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A Microwave Semi Lumped Low Pass Filter Design at 3 GHz Frequency

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Abstract: Microwave filter design is an important task in microwave communication. This paper presents the designing of microwave low pass filter at 3 GHz frequency using FR4 as the dielectric material with a thickness of 2.4 mm. A semi lumped method is used to implement the LPF due to its accuracy in achieving ideal characteristics. Two poles are obtained at 3.6 GHz and 4.6 GHz by placing open circuited stubs. LPF is designed and simulated using High Frequency Structure Simulator (HFSS) and Advanced Design System (ADS) and S_{11} and S_{12} parameters are observed. The fabricated LPF is tested using Network Analyzer and measured S_{11} and S_{12} are compared with the simulated results.

Keywords: Semi lumped, HFSS, ADS,S-parameters, Network Analyser.

1. INTRODUCTION

Filter design at microwave frequency i.e. above 1 GHz has a difficulty while implementing it with the lumped elements. Usually the characteristics of these lumped elements changes as the frequency increases. They will not act like lumped elements at higher frequencies rather they work like distributed elements. However, while implementing filter design at higher frequencies, the better choice is to select the distributed elements like microstrip line, strip line, co planar waveguides etc. Even though these distributed lines are implemented at microwave frequency, abrupt changes across the lines causes reflection of power. So propagation of EM energy does not take place from input end to output end continuously. These power losses can be corrected by using distributed line correction factors and/or by using tuning and optimization techniques in simulated software like Advanced Design System (ADS), High Frequency Structure Simulator (HFSS) etc.This paper presents the designing of semi lumped low pass filter at 3 GHz frequency. Various filter techniques are available in literature [1]. Implementation of filters as low pass/ high pass can be done by using Kuroda's identities [2], step impedance method [3], open circuit stub method [4]. Each method has its own advantages and disadvantages while implementing the filters with microstrip lines. In all these methods the stop band characteristics does not approach the ideal characteristics i.e, sharp cut off frequency. To achieve this ideal characteristic, a semi lumped filter design is suggestible, and external poles at different frequencies within stop band can be placed by using semi lumped open circuited stubs. A 3 GHz low pass filter is widely used in microwave communication system design, wireless communication applications, transmitter and receiver section and modem applications. A 6^{th} order elliptical type low pass filter designing with FR4 material having a dielectric constant of 4.2, and a thickness of 2.4 mm with microstrip line implementation is presented in this paper. Simulation of this filter is done by using Advanced Design System (ADS), High Frequency Structure Simulator (HFSS). Below Figure 1 and Figure 2 shows the layout design of semi lumped filter. Measurement of S parameters describes how efficiently the filter can work. Parameters like S_{11}, S_{12} are observed in simulations and they are made agreement with the requirement.

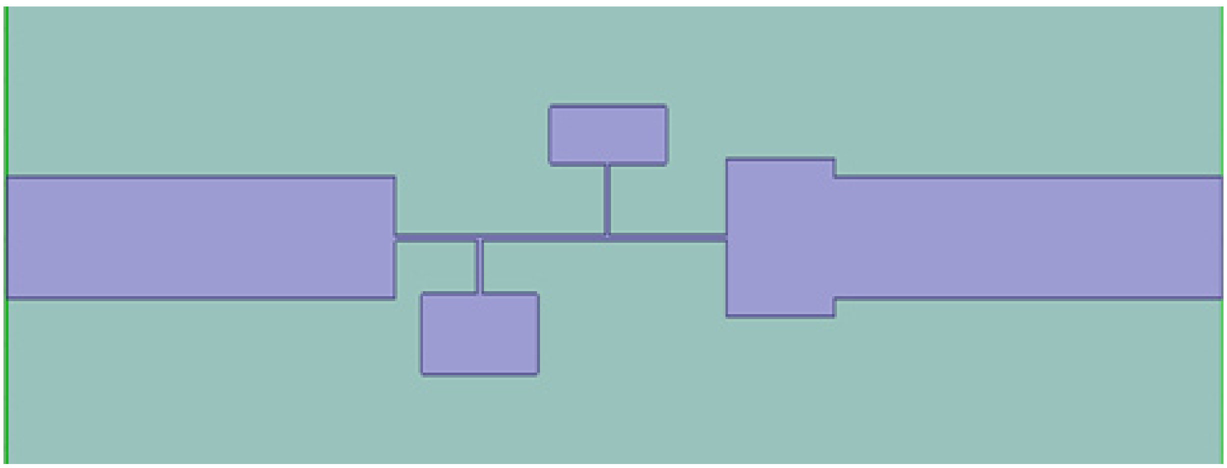

Figure 1: Top view Layout design of LPF using HFSS

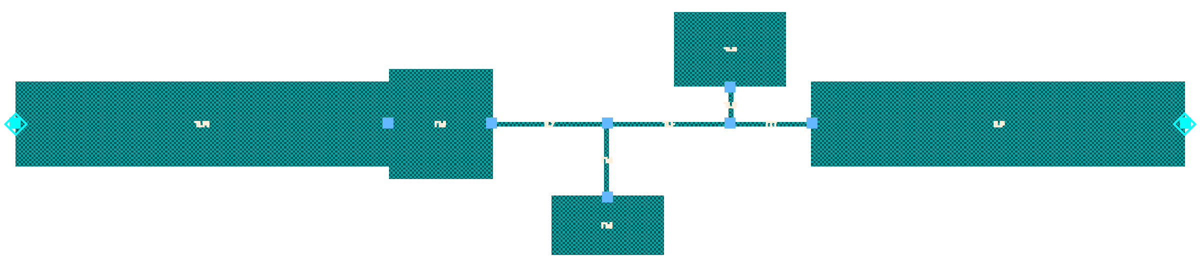

Figure 2: Top view Layout design of LPF using ADS

2. DESIGN OF SEMI LUMPED LPF

Specifications: The following are the specifications of the semi lumped elliptical low pass filter:

Cut off frequency (f_c) = 3 GHz,

Dielectric constant (ε_r) = 4.2 (FR4 material),

Thickness (h) = 2.4 mm,

Matched termination (Z_0) = 50 Ω.

Design procedure: The prototype elements coefficients of sixth order elliptical semi lumped low pass filter is given in Table 1 from [5] and [6] and are:

Table 1
List of elliptical LPF coefficients

$g_0 = 1.000$	$g_{L4} = g'_4 = 0.7143$
$g_{L1} = g_1 = 0.8214$	$g_{C4} = g_4 = 0.9077$
$g_{L2} = g'_2 = 0.3892$	$g_{L5} = g_5 = 1.1170$
$g_{C2} = g_2 = 1.0840$	$g_{C6} = g_6 = 1.1360$
$g_{L3} = g_3 = 1.1880$	$g_7 = 1.000$

The inductor and capacitor values are given by using the following formulae:

$$L_i = \frac{1}{2\pi f_c} Z_0 g_{Li} \tag{1}$$

$$C_i = \frac{1}{2\pi f_c} \frac{1}{Z_0} g_{Ci} \tag{2}$$

The values obtained using equations (1) and (2) are tabulated in Table 2.

Table 2
Calculated values of inductor and capacitor

Inductance (nH)	*Capacitance (pF)*
$L_1 = 2.17883$	$C_2 = 1.15016$
$L_2 = 1.032386$	$C_4 = 0.9631$
$L_3 = 3.151267$	$C_6 = 1.2053$
$L_4 = 1.96636$	
$L_5 = 2.92629$	

The attenuation poles in stop band of LPF are given by:

$$f_{p1} = \frac{1}{2\pi\sqrt{L_4 C_4}} = 3.65 \text{ GHz}$$

$$f_{p1} = \frac{1}{2\pi\sqrt{L_2 C_2}} = 4.61 \text{ GHz}$$

The guided wavelength is calculated by using the following formulae:

$$u = \frac{w}{h} \tag{3}$$

$$a = 1 + \frac{1}{49}\ln\left[\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0.432}\right] + \frac{1}{18.7}\ln\left[1 + \left(\frac{u}{18.1}\right)^3\right] \tag{4}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{10}{u}\right]^{-ab} \tag{5}$$

The guided wavelength in mm is given by the formula:

$$\lambda_g = \frac{300}{f_c(\text{GHz})\sqrt{\varepsilon_{re}}}\ mm \tag{6}$$

For a capacitor, the width of the line is chosen as 6 mm and the guided wavelength using the equations (3), (4), (5) and (6) is given by:

$$u = \frac{w}{h} = \frac{6}{2.4} = 2.5$$

$$a = 0.999923998$$

$$b = 0.541155056$$

$$\varepsilon_{re} = 3.269727732$$

$$\lambda_{gc} = 55.242871 \text{ mm}$$

For inductor width of the line is chosen as 0.2 mm and the guided wavelength using the equations (3), (4), (5) and (6) is given by:

$$u = \frac{w}{h} = \frac{0.2}{2.4} = 0.0834$$

$$a = 0.815336225$$

$$b = 0.541155056$$

$$\varepsilon_{re} = 2.792817492$$

$$\lambda_{gl} = 60 \text{ mm}$$

The inductor and the capacitor length values are obtained by using the formulae:

$$l_{\mathrm{L}i} = \frac{\lambda_{gl}(f_c)}{2\pi}\sin^{-1}\left[2\pi f_c \cdot \frac{\mathrm{L}_i}{\mathrm{Z}_{0\mathrm{L}}}\right] \tag{7}$$

$$l_{\mathrm{C}i} = \frac{\lambda_{gc}(f_c)}{2\pi}\sin^{-1}\left[2\pi f_c \cdot \mathrm{Z}_{0\mathrm{C}} \cdot \mathrm{C}_i\right] \tag{8}$$

where, $Z_{0L} = 93\Omega$ and $Z_{0C} = 26\Omega$

The length values of the inductors and capacitors are as shown in the below Table 3:

Table 3
Length values of inductor and capacitor

Line lengths for Inductance (mm)	*Line lengths for Capacitance (mm)*
$l_{L1} = 4.36$	$l_{C2} = 3.05$
$l_{L2} = 2.00$	$l_{C4} = 2.20$
$l_{L3} = 6.61$	$l_{C6} = 5.53$
$l_{L4} = 2.90$	
$l_{L5} = 6.15$	

3. SIMULATION USING HFSS AND ADS

HFSS (High Frequency Structure Simulator software) and ADS (Advanced Design System) are based on Finite Element Method (FEM) and Method of Momentum (MOM). These are powerful simulators which are widely used in all microwave passive component design. HFSS is 3D view software which gives a better view for the designer to work and simulate. ADS is 2.5D view software that works good for all planar structures like microstrip lines. This paper gives the required LPF design in both HFSS and ADS simulators at 3 GHz frequency. The mesh frequency is selected as 4 GHz for better results of S_{11} and S_{12} .After the completion of validation check, the simulation is done. The simulated S_{11} and S_{12} parameters are observed in both HFSS and ADS which agree with the desired results.

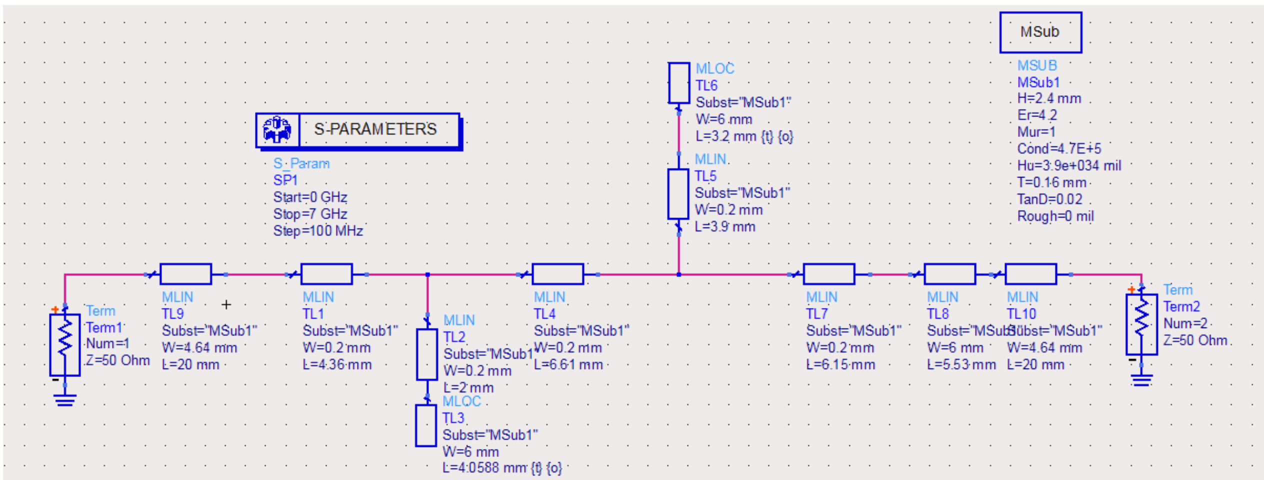

Figure 3: Schematic diagram in ADS RF Momentum

Figure 3 represents the schematic diagram of a semi lumped LPF in ADS After satisfactory result of simulation, LPF is fabricated using Photolithography process. On FR4 material, etching and masking process has been done for the desired structure and final layout of fabricated LPF at 3 GHz is shown in below Figure 4 and Figure 5.

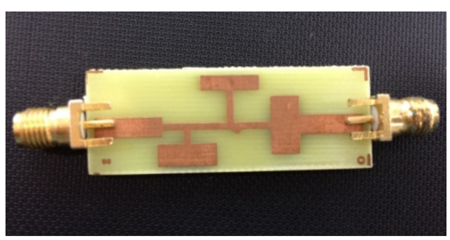

Figure 4: Fabricated LPF

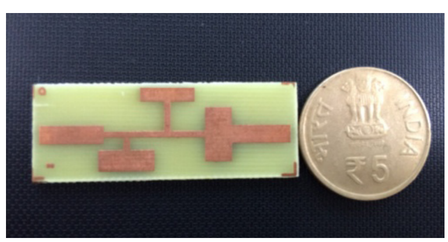

Figure 5: Dimension comparision of LPF

4. RESULTS AND DISCUSSIONS

The fabricated LPF is tested with Network Analyzer as in Figure 9. S parameters i.e, S_{11} and S_{12} are measured and are shown in Figure 8. These values are –3.21 dB at 3.35 GHz and –3.075 dB 3.1 GHz respectively. Additional two poles are observed at frequency having S_{12} of –35dB at 3.8 GHz and –34.8dB at 4.9GHz. These values are almost agreed with simulated S parameters.

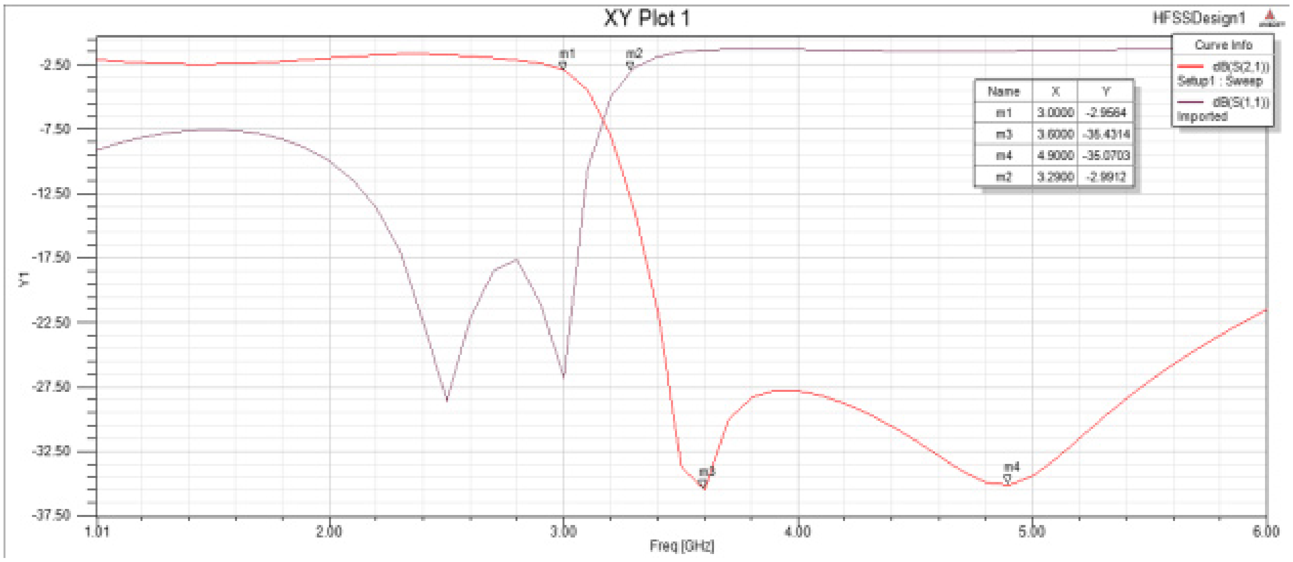

Figure 6 Simulated S parameters using HFSS

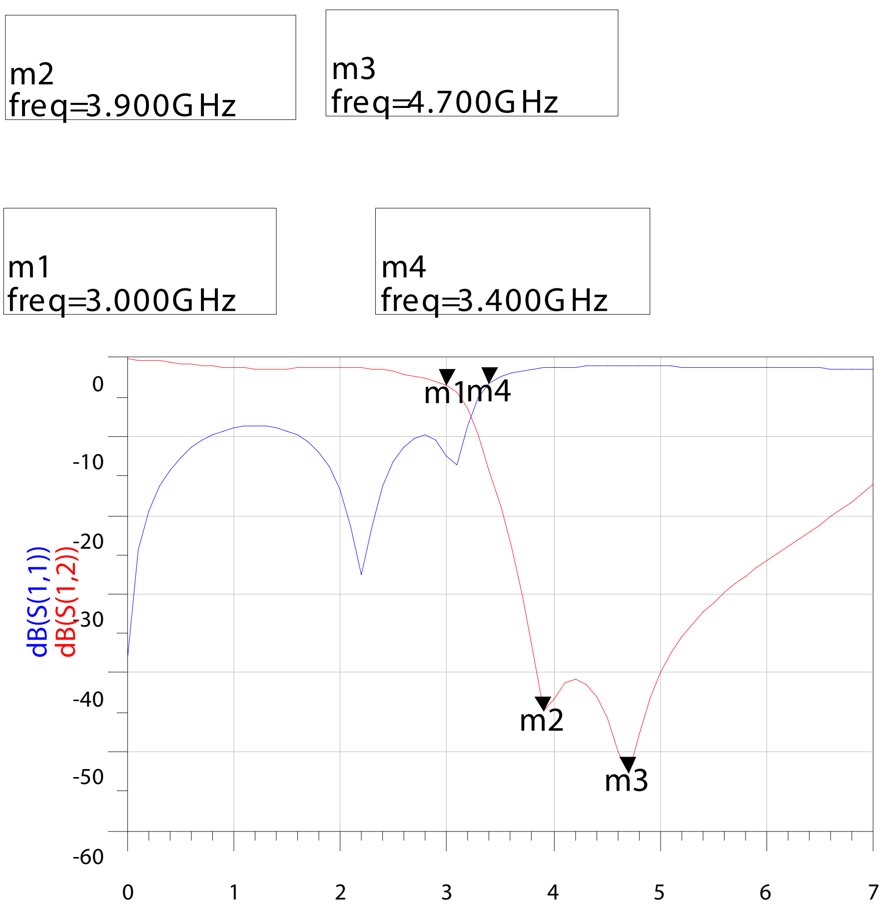

Figure 7: Simulated S parameters in ADS

Figure 6 and Figure 7 shows simulated S parameters using HFSS and ADS. Values of simulated parameters are tabulated in table 4 and are compared with measured parameters using Network analyzer. Using HFSS and ADS S parameters are observed and are –2.99dB at 3.29GHz, –3.26dB at 3.41GHz and –2.96dB at 3 GHz and –3.4dB at 3 GHz respectively. Compared to ADS, HFSS results are accurate and are approached the required values.

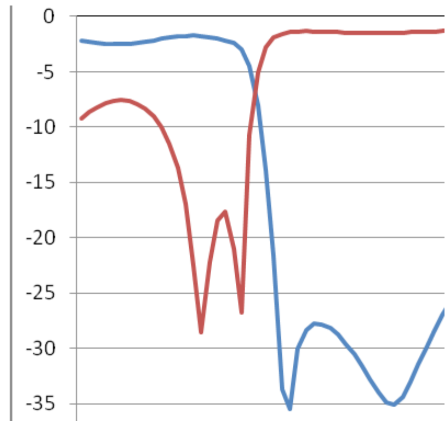

Figure 8: Measured S parameters using Network Analyzer

Two poles are inserted by placing external capacitors (open circuit stubs) at frequency 3.6 GHz and 4.61GHz. In HFSS simulation these are –36.4dB at 3.6 GHz and –36.78 dB at 4.94GHz. In simulation of ADS two pole are observed at 3.9GHz with –44dB of S_{12} and at 4.7 GHz with –52.7dB of S_{12}. In comparison with HFSS, better stop band characteristics are observed in ADS.

Figure 9: Testing with Network Analyzer

Table 4
Comparison of S parameters

S parameters	*HFSS*	*ADS*	*Network Analyzer*
S_{11}	–2.99 dB at 3.29 GHz	–3.26 dB at 3.41 GHz	–3.21 dB at 3.35 GHz
S_{12}	–2.96 dB at 3 GHz	–3.4 dB at 3 GHz	–3.075 dB at 3.1 GHz
Two poles at frequencies	–36.4 dB at 3.6 GHz and –36.78 dB at 4.94 GHz	–44 dB at 3.9 GHz and –52.7 dB at 4.7 GHz	–35 dB at 3.8 GHz and –34.8 dB at 4.9 GHz

5. CONCLUSION

This paper presents design procedure for semi lumped low pass filter at 3 GHz. Open circuit stubs are placed to get two poles at 3.6 GHz and 4.6GHz. This method is best suited to achieve ideal characteristics as compared to remaining methods like step impedance, open circuited etc. Simulated S parameters are observed using HFSS and ADS and are S_{11} and S_{12}, whose values are –2.99 dB, 3.00 dB at 3 GHz and –2.95 dB, 3.01 dB at 3.22 GHz respectively. These results are comparable with measured S parameters using Network Analyzer which are –3.2 dB at 3 GHz and –3.1 dB at 3.1 GHz for S_{11} and S_{12}. Measured results are agreed with observed results. By knowing the procedure to implement semi lumped low pass filter one can easily design at any other frequency for any microwave applications.

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