INSTITUTE OF ENGINEERING
CENTRAL CAMPUS,PULCHOWK

FILTER DESIGN

LAB #6

DESIGN OF HIGHER ORDER ACTIVE FILTERS

Submitted BY:
AMRIT PRASAD PHUYAL
Roll: PULL074BEX004

Submitted To:
SHARAD KUMAR GHIMIRE
Department of Electronics and
Computer Engineering

August 27, 2021

Table of Contents

List of Figures

List of Tables

1 Title

DESIGN OF HIGHER ORDER ACTIVE FILTERS

2 Objective

- To be familiar with design of high order active filter using simulated inductors.
- To be familiar with design of high order active filter using FDNR.
- To be familiar with design of high order active filter using Leapfrog simulation.

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 Generalized Impedance Converter (GIC)

A Generalized Impedance Converter (GIC) is an active two port network in which the input impedance is equal to the load impedance times a conversion function of the complex frequency variable .

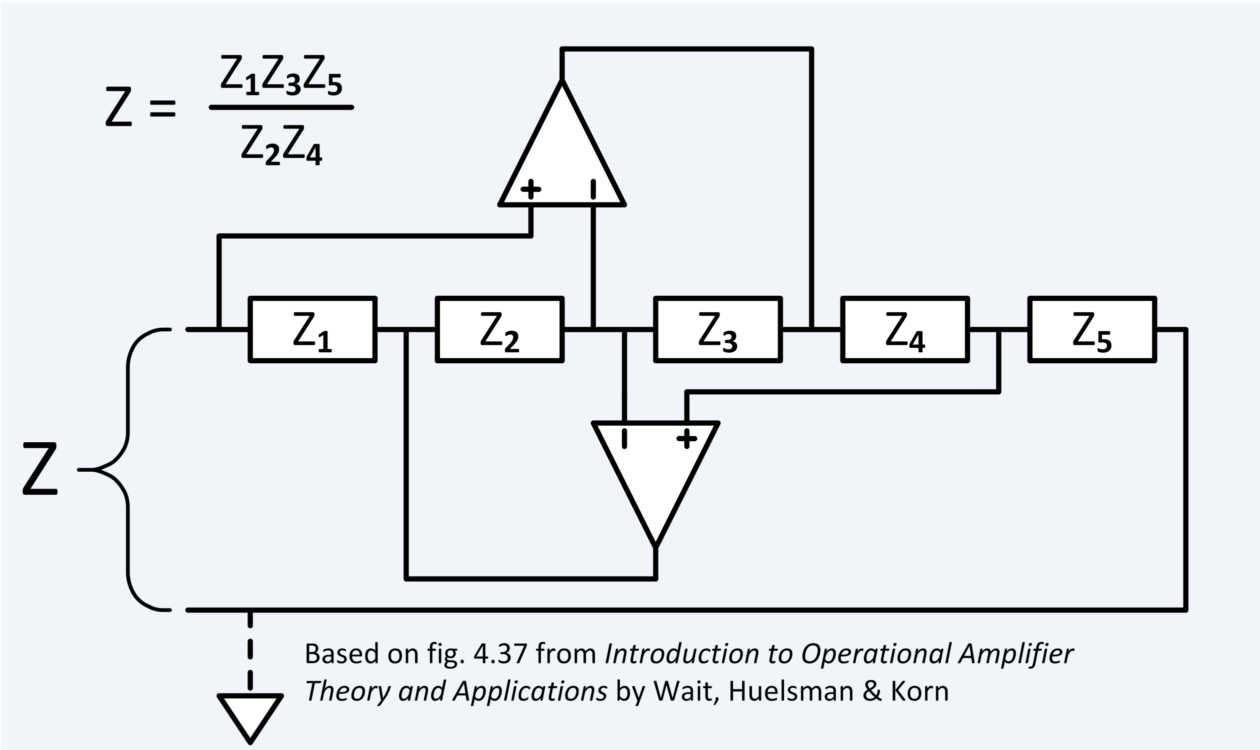


Figure 1: Generalized Impedance Converter (GIC)

$$Z = Z_{in} = \frac{Z_1 Z_3 Z_5}{Z_2 Z_4} \tag{1}$$

4.2 Simulated Inductors

In this method of designing Higher order active filter, we use simulated inductors to simulate thr grounded inductor in a passive circuit. In the above figure if value of all impedance except Z_5 is 1 i.e $Z_1 = Z_2 = Z_3 = 1\Omega, Z_4 = 1F$ and $Z_5 = k\Omega$. Then new value of Z will be

$$Z = Z_{SimulatedInductor} = \frac{1 \times 1 \times k}{\left(\frac{1}{s}\right) \times 1} = ks$$

4.3 Frequency Dependent Negative Resistor (FDNR)

Burton's FDNR technique involves eliminating the use of inductor by scaling all impedances by frequency dependent factor $\frac{1}{s}$ converting a resistor to a capacitor $\left(\frac{R}{s}\right)$, an inductor to a resistor (L), and the capacitor to a Frequency Dependent Negative Resistor (FDNR) $\left(\frac{1}{s^2C}\right)$ with symbol $\|\|$. In the above figure if $Z_1 = Z_2 = 1\ \Omega$, $Z_3 = Z_5 = 1$ F and $Z_4 = k\ \Omega$ is used. Then new value of Z will be

$$Z = Z_{FDNR} = \frac{\left(\frac{1}{s}\right) \times \left(\frac{1}{s}\right) \times 1}{1 \times k} = \frac{1}{ks^2}$$

4.4 Leapfrog Simulation

This method simulates the operation of the ladder rather than its components by modeling all circuit equations and the voltage–current relationship of the elements.Simulation involve step of determining lowpass prototype, identifying admittance and impedance of the ladder, selecting Leapfrog parameters, and simulating the circuit.If needed frequency and Magnitude scaling is performed .

5 Exercises:

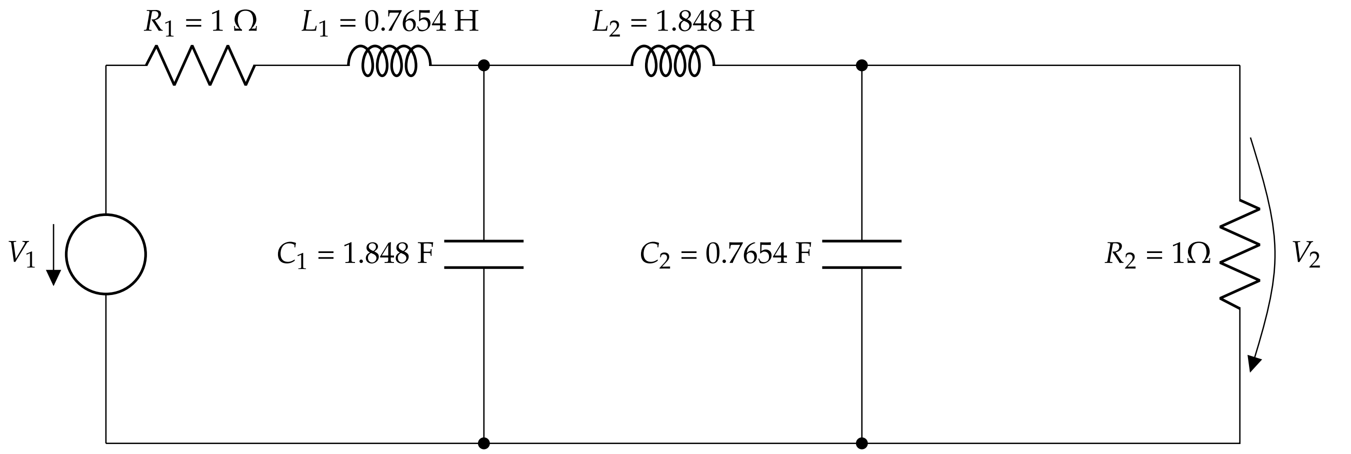


Figure 2: Fourth order Butterworth lowpass ladder circuit

5.1 Question -1

The network given in figure 1 is the fourth order Butterworth lowpass filter at normalized frequency of 1 rad/sec. From this network, design a lowpass filter having half power frequency of 20000 rad/sec using FDNR. Realize the network and observe the magnitude response.

After applying Bruton's Transformation on above circuit we get,

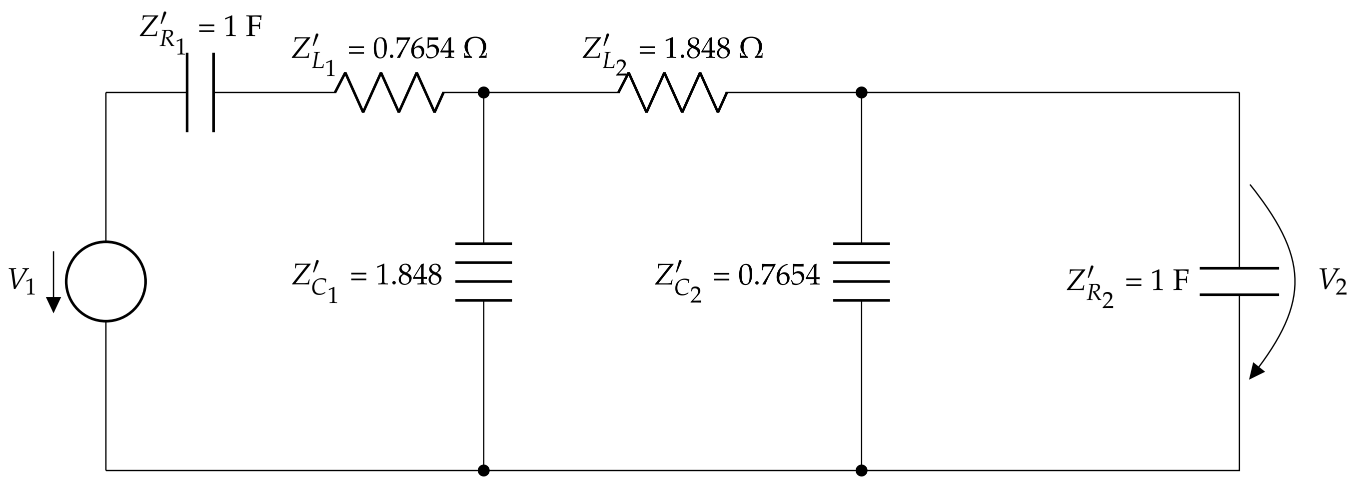


Figure 3: Fourth order Butterworth Lowpass Circuit using FDNR

Using magnitude scaling factor of $K_m = \frac{1}{s}$ on Figure 2, we get,

$$\begin{aligned} Z'_{R_1} &= 1\text{ F} & Z'_{R_2} &= 1\text{ F} \\ Z'_{L_1} &= 0.7654\ \Omega & Z'_{L_2} &= 1.848\ \Omega \\ \text{(FDNR) } Z'_{C_1} &= 1.848 & \text{(FDNR) } Z'_{C_2} &= 0.7654 \end{aligned}$$

To realize first FDNR Z'_{C_1} we use $Z_1 = Z_2 = 1\ \Omega$, $Z_3 = Z_5 = 1$ F and $Z_4 = k\ \Omega$,

$$Z_{in} = Z'_{C_1} = \frac{1 \times \left(\frac{1}{s}\right) \times \left(\frac{1}{s}\right)}{1 \times k}$$
$$\frac{1}{1.848s^2} = \frac{1}{ks^2}$$
$$\therefore k = 1.848\ \Omega$$

To realize Second FDNR Z'_{C_2} we use $Z_1 = Z_2 = 1\ \Omega$, $Z_3 = Z_5 = 1$ F and $Z_4 = k\ \Omega$,

$$Z_{in} = Z'_{C_2} = \frac{1}{0.7654s^2} = \frac{1}{ks^2}$$
$$\therefore k = 0.7654\ \Omega$$

As per the question we require a halfpower frequency of 20000 rad/sec so, Frequency Scaling is calculated to K_f=2000.

Thus final value will be after Frequency scaling $K_f = 20000$ and Impedance Scaling $K_m = 1000$.

Component Symbol	**Normalized value**	**Final value after scaling**
Z'_{R_1}	$1\ F$	$50nF$
Z'_{R_2}	$1\ F$	$50nF$
Z'_{L_1}	0.7654Ω	$765\ \Omega$
Z'_{L_1}	$1.848\ \Omega$	$1.848\ K\Omega$

Table 1: Component Values of LPF excluding FDNR's

Component Symbol	**Normalized value**	**Final value after scaling**
Z_1	$1\ \Omega$	$1K\Omega$
Z_2	$1\ \Omega$	$1K\Omega$
Z_3	$1F$	$50\ nF$
Z_4	$1.848\ \Omega$	$1.848\ K\Omega$
Z_5	$1\ F$	$50nF$

Table 2: Component Values of First FDNR Z'_{C_1}

Component Symbol	Normalized value	Final value after scaling
Z_1	$1\,\Omega$	$1K\Omega$
Z_2	$1\,\Omega$	$1K\Omega$
Z_3	$1F$	$50\ nF$
Z_4	$0.7654\ \Omega$	$765\ K\Omega$
Z_5	$1\ F$	$50nF$

Table 3: Component Values of Second FDNR Z'_{C_2}

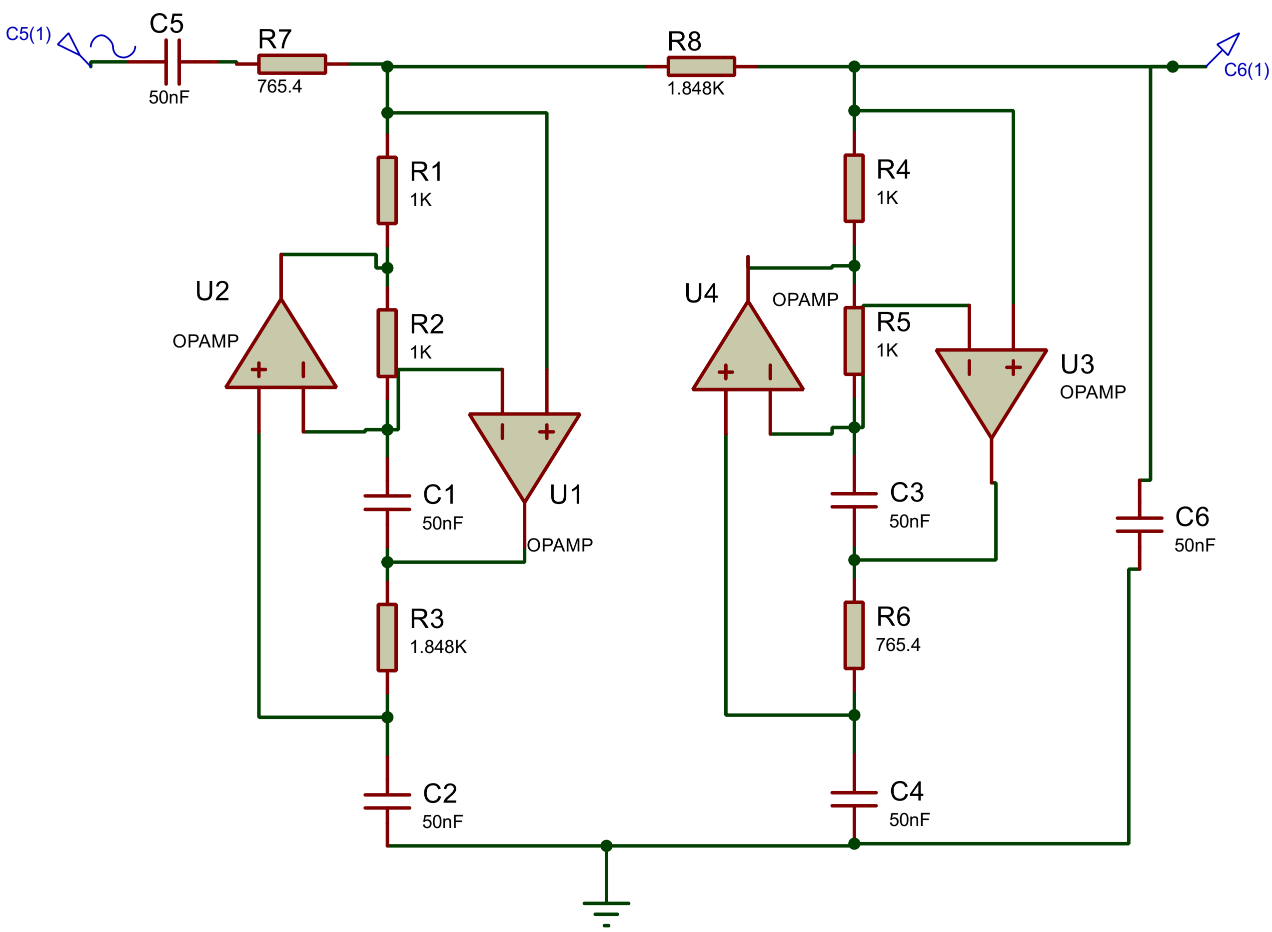
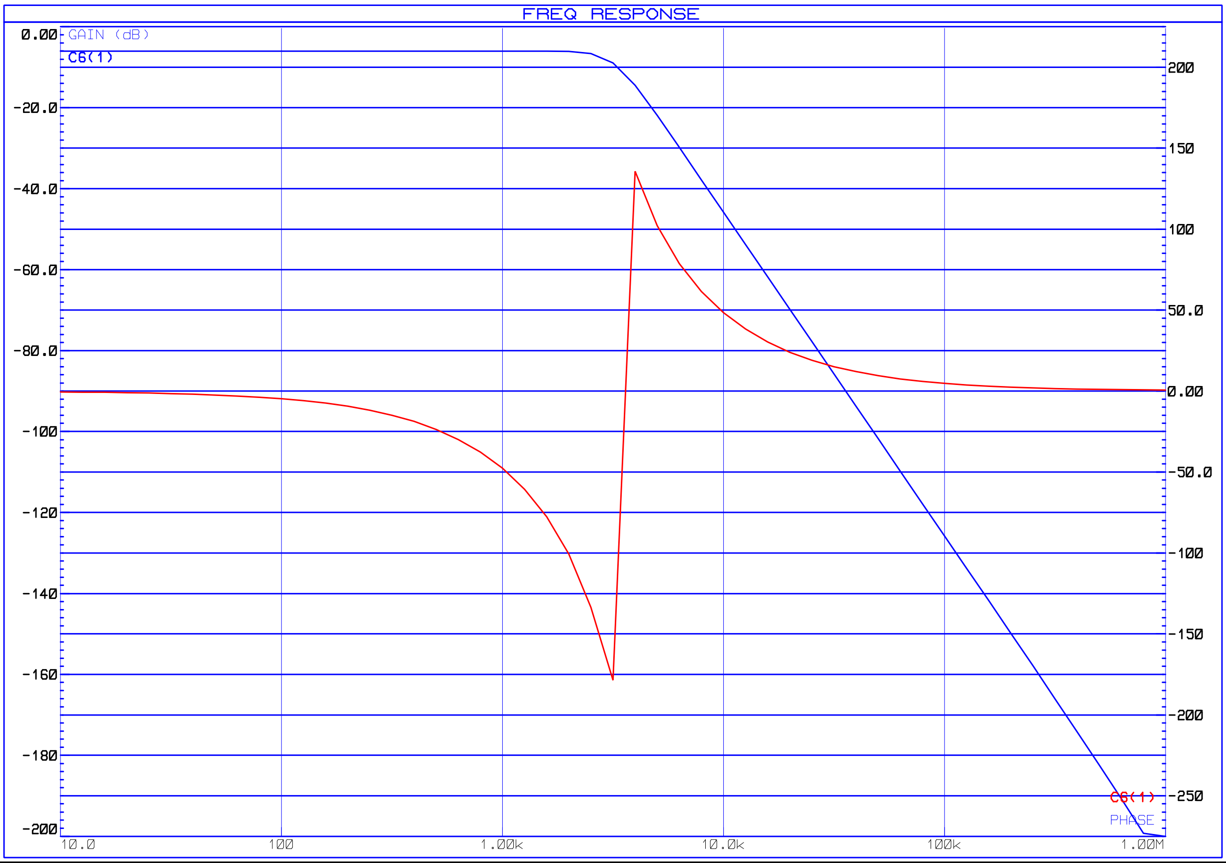


Figure 4: Proteus Circuit for low pass FDNR



Gain	**Half power frequency**
-6.02 dB	(3.1765) KHz

Figure 5: Proteus Observation for low pass FDNR

5.2 Question -2

Obtain a Highpass filter at normalized frequency of 1 rad/sec from the lowpass filter given in figure 1 using frequency transformation. From the circuit obtained, design a Highpass filter using simulated inductors. In your final design the half power frequency should be 4775 Hz and practically realizable elements. Realize the filter network. Also observe and analyze the magnitude response of the filter network.

Applying frequency transformation to get Highpass filter at normalized frequency of 1 rad/sec, we get,

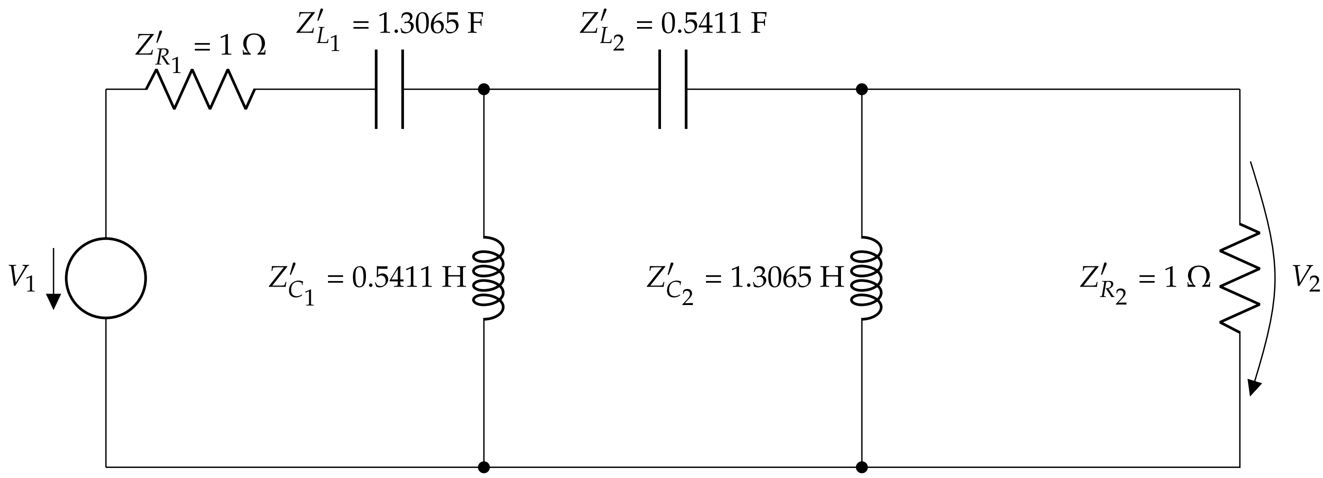


Figure 6: Fourth order Highpass ladder circuit at at normalized frequency of 1 rad/sec

To realize the inductor Z'_{C_1} we use $Z_1 = Z_2 = Z_3 = 1\ \Omega$, $Z_4 = 1$ F and $Z_5 = k\ \Omega$, we get,

$$Z_{in} = Z'_{C_1} = \frac{1 \times 1 \times k}{\left(\frac{1}{s}\right) \times 1}$$

$$\Rightarrow 0.5411s = s \times k$$

$$\therefore k = 0.5411\ \Omega$$

Similarly, for the inductor $Z'_{C_1} = 1.3605\Omega$ we get $K = Z_5 = 1.3605\Omega$.As we require the highpass filter having frequency of 4775 Hz, a frequency scaling factor of $K_f = \frac{2\pi \times 4775}{1} \approx 3 * 10^4$ is used and a magnitude scaling factor of $K_m = 10^3$ is used. Hence a final value obtained will be after Frequency and Magnitude scaling,

Component Symbol	**Normalized value**	**Final value after scaling**
Z'_{R_1}	$1\ \Omega$	$1\ K\Omega$
Z'_{R_2}	$1\ \Omega$	$1\ K\Omega$
Z'_{L_1}	0.1.3065 F	45.35 nF
Z'_{L_1}	0.5411 F	18.04 nF

Table 4: Component Values of HPF excluding FDNR's

Component Symbol	**Normalized value**	**Final value after scaling**
Z_1	$1\ \Omega$	$1K\Omega$
Z_2	$1\ \Omega$	$1K\Omega$
Z_3	$1\ \Omega$	$1K\Omega$
Z_4	1 F	33.33 nF
Z_5	$0.5411\ \Omega$	$541\ \Omega$

Table 5: Component Values of simulated inductor Z'_{C_1}

Component Symbol	**Normalized value**	**Final value after scaling**
Z_1	$1\ \Omega$	$1K\Omega$
Z_2	$1\ \Omega$	$1K\Omega$
Z_3	$1\ \Omega$	$1K\Omega$
Z_4	1 F	33.33 nF
Z_5	$1.3605\ \Omega$	$1.36\ K\Omega$

Table 6: Component Values of simulated inductor Z'_{C_2}

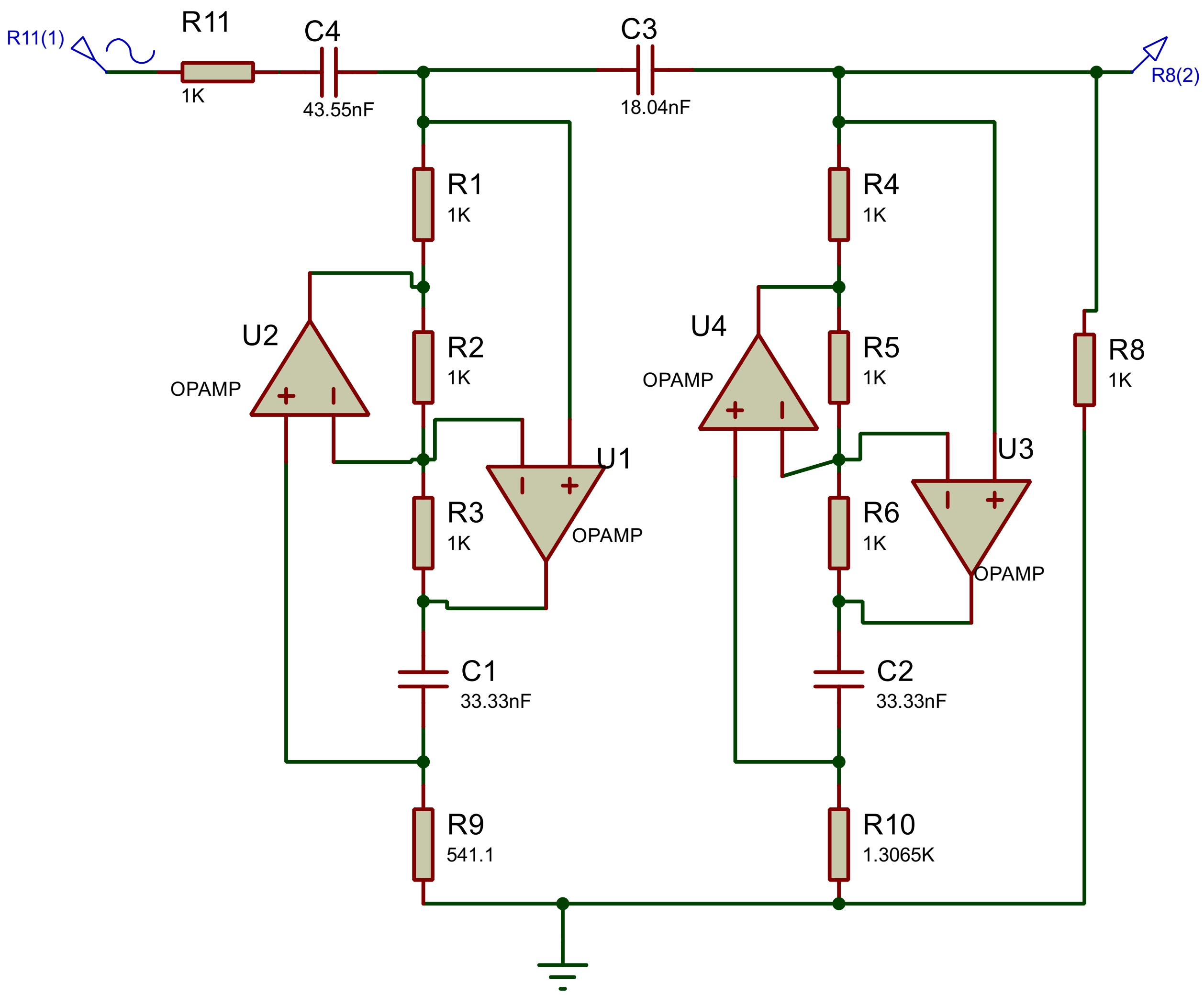
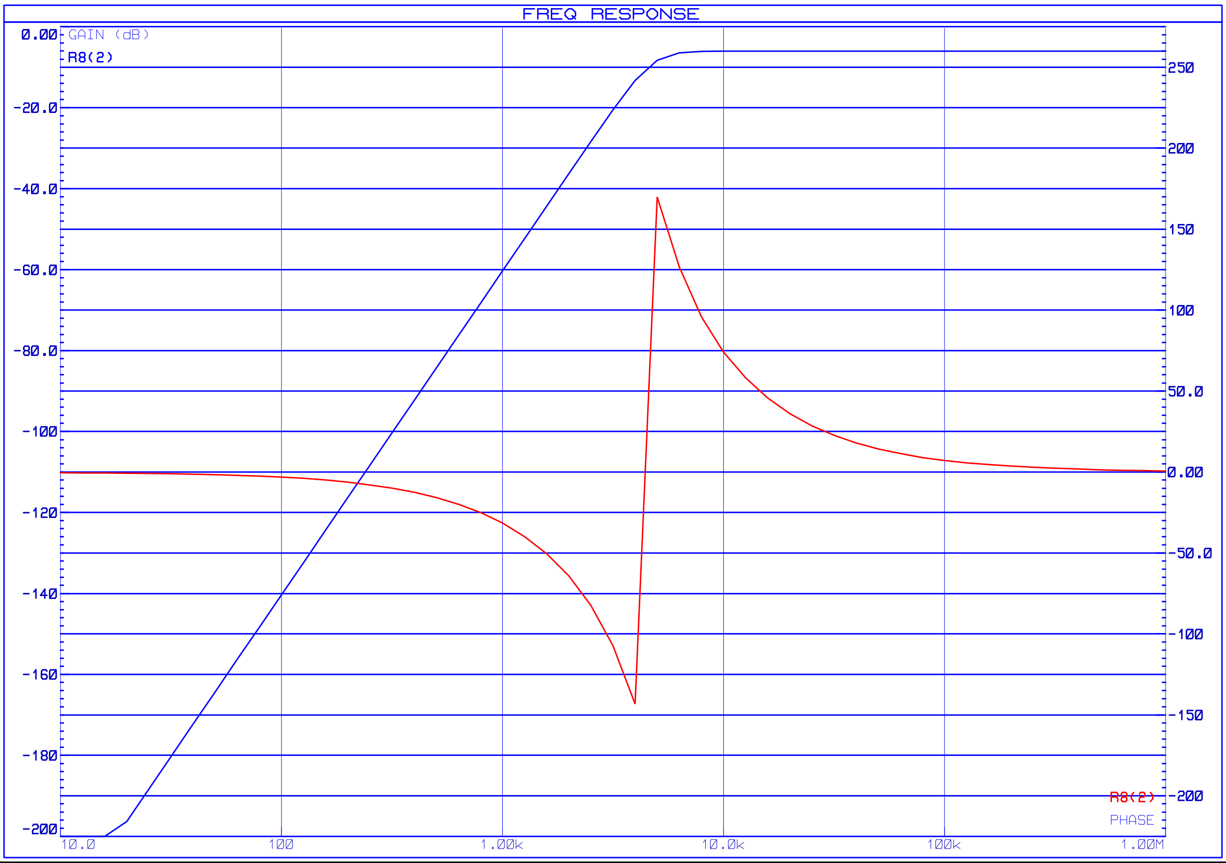


Figure 7: Proteus Circuit for high pass simulated inductor



Gain	Half power frequency
-6.02 dB	(4.857) KHz

Figure 8: Proteus Observation for high pass simulated inductor

5.3 Question -3

From the circuit given in figure 1, design a lowpass passive filter having half power frequency of 40000 rad/sec with practically suitable elements, using Leapfrog simulation. Realize the filter network and observe the magnitude response of the network.

We can represent the figure 2 as,

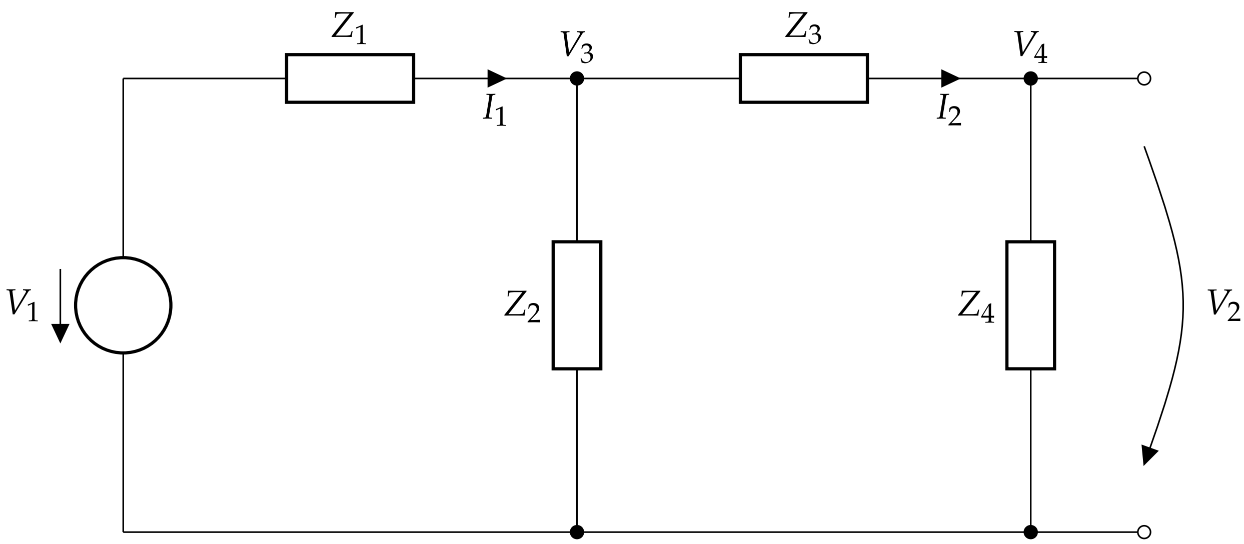


Figure 9: Block diagram representation of the fourth order Butterworth lowpass filter

Applying voltage and nodal analysis for Figure 9 , we get,

$$I_1 = \frac{V_1 - V_3}{Z_1} = T_1(V_1 - V_3)$$
$$V_3 = Z_2(I_1 - I_2) = T_2(I_1 - I_2)$$
$$I_2 = \frac{V_3 - V_4}{Z_3} = T_3(V_3 - V_4)$$
$$V_4 = Z_4 I_2 = T_4 I_2$$

Where,

$$T_1 = \frac{1}{Z_1} = \frac{1}{1 + 0.7654s}$$
$$T_2 = Z_2 = \frac{1}{1.848s}$$
$$T_3 = \frac{1}{Z_3} = \frac{1}{1.848s}$$
$$T_4 = Z_4 = \frac{1}{1 + 0.7654s}$$

Let $V_{I1} = I_1$ and $V_{I2} = I_2$ and rearranging the signs we get,

$$V_{I1} = -(-T_1)(V_1 - V_3) \tag{2}$$

$$-V_3 = -T_2(V_{I1} - V_{I2}) \tag{3}$$

$$-V_{I2} = -(-T_3)(V_4 - V_3) \tag{4}$$

$$V_4 = (-T_4)(-V_{I2}) \tag{5}$$

Above equation can be represented in block Diagram as,

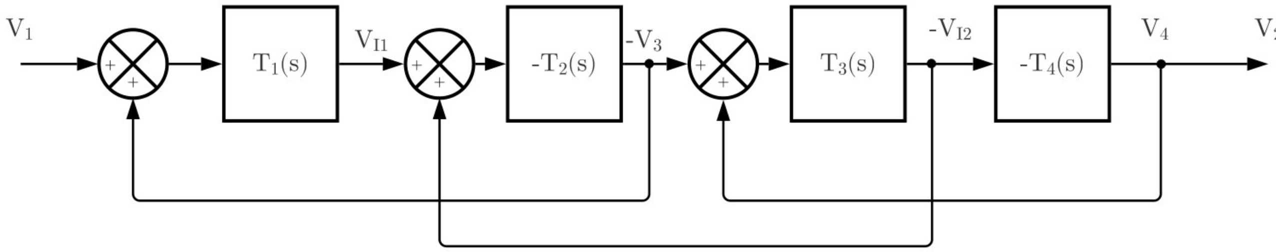


Figure 10: Block diagram representation of circuit equations

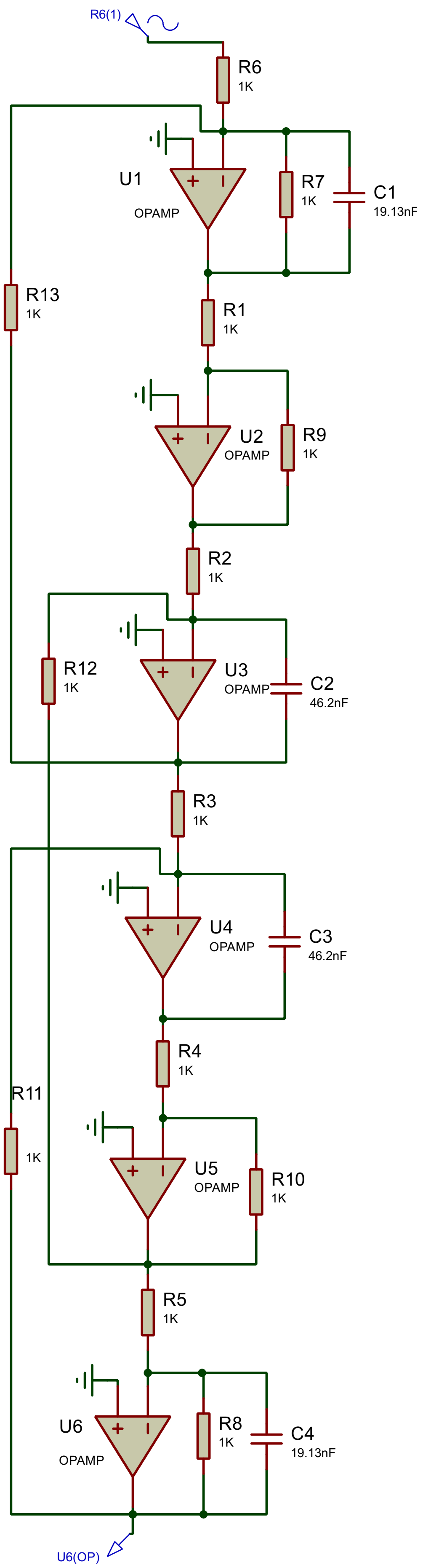
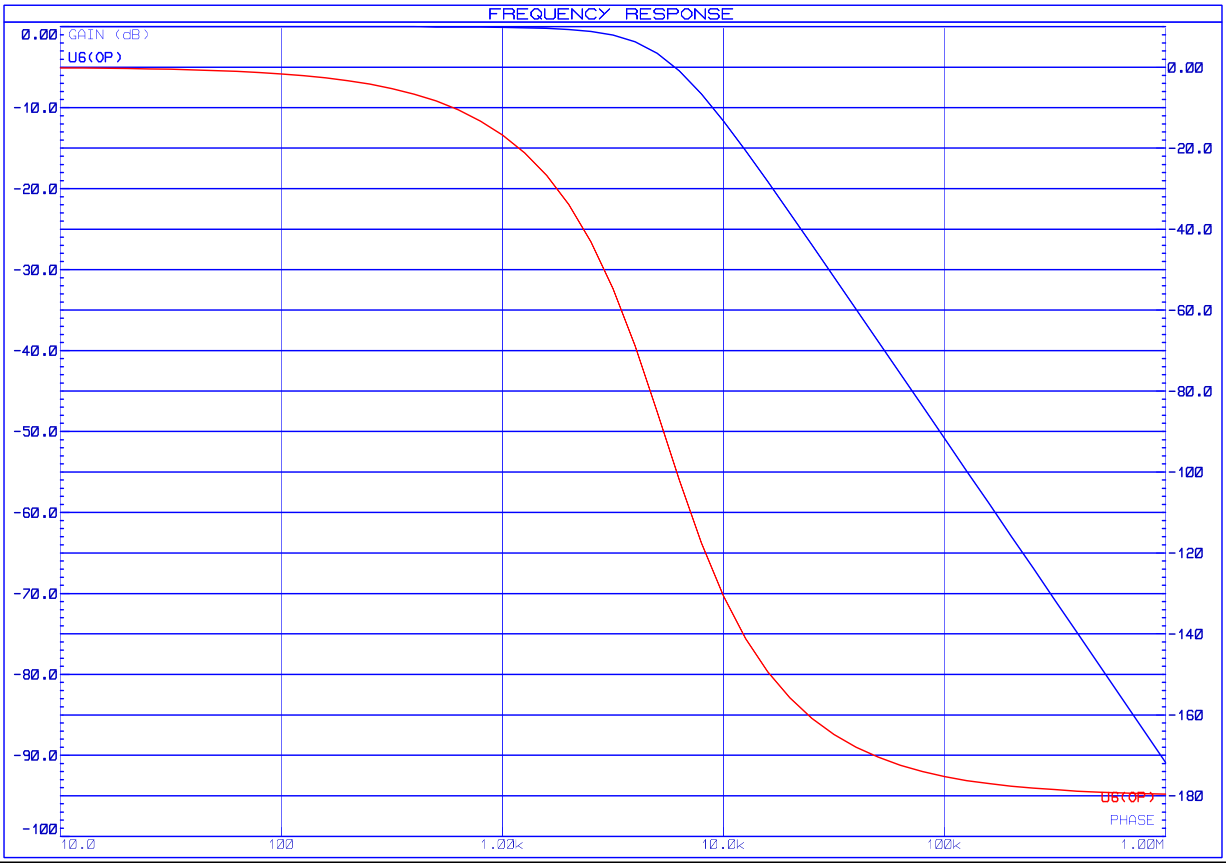


Figure 11: Proteus Circuit for low pass Leapfrog



Gain	Half power frequency
0 dB	(4.807) KHz

Figure 12: Proteus Observation for low pass leapfrog

6 Discussion and Conclusion

In this lab we designed the higher order filter using Active simulation of passive circuit. We used simulated inductors, FDNR and Leapfrog Simulation to design the filter. GIC is extensively used in above discussed methods. We also simulated the circuits designed using these methods and observe its magnitude hence fulfilling our Lab objective.