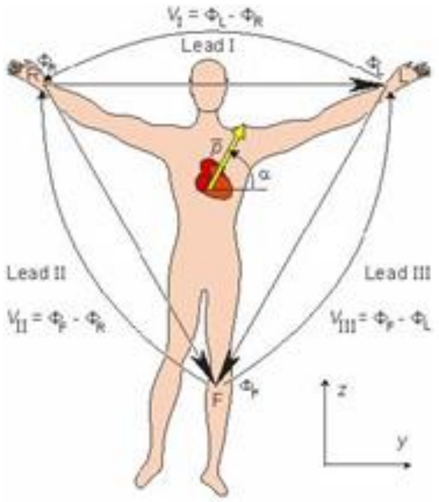


# ECG AMPLIFIER

ECAD LAB PROJECT

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Btech ECE,Sem III

# 1) <u>Introduction</u>

The electrocardiogram (EKG or ECG) is a graph that records the electrical activity of the heart. Its amplitude has a range of 0.1mV-10mV; while its frequency falls into 0.05Hz-120Hz. ECG waveform is an important source for a person's heart health. ECG bio-signal conditioning (BC) is critical because it directly affects measurement accuracy, reliability, and repeatability. Thus for correct evaluation, a precise instrument is needed to make measurement. The small amplitude of ECG raw signals and their ease of corruption with noise and other disturbances makes it challenging.

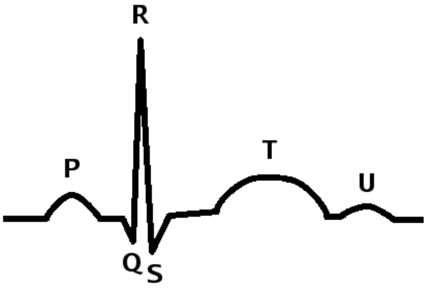



*Figure 1QRS COMPLEX*

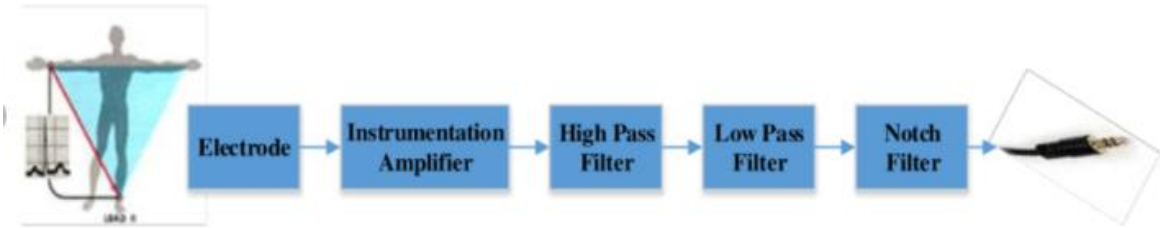



*Figure 2Block Diagram*

In this project , we aim to describe how an ECG bio-signal conditioning circuitry can be designed. The input signal is read from the right arm and the left arm of the patient and fed to the circuit. The right leg of the patient will act as the ground. The circuit will have noises due to factors such as power line interference, electrode pop or contact noise, patient- electrode motion artifacts, Electromyographic (EMG) noise, Baseline wandering, etc. To effectively remove unwanted noise and preserve the useful components of ECG signals, the circuit consists of the following:

- An instrumentation amplifier to amplify the ECG signal obtained from the potential difference between the right and left arm electrodes.
- A low-pass filter to remove high frequency noise.
- A high-pass filter to remove the very low frequency noises.
- A notch filter to filter out the power line interference.
- A half-wave rectifier to remove the negative signal.

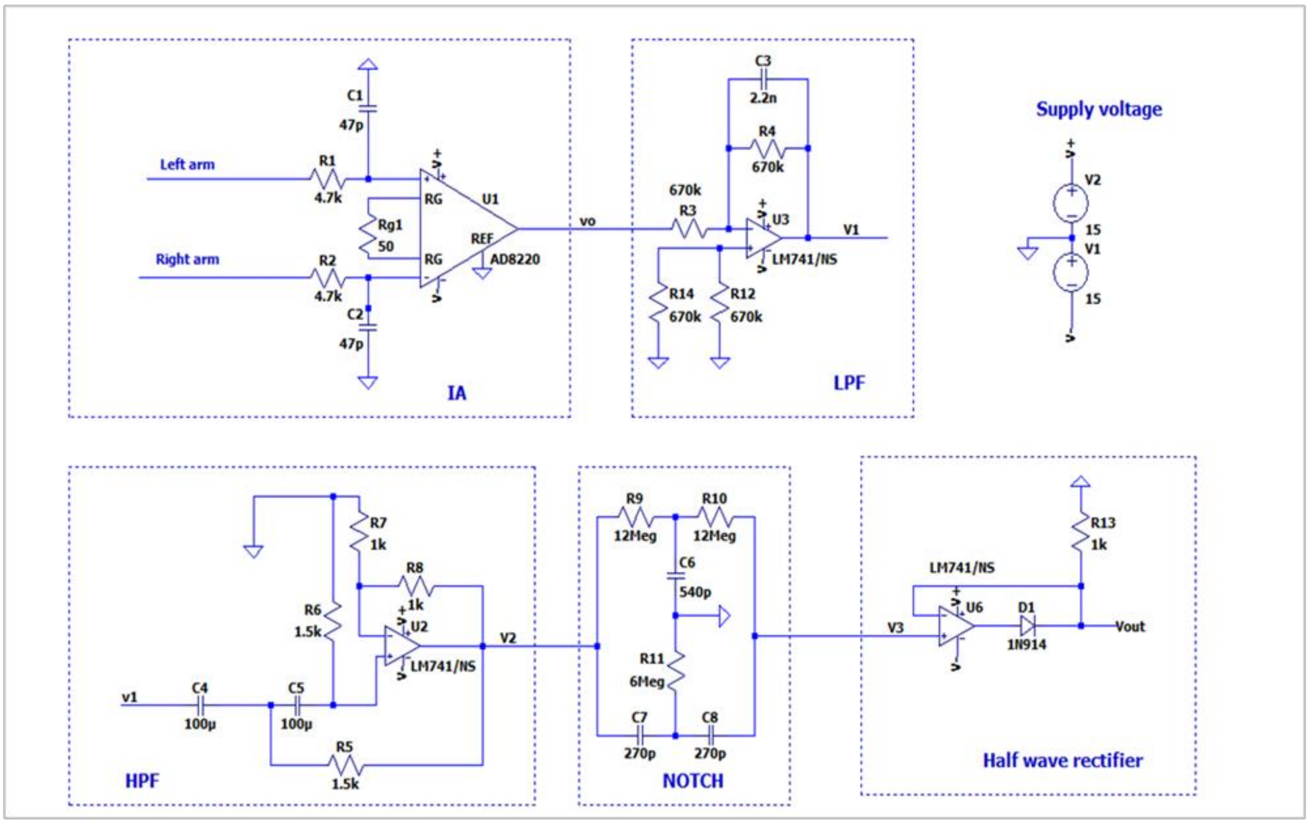



*Figure 3Circuit Diagram*

## 2) <u>Circuit Design</u>

For the ECG amplifier, we need to design the following:

- An amplifier
- A low-pass filter
- A high-pass filter
- A notch filter
- A half-wave rectifier

We also need to choose a suitable op-amp and an instrumentation amplifier for the circuit.

**<u>Instrumentation Amplifier Chosen:</u>**

The instrumentation amplifier chosen is AD8220. It has a very low input bias current of 10pA and a low input offset current of 0.6pA. It has a good CMRR of 100dB and a high small signal bandwidth of 1.5MHz.

**<u>Opamp Chosen:</u>**

The op-amp chosen is LM741. The slew rate of LM741 is 0.5V/µs. The input offset voltage is 0.8mV. Its main applications are as comparators multivibrators, DC Amplifiers, summing amplifiers, integrator or differentiators and as active filters. Its operating temperature is between -50 to 125°C. LM741 is an easily available op-amp at a considerable price.

## i) Amplifier Circuit

The ECG signal is a very weak signal with a range of 1mV in amplitude. Since the amplitude of the signal is very small, it needs to be amplified with a very high gain of about 1000. This high gain is attained using the instrumentation amplifier, AD8220. The input signal can be first passed through an RC circuit to filter out the noise due to very high frequencies.

The table given below show the value of gain obtained against the various values of $R_G$.

| 1% Standard Table Value of $R_G$ (Ω) | Calculated Gain |
|---|---|
| 49.9 k | 1.990 |
| 12.4 k | 4.984 |
| 5.49 k | 9.998 |
| 2.61 k | 19.93 |
| 1.00 k | 50.40 |
| 499 | 100.0 |
| 249 | 199.4 |
| 100 | 495.0 |
| 49.9 | 991.0 |

As given in the datasheet, the value of $R_G$ for the required gain can be calculated as:

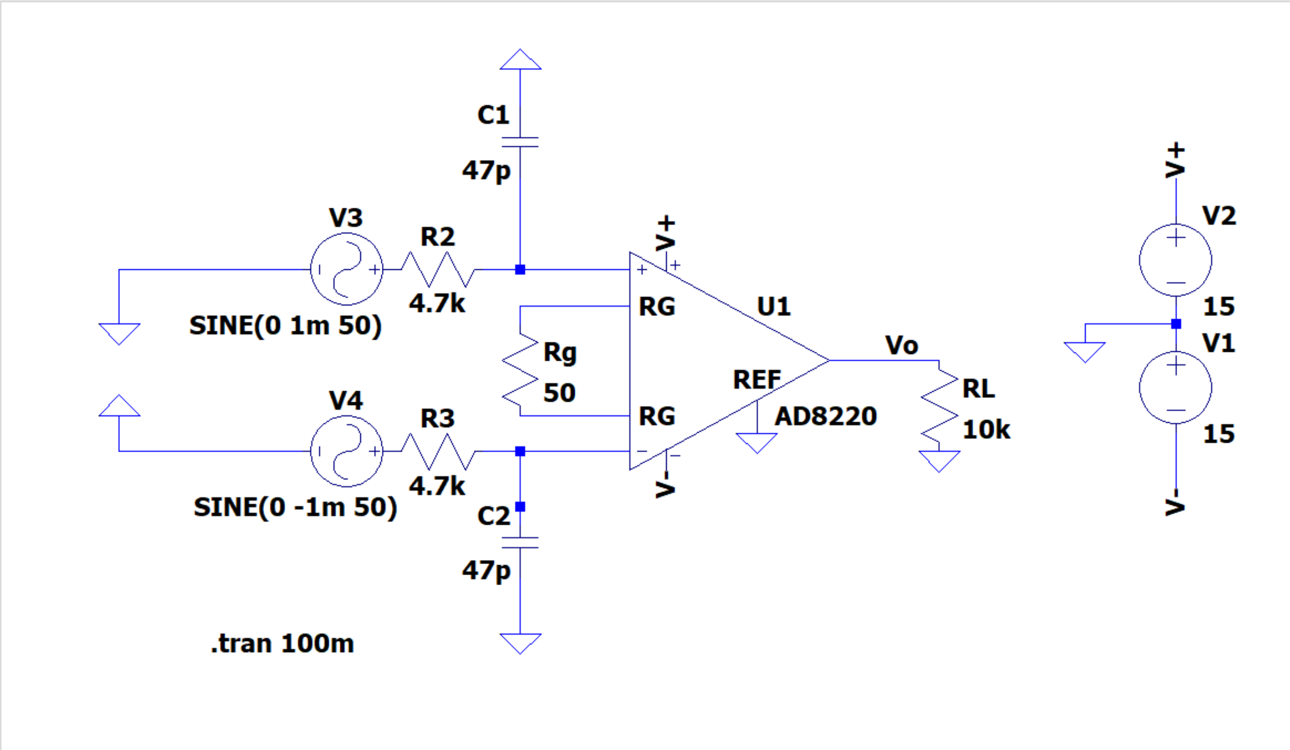
$$R_G = \frac{49.4\ \mathrm{k\Omega}}{G-1}$$

Where G is the required gain.

Here, we require a gain of 1000.
Therefore, $R_G = 49.4\mathrm{k\Omega}/(1000-1) = 50\Omega$

The capacitor and resistance values chosen for the low pass filter provided at the beginning of the circuit is given by:
R2 = R3 = 4.7kΩ
C1 = C2 = 47pF

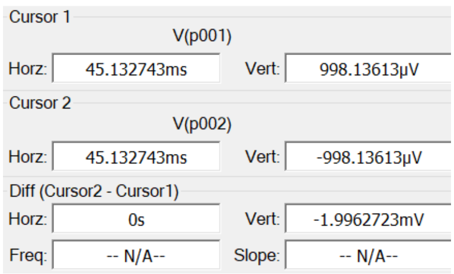
## Circuit Diagram:



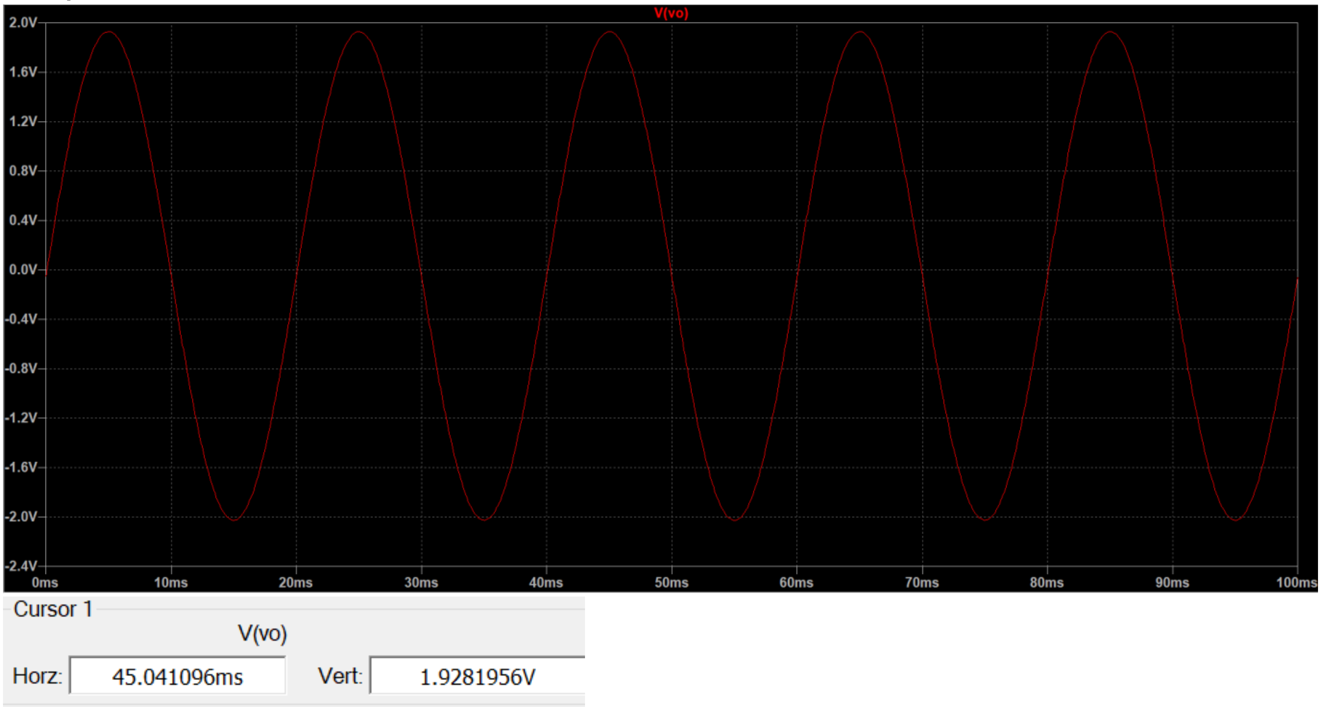

## Simulation using Ltspice:

Input Voltage Waveform:


The difference between the amplitude of two input voltages = 1.9962723mV



Output Waveform:




The peak of the output waveform = 1.9281956V

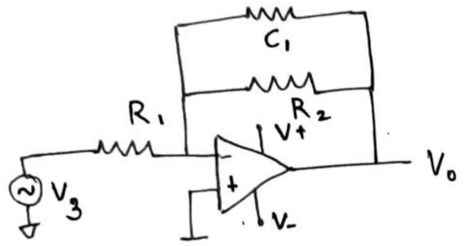
Gain obtained = 1.9281956V/1.9962723mV = 965.8980892

= 1000(approx.)

## ii) Low Pass Filter:

The ECG signals have a frequency below 120Hz. Therefore, we need a low pass filter which can filter out the high frequency noises above 100Hz.

Here, an active low pass filter is designed with a cut-off frequency of about 100Hz.




Choosing $C_1 = 2.2nF$

Cut-off frequency $= \dfrac{1}{2\pi R_2 C_1}$

$= 100$

$$R_2 = \frac{1}{2\pi C_1 \times 100}$$

Taking the standard value of $R_2$,

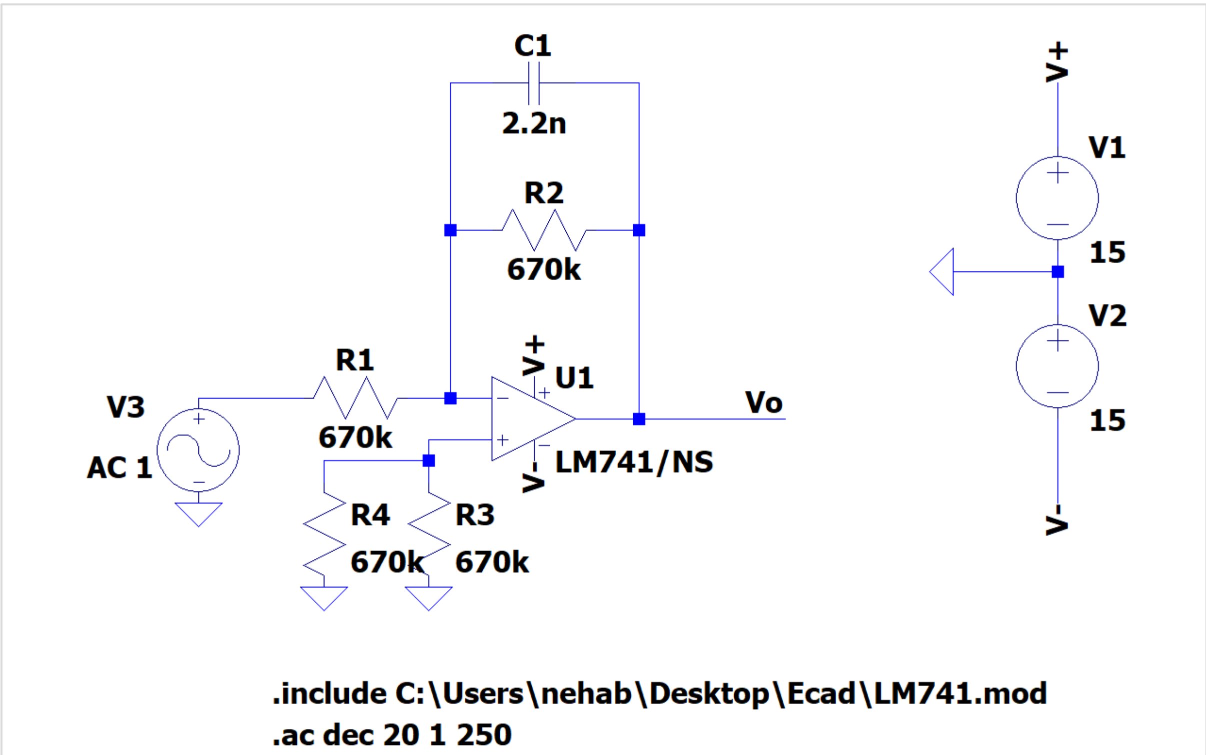
$R_2 = 670k\Omega$

For a gain of 1, $R_1$ can be chosen as:

$R_1 = 670k\Omega$

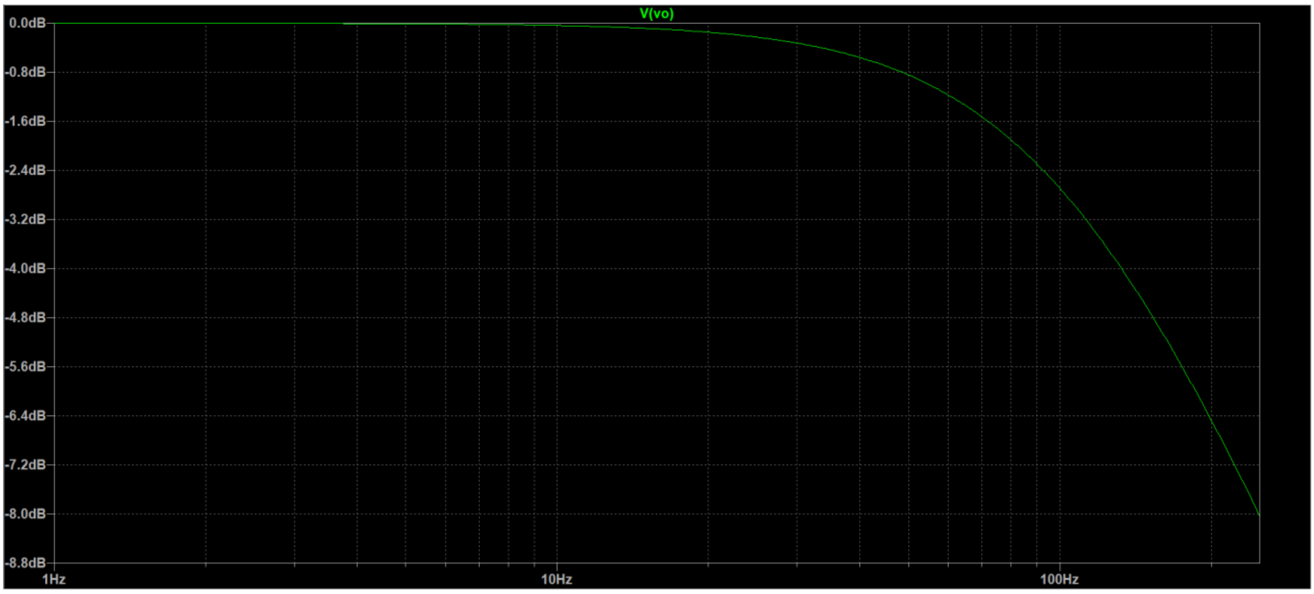
To avoid error in output voltage due to input bias current, a resistor can be provided at the positive terminal of the opamp, whose value should be equal to $R_1 // R_2$.

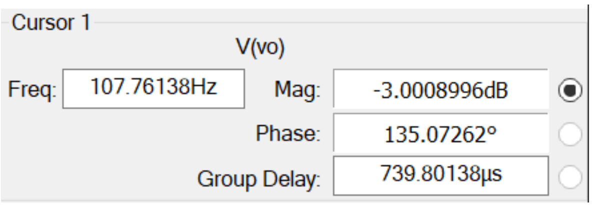
## Circuit Diagram:



**Simulation using LtSpice:**

<u>Transient Analysis:</u>



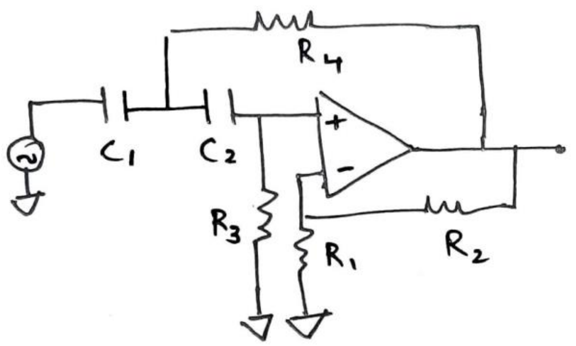




Cut-off frequency = frequency at -3dB = 107.76138Hz

## iii) High Pass Filter

The ECG signals have a frequency above 0.5Hz. Therefore, we need a high pass filter which can filter out the low frequency noises above 100Hz.

Here, a second order sallen key high pass filter is designed with a cut-off frequency of about 1Hz.




For a second-order Sallen Key High Pass Filter,

$$\text{Cut-off frequency} = \frac{1}{2\pi\sqrt{R_3 R_4 C_1 C_2}}$$

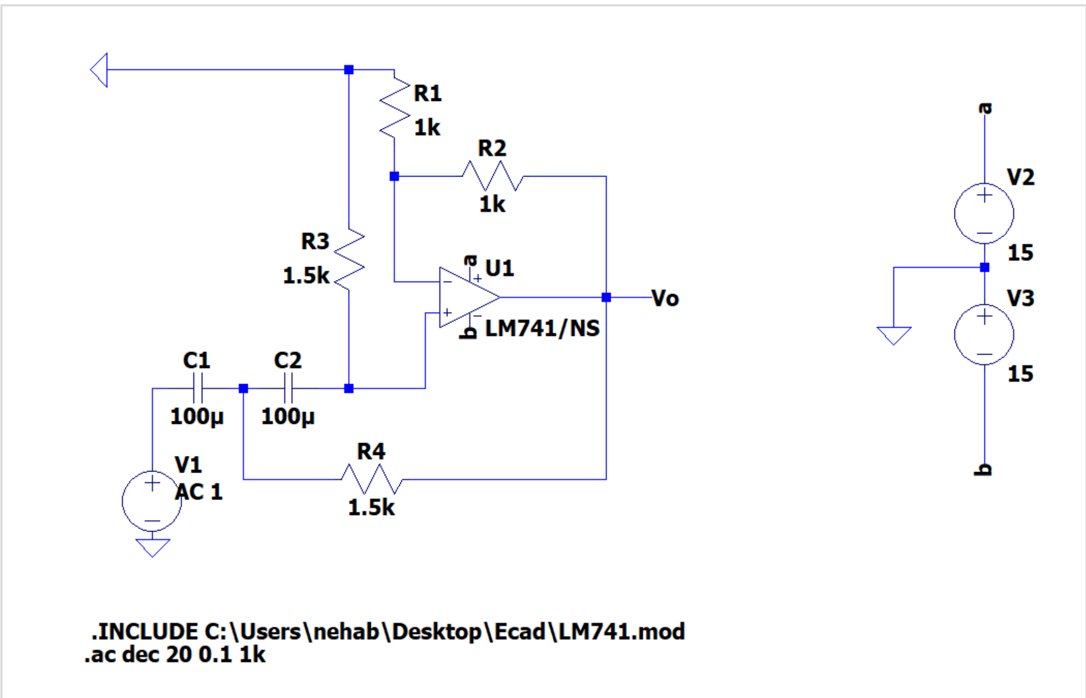
Here, choosing $C_1 = C_2 = 100\mu F$, $R_3 = R_4$

$R_3 = R_4 = 1.5k\Omega$

Now by taking, $R_1 = R_2 = 1k\Omega$,

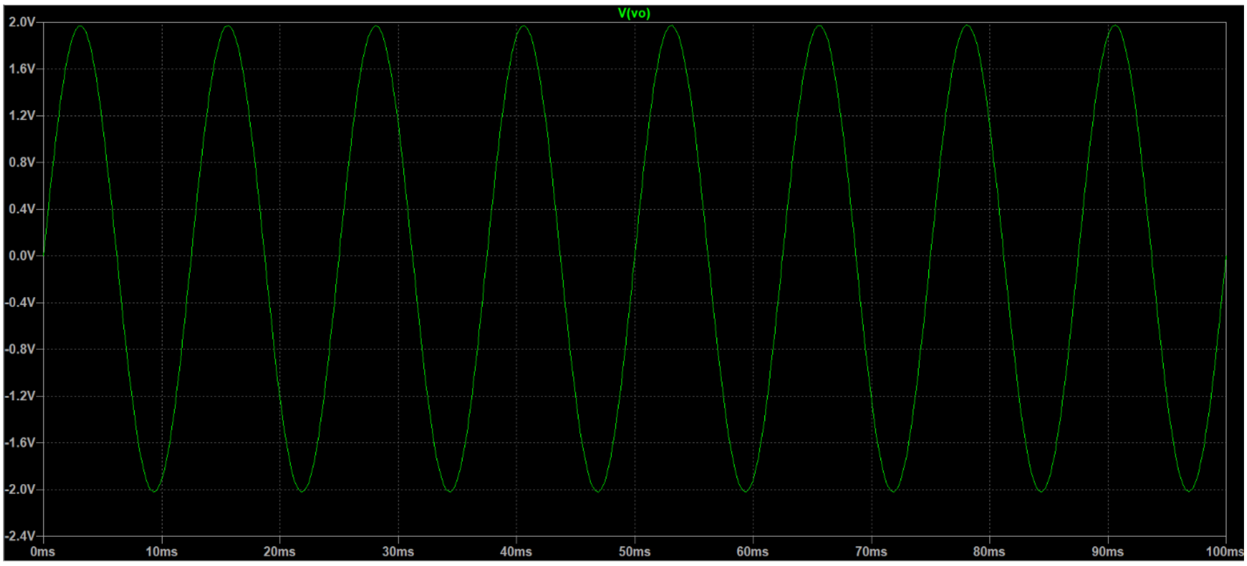
$$\text{Gain} = 1 + \frac{R_2}{R_1} = \cancel{2} \; \underline{\underline{2}}$$

## Circuit Diagram:



## Simulation using LtSpice:

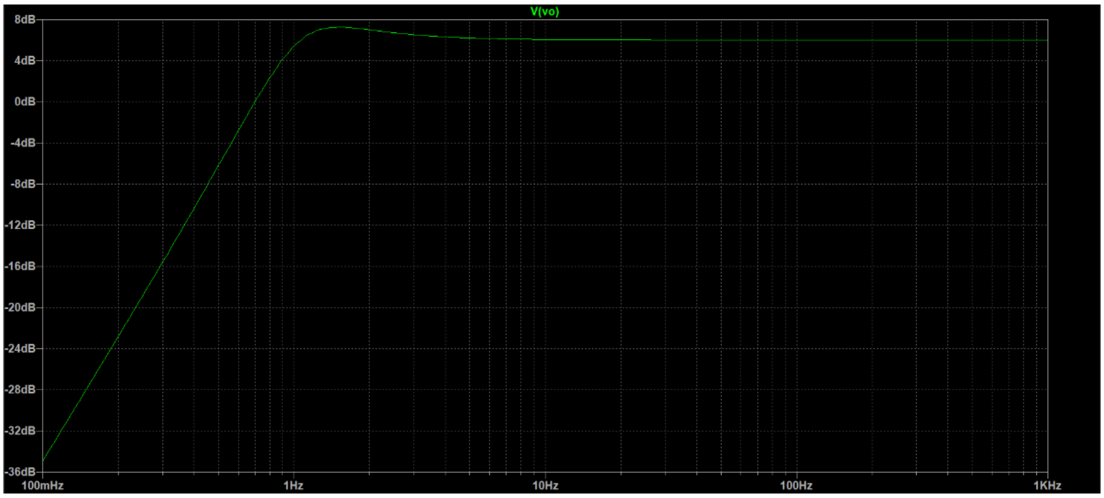
Transient Analysis: (when input is of amplitude = 1V)

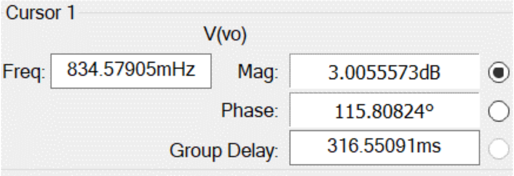




Gain = 1.9724972 = 2(approx.)

AC Analysis:

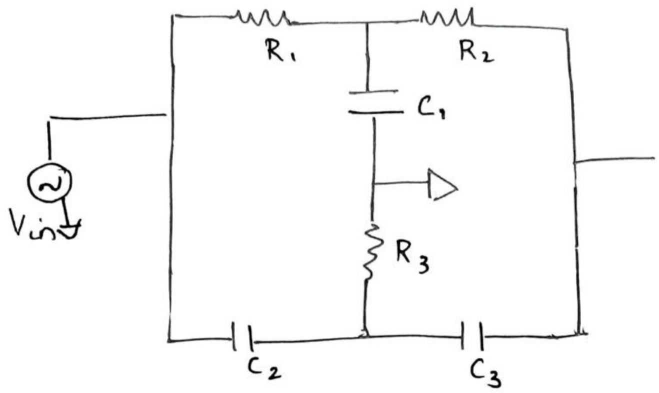



Cut-off frequency = frequency at $20\log(2/\sqrt{2})$ = 3dB = 0.834Hz

## iv) Notch Filter:

In our country, the power line interference is at 50Hz with a bandwidth of about 50Hz. Therefore, the circuit should have a notch filter to remove the interference due to 50Hz frequency. Here, we are using a Twin-T notch filter.




For a Twin-T notch filter,

$R_1 = R_2 = 2R_3$

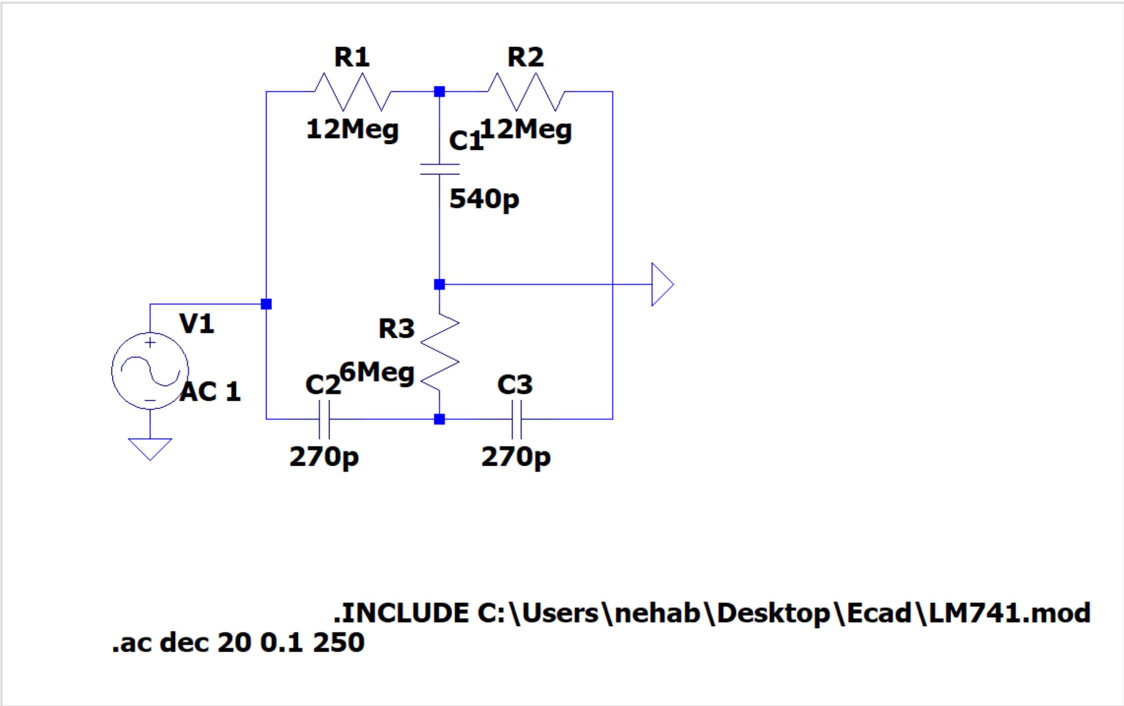
$C_2 = C_3 = C_1/2$

$$\text{Cut-off frequency} = \frac{1}{2\pi R_1 C_2} = 50\,Hz$$

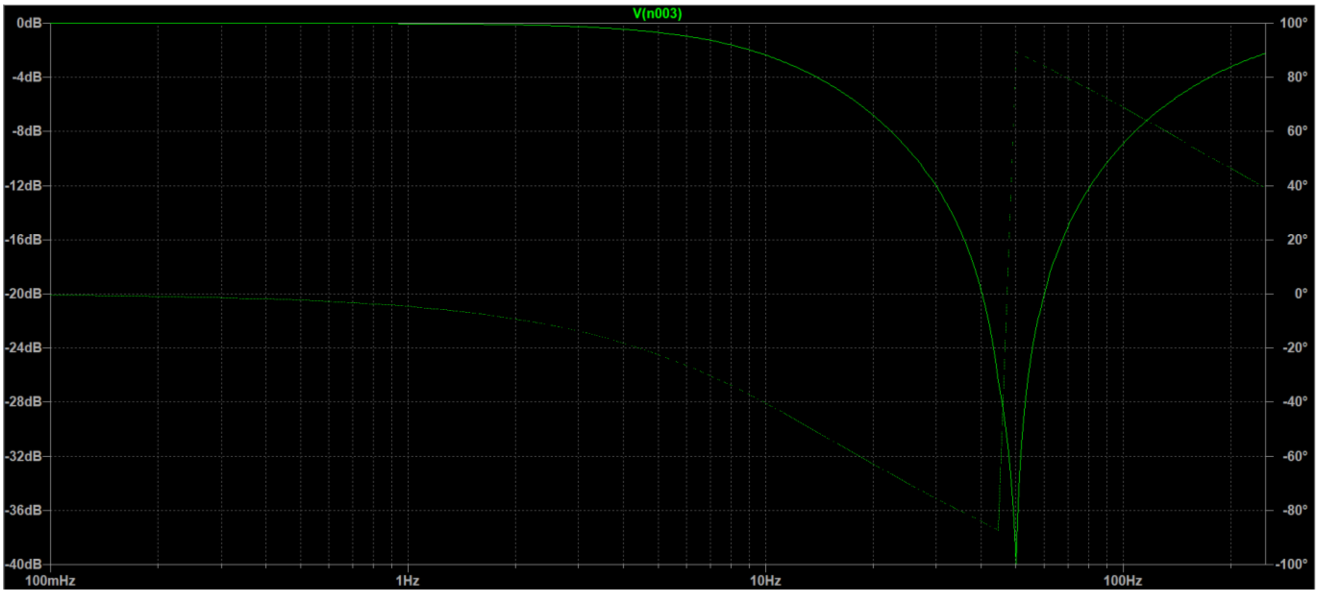
Choosing $C_2 = 270\,pF$

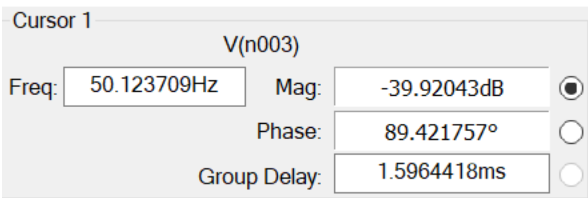
$R_1 = 12M\Omega$ (Taking the standard value of resistor)

## Circuit Diagram:




## Simulation using LtSpice:



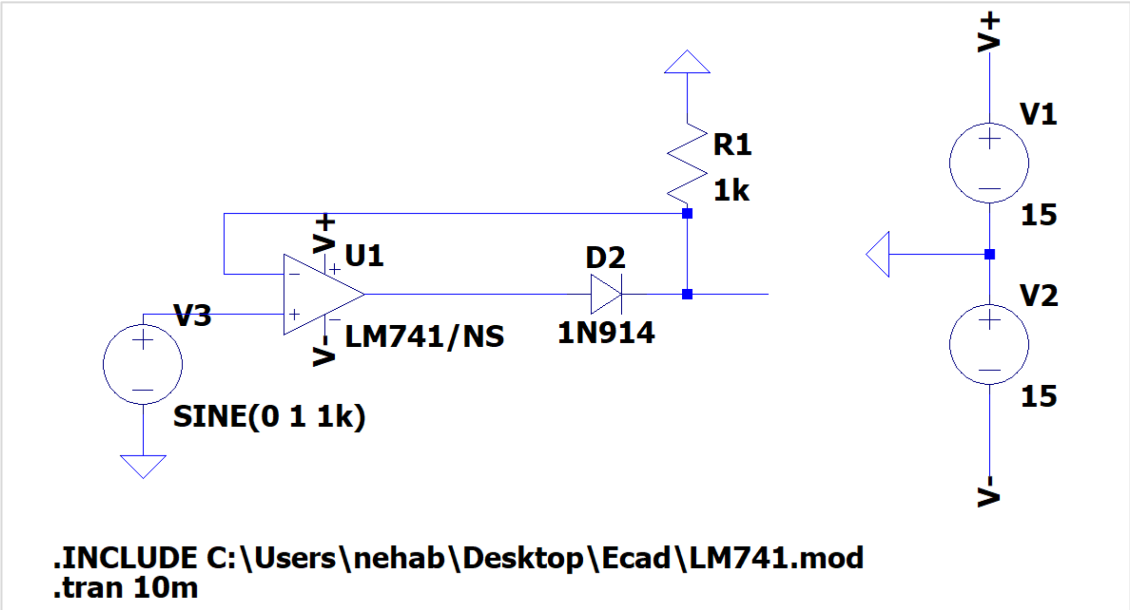




Cut-off Frequency = 50.123709Hz

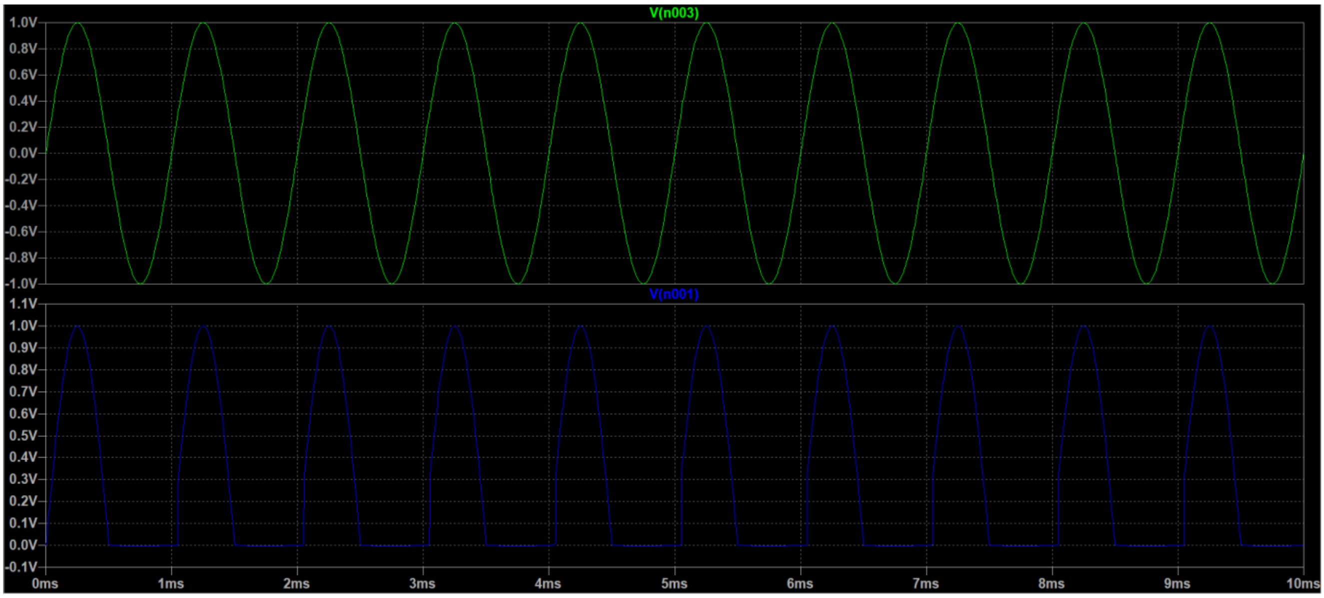
### v) Half-Wave Rectifier:

For the ECG application, we need to determine the QRS peak. QRS is a positive peak. Therefore, we need to rectify the negative peaks. Hence, we need to use a half-wave rectifier for this purpose. Here, the diode acts as a half-wave rectifier.

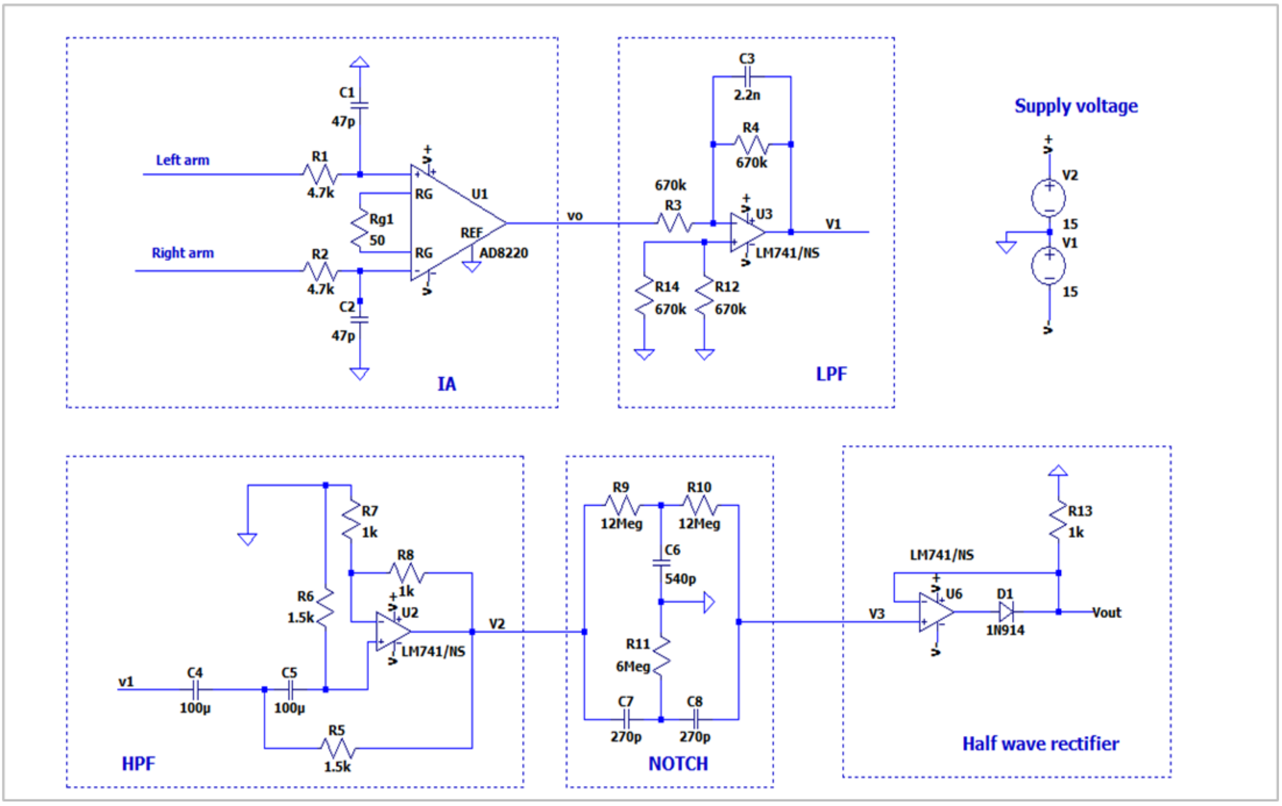
**Circuit Diagram:**




**Simulation using LtSpice:**



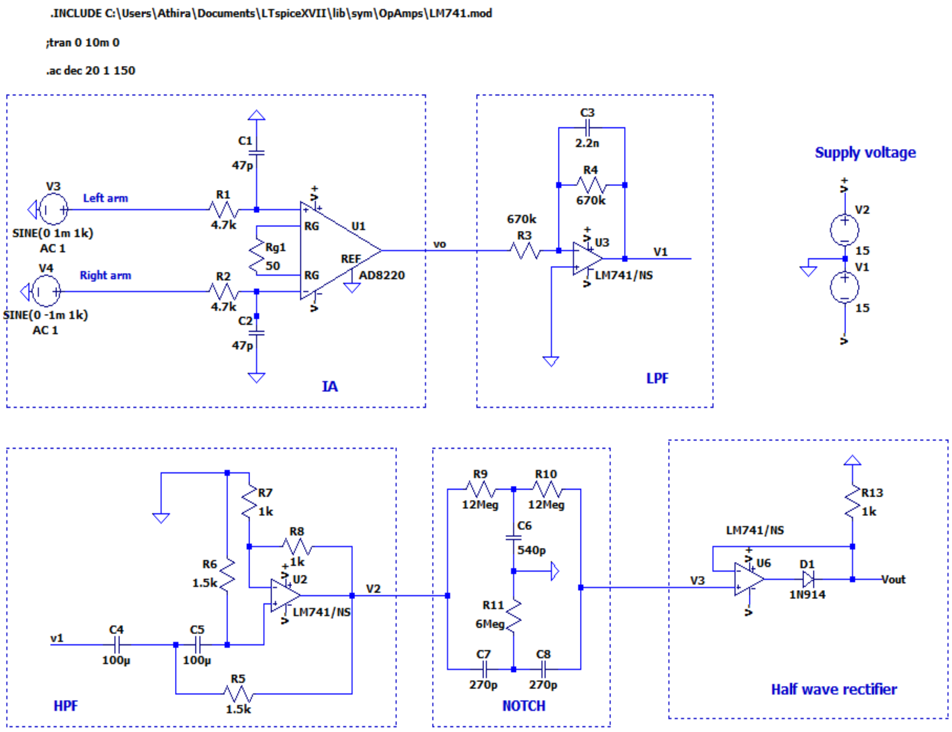
## 3) Final Cascaded Circuit



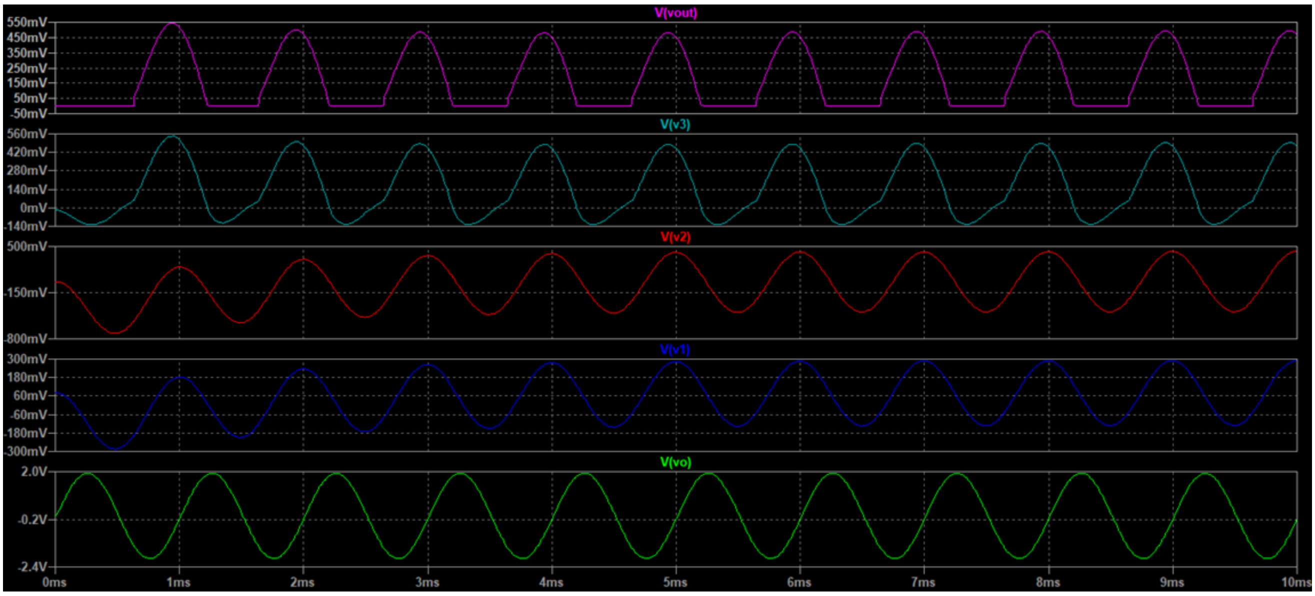

## Simulation using LtSpice:

### Transient Analysis:

Taking inputs as sinusoidal waveforms with amplitude 1mV and -1mV respectively.

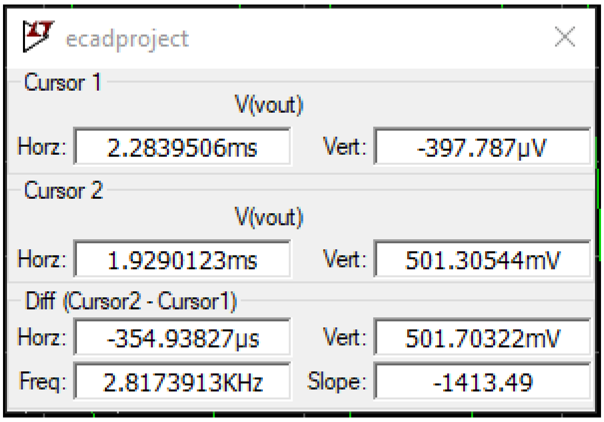


The output waveforms after each stage:




## 4) Inference

- Taking inputs as sinusoidal waveforms with amplitude 1mV and -1mV respectively, the amplitude of final output waveform is 501.7mV(pp).




- Thus the overall gain = Vout(pp)/ Vin(pp)
  = 501.7m/2m
  = 250.85

- The output signal obtained is rectified(i.e has only positive peaks which is desired for QRS peak detection).
- The noises have been filtered out using high and low pass filters and the power line interupption was also eliminated using a notch filter of 50Hz.

## 5) Result

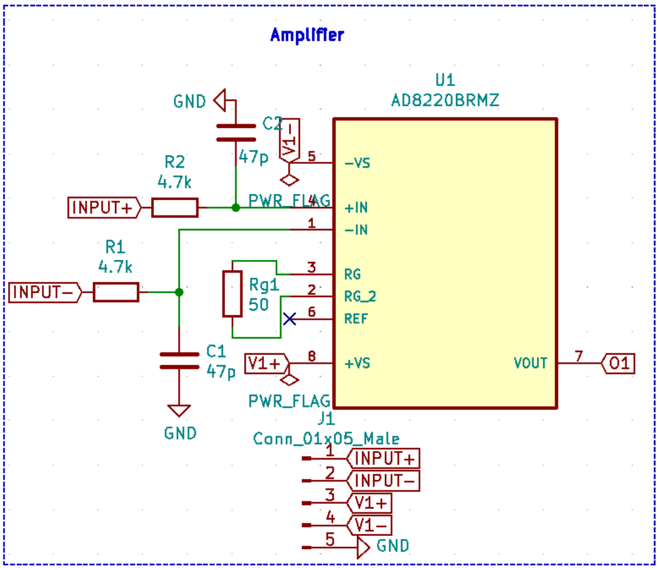
An ECG Amplifier circuit has been designed and simulated using cascaded IA, HPF, LPF, notch filter and half wave rectifier . The output from the circuit can further be connected to peak detector circuit and trigger unit to determine the heart rate.

# 6) <u>PCB Design</u>

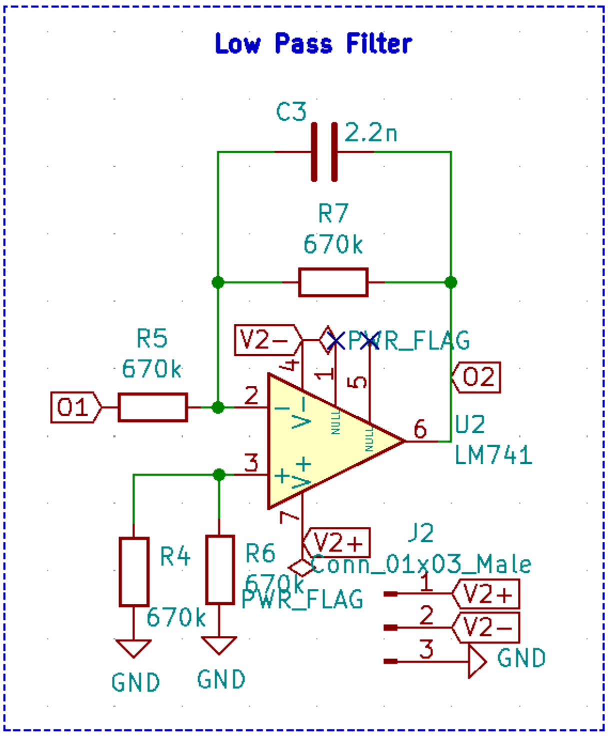
First, the schematic of the circuit is made in Kicad. Then, the footprints are assigned to all the schematic symbols. The netlist is then generated. The PCB layout is then obtained on Kicad.

## a. <u>Schematic</u>

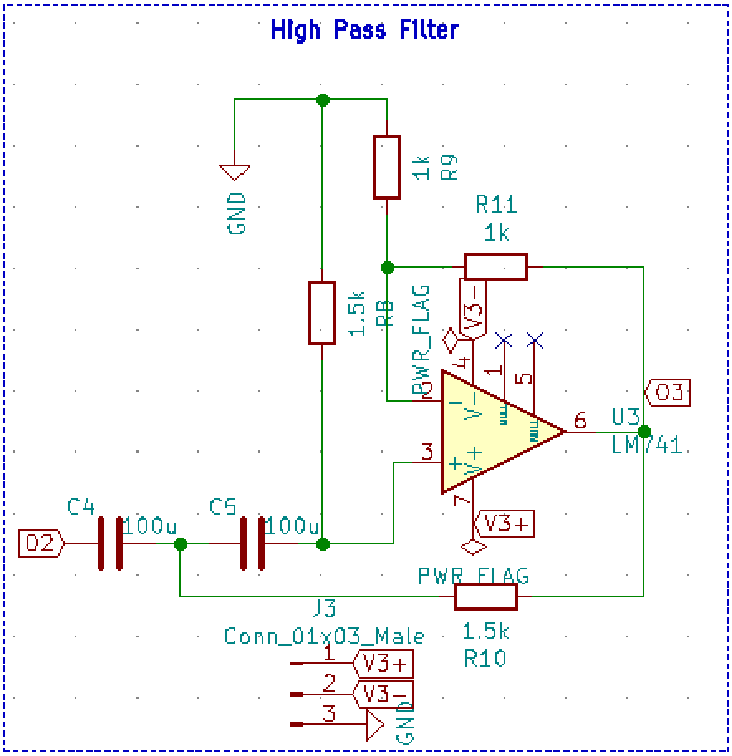
### i) Amplifier:



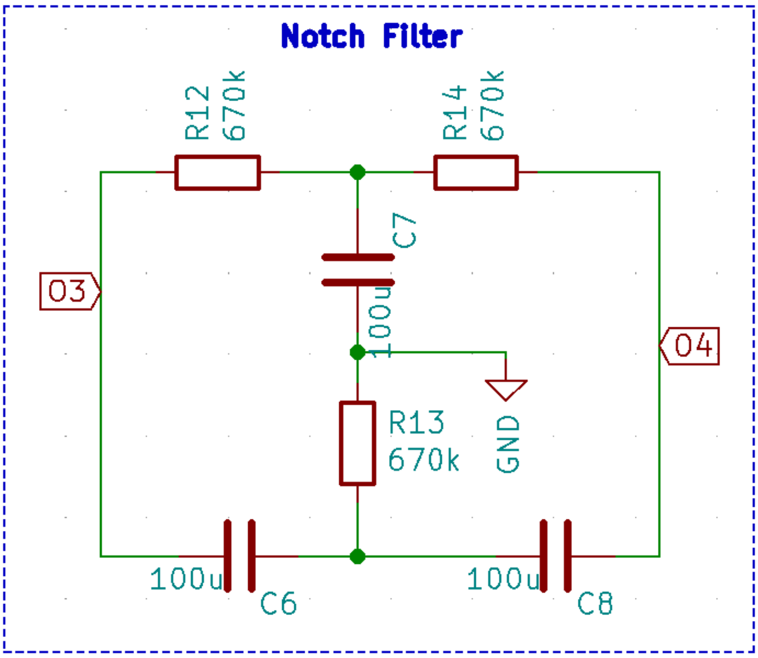

### ii) Low Pass Filter:



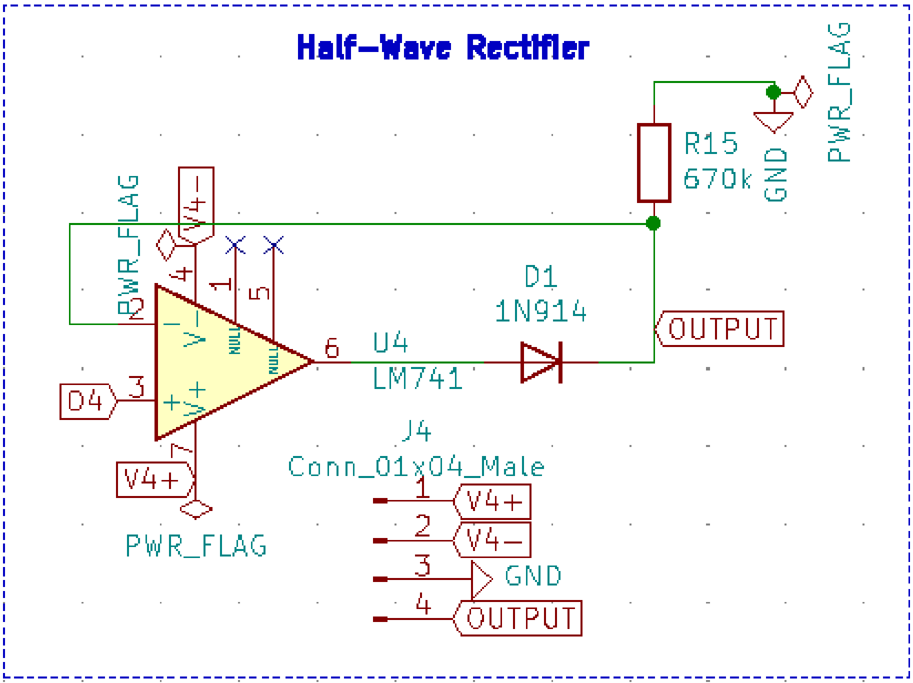
### iii) High Pass Filter:



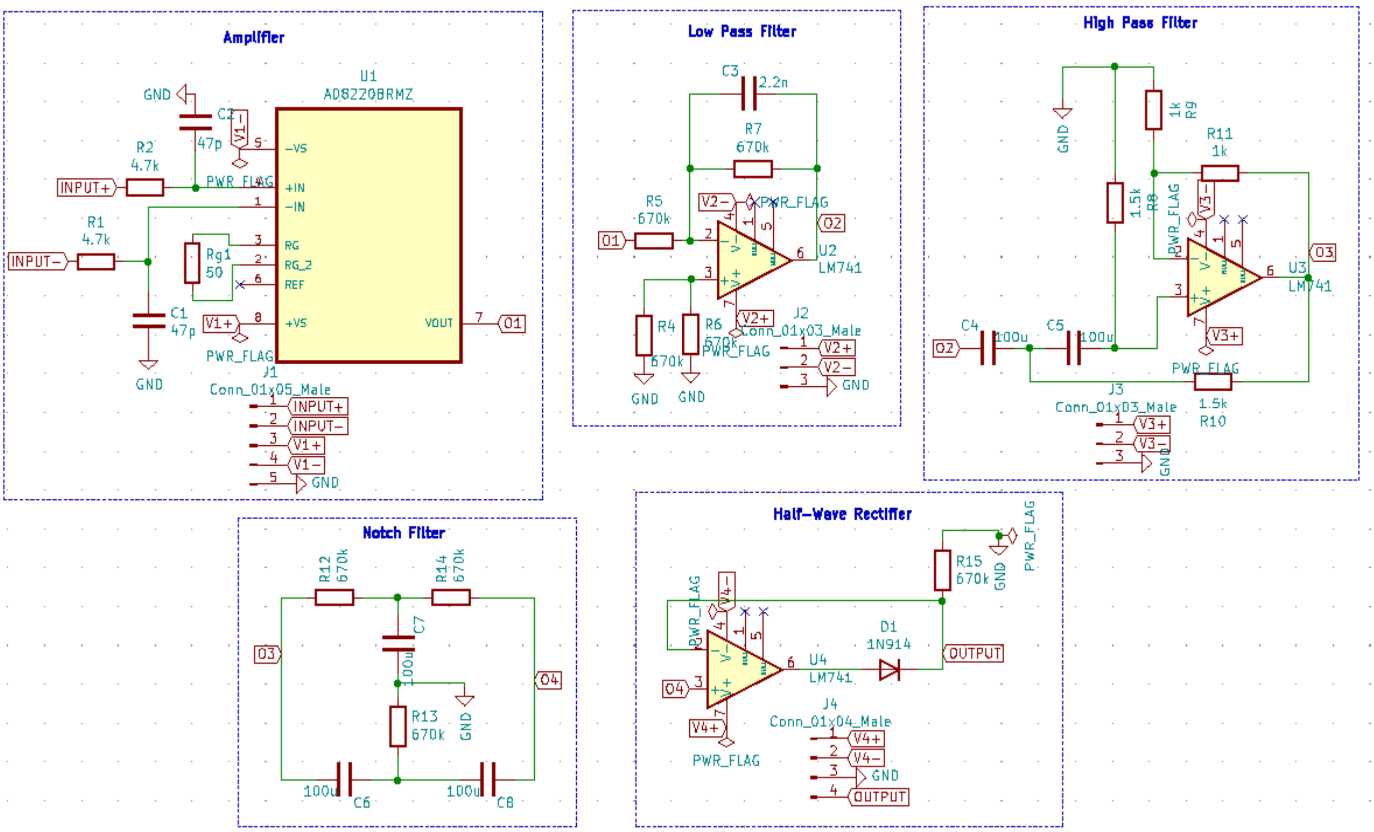

### iv) Notch Filter:



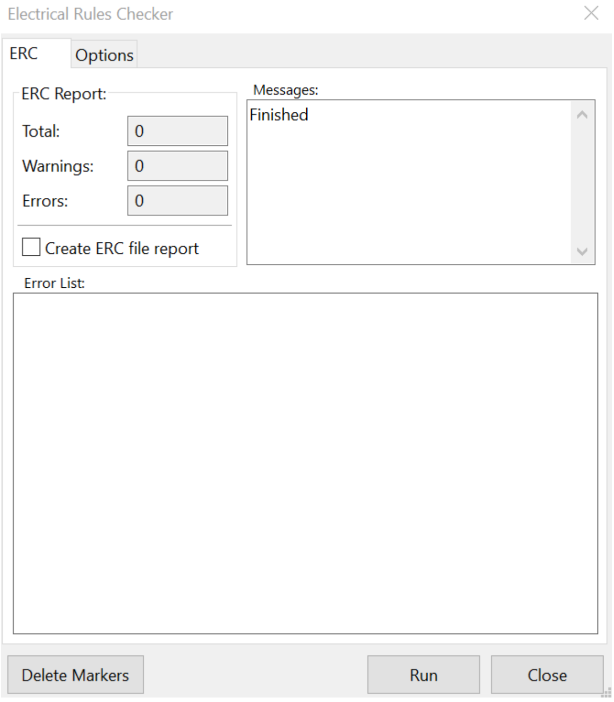
### v) Half-wave Rectifier:




## b. Schematic of the Cascaded Circuit:



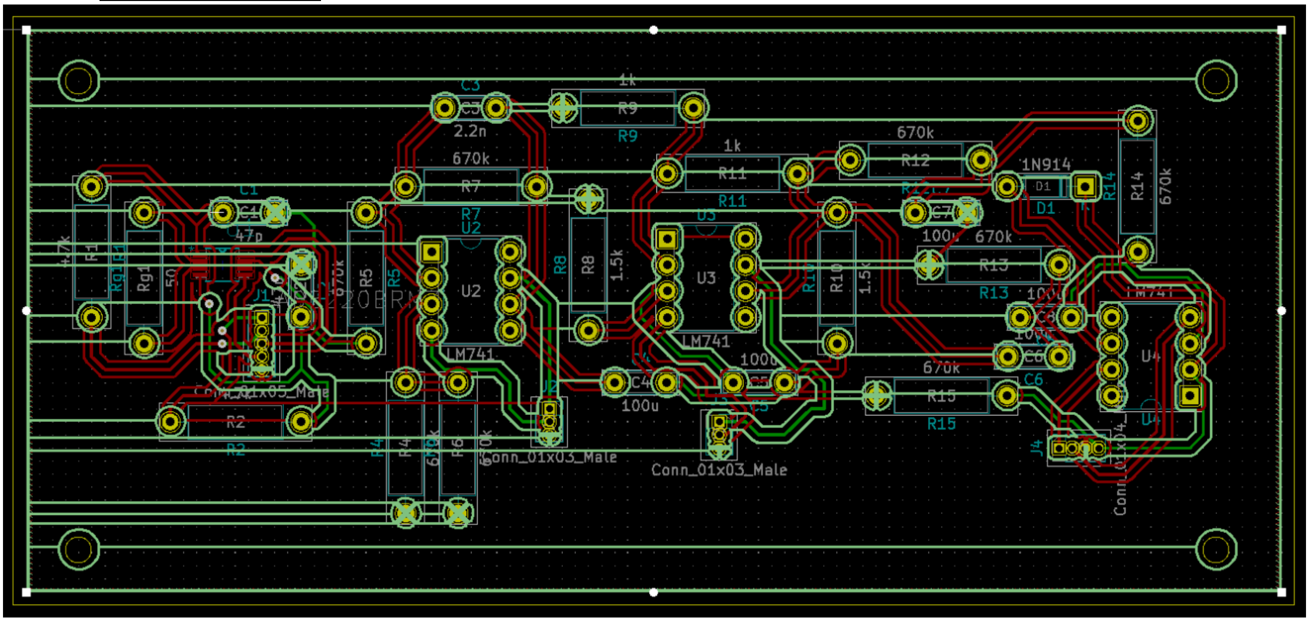
## c. Checking the Errors:




## d. <u>Footprints Assigned to the Schematic Symbols</u>

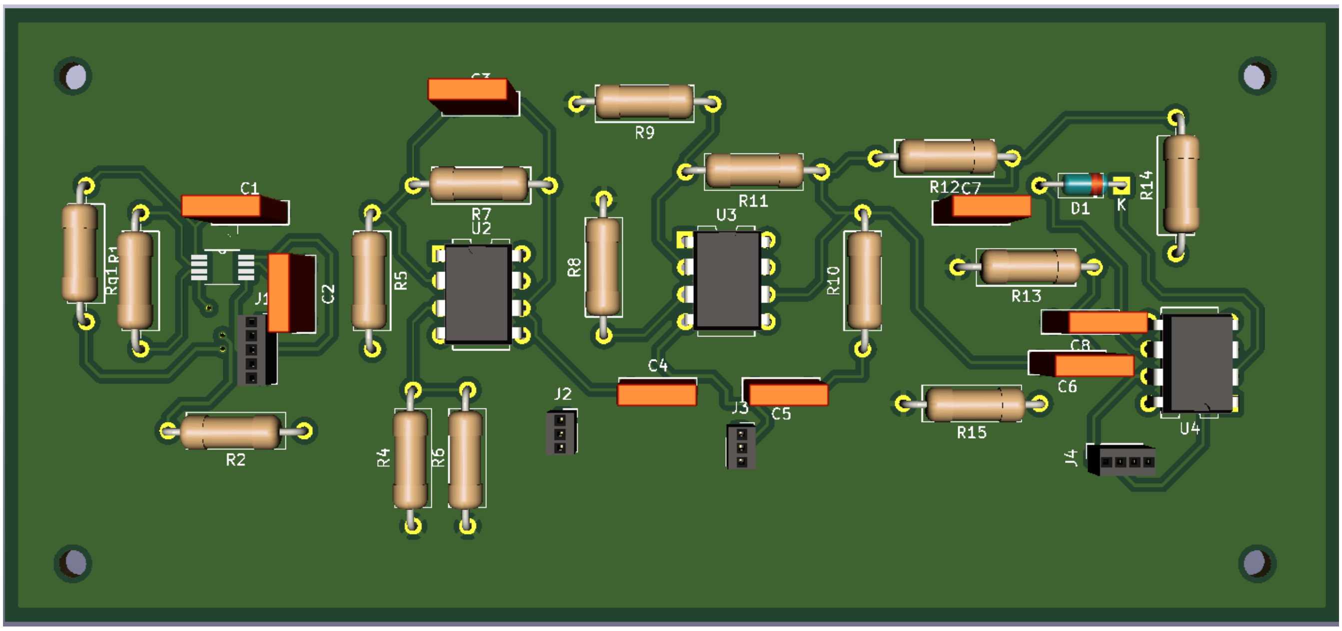
```
1    C1 -             47p : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
2    C2 -             47p : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
3    C3 -            2.2n : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
4    C4 -            100u : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
5    C5 -            100u : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
6    C6 -            100u : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
7    C7 -            100u : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
8    C8 -            100u : Capacitor_THT:C_Rect_L7.0mm_W2.0mm_P5.00mm
9    D1 -           1N914 : Diode_THT:D_DO-35_SOD27_P7.62mm_Horizontal
10   J1 - Conn_01x05_Male : Connector_PinSocket_1.27mm:PinSocket_1x05_P1.27mm_Vertical
11   J2 - Conn_01x03_Male : Connector_PinSocket_1.27mm:PinSocket_1x03_P1.27mm_Vertical
12   J3 - Conn_01x03_Male : Connector_PinSocket_1.27mm:PinSocket_1x03_P1.27mm_Vertical
13   J4 - Conn_01x04_Male : Connector_PinSocket_1.27mm:PinSocket_1x04_P1.27mm_Vertical
14   R1 -            4.7k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
15   R2 -            4.7k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
16   R4 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
17   R5 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
18   R6 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
19   R7 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
20   R8 -            1.5k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
21   R9 -              1k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
22  R10 -            1.5k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
23  R11 -              1k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
24  R12 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
25  R13 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
26  R14 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
27  R15 -            670k : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
28  Rg1 -              50 : Resistor_THT:R_Axial_DIN0309_L9.0mm_D3.2mm_P12.70mm_Horizontal
29   U1 -      AD8220BRMZ : AD8220BRMZ:SOP65P490X110-8N
30   U2 -           LM741 : Package_DIP:DIP-8_W7.62mm
31   U3 -           LM741 : Package_DIP:DIP-8_W7.62mm
32   U4 -           LM741 : Package_DIP:DIP-8_W7.62mm
```

## e. PCB Layout

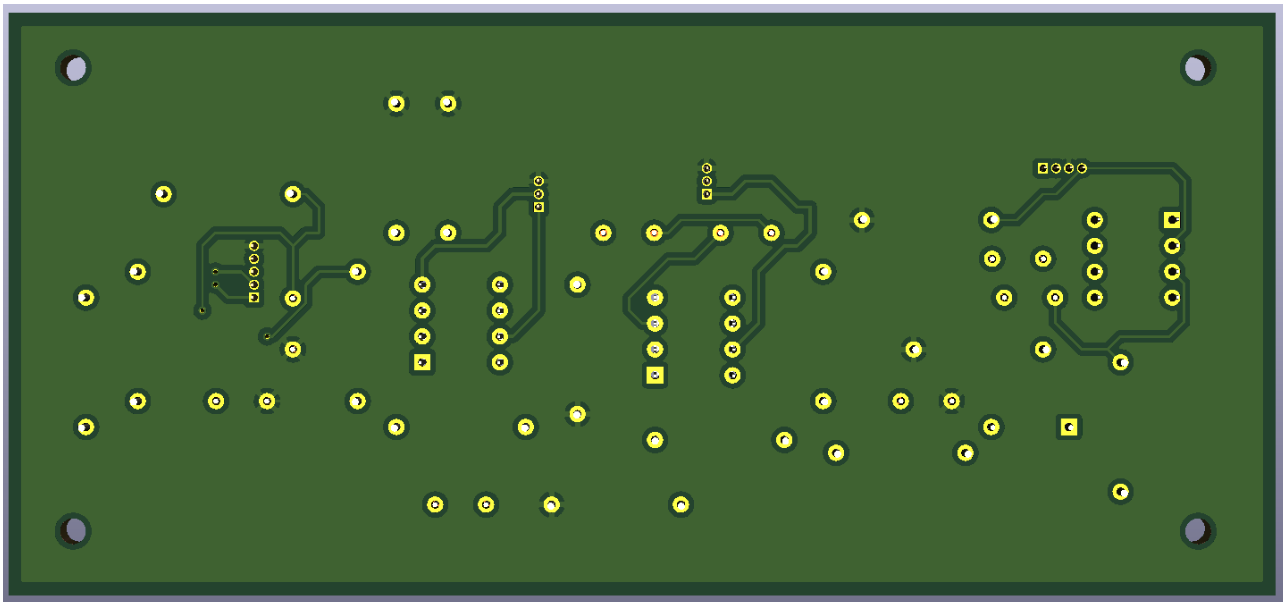


## f. 3D view of the PCB Layout

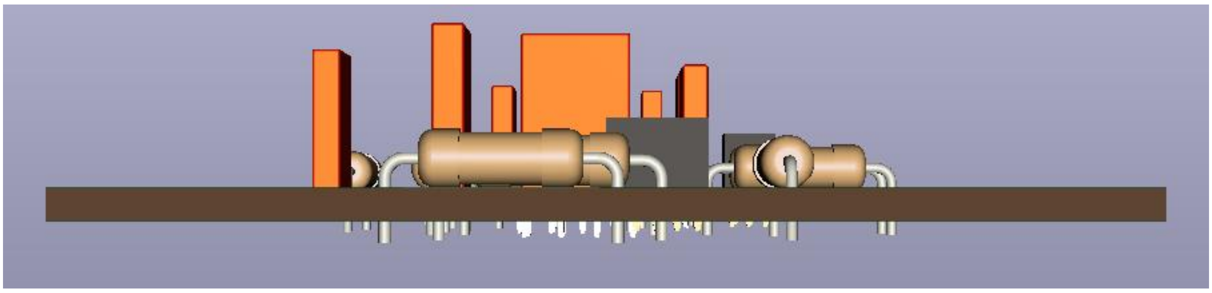
**Top View:**



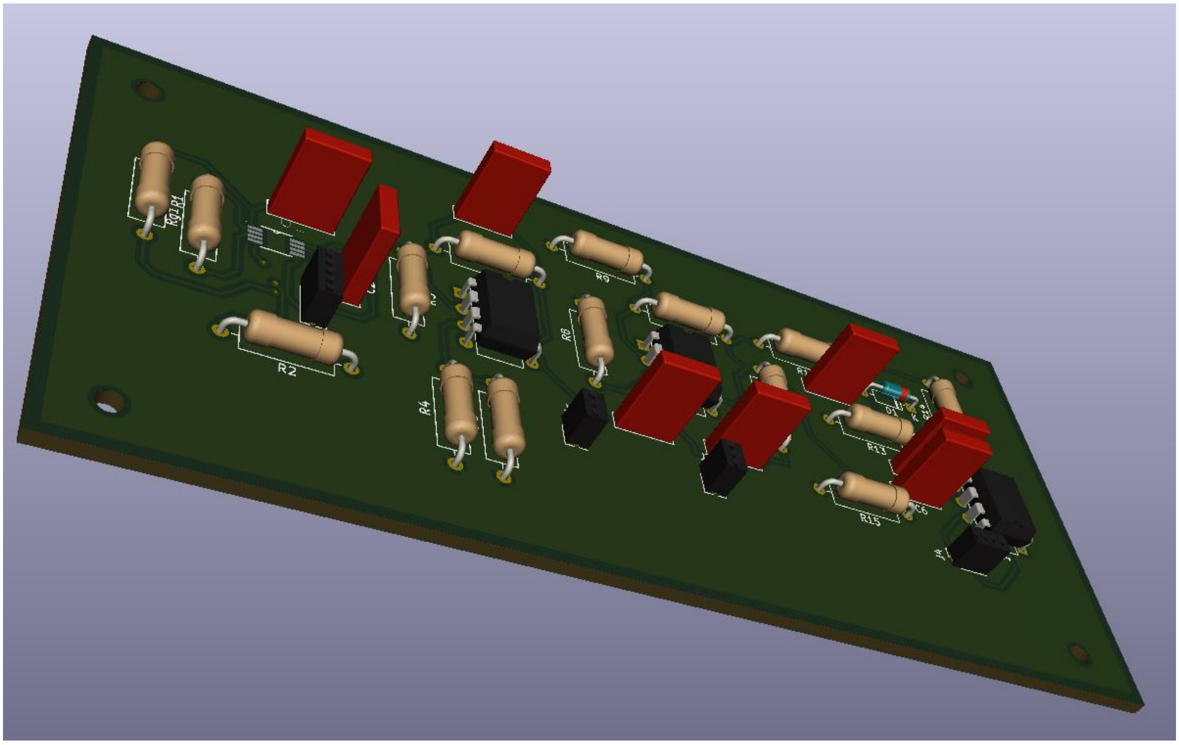
**Bottom View:**



**Side View:**



**Tilted View:**



## 7) Conclusion

The sequential usage of the IA, the HPF, the LPF, the notch filter and the half wave rectifier have resulted a successfully conditioning a raw ECG wave . The merits of this circuity not only lie its excellent functionality, but also its flexible modularity. Each filter unit, as well as their associated components, can be easily changed or modified to adapt to other bio signals with different amplitudes and frequencies. The system could also be used to condition other non-bio signals. The device provides a useful educational platform for students to learn, step-by-step, signal conditioning principles, function and construction of active and passive filters, electronic components, interface, and  programming tools.