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Low Pass Filter Design Comparison Using Agilent Genesys

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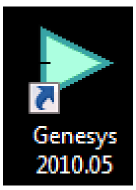
Abstract: Wireless communication is becoming more and more popular. In this paper, a maximally flat low-pass filter and a equal-ripple low-pass filter have been designed for Ultra High Frequency (UHF) band ie I.T.U. band 9 (Frequency 300Mhz – 3000Mhz; Wavelength 1m – 100mm).Application of UHF band includes television, microwave ovens, mobile phones, wireless LAN, Bluetooth, etc. The filters are designed from the method of ‘Impedance and Frequency Scaling’. The design parameters and return loss are discussed. Also the amplitude (attenuation in dB) vs frequency graph is obtained for both the filters and their results are compared and suitable conclusions are drawn. The filters are designed using **Agilent Genesys 2010.05**

Keywords: Agilent Genesys Simulator; Low Pass Filter; Equal-ripple filter; Smith chart; Polar Chart; Maximally flat filter; Wireless communication; UHF Band Spectrum; S Parameters.

I. INTRODUCTION

Various mobile cellular systems need a miniaturised size filter which should ideally have a sharp cut-off. Also, various radio frequency communication filters are gaining popularity**.** Low pass filters are widely preferred today. The need to filter out the transmitted and received signals with a specific bandwidth has been the task for many engineers today. Filter designs beyond 500MHz are difficult to realize with discrete components because the wavelength becomes comparable with the physical filter element dimensions, resulting in various losses severely degrading the circuit performance. Thus to arrive at practical filters, Impedance and Frequency Scaling is done and the lumped elements are directly simulated using RF simulator Agilent Genesys 2010.05.

In this paper, a maximally flat low-pass filter and a equal-ripple low-pass filter have been designed for Ultra High Frequency (UHF) band with a cutoff frequency of 700Mhz and order 7. A lumped L-C network is modelled with the ‘minimum inductor’ and ‘minimum capacitor’ configurations after Impedance and Frequency Scaling. Then, the amplitude (attenuation in dB) vs frequency plot is compared between the two filters. RF synthesis software ‘Agilent Genesys 2010.05’ is used for the purpose.



Agilent Genesys 2010.05 is an affordable, accurate, easy-to-use RF and microwave simulation software created for the circuit board and subsystem designer. It’s key features includes RF system analysis and frequency planning with interactive root-cause problem identification and linear and nonlinear RF circuit simulators with optimization and statistical analysis for high-performance and high-yield designs.

II. RELATED WORK

In this paper, a maximally flat low-pass filter and a equal-ripple low-pass filter have been designed for Ultra High Frequency (UHF) band with a cutoff frequency of 700Mhz and order 7. The filters have input and output resistances of 50 ohms. The filters are designed from the method of ‘Impedance and Frequency Scaling’. The design parameters and return loss are discussed. Also the amplitude (attenuation in dB) vs frequency graph is obtained for both the filters and their results are compared and suitable conclusions are drawn. The filters are designed using Agilent Genesys 2010.05

III. THEORY [6]

For a normalized low-pass design, where the source impedance is 1 Ω and the cutoff frequency is ωc = 1 rad/sec, the element values for the ladder-type circuits in the below figures can be tabulated by using the standards tables.

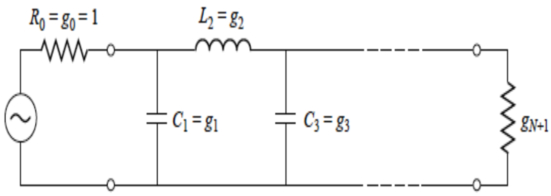


Fig.1. Ladder circuits for low-pass filter prototypes - Prototype beginning with a shunt element.

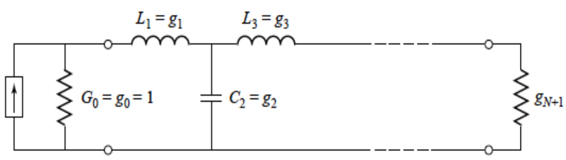


Fig.2. Ladder circuits for low-pass filter prototypes - Prototype beginning with a series element.

IV. IMPEDANCE SCALING [6]

In the prototype design, the source and load resistances are unity . A source resistance of $R0$ can be obtained by multiplying all the impedances of the prototype design by $R0$. Thus, if we let primes denote impedance scaled quantities, the new filter component values are given by

$$L^{'} = R_0 L;$$

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$$C' = \frac{C}{R_0};$$

$$R'_S = R_0;$$

$$R'_L = R_0 R_L;$$

where L, C, and R_L are the component values for the original prototype.

V. FREQUENCY SCALING [6]

To change the cutoff frequency of a low-pass prototype from unity to ωc requires that we scale the frequency dependence of the filter by the factor $\frac{1}{\omega c}$, which is accomplished by replacing ω by $\frac{\omega}{\omega c}$:

$$\omega \leftarrow \frac{\omega}{\omega c}$$

Then the new power loss ratio will be

$$P'_{LR}(\omega) = P_{LR}\left(\frac{\omega}{\omega_c}\right);$$

where ωc is the new cutoff frequency; cutoff occurs when $\frac{\omega}{\omega c} = 1$, or $\omega = \omega c$. This transformation can be viewed as a stretching, or expansion, of the original passband. The new element values are determined by applying the substitution of $\omega \leftarrow \frac{\omega}{\omega c}$ to the series reactances, $j\omega Lk$, and shunt susceptances, $j\omega Ck$, of the prototype filter. Thus,

$$j\,X_k = j\left(\frac{\omega}{\omega_c}\right)L_k = j\omega L'_k,$$

$$j\,B_k = j\left(\frac{\omega}{\omega_c}\right)C_k = j\omega' C_k,$$

which shows that the new element values are given by

$$L'_k = \frac{L_k}{\omega c}$$

$$C'_k = \frac{C_k}{\omega c}$$

When both impedance and frequency scaling are required, the results of both Impedance and Frequency Scaling can be combined to give

(1.) $$L'_k = \frac{R_0 L_k}{\omega_c}$$

(2.) $$C'_k = \frac{C_k}{R_0 \omega_c}$$

VI. CALCULATIONS AND DISCUSSION FOR BUTTERWORTH FILTER

First we find the order of the maximally flat filter to satisfy the insertion loss of 30 dB specification at 1200 MHz. We have that by $|\omega/\omega c| - 1$ and from attenuation versus normalized frequency for maximum flat filter prototypes, we find the order to be N=7.

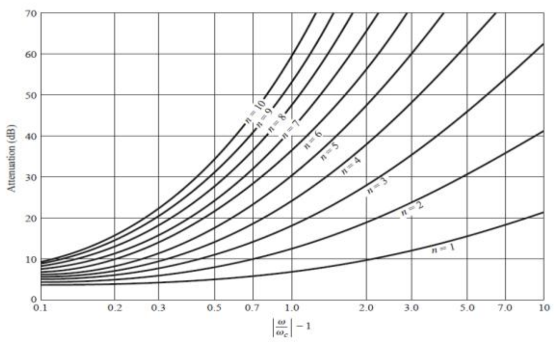

Fig.3. Attenuation versus normalized frequency for maximally flat filter prototypes.

Order									
1	1	2	1						
2	1	1.41421	1.41421	1					
3	1	1	2	1	1				
4	1	0.765367	1.84776	1.84776	0.765367	1			
5	1	0.618034	1.61803	2	1.61803	0.618034	1		
6	1	0.517638	1.41421	1.93185	1.93185	1.41421	0.517638	1	
7	1	0.445042	1.24698	1.80194	2	1.80194	1.24698	0.445042	1

Fig.4. Element Values for Maximally Flat LowPass Filter Prototypes.

Now, we get the lowpass prototype values from the standard Butterworth table given above:

$g_1 = 0.445042$
$g_2 = 1.24698$
$g_3 = 1.80194$
$g_4 = 2$
$g_5 = 1.80194$
$g_6 = 1.24698$
$g_7 = 0.445042$

Then Impedance and Frequency Scaling method {(1.) and (2.)} can be used to obtain the scaled element values for 'minimum inductor' type as : (Here : R0 = 50 Ohms ; fc = 700Mhz)

$C'_1 = 2.023\text{pF}$
$L'_1 = 14.175\text{nH}$
$C'_2 = 8.193\text{pF}$
$L'_2 = 22.736nH$
$C'_3 = 8.193\text{pF}$
$L'_3 = 14.175\text{nH}$
$C'_4 = 2.023\text{pF}$

Similarly, the Impedance and Frequency Scaling method {(1.) and (2.)} can be used to obtain the scaled element values for 'minimum capacitor' type as : (Here : R0 = 50 Ohms ; fc = 700Mhz)

$L'_1 = 5.059\text{nH}$
$C'_1 = 5.670\text{pF}$
$L'_2 = 20.484nH$
$C'_2 = 9.094\text{pF}$
$L'_3 = 20.484\text{nH}$
$C'_3 = 5.670\text{pF}$
$L'_4 = 5.059nH$

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VII. CALCULATIONS AND DISCUSSION FOR EQUI-RIPPLE FILTER

Here too, we first find the order of the maximally flat filter to satisfy the insertion loss of 35 dB specification at 1000 MHz and a passband ripple of 0.25dB. We have that by $|\omega/\omega c| - 1$ and from attenuation versus normalized frequency for equi-ripple filter prototypes, we find the order to be N=7.

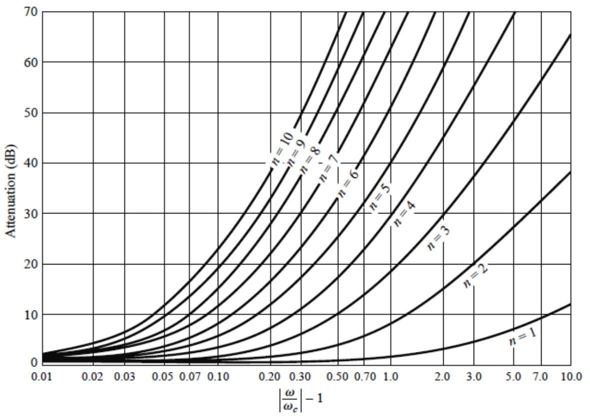

Fig. 5. Example of an attenuation versus normalized frequency for equal-ripple filter prototypes with 0.5 dB ripple level (In this paper 0.25 dB ripple level plot is considered and the order thus calculated is 7).

The order can also be found out by using the equation the standard Chebyshev model

$$n = \frac{cosh^{-1}\sqrt{(10^{\frac{L}{10}} - 1)/(10^{\frac{G}{10}} - 1)}}{cosh^{-1}(\frac{f}{f_c})}$$

Order									
1	1	0.486867	1						
2	1	1.1132	0.687327	1.61961					
3	1	1.30344	1.14628	1.30344	1				
4	1	1.37824	1.26933	2.05581	0.850972	1.61961			
5	1	1.41446	1.318	2.24141	1.318	1.41446	1		
6	1	1.43458	1.34217	2.3126	1.42788	2.17378	0.885758	1.61961	
7	1	1.44686	1.35597	2.34759	1.4689	2.34759	1.35597	1.44686	1

Fig.6. Standard Chebyshev table with passband ripple of 0.25dB.

Now, we get the lowpass prototype values from the standard Chebyshev table given above:

$g_1 = 1.44686$
$g_2 = 1.35597$
$g_3 = 2.34759$
$g_4 = 1.4689$
$g_5 = 2.34759$
$g_6 = 1.35597$
$g_7 = 1.44686$

Then Impedance and Frequency Scaling method {(1.) and (2.)} can be used to obtain the scaled element values for 'minimum inductor' type as : (Here : R0 = 50 Ohms ; fc = 700Mhz)

$C'_1 = 6.579\text{pF}$
$L'_1 = 15.415\text{nH}$
$C'_2 = 10.675\text{pF}$
$L'_2 = 16.699nH$
$C'_3 = 10.675\text{pF}$
$L'_3 = 15.415\text{nH}$
$C'_4 = 6.579\text{pF}$

Similarly, the Impedance and Frequency Scaling method {(1.) and (2.)} can be used to obtain the scaled element values for 'minimum capacitor' type as : (Here : R0 = 50 Ohms ; fc = 700Mhz)

$L'_1 = 16.448\text{nH}$
$C'_1 = 6.166\text{pF}$
$L'_2 = 26.688nH$
$C'_2 = 6.679\text{pF}$
$L'_3 = 26.688nH$
$C'_3 = 6.166\text{pF}$
$L'_4 = 16.448\text{nH}$

VIII. SIMULATION DESIGN, RESULTS AND DISCUSSION FOR BUTTERWORTH FILTER

The design was simulated using Agilent Genesys 2010.05 and a response was generated. The filter is a lowpass Butter worth filter with input resistance = 50 ohm, cutoff frequency = 700 MHz and Order = 7.

The Minimum Inductor type 7^{th} order filter layout is shown below.

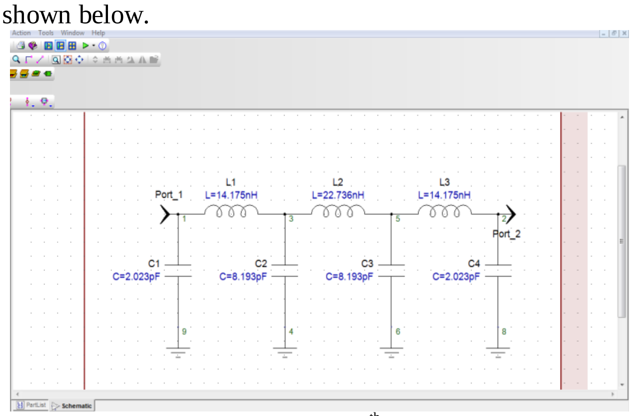

Fig.7. Minimum Inductor type 7^{th} order filter layout.

The result is generated, with parameter values which meet the requirements. A plot of S21 and S11 are produced.

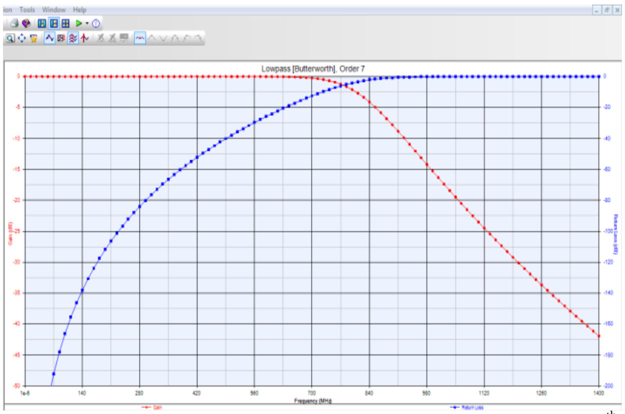

Fig. 8. The amplitude (attenuation in dB) vs frequency results for the 7th order minimum Inductor type filter.

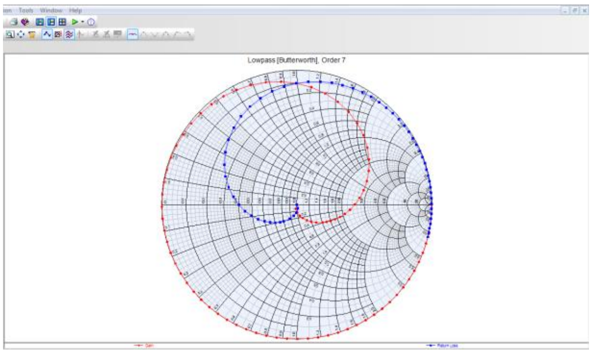

Fig.9. Gain and return loss on a smith chart of the filter .

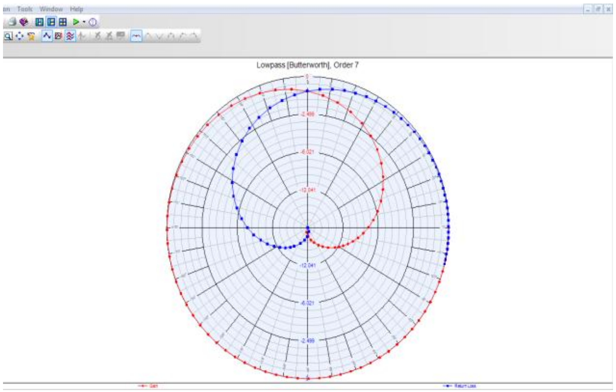

Fig.10. Gain and return loss on a polar chart of the filter .

The Minimum Capacitor type 7th order filter layout is shown below.

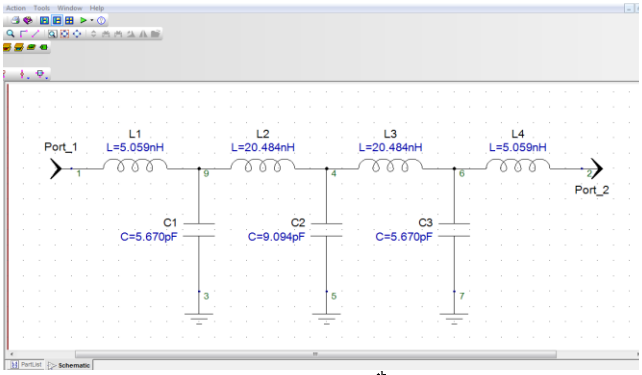

Fig.11. Minimum Capacitor type 7th order filter layout.

The required results were obtained for the minimum capacitor type filter. A plot of S21 and S11 are produced.

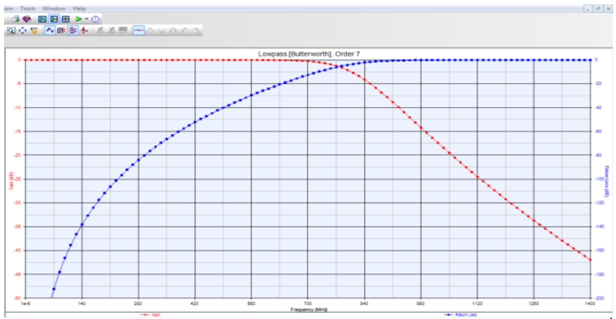

Fig.12. The amplitude (attenuation in dB) vs frequency results for the 7th order minimum Capacitor type filter.

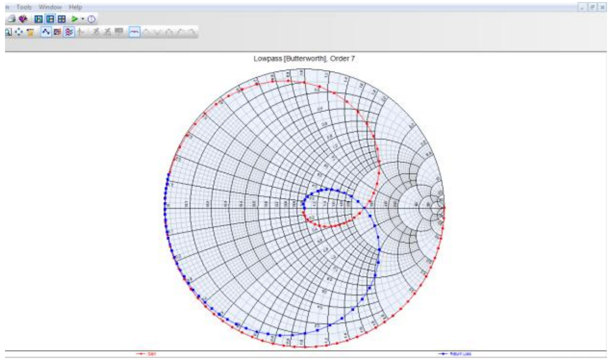

Fig.13. Gain and return loss on a smith chart of the filter.

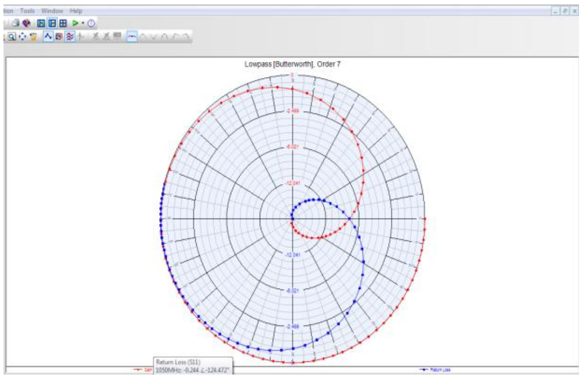

Fig.14. Gain and return loss on a polar chart of the filter.

IX. SIMULATION DESIGN, RESULTS AND DISCUSSION FOR CHEBYSHEV FILTER

The design was simulated using Agilent Genesys 2010.05 and a response was generated. The filter is a lowpass Chebyshev filter with input resistance = 50 ohm, cutoff frequency = 700 MHz and Order = 7.

The Minimum Inductor type 7th order filter layout is shown below.

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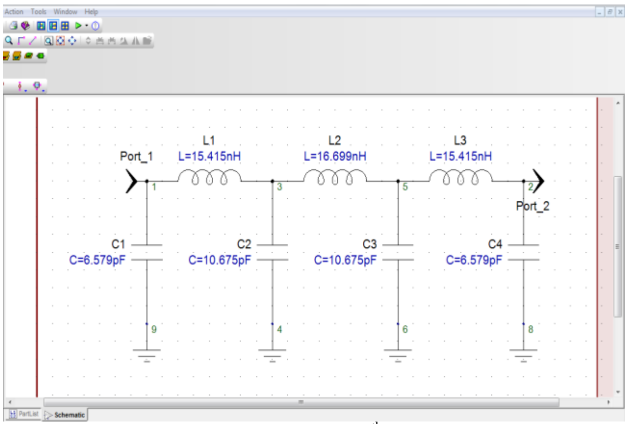

Fig.15. Minimum Inductor type 7th order filter layout.

The result is generated, with parameter values which meet the requirements. A plot of S21 and S11 are produced.

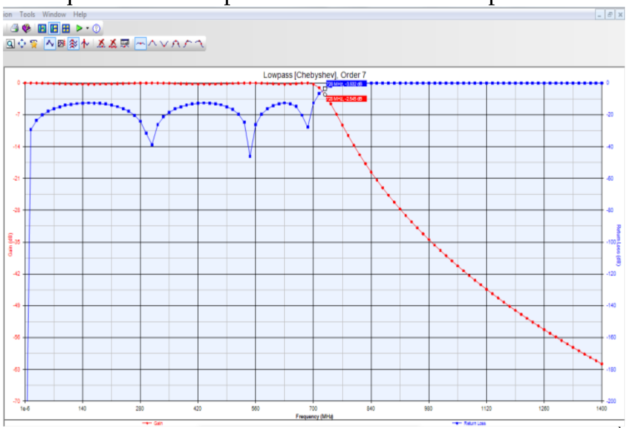

Fig.16. The amplitude (attenuation in dB) vs frequency results for the 7th order minimum Inductor type filter.

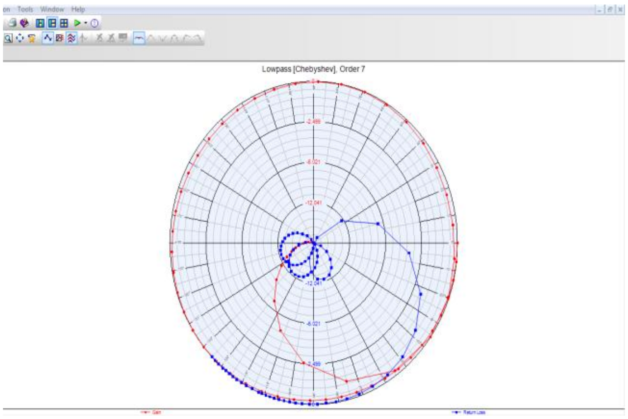

Fig.17. Gain and return loss on a polar chart of the filter .

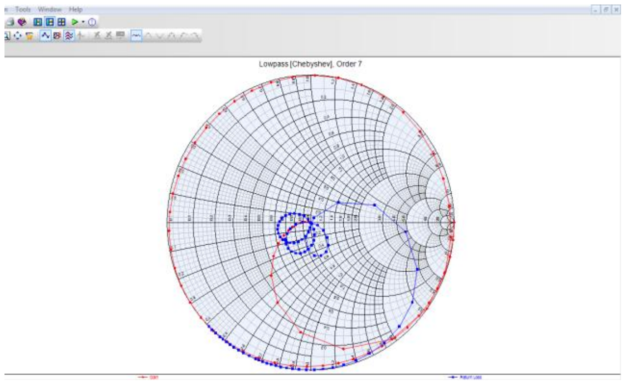

Fig.18. Gain and return loss on a Smith chart of the filter.

The Minimum Capacitor type 7th order filter layout is shown below.

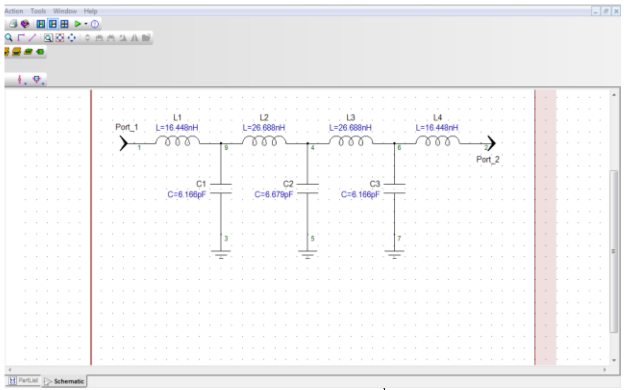

Fig.19. Minimum Capacitor type 7th order filter layout.

The result is generated, with parameter values which meet the requirements. A plot of S21 and S11 are produced.

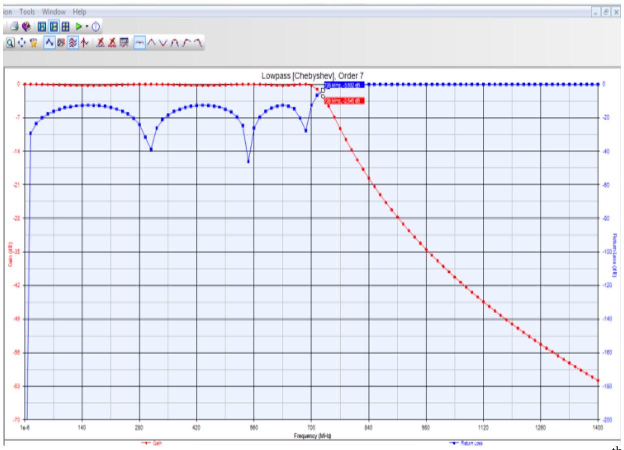

Fig. 20. The amplitude (attenuation in dB) vs frequency results for the 7th order minimum Capacitor type filter.

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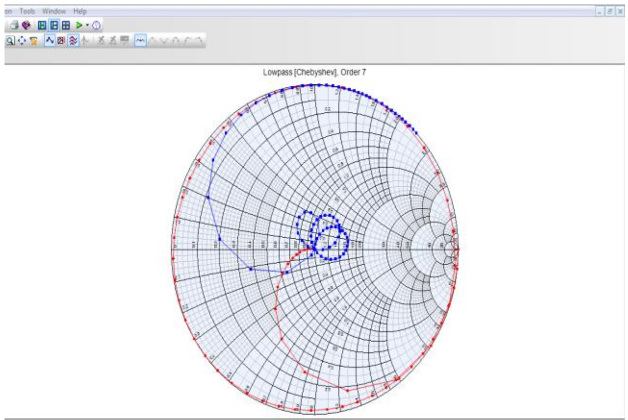

Fig.21. Gain and return loss on a Smith chart of the filter.

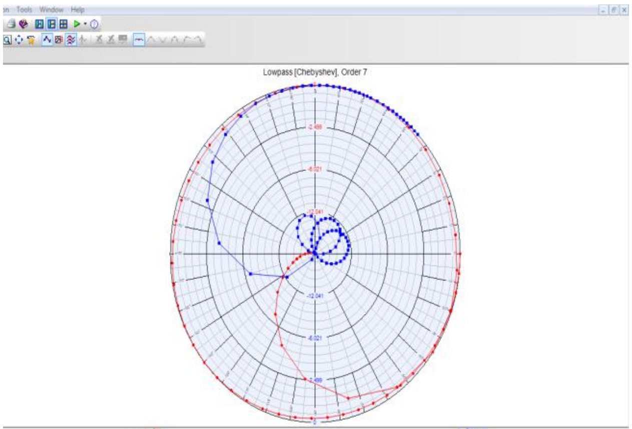

Fig.22. Gain and return loss on a polar chart of the filter

X. CONCLUSION

This paper deals with the design of a maximally flat low-pass filter and a equal-ripple low-pass filter(pass band ripple = 0.25 dB ripple). Both the filters have a cutoff frequency of 700 MHz, input resistance of 50 ohms and a order of 7. The amplitude (attenuation in dB) vs frequency results for these filters are shown in the above figures. These results clearly show the trade-offs involved with the two types of filters. The equal-ripple response has the sharpest cutoff . The maximally flat response has a flatter attenuation characteristic in the passband but a slightly lower cutoff rate.

The measured 3 dB frequency is 818.99 MHz for butter worth filter and the measured 3 dB frequency for Chebyshev filter is 731.46 Mhz.

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BIOGRAPHY

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