EE230: Analog Circuits Lab
ECG PROJECT

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Contents

ECG Signal Acquisition and Amplifier Design

1 Aim of the Experiment

To design, simulate and analyze an ECG amplifier system using operational amplifiers and passive components. The setup includes multiple stages: a high-pass filter to remove baseline drift, a notch filter to eliminate power-line interference at 50 Hz, and a low-pass filter to remove high-frequency noise. This ensures proper signal conditioning for low-amplitude ECG signals.

2 Theory

An Electrocardiogram (ECG) records the electrical activity of the heart over time. The signal captured from the skin surface is in the range of 0.5 to 5 mV and is susceptible to various types of noise and interference. To process this weak signal, an amplifier with proper filtering stages is essential. The major goals of the filtering circuit are:

- **High-pass filtering:** To remove DC offset and baseline wandering typically caused by respiration and electrode movement.
- **Notch filtering:** To eliminate 50 Hz power line interference that is superimposed on the ECG signal.
- **Low-pass filtering:** To attenuate muscle noise and other high-frequency artifacts.

The filters are implemented using passive RC circuits for simplicity and reliability.

3 Circuit Description

The ECG amplifier system comprises three stages:

- **High-Pass Filter:** Cutoff frequency set at 0.5 Hz using an RC network.
- **Notch Filter:** A twin-T network centered at 50 Hz for power line rejection.
- **Low-Pass Filter:** Cutoff frequency set at 150 Hz to preserve the bandwidth of interest.

These stages are cascaded to progressively clean the signal while preserving its integrity for further amplification or digitization.

3.1 Circuit Design and Parameters

Overview

The ECG amplifier system comprises three primary sections:

- Instrumentation Amplifier (INA)
- Right Leg Drive (RLD)
- Filter Section (Low-pass, Notch)

Instrumentation Amplifier (INA)

- INA: INA118/128
- Gain: $G = 10.25$
- Input: RA and LA
- Power Supply: $\pm 15\,V$

Right Leg Drive (RLD)

- Op-amp: uA741
- Feedback: 100kΩ, 390kΩ, 33pF
- Output: RL node

Filter Section

- Low Pass Filter (LPF): Cut-off at 150 Hz
- Notch Filter: Centered at 50 Hz
- Resistors: $R_7 = 472.256\,k\Omega$, $R_8 = 361.075\,k\Omega$, $R_9 = 28.937\,k\Omega$, $R_{10} = 18.734\,k\Omega$ variable
- Capacitors: $C_1 = 2\,nF$, $C_2 = 100\,nF$, $C_3 = 220\,nF$, $C_4 = 1\,nF$

3.2 Theoretical Background

Instrumentation Amplifier

An INA provides differential gain while rejecting common-mode signals. Gain is set using precision resistors.

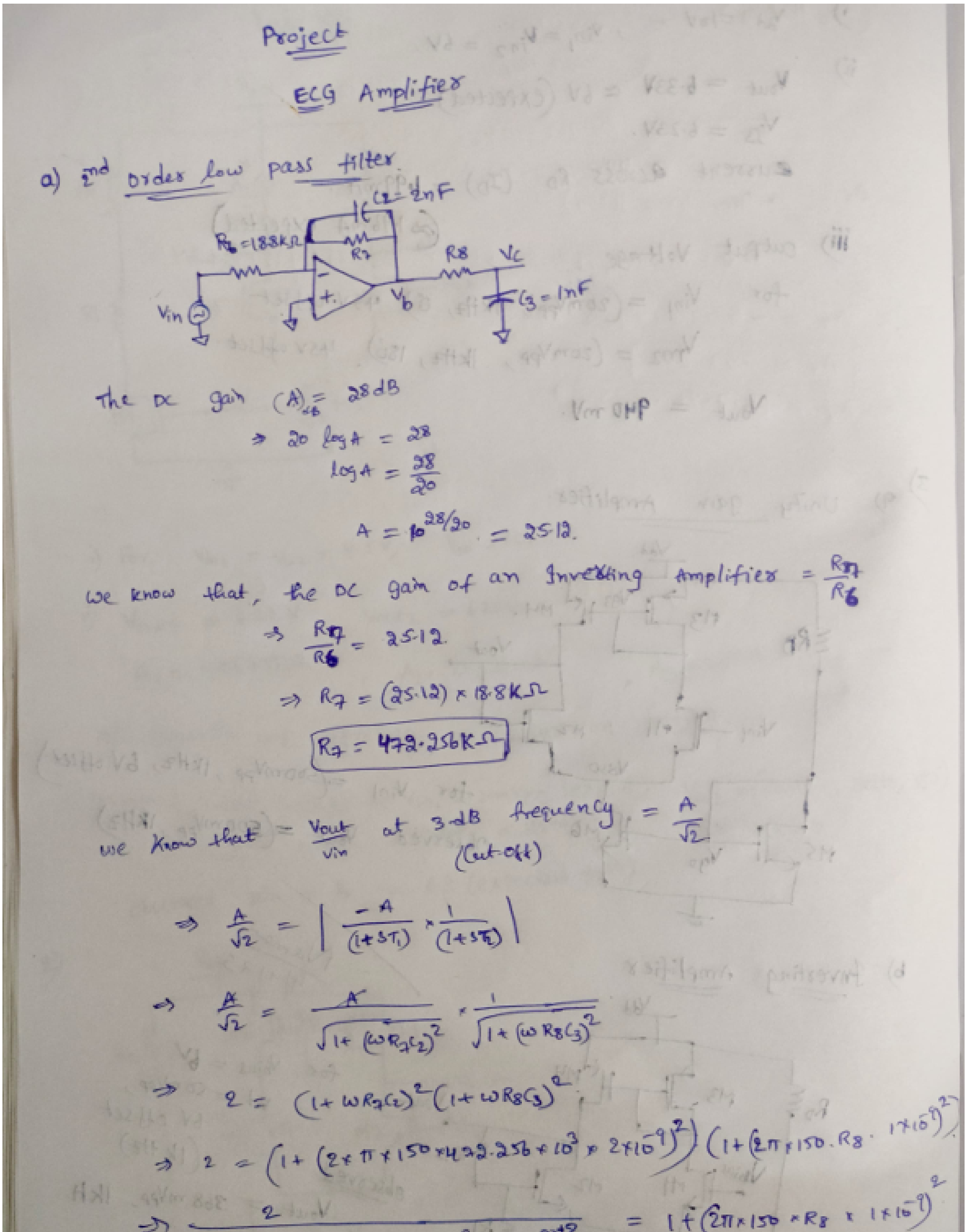
Right Leg Drive

This feedback configuration reduces common-mode voltage on the body, improving CMRR and reducing interference.

Filter Design

- LPF helps attenuate noise above 150 Hz.
- Notch filter targets 50 Hz mains noise.

4 Hand Calculations



Project

ECG Amplifier

a) 2nd order low pass filter

The DC gain $(A)_{dB} = 28\,dB$

$\Rightarrow 20 \log A = 28$

$\log A = \frac{28}{20}$

$A = 10^{28/20} = 25.12$

We know that, the DC gain of an Inverting Amplifier $= \frac{R_7}{R_6}$

$\Rightarrow \frac{R_7}{R_6} = 25.12$

$\Rightarrow R_7 = (25.12) \times 18.8\,k\Omega$

$\boxed{R_7 = 472.256\,k\Omega}$

We know that $\frac{V_{out}}{V_{in}}$ at 3-dB frequency (Cut-off) $= \frac{A}{\sqrt{2}}$

$$\Rightarrow \frac{A}{\sqrt{2}} = \left| \frac{-A}{(1+sT_1)} \times \frac{1}{(1+sT_2)} \right|$$

$$\Rightarrow \frac{A}{\sqrt{2}} = \frac{A}{\sqrt{1+(\omega R_7 C_2)^2}} \times \frac{1}{\sqrt{1+(\omega R_8 C_3)^2}}$$

$$\Rightarrow 2 = (1+\omega R_7 C_2)^2 (1+\omega R_8 C_3)^2$$

$$\Rightarrow 2 = \left(1+(2\times\pi\times150\times472.256\times10^3\times2\times10^{-9})^2\right)\left(1+(2\pi\times150 . R_8 . 1\times10^{-9})^2\right)$$

$$\Rightarrow \frac{2}{1+(2\pi\times150\times472.256\times10^3\times2\times10^{-9})^2} = 1+(2\pi\times150\times R_8\times1\times10^{-9})^2$$

$$\Rightarrow 1.1158078813236 = 1 + (300\pi \times R_8 \times 10^{-9})^2$$

Figure 1: Calculations - 1

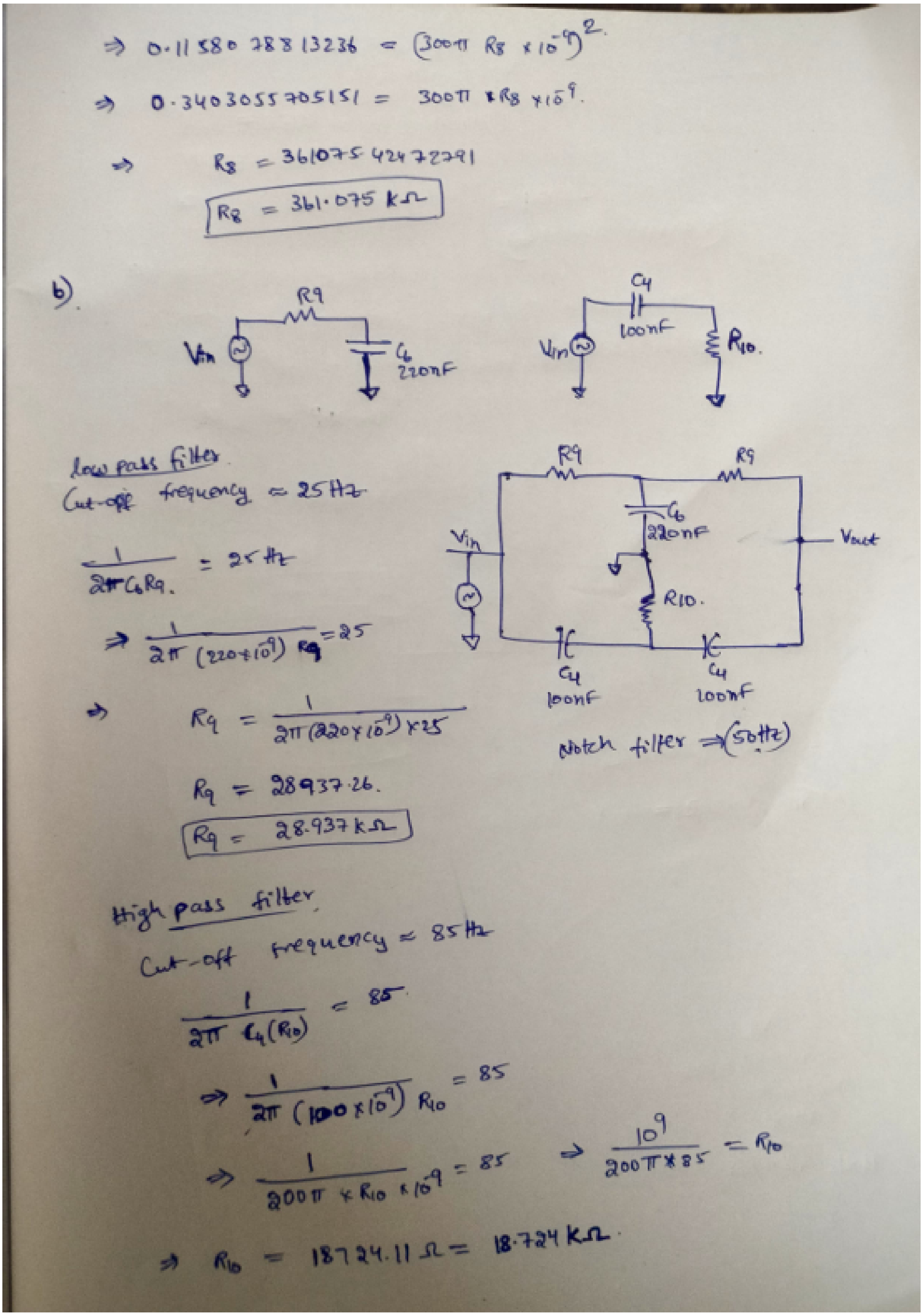


Figure 2: Calculations - 2

5 LTSpice Simulations

To verify the performance of each filter stage, LTSpice was used to simulate the circuits. Below are the key results:

5.1 High-Pass Filter Response

- Simulated with a 1 Hz input sine wave.
- Output showed correct attenuation below 0.5 Hz.
- 0.1 Hz signal was significantly attenuated.

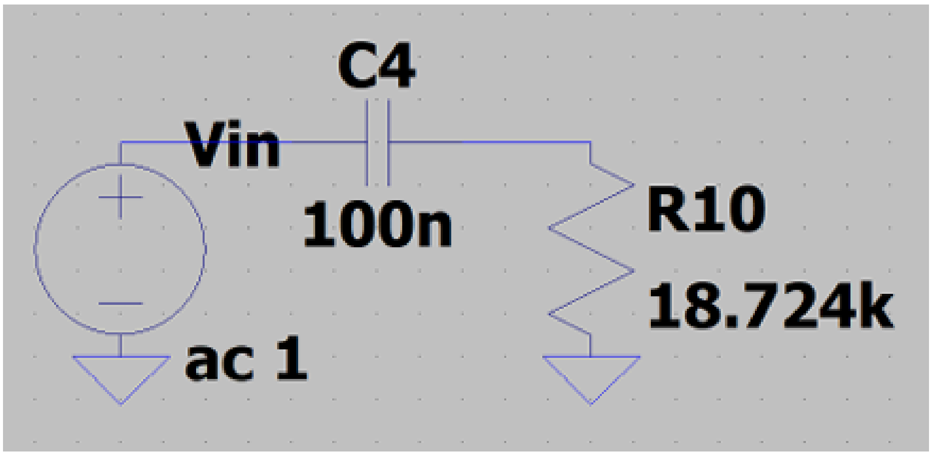


Figure 3: High-Pass Filter Circuit Diagram (LTSpice)

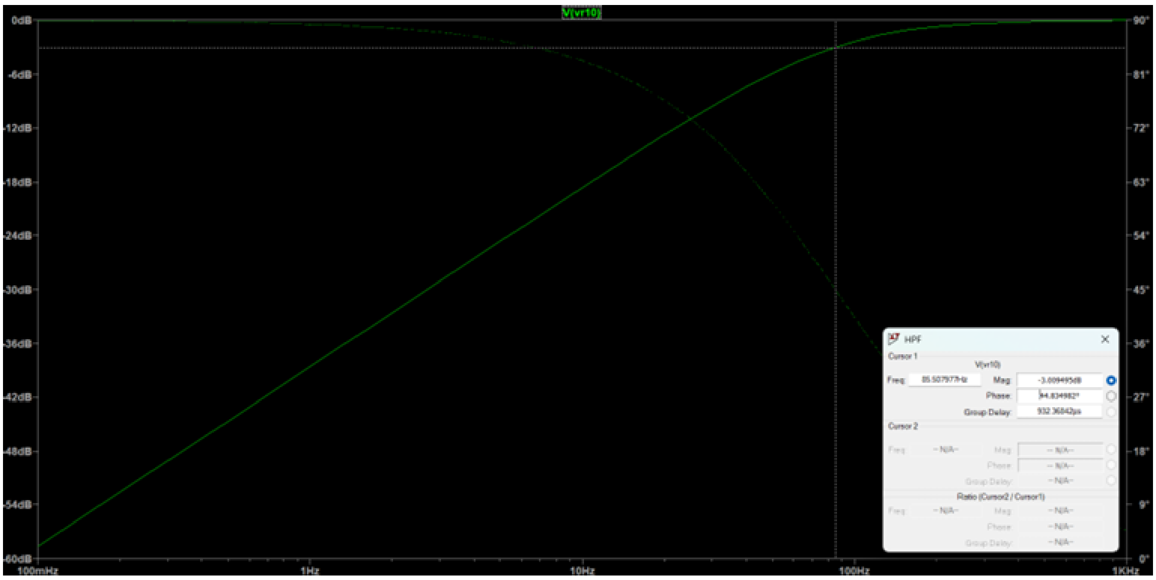


Figure 4: High-Pass Filter Frequency Response (LTSpice)

5.2 Notch Filter Response

- Simulated using an input that includes 50 Hz and nearby frequencies.
- 50 Hz component was sharply attenuated.
- Frequencies below and above 50 Hz were retained.

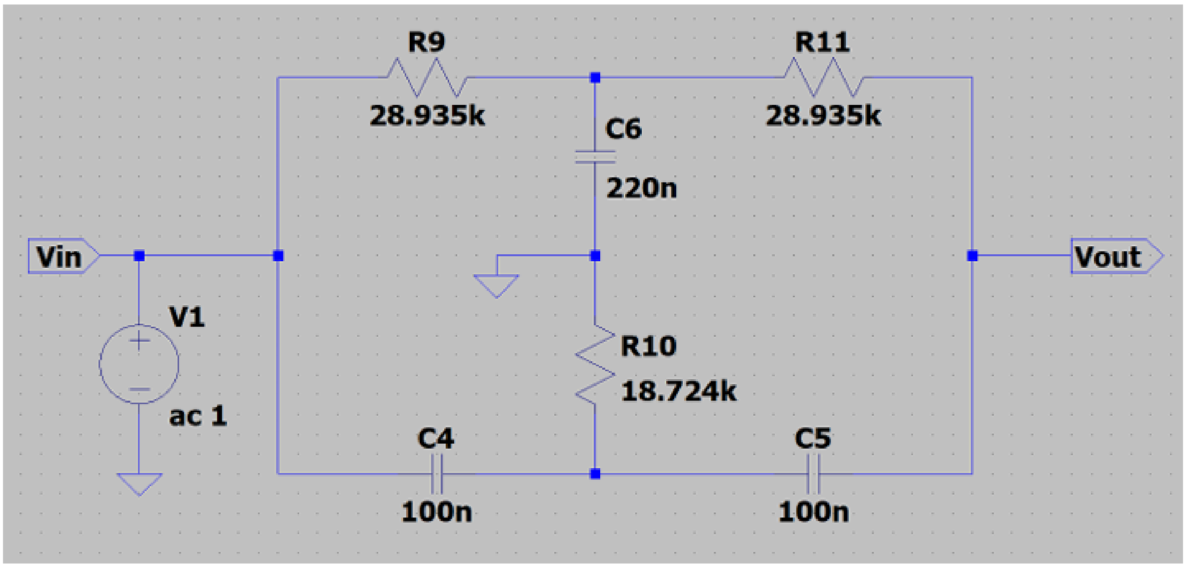


Figure 5: Notch Filter Circuit Diagram (LTSpice)

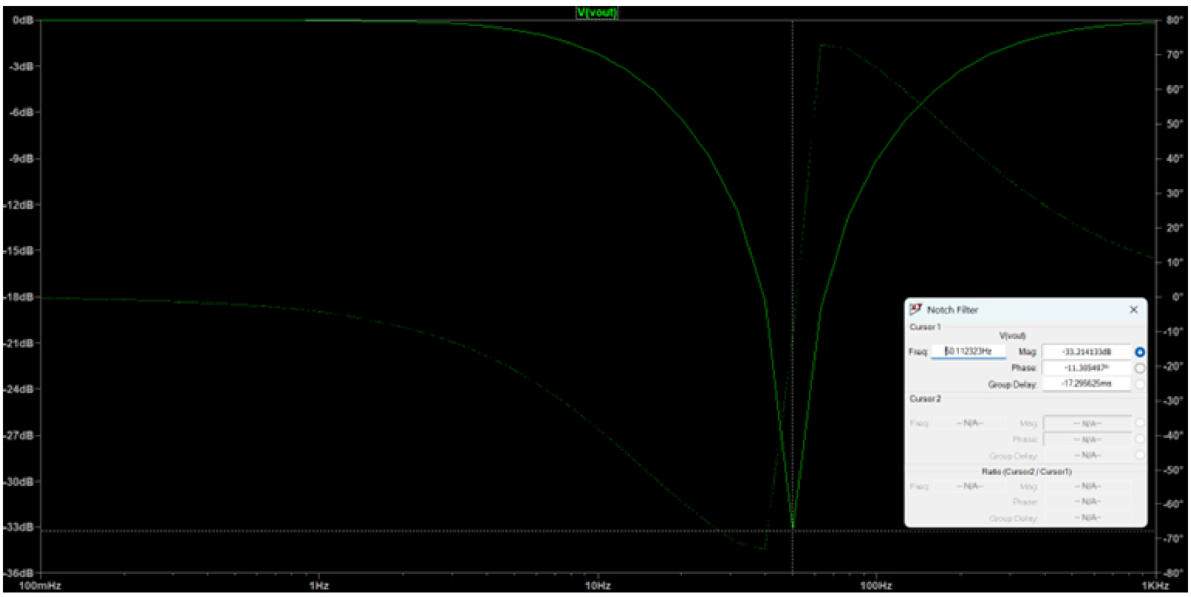


Figure 6: Notch Filter Response Showing Dip at 50 Hz (LTSpice)

5.3 Low-Pass Filter Response

- 150 Hz is the -3dB point.
- Frequencies above 150 Hz were gradually attenuated.

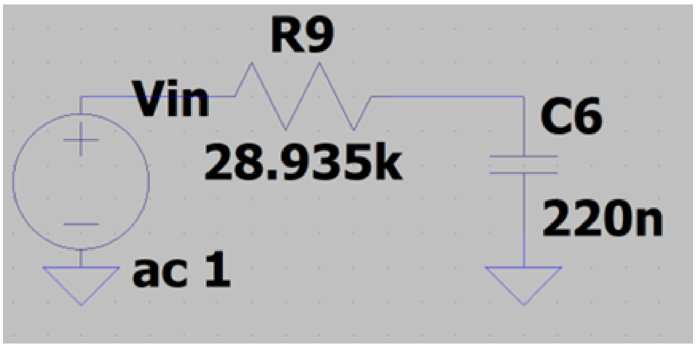


Figure 7: Low-Pass Filter Circuit Diagram (LTSpice)

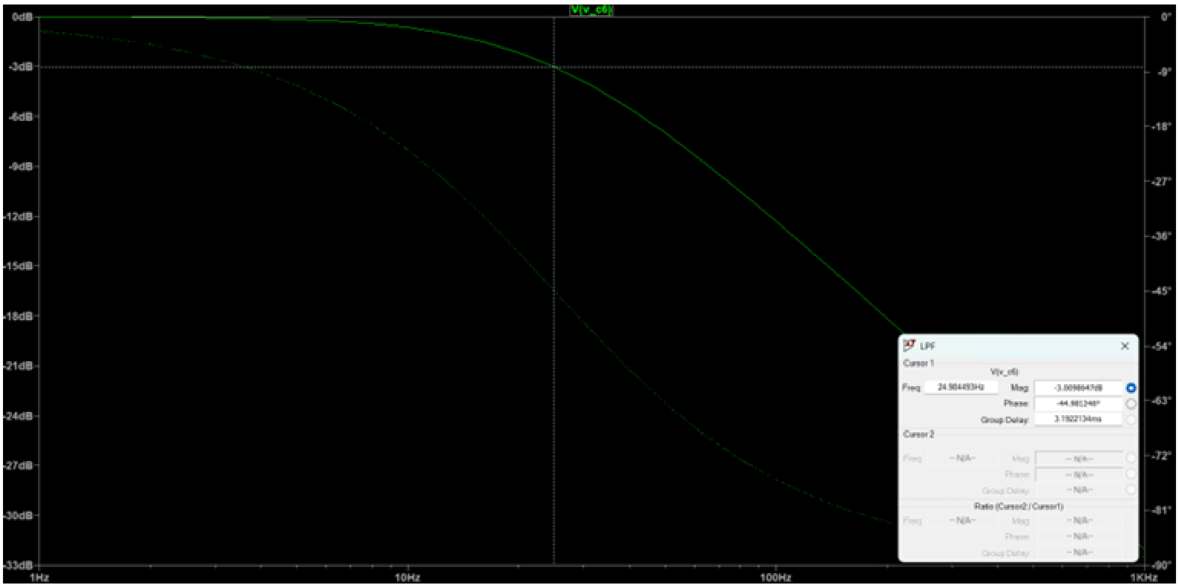


Figure 8: Low-Pass Filter Response (LTSpice)

5.4 Combined Response

- A clean ECG-like signal with 0.5–100 Hz frequency content was passed.
- 50 Hz component was removed without distorting the waveform.
- Final output resembled a denoised ECG signal.

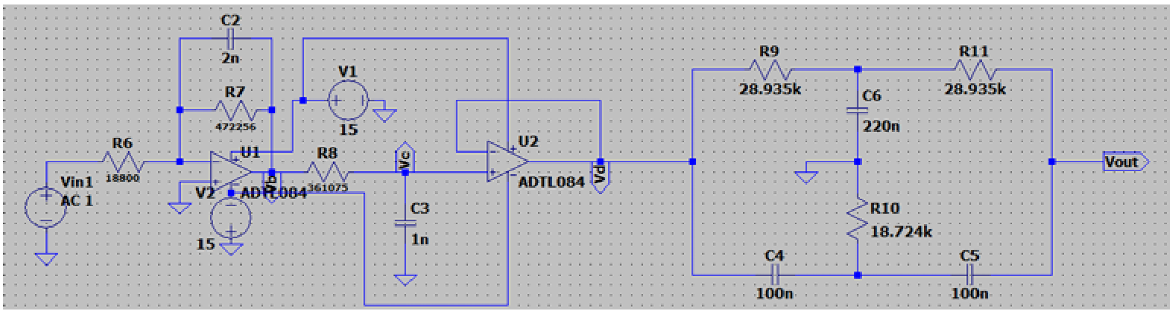


Figure 9: Filtered ECG Signal Circuit Diagram (LTSpice)

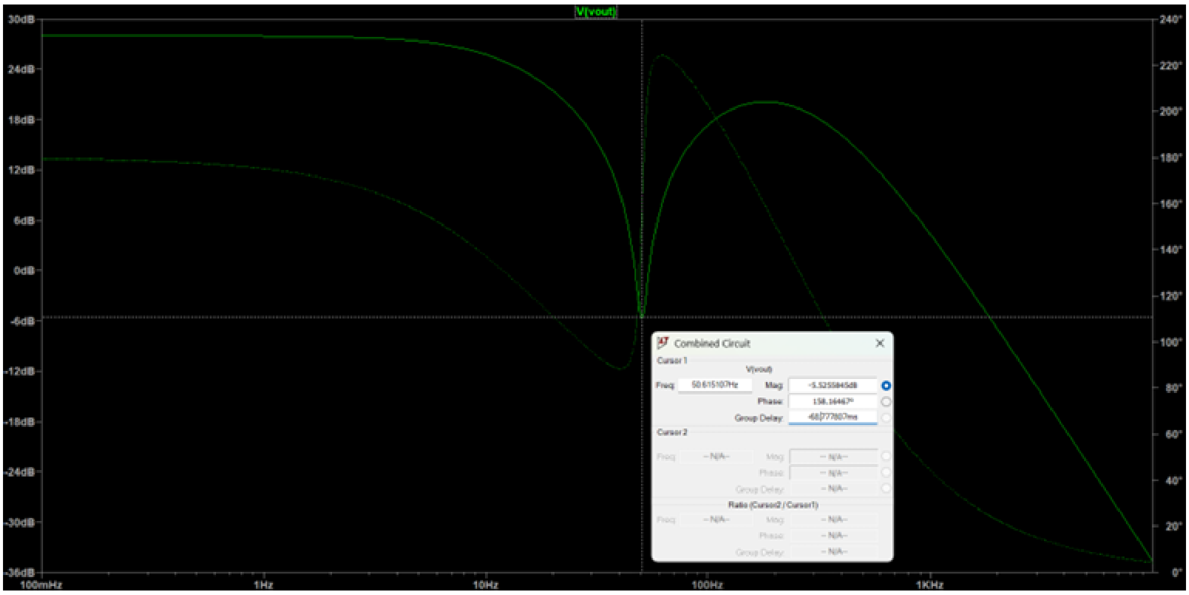


Figure 10: Simulated Output of Filtered ECG Signal (LTSpice)

6 Experimental Procedure

1. Assemble the ECG amplifier on a breadboard or PCB with proper grounding.
2. Begin with the high-pass filter stage and test its response using a low-frequency signal.
3. Connect the notch filter and observe the 50 Hz attenuation by feeding in a sinusoidal waveform.
4. Add the low-pass filter and verify its ability to block frequencies above 150 Hz.
5. Connect the system to a function generator simulating ECG pulses.
6. Use an oscilloscope to observe the output after each filter stage.
7. Document the amplitude, frequency response, and phase shift at each stage.
8. Compare the simulated and experimental waveforms.

7 Experimental Results

The ECG amplifier was successfully constructed using discrete components. The following observations were recorded:

Stage-wise Observations:

- **High-Pass Filter:** Signals below 0.5 Hz were attenuated, confirming removal of baseline drift.
- **Notch Filter:** A sharp dip at 50 Hz was observed in the frequency spectrum, validating interference suppression.
- **Low-Pass Filter:** Frequencies above 150 Hz were attenuated, reducing EMG and power supply noise.

Waveform Quality: The final ECG signal was clean and preserved essential features such as P, QRS, and T waves.

INA Testing

- Differential Mode Gain Measured: $\sim 1.025\,V_{out}$ for 100 mVpp input $\Rightarrow G = 10.25$
- Common Mode Gain: $\sim 10 - 20\,mV$ output $\Rightarrow$ Good CMRR

Right Leg Drive

- Output at RL: $\sim 390\,mV$
- Gain approximately unity, but stabilizes common-mode signals

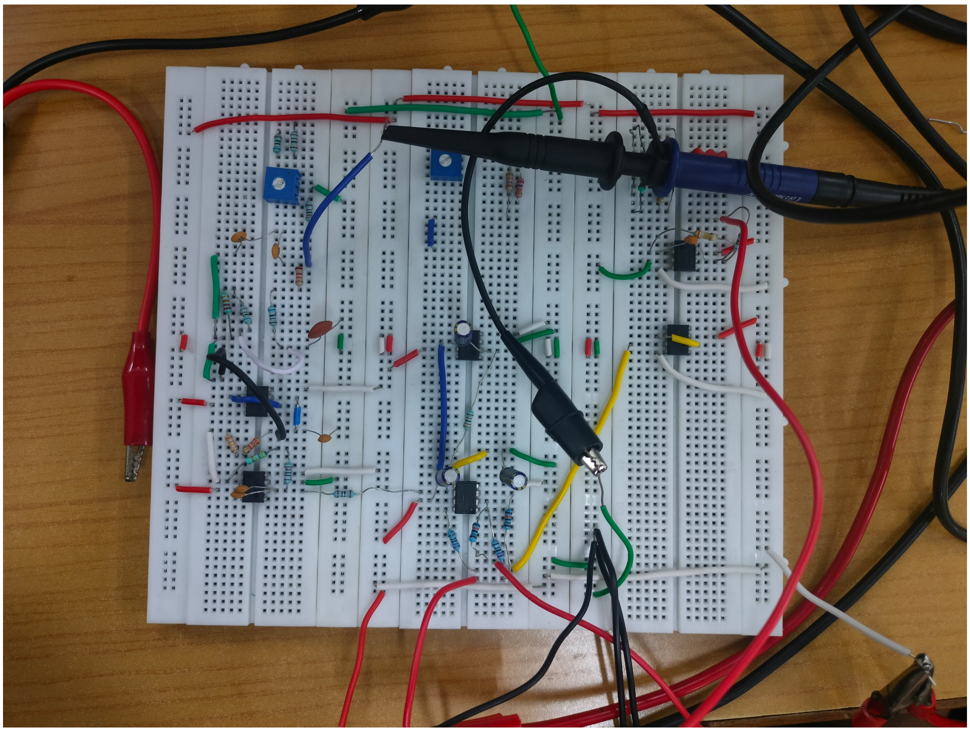
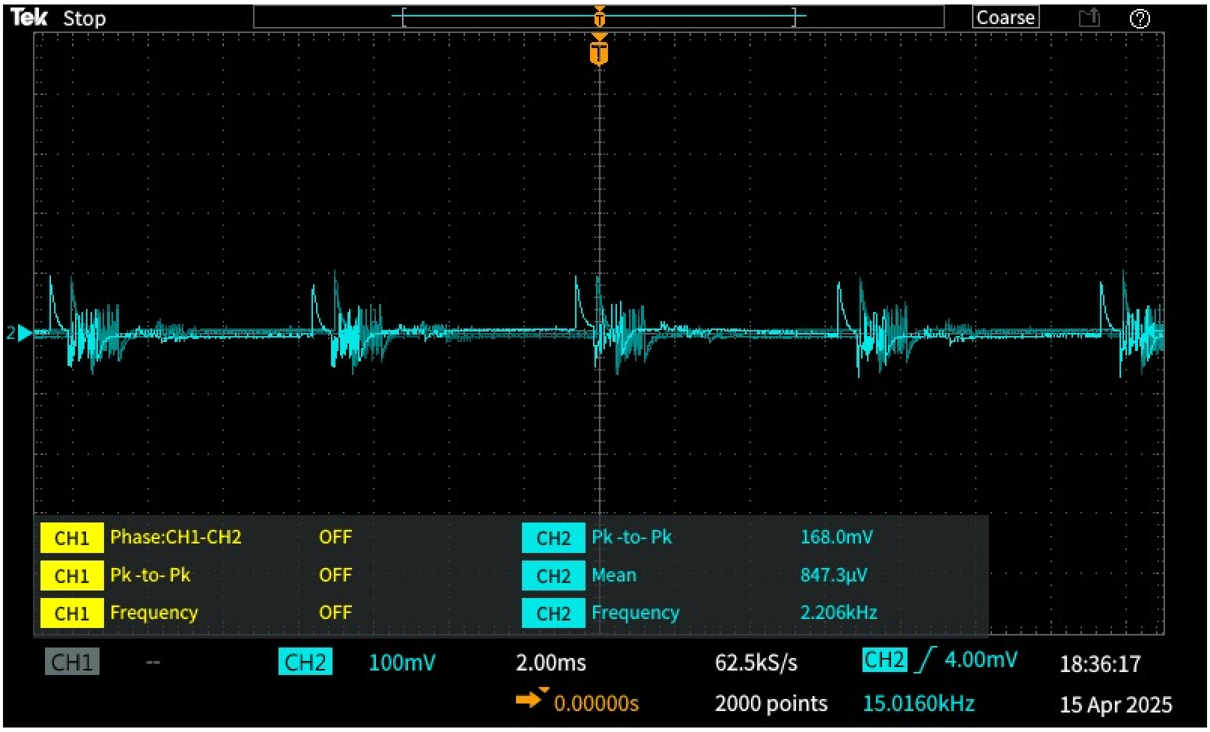
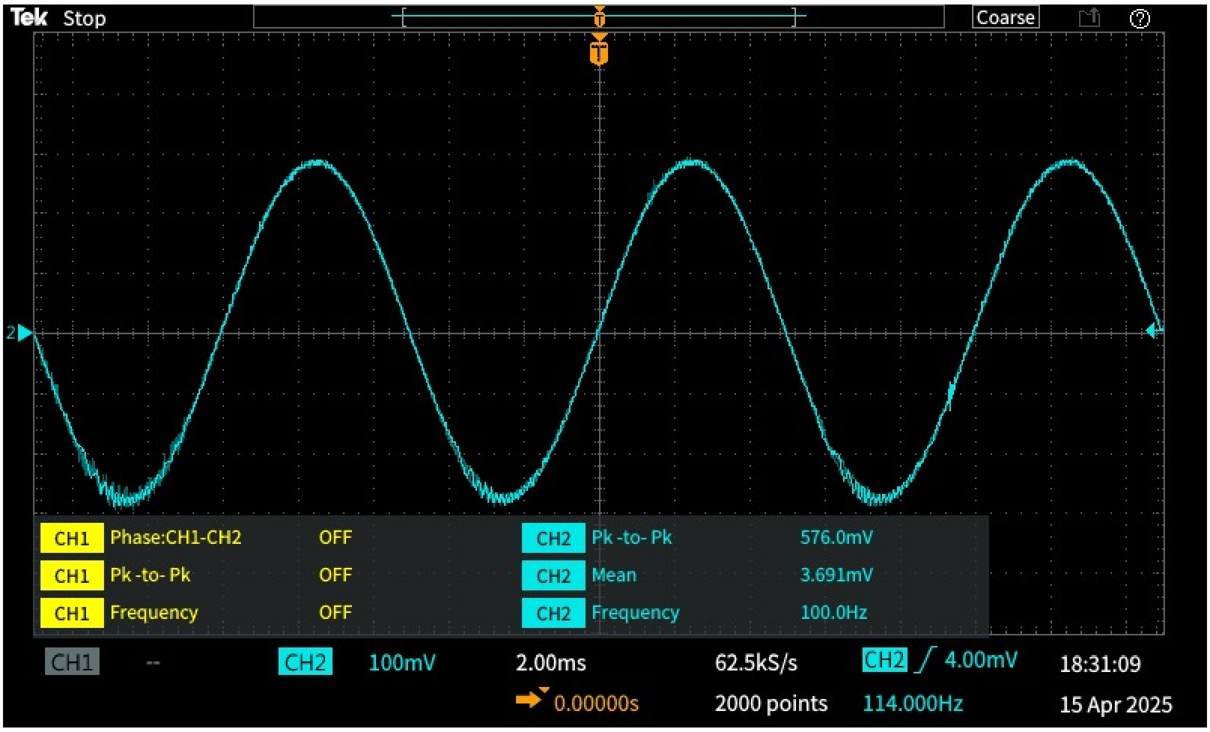
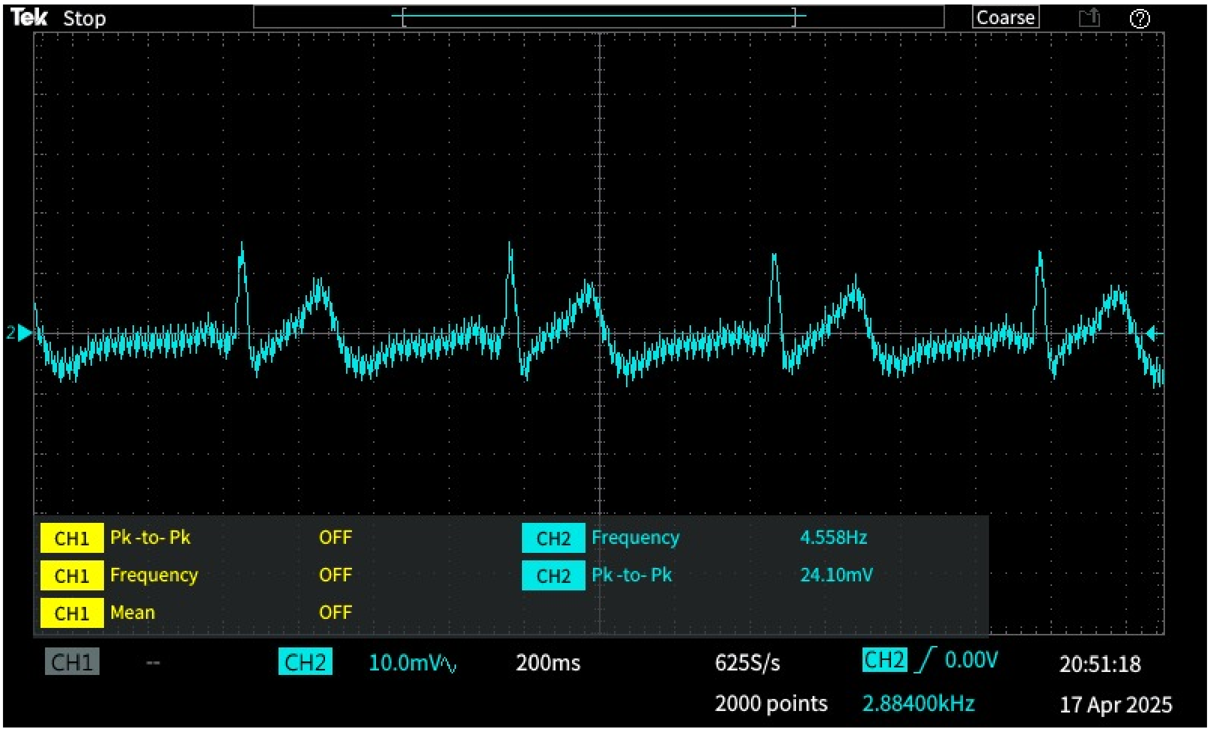


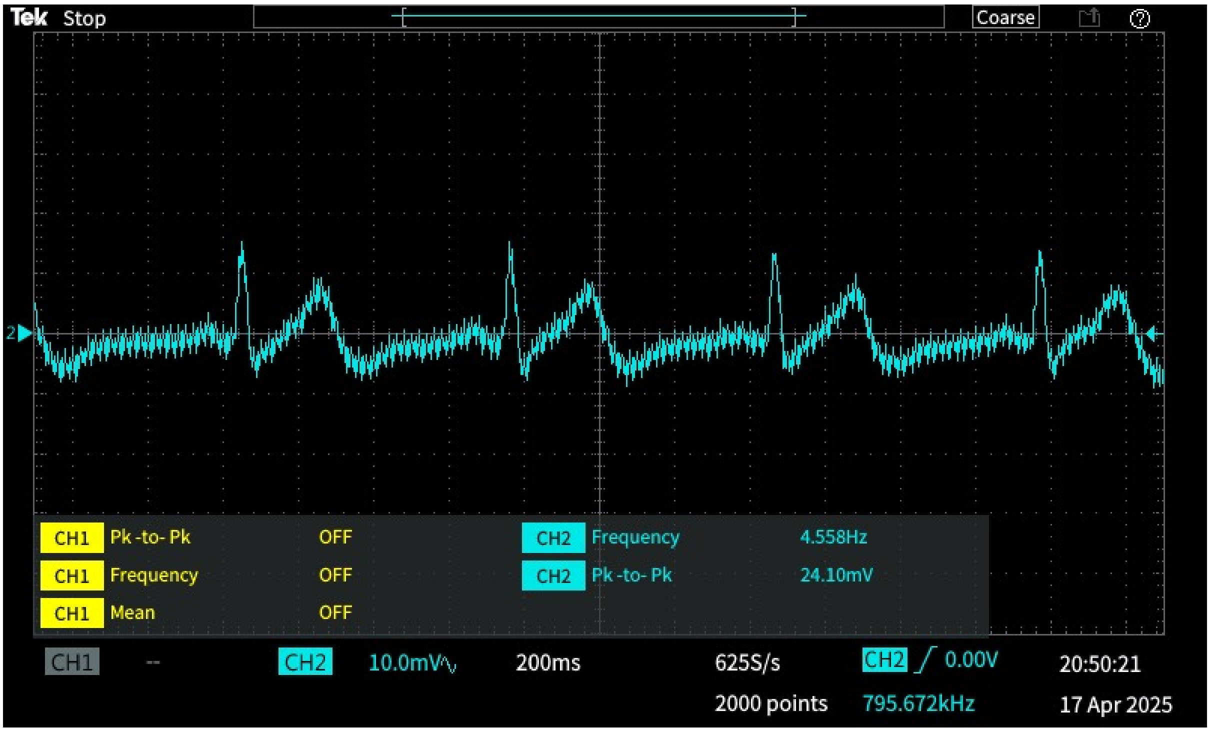
Figure 11: Complete Circuit

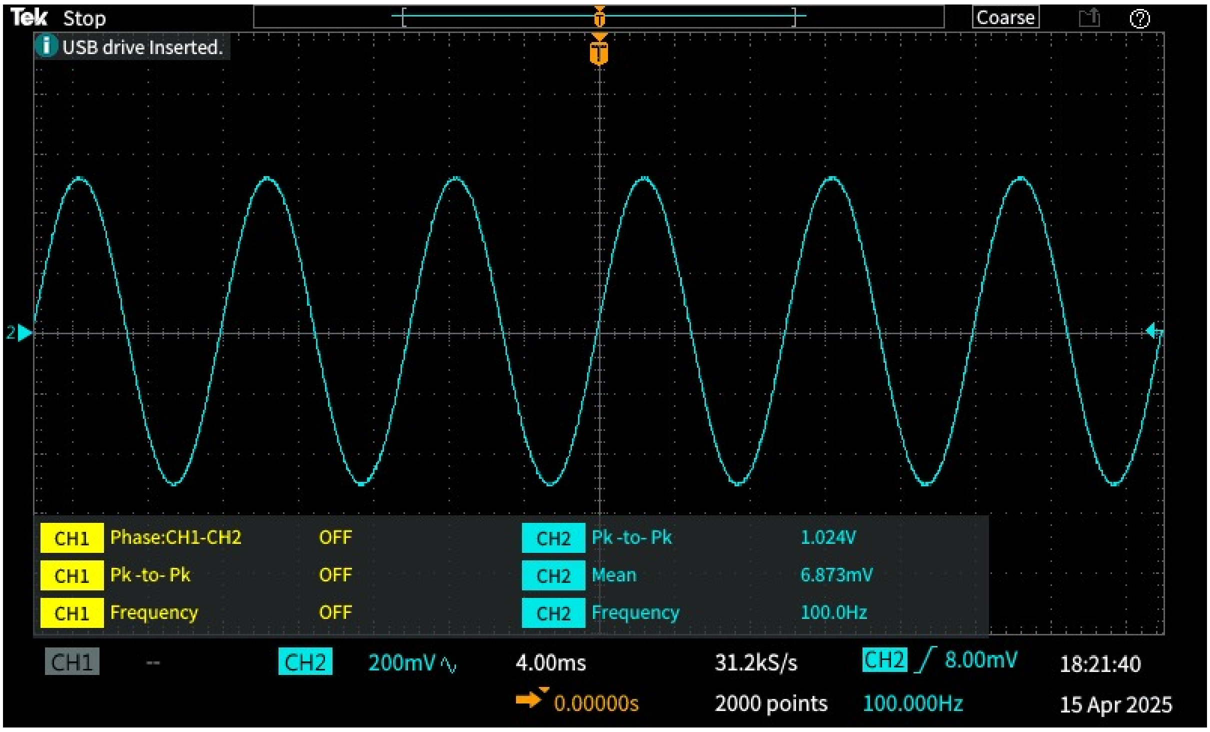
7.1 Plots from the DSO

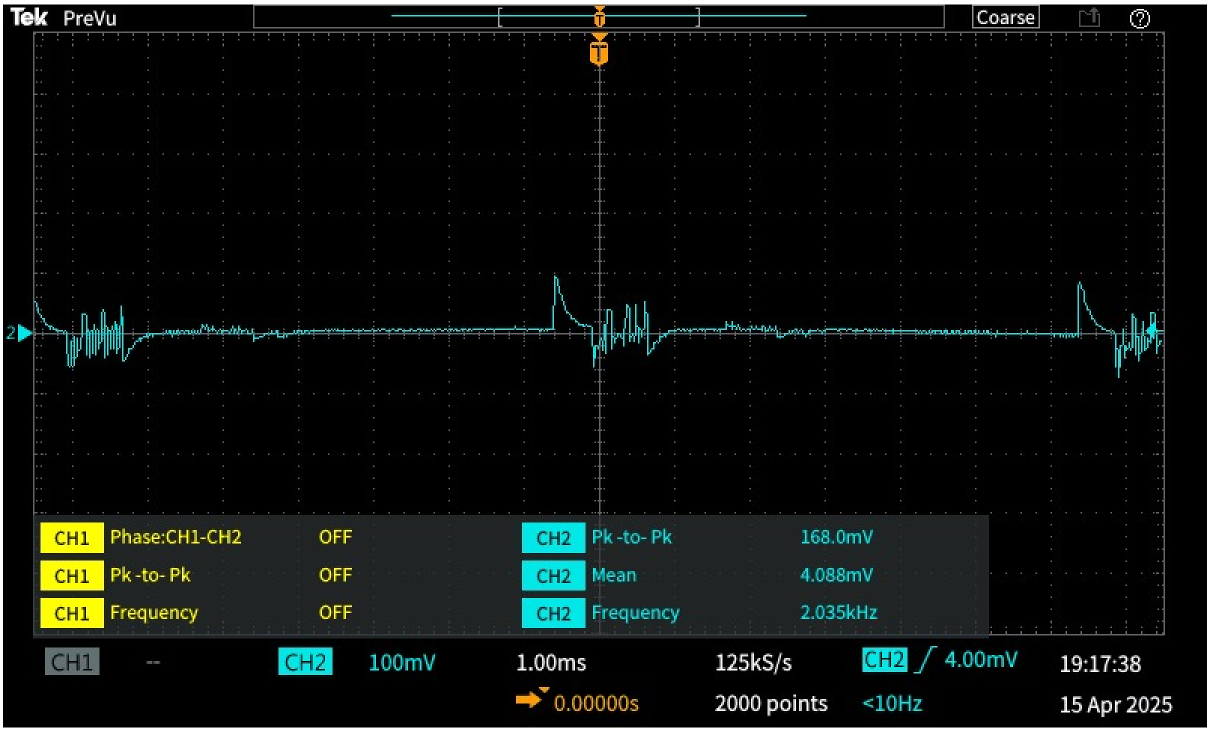





Tek Stop
Coarse
CH1 Pk-to-Pk OFF
CH1 Frequency OFF
CH1 Mean OFF
CH2 Frequency 4.558Hz
CH2 Pk-to-Pk 24.10mV
CH1 --
CH2 10.0mV
200ms
625S/s
2000 points
CH2 0.00V
2.88400kHz
20:51:18
17 Apr 2025


Tek Stop
Coarse
CH1 Pk-to-Pk OFF
CH1 Frequency OFF
CH1 Mean OFF
CH2 Frequency 4.558Hz
CH2 Pk-to-Pk 24.10mV
CH1 --
CH2 10.0mV
200ms
625S/s
2000 points
CH2 0.00V
795.672kHz
20:50:21
17 Apr 2025





8 Key Observations

1. INA output had gain ≈ 10.25, verified.
2. Common-mode signal was rejected effectively using RLD.
3. Notch filter reduced 50 Hz noise significantly.
4. Final ECG waveform was clean and clearly visible.

9 Conclusion and Inference

The experiment successfully demonstrated the design and testing of an ECG signal acquisition system. The use of INA, RLD, and filters together provided effective signal conditioning. The final signal displayed on the oscilloscope resembled a real ECG waveform with minimal noise, confirming correct design and implementation.

10 Experiment Completion Status

I have successfully completed all the parts of this experiment, including verification, signal conditioning, and final waveform recording.