INSTITUTE OF ENGINEERING
CENTRAL CAMPUS,PULCHOWK

FILTER DESIGN

LAB #3

COMPARISON OF MAGNITUDE & PHASE RESPONSE OF DIFFERENT FILTERS

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Table of Contents

List of Figures

1 Title

COMPARISON OF MAGNITUDE & PHASE RESPONSE OF DIFFERENT FILTERS

2 Objective

- To design Butterworth, Chebyshev and Bessel filters
- To observe and compare the magnitude and phase response of different filters

3 Requirement

3.1 Proteus Design Suite

Proteus is a simulation and design software tool developed by Labcenter Electronics for Electrical and Electronic circuit design.It is used to create schematic of a circuit and Visualization of its operation.

4 Theory

4.1 Butterworth Filter

Butterworth Filter is signal processing filter designed in such a way that the passband has flat frequency response and roll-offs towards zero in stopband.Frequency response of Butterworth filter having halfpower frequency (ω) is given by

$$|H(w)| = \frac{1}{\sqrt{1 + (\frac{w}{w_0})^{2n}}}$$

Here, n is order of Butterworth Filter.

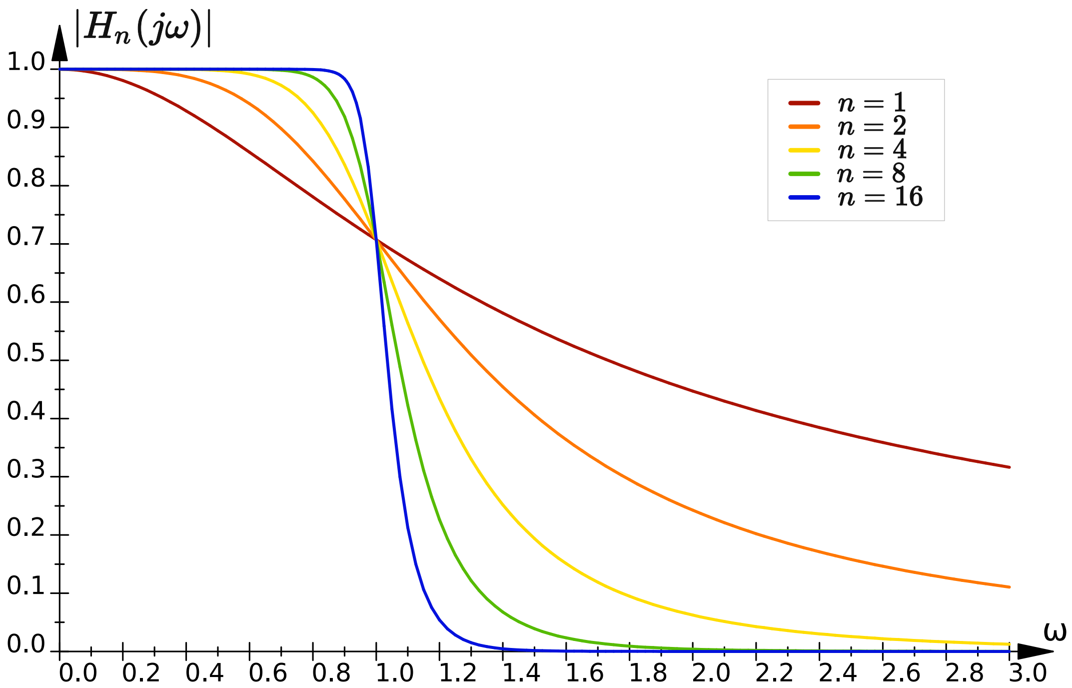


Figure 1: Frequency response off Butterworth filter for various order

4.2 Chebyshev Filter

Chebyshev Filter is signal processing filter designed in such a way that transition band has steeper frequency response than Butterworth filter.There are two types of Chebyshev filters. Type I (Chebyshev) has ripple only in Passband and Type II (Inverse Chebyshev) has ripple only in Stopband. For Chebyshev Filter of order n, the frequency response is given by:

$$|T(jw)|^2 = \frac{1}{1+\epsilon^2 C_n^2(w)}$$

where $C_n(w)$ is the Chebyshev polynomial of order n.

$$C_n(\omega) = \begin{cases} \cos(n\cos^{-1}\omega), & 0 \le \omega \le 1 \\ \cosh(n\cosh^{-1}\omega), & \omega \ge 1 \end{cases}$$

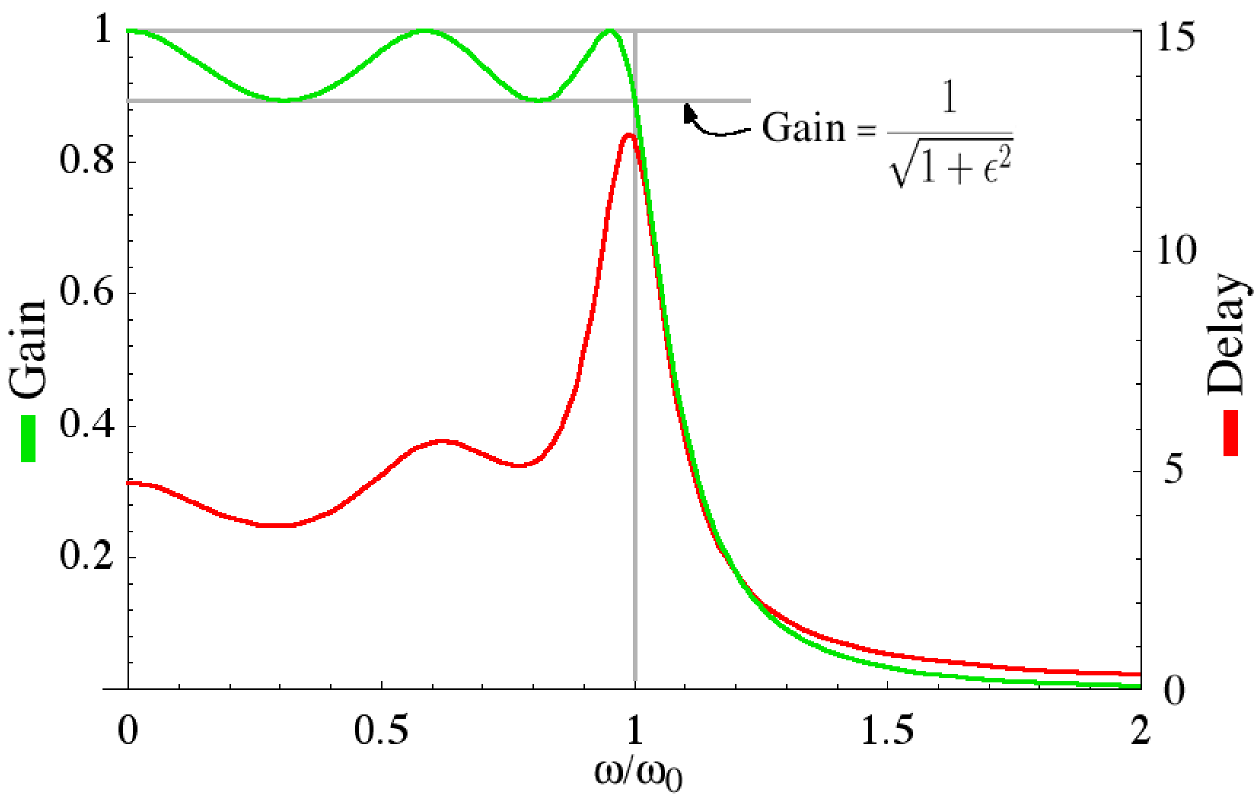


Figure 2: Frequency response of Chebyshev I filter

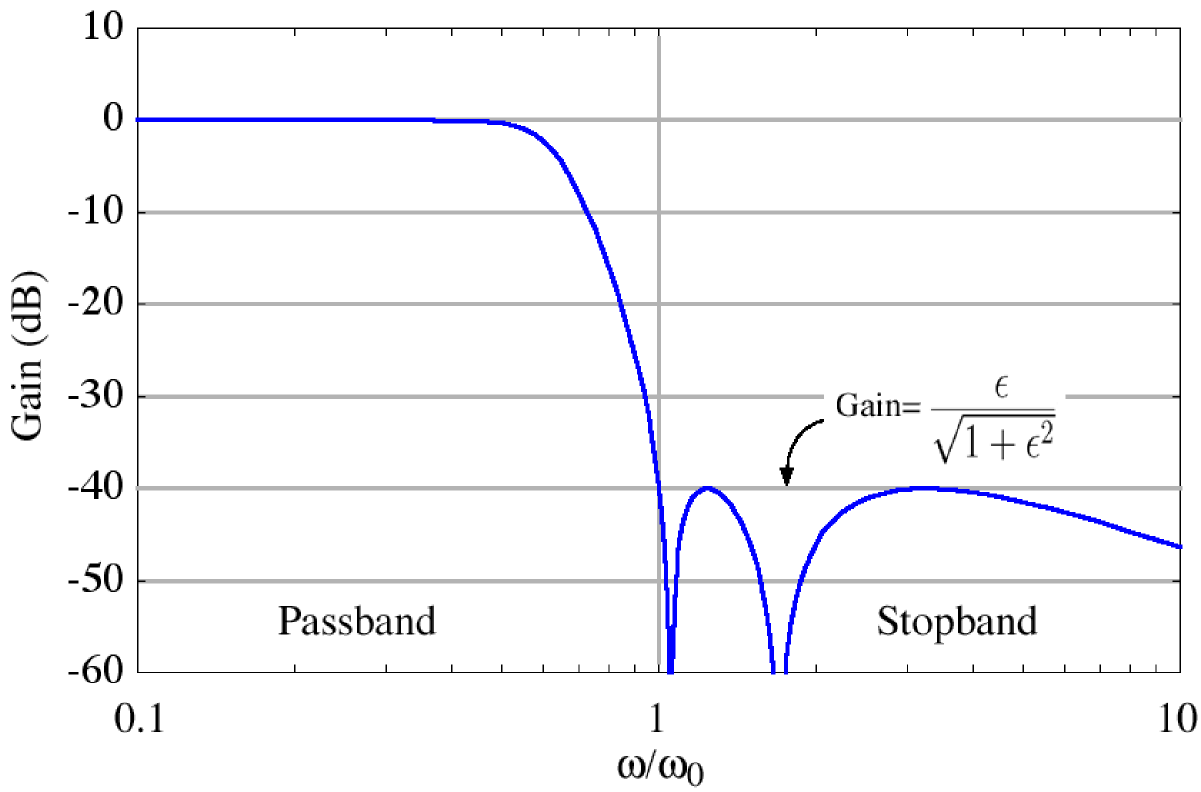


Figure 3: Frequency response of Chebyshev II (Inverse) filter

4.3 Bessel Filter

Bessel Filter is signal processing filter designed to provide a constant group delay in passband thus preserving the wave shape and generally used in audio crossover system. It's frequency response is given by:

$$T_n(s) = \frac{\theta_n(0)}{\theta_n(s/w_0)}$$

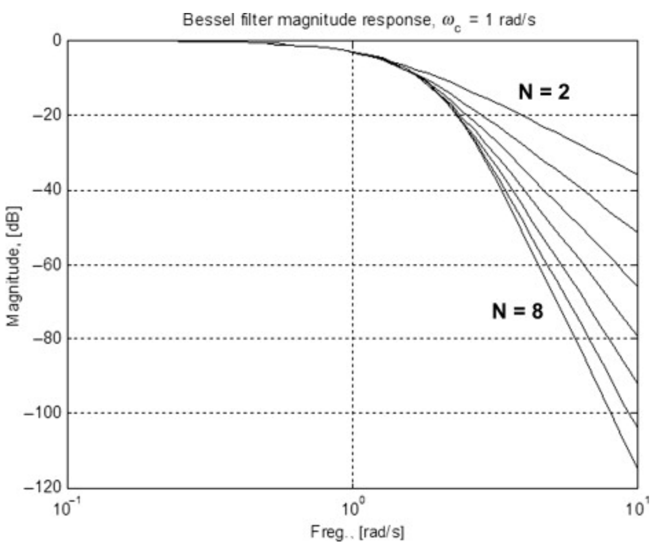


Figure 4: Frequency response of Bessel filter

5 Exercises:

5.1 Question -1

The circuit given in figure 1 below is a Butterworth low-pass filter having half power frequency of 1 rad/sec. From this circuit design a lowpass filter having half power frequency of 10000 rad/sec and practically realizable elements. Realize the circuit, observe and plot the magnitude as well as phase response. Also show the highest gain in dB and half power frequency in your plot.
Observe the output in the oscilloscope when a square wave of 100 Hz is applied at input. Observe the output by increasing frequency upto 5 KHz. Comment on the result.
Typically note down the output when the square wave around 1.6 KHz is applied at input.

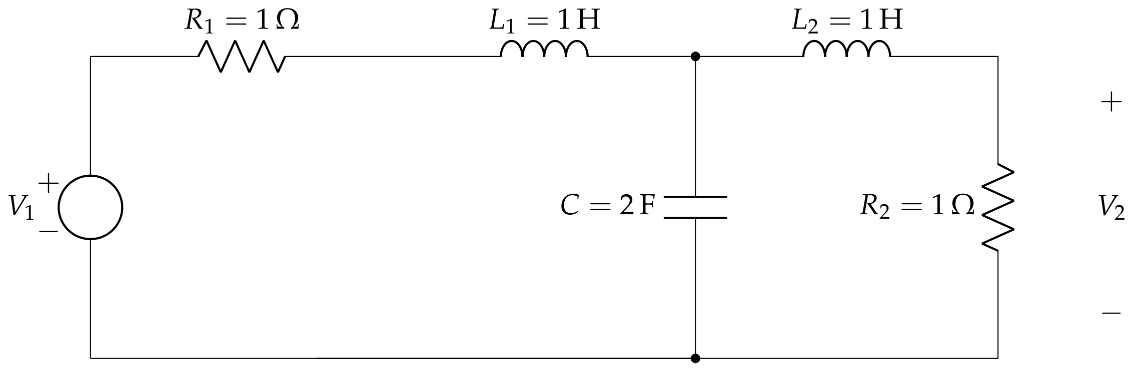


Figure 5: Third order Butterworth Filter at half power frequency (ω_0 = 1 rad/sec)

Given,
Half power frequency of normalized filter (ω_0) = 1 rad/sec
Required half power frequency (ω)= 10000 rad/sec

$$k_f = \frac{(\omega)}{(\omega_0)} = \frac{10000}{1} = 10000$$

To make filter practically realizable we consider Impedance scaling K_m be 500

$$R_{new} = K_m.R_{old} = 500 * 1 = 500\Omega$$
$$\rightarrow R_1 = R_2 = 500\Omega$$

$$L_{new} = \frac{K_m}{K_f} L_{old} = \frac{500}{10000} * 1 = 0.05\,\mathrm{H}$$
$$\rightarrow L_1 = L_2 = 0.05\,\mathrm{H} = 50\,\mathrm{mH}$$

$$C_{new} = \frac{1}{K_m.K_f} C_{old} = \frac{1}{500 * 10000} * 2 = 4 * 10^{-7} F$$
$$\rightarrow C = 4 * 10^{-7} F = 0.4\,\mu\mathrm{F}$$

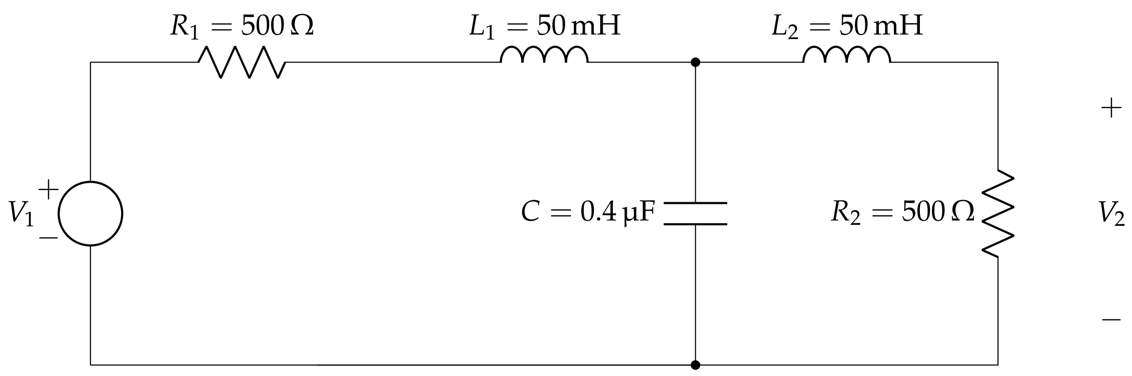


Figure 6: Butterworth Filter at half power frequency (ω_0 = 10000 rad/sec)

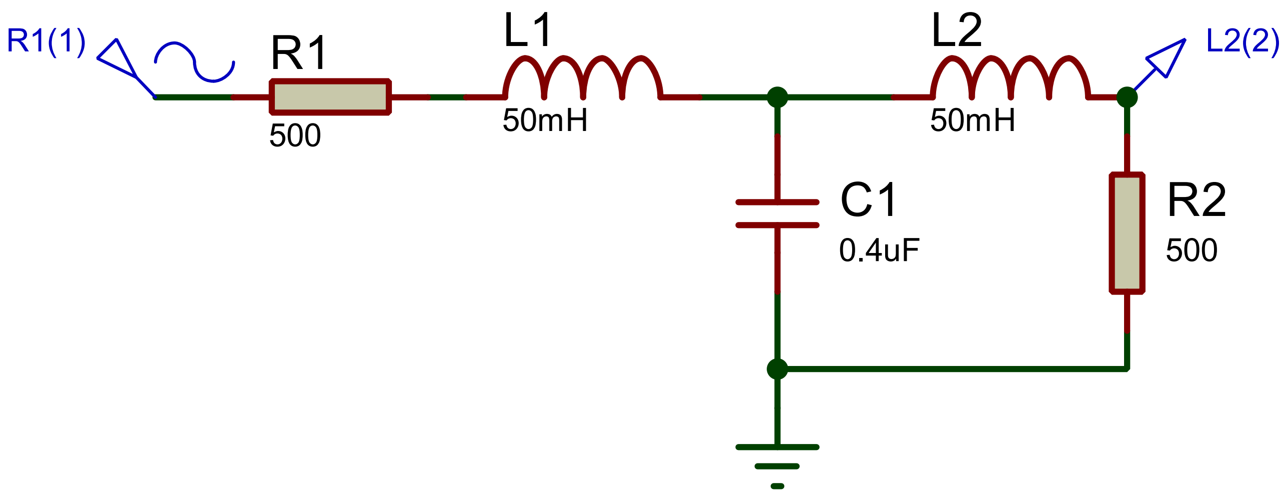
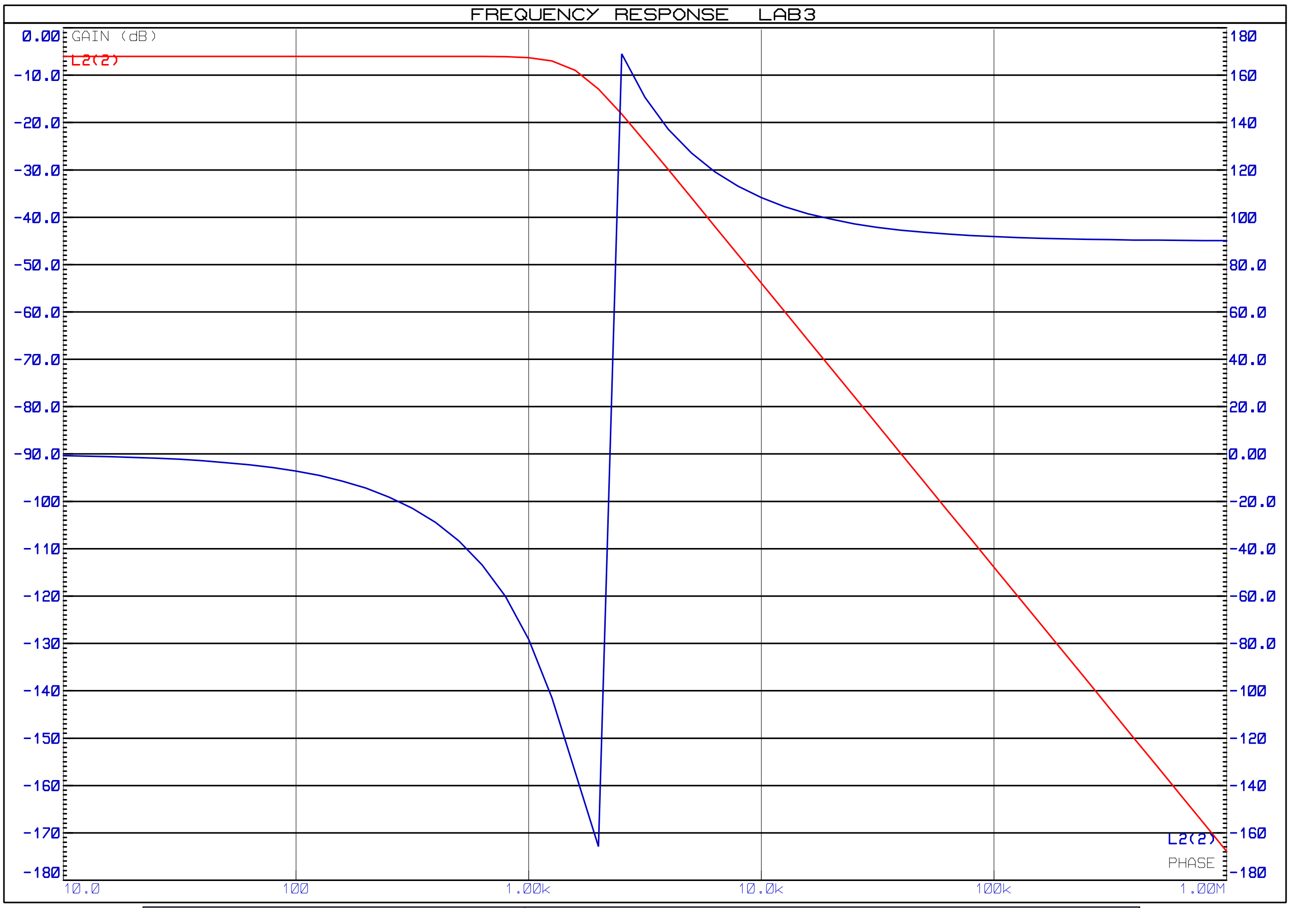


Figure 7: Proteus Circuit Figure a



Highest Gain	Half power frequency
-6.02 dB	(1.589) KHz

Figure 8: Proteus Observation Figure a

No ripple is seen in Passband and transtion is gradual till stopband.

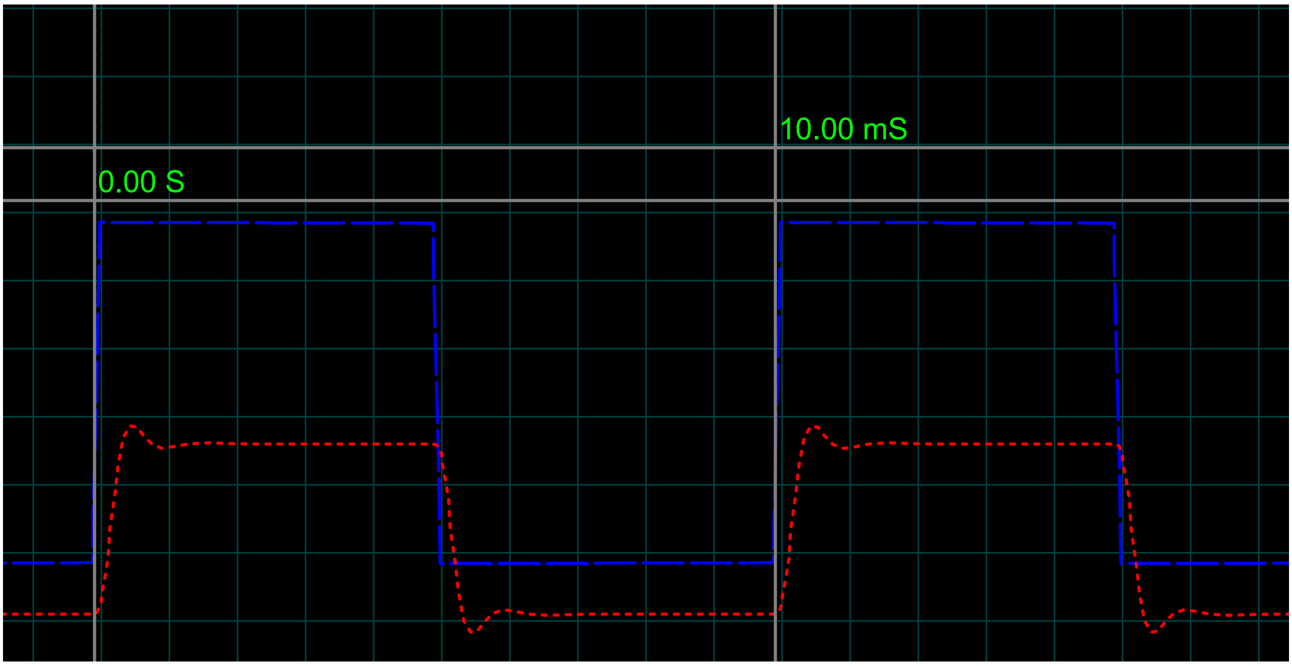


Figure 9: Output signal for input square wave of 100Hz

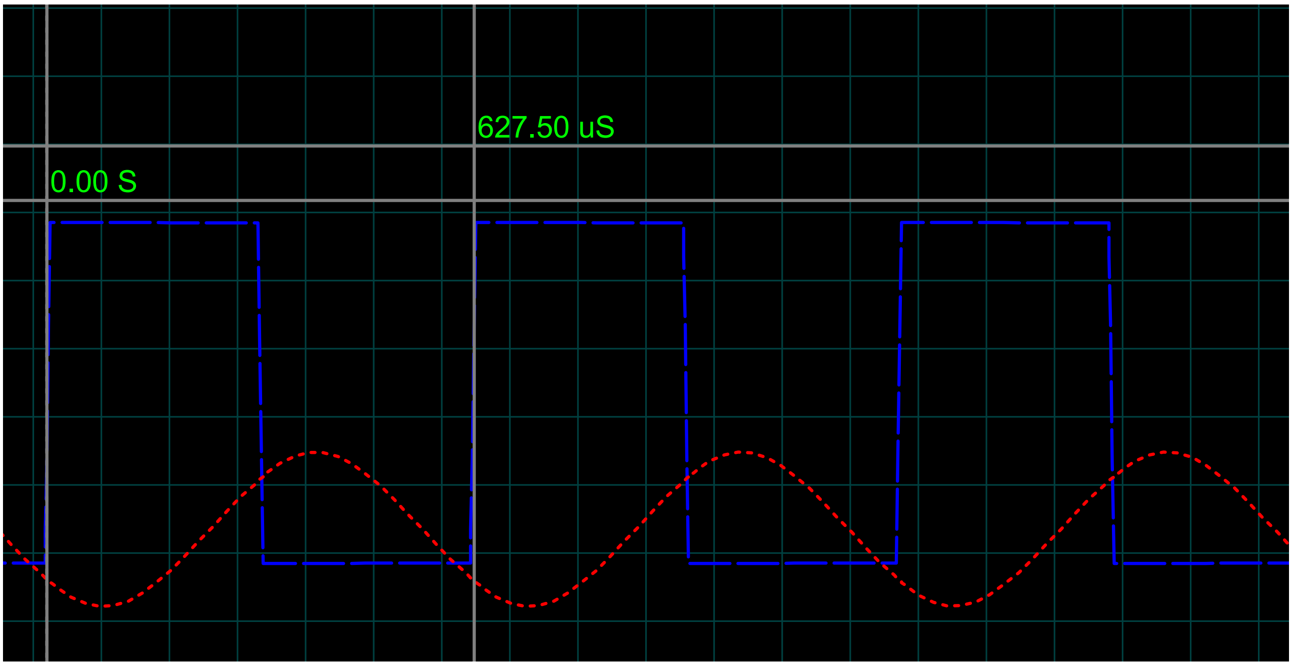


Figure 10: Output signal for input square wave of 1.6kHz

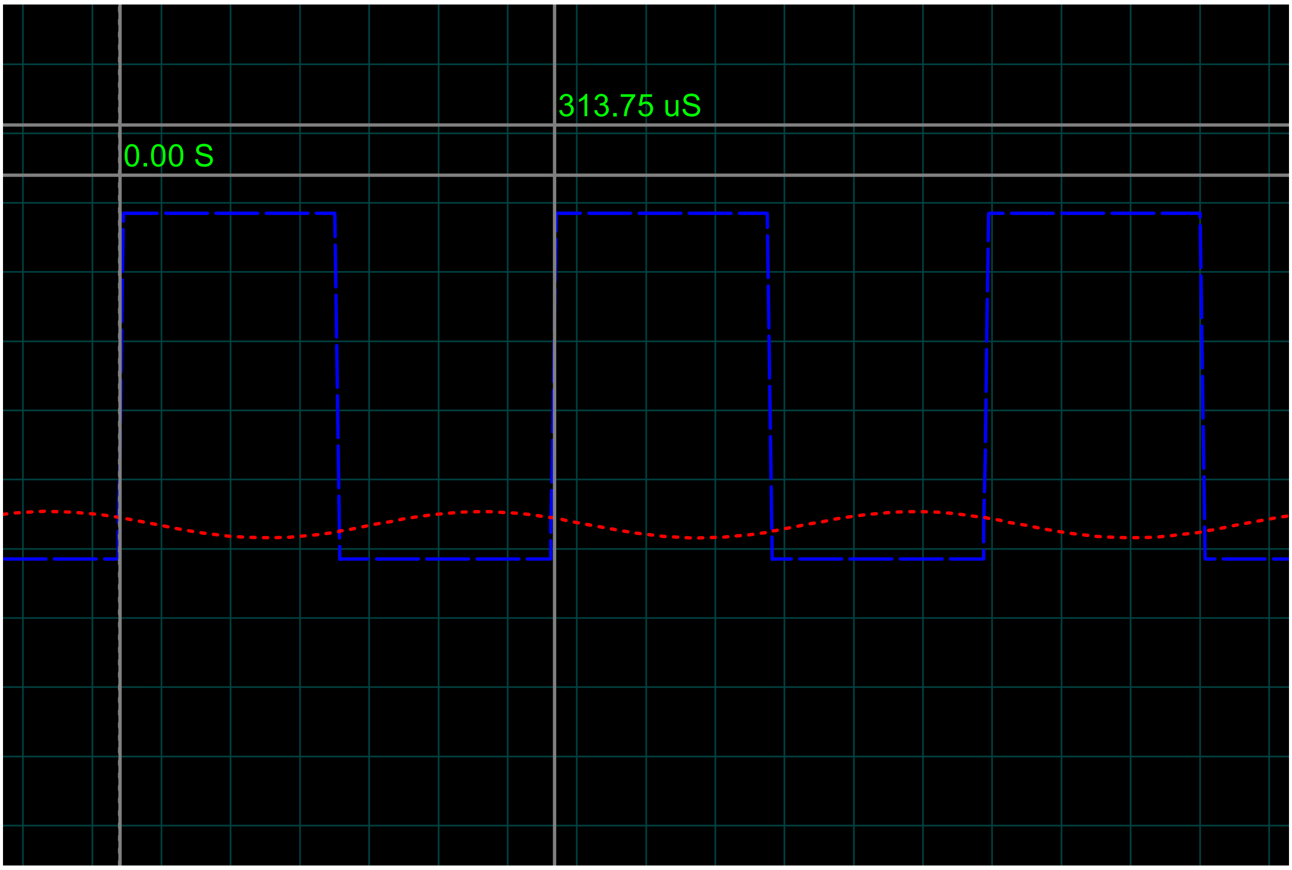


Figure 11: Output signal for input square wave of 3.2kHz

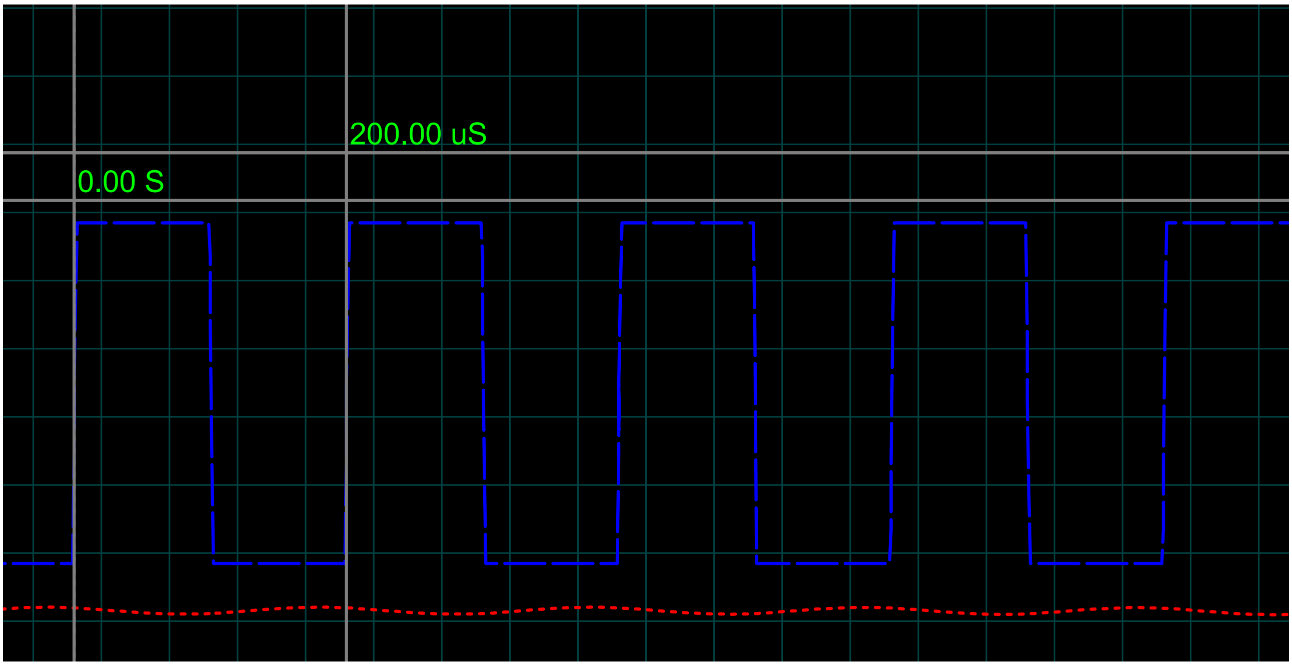


Figure 12: Output signal for input square wave of 5kHz

In above observation , in 100 Hz spikes is seen near the edges . As the frequency increases and reached 1.6kHz sine wave is seen in the middle.From 3.2 khz to 5.0 khz , the output is getting smother.

5.2 Question -2

The circuit given in figure 2 below is a low-pass Chebyshev filter having passband frequency of 1 rad/sec and attenuation of 1dB. From this circuit design a lowpass filter having passband frequency of 10000 rad/sec and practically realizable elements. Realize the circuit, observe and plot the magnitude as well as phase response. Also show the highest gain in dB and half power frequency in your plot. Note down the ripple within the entire passband.
Observe the output in oscilloscope when square wave of 100 Hz is applied at input. Observe the output by increasing frequency upto 5 KHz. Comment on the result.
Typically note down the output when square wave around 1.6 KHz is applied at input.

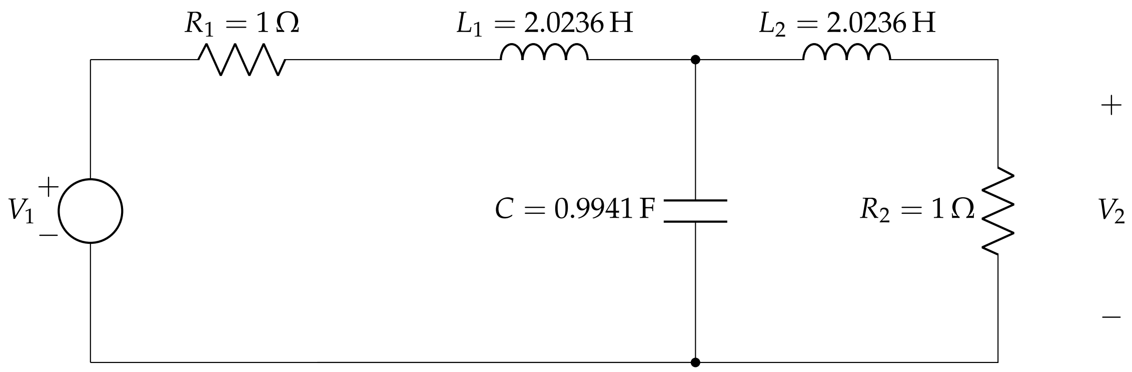


Figure 13: Chebyshev having passband frequency of 1 rad/sec and 1 dB ripple

Given,
Half power frequency of normalized filter (ω_0) = 1 rad/sec
Required half power frequency (ω)= 10000 rad/sec

$$k_f = \frac{(\omega)}{(\omega_0)} = \frac{10000}{1} = 10000$$

To make filter practically realizable we consider Impedance scaling K_m be 500

$$R_{new} = K_m.R_{old} = 500 * 1 = 500\Omega$$
$$\rightarrow R_1 = R_2 = 500\Omega$$

$$L_{new} = \frac{K_m}{K_f} L_{old} = \frac{500}{10000} * 2.0236 = 0.101\,18\,\mathrm{H}$$
$$\rightarrow L_1 = L_2 = 0.101\,18\,\mathrm{H} = 101.18\,\mathrm{mH}$$

$$C_{new} = \frac{1}{K_m.K_f} C_{old} = \frac{1}{500 * 10000} * 0.9941 = 1.9882 * 10^{-7}F$$
$$\rightarrow C = 1.9882 * 10^{-7}F = 0.198\,82\,\mu\mathrm{F}$$

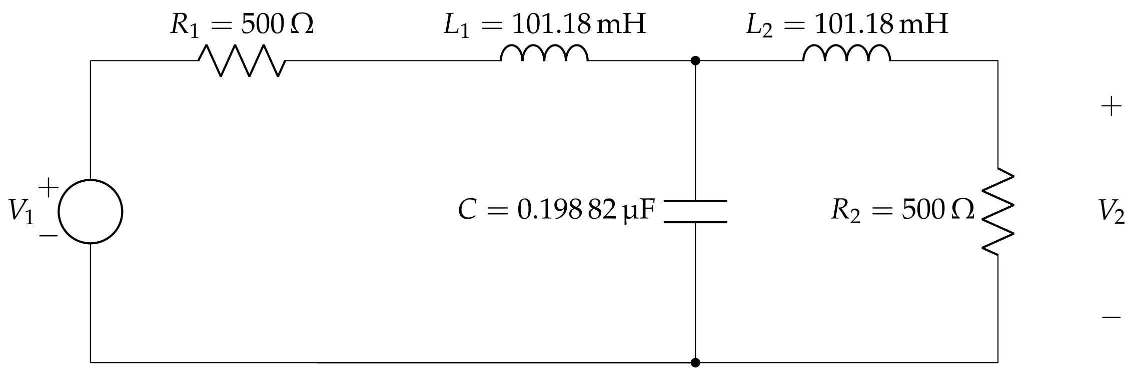


Figure 14: Chebyshev having passband frequency of 1000 rad/sec and 1 dB ripple

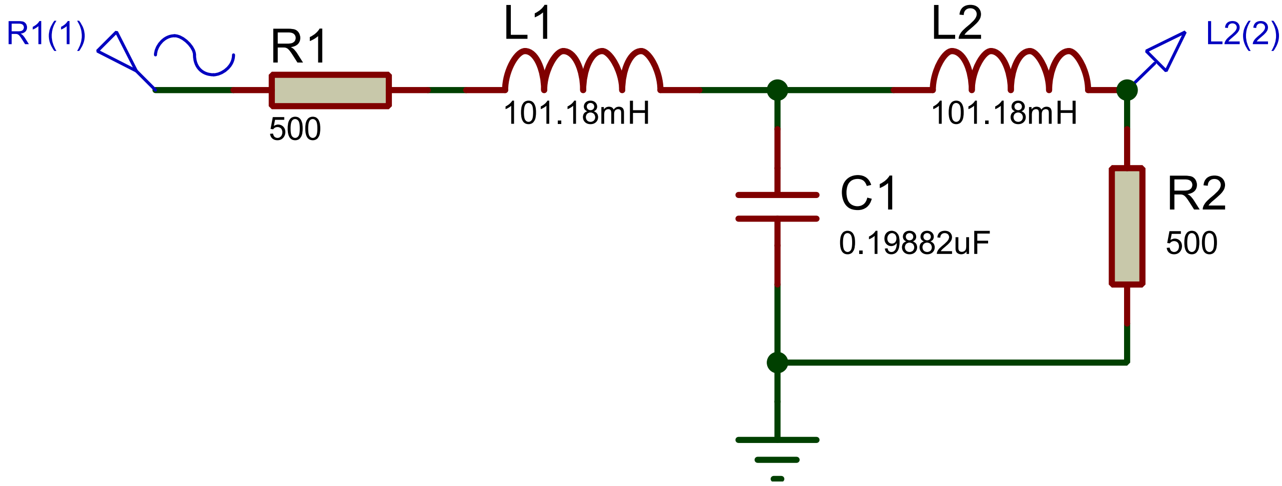
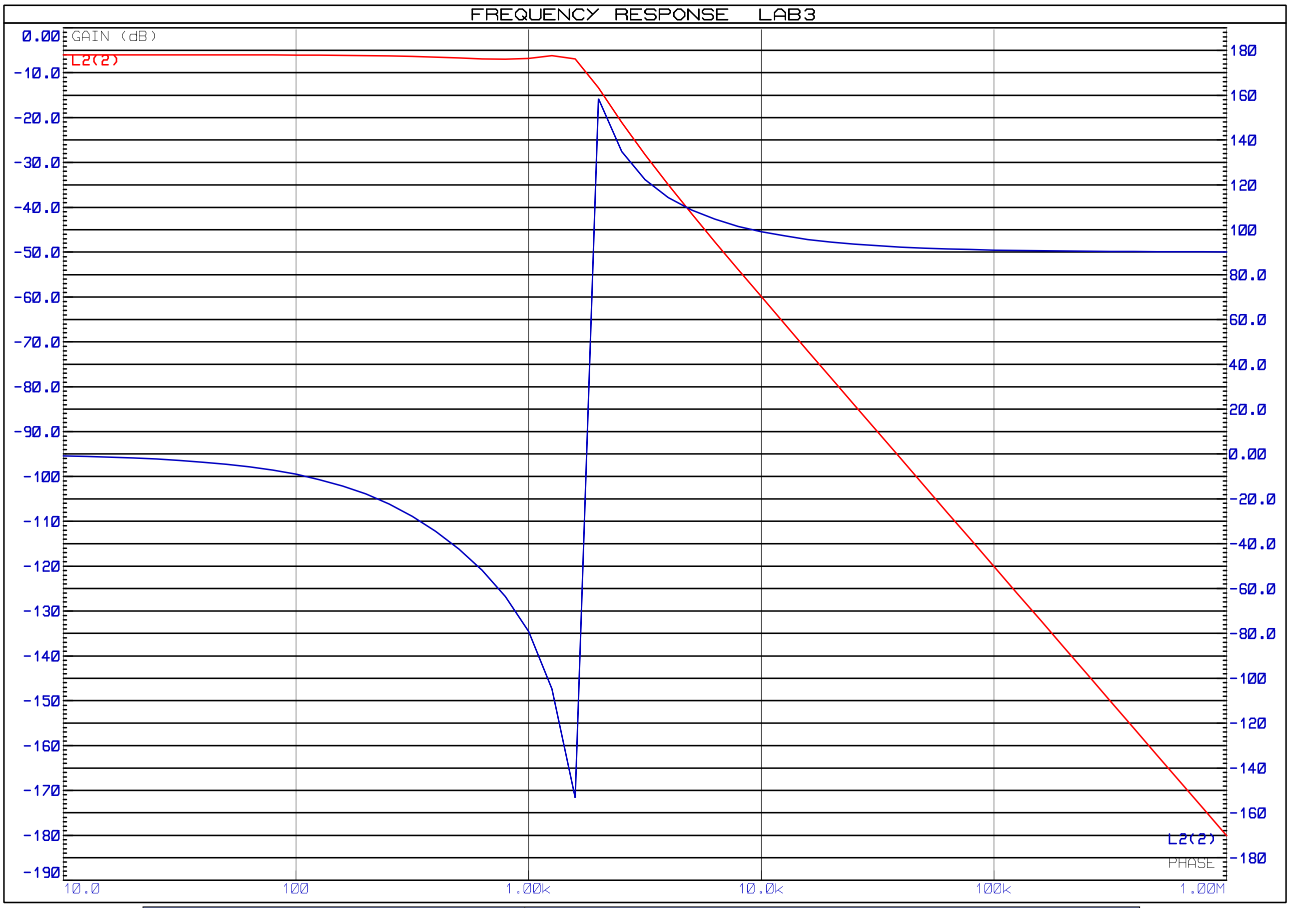


Figure 15: Proteus Circuit Figure b



Highest Gain	Half power frequency
-6.02 dB	(1.718) KHz

Figure 16: Proteus Observation Figure b

Lowest ripple = -7.02 dB thus ripple in the passband = 1 dB

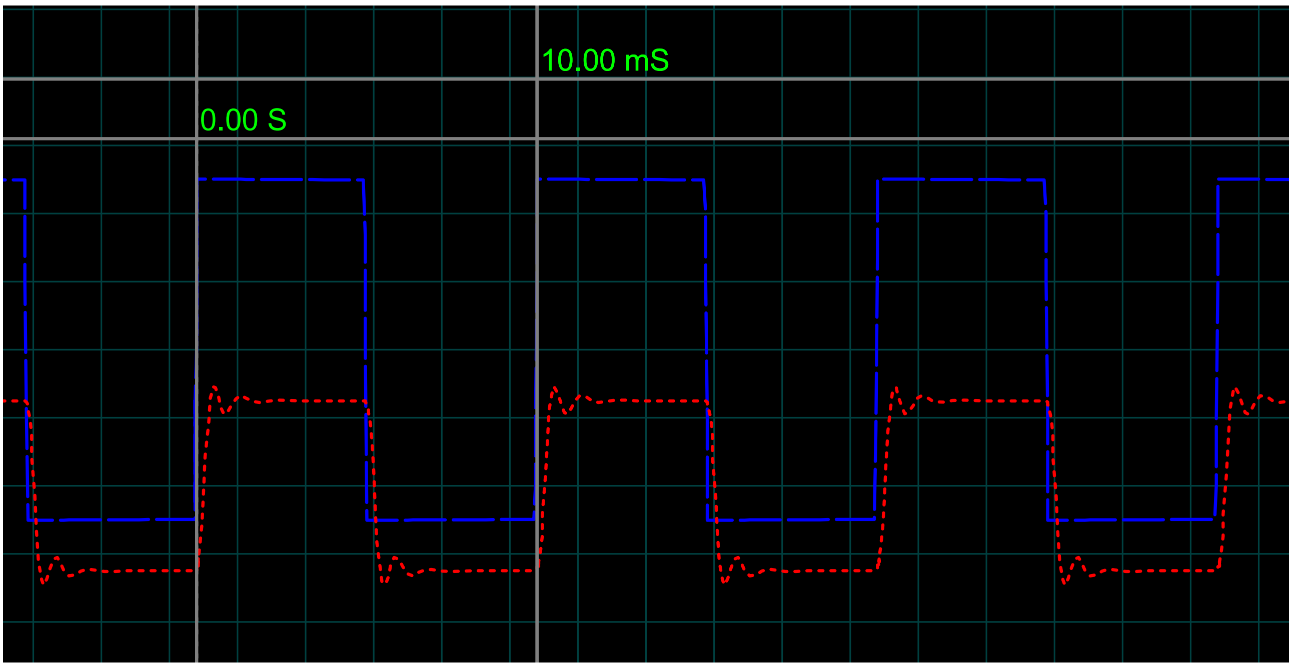


Figure 17: Output signal for input square wave of 100Hz

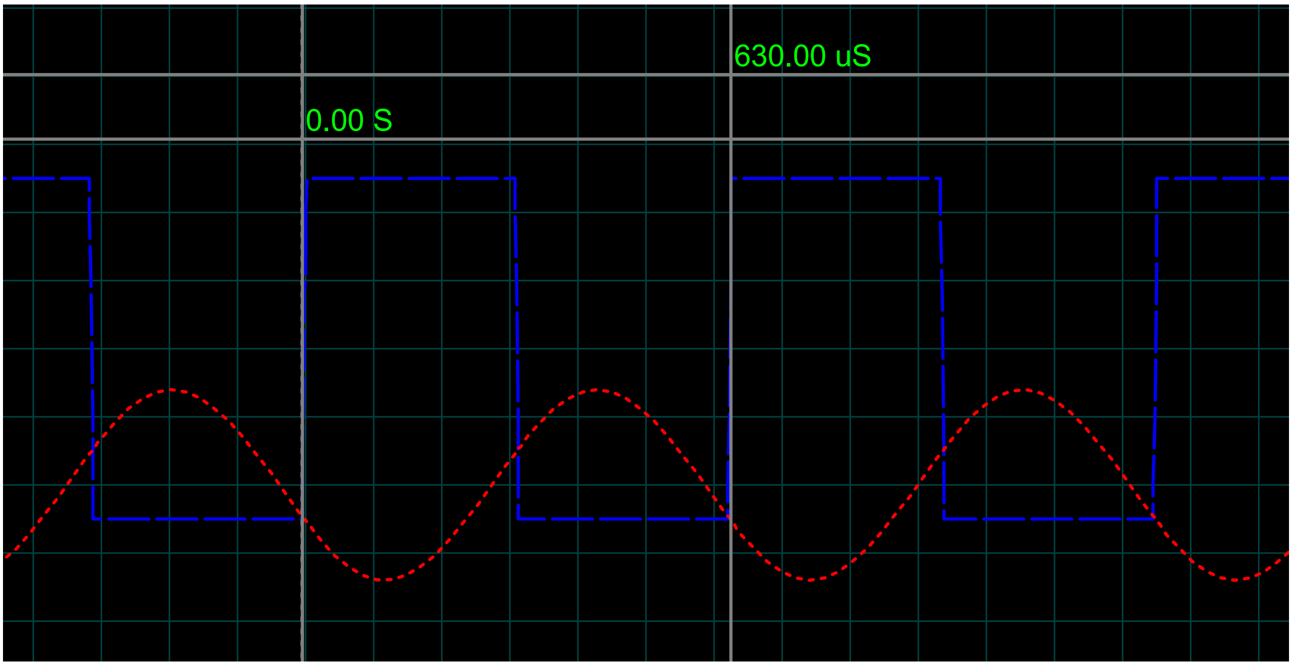


Figure 18: Output signal for input square wave of 1.6kHz

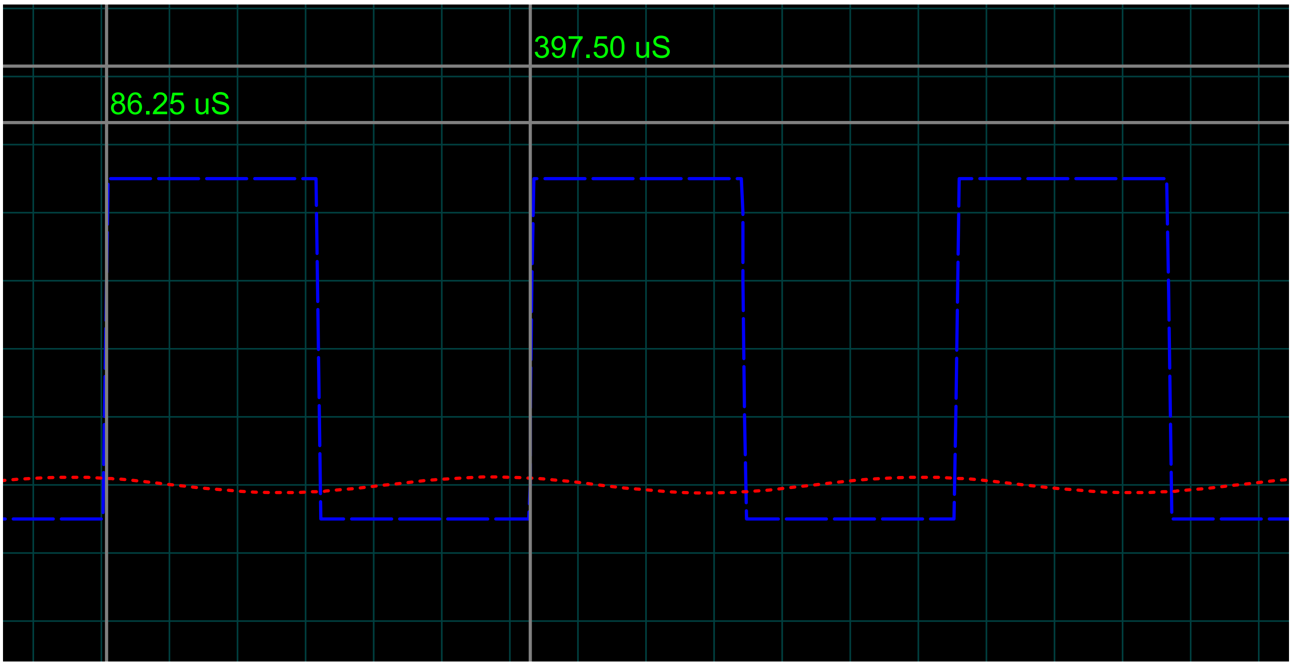


Figure 19: Output signal for input square wave of 3.2kHz

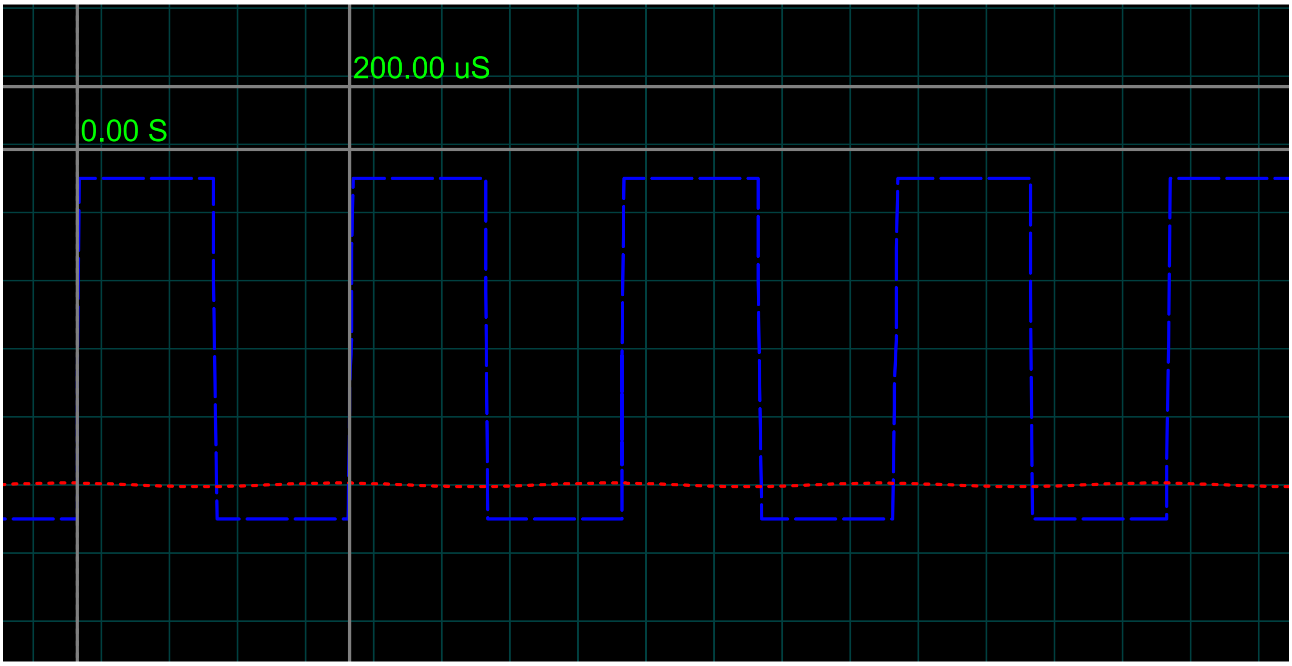


Figure 20: Output signal for input square wave of 5kHz

In above observation , in 100 Hz spikes is seen near the edges . As the frequency increases and reached 1.6kHz sine wave is seen in the middle.From 3.2 khz to 5.0 khz , the output is getting smother.

5.3 Question -3

Let us modify the elements as shown in figure 3 below to have the Chebyshev lowpass filter with 3 dB ripple. From this circuit design a lowpass filter having passband frequency of 10000 rad/sec and practically realizable elements. Realize the circuit, observe and plot the magnitude as well as phase response. Also show the highest gain in dB and half power frequency in your plot. Note down the ripple within the entire passband. Compare the response with that of problem B.

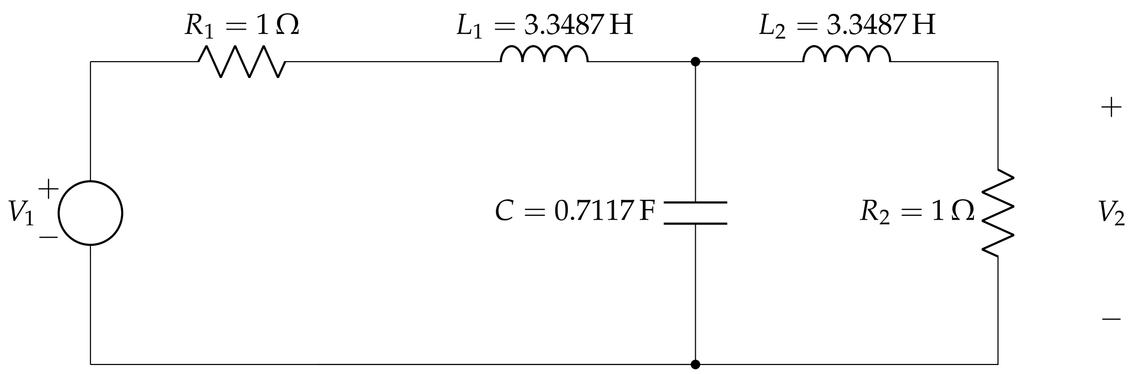


Figure 21: Chebyshev having passband frequency of 1 rad/sec and 3dB ripple

Given,
Half power frequency of normalized filter (ω_0) = 1 rad/sec
Required half power frequency (ω)= 10000 rad/sec

$$k_f = \frac{(\omega)}{(\omega_0)} = \frac{10000}{1} = 10000$$

To make filter practically realizable we consider Impedance scaling K_m be 500

$$R_{new} = K_m.R_{old} = 500 * 1 = 500\Omega$$
$$\rightarrow R_1 = R_2 = 500\Omega$$

$$L_{new} = \frac{K_m}{K_f} L_{old} = \frac{500}{10000} * 3.3487 = 0.167\,435\,\mathrm{H}$$
$$\rightarrow L_1 = L_2 = 0.167\,435\,\mathrm{H} = 167.435\,\mathrm{mH}$$

$$C_{new} = \frac{1}{K_m.K_f} C_{old} = \frac{1}{500 * 10000} * 0.7117 = 1.4234 * 10^{-7} F$$
$$\rightarrow C = 1.4234 * 10^{-7} F = 0.142\,34\,\mu\mathrm{F}$$

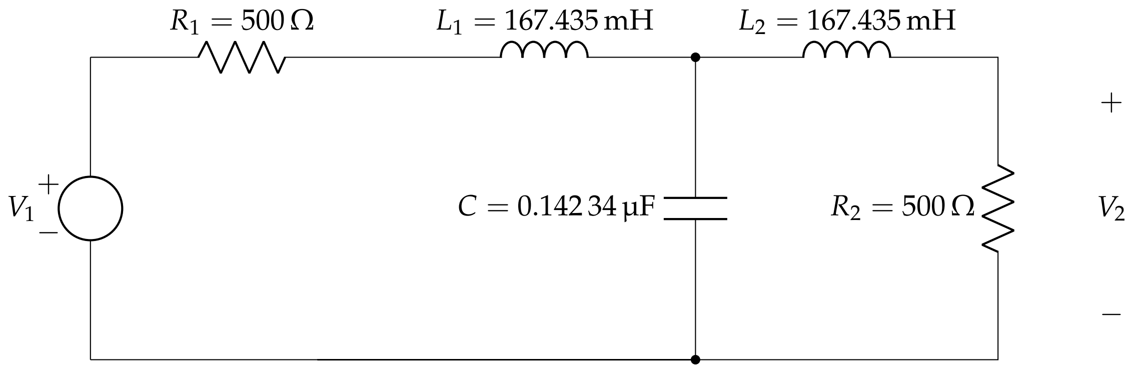


Figure 22: Chebyshev having passband frequency of 1000 rad/sec and 3 dB ripple

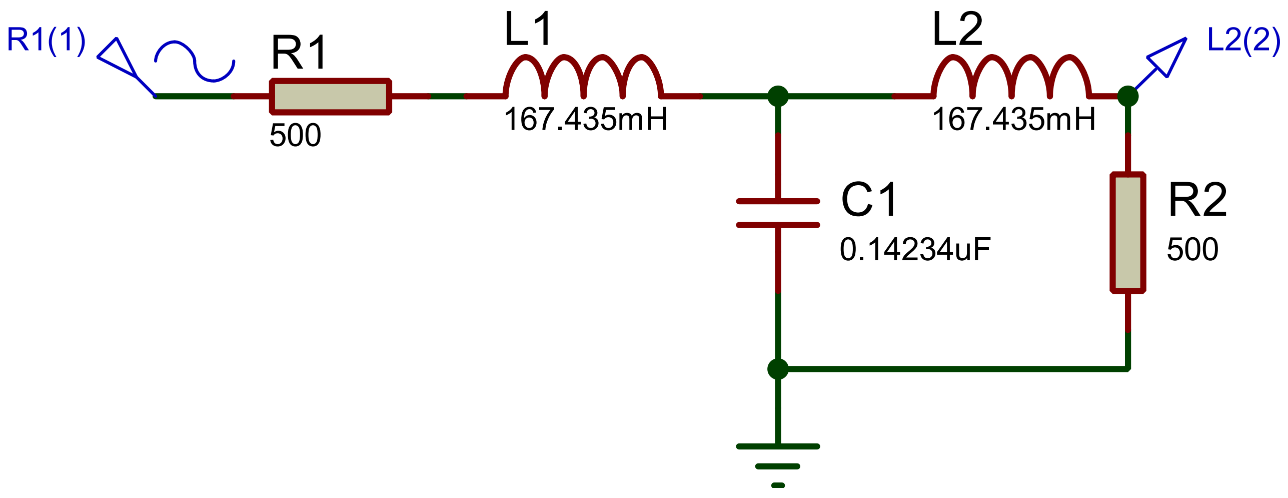
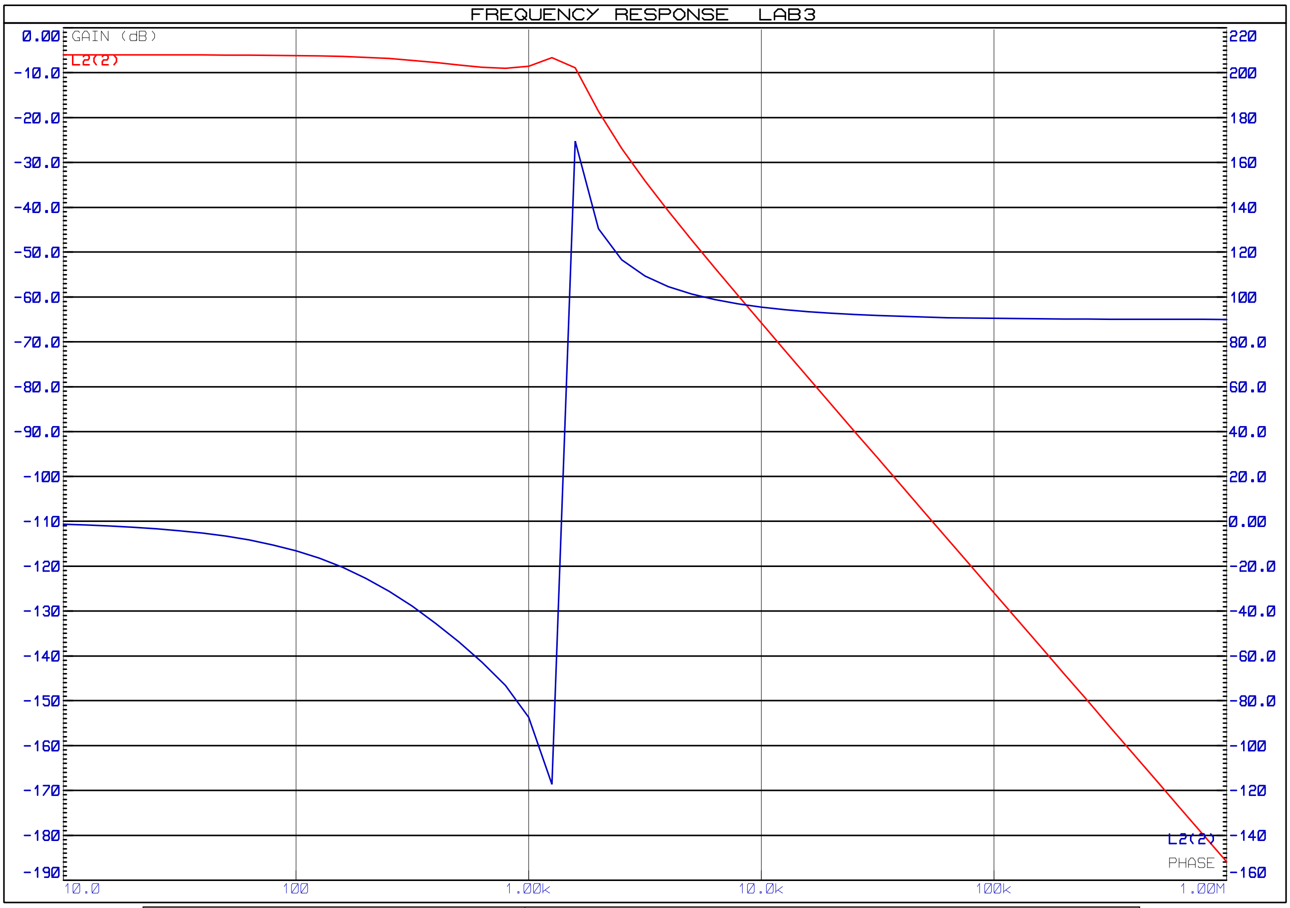


Figure 23: Proteus Circuit Figure c



Highest Gain	Half power frequency
-6.02 dB	(1.592) KHz

Figure 24: Proteus Observation Figure c

Lowest ripple= -9.02 dB thus ripple in pass band is 3 dB.
Compared to Problem 2 sharper transition is seen in Problem 3.

5.4 Question -4

The circuit given in figure 4 below is a low-pass Bessel filter with normalized frequency. From this circuit design a lowpass filter for the frequency of 10000 rad/sec. All the elements of your final design should be practically realizable. Realize the circuit, observe and plot the magnitude as well as phase response. Also show the highest gain in dB and half power frequency in your plot.
Observe the output in oscilloscope when square wave of 100 Hz is applied at input. Observe the output by increasing frequency upto 5 KHz. Comment on the result.
Typically note down the output when the square wave around 1.6 KHz is applied at input.

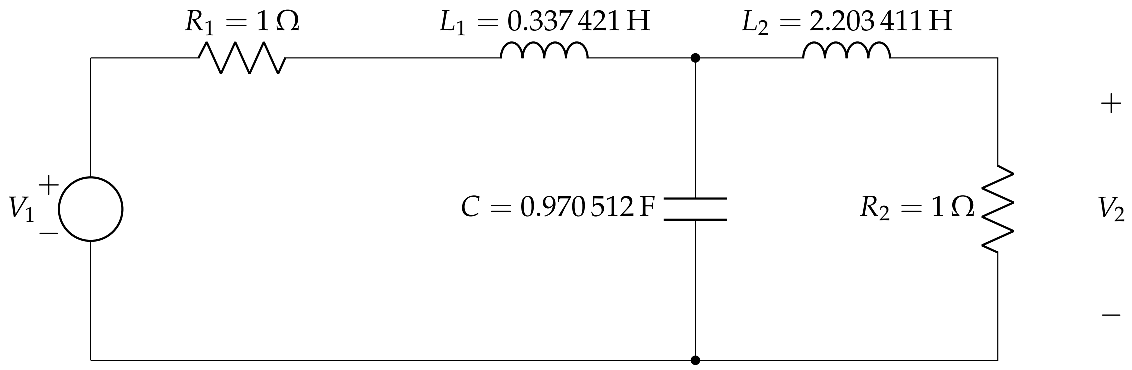


Figure 25: Bessel filter at normalized frequency of 1 rad/sec

Given,
Half power frequency of normalized filter (ω_0) = 1 rad/sec
Required half power frequency (ω)= 10000 rad/sec

$$k_f = \frac{(\omega)}{(\omega_0)} = \frac{10000}{1} = 10000$$

To make filter practically realizable we consider Impedance scaling K_m be 500

$$R_{new} = K_m.R_{old} = 500 * 1 = 500\Omega$$
$$\rightarrow R_1 = R_2 = 500\Omega$$

$$L_{new} = \frac{K_m}{K_f} L_{old}$$
$$\rightarrow L_1 = \frac{500}{10000} * 0.337421 = 0.016\,871\,05\,\mathrm{H} = 16.871\,05\,\mathrm{mH}$$
$$\rightarrow L_2 = \frac{500}{10000} * 2.203411 = 0.110\,170\,55\,\mathrm{H} = 110.170\,55\,\mathrm{mH}$$

$$C_{new} = \frac{1}{K_m.K_f} C_{old} = \frac{1}{500 * 10000} * 0.970512 = 1.941024 * 10^{-7} F$$
$$\rightarrow C = 1.941024 * 10^{-7} F = 0.194\,102\,4\,\mu\mathrm{F}$$

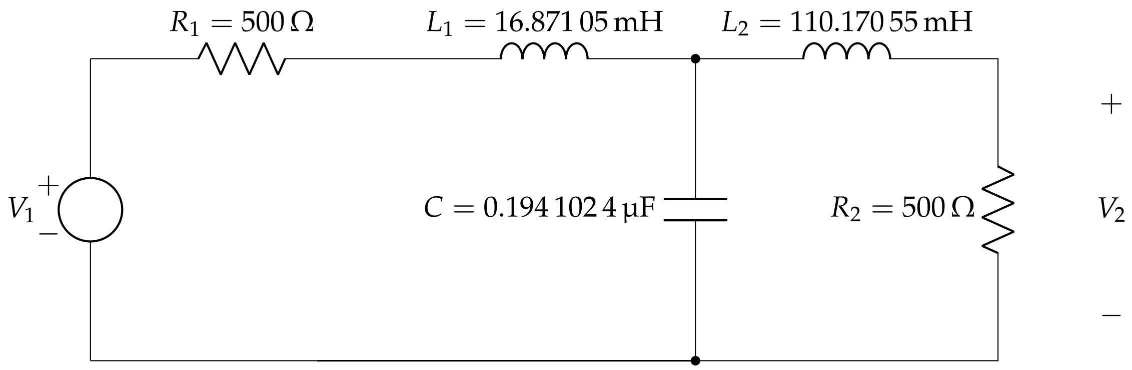


Figure 26: Bessel filter at normalized frequency of 1000 rad/sec

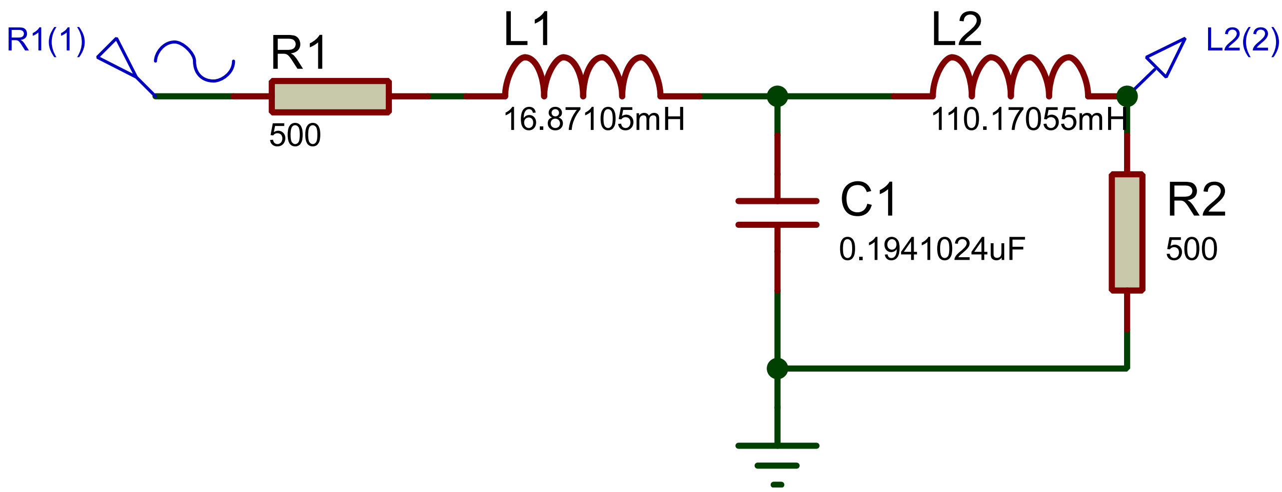
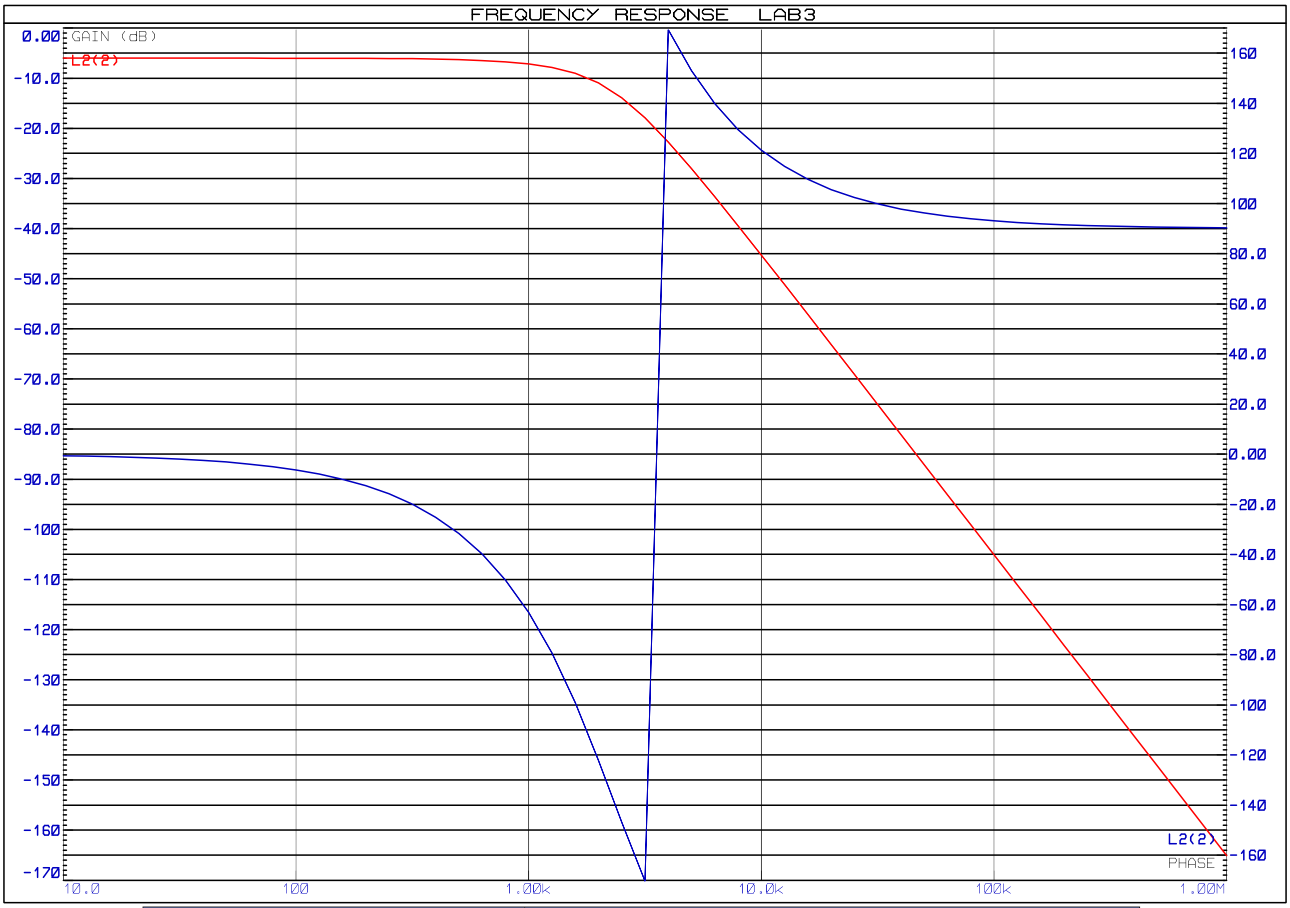


Figure 27: Proteus Circuit Figure d



Highest Gain	**Half power frequency**
-6.02 dB	(1.589) KHz

Figure 28: Proteus Observation Figure d

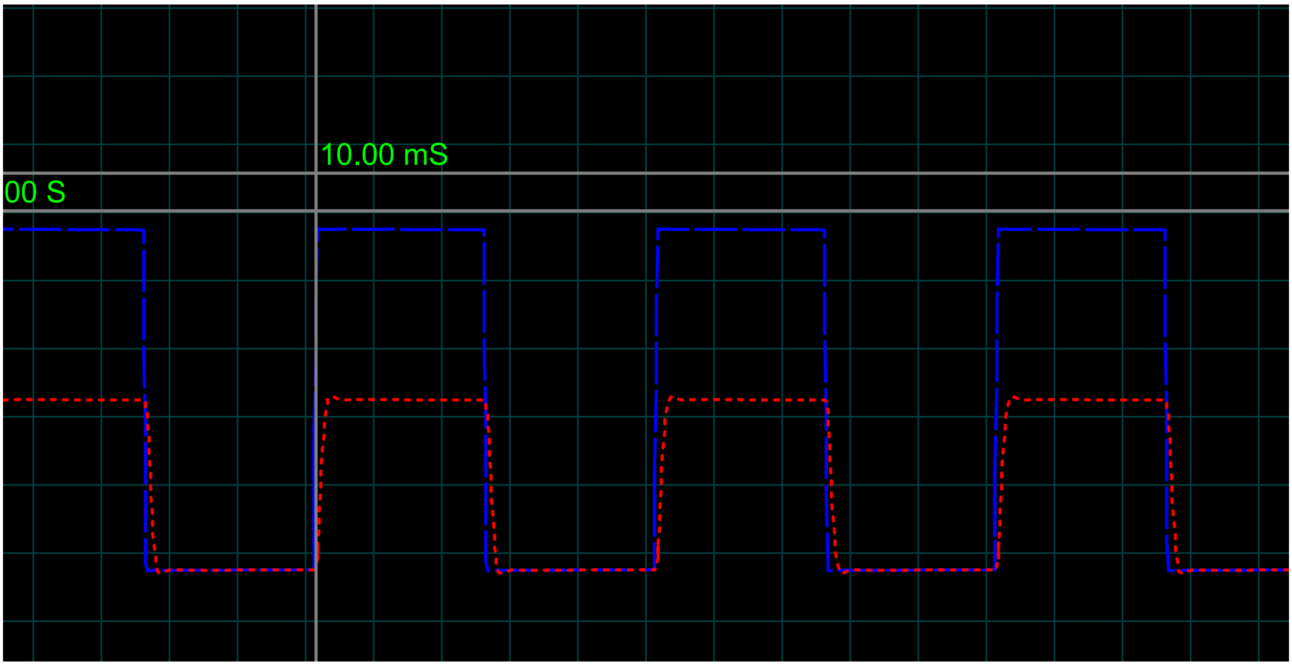


Figure 29: Output signal for input square wave of 100Hz

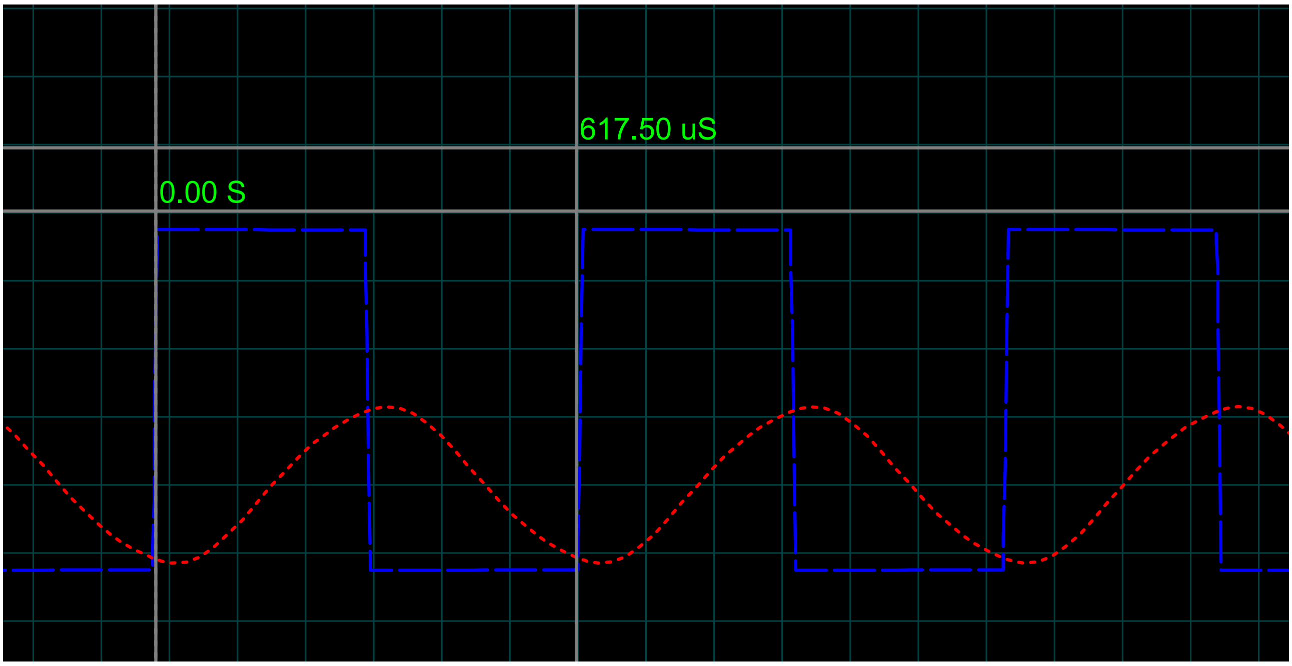


Figure 30: Output signal for input square wave of 1.6kHz

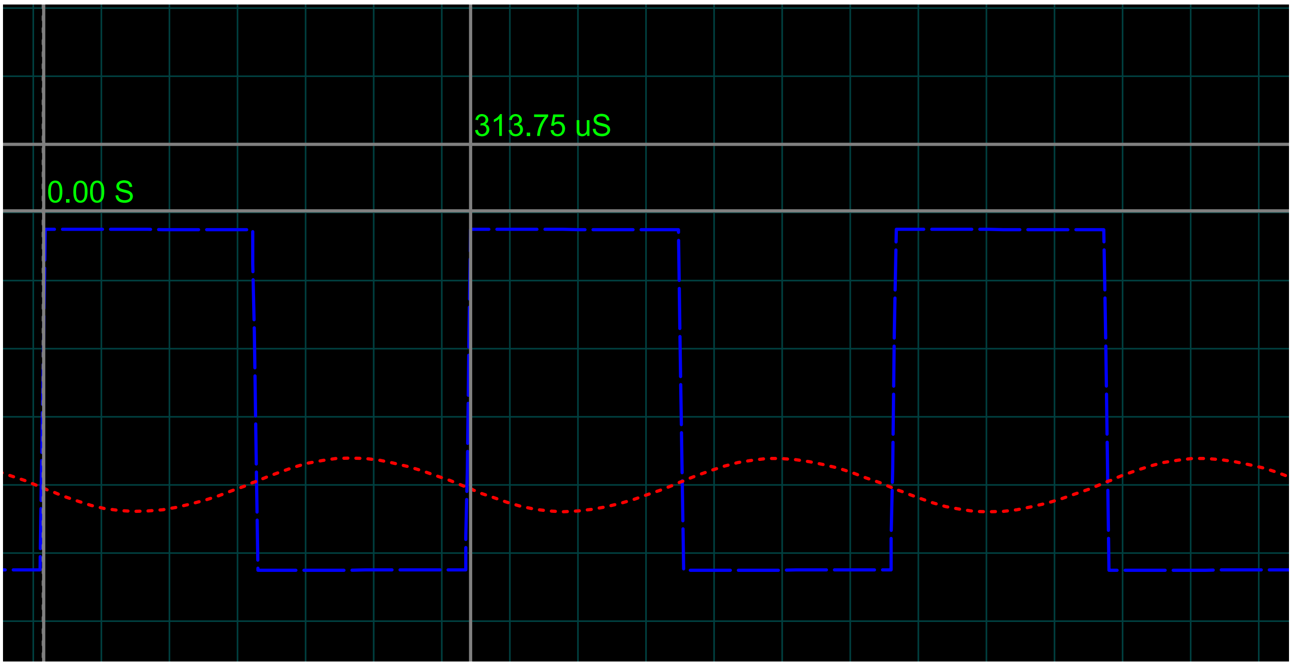


Figure 31: Output signal for input square wave of 3.2kHz

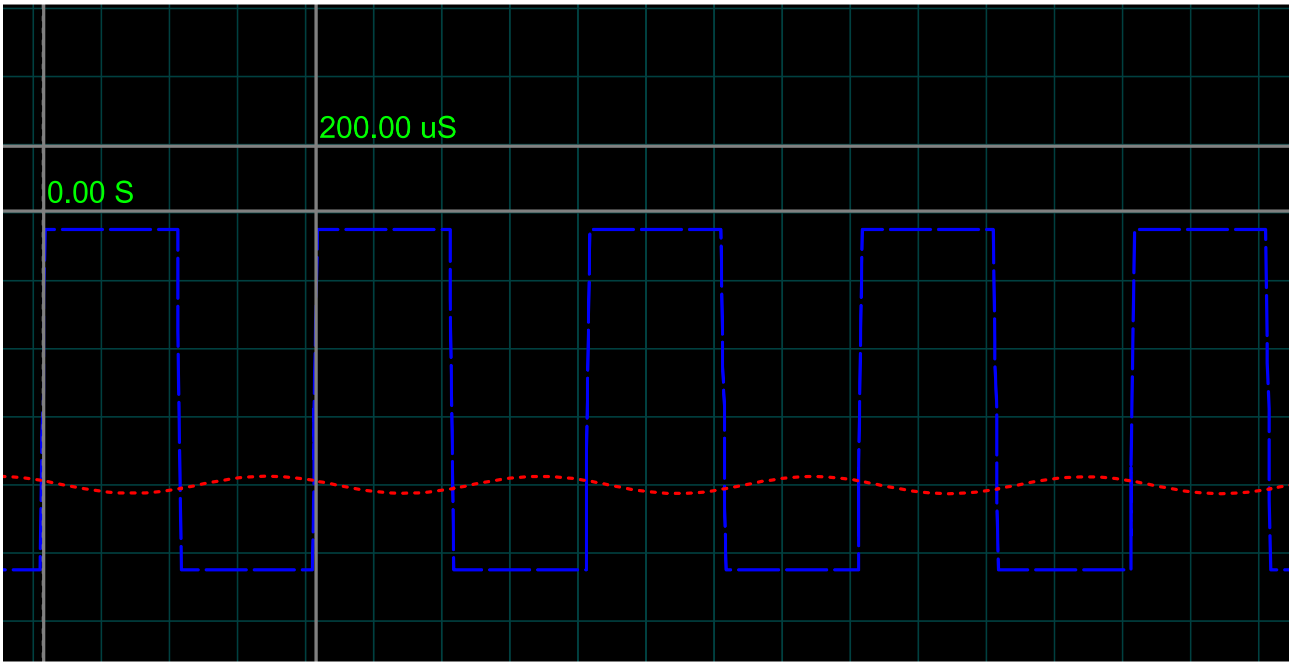


Figure 32: Output signal for input square wave of 5kHz

In above observation , in 100 Hz spikes is seen near the edges . As the frequency increases and reached 1.6kHz sine wave is seen in the middle.From 3.2 khz to 5.0 khz , the output is getting smother.

6 Discussion & Conclusion

In this Lab we did comparison of magnitude & phase response different Filter Networks. We used Proteus design suite to design and plot frequency response for the circuit. We studied and design practically realizable Butterworth, Chebyshev and bessel filters. We also derive transfer function for these filters hence fulfilling our objectives of lab.