EE 230: Analog Circuits Lab
Lab No. 12 - 13
ECG Amplifier

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April 12, 2024

A. Homework

1.(a) 2nd Order Low Pass Filter

1.(a).1 Aim of the experiment

The experiment aims to realise a 2nd Order Low Pass Filter.

1.(a).2 Design

1.(a).2.0 Required Specifications

We need to implement a low pass filter for a DC-gain around 28 dB with 150 Hz of 3-dB cut-off frequency.

1.(a).2.1 Equations

The transfer function from V_{in} to V_b of the ideal opamp is given by,

$$\frac{V_b}{V_{in}} = \frac{-A}{1 + s\tau_1} \tag{1}$$

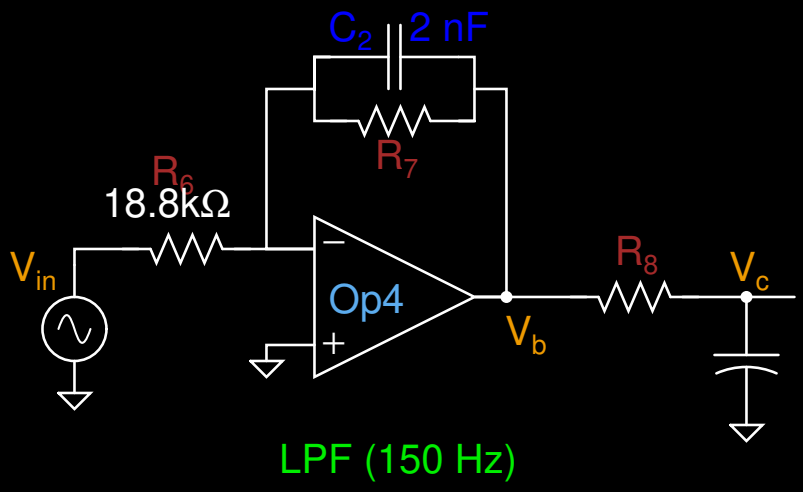
where **A** is the DC Gain of the inverting Amplifier and τ_1 is the time constant of the transfer function from V_{in} to V_b.

The transfer function from V_{in} to V_c is,

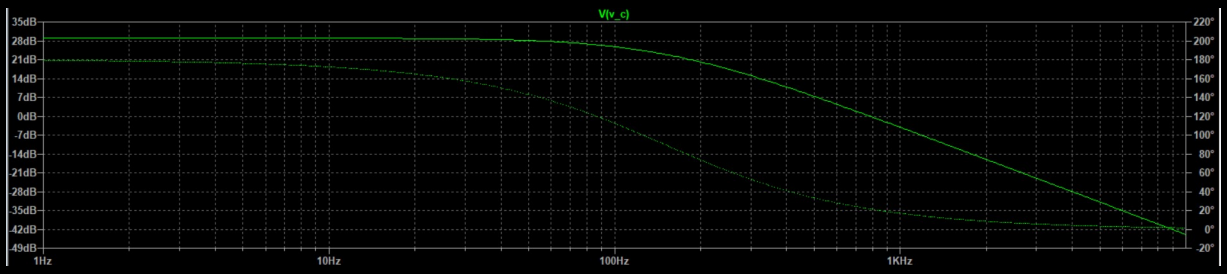
$$\frac{V_c}{V_{in}} = \frac{-A}{1+s\tau_1} \cdot \frac{1}{1+s\tau_1} \tag{2}$$

There are two poles located at $\frac{1}{\tau_1}$ and at $\frac{1}{\tau_2}$

1.(a).2.2 Circuit Design



1.(a).3 Simulation Results



1.(a).4 Experimental Results

We need a 28dB gain, $20 \cdot \log\left(\frac{R_7}{R_6}\right) = 28$
$R_7 = R_6 \cdot 25.12$

To satisy the 3dB cutoff frequency, we need to have $R_7 \cdot C_2 = R_8 \cdot C_3$, $C_2 =$ 2nF and $C_3 = 1$nF
$2_7 = R_8$
$f_c = \frac{1}{2 \cdot \pi R_8 \cdot C_3} = 150$Hz
$R_8 = 1.061M\Omega, R_7 = 0.531M\Omega$
At 3dB cutoff frequency, $R_8 = 681.49k\Omega, R_7 = 340.746k\Omega and R_6 = 13.56k\Omega$
We get, $f_{cutoff(simulated)} = 130$kHz and $A_{dc} = 28.02$dB.

1.(a).5 Experiment Completion Status

The homework was completed well in time.

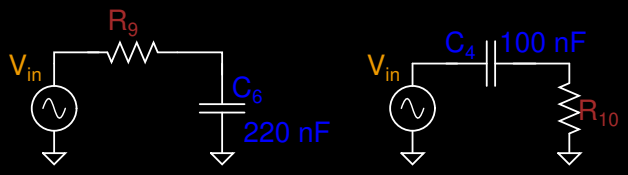
1.(b) Notch Filter

1.(b).1 Aim of the experiment

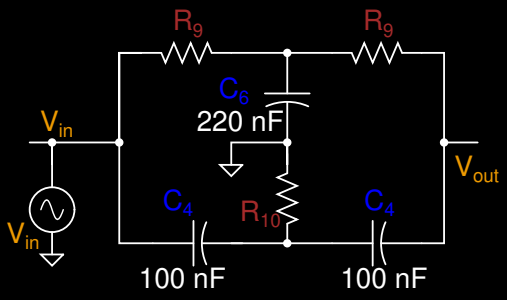
The experiment aims to implement Notch Filter

1.(b).2 Design

1.(b).2.1 Circuit Design

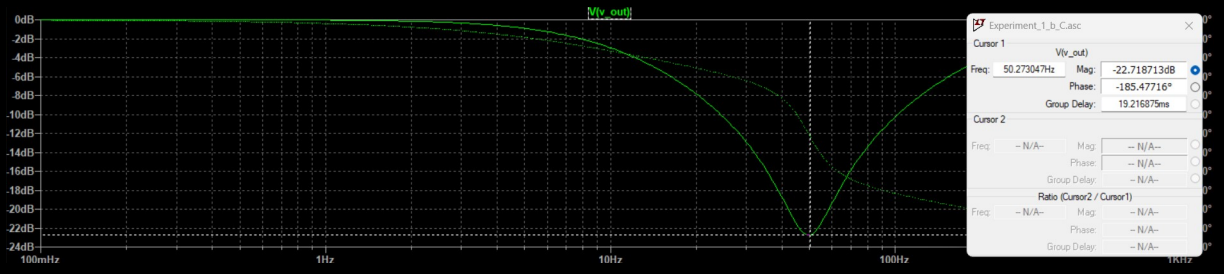


LPF & HPF for Notch Filter



Notch Filter 50 Hz

1.(b).3 Simulation Results



1.(b).4 Experimental Results

1.(b).4.A LPF (Low Pass Filter):- We get $R_9 = 72.34k\Omega$, $f_{L(theoretical)} = 10$Hz and $f_{L(simulation)} = 10.01$Hz at (-3dB)
1.(b).4.A HPF (High Pass Filter):- We get $R_10 = 17.683k\Omega$, $f_{L(theoretical)} = 90$Hz and $f_{L(simulation)} = 90.02$Hz at (-3dB)
1.(b).4.C Notch Filter:- We get $f_{N(simulated)} = 50$Hz (after taking $R_9 = 39k\Omega$ and $R_10 = 9k\Omega$.

1.(b).5 Experiment Completion Status

The homework was completed well in time.

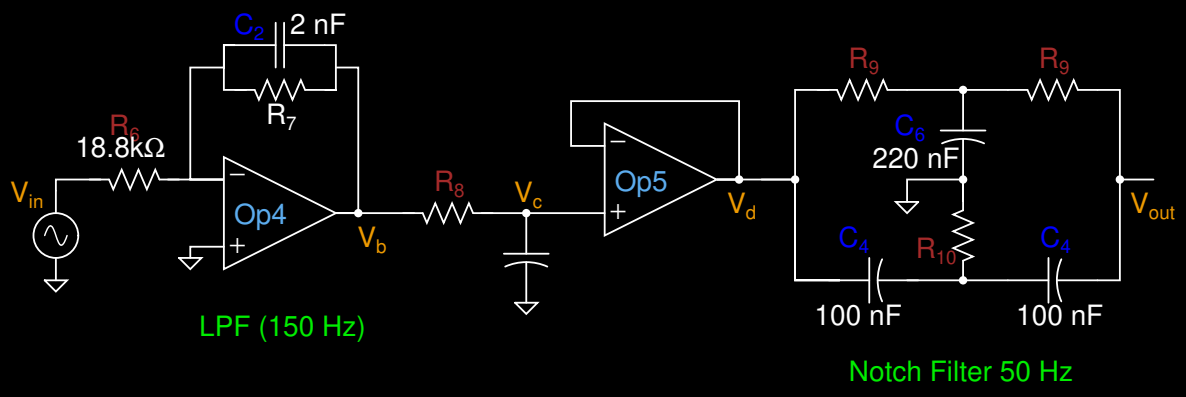
1.(c) Combined 2nd Order Low Pass Filter and Notch Filter Response

1.(c).1 Aim of the experiment

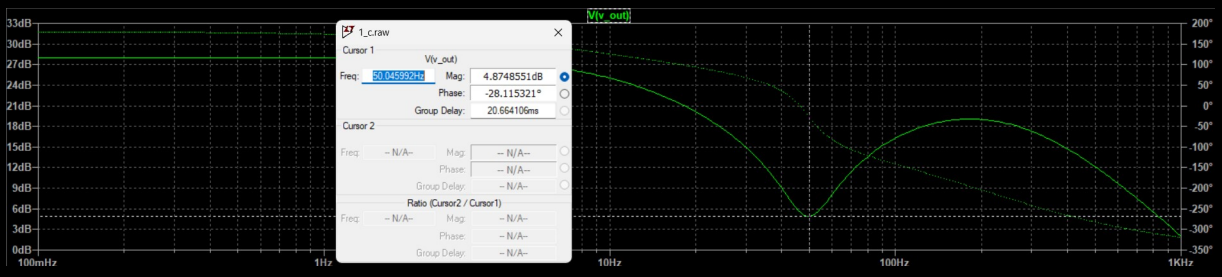
The experiment aims to implement a Low Pass Filter and Notch Filter in a combined circuit.

1.(c).2 Design

1.(c).2.1 Circuit Design



1.(c).3 Simulation Results



1.(c).4 Experimental Results

We get a notch filter which filters out values at 50Hz frequency.

1.(c).5 Experiment Completion Status

The homework was completed well in time.

B. Experimentation

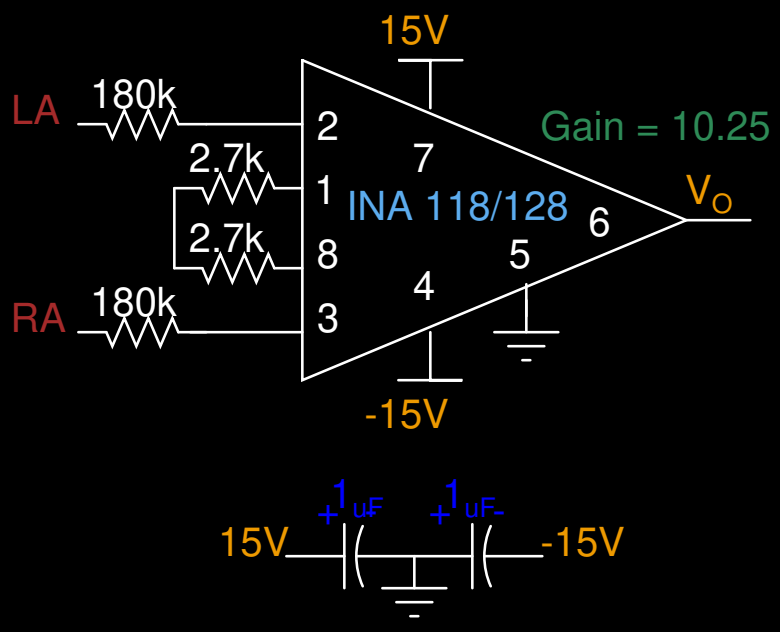
1. ECG Amplifier

1.(a) Instrumentation Amplifier (INA)

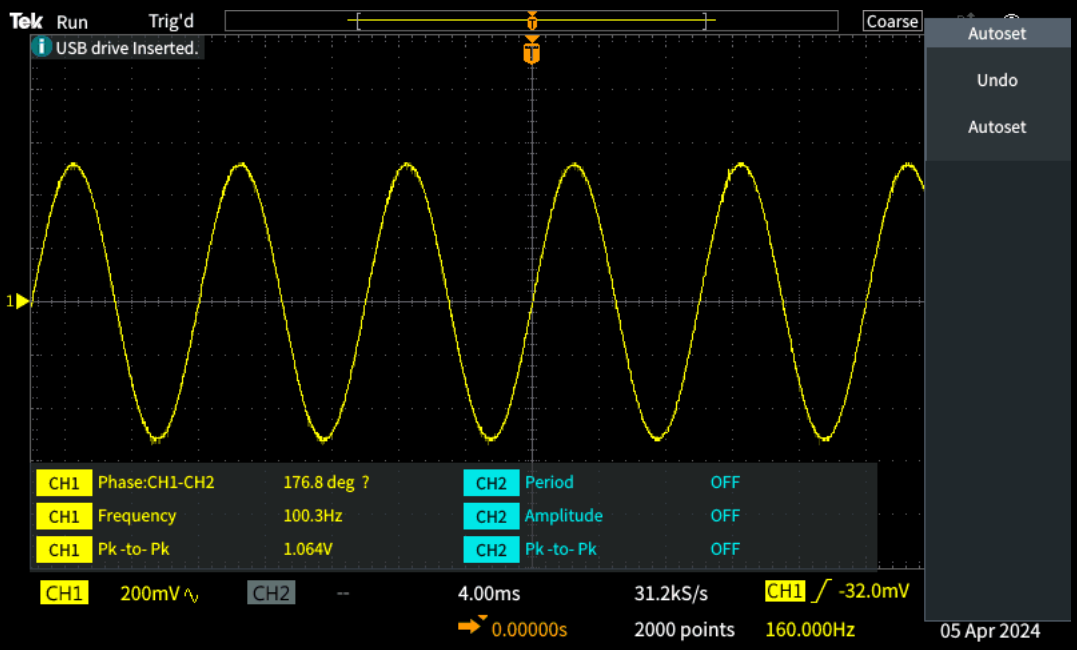
1.(a).1 Aim of the experiment

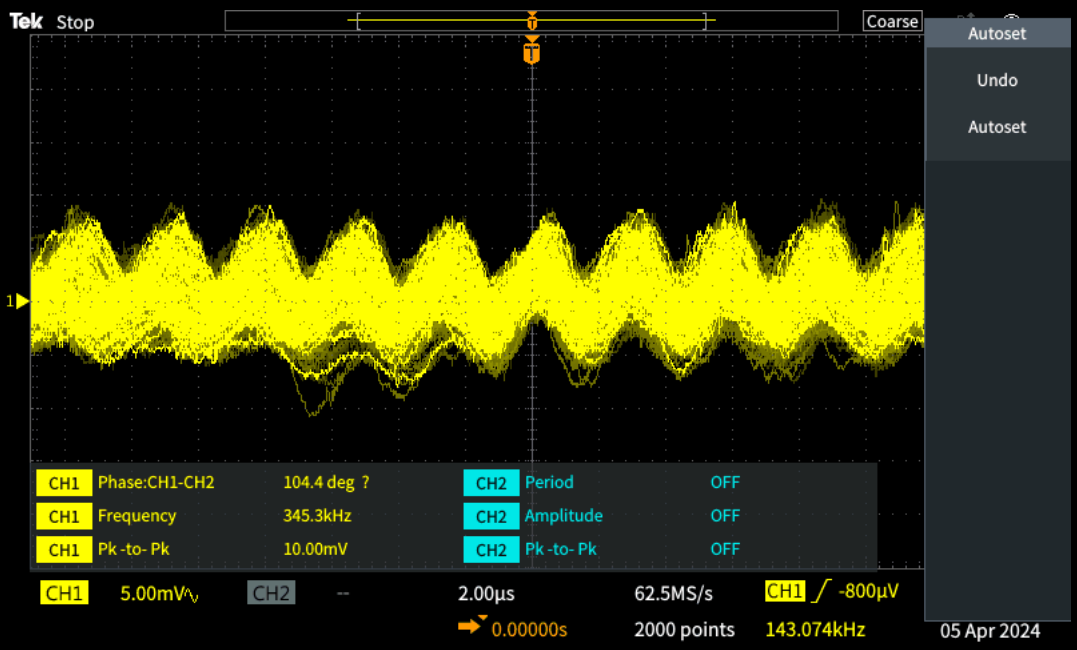
The experiment aims to design an instrumentation amplifier, which helps to identify even the minutest signals and amplify them.

1.(a).2 Design



1.(a).3 Simulation Results:





1.(a).4 Experiment Results

Gain of an Instrumentation Amplifier is given by $1 + 50/R_G$, where R_G is in $k\Omega$. Hence gain in our case becomes 10.25 times.

A. Differential Gain:

Inputs at the input nodes are - LA is grounded and RA is supplied a $100mV_{pp}$, 100 Hz. The expected output should be $1.025V_{pp}$ because of ideal gain of 10.25. For us the gain was *10.63* and the output at V_o is $1.063V_{pp}$ at 100.3 Hz.

B. Common Mode Gain:

We get a noise of approximately 3mV.

1.(a).5 Experiment completion status

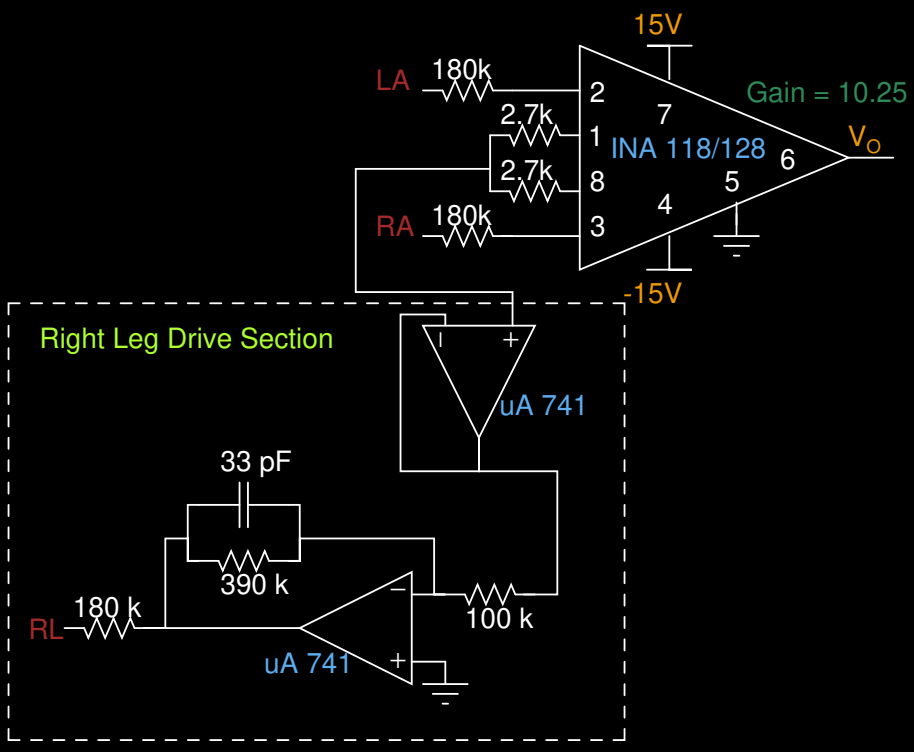
This experiment was completed within the lab itself in its entirety.

1.(b) Right Leg Drive

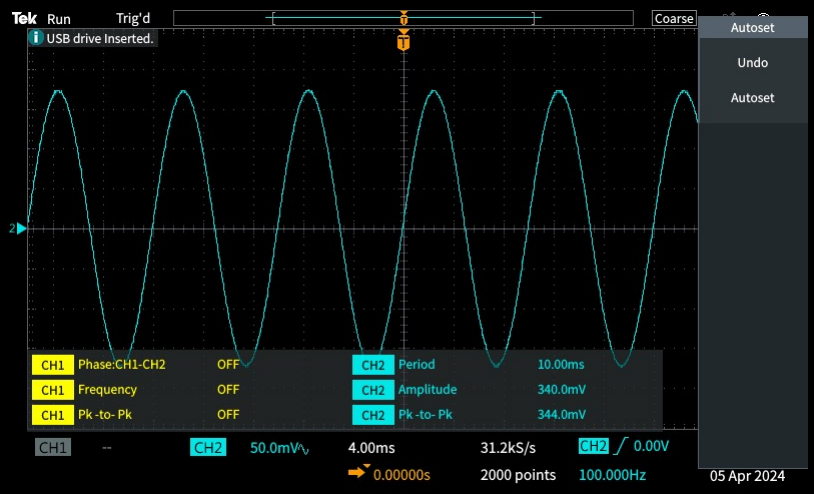
1.(b).1 Aim of the experiment

The aim of this experiment is to design, simulate, and implement the Right Leg Drive part of an ECG which is used to minimize the common mode interference.

1.(b).2 Design



1.(b).3 Simulation Results:



1.(b).4 Experiment Results

For the inputs on LA & RA being 100 mV_{pp} at 100Hz each, the value at output RL is 340 mv_{pp}, leaving us with a gain of about 3.4

1.(b).5 Experiment completion status

This experiment was completed entirely in the lab.

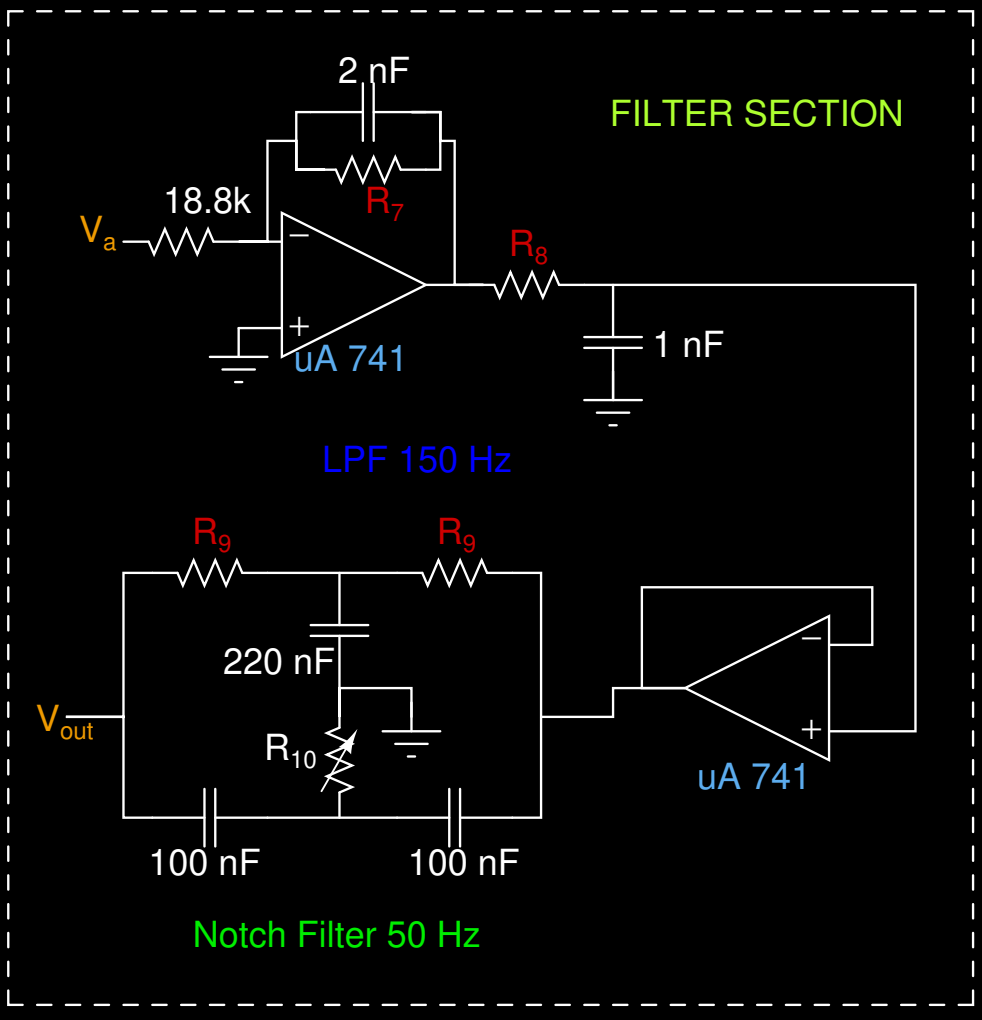
1.(c) Filter Section:

1.(c).1 Aim of the experiment

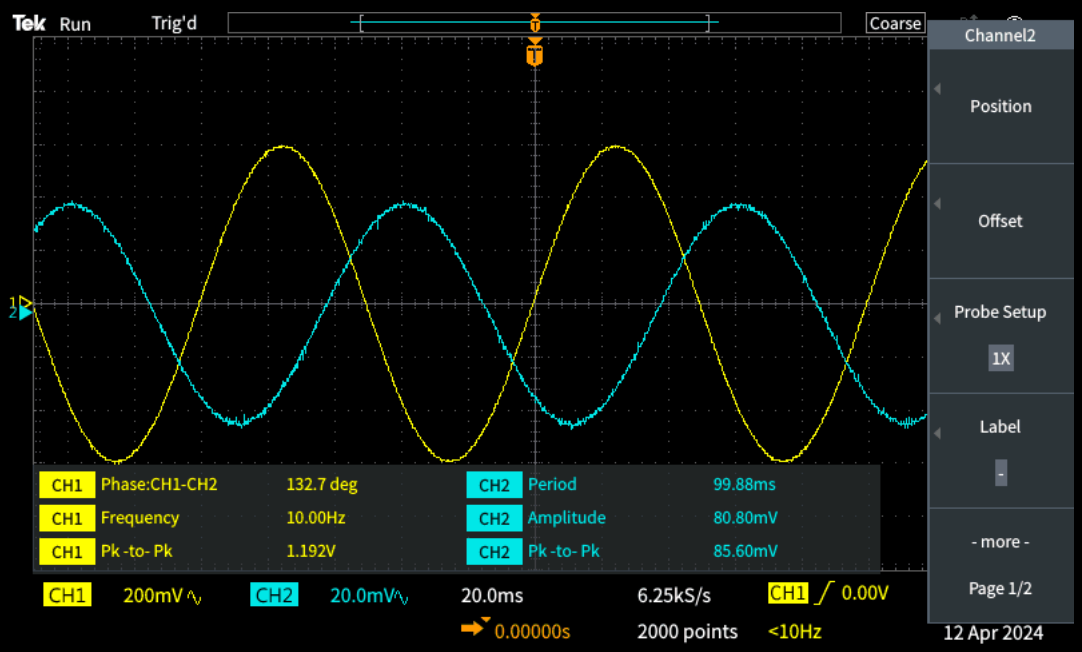
The experiment aims to implement the filter section.

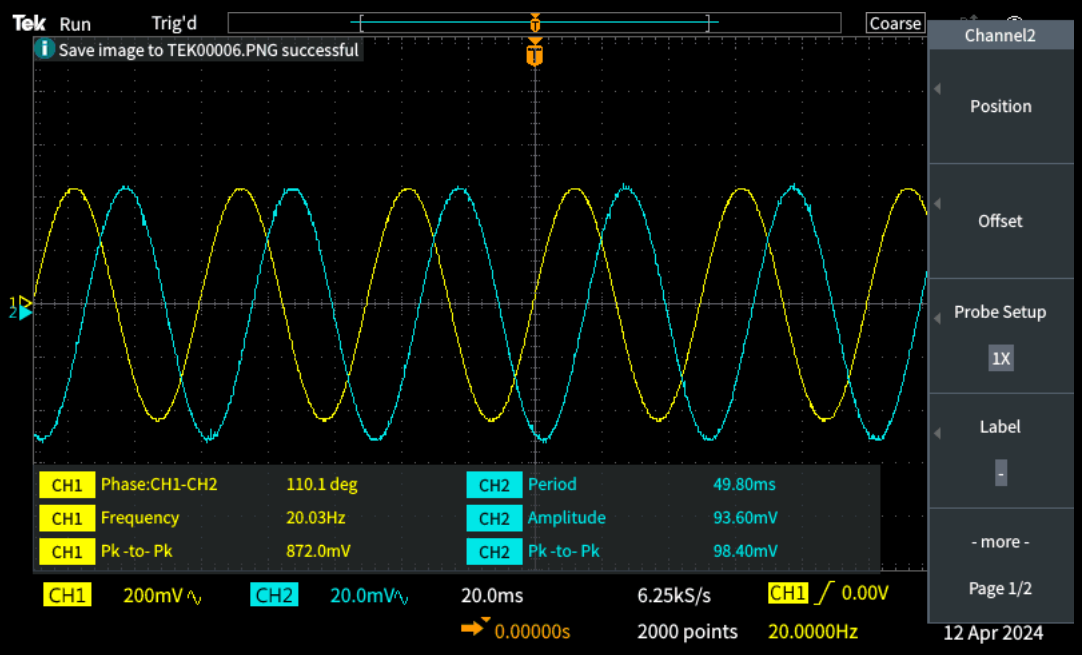
1.(c).2 Design:

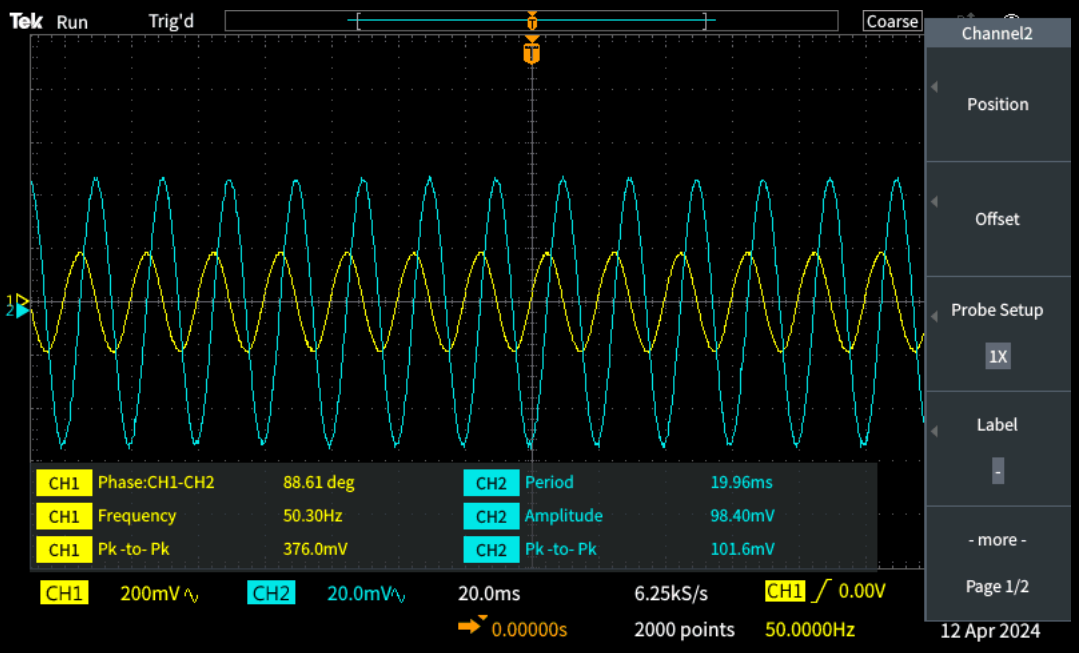
1.(c).2.1 Circuit Design:

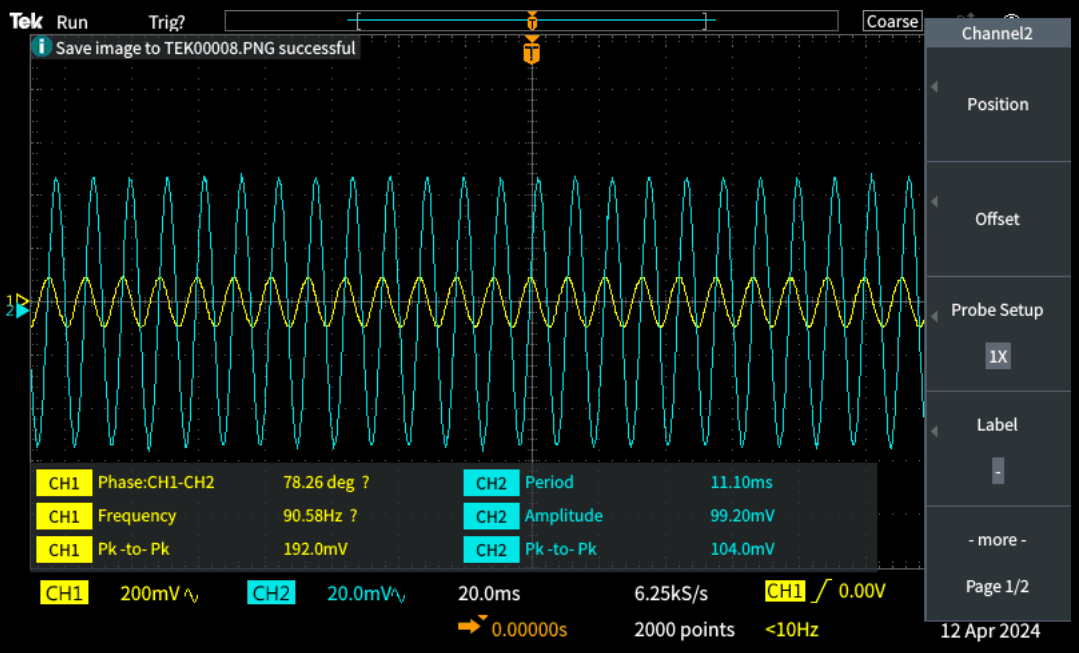


1.(c).3 Simulation Results:



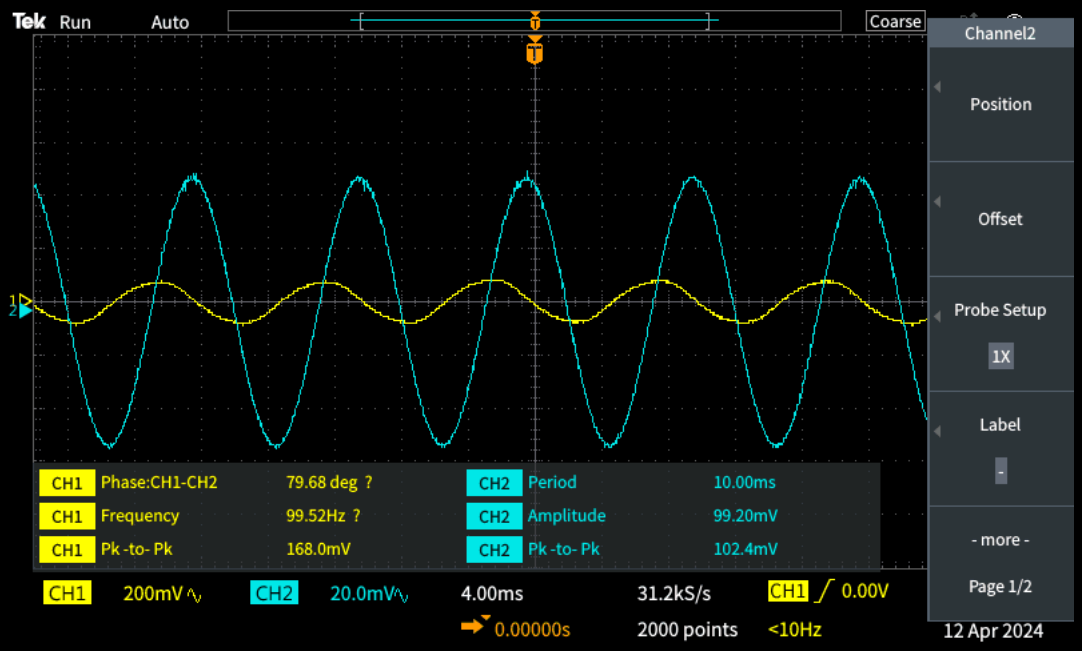






1.(c).4 Experimental Results:

The values of resistances that we calculated that worked in the simulation don't seem to work so nicely in actual circuits. Hence we had to tweak a



lot of values and we arrived at the final conclusion that taking the $R_7 = 380k\Omega, R_8 = 420k\Omega, R_9 = 33k\Omega and R_10 = 12k\Omega$ leads to a perfect notch filter.
The filter when supplied with $V_a = 1V_{pp}$, attenuates the signal at 50Hz, to approximately one third of its value and allows other signals from 10Hz to 150Hz to pass through.

1.(c).5 Conclusion and Inferences:

Since, we obtain the V_{out} and V_{in1} to be completely in sync in all terms, we can conclude that this is a unity gain amplifier.

1.(c).6 Experiment Completion Status:

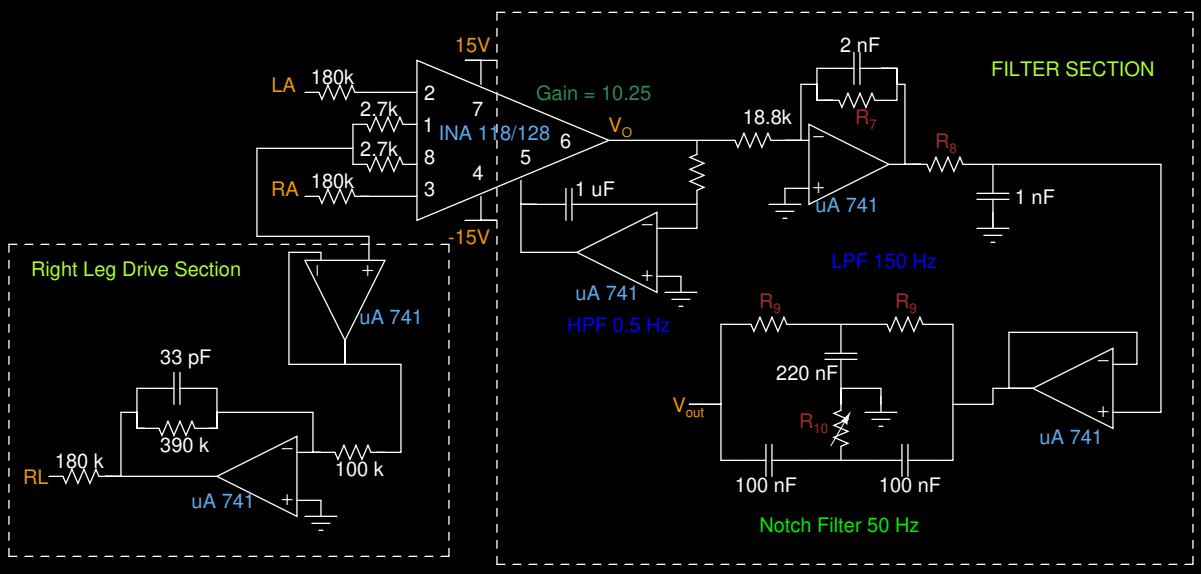
This experiment was completed within the lab itself in its entirety.

2 ECG:

2.1 Aim of the experiment

The experiment aims to combine the Instrumentation Amplifier (INA), Right Leg Drive and Notch Filter together to implement a food fledged ECG.

2.2 Design:



2.3 Simulation Results:

2.4 Experimental Results:

We get a perfect ECG wave highlighting all the P-Q-R-S-T segments of an ECG wave.

2.5 Experiment Completion Status:

This experiment was completed within the lab itself in its entirety.