Electronic Workshop-2 : Course Project Transmission and Monitoring ECG Signal

Ashish Chokhani
Roll No: 2021102016
ashish.chokhani@students.iiit.ac.in

Vedant Nipane
Roll No: 2021102040
vedant.nipane@students.iiit.ac.in

Link to the Video

I. Introduction

Many electrical devices are used to measure and record biological activity in the human body. One such device is the electrocardiogram, which measures the electrical signals produced by the heart. These signals give objective information about the structure and function of the heart. The ECG was first developed in 1887 and gave physicians a new way to diagnose heart complications. ECGs can detect heart rhythm, heart rate, heart attacks, inadequate blood and oxygen supply to the heart, and structural abnormalities. Using simple circuit design, an ECG can be made that could monitor all of these things. The basic building blocks in the ECG monitoring system are as follows:

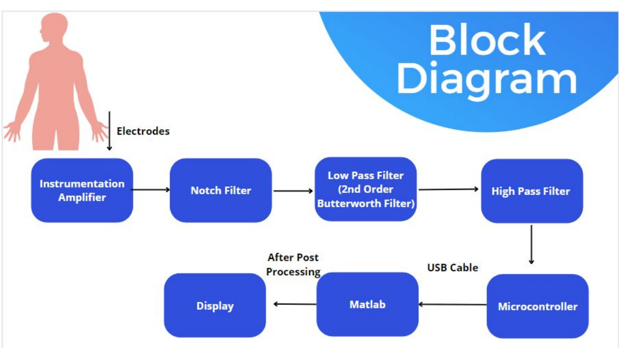

Fig. 1. Block diagram of an ECG Monitoring System

In hardware, we are interested to design the following building blocks:

- Instrumentation Amplifier of Gain 1000
- Notch Filter to remove 50 Hz noise
- Low Pass Filter with cutoff Frequency 150 Hz
- High Pass Filter with cutoff Frequency 0.5 Hz

II. Motivation

- Cardiovascular diseases (CVDs) are the leading cause of death globally. An estimated 17.9 million people died from CVDs in 2019, representing 32 of 100 of all global deaths. Of these deaths, 85 percentage were due to heart attack and stroke.
- Research opportunities: ECG monitoring circuit could also provide opportunities for research into cardiac function and disease. Educational tool: This circuit could also serve as an educational tool for medical students or healthcare professionals, allowing them to learn more about ECG signals and how they are used to diagnose and treat cardiac conditions.
- Detection of cardiac abnormalities: ECG signals are a widely-used diagnostic tool in the medical field, allowing doctors to detect abnormalities in heart function.
- Non-invasive monitoring: ECG monitoring is a non-invasive technique that is safer and less invasive than other methods of cardiac monitoring, such as angiography.

III. Result And Analysis

A. Instrumentation Amplifier

*1) **Why we need it**:* We built an instrumentation amplifier in order to amplify the small amplitude measured from the body. Using two amplifiers in our first stage will allow us to cancel out the noise created by the body (which will be the same at both electrodes). We will use two stages of about equal gain – this protects the user if the system is connected to a person by preventing all the gain from happening in one place. Since the normal amplitude of an ECG signal is between 0.1 and 5 mV, we want the gain of the instrumentation amplifier to be about 1000.

*2) **How to build it**:* The instrumentation amplifier using op-amp circuit is shown below. The op-amps 1 2 are non-inverting amplifiers and op-amp 3 is a difference amplifier. These three op-amps together, form an instrumentation amplifier. Instrumentation amplifier's final output $V_(out)$ is the amplified difference of the input signals applied to the input terminals of op-amp 3.Let the outputs of op-amp 1 and op-amp 2 be V_{o1} and V_{o2} respectively.

Values of all the resistors used is as follows:

- R_1 = **3.3 k** Ω
- R_2 = R_3 = **56 k** Ω
- R_4 = R_5 = **1.5 k** Ω
- R_9 = R_9 = **47 k** Ω

$$V_{out} = \frac{R5}{R7}(V_{o1} - V_{o2})...eqn1$$

The working of the instrumentation amplifier is, Ideally the current to the input stage op-amps is zero. Therefore the current I through the resistors R2, R1, and R3 remain the same.

Applying Ohm's law:

$$I = \frac{(V_{o1} - V_{o2})}{R3 + R2 + R1} ...eqn2$$

Since no current is flowing to the input of the op-amps 1 and 2, the current I across R1 can be given as,

$$I = \frac{(V1 - V2)}{R1} ...eqn3$$

Comparing eqn2 and eqn3,

$$(V_{o1} - V_{o2}) = \frac{(V1 - V2)(R3 + R2 + R1)}{R1}$$

Substituting $V_{o1} - V_{o2}$ value in equation 1, we get

$$V_{out} = \frac{R5}{R7} \frac{(V1 - V2)(R3 + R2 + R1)}{R1}$$

So, gain will be:

$$Gain = -\frac{R5}{R7} \frac{(R3 + R2 + R1)}{R1}$$

$$Gain = -\frac{R5}{R7} \frac{(2 * R2 + R1)}{R1}$$

Now, K1 and K2 are can be formulated as:

Equations to calculate K1 and K2 are as follows:

- $K1 = 1 + 2 * \frac{R2}{R1}$
- $K2 = -\frac{R5}{R7}$

So, calculated values of K1, K2 and Gain is:

- $K1$ = **34.93**
- $K1$ = **31.33**
- $Gain = K1 * K2 = 34.93 * 31.33 = 1094.7$

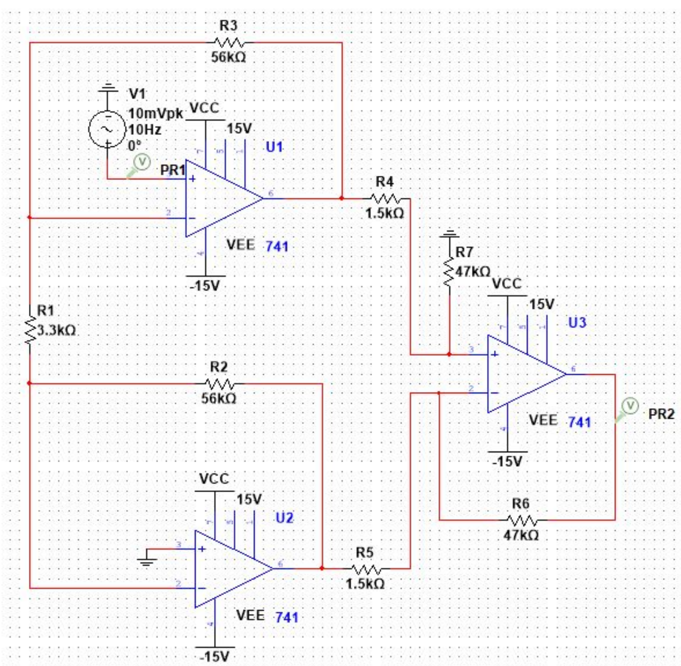

Fig. 2. Circuit Diagram of Instrumentation Amplifier

*3) **Simulation Result:*** Simulation Result of the Transient Analysis

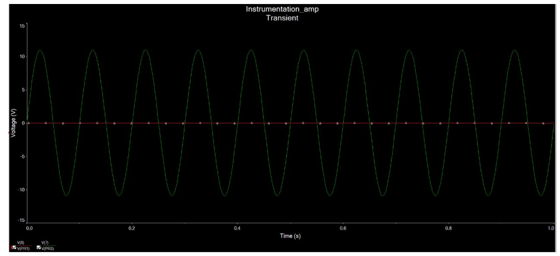

Fig. 3. Transient Analysis of Instrumentation Amplifier (Simulation)

*4) **Hardware Result:*** Input is a 10 mV sinusoid of frequency 10 Hz

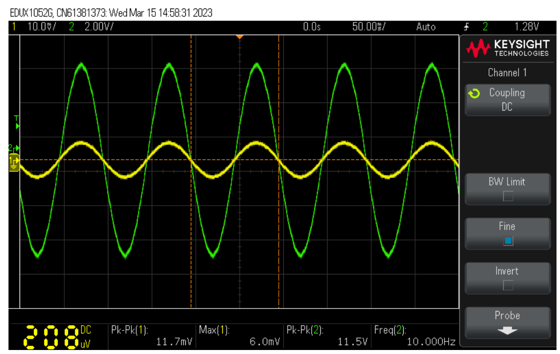

Fig. 4. Transient Analysis of Instrumentation Amplifier (Hardware)

B. Notch Filter

*1) **Why we need it:*** We have used a notch filter to remove the 50 Hz noise present in all power supplies.

*2) **How to build it:*** We set the quality factor Q to be 8, which will provide an acceptable filtering output while keeping component values in a feasible range. We also set the capacitor value to be **0.1** μ**F** so that calculations affect the resistors only. Calculations are as follows:

- Q = w/B. set Q to 8
- w = 2*pi*f. Use f = 50 Hz
- C: set to **0.1** μ**F**
- R1 = 1/(2*Q*w*C). R_1 = **1.992 k** Ω
- R2 = 2*Q/(w*C). R_2 = **508.8 k** Ω
- R3 = R1*R2/(R1+R2). R_3 = **1.9842 k** Ω

*3) **Simulation Result:*** Simulation Result of Frequency Analysis

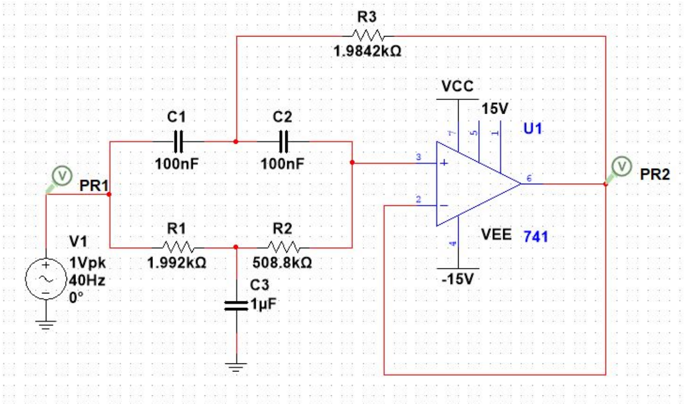

Fig. 5. Circuit Diagram of Notch Filter

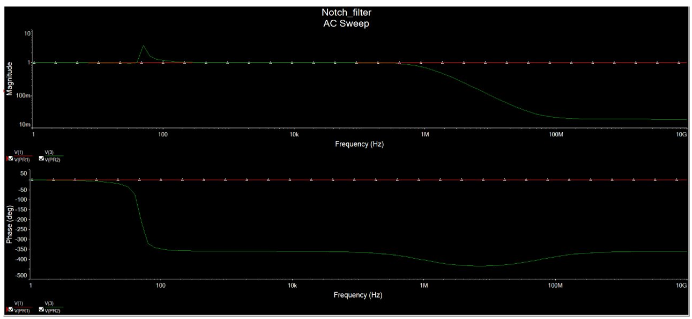

Fig. 6. Frequency Analysis of Notch Filter (Simulation)

*4) **Hardware Results**:* Input is a 10 V sinusoid of frequency 10 Hz

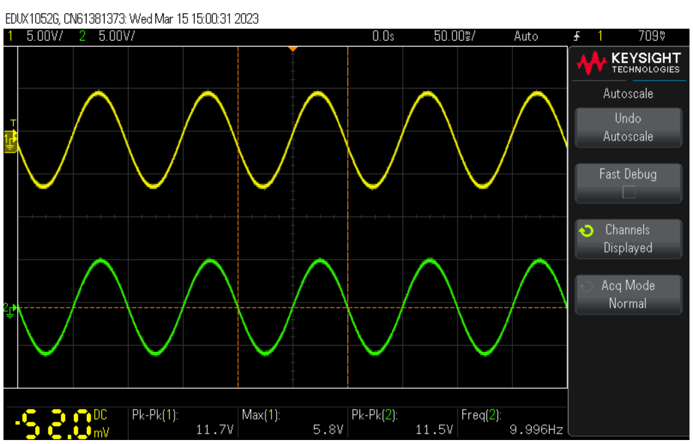

Fig. 7. Transient Analysis of Notch Filter

C. Low Pass Filter

*1) **Why we need it**:* The next stage of the device is an active low-pass filter. The ECG signal is made of many different waveforms, which each have their own frequency. We want to capture all these, without any high-frequency noise. The standard cutoff frequency for ECG monitors of 150 Hz is selected. (Higher cutoffs are sometimes chosen to monitor for

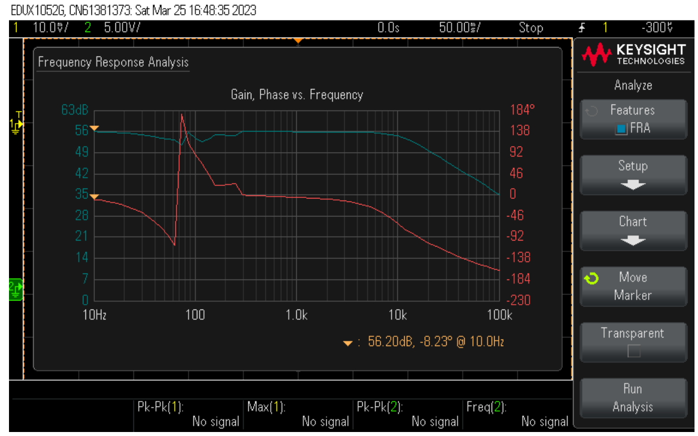

Fig. 8. Frequency Analysis of Notch Filter

specific heart problems, but for our project, we will use a normal cutoff.)

*2) **How to build it**:* We designed it as a Second order Butterworth filter, which has coefficients a and b equal to 1.414214 and 1, respectively. Setting the gain to 1 makes the operational amplifier into a voltage follower.

Calculations are as follows:

- w=2*pi*f. Set f = 150 Hz. w = 942.5 rad/sec.
- C2 = 10/f. Calculate. Our value is **0.067** μ**F**
- $C1 <= C2 * (a^2)/(4b)$. Calculate. Our value is **0.033** μ**F**
- $R1 = 2/(w * (aC2 + sqrt(a^2 * C2^2 - 4b * C1 * C2)))$. R_1 **= 18.836 k** Ω
- $R2 = 1/(b * C1 * C2 * R1 * w^2)$. R_2 **= 26.634 k** Ω

*3) **Simulation Result**:* Simulation Result of Low Pass Filter

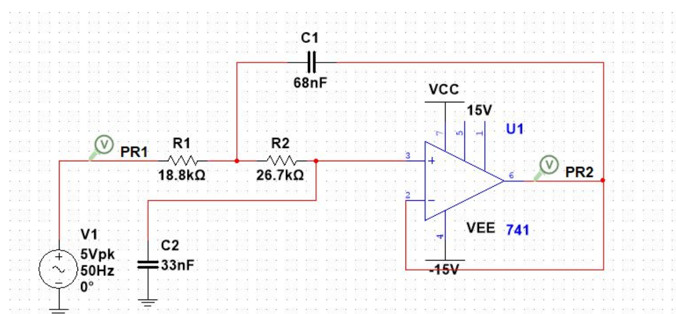

Fig. 9. Circuit Diagram of Low Pass Filter

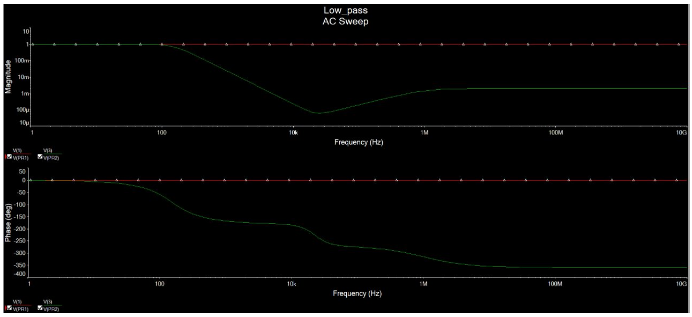

Fig. 10. Frequency Analysis of Low Pass Filter

*4) **Hardware Result**:* Input is a 10 V sinusoid of frequency 10 Hz

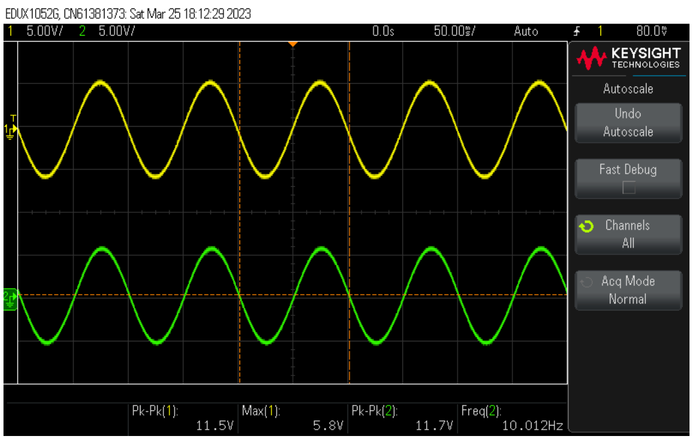

Fig. 11. Transient Analysis of Low pass Filter

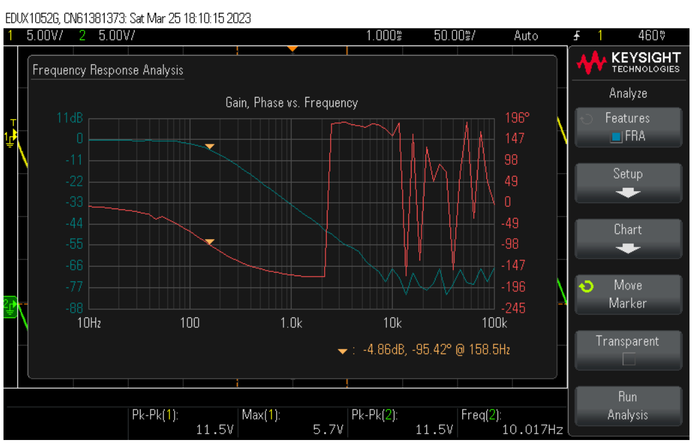

Fig. 12. Frequency Analysis of Low Pass Filter

D. High Pass Filter

*1) **Why we need it**:* The high-pass filter is used so that frequencies below a certain cut-off value are not recorded, allowing a clean signal to be passed through. The cut-off frequency is chosen to be 0.5 Hz (a standard value for ECG monitors).

*2) **How to build it**:* The resistor and capacitor values needed to achieve this are seen below. Our actual resistance used was R = **318.2** Ω.

$$R = \frac{1}{2\pi f * C}$$

Set f = 0.5 Hz, and C = 1 uF.
Calculate R. Our value is 318.310 kohm

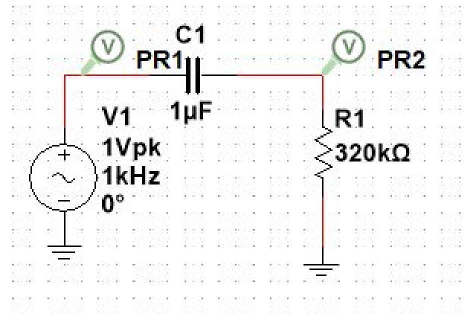

Fig. 13. Circuit Diagram of High Pass Filter

*3) **Simulation Result**:* Simulation Result for High Pass Filter are as follows:

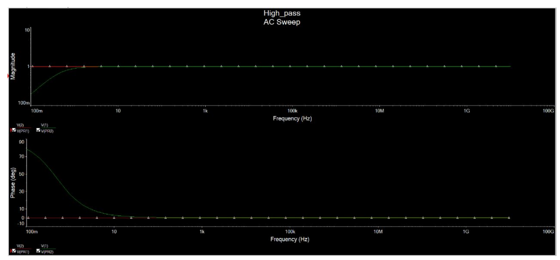

Fig. 14. Frequency Analysis of High Pass Filter

*4) **Hardware Result**:* Input is a 10 mV sinusoid of frequency 10 Hz

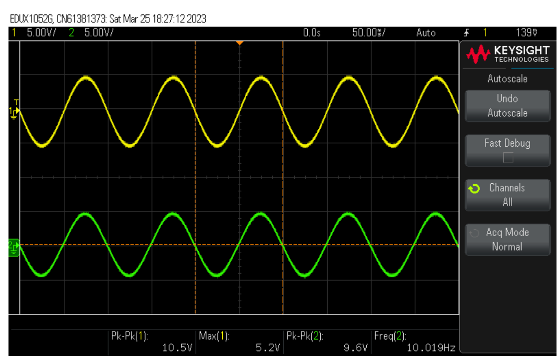

Fig. 15. Transient Analysis of High Pass Filter

E. Cascaded Circuit

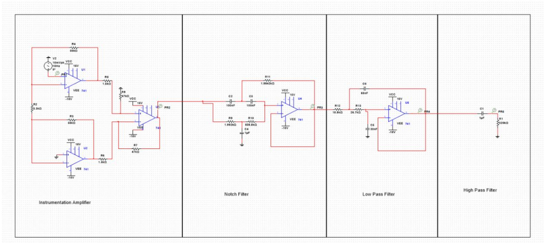

Fig. 16. Cascaded circuit

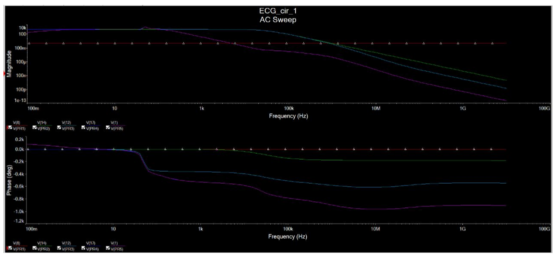

Fig. 17. Frequency Analysis of Cascaded Circuit

*1) **Simulation Result**:* Transient Analysis of cascaded Circuit

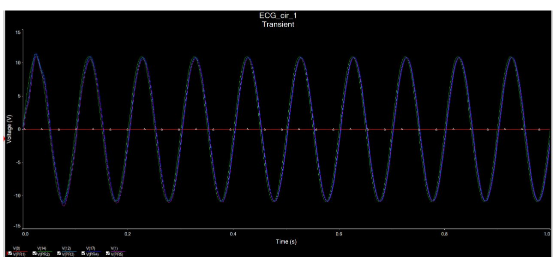

Fig. 18. Transient Analysis of Cascaded Circuit

*2) **Hardware Result**:* Input is a 10 mV sinusoid of frequency 10 Hz

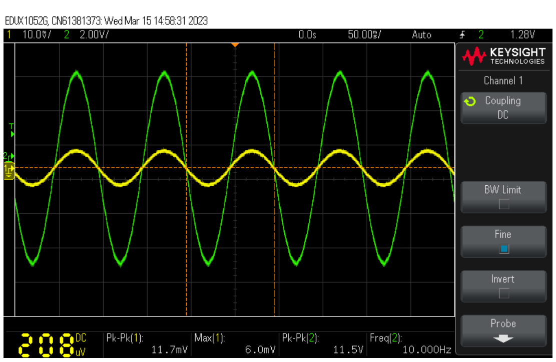

Fig. 19. Transient Analysis of Cascaded Circuit

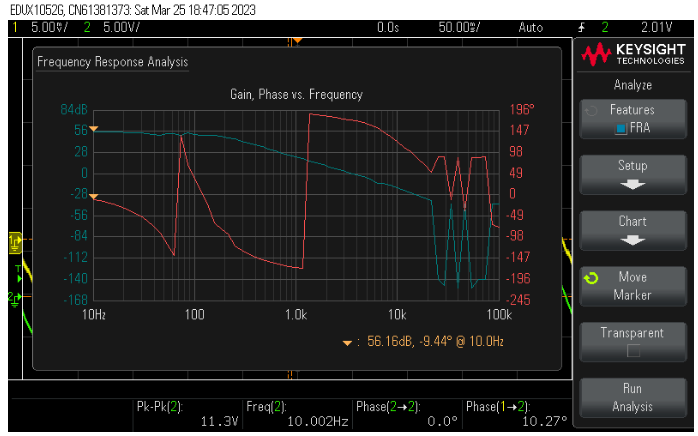

Fig. 20. Frequency Analysis of Cascaded Circuit

IV. Further Analysis

A. Gain analysis

The Instrumentation amplifier is designed such a way that the gain of the amplifier stages collectively is 1000.

B. Min-Max input range

Minimum and Maximum input range of the circuit is 0.5mV to 28mV respectively. Clipping was observed at 28mV as observed in the below plot.

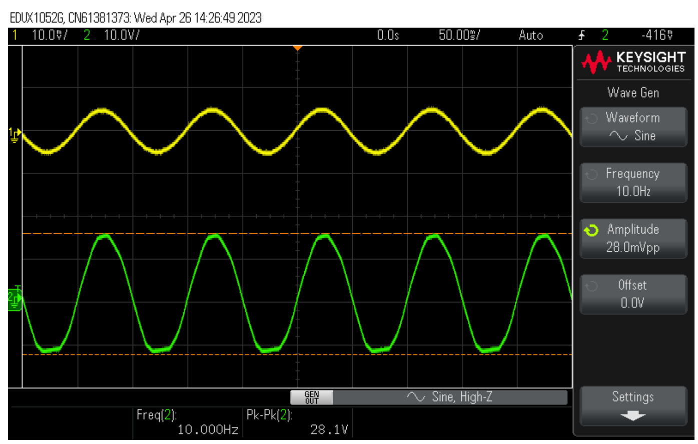

Fig. 21. Clipping at 28 mV

C. Frequency analysis

The cut-off frequencies for the overall circuit are 0.5 Hz and 150 Hz with notch filtering at 50 hz.

D. Distortion analysis

Nonlinear circuits cause harmonic generation in an input waveform, leading to distortion in the time domain and additional peaks in the frequency domain.
So, Total harmonic distortion (THD) is the measure of the deviation of voltage or current waveform from ideal sinusoidal shape.

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + ...}}{V_1}$$

Distortion power factor defines how the total harmonic distortion of a nonlinear load decreases the total average power delivered to the load.

$$\textbf{Distortion Power Factor} = \frac{V_1}{\sqrt{V_1^2 + V_2^2 + V_3^2 + V_4^2 + ...}}$$

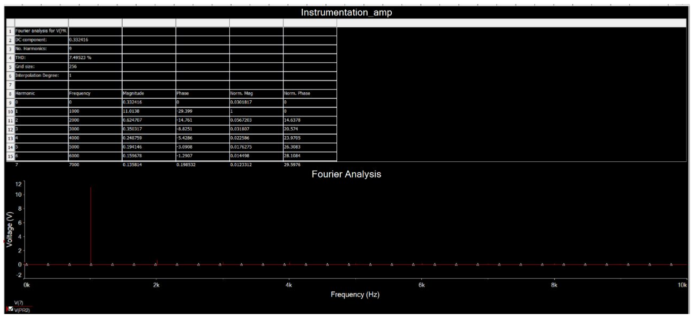

Fig. 22. THD of the circuit

E. *Slew rate*

Slew rate is defined as the maximum rate of change of an op amps output voltage. Slew rate is measured by applying a large signal step, such as one volt, to the input of the op amp, and measuring the rate of change from 10 to 90 percentage of the output signal's amplitude. Slew Rate, S:

$$S = \frac{dV_o}{dt} = \frac{V_{o90} - V_{o10}}{t_{90} - t_{10}}$$

Calculated slew rate for the circuit is **0.4 V/millisecond**.

V. Post processing As done in Matlab

ECG signals are frequently non-stationary meaning that their frequency content changes over time. These changes are the events of interest.

Wavelets decompose signals into time-varying frequency (scale) components. Because signal features are often localized in time and frequency, analysis and estimation are easier when working with sparser (reduced) representations.

The QRS complex consists of three deflections in the ECG waveform. The QRS complex reflects the depolarization of the right and left ventricles and is the most prominent feature of the human ECG.

Steps to follow:

- Remove low frequency components. Change to frequency domain using FFT. Change back to time domain using FFT.
- Find Local Maxima under windowed filter
- Adjust Filter size and repeat 2,3
- Heart Beat rate can be calculated by the formula $Rate = 60 * Sampling_rate/(R - Rinterval)$

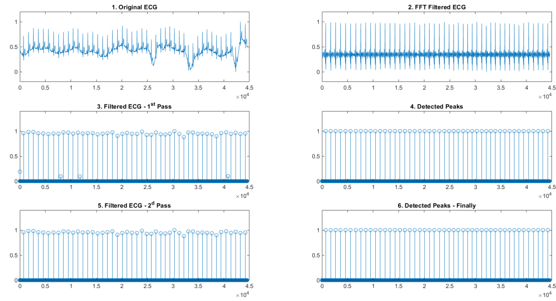

Fig. 23. Matlab Outputs

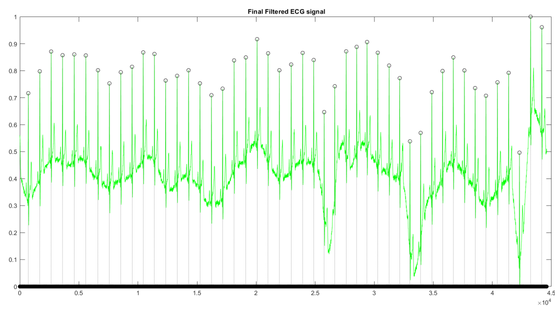

Fig. 24. Final Filtered Signal

VI. Challenges Faced

- The major challenge we faced was in transmission part. As we needed more no of samples for an ecg signal, transmission part was challenging.
- Figuring out what gain and cutoff should we use in the circuit was a challenging part.
- Remove Small values, store significant values
- Deciding optimal window size and deciding optimal threshold for peak detection in Matlab.

VII. Proposed Improvements Constraints

- The circuit design could be modified further to operate with 12 lead electrodes to get better results at the cost of hardware complexity . Using Raspberry Pi Micro-controller instead of ESP-32 to provide better data rate transmission. But due to cost constraints, we continued with ESP32 Apart from measuring the heart-beat, the signal can also be processed to identify certain cardiac diseases.
- There is MUCH, MUCH more we can do to this circuit ti make it robust. The purpose of the project was to provide the minimal circuitry necessary to obtain reasonable ECG signal.
- In future, the drawbacks of this current prototype will be reduced and more biosignals will be transmitted for a larger distance with less error rate and more accuracy. FIR filter designed will be modified further so that its efficiency in noise reduction will be more.

REFERENCES

[1] Advances in Cardiac Signal Processing by U Rajendra Acharya
[2] ECG Montitoring System(Paper)
[3] Wireless ECG Monitoring System: Design, Construction and Analysis(Paper)
[4] Electrocardiography Circuit Design - by Nathan M. Kesto (Paper)