Stepped Impedance Microstrip Low-Pass Filter Implementation for S-band Application

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Abstract—In this era, life cannot be imagined without wireless communication. It is the need of world. Almost all communication systems contain an RF front end which performs signal processing using RF filters. Microstrip filter play an important role in microwave applications. The method of step impedance lowpass prototype filter is used to design microstrip filter. For stepped impedance filter design, low and high characteristic impedance lines are used. This paper describes the design of S-band low pass filter by using microstrip layout operating at 2.5 GHz for permittivity 4.1 with a substrate thickness 1.6 mm for order n=6. Microstrip technology is used because of its simplicity and ease of fabrication. The design and simulation of lowpass filter are performed using AWR microwave office software which is developed by Applied Wave Research USA. After simulation the lowpass filter was fabricated by photolithographic process. Finally, it was tested using vector network analyzer. The practical simulation and measured results have been a fairly good agreement together.

Keywords—Microstrip lowpass filter, stepped impedance, Richard's transforms, AWR Microwave office software, FR4 substrate

I. INTRODUCTION

A filter that allows low frequency signals and rejects high frequency signals and transmits low frequency signals from the input to the output port with less attenuation is called low pass filter. However, attenuation increases with the amplitude-reduced signal as frequency exceeds certain cut-off point. The real amount of attenuation for each frequency changes from filter to filter. A low-pass filter is the opposite of a high-pass filter, and band-pass filter is a combination of a low-pass and a high-pass filter. Low-pass filters are applied in many different forms such as audio applications, acoustic barriers, electronic circuits, blurring of images etc. Low-Pass filters are used in huge amount in many millimeter-wave and microwave systems to pass the desired low frequencies below cut-off and reject the higher frequencies. A microstrip low-pass filter has many useful properties like very low insertion loss, easy fabrication and compact size. Hence, it has increased applications in microwave circuits and mobile communication. Filters are required to have large return loss and small insertion loss for good impedance matching to prevent interference [2].

For this filter design, microstrip line is a good transmission line due to advantages of light weight, planar structure, low cost, compact size and easy integration with other components on a single fabrication method. Conventional low frequency techniques for fabrication do not fit at these frequencies due to the very high losses associated. Although many recent advents of novel materials and fabrication techniques like Micro-Electro-Mechanical Systems (MEMS), Monolithic Microwave Integrated Circuit (MMIC), etc are available, because of easiness; thin microstrip film fabrication technique is preferred [1].

In this paper, the design of filter is done in the S-band whose frequency lies between 2GHz-4GHz. After getting the required specifications, the filter structure has been realized with the help of AWR microwave office. This is user-friendly software with all the capabilities needed for the accurate modelling, design and simulation of microwave components.

II. FILTER DESIGN METHOD

In this section filter has been designed using AWR microwave office simulation software and display the parameter by the circuits. Design and optimization of lowpass filter is done using microstriplines.

Filter designs beyond 500MHz are difficult to realize with lumped elements because the wavelength becomes comparable with the dimensions of the physical filter element, resulting in different losses severely degrading the performance of the circuit. Thus the lumped component filters must be converted into distributed element realizations to arrive at practical filters [3]. Two major problems associated with microwave filter design are, first is that only lumped elements work properly within the limited frequency range and second is that there is no negligible distance between components at microwave frequency. Richard's transforms is used to solve the first problem which converts lumped elements into transmission line section. Kuroda's identities can be used to solve second problem by separating filter elements using transmission elements. [3]

Richards Transformation:

For conversion from lumped to distributed circuit designs, Richard proposed a unique transformation that allows open and short circuit transmission line segments for emulating the capacitive and inductive behavior of the discrete components. The input impedance is purely reactive of a short circuit transmission line of characteristic impedance Zo. [3]

$$Zin = j\, Zo \tan(\beta l) = j\, Zo \tan \Theta$$

To make the frequency behavior explicit, the electric length Θ can be rewritten. At a particular reference frequency $f_o = Vp/\lambda_o$ if we choose the line length to be λo/8, the electric length becomes

$$\Theta = (\Pi/4)\, \Omega$$

On substituting we get

$$j\omega L = j\, Z_0 \tan((\Pi/4)\, \Omega) = SZ_0$$

Similarly

$$j\omega C = j\, Y_0 \tan((\Pi/4)\, \Omega) = SY_0$$

Where, $S = j \tan((\Pi/4)\, \Omega)$ is Richards transform. Richards transformation allows to replace lumped capacitors with open circuit stubs and inductors with short circuit stubs of characteristic impedance $Zo=1/C$ [3].

The design of low pass filters involves two steps. The first one is to select an appropriate low pass prototype. Depending on the required specifications, the type of response including pass band ripple and the order of the filter are chosen. The values of the elements of the lowpass prototype filters are normalized to make a source impedance $g_0=1$ and a cutoff frequency $\Omega_c=1$. They are then subjected to transformation to obtain the L-C elements for the required cutoff frequency and the source impedance. The source impedance is normally 50 Ω for microstrip filters. The next step in the design of microstrip lowpass filters [2] is to find an appropriate microstrip realization that approximates the lumped element filter. The values of the elements for the lowpass prototype filter with maximally flat response at passband ripple factor L_{AR}=0.1dB. Characteristic impedance of source or load Z_0=50 Ω, are taken from the normalized values g_i i.e. g_1, g_2, g_3, g_4……g_n .The filter is assumed to be fabricated on an Fr4 substrate of permittivity ε_r and of thickness h mm for normalized cutoff frequency Ω_c, using the element transformation [1].

The filter design steps are as follows:

1. Determine the number of sections from the filter specification of microstrip parameters

Filter Specifications:
Topology: stepped impedance
Passband: lowpass
Relative Dielectric Constant ε_r =4.1
Height of substrate h=1.6mm
Cutoff frequency=2.5GHz
The loss tangent tanδ=0.06
The filter impedance Z_0 =50Ω

The highest line impedance Z_H=Z_{OL}=120Ω
The lowest line impedance Z_L=Z_{OC}=20Ω

2. Determine order of the filter

For proposed design work, to get maximally flat response in passband we assume Butterworth approximation. For normalized LPF design with source impedance 1 Ω and cut off frequency ω_c =1, the elemental values for ladder type circuits are tabulated in table 1 for N=1 to N=6. Figure 1 shows attenuation characteristics for various N values versus normalized frequency.

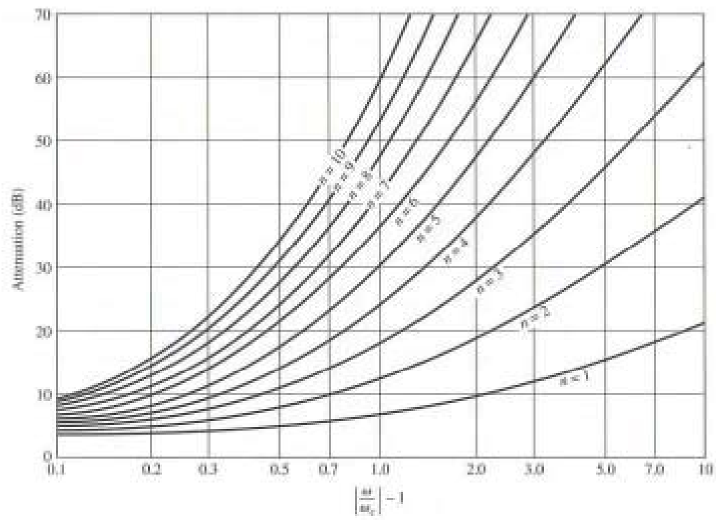

Fig. 1 Attenuation versus Normalized Frequency for Maximally Flat Filter [1]

Table I
Element Values for Maximally Flat LPF Prototype (Butterworth) (N=1 to N=6) [3]

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7
1	2.0000	1.0000					
2	1.4142	1.4142	1.0000				
3	1.0000	2.0000	1.0000	1.0000			
4	0.7654	1.8478	1.8478	0.7654	1.0000		
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000	
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000

In practical filter design procedure, it is necessary to determine the order of the filter. In this paper, the order of the filter is selected from figure 1. i.e, N=6 and filter element co-efficients are

$g_1 = 0.5176 = C_1$, $g_4 = 1.9318 = L_4$,
$g_2 = 1.4142 = L_2$, $g_5 = 1.4142 = C_5$,
$g_3 = 1.9318 = C_3$, $g_6 = 0.5176 = L_6$.

The actual or demoralized amount of inductors L_i and Capacitors C_i is calculated from equations 1 and 2. [3]

$$L_i = Z_0 g_i / 2\pi f_c \qquad (1)$$

$$C_i = g_i / Z_0 2\pi f_c \qquad (2)$$

The electrical length of the inductor $\beta l = LZ_0 / Z_H$

The electrical length of the capacitor $\beta l = CZ_L / Z_0$

L and C values are the normalized element values of the low pass prototypes.
The implementation of the microstrip lowpass filter with step impedance is done on FR4 substrate with dielectric coefficient 4.1 and thickness 1.6 mm with copper conductor 35 microns. The highest practical characteristic impedance considered is 120 ohm and lowest 20 ohm of the line. The width of high impedance line assuming $w/h \leq 2$ and the width of low impedance line assuming $w/h \geq 2$ are calculated as follows [1]:

$$\frac{w}{h} \leq 2 \Rightarrow \frac{w}{h} = \frac{8\exp(A)}{\exp(2A) - 2}$$

$$A = \frac{Z0}{60}\left\{\frac{er+1}{2}\right\}^{.5} + \left(\frac{er-1}{er-1}\right)\left\{0.23 + \frac{.11}{er}\right\}$$

$$\frac{w}{h} \geq 2 \Rightarrow \frac{w}{h} = \frac{2}{M}\{(B-1) - \ln(2B-1)\} + \frac{er-1}{2er}\left[\ln(B-1) + 0.39 - \frac{.61}{er}\right]$$

$$B = \frac{60\pi^2}{Z0\sqrt{er}}$$

III. DIMENSIONS OF THE FILTER

Table 2: Dimensions of the stepped impedance microstrip lowpass filter (For N = 6)

Section	Z_i=$Z_L$or Z_H (Ω)	βl_i(degree)	w_i(mm)	l_i(mm)
1	20	11.84	11.1	2.04
2	120	33.75	0.4084	6.55
3	20	44.27	11.1	7.64
4	120	46.12	0.4084	8.95
5	20	32.4	11.1	5.59
6	120	12.34	0.4084	2.39
7	20	23.86	3.0590	4.35

IV. SIMULATION AND MEASURED RESULTS

For the simulation purpose we have used AWR microwave office software.
The final filter prototype section is shown in Fig. 2

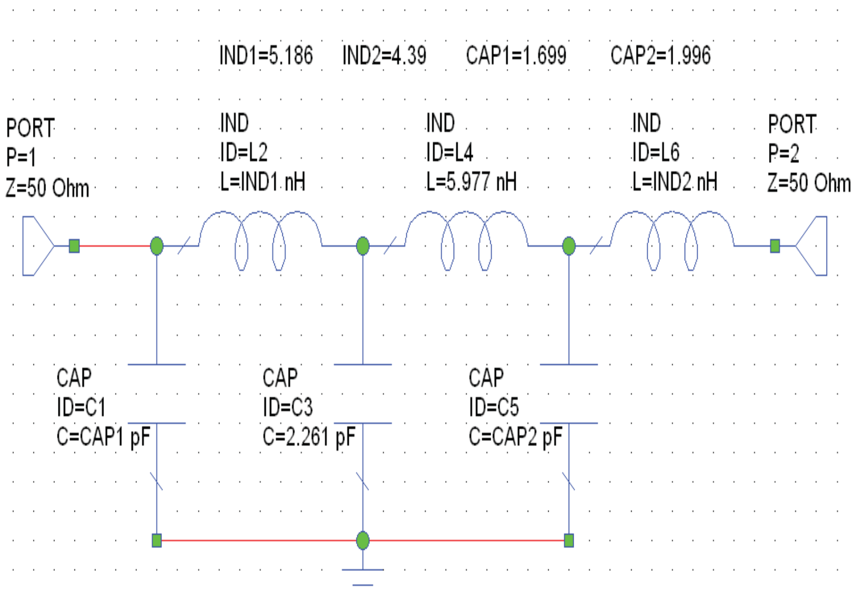

Fig. 2 Low Pass Filter Prototype

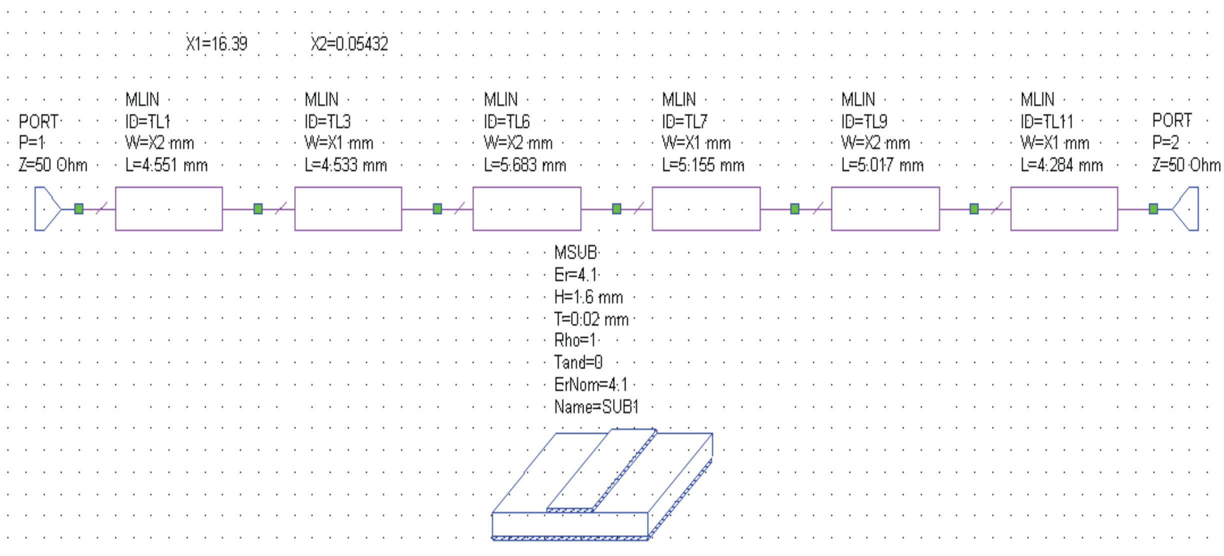

Fig. 3 Schematic diagram of LPF Using microwave office

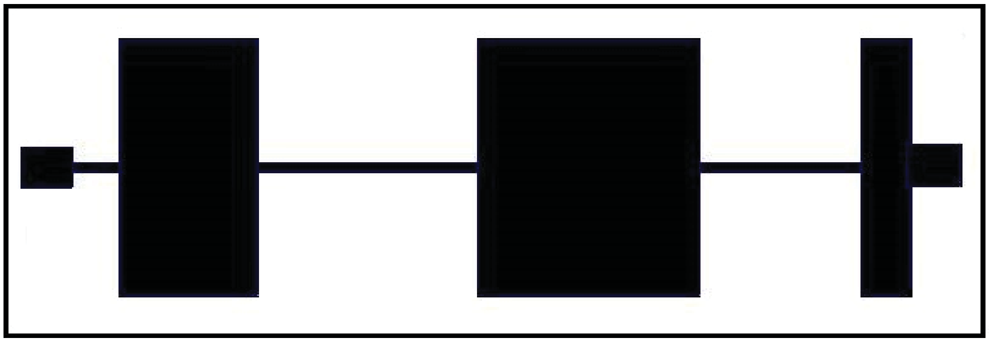

Fig. 4: Layout of a 6-Pole Stepped Impedance Microstrip Low Pass Filter on a Substrate with εr =4.1and h=1.6mm at 2.5GHz

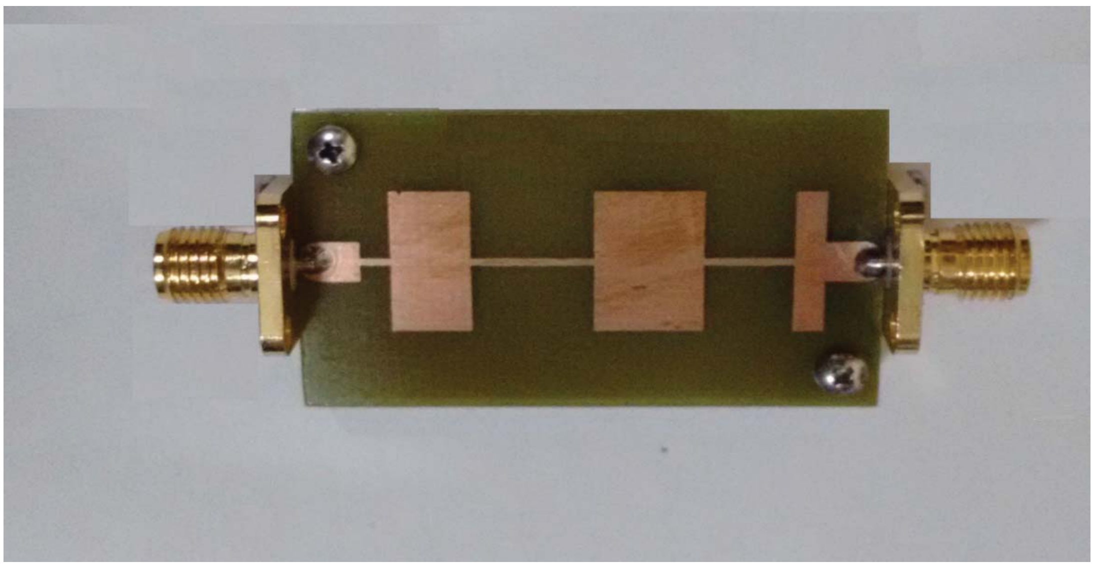

Fig. 5: Fabricated 6-pole Stepped Impedance Microstrip Low Pass Filter on a Substrate with εr =4.1 and h=1.6mm at 2.5GHz

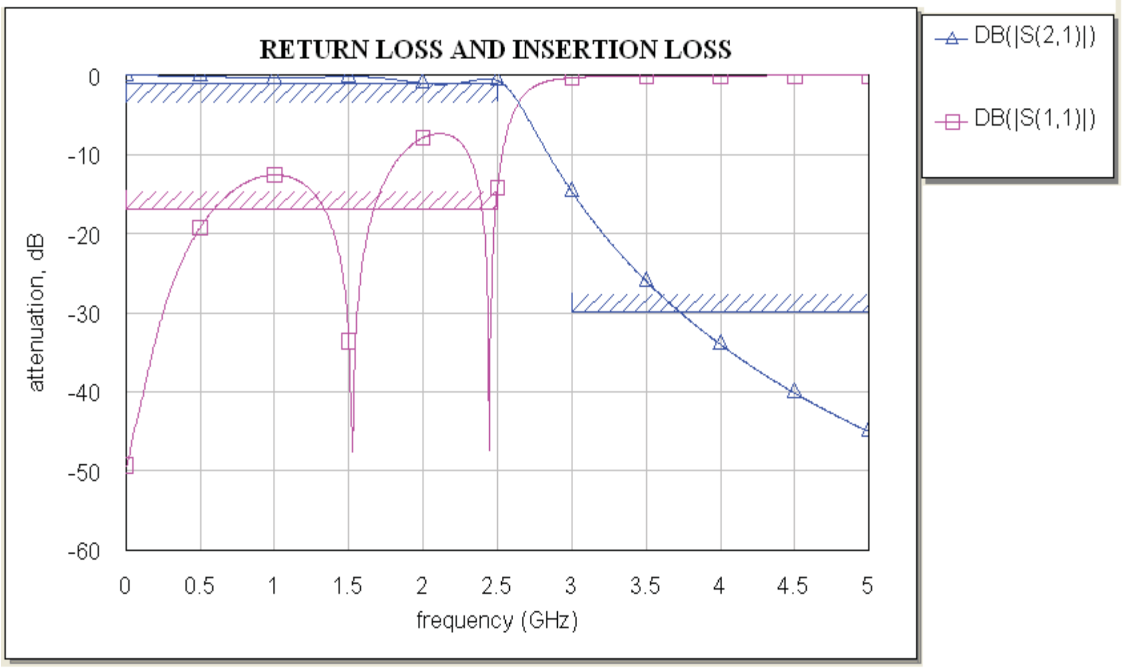

Fig. 6: Simulated Performance of the Stepped Impedance Low Pass Filter n=6 at 2.5GHz

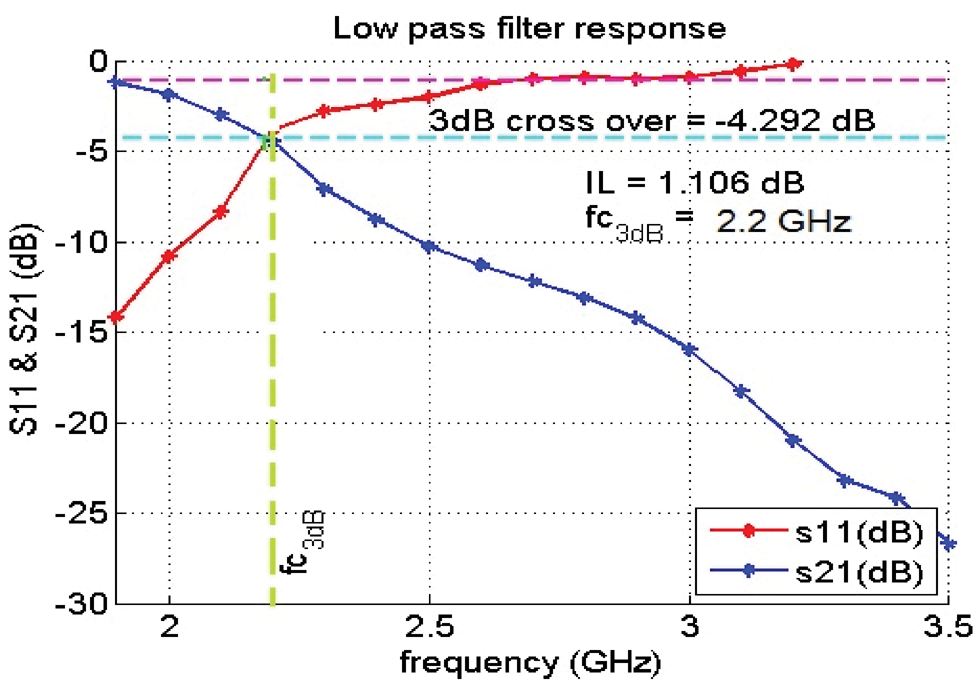

Fig. 7: Response of Stepped Impedance Low Pass Filter Measured

V. RESULTS

The simulated lowpass filter structure and its response is shown in fig. 4 and fig. 6. The fabricated structure and measured response is shown in fig. 5 and fig. 7. In the response graph, frequency (GHz) is plotted on the X-axis and gain (dB) on Y-axis. From the graph shown in fig. 6, the simulated cut-off frequency is 2.5 GHz for stepped-impedance low pass filter and from fig. 7, it is clear that the measured value is 2.2 GHz at -4.292dB. Hence the low pass filter is capable of passing the frequency less than 2.2 GHz & rejects the frequency after 2.2 GHz. The insertion loss of simulated result is -0.6975 dB at 2.5 GHz and measured result is -1.106 dB. So this filter can be used for S-band applications i.e. above 2 GHz.

VI. APPLICATIONS

The filters are the primary and vital components of a microwave system. Any communication system cannot be designed without filters. Lowpass filter must be included at the RF front end to get desired spectrum. We have designed stepped impedance lowpass filter because it occupies less space than a similar lowpass filter using stubs. The required space for realization is minimized by its compactness and is quiet suited for integration within Wireless system.

VII. CONCLUSION

A stepped impedance lowpass microstrip filter has been designed, simulated, fabricated and tested. The cutoff frequency achieved is lower than the design specification value i.e 2.5GHz. This may be due to imperfect fabrication and connection of SMA connector.

REFERENCES

[1] D.M.Pozar, “Microwave Engineering”, John Wiley, 2000.

[2] JiaShen G.Hong, M.J.Lancaster, “Micro strip Filters for RF/Microwave Applications”, John Wiley &Sons Inc., 2001...

[3] Ludwig, Reinhold and Bretchko, Pavel (2000). “RF Circuit Design - Theory and Application” New Jersey, USA: Prentice-Hall, Inc.

[4] Sudipta Das, Dr. S.K.Chowdhury, “Design Simulation and Fabrication of Stepped Impedance Microstrip line Low Pass Filter for S-band Application using IE3D and MATLAB” IJECT Vol. 3, Issue 1, Jan. - March 2012.

[5] Omid Borazjani and Arman Rezaee, “Design, simulation and construction of a low pass microwave filters on the microstrip transmission line” International Journal of Computer Theory and Engineering, Vol. 4, No. 5, October 2012.

[6] Aarti Solanki, Nidhi Sharma and Hemant Kumar Gupta, “Design of Microstrip Low Pass Filter for L-Band Application” International Journal of Electronics and Electrical Engineering Vol. 3, No. 3, June 2015.

[7] G. Mathaei, L.Young, E.M.T. Jones, “Microwave Filter impedance matching networks and coupling structures”, Artech House, Norwood, MA, 1980.

[8] M. Makimoto, S.Yamoshita, “Microwave Resonators and Filters”, IEEE Trans. Wireless communication Vol. 2, August 1986.

[9] Tae-Yeoul Yun, Kai Chang, “Transaction on Microwave Theory and Techniques”, IEEE Trans, Vol. 49, No. 3.

[10] Phani kumar TVB, Nagraju N, Santhosh Kumar Ch “Microwave Stepped Impedance LPF Design at 1.2GHz” International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 11, November 2013.