ECG Amplifier Design

WEL Lab
IIT Bombay

2018

Objective of the experiment

The goal of this lab is to construct an ECG front-end amplifier, and record your ECG signal using the probes provided.

General Block Diagram

A general block diagram of a modern ECG amplifier is shown in Figure. It is designed around an instrumentation amplifier.

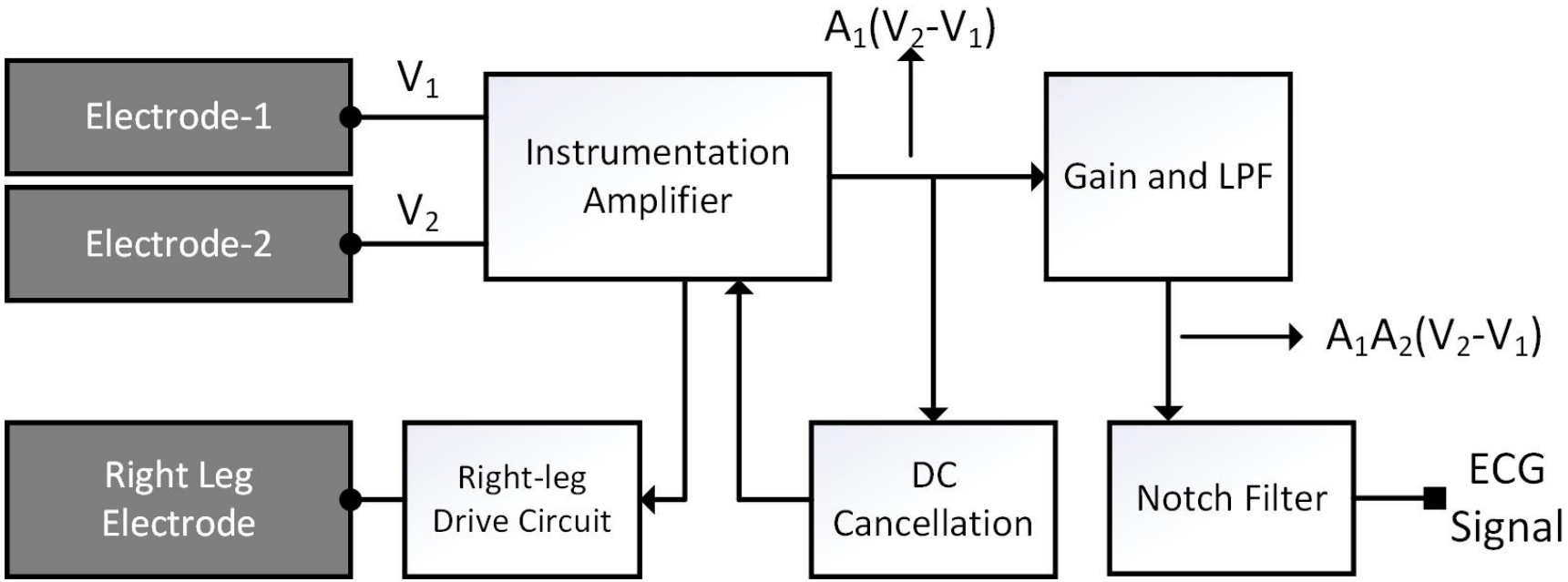


Figure: Block Diagram of ECG system

General Block Diagram

In addition to the instrumentation amplifier it contains:

- An automatic offset (DC) cancellation circuit to keep the output always zero averaged.
- A driven-right leg circuit to provide electrical safety and reduce the interference under normal operational conditions.
- A low-pass filter that provides further amplification and limit the bandwidth of the overall system, and
- A notch filter to remove interference at 50 Hz frequency.

The Instrumentation Amplifier

A. Preliminary Work

- Familiarize yourself with the concept of common mode and differential gain of INA.
- Carefully go though the data-sheet of INA118 or INA128.
- Calculate the component values for a gain of 10.

B. Experimental Work (You can use either INA118 or INA128)

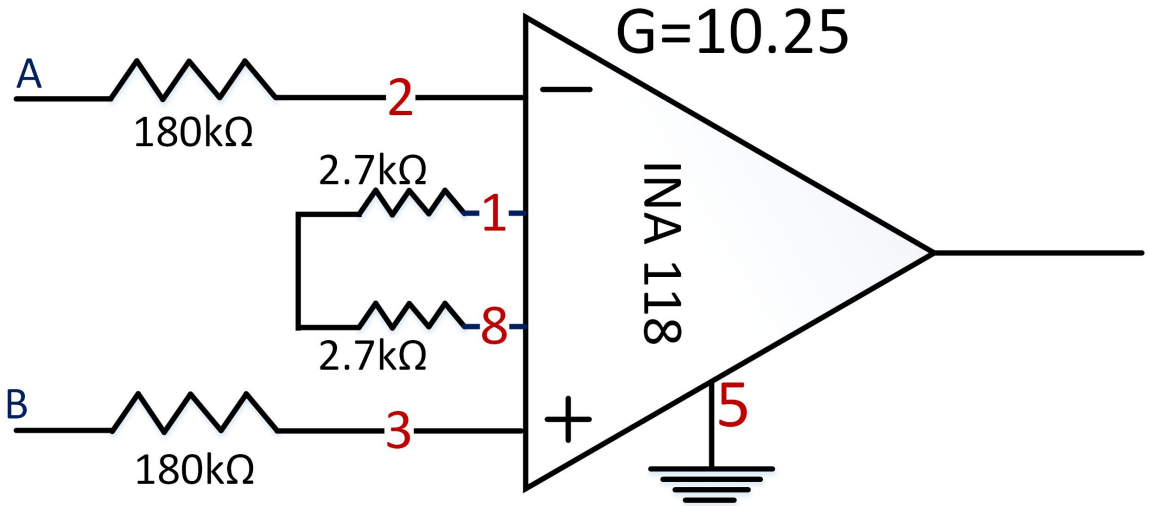


Figure: An example of INA118 for a gain of 10.2

The Instrumentation Amplifier

- Construct the circuit on breadboard following the diagram above. Use $\pm 12V$ supply for INA. Connect a $1\mu F$ capacitance from supply to ground. Be aware of the polarity of the electrolytic capacitor.
- Verification:
  a) Differential gain:Connect a sinusoidal signal of 10mV, 100 Hz at input B of the figure above. Connect A to ground. Verify the gain of INA.
  b) Common mode gain: Now, Verify the INA operation by applying 20mV, 100 Hz on both A & B. Common mode input to INA should give zero output. What is the noise level you measure at the output?

Offset (DC) Cancellation Circuit

Modify the instrumentation amplifier as shown in Fig. 3 by inserting an integrator between the output and pin 5 of INA118.
This configuration works as HPF for ECG signal to remove the DC offset voltage.

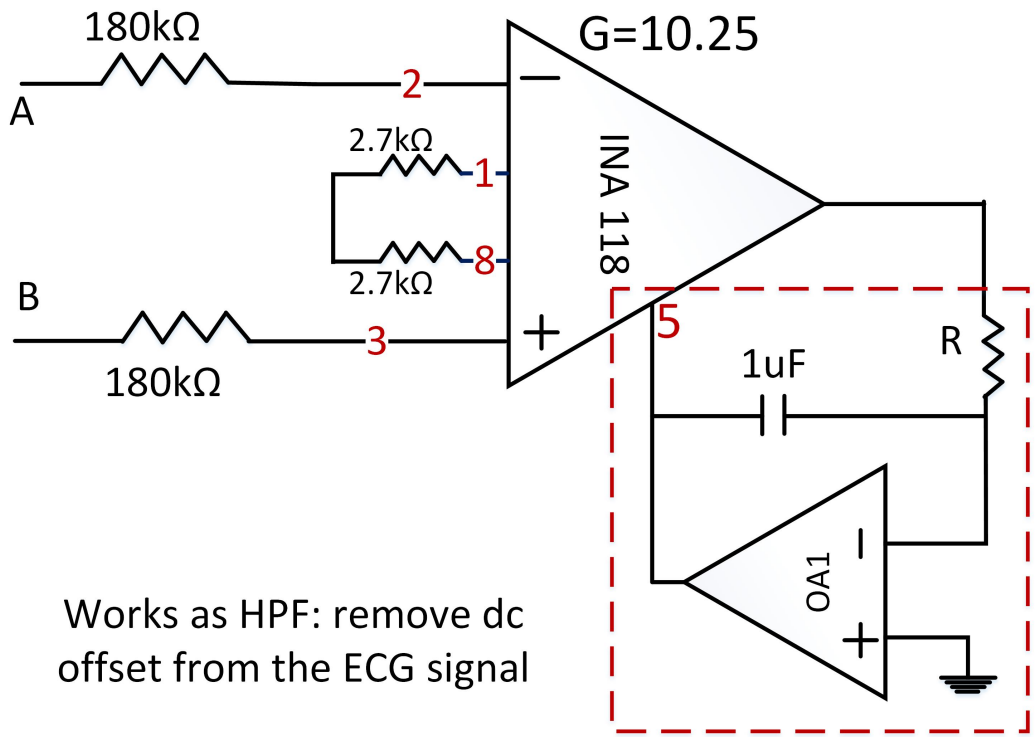


Figure: INA118 with offset voltage cancellation

Offset (DC) Cancellation Circuit

- Preliminary Work
  a) Prove that the instrumentation amplifier with offset voltage cancellation circuitry will include a high-pass filter feature. (By deriving the expression)
  b) Select R to have a cut-off frequency at around 0.3 Hz.
- Experimental Procedure
  a) Go through the datasheet of LT072 (Dual op-amp)
  b) Connect a sinusoidal signal of 20mV, 100 Hz with a DC offset of 0.1V to input B of the INA. Connect A to ground.
  c) The output should settle around 0 volt (DC) immaterial of the level of the input voltage. If not, check your circuit.

The Driven-Right Leg Circuit

The driven-right leg circuit serves two purposes:

- It reduces the common-mode voltage due to interference.
- It provides safety to the patient in case a dangerously high voltage is applied by isolating the patient from the ground.

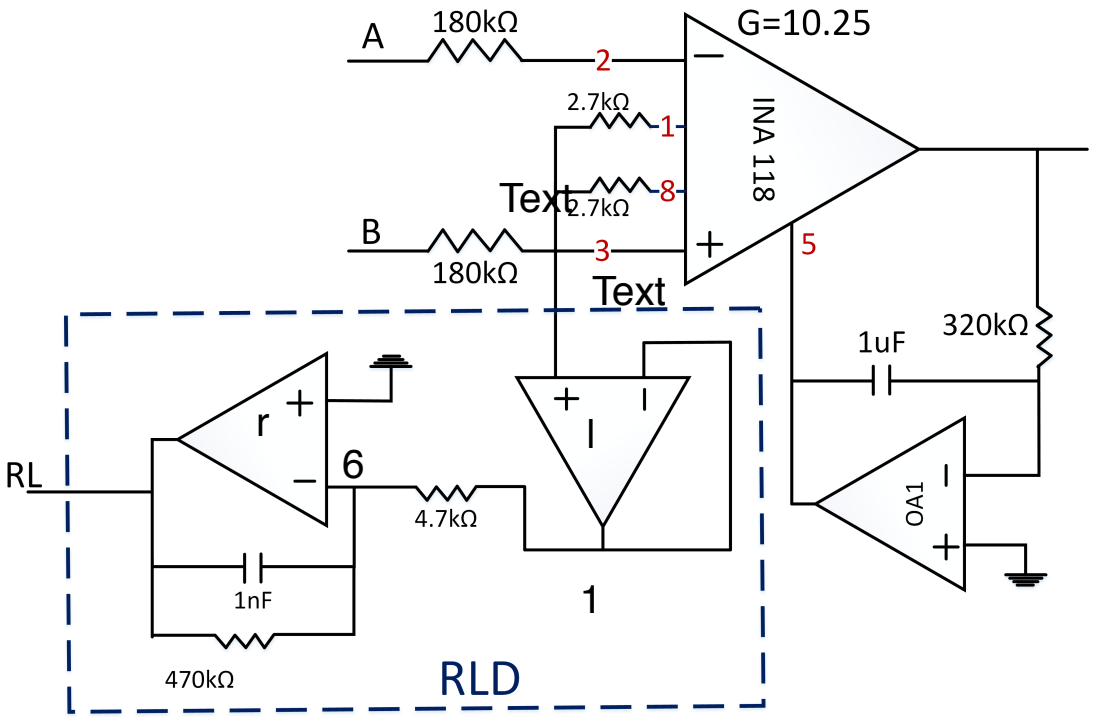


Figure: An example of INA118 with RLD

The driven-right leg circuit

Experimental Work

- Apply 20mV, 100 Hz on both A & B
- Connect a wire between the 2.7k (or the resistance you have used for desired gain) resistors and input of the buffer in RLD section as shown in the figure above.
- Verify the gain of the inverting amplifier in right leg drive section (G=3.9).

Gain and Low pass filter

- ECG signal lies in the frequency range of 0.5 Hz to 150 Hz.
- Filtering is one of the most critical block in ECG signal processing.
- Low-pass filter is used to limits the bandwidth of the amplifier.

Gain and Low pass filter

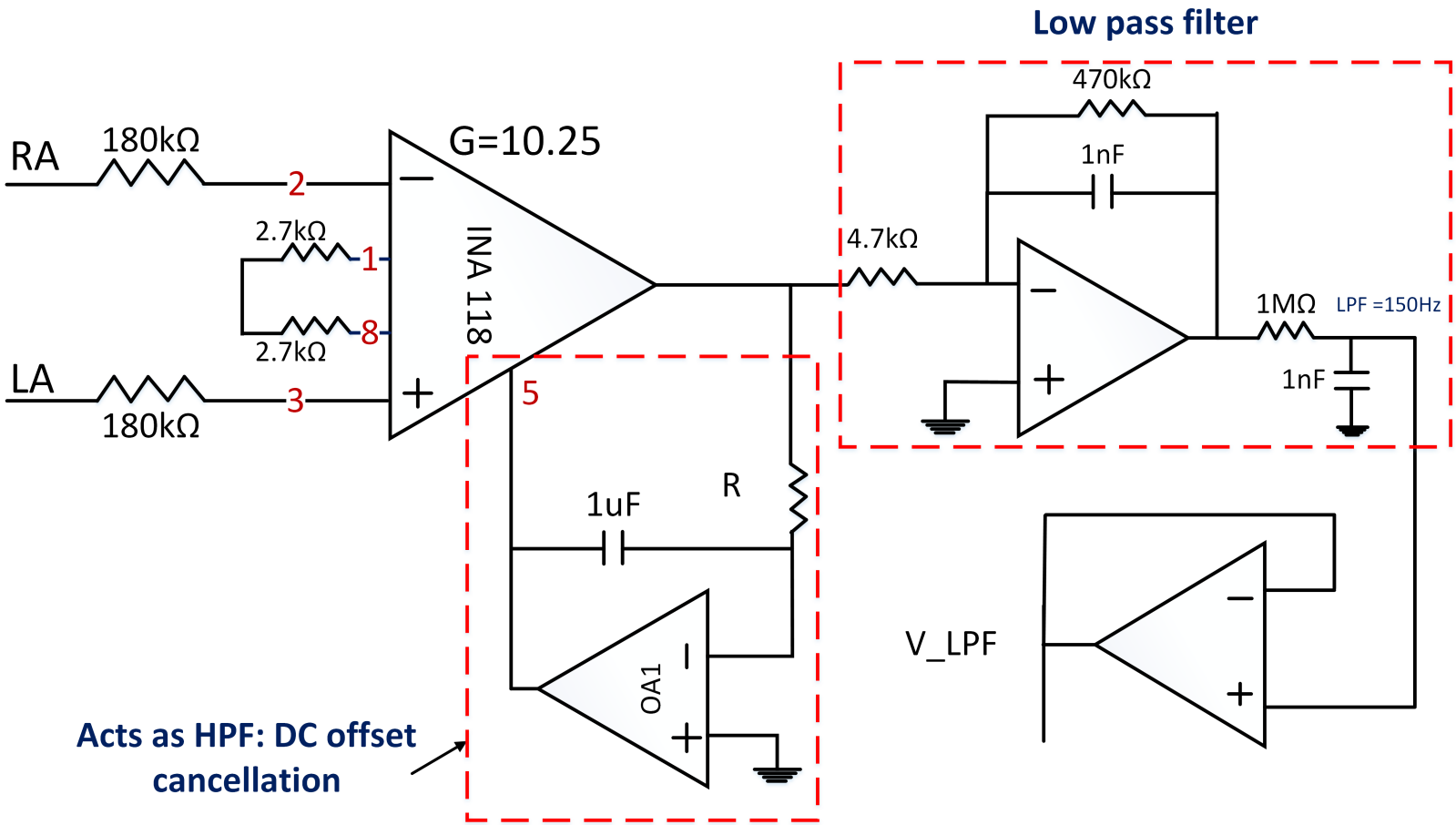


Figure: An example of INA118 with LPF

Gain and Low pass filter

Experimental work

- Connect the output of INA to filter section. (Inputs of INA: LA = 20mV-100Hz,RA = ground).
- Verify the gain of the inverting amplifier (G=100).
- Now change the frequency to 1KHz and check the output of LPF (V_{LPF}).
- Verify the low pass filter response.

Notch Filter

The notch filter is used to eliminate the line frequency and is usually superimposed on the ECG signal (50 Hz)

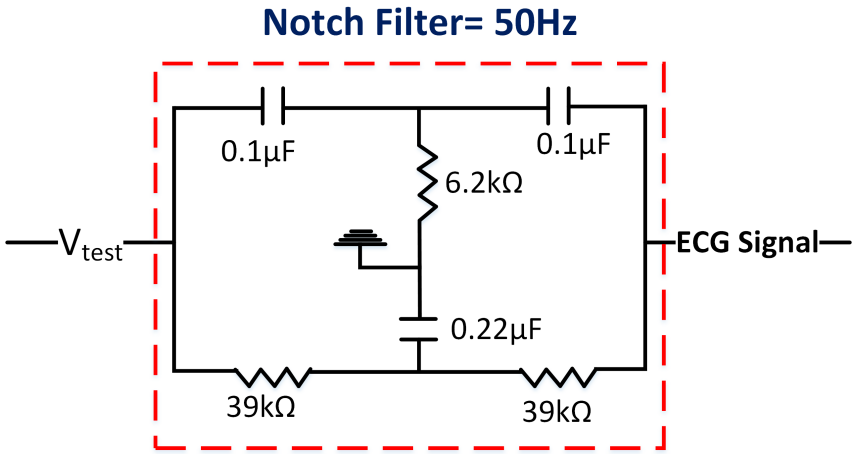


Figure: Notch Filter for 50 Hz signal

Experimental Work

- Apply a sine wave of 50Hz frequency and 20mV amplitude.
- Observe the output of notch filter

ECG Electrodes placement

Consult with the TAs for placing the electrodes on the body

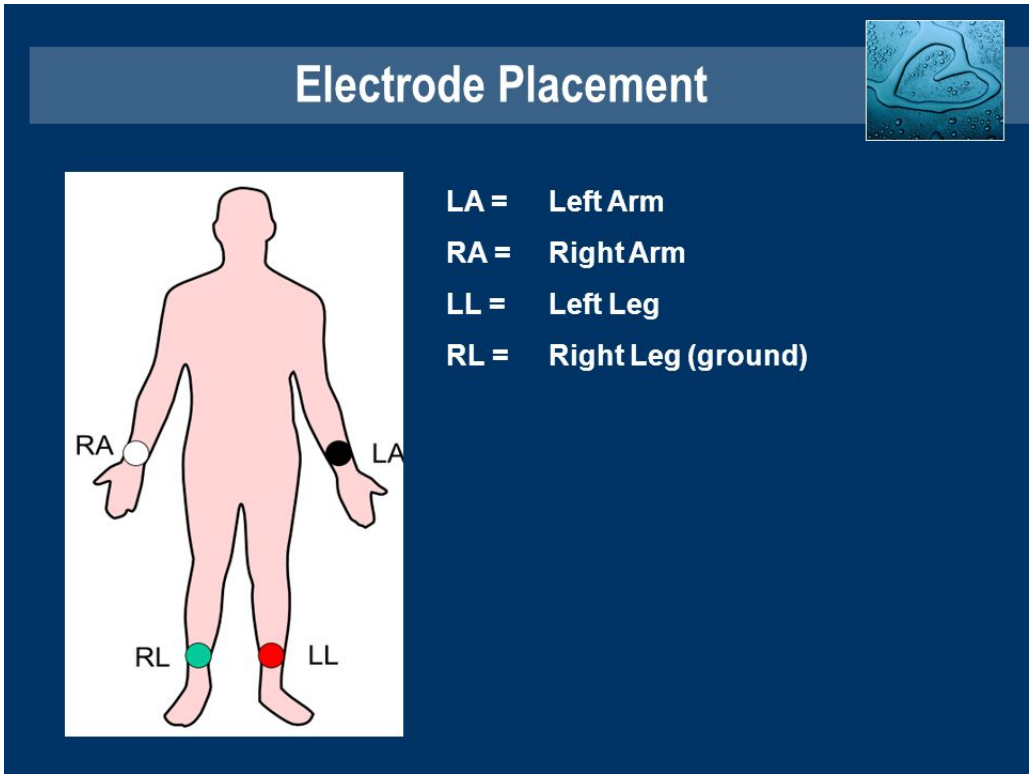


Figure: Electrodes placement for ECG signal

ECG Complete Circuit

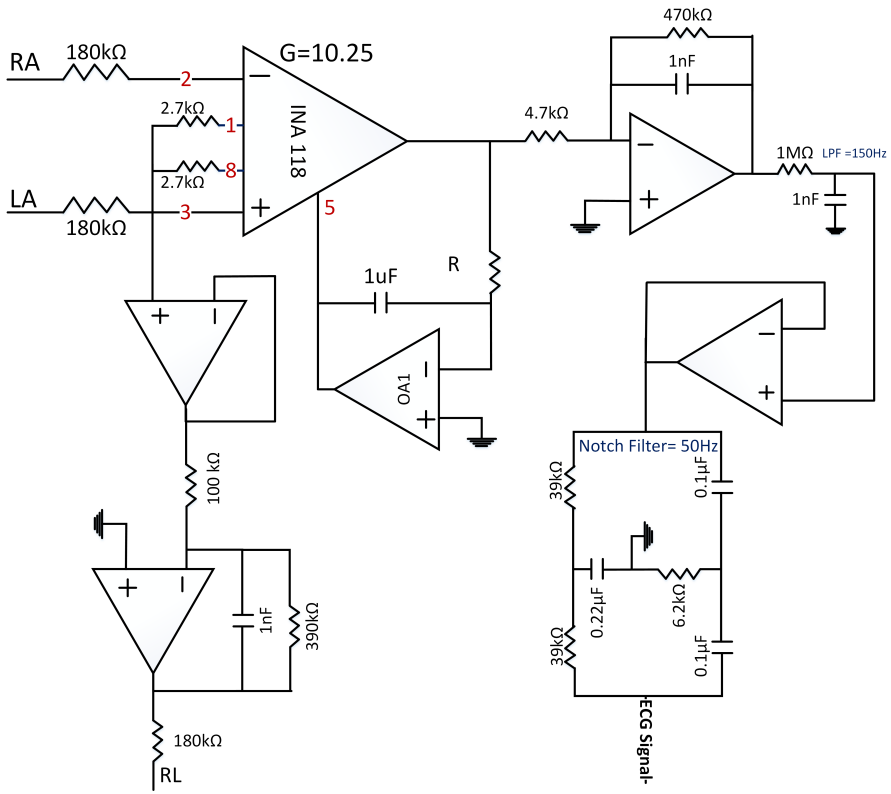


Figure: Complete ECG amplifier circuit

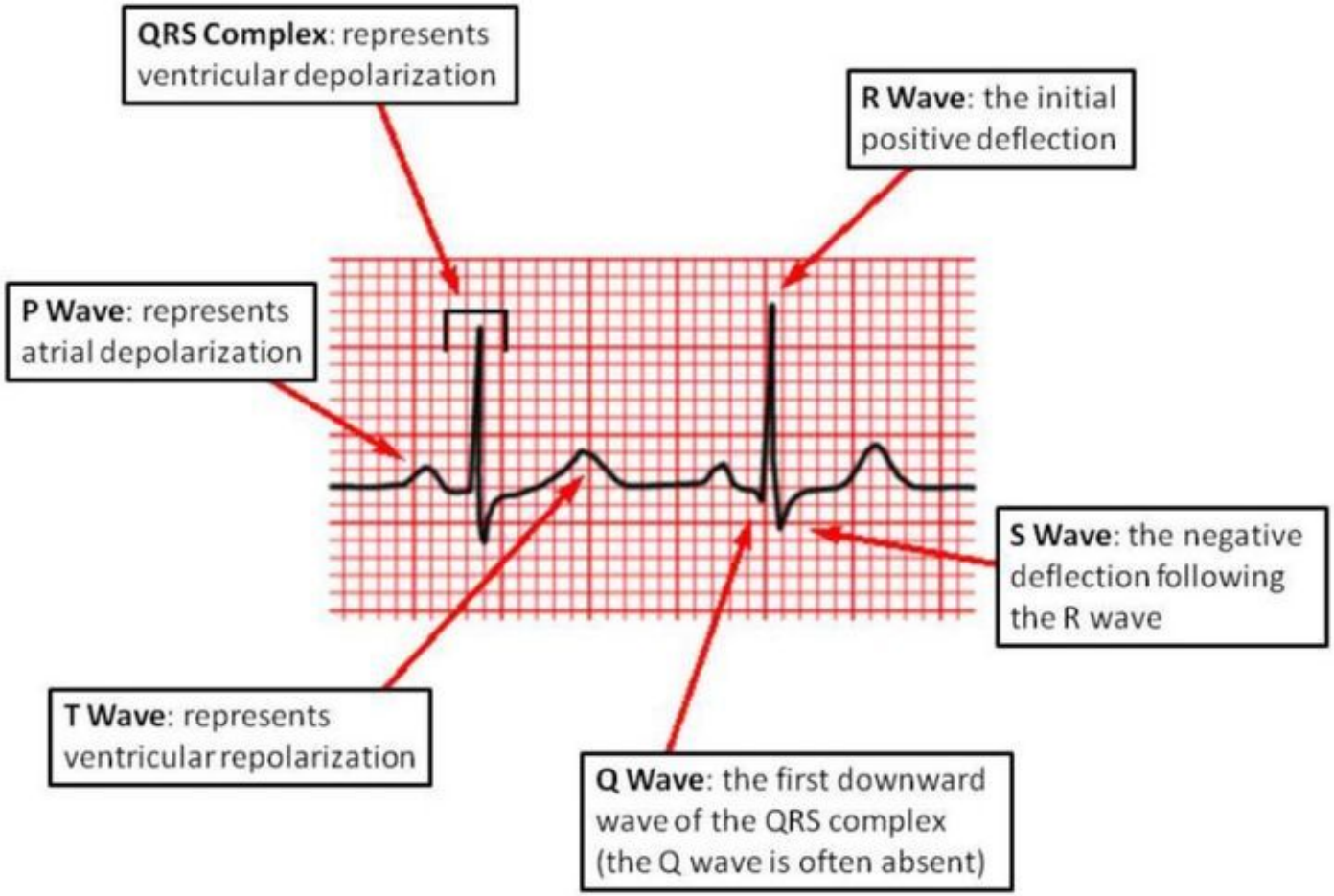
Note: Take a photograph of the circuit designed on the breadboard to include in the report. Label different sections of the circuit.

ECG Complete Circuit

- Connect ECG probe and electrodes on right arm (RA), Left arm (LA) and right leg (RL).
- Check the outputs of INA, RLD and filter using oscilloscope. Which of these nodes are high impedance nodes?
- You will get a clean ECG signal at the output of notch filter. Enjoy your free heart check-up using the instrumentation circuit that you designed

ECG Waveform

Compare the obtained ECG waveform with the wave shown below. Identify different points.



Troubleshooting

If the noise is too high, you can further improve the circuit by:

- Reducing the arm leads to the shortest practical length
- Making your circuit compact, with short wires and resistor leads
- Adjusting the cutoff frequency of the low pass filter