DESIGN AND IMPLEMENTATION OF LOW PASS BUTTERWORTH FILTER

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Abstract: Today's 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. Micro strip filter play an important role in microwave applications. There is an increasing demand for microwave systems to meet the emerging telecommunication challenges with respect to size, performance and cost. This project describes a general design technique for micro strip low pass filters that are used to convey microwave frequency signals. This paper describes the design of low cost and low insertion loss S-band Low Pass Filter (LPF) by using micro strip layout which works at 2.4 GHz for permittivity 4.4 value with a substrate thickness 1.2 mm for order n=3. After the development of micro strip filter we simulate it by using 3D full wave electromagnetic simulator IE3D. Photo-litho-graphic process is used for fabrication and after fabrication final testing had done by using the Vector network analyzer.

Keywords: Low Pass Filter, IE3D simulator, Vector Network Analyzer, Micro strip Filter

I. INTRODUCTION:

Micro strip filters in variety microwave Systems such as radars, measurement and test systems, satellite communications and electronic war to transfer energy in one or more pass band and to weaken the power in one or more Cut band is used very high [1],[2]. They provide advantages include low price, low volume, high selectivity and simple structure. Extensive efforts of researchers in order to apply this benefit of the filters and minimize the disadvantages of it caused to build a wide variety of filters and also to create much analytically methods. These come in much forms such as: Champlain, Inter digital, coupled in parallel, and step impedance filters [3]. However, latter from electrical performance in comparison with other structures is placed in secondary step and it is further used to filter out unwanted signals outside the bandwidth. Generally, micro strip filters is designed using injection losses [4],[5]. Implementing design as its starting is done in low pass filter form in terms of normalized impedance and frequency [6]. Then the transformations we used to imply the pattern design and sample to impedance level and desired frequency band. The losses injection method for filter includes circuits with pressed elements. For applications such as microwave design it should be modified so that they use from the extensive elements includes transmission line sections [7]. Step impedance filters, through the sections with very high and very low micro strip lines characteristic impedance are produced and hence such filters generally is Known as high impedance and Low Impedance that common and zonal structure of this type of filters is shown as in Fig. 1.

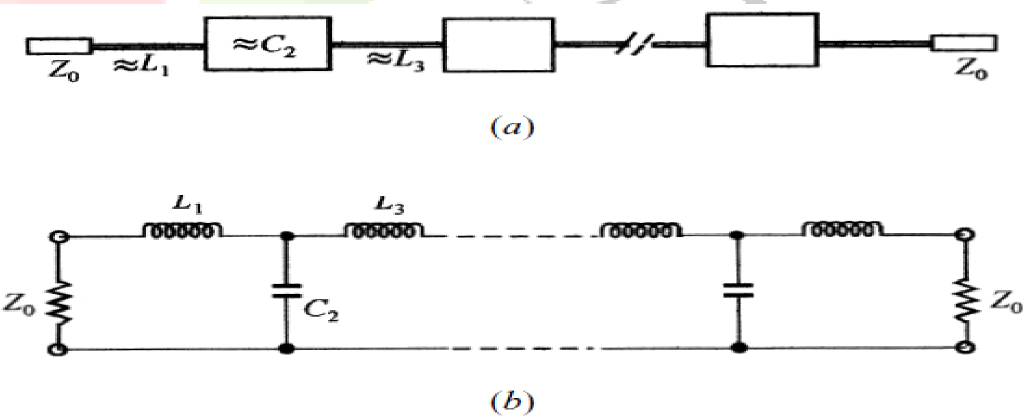

Figure:1 (*a*) General structure of the stepped-impedance micro-strip low pass filters. (*b*) Circuit structure of low pass filters to be approximated

In Fig. 1, a serial inductor of a low-pass model can be replaced with high impedance transmission line sections and parallel capacitor, with low impedance transmission line sections. Also areas with low impedance, usually is in the form of very broad transmission lines that are opposing with generic densities of filters. Other hand, a destination with high impedance with small characteristic size maybe not suitable for made, and it depend to acceptable limiting processes. In order to get advantages of larger bandwidth and smaller device size as compare to wireless links microwave communication systems are expanding rapidly towards high frequency such as S-band. Such type of filters is realized with micro-strip lines. The goal is to achieve high accuracy in obtaining the desired cut-off frequency and return loss. Micro-strip line is a good candidate for the designing of filters due to the advantages it provides like low cost, light weight, compact size, planar structure and easy integration with other components on a single board. Here we use Stepped impedance low pass micro-strip filters, because they offer better stop band characteristics and are simpler to design. It use a cascaded structure of alternating high and low impedance transmission lines. It act as semi lumped elements due to much shorter size than the associated guided wavelength. The design and simulation are performed using 3D full wave method of moment based electromagnetic simulator IE3D.

II. DESIGN AND MATHEMATICAL CALCULATION

The design of low pass filters involves two main steps. The first step is to select an appropriate low pass prototype. The choice of the type of response, including the number of reactive elements (order of the filter) and pass band ripple will depend on the required specifications. In microwave filters, lumped elements of the of filter circuit sections are simulated by means of waveguides, coaxial lines, strip (or) micro strip lines, cavity resonators, etc. [2].The equivalent lumped elements values of the microwave components are themselves functions of the frequency [2].

There are two design techniques properly used to design a low pass filter but here we use only one.

1) Image parameter method.

2) Insertion loss method.

A. *Insertion Loss method*
Complete specification of a physically realizable frequency characteristic over the entire pass and the stop bands from which the microwave filters are synthesized.

B. Low-Pass Design
Basic design of microwave filters of type's low-pass, band-pass and band-stop, operating at arbitrary frequency bands and between arbitrary resistive loads, are made from a prototype low-pass design through:
1) Some frequency transformer,
2) Element normalization and Simulation of these elements by means of sections of microwave transmission line,
3) Design of a prototype low-pass filter with the desired pass band characteristics,
4) Transformation of this prototype network to the required type (low-pass, high-pass, band-pass) filter with the specified center and band-edge frequencies.
5) Realization of the network in microwave form by using sections of microwave transmission lines.

C. *Flow Diagram to Design a Filter*
Following figure as shown in fig. 2 which shows process of the implementation of filter

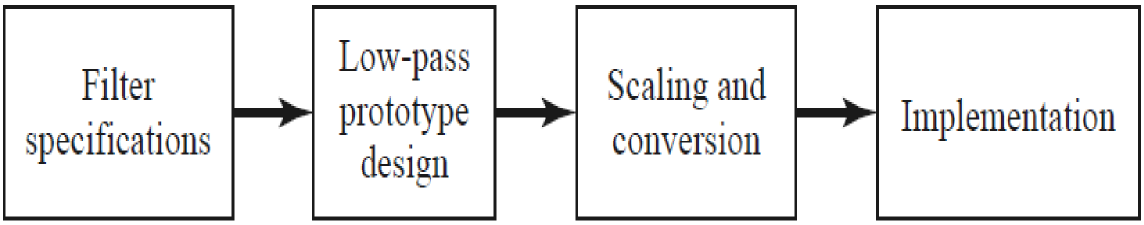

Figure 2: Flow diagram of design filter.

D. Filter Specifications
Considering the specifications required as given in Table 1 for the designing of micro strip low pass filter.

Table 1: Filter design specifications

Response Type	Butterworth (or) Maximally flat
Cut off frequency(f_c)	2.4 GHz
Source and load impedance (Z_o)	50 ohm
Substrate height	1.2 mm
Dielectric Constant	4.4
Normalized frequency(Ω_c)	1 GHz
Loss tangent tan δ	0.01
Highest line impedance	93 ohm

$Z_H = Z_{oL}$	
Lowest line impedance $Z_L = Z_{oc}$	24 ohm

III DESIGN PROCEDURE OF FILTER

The element values of the low pass prototype filters, which are usually normalized to make a cutoff frequency f_c=2.4GHz and a source impedance g_0=1, are then transformed to the L-C elements for the desired cutoff frequency and the desired source impedance, which is normally 50 ohms for micro strip filters. After obtaining a suitable lumped element filter, the second step is to find an appropriate micro strip realization that approximates the lumped element filter. The design procedure for conventional micro-strip butter-worth low pass filter of order n = 3 (3-pole low pass filter) are as follows:-
First of all considering the specifications required in the designing of micro-strip low pass filter.

Cut-off frequency fc = 2.4 GHz

Source/load impedance $Z0$ = 50 ohms

Normalized frequency Ωc = 1 GHz

Loss tangent tan δ = 0.01

1) As we have already discussed that we use the low pass prototype value of Butterworth response, which for order n = 3 are as follows

$g_0 = g4 = 1$

$g_1 = g3 = 1$

$g_2 = 2$,For the normalized cut-off frequency.

2) By using the element transformations, we have,

$L_1 = L_3 = \left(\frac{Z_0}{g_o}\right)\left(\frac{\Omega_c}{2\Pi f_c}\right) g_1 = 3.617$ nH

$C_2 = \left(\frac{g_o}{Z_0}\right)\left(\frac{\Omega_c}{2\Pi f_c}\right) g_2 = 2.894$ pF

3) Calculation for width of capacitor and inductor is done by these formulas,

Width of inductor is given by: $\frac{W}{h} = \frac{8\exp(A)}{\exp(2A)-2}$

Where A is given by,

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r+1}{2}\right\}^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\}$$

Width of capacitor is given by:

$$\frac{W}{h} = \frac{2}{\pi}\left\{(B-1) - ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\}$$

Where B is given by,

$B = 60\pi^2 / Z_c.\sqrt{\varepsilon_r}$

4) The effective dielectric constant and characteristic impedance is calculated by using formula,

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left\{\left(1 + 12\frac{h}{W}\right)^{-0.5} + 0.04\left(1 - \frac{W}{h}\right)^2\right\}$$

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} ln\left(\frac{8h}{W} + 0.25\frac{W}{h}\right)$$

Where $\eta = 120\,\pi$ ohms is the wave impedance in free space.

Hammerstad and Jensen give more accurate expressions for the effective dielectric constant and characteristic impedance as:

$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{10}{u}\right)^{-ab}$, where $u = W/h$,

The accuracy of this model is better than 0.2% for $\varepsilon_r \leq 128$ and $0.01 \leq u \leq 100$. The more accurate expression for the characteristic impedance is given by,

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} \ln\left[\frac{F}{u} + \sqrt{1+\left(\frac{2}{u}\right)^2}\right],$$

Where $u = W/h$, $\eta = 120\pi$ ohms, and

$$F = 6 + (2\pi - 6)\exp\left[-\left(\frac{30.666}{u}\right)^{0.7528}\right]$$

The accuracy for $Z_c\sqrt{\varepsilon_{re}}$ is better than 0.01% for $u \leq 1$ and 0.03% for $u \leq 100$.

5) The calculation for Guided wavelength is done with the help of ,

$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}}$, Where λ_0 denotes the free space wavelength at operation frequency *f*. More conveniently, when the frequency is given in gigahertz (GHz), the guided wavelength can then be evaluated directly in millimeters as follows: $\lambda_g = \frac{300}{f(GHz)\sqrt{\varepsilon_{re}}}$ mm.

6) *Calculated Dimensions of the Filter*

Length and width of the capacitor and inductor as tabulated in Table 2.

Table 2: Calculated values of the filter.

Length of capacitor	7.5 mm
Width of capacitor	7.56
Length of inductor	10.53 mm
Width of inductor	0.64 mm

IV RESULT AND DISCUSSION

Low pass filters with step impedance can be designed with replies in form of max flat or response with equal Ripple. Design is based on normalized g values. These values should convert to inductors and capacitors. We do here the design for a microwave low pass filter with 2.4GHZ cutting frequency and the flat maximum response with inserting losses more than 20dB in frequency 2.86 GHZ and filter characteristic impedance 50ohm.By using the dimensions as per calculation we design the micro-strip low pass filter on IE3D simulator. Layout of a three pole stepped impedance micro-strip low pass filter on an FR-4 substrate with ε_r = 4.4 and height h = 1.2 mm at cut-off frequency f_c = 2.4 GHz is shown in fig. 3 below-

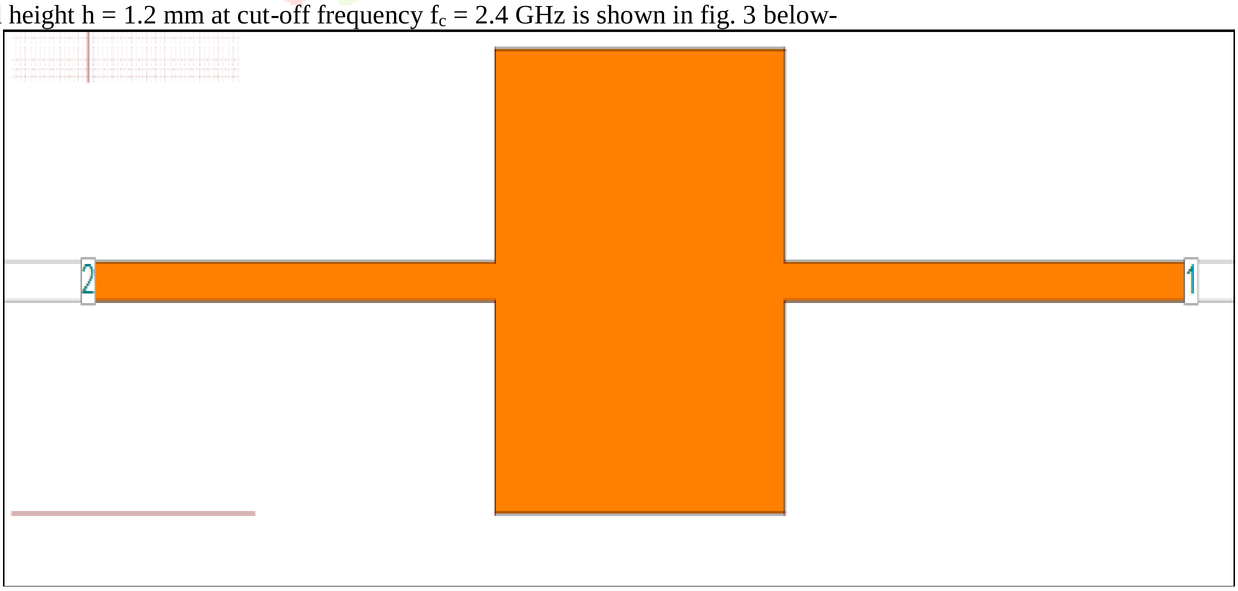

Figure 3: Layout of third order micro-strip low pass filter using IE3D simulator.

As shown in above fig. 3, there are two ports in this micro-strip low pass filter, one is input port and another is output port across which the result is going to be taken. The loss tangent taken here is tan δ = 0.01. We will check the response of this filter on simulator by selecting frequency range from 1 GHz to 6 GHz. As we can see in the above figure the narrow line represents the inductor and broad line represents the capacitor. At input and output port there are two SMA switches across which the result is to be measured by using vector network analyzer.

The response of a three pole stepped impedance micro-strip low pass filter on an FR-4 substrate with εr = 4.4 and height h = 1.2 mm at cut-off frequency fc = 2.4 GHz obtained by full wave EM simulation as shown in fig. 4.

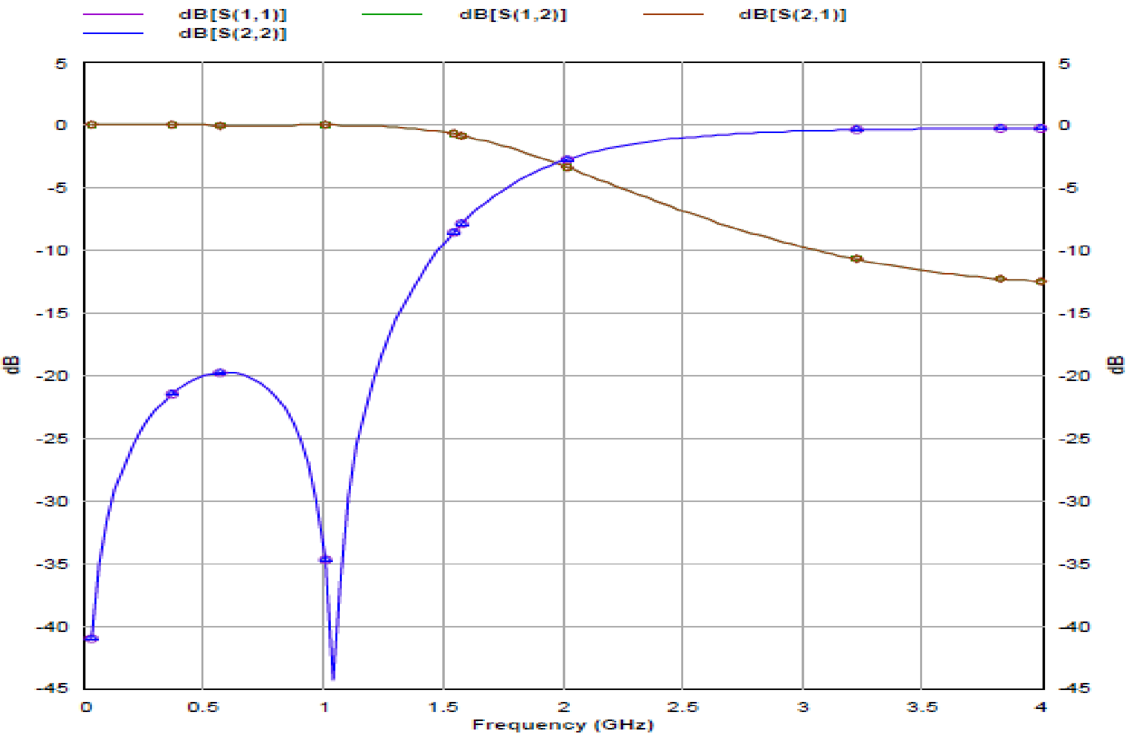

Figure 4: full-wave em simulated performance of third order stepped impedance low pass filter

The performance of stepped impedance low pass filter in IE3D simulator is measured by taking frequency on the X-axis in GHz and gain on the Y-axis in dB. Here we can see in the figure that the stepped impedance low pass filter is capable of passing the frequency less than 2.4 GHz & reject the frequency after 2.4 GHz for the thickness of the substrate 1.2 mm and relative dielectric constant 4.4.

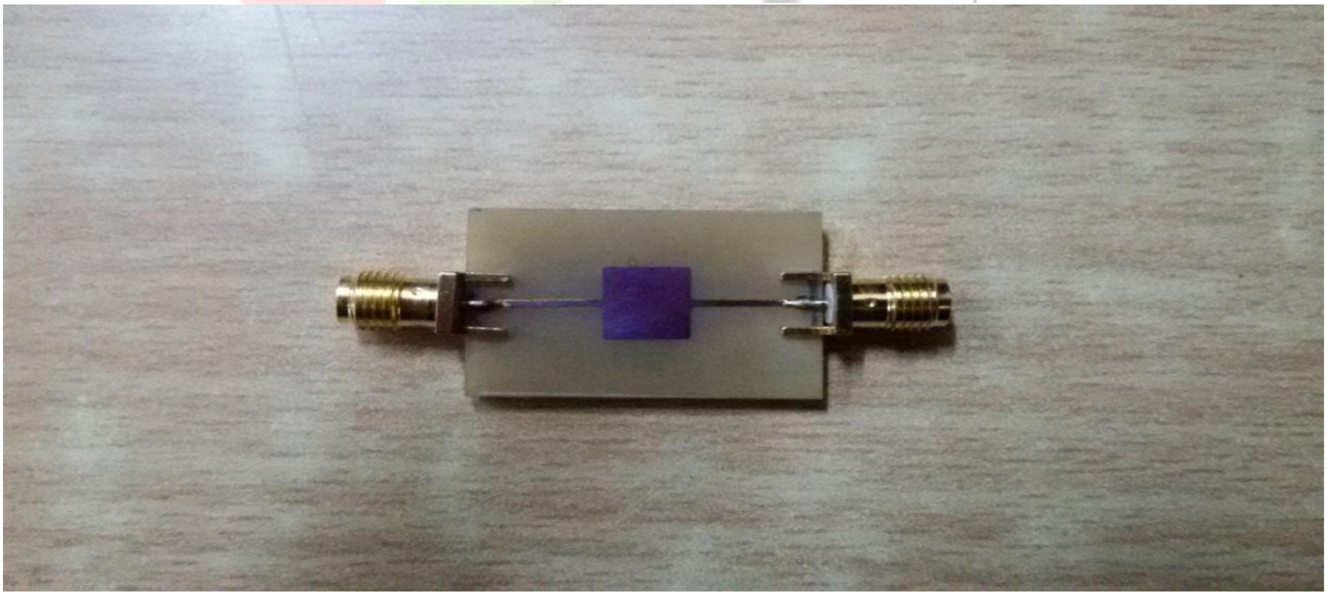

Figure 5: Prepared hardware of the micro-strip low pass filter

Firstly prepare hardware of the micro strip low pass filter as shown in figure 5, to allow low frequency signals and stop high frequency range. We are using vector network analyzer as a hardware tool in order to verify the simulated result. In the hardware we designed on PCB the SMA connector is connected at both input and output port. The locations of SMA connectors are properly drilled at the side of the copper. More care should be taken when drilling the holes for SMA connectors ensure by properly aligned. Responses of the stepped impedance micro-strip low pass filter by using vector network analyzer are shown in figure 6 as given below:

Figure 6: Response of third order stepped impedance micro-strip low pass filter (insertion loss) using network analyzer

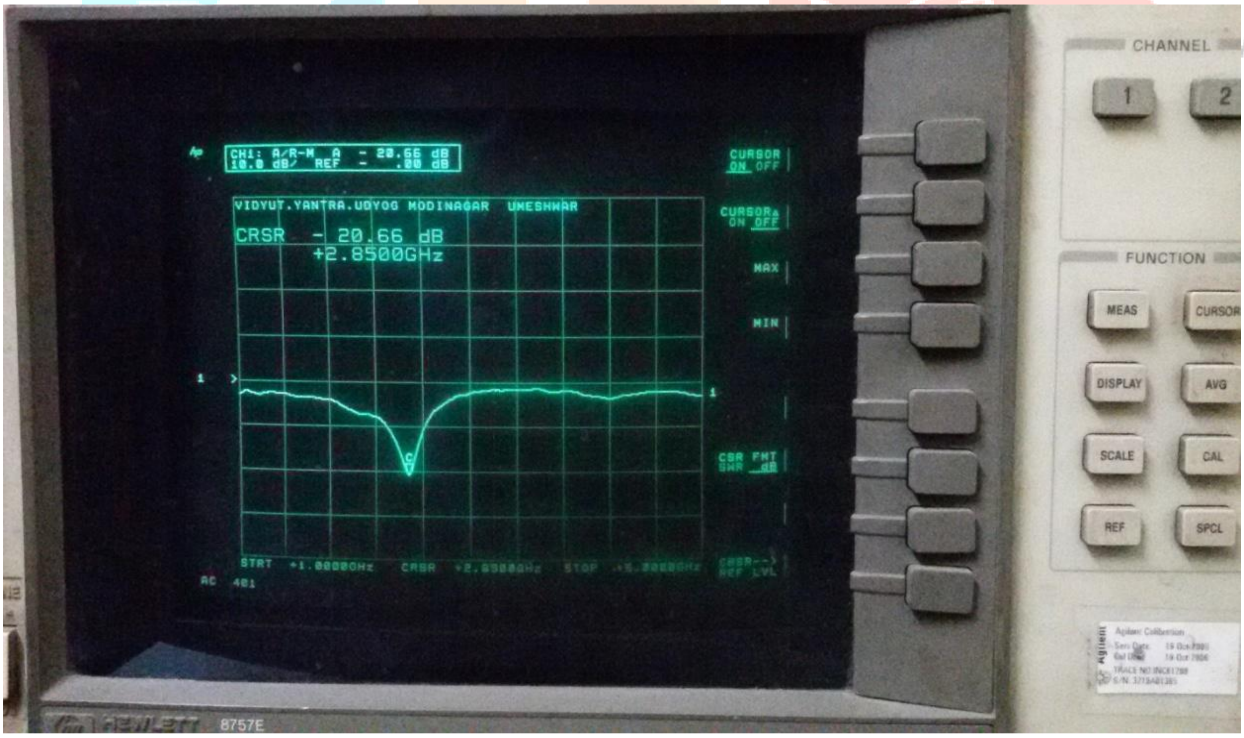

Figure 7: Response of third order stepped impedance micro-strip low pass filter (return loss) using network analyzer.

As we can see above fig. 7, the cut-off frequency achieved in the response of vector network analyzer is different than the design specification value i.e. 2.4GHz but it comes out to be 2.86 GHz. This discrepancy is may be due to imperfect fabrication and connection of SMA connector. On comparing the graph of two we observe a good compromise between the results of simulation and construction. From this it is clear that the results are much closed to each other. The insertion loss in simulated result is approximately -2.10 dB whereas in analyzer verified result it is -20.61 dB. From this difference we can see that simulated result provides good response and difference between the two results may be because of imperfect fabrication and connection of SMA connector.

V. CONCLUSION

In this paper a low pass microwave filter by using stepped impedance method is designed which uses micro-strip line with high impedance characteristic and low impedance characteristic. The designing will depend on the substrate because these are advanced filters and there are restrictions on the small size by being compact and dense throughout it. This research work provides an executive step of micro-strip filter with method of stepped impedance from designing to building. A stepped impedance low pass micro-strip filter has been designed, simulated by using IE3D simulator, fabricated and tested by using vector network analyzer. The cut-off frequency achieved is lower than the design specification value i.e. 2.4 GHz. This discrepancy is may be due to imperfect fabrication and connection of SMA connector. The paper presents an efficient approach to improve conventional low-pass filter performance with a miniaturized area. Thus this method is very flexible for configuration and specially use full low pass filter design to develop sharp transition band.

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