TEAM - 2

PROJECT NAME: ECG SIGNAL PROCESSING AND HEART BEAT RATE CALCULATION CIRCUIT

TASK 1:

GOALS ASSIGNED-

1. Research about the ECG signal structure
2. Study about different types of noise affecting the ECG signal
3. Study about operational amplifiers and basic circuits

I. ECG SIGNAL STRUCTURE:-

➔ **ECG (Electrocardiogram)-**

Electrical and chemical signals are used to communicate between nerve and muscle cells. Our heartbeat is also controlled by electrical signals. The sinoatrial node, a group of cells in the right atrium of the heart, sends these signals, which travel through the heart muscle tissue as small electrical impulses. The atria and then the ventricles of the heart contract as a result of this. On the surface of our skin, we can measure how these signals spread through the heart. An ECG plots these changes in electrical signals on different areas of the skin as a graph. The resulting graph is called an ECG or Electrocardiogram.

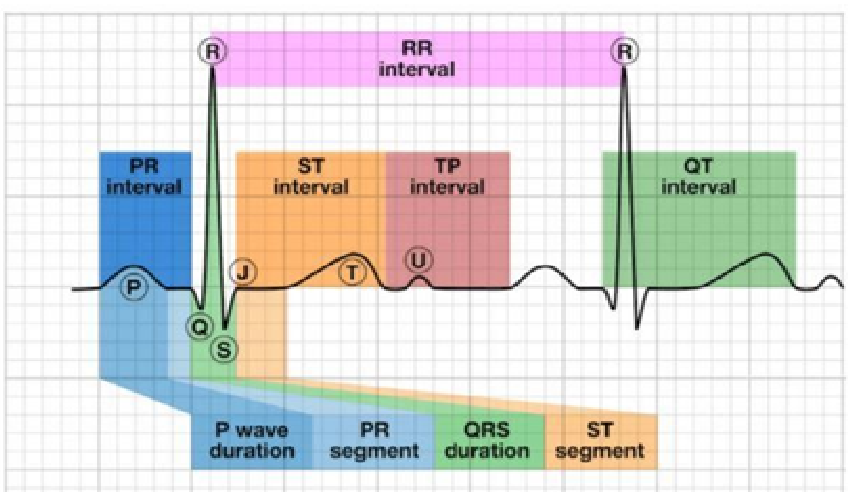


Figure 1: Electrocardiograph

➔ **Types of ECG**-

1. Resting ECG
2. Exercise ECG
3. Holter Monitor

➔ **PQRST Waves**-

P, QRS, and T-U waves are the alphabetical names for the various ECG waves. Their shape, amplitude, and time intervals provide vital information about one's health and heart condition. Atrial depolarization is reflected by the P wave. Ventricular depolarization is reflected in the QRS complex and the T-U wave reflects the repolarization of ventricles.

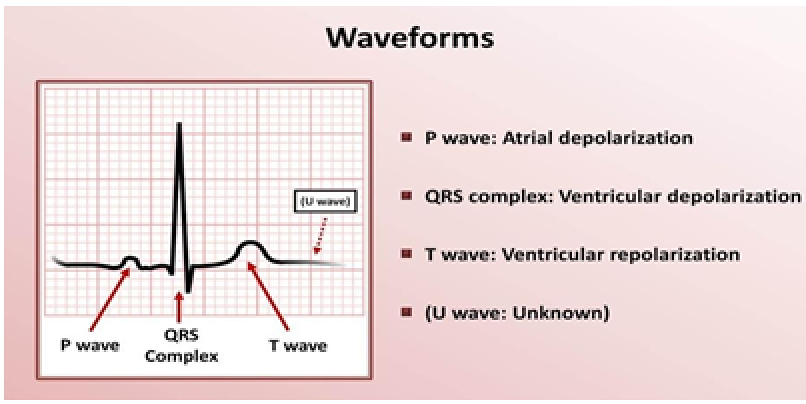


Figure 2: P-QRS-TU Waveform

II. NOISES AFFECTING ECG SIGNAL:-

➔ **Power Line Interference** - It features harmonics and a 50/60Hz pickup. Electromagnetic interference from power lines, electromagnetic fields (EMF) from nearby machines, stray effects of alternating current fields due to cable loops, and improper grounding of the patient or the ECG machine are the main causes of interference. In the input circuits of the ECG machine, electrical equipment generates 50 Hz signals. Examples: air conditioners, elevators and x-ray units which draw heavy power line current.

➔ **Electromyogram Noise** - The noise generated by the Electromyogram (EMG) is caused by electrical activity in the muscle. A maximum frequency of 10 KHz is found in EMG. Surface EMG can interfere with and corrupt ECG sections, making data processing and analysis more difficult.

➔ **<u>Baseline Wander</u>** - The ECG signal contains a low-frequency noise component called baseline wander. This is primarily due to breathing and movement of the body. The frequency of baseline wander is greater than 1Hz. Baseline wander, a low- frequency noise, makes peak detection and analysis difficult.

➔ **<u>Channel Noise</u>** - When an ECG signal is sent through channels, channel noise is introduced. The reason for this is because the channel is in bad shape. It resembles white Gaussian noise in that all frequency components are present. For instance, AWGN.

➔ **<u>Electrode Contact Noise</u>** - Loss of contact between the electrode and the skin causes electrode contact noise, effectively disconnecting the measurement system from the subject. The noise lasts for one second.

➔ **<u>Motion Artifacts</u>** - Changes in the electrode-skin impedance with electrode motion cause motion artifacts, which are transient baseline changes. The ECG amplifier sees a different source impedance as the electrode position changes, forming a voltage divider with the amplifier input impedance. As a result, the amplifier input voltage is determined by the source impedance, which changes as the electrode position changes.

III. OPERATIONAL AMPLIFIERS:-

➔ An operational amplifier is a circuit that can boost weak electric signals. An operational amplifier (op amp) is a type of analogue circuit that takes a differential voltage input and outputs a single-ended voltage. Op amps typically have three terminals: two high-impedance inputs and one low-impedance output.

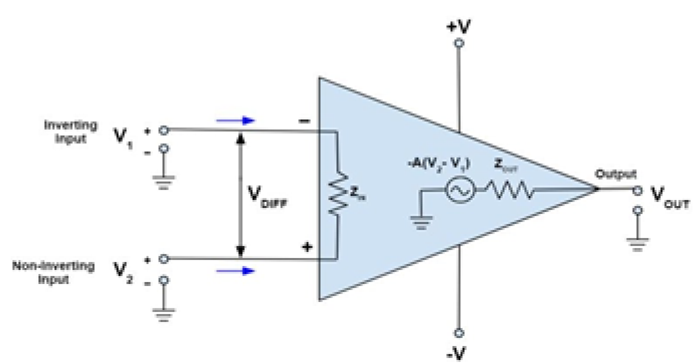


Figure 3: Basic Op-amp circuit

TASK 2:

GOALS ASSIGNED-

1. Download and Install LTSpice.
2. Explore the application and run a basic amplifier simulation.

➔ LTSpice was installed successfully and a basic circuit was simulated on it to get a hands-on experience of the software to be used for this project.

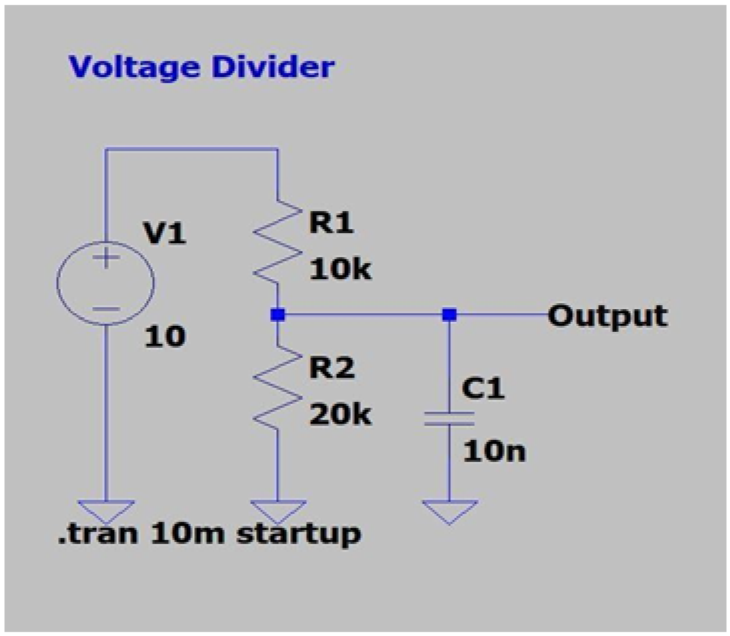


Figure 4: Sample circuit build on LTSpice

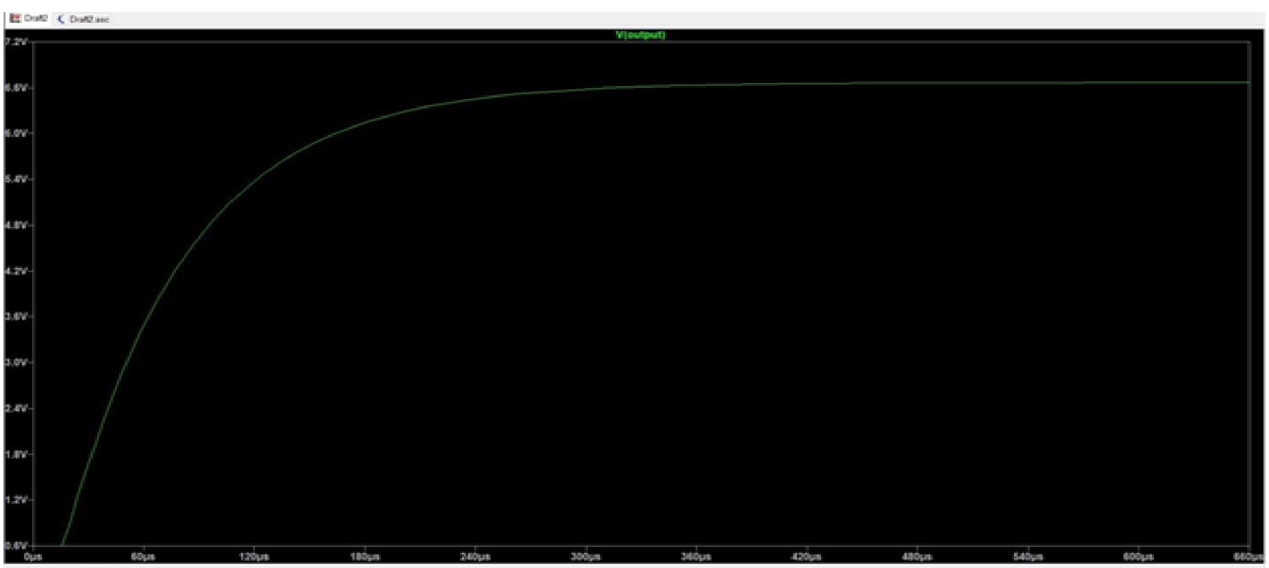


Figure 5: Graph of the sample circuit

TASK 3:

GOALS ASSIGNED-

1. Studying the design process for op-amp blocks.
2. Simulation of individual blocks.
3. Studying the sample noisy signal using FFT.

- ➔ CIRCUIT - Non Inverting Amplifier
  ASSIGNED TO - Aryan Andhare

  Non- Inverting Amplifier: An op-amp circuit arrangement that provides an amplified output signal that is in phase with the applied input signal is known as a non-inverting amplifier. In other words, a non-inverting amplifier acts as a voltage follower. Instead of feeding the entire output signal to the input, only a portion of the output signal voltage is given back as input to the inverting input terminal of the op-amp in a non-inverting amplifier. The non-inverting amplifier's high input and low output impedance make it perfect for impedance buffering applications.

  Calculation of gain :

  Av=1+(R2/R1)

  Where:
  Av = voltage gain of op amp circuit
  R2 = feedback resistor resistance in Ω
  R1 = resistance of resistor to ground in Ω

  On substituting values of R1 and R2
  Av=1+(10000/10000)
  Av=1+1
  Av=2

  voltage gain of above op amp circuit is 2

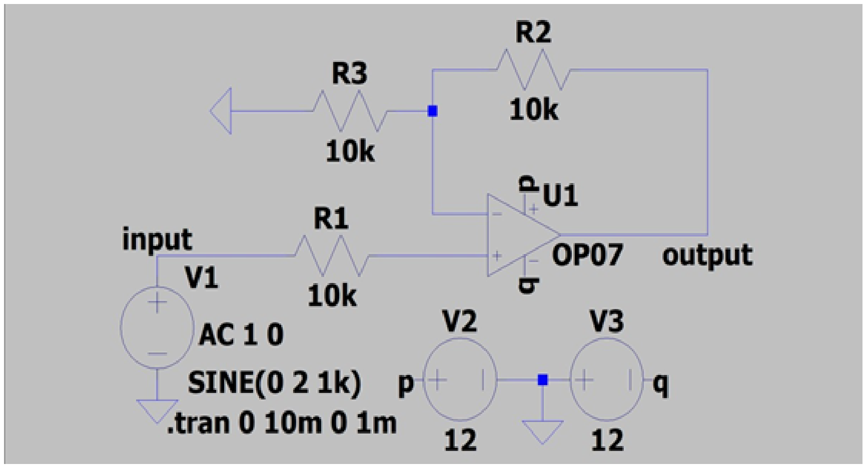


Figure 6: Non-inverting amplifier circuit on LTSpice

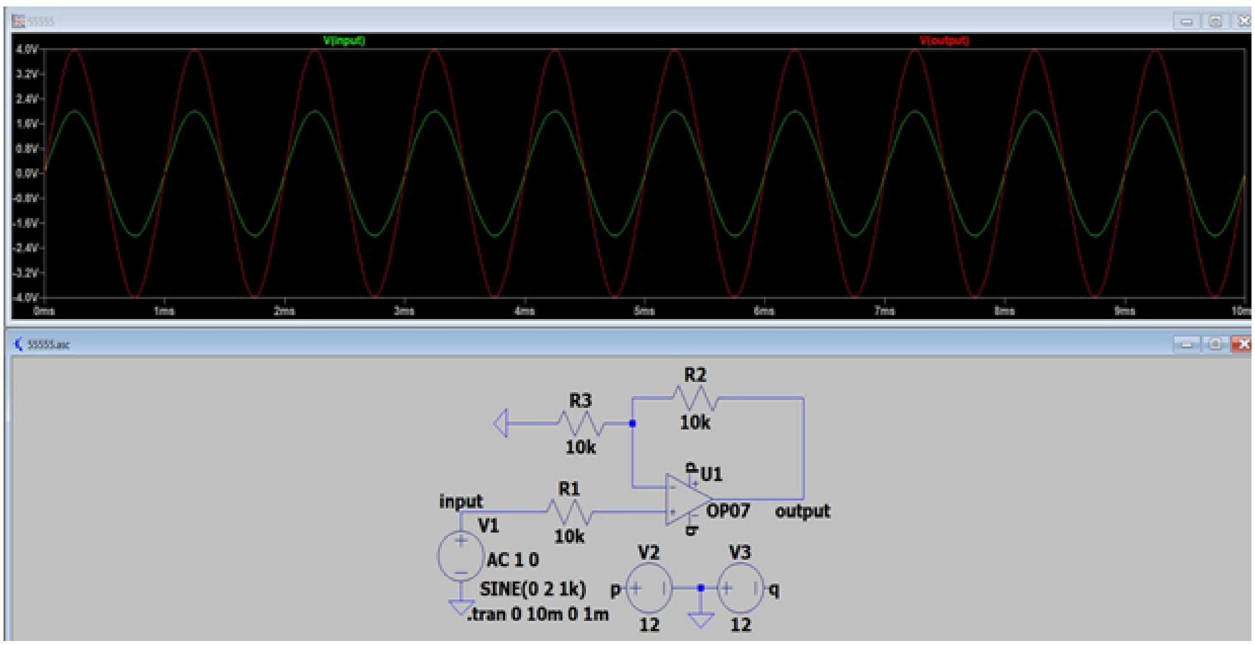


Figure 7: Graph of the circuit on LTSpice

➔ CIRCUIT - Low Pass Filter
ASSIGNED TO - Smriti Karn

Low Pass Filter : A low-pass filter is a filter that allows signals with lower frequencies to pass while attenuating sounds with higher frequencies. The filter's precise frequency response is determined by its design. A low-pass filter, by definition, is a circuit that allows low-frequency signals to flow easily while high-frequency signals are difficult to get through. The inductive low-pass filter and the capacitive low-pass filter are two main types of circuits capable of attaining this goal, each with numerous variations.

Calculations :

- Taking frequency to be 1kHz and capacitance
  0.01uF,

  Fc = 1/ 2x3.14 RC
  R = 1/ 2x3.14 FcC = 1/ 2 x 3.14 x 1 x 10^3 x 0.01 x 10^{-6} = 15.9kohm

- Now to find Rf and Ri, Taking gain as 2,
  Am = 1 + Rf / Ri
  2 = 1 + Rf / Ri
  Therefore, Rf = Ri = 10K

- After finding all the values for the components, build a circuit using these values in LTSpice.

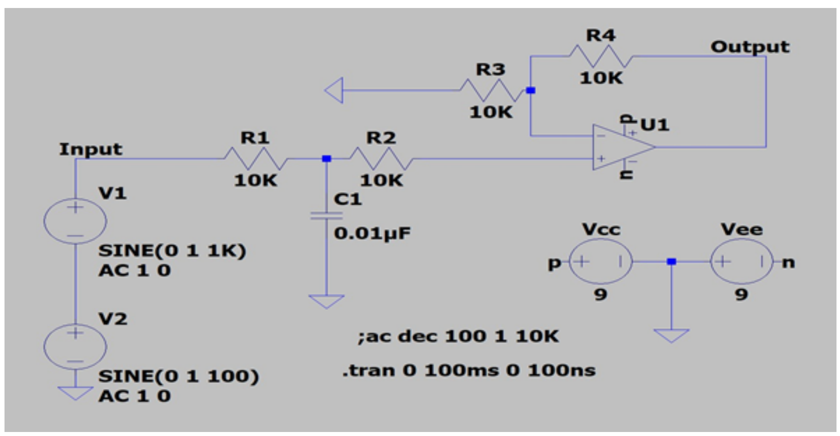


Figure 8: LPF circuit on LTSpice (Transient)

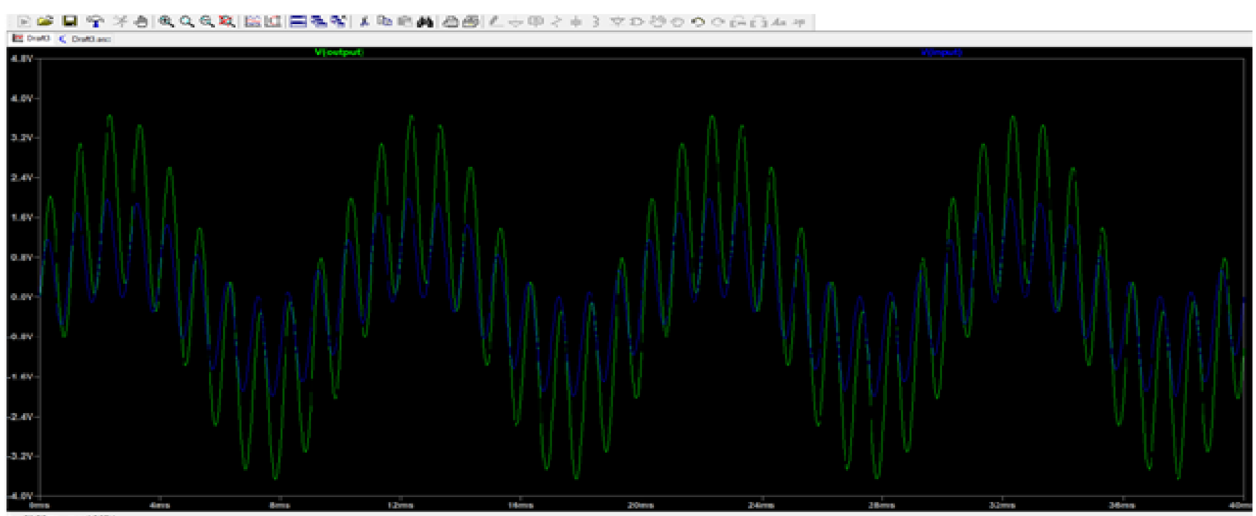


Figure 9: Graph of transient analysis

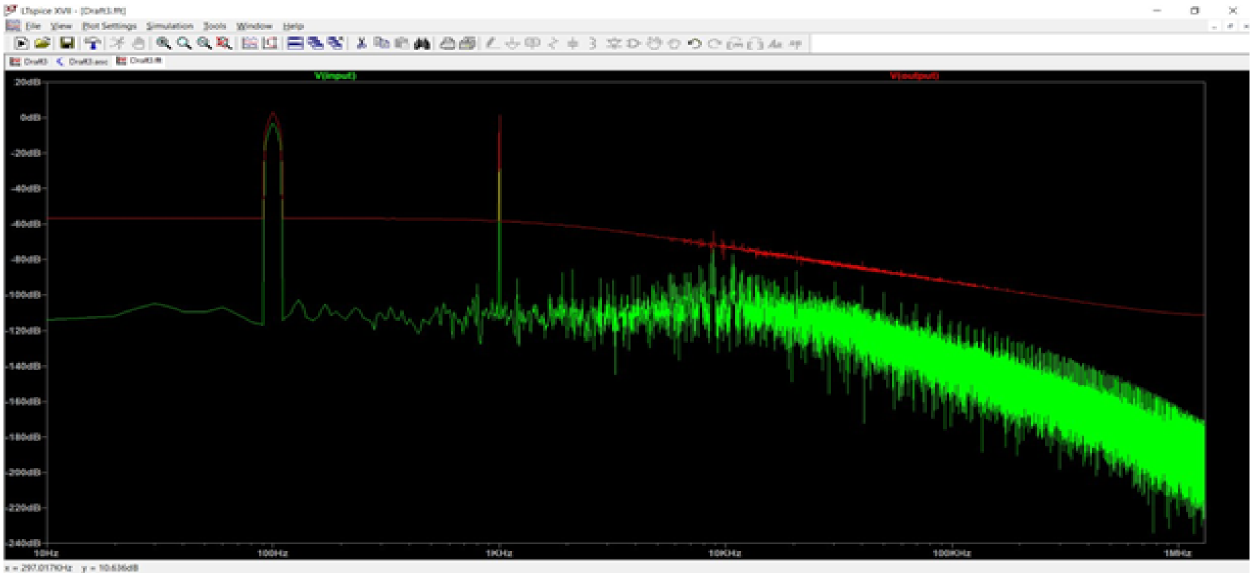


Figure 10: FFT of the transient waveform

➔ CIRCUIT - High Pass Filter
ASSIGNED TO - Hrushikesh Lad

High Pass Filter : A high-pass filter (HPF) is an electrical filter that allows signals with higher frequencies to pass while attenuating sounds with lower frequencies. The filter's design determines the amount of attenuation for each frequency. A linear time-invariant system is commonly used to simulate high-pass filters. A series connection of capacitor and resistor forms the fundamental High Pass Filter. The output of the capacitor is pulled across the resistor while the input signal is applied to it.

Calculations :

Taking Cutoff frequency =300khz

FC = 1 / 2 x 3.14 RC

C = 1 / 2 x 3.14 RF   taking R = 0.5 Kohms and FC = 300 KHz

C = 1 / 2 x 3.14 x 0.5 K x 300 KHz

C = 1.06uF

After these values were used to make the circuit in LTSpice.

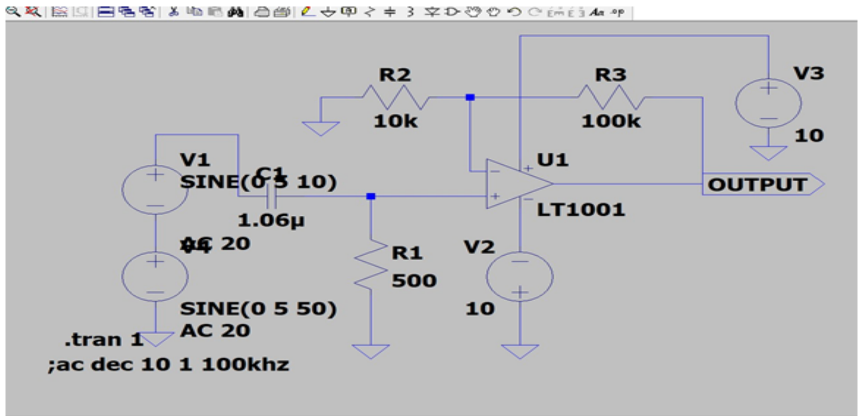


Figure 11: HPF circuit on LTSpice (Transient)

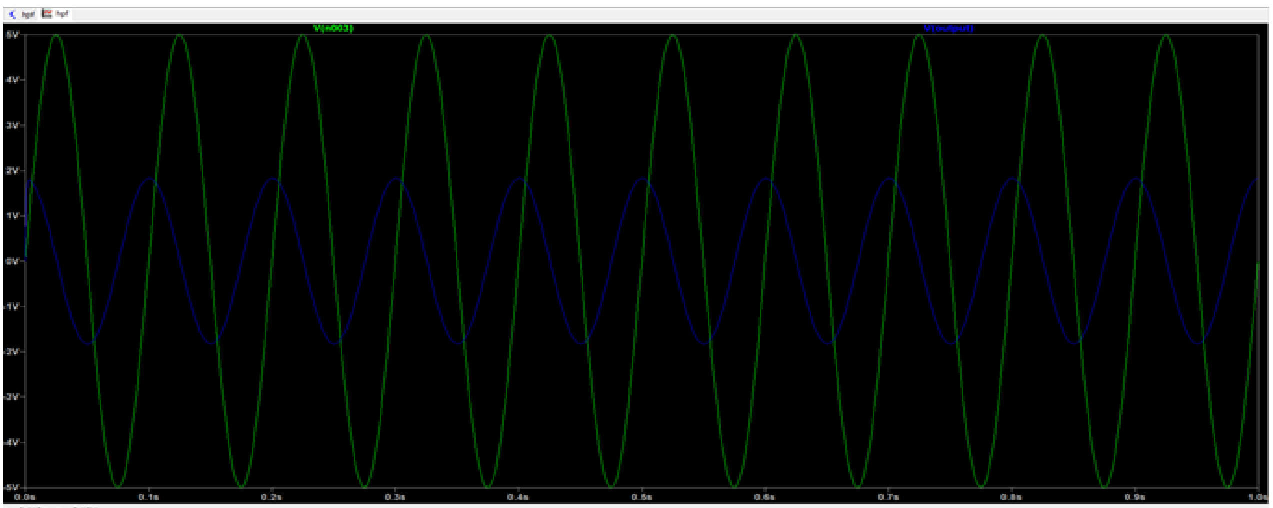


Figure 12: Frequency response graph

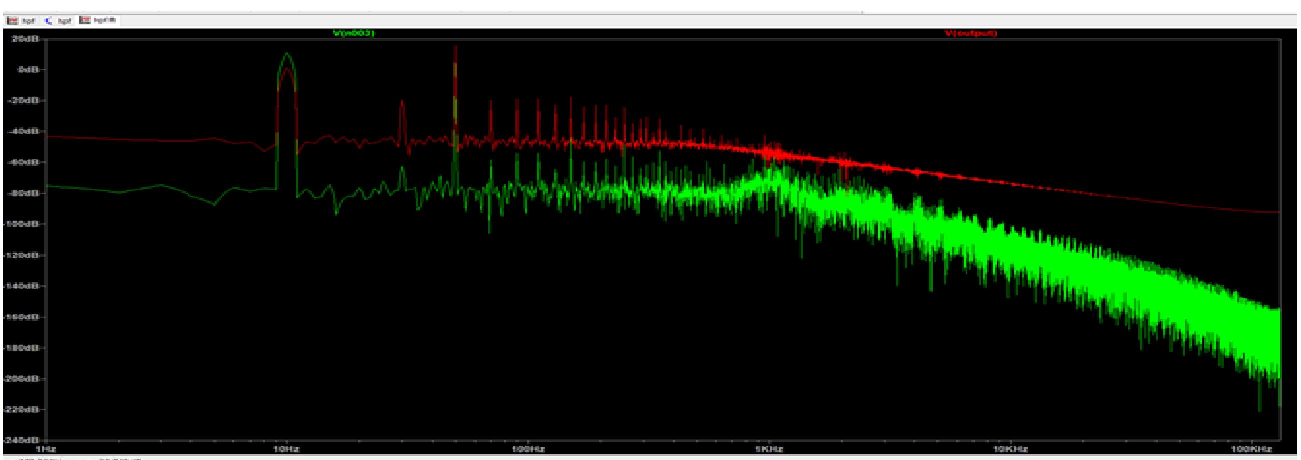


Figure 13: FFT of the transient waveform

➔ CIRCUIT - Notch Filter
ASSIGNED TO - Shlok Jagushte

Notch Filter : The stopband of a bandstop filter is a range of frequencies and this range can be small or large. A small stopband is called narrowband and a large stopband is called wideband. Similarly, a bandstop filter with a narrowband is called a notch filter and one with a wideband is called a band-reject filter. Basically, a notch filter is a bandstop filter with a narrow stopband, with a bandwidth of only around a few hertz. Figure 1 shows the behaviour of an ideal notch filter.

Calculations :

We are going to design a notch filter at 100Hz, with a = 2.

Given, Wn = 100Hz and a = 2.

Therefore, Wl = Wn/a = 100Hz/2 = 50Hz.

And, Wh = Wn x a = 100Hz x 2 = 200Hz.

For LPF, Wl = 1 / (2*pi*R*C)

Assume C = 0.1 uF

R = 1 / (2*pi*Wl*C) = 1 / (2*pi*50*0.1*10^-6) Ohm = 31.83 kOhm

For HPF, Wh = 1 / (2*pi*R*C)

Assume C = 0.047 uF

R = 1 / (2*pi*Wh*C) = 1 / (2*pi*200*0.047*10^-6) Ohm = 16.93 kOhm

<u>Cross Checking from final circuit:</u>
For LPF:
R = 34.8 kOhm and C = 0.1 uF
Wl = 1 / (2*pi*R*C) = 45.75 Hz
This value is close enough to our theoretical Wl = 50 Hz on the log scale.
For HPF:
R = 11.5 kOhm and C = 0.047 uF
Wh = 1 / (2*pi*R*C) = 294.45 Hz
This value is close enough to our theoretical Wh = 200 Hz on the log scale.

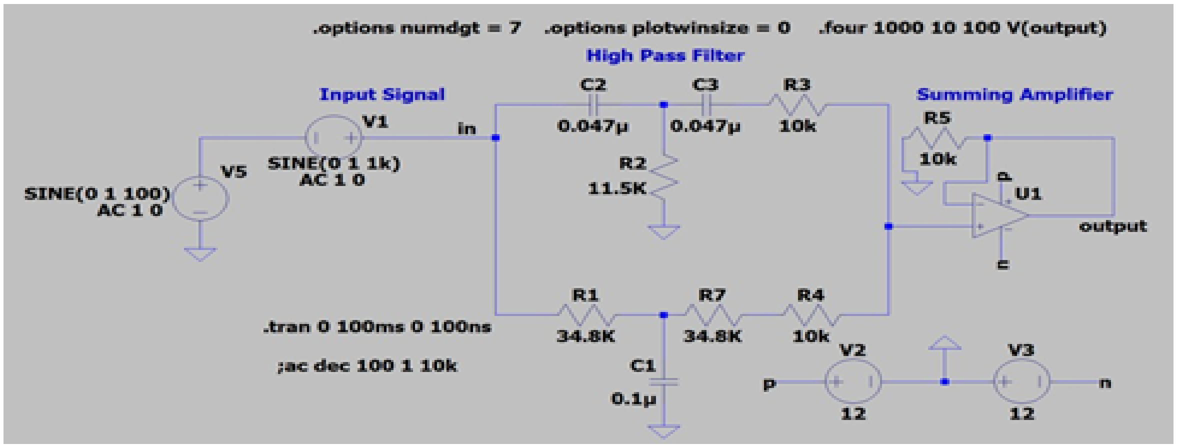


Figure 14: - Circuit diagram of a notch filter for 100Hz.

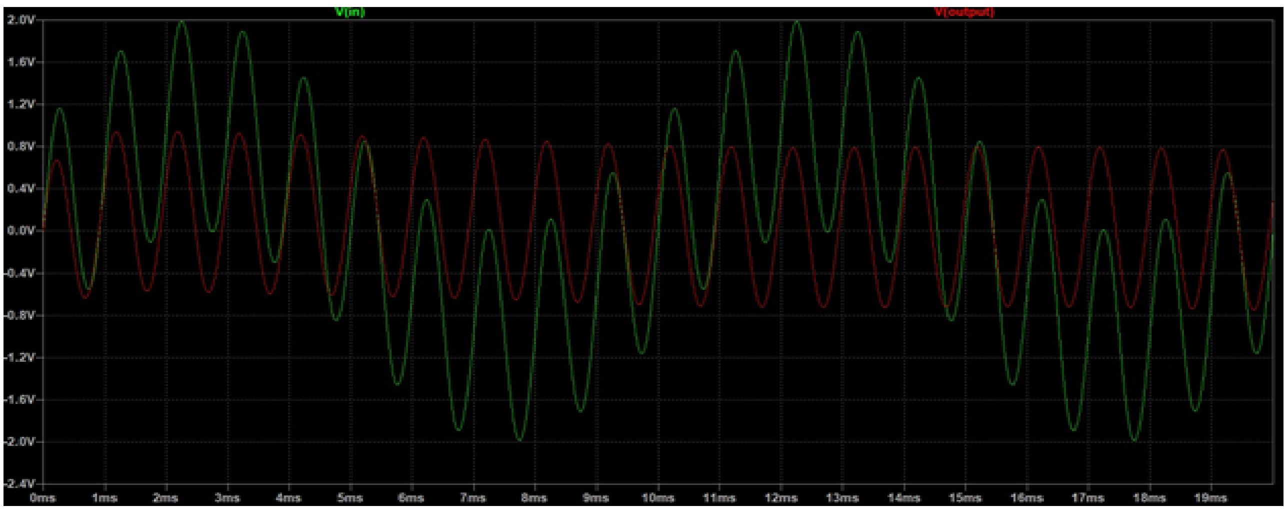


Figure 15: - Input and output waveforms for transient analysis.

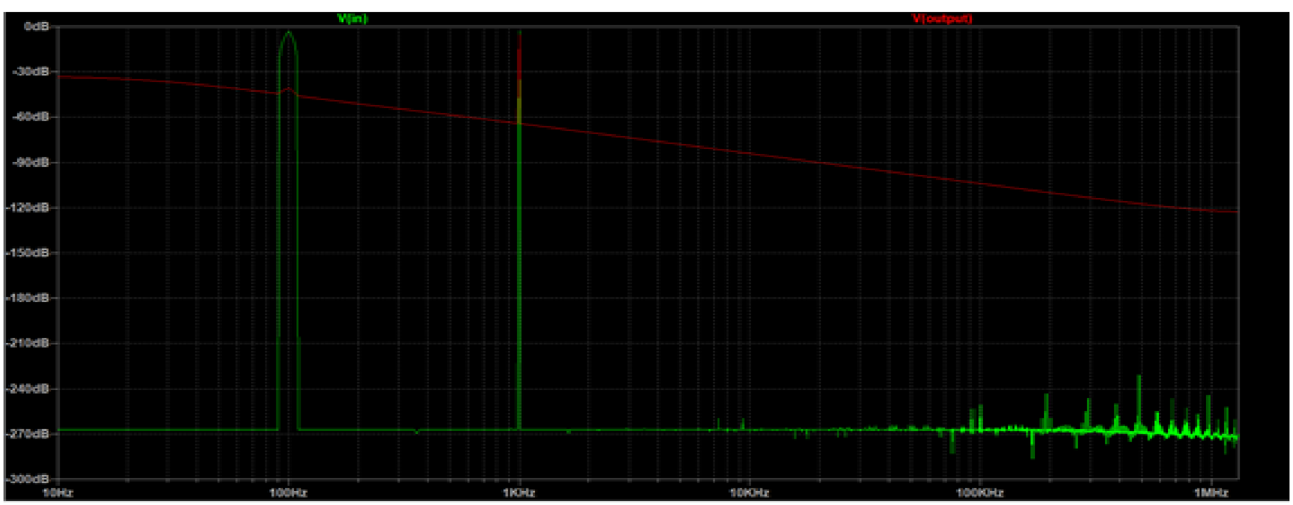


Figure 16: - FFT of the transient response.

➔ CIRCUIT - Comparator
ASSIGNED TO - Smriti Karn

Comparator : A comparator is a type of electrical circuit that compares two inputs and outputs a result. The comparator's output value indicates whether one of the inputs is more or smaller than the other. Please keep in mind that the comparator is a non-linear IC application. Because an op-amp has two input terminals, an op-amp-based comparator compares the two inputs that are applied to it and outputs the result of the comparison.

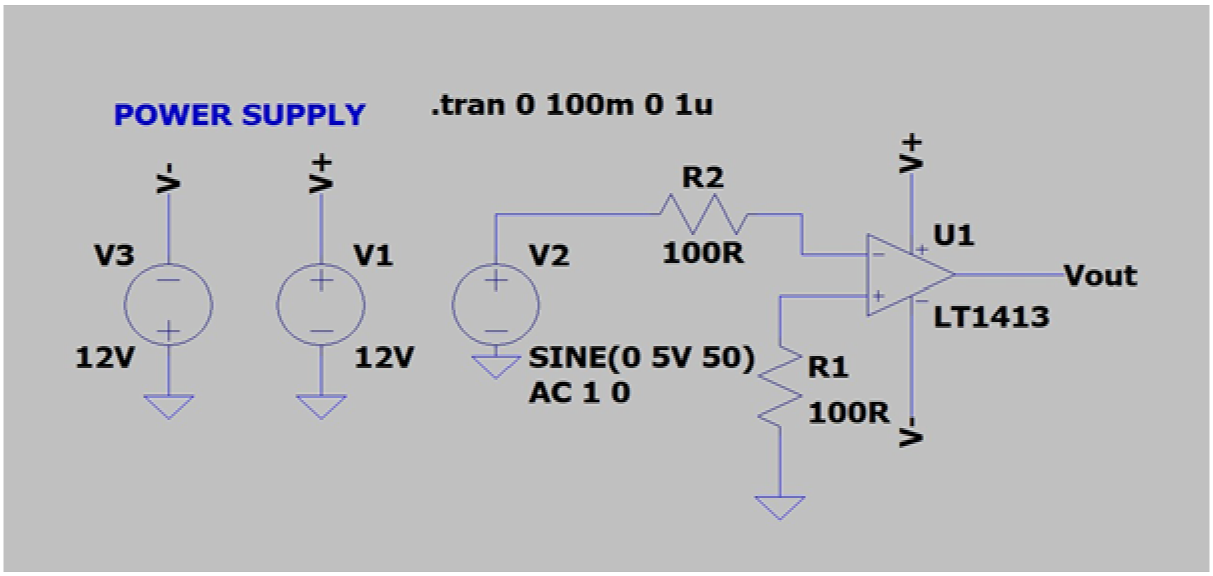


Figure 17: Comparator circuit on LTSpice

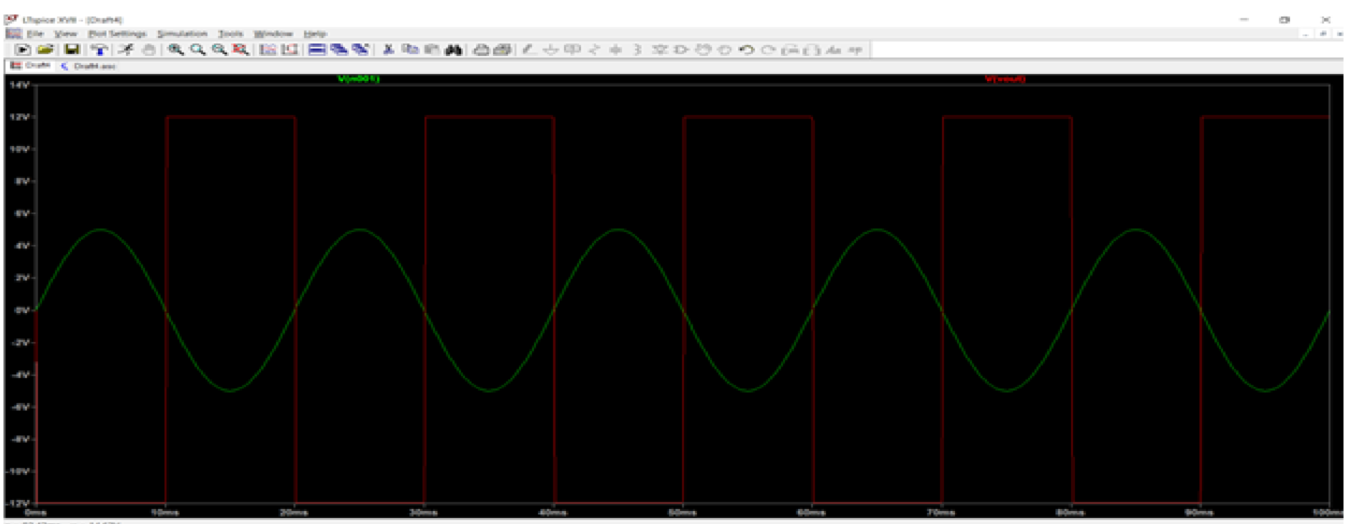


Figure 18: Graph of comparator circuit on LTSpice

TASK 4:

GOALS ASSIGNED -

1. Combining all the blocks.
2. Simulation of the denoising circuit and FFT analysis.
3. Design of a comparator and search for better alternatives.

➔ <u>STEPS INVOLVED IN MAKING THE CIRCUIT</u> -

1. To begin, all the previously studied circuits (non-inverting amplifier, low pass filter, high pass filter, notch filter, band pass filter and Schmitt trigger) are combined to create a denoising circuit.
2. Different combinations of the above said circuits were tried in every possible way in order to achieve the desired output, i.e., a denoised ECG signal.
3. The final denoising signal is then simulated in the LT Spice software to obtain the appropriate denoised ECG signal.
4. Next, we find the FFT of the obtained signal.

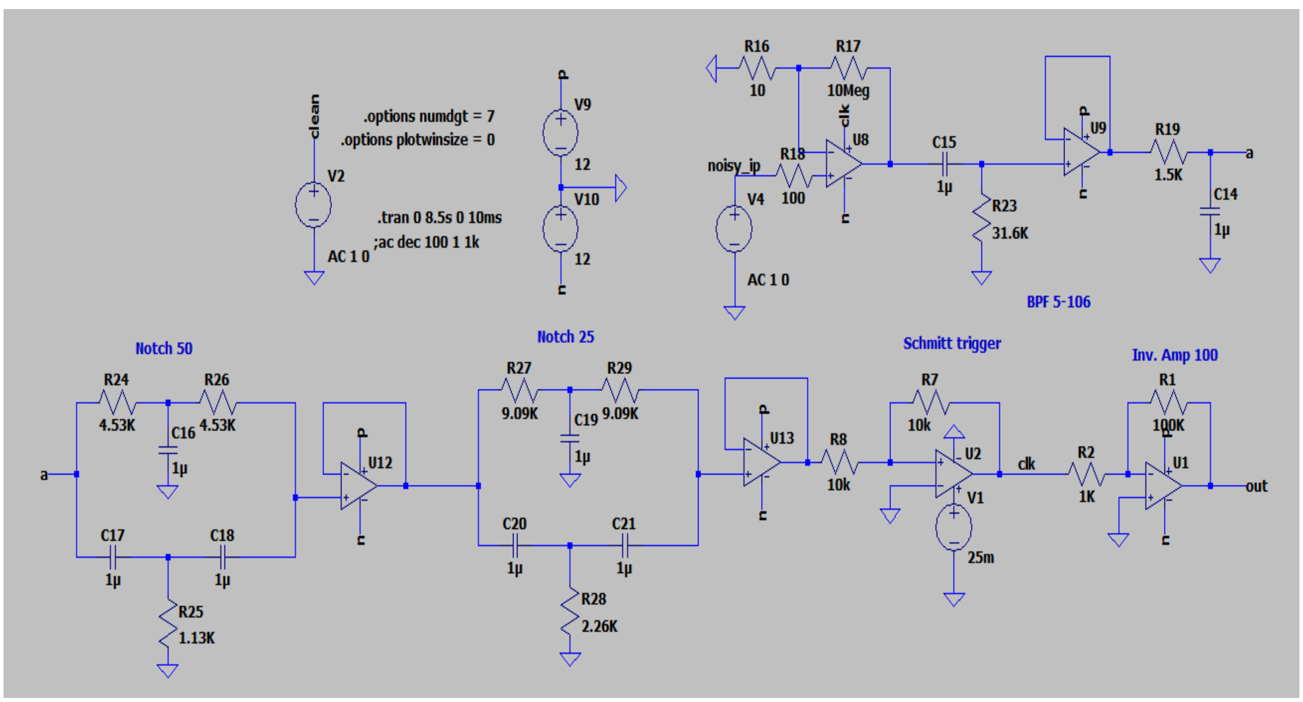


Figure 19: Denoising circuit on LTSpice

➔ BRIEF DESCRIPTION OF EACH SMALL CIRCUIT -

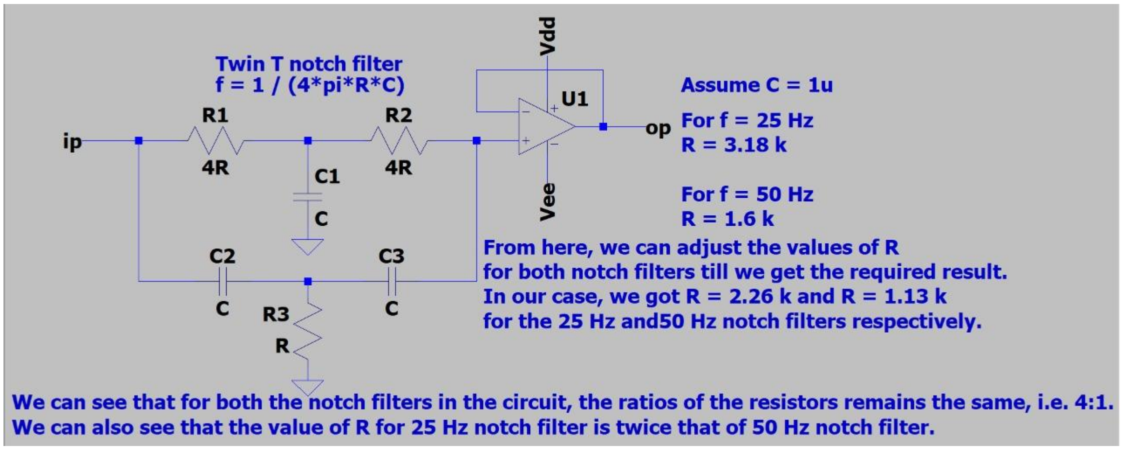
- NON- INVERTING AMPLIFIER CIRCUIT: An op-amp circuit arrangement that provides an amplified output signal that is in phase with the applied input signal is known as a non-inverting amplifier. In other words, a non-inverting amplifier acts as a voltage follower. Instead of feeding the entire output signal to the input, only a portion of the output signal voltage is given back as input to the inverting input terminal of the op-amp in a non-inverting amplifier. The non-inverting amplifier's high input and low output impedance make it perfect for impedance buffering applications.

  Calculation for amplifier -
  For non-inverting:-
  Given : Gain (Av) = 1000001
  So, Av = 1 + (R2/R1)
  1000001 = 1 + (R2/R1)
  R2/R1 = 1000001-1 = 1000000
  Therefore, R1 = 10ohm and R2 = 10M

  For inverting:-
  Given : Gain (Av) = -100
  So, Av = - R2/R1
  -100 = - R2/R1
  R2/R1 = 100
  Therefore, R1 = 1K and R2 = 100K

- NOTCH FILTER : A notch filter is a sort of band-stop filter that attenuates frequencies within a certain range while passing all other frequencies unchanged. This frequency range is quite small for a notch filter. The stopband refers to the frequency range that a band-stop filter attenuates. For a fixed-frequency noise source, such as line frequency (50 or 60 Hz) noise, notch filters can be useful on the command. Notch filters are also used to eliminate system resonances. Low-pass and notch filters can both cure resonance, but notch filters do so with less phase lag in the control loop.

Calculations for notch -



- <u>BAND PASS FILTER CIRCUIT</u>: A bandpass filter is an electrical device or circuit that permits signals between two frequencies to pass while rejecting signals at other frequencies. Active bandpass filters use active components like transistors and integrated circuits and require an external source of power. Wireless transmitters and receivers primarily use bandpass filters. The main purpose of such a filter in a transmitter is to keep the output signal's bandwidth to a bare minimum in order to send data at the acceptable speed and in the correct format.

  Calculation for BPF -
  Given : F_{high} = 5.04KHz, F_{low} = 106.15KHz, C1 = 1uF and C2 = 1uF
  F_{high} = 1 / 2 x 3.14 x R1.C1
  R1 = 1 / 2 x 3.14 x F_{high}.C1
  R1 = 1 / 2 x 3.14 x 5.04 x 10^3 x 10^-6 = <u>31.6 KHz</u>

  Flow = 1 / 2 x 3.14 x R2.C2
  R2 = 1 / 2 x 3.14 x Flow. C2
  R2 = 1 / 2 x 3.14 x 106.15 x 10^3 x 10^-6 = <u>1.5 KHz</u>

- <u>SCHMITT TRIGGER CIRCUIT</u>: A Schmitt Trigger is a hysteresis comparator circuit that uses positive feedback on the comparator or differential amplifier's non inverting input. To avoid noise in the input signal, a Schmitt Trigger uses two inputs with distinct threshold voltage levels. Hysteresis is the result of this dual-threshold activity. Even with a noisy input signal, the Schmitt trigger produces accurate output. The upper threshold voltage (VUT) and the lower threshold voltage (VLT) are the two threshold voltages used (VLT).

➔ OUTPUT -

The output obtained was remarkably similar to the given sample signal.

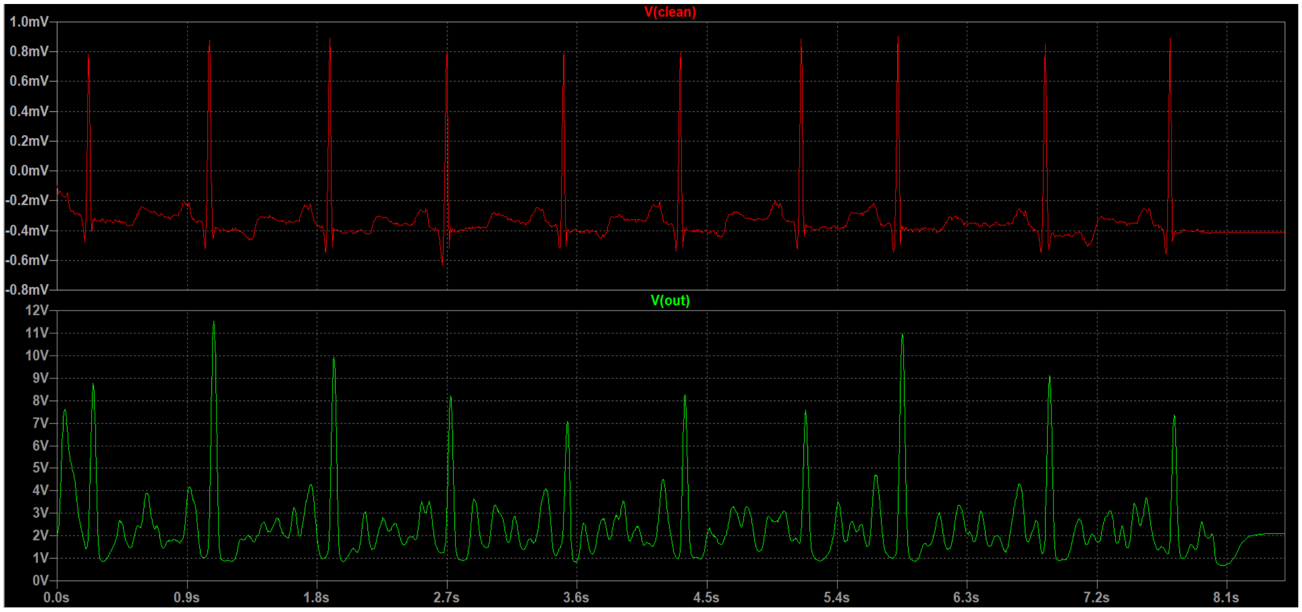


Figure 20: Graph/ Signal of the denoising circuit

➔ FFT ANALYSIS -

1. In the noisy signal (blue), there were prominent peaks at 25Hz and 50Hz, these are undesirable noises that we wish to remove. Similarly, all the disturbance after 100Hz is not required. Hence, we deploy relevant filters to remove these noises.
2. In the output signal (red), we can see that the noise spikes at 25Hz and 50Hz are absent and thus those noise components are removed. This denoised output (red) has a remarkably similar FFT waveform to the reference signal (green).

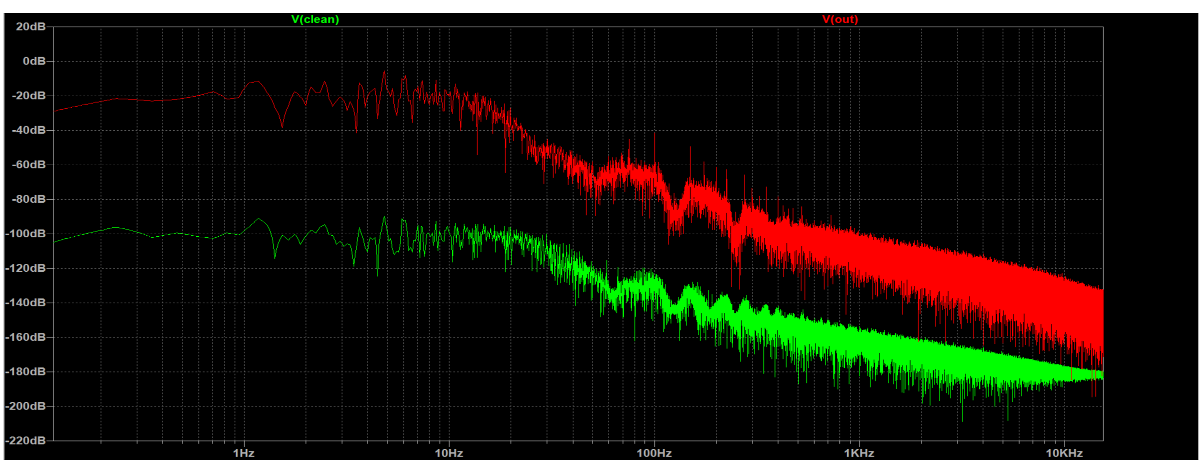


Figure 21: FFT of the signal obtained on LTSpice.

➔ COMPARATOR ALTERNATIVES -

1. Comparators are frequently used to determine whether an input has achieved a predetermined value. A comparator is usually implemented with a dedicated comparator IC, but op-amps can also be used. The symbols used in comparator and op-amp diagrams are the same.
2. So, Op-amps and clipper circuits can be used as an alternative for comparator circuits in the ECG denoising circuit.

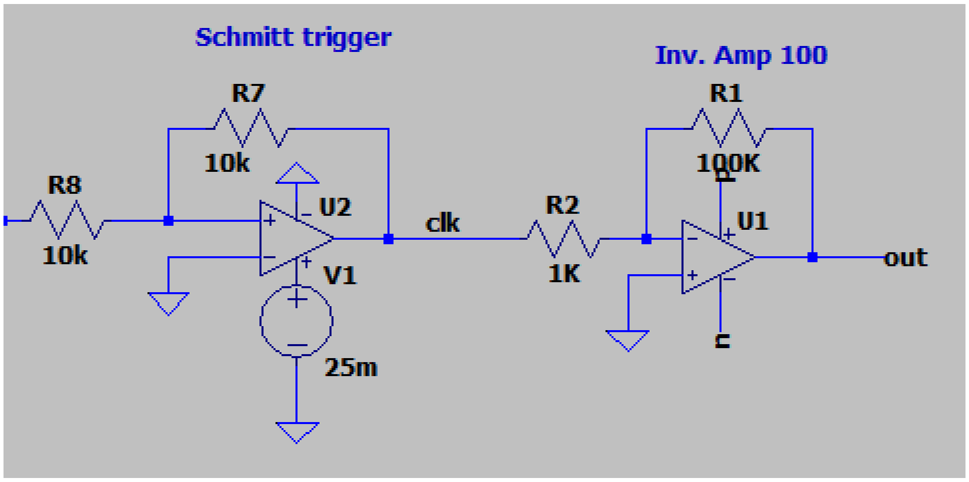


Figure 22: Denoising comparator

PROBLEMS ENCOUNTERED :

1. **Problem:** The output does not match the intended result. The filters are not performing as expected.
   Diagnosis: The input signal is very small causing the filters to give incorrect results.
   Solution: Increase the gain of the initial amplifier.

2. **Problem:** Active filters are not providing enough attenuation to give proper output.
   Diagnosis: Active filters, especially active notch filters, have a less steep signal attenuation. Passive filters have a steeper slope.
   Solution: Use passive notch filters instead of active notch filters.

3. **Problem:** The comparator at the end only gives rectangular pulses signifying R peaks at output. We are losing P1c waves, T waves and the QRS complex.
   Diagnosis: The output of a comparator is generally in the form of pulses.
   Solution: Use the pulses obtained from the comparator as a switching signal for the initial amplifier.

4. **Problem:** The output achieved at the comparator is inverted.
   Diagnosis: The initial amplifier has higher Vee which results in inversion of output.
   Solution: Add an inverting amplifier to achieve the desired output.

TASK 5:

GOALS ASSIGNED -

1. Combining the whole circuit.

➔ <u>CIRCUIT ON LT SPICE</u> -

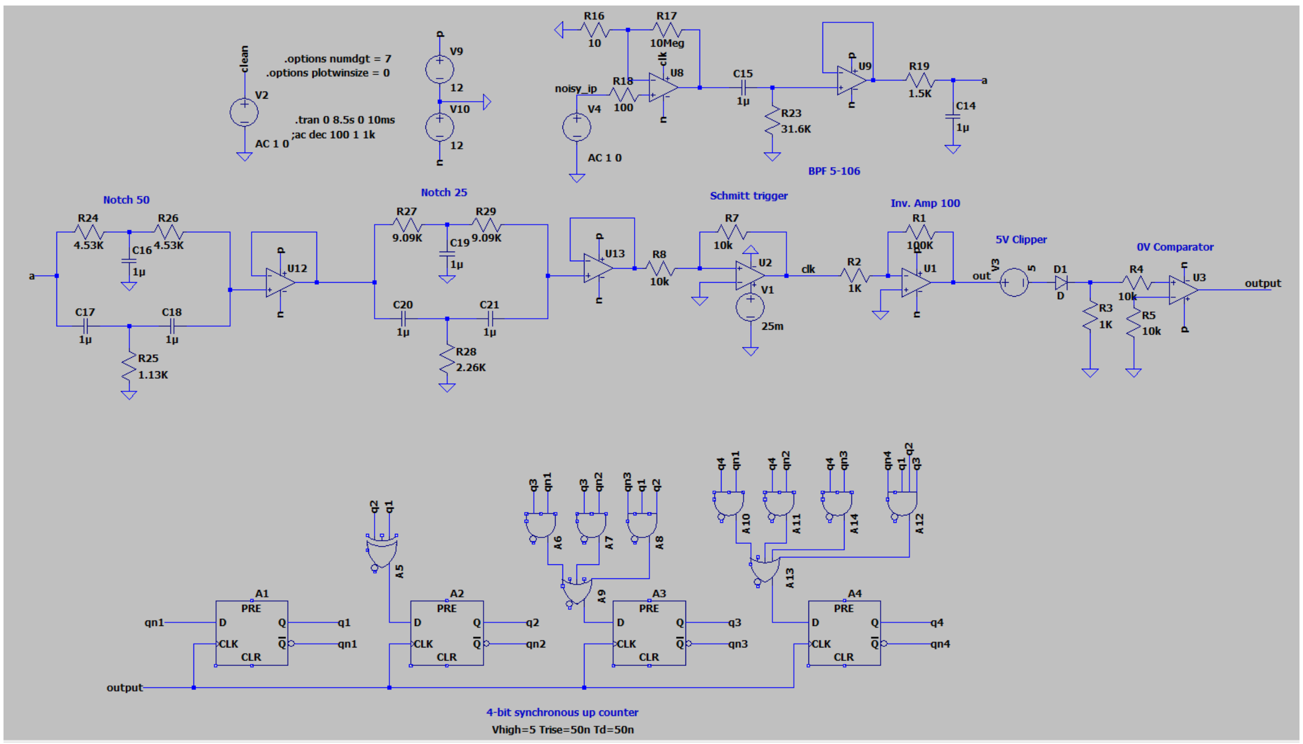


Figure 23: Circuit on LTSpice

➔ <u>COMPARATOR</u> : A comparator is a type of electrical circuit that compares two inputs and outputs a result. The comparator's output value indicates whether one of the inputs is more or smaller than the other. Please keep in mind that the comparator is a non-linear IC application. Because an op-amp has two input terminals, an op-amp-based comparator compares the two inputs that are applied to it and outputs the result of the comparison.

➔ Addition of a clipper circuit (used in place of a comparator) and digital counting interface were made in the existing denoising circuit to differentiate R peaks from the denoised signal.

➔ CLIPPER CIRCUIT : These are the circuits that clip off or remove a portion of an input signal, without causing any distortion to the remaining part of the waveform. Clippers are basically wave shaping circuits that control the shape of an output waveform.

Here, a clipper circuit was used to clip off or extract the R peaks from the denoised signal. After extraction of R peaks by the clipper circuit, they were converted into rectangular pulses for easier counting.

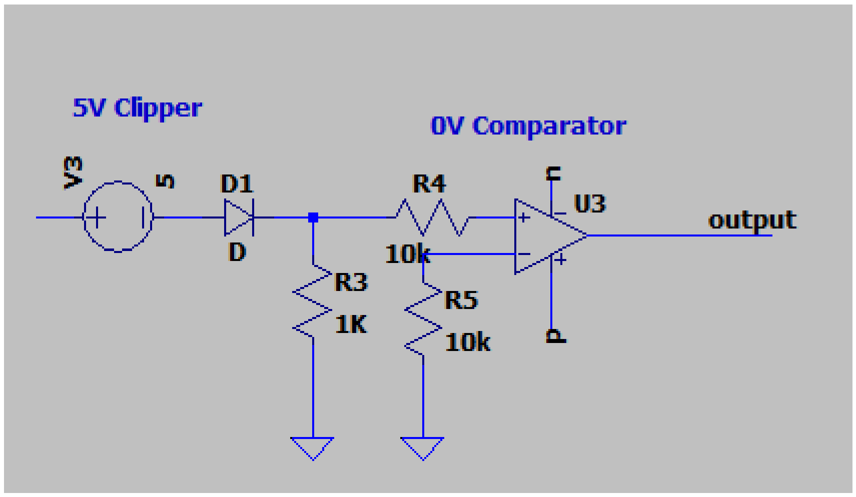


Figure 24: R peak counter circuit

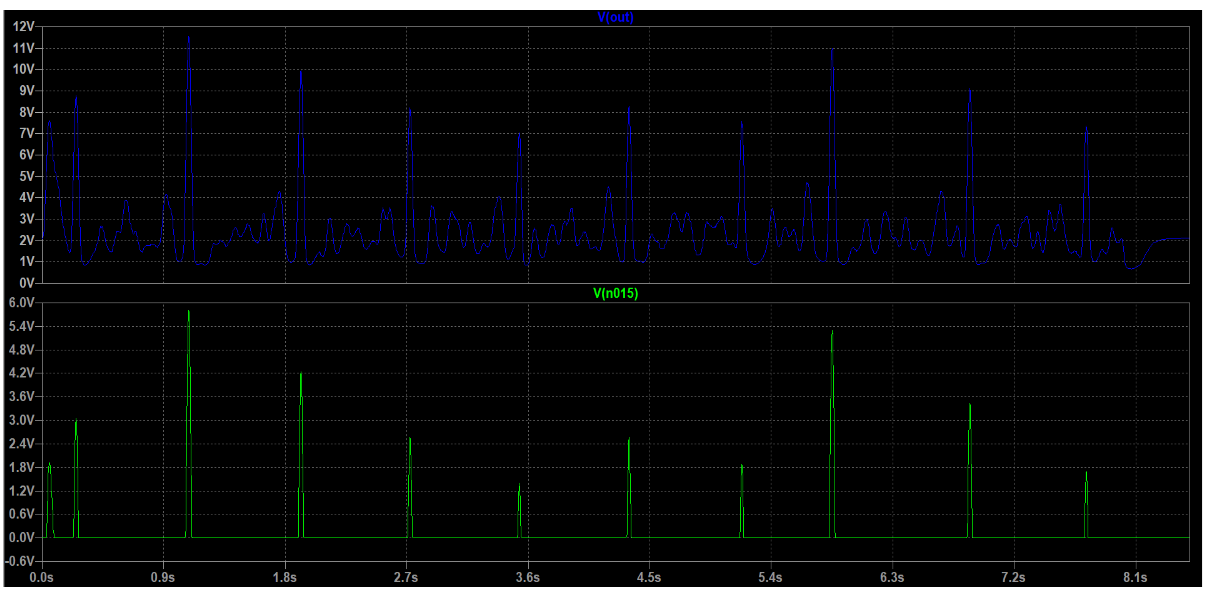


Figure 25: R peak isolated output graph

Figure 26: R peak detector output

➔ <u>DIGITAL COUNTING INTERFACE</u> : Digital counters perform a variety of counting functions. In addition to the number and types of functions, these electronic devices differ in terms of count direction and reset functions.

Here, a digital counting interface was a 4 bit synchronous up counter. The clock pulses for this counter was the output of the comparator which were the R peaks we extracted from the previous circuit. The output of the counting interface was a binary counter which counted the total number of R peaks (heartbeat) which numbered 11.

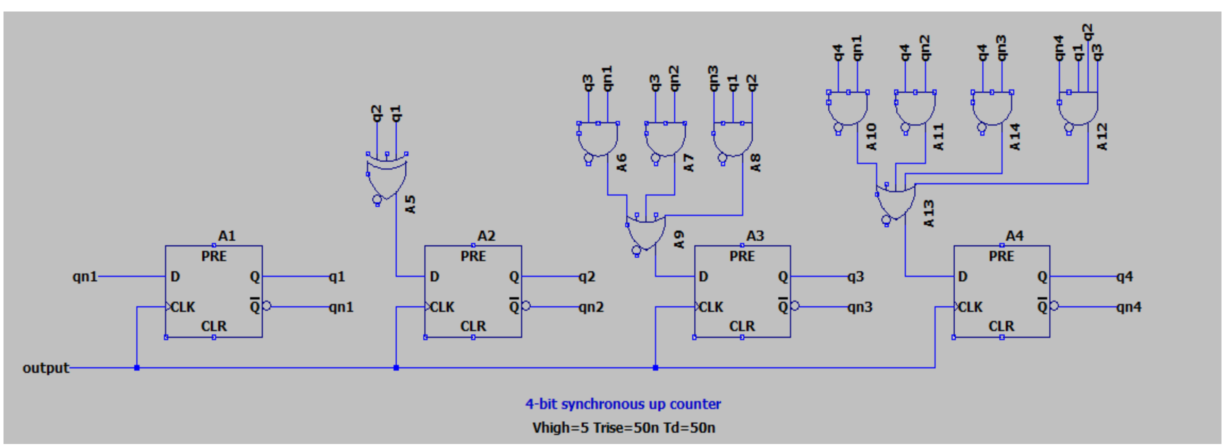


Figure 27: Digital display circuit

Calculations:

EXCITATION STATES:

Present State				Next State				Excitation states			
q4	q3	q2	q1	q4	q3	q2	q1	D4	D3	D2	D1
0	0	0	0	0	0	0	1	0	0	0	1
0	0	0	1	0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	1	0	0	1	1
0	0	1	1	0	1	0	0	0	1	0	0
0	1	0	0	0	1	0	1	0	1	0	1
0	1	0	1	0	1	1	0	0	1	1	0
0	1	1	0	0	1	1	1	0	1	1	1
0	1	1	1	1	0	0	0	1	0	0	0
1	0	0	0	1	0	0	1	1	0	0	1
1	0	0	1	1	0	1	0	1	0	1	0
1	0	1	0	1	0	1	1	1	0	1	1
1	0	1	1	1	1	0	0	1	1	0	0
1	1	0	0	1	1	0	1	1	1	0	1
1	1	0	1	1	1	1	0	1	1	1	0
1	1	1	0	1	1	1	1	1	1	1	1
1	1	1	1	0	0	0	0	0	0	0	0

K – MAPS:

1. D1

q4 q3 \ q2 q1	00	01	11	10
00	1	0	0	1
01	1	0	0	1
11	1	0	0	1
10	1	0	0	1

D1 = q1’

2. D2

q4 q3 \ q2 q1	00	01	11	10
00	0	1	0	1
01	0	1	0	1
11	0	1	0	1
10	0	1	0	1

D2 = q2’q1 + q2q1’

= q2 (+) q1

3. D3

q4 q3 \ q2 q1	00	01	11	10
00	0	0	1	0
01	1	1	0	1
11	1	1	0	1
10	0	0	1	0

D3 = q3q2’ + q3q1’ + q3’q2q1

4. D4

q2 q1 / q4 q3	00	01	11	10
00	0	0	0	0
01	0	0	1	0
11	1	1	0	1
10	1	1	1	1

$$D4 = q4q3' + q4q2' + q4q1' + q4'q3q2q1$$

Output:-

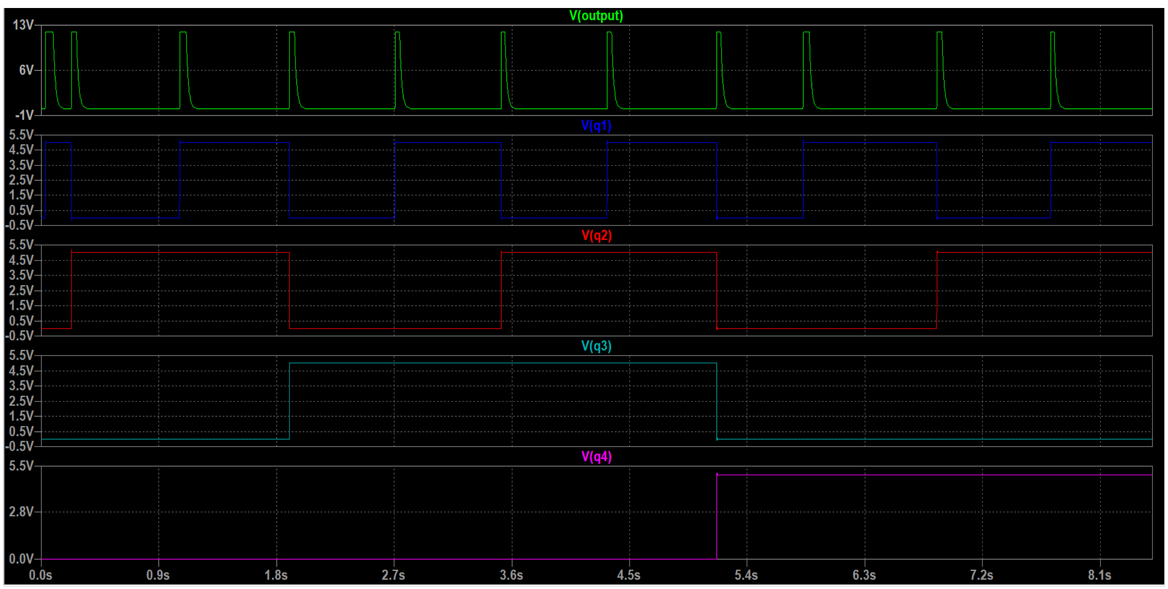


Figure 28: R peak counter display Output graph of the denoising circuit

➔ FFT ANALYSIS :

1. In the noisy signal (blue), there were prominent peaks at 25Hz and 50Hz, these are undesirable noises that we wish to remove. Similarly, all the disturbance after 100Hz is not required. Hence, we deploy relevant filters to remove these noises.
2. In the output signal (red), we can see that the noise spikes at 25Hz and 50Hz are absent and thus those noise components are removed. This denoised output (red) has a remarkably similar FFT waveform to the reference signal (green).

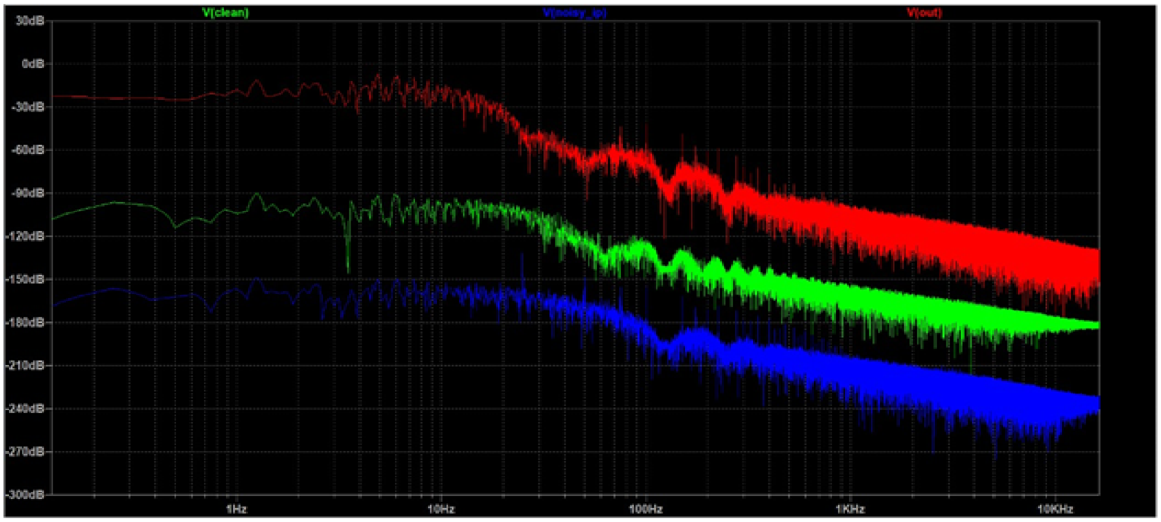


Figure 29: FFT of the signal obtained on LTSpice.

<u>PROBLEMS ENCOUNTERED</u> :

1. **Problem:** The logic gates and flip flops in the digital counting interface are not performing as expected.
   Diagnosis: Parameters like Vhigh, Trise and Td were not defined, which caused problems in the circuit.
   Solution: Right click on the logic gates/ flip flops and set the Value field to "Vhigh = 5 Trise = 50n Td = 50n".

CONCLUSION :

1. Research and study about ECG signals, types of noise affecting ECG signals and basic circuits of operational amplifiers were done successfully.
2. Exploring LTSpice and running basic circuits on it was completed.
3. Individual small circuits of non-inverting amplifiers, low pass filter, high pass filter and notch filter were studied.
4. Values of components to be used in the circuits mentioned above were calculated and found to complete the circuits and were successfully simulated on LTSpice.
5. FFT of the signal of each small circuit was determined.
6. Several combinations of the circuits were tried to form the final denoising circuit.
7. After forming the final denoising circuit, a comparator circuit was added to it for comparing the inputs to the signal.
8. FFT of the final signal was determined and added to the report.