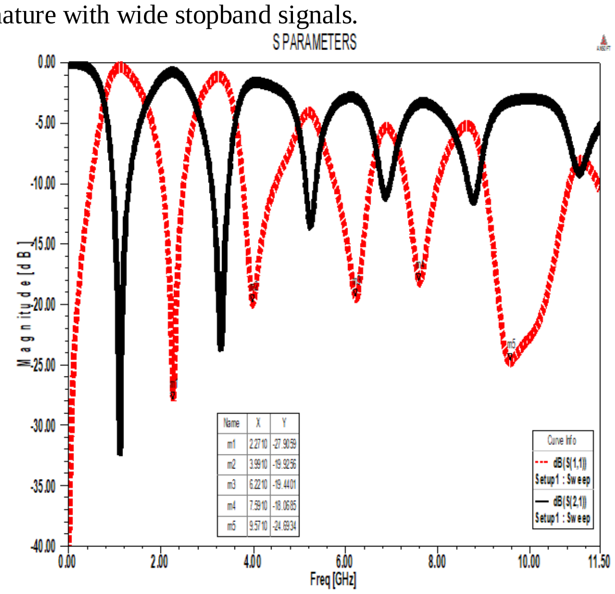

Figure 8: (d) Simulation result of Penta-band filter

Table 4: Parameters of the investigated filter

Band	Pass bands (GHz)	Center frequency (GHz)	FBW (%)	IL (dB)	RL (dB)
Single band	3.1-9.5	6.7	87.35	2	22.94
Dual band	1.0-2.9/3.1-5.1	1.8, 4.3	98.08,46.99	1,2	32.17,26.95
Quad band	1.1-2.7/3-4.3/4.5-6.1/6.3-8.2	1.8,3.6, 5.2,7.1	89.30,37.60, 29.92,26.85	1,1.5, 2,3	37.62,24.70, 27.17,32.67
Penta band	1.3-3.1/3.4-5.2/5.3-6.7/6.9-8.6/8.8-11.0	2.2,4.0, 6.2,7.6, 9.5	78.75,41.89, 23.07,22.41, 23.19	1,1,2, 2.5,3, 2.5	27.90,19.78, 19.39,17.93, 24.69

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X. EXPERIMENTAL RESULTS

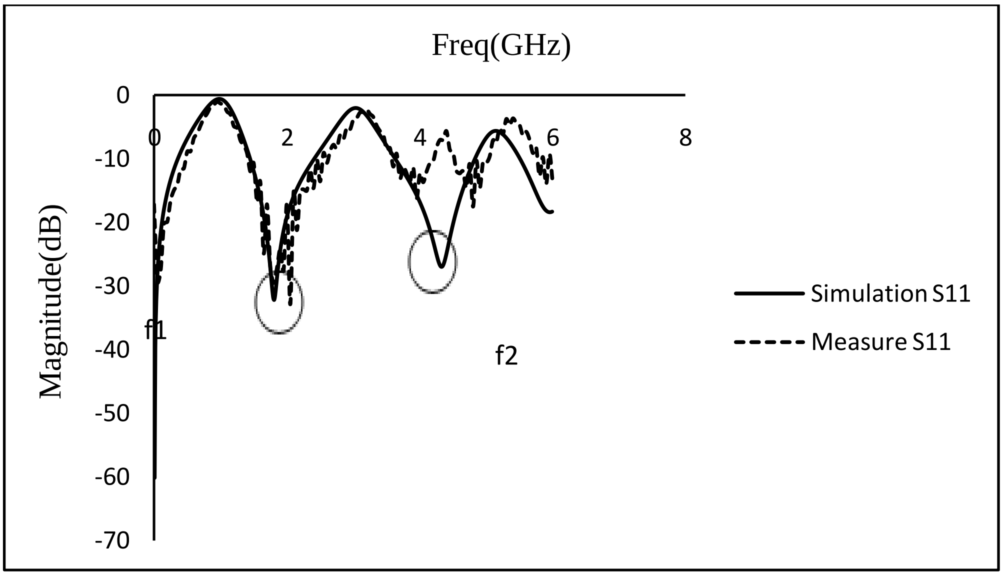

Figure 9: (a) Insertion loss of dual band filter

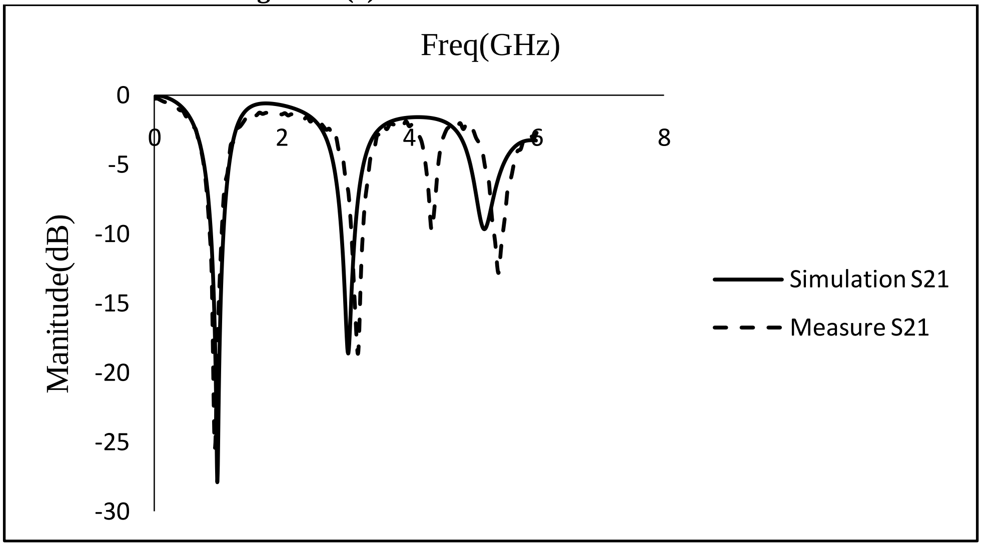

Figure 9: (b) Return loss of dual band filter

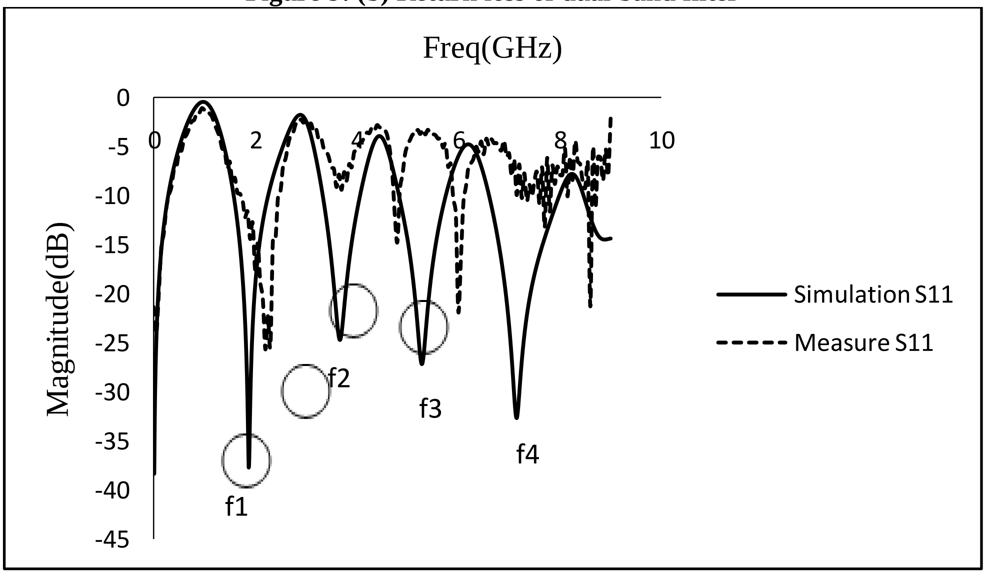

Figure 10 : (a) Insertion loss of quad band filter

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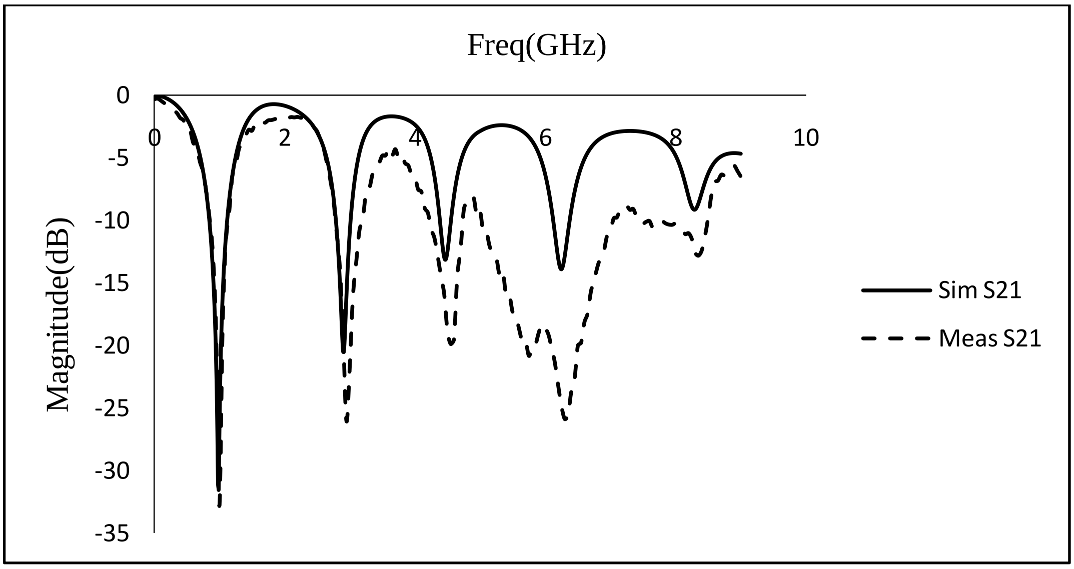


Figure 10 :(b) Return loss of Quad band filter

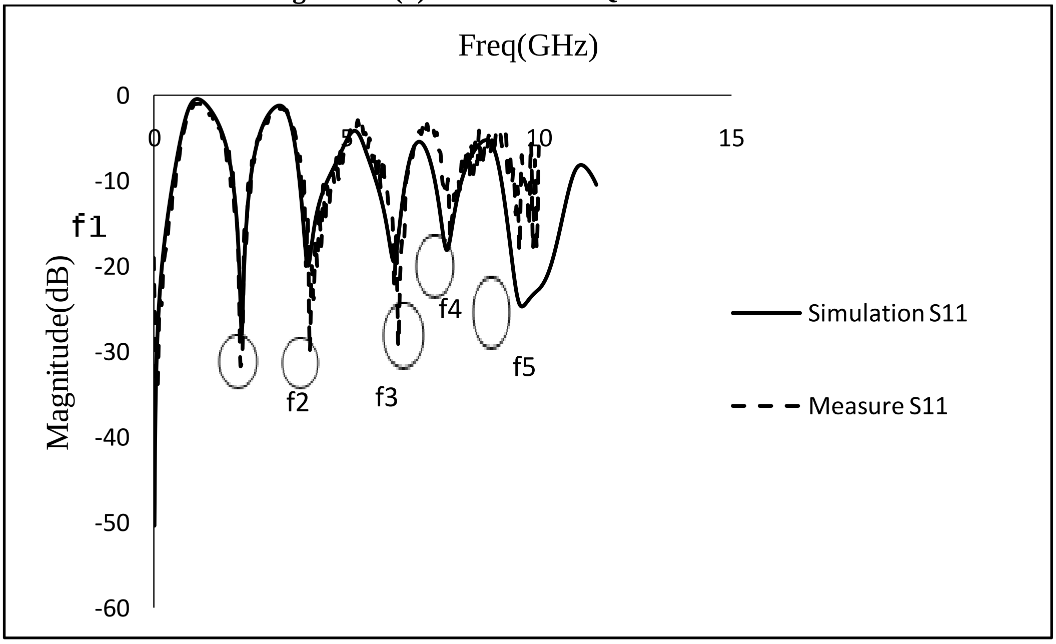


Figure 11: (a) Insertion loss of Penta band filter

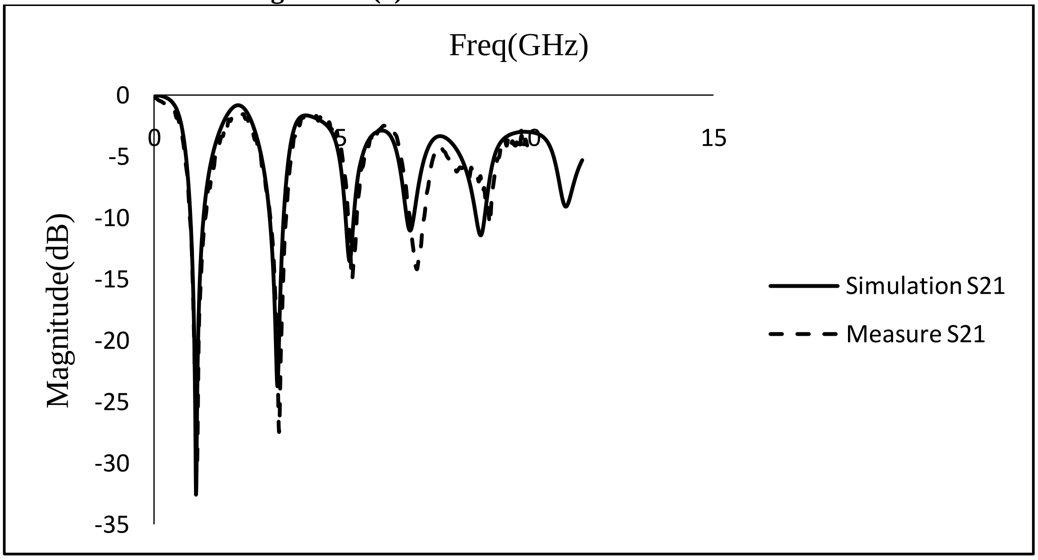


Figure 11: (b) Return loss of penta band filter

From figure 8 to 10 shows proposed filter has multiband nature. The filter was operated from 30 kHz to 10GHz. Based on the dimension proposed filter structure has dual/quad and penta bands of passbands responses. Fabricated structure was shown in figure 6. The same filter structure provides single/dual/quad and penta band nature for various dimensions. Those dimension specification was listed following table 5.

Table 5: Dimension of the multi-band BPF

Band	L1(mm)	L2 (mm)	L3 (mm)	W1 (mm)	W2 (mm)	W3 (mm)
Single band	10	10	5	1.5	1.5	1.5
Dual band	31.25	31.25	10.417	3	1.5	3
Quad band	31.25	31.25	15.625	3	4	3
Penta band	31.25	31.25	10.417	1.5	3	1.5

Table 5 indicates the dimension of the proposed BPF. At L1=L2 condition the investigated filter has multiband nature. Based on L3 to L1 proportion bands of the filter have been changed.

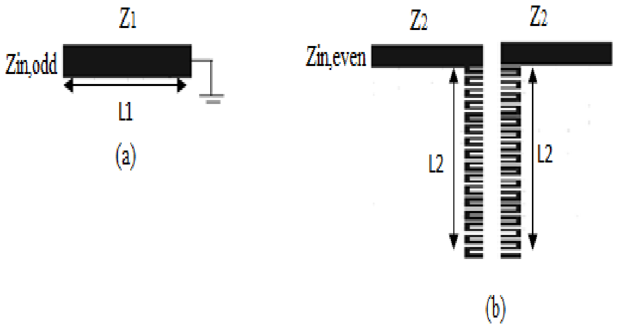


Figure 12:(a) Odd mode equivalent circuit (b) Even mode equivalent circuit ofT shaped resonator using meander line

Figure 11 indicates T shaped resonator using meander line. The proposed filter has single open stub loaded resonator. This open stub was changed as meander line structure which makes the filter should operated lower frequency bands in the range of 30 KHz to 5GHz. Because meander line act as inductor. This filter used for GSM and WLAN application.

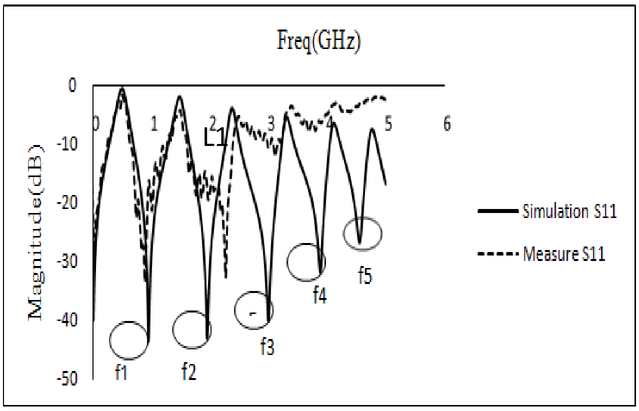


Figure 13: (a) Return loss of proposed filter

Figure 13(a) indicates return loss of proposed filter and it shows simulated and measured results of the T shaped resonator. Changes were made at single open stub (i.e. Meander line used) which makes the filter was operated lower frequency bands. Because inductor value is directly proportional to frequency. This filter is used for GSM as well as WLAN applications. Penta band response was obtained with single transmission zeros in the pass bands. High selectivity was obtained above 20 dB.

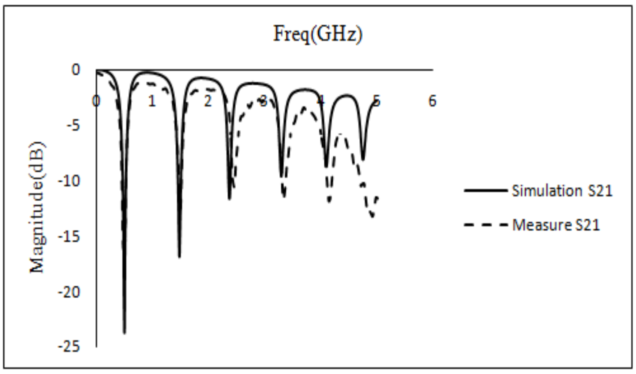
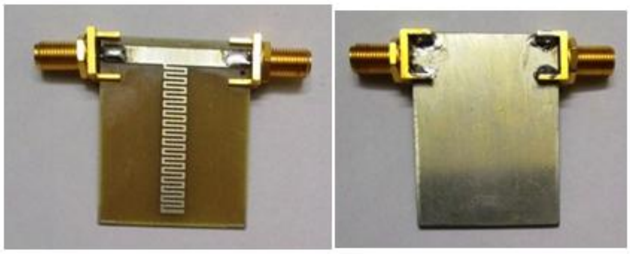


Figure 13: (b) Insertion loss of the proposed filter

Figure 13(b) indicates insertion loss of proposed filter and it shows simulated and measured results of the T shaped resonator. Agreed results of insertion loss were not more than 5 dB. Fabricated structure was shown below.



(a) Front view **(b) Back view**

Figure 14: Photograph of T shaped resonator using meander line

Table 6: Dimensions and parameters of penta band filter

DIMENSION SPECIFICATION(mm)			
L1	L2	W1	W2
31.25	31.25	3.5	5

Center Freq(GHz)	FBW (%)	IL(dB)	RL(dB)
f1(0.95)	97.89	0	43.65
f2(1.9)	43.58	0.5	43.19
f3(3)	29.66	1	40.20
f4(3.8)	19.07	1.5	32.02
f5(4.56)	12.93	2	26.77

At resonance condition (i.e. Purely Resistive) impedance should be matched. From above table we identified that center frequency 0.95 GHz and 1.9GHz should operatedfor GSM application and 3GHz, 3.8 GHz and 4.6GHz should applicable for WLAN application.

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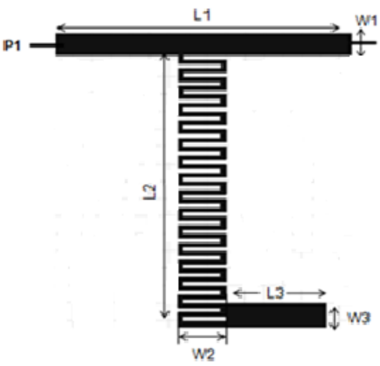


Figure 15: Proposed BPF using meander line (center stub

The investigated BPF consists of two open stub loaded resonators placed in L shape at the mid of transmission line. Meander line structure used in shut open stub resonator which reduces electrical length of the filter. So that the filter should operated in the lower frequency range. Series open stub resonator connected at the end of shunt open stub resonator. This introduces multiple passband with single transmission zero. This meander line stub act as inductor.

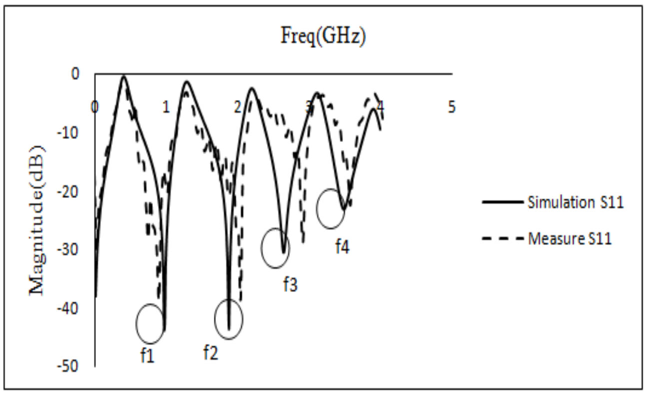


Figure 16 : (a) Return loss of proposed filter with meander line structure

Figure 16 (a) indicates return loss of proposed filter and it shows simulated and measured results of the proposed filter with meander line structure. Changes were made at the center of transmission line (i.e. Meander line structure used). High selectivity was obtained above 22 dB.

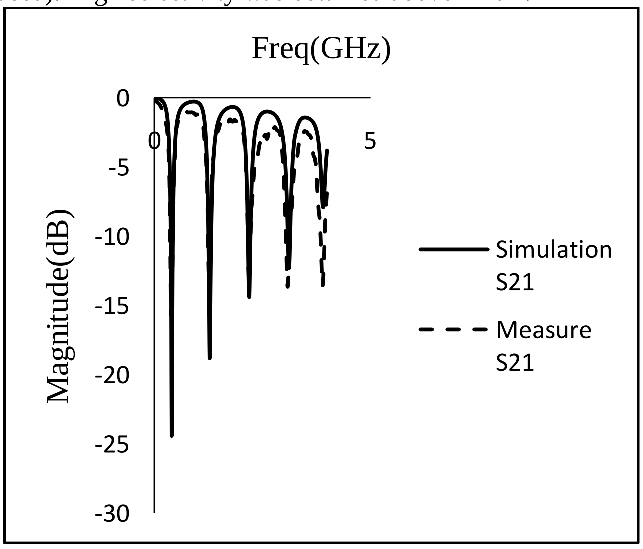
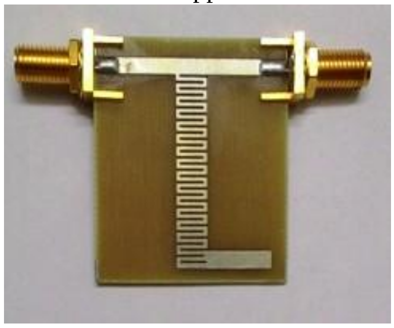
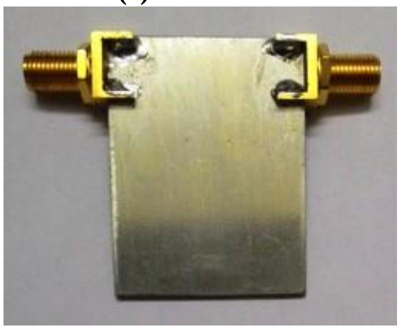


Figure 16: (b) Insertion loss of proposed filter with meander line structure

Figure 16 (b) indicates insertion loss of proposed filter and it shows simulated and measured results of the proposed filter with hairpin structure. Insertion loss is not more than 2 dB. This structure should operate in the frequency range of 0.97 GHz, 1.8 GHz, 2.6 GHz and 3.5 GHz. The first two center frequencies used for GSM application the last two frequencies used for WLAN application.



(a) Front view



(b) Back view

Figure 17: Photograph of proposed filter with meander line structure

Table 7: Dimensions and parameters of quad band filter

DIMENSION SPECIFICATION (mm)					
L1	L2	L3	W1	W2	W3
31.25	31.25	15.625	3.5	5	2.5

Center Freq (GHz)	FBW (%)	IL(dB)	RL(dB)
f1(0.97)	84.53	0	43.86
f2(1.88)	45.21	0.4	43.70
f3(2.65)	32.45	0.8	30.63
f4(3.51)	21.74	1	22.93

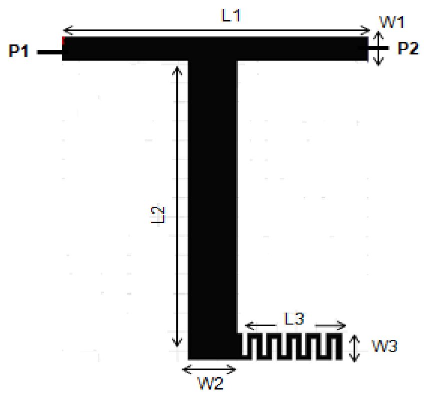


Figure 18:Tri-band filter with meander line structure

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The investigated BPF consists of two open stub loaded resonators. Shunt open stub resonator placed at the mid of transmission line. Series open stub resonator connected at the end of shunt resonator (meander line structure used). This introduces three pass bands with single transmission zero. Compared to previous structure pass bandof the filter was decreased due to electrical length of meaderline.

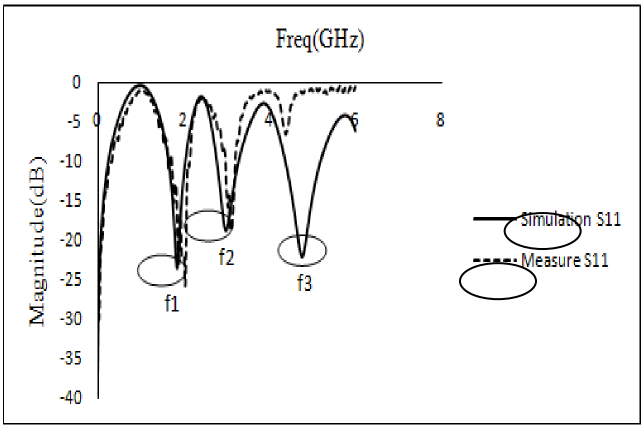


Figure 19: (a) Return loss of tri-band BPF

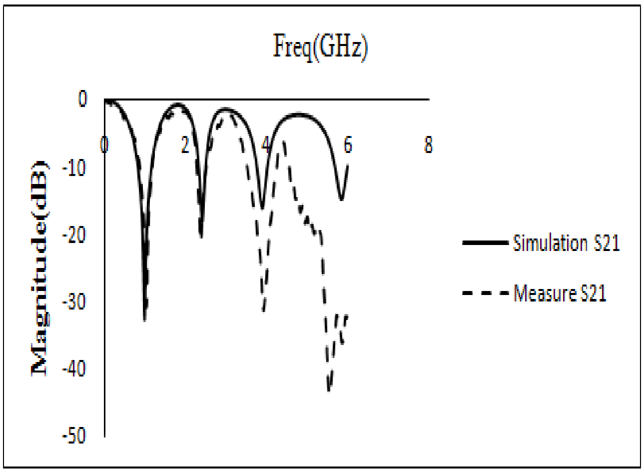
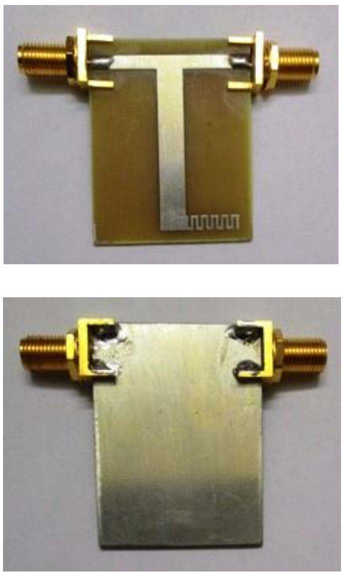


Figure 19 :(b) Insertion loss of tri-band BPF

Figure 20 indicates return loss and insertion loss of proposed filter and it shows simulated and measured results of the proposed filter with meander line structure.



(a) Front view (b) Back view

Figure 20: Photograph of proposed filter with meander line structure

Table 8: Dimension and parameters of tri-band filter

DIMENSION SPECIFICATION(mm)					
L1	L2	L3	W1	W2	W3
31.25	31.25	15.625	2.5	5	2.5

Center Freq(GHz)	FBW (%)	IL(dB)	RL(dB)
f1(1.86)	62.9	0.8	23.56
f2(3)	42	1.4	18.81
f3(4.76)	38.4	2	22.14

Changes were made at the series stub resonator (i.e. Meander line structure used). High selectivity was obtained above 10 dB. Insertion loss was not more than 4 dB. This structure suitable for both GSM and WLAN application in the frequency ranges of 1.8 GHz, 3 GHz and 4.7 GHz respectively.

XI. CONCLUSION

This paper deals with estimation of insertion loss, return loss and fractional bandwidth of the optimized microstripbandpass filter along with its results. Agreed simulated and measured result was discussed. Multi band nature was identified in investigated filter. Using meander line structure at L shaped resonator, the filters were operated in lower frequency ranges. Investigated bandpass filter was fabricated using FR4 substrate, to achieve low cost with high performance.

Different designs for micro strip stub loaded BPF has been presented in this thesis work. Size reduction objective has been achieved with satisfactory results. Response characteristics of all the filters were suitable for manufacturing purposes.

Furthermore, the analysis presented for overall design procedure is extremely handy. The conclusions drawn from the analysis can be employed for further designing procedures and the resulting designs can be extremely accurate and efficient. Coupling procedure presented is also pretty useful for the further miniaturizing of the filter designing.

Compact multiband bandpass filter using single stub loaded resonator is presented and two operating modes (even & odd) of the resonator have been investigated by full-wave analysis. A bandpass filter based on the resonator is designed and fabricated. The whole filter has a size around 31.25 x 31.25mm. Simple structure provides multiple pass band is an added advantage. The simulation result shows that this type of filter not only has an inherent transmission zero, but also has a very wide stop band to improve selectivity.

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