ECG Amplifier

Aniket Bhatia
aniketb@iitb.ac.in

Pradnesh Patil
160010021@iitb.ac.in

1 Introduction

Firstly we must know what an ECG is, before we start measuring it. Just like skeletal muscles, heart muscles are electrically stimulated to contract. This stimulation is also called activation or excitation. Cardiac muscles are electrically charged at rest. The inside of the cell is negatively charged relative to the outside (resting potential). If the cardiac muscle cells are electrically stimulated, they depolarize (the resting potential changes from negative to positive) and contract. The electrical activity of a single cell can be registered as the action potential. As the electrical impulse spreads through the heart, the electrical field changes continually in size and direction. The ECG is a graph of these electrical cardiac signals. ECG signals thus show the bio-potential generated by the activity of the heart.

The individual action potentials of the individual cardiomyocytes are averaged. The final result, which is shown on the ECG, is actually the average of billions of microscopic electrical signals. During the depolarization, sodium ions stream into the cell. Subsequently, the calcium ions stream into the cell. These calcium ions cause the actual muscular contraction. Finally the potassium ions stream out of the cell. During repolarization the ion concentration returns to its precontraction state. On the ECG, an action potential wave coming toward the electrode is shown as a positive (upwards) signal.

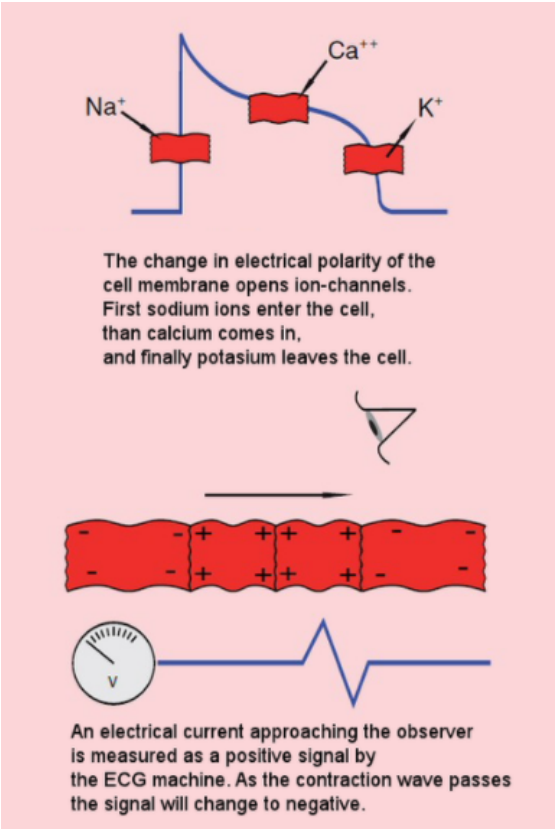

Figure 1: Ion currents resulting in an ECG, source here

This signal can be very useful in diagnosing and predicting cardio-vascular diseases. However, these signals are quite small and hence amplification and is necessary. In this project we build an ECG amplifier from scratch. We pursue tasks running the gamut from deciding which electrodes to use to finally viewing the signal!

2 Electrodes

The very first requirement to build an ECG Amplifier is to get the input for the same. The input would come from the body. Electrical activity going through the heart can be measured by external (skin) electrodes. The ECG registers these activities from electrodes which have been attached onto

different places on the body. In total, twelve leads are calculated using ten electrodes. The ten electrodes are:

- The four extremity electrodes:
  - LA (left arm)
  - RA (right arm)
  - N (neutral, on the right leg (= electrical earth, or point zero, to which the electrical current is measured))
  - F (foot, on the left leg)
- The six chest electrodes:
  - V1 (placed in the 4th intercostal space, right of the sternum)
  - V2 (placed in the 4th intercostal space, left of the sternum)
  - V3 (placed between V2 and V4)
  - V4 (placed 5th intercostal space in the nipple line. Official recommendations are to place V4 under the breast in women)
  - V5 (placed between V4 and V6)
  - V6 (placed in the midaxillary line on the same height as V4 (horizontal line from V4, so not necessarily in the 5th intercostal space))

It makes no difference whether the electrodes are attached proximal or distal on the extremities. However, it is best to be uniform in this (eg: one electrodes must not be attached to the left shoulder and the other on the right wrist). With the use of these 10 electrodes, 12 leads can be derived. There are 6 extremity leads and 6 precordial leads. Four simplicity we use the first four extremity electrodes.

The extremity leads are as follows:

- I from the right to the left arm
- II from the right arm to the left leg
- III from the left arm to the left leg

where lead I + lead II = lead III.
Other extremity leads are:

- AVL points to the left arm
- AVR points to the right arm
- AVF points to the feet

where aVR + aVL + aVF = 0.

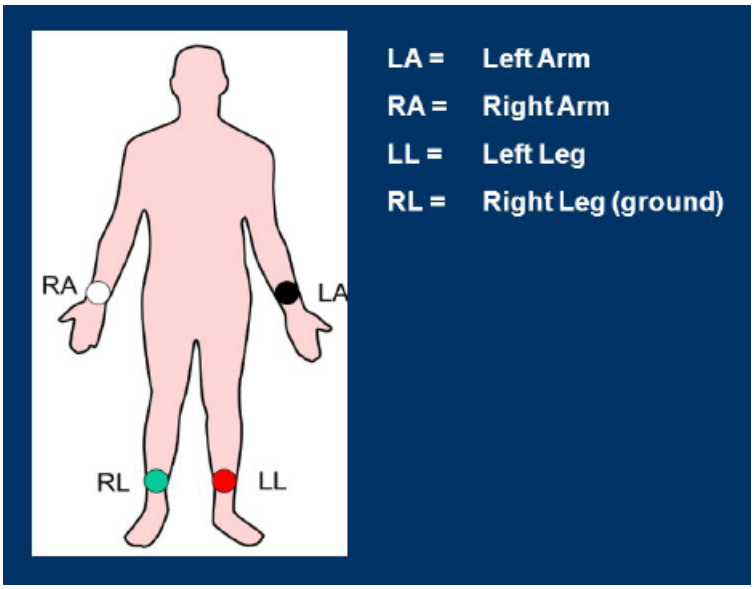

Figure 2: The employed electrode placement

3 Amplifier Design

The general requirements of an amplifier built for amplifying bio-potentials are as follows:

- High input impedance: This should generally be greater than 10 MΩ
- Low output impedance: This should be low to drive any external load with a minimum distortion

- Gain: The overall gain of the system should be greater than 1000 because bio-potentials are generally in the less than a millivolt.
- Differential: Most amplifiers are differential and are recorded using bipolar electrodes which, as mentioned in the previous section, should be symmetrically located.
- Common mode rejection ratio: The common mode rejection ratio should be high owing to the fact that that biopotentials ride on a large offset signals.
- There should be a possibility of a rapid calibration in the laboratory.
- Safety: We need to protect the subject which is being used to demonstrate the device. The design should prevent micro and macro shocks to the subject, and there should isolation and protection circuitry to limit the current through the electrode to safe level.

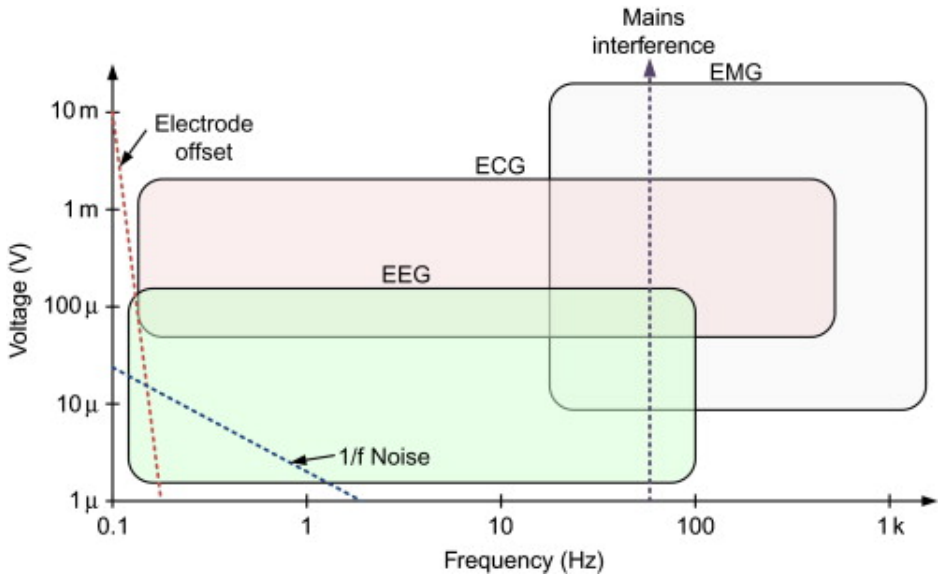

Figure 3: Range of voltage & frequency for various biopotentials, source here

4 Challenges

There are various problems in an ECG Amplfieir design. They are given and not limited to the following.

- Frequency Distortion: This generally would happen if the filter specifications do not match the frequency content of biopotential.
- Saturation or cutoff distortion: This would usually happen in case of a high electrode offset voltage or improperly calibrated amplifiers which then can drive the amplifier into saturation. This results in the QRS waveforms to get cut off.
- Ground loops: This would ensue when two monitoring instruments are placed at disjoint ground points, which would then result in a small current which could flow through the patient's body making it dangerous for the safety of the patient.
- Electric/magnetic field coupling: Open lead wires (floating connections) pick up EMI because of which the long leads produce loops that pick up EMI and then induces loop current, making the observation erroneous.
- Interference from power lines (common mode interference): This can couple onto ECG signal.
- Electrode Artifacts: The microelectrodes detect potentials on the order of 50-100mV. Their small size implies high source impedance which also results in a large shunting capacitance and in turn a degraded frequency response.

5 Interference

Interference in biopotential amplifiers can be caused by common mode voltages. There can be two ways to remove the interference- first to use an amplifier with a very high common-mode rejection and the second to reduce the source of interference. The second solution would involve some shielding mechanisms like electrostatic shielding by placing a grounded conducting plane between the source of the electric field and the measurement system.

A magnetic shielding can also be done by using high permeability materials (sheet steel). Interference can also be eliminated to an extent by using twisted cables to reduce magnetic flux, reduce lead loop area. The ways to eliminate the interference were very cumbersome so we decided to include the following circuit ('driven right leg circuit' to reduce the interference)

The driven right leg system is used to reduce the interference in the instrumentation amplifier and is also important for safety. The safety is required in case a dangerously high voltage is applied by isolating the subject from the ground. The approach is to tie the subject's leg to the output of an auxiliary amplifier instead of the ground. The common mode voltage on the body is sensed by averaging resistors & fed back to right leg. This then provides a negative feedback to reduce common mode voltage. In case a high voltage appears between the subject and ground, the auxiliary amplifier effectively un-grounds the subject to stop the current flow, thus ensuring safety. The driven leg circuit is shown below where RL represents 'Right Leg' and IA represents 'Instrumentation Amplifier'.

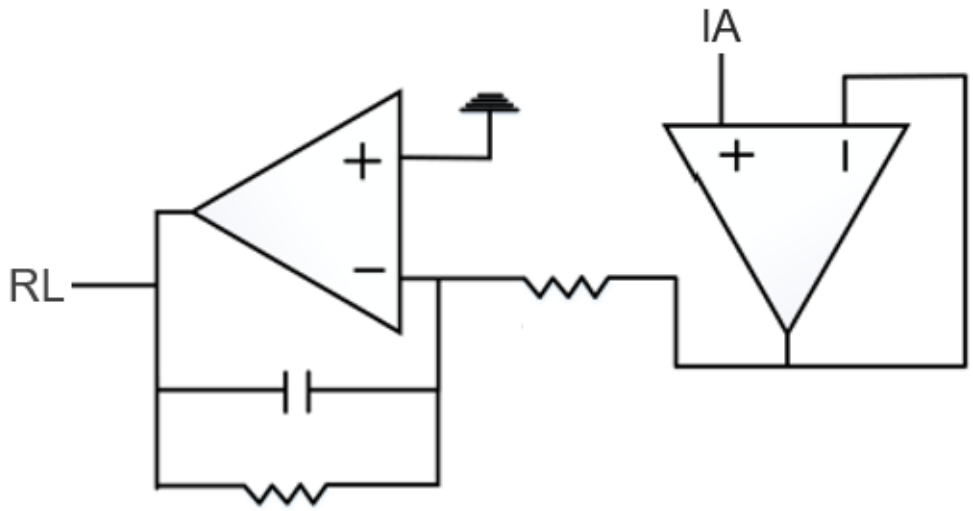

Figure 4: Driven Right Leg Circuit

6 Differential Amplifier

We use the instrumentation amplifier for our case, because of its many advantages including low DC offset, low noise, low drift, a very high common mode rejection ratio and a very high input input impedance. Since it is a type of a differential amplifier it only amplifies the difference in its inputs. Also, since it has a high input impedance it is quite suitable for biopotential electrodes which generally have a high output impedance. We use the IC INA118 for our purpose. Additonally, we add a high pass filter (HPF) to remove the DC offset from the ECG signal. The HPF is shown in a red dotted box in the below figure containing the setup for the differential amplification. The numbers in red denote the numbers corresponding to the IC ports.

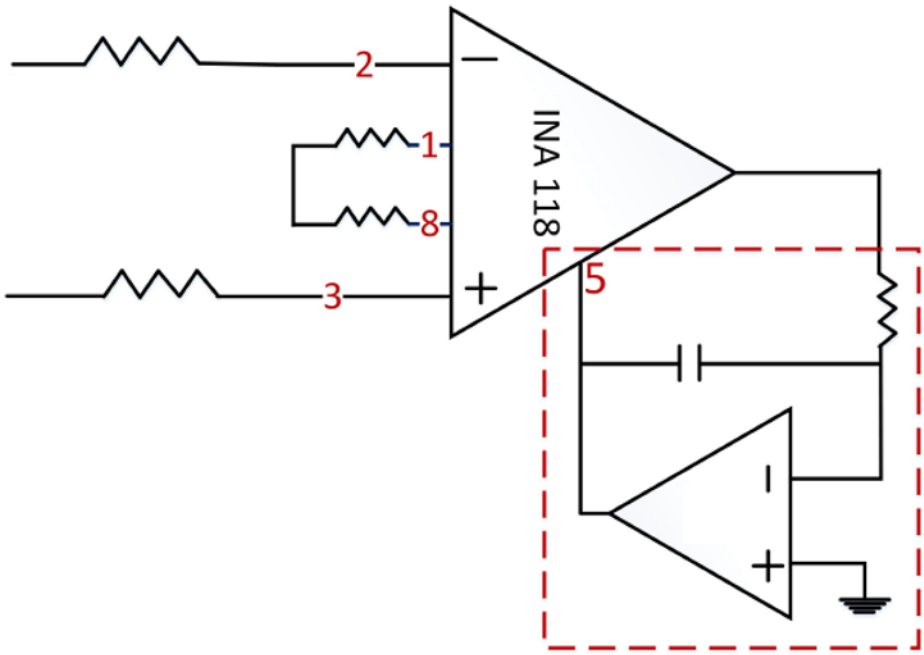

Figure 5: Instrumentation Amplifier with DC cacellation

7 Overall Method

The entire setup was broken into various stages, and each stage was checked cumulatively along with the previous stages.

- We first researched on various kinds of **electrodes** that take input from our body and settled on the four extremity electrodes.
- The first stage was the **Instrumentation Amplifier**. Also a 1μF was connected from the power supply to the ground. After making the circuit one of the end (the inverting end through the resistor, referred to as A) was grounded and the other (the non-inverting end through the resistor, referred to as B) was connected to a 10 mV, 100 Hz sinusoidal signal. Then a common mode input (20 mV, 100 Hz sinusoidal signal) was given to both the input. The output for the common mode input was around 5mV sinusoidal pk-pk.
- The next stage was the **Offset Cancellation Circuit**. Here the input was given a DC Offset but the output obtained had no (i.e. 0) DC Offset, as expected. Thus the offset was "cancelled". This configuration also acts as a High Pass Filter for the ECG signal.
- The next stage was **Driven Right Leg Circuit**. This stage serves the purpose of reducing the common-mode voltage due to interference, and to provide safety to the patient in case a very high voltage gets applied when the patient is isolated from the ground.
- The next stage is a **Low Pass Filter**, which also provides further amplification. This also limits the bandwidth of the amplifier.
- The next stage is the **Notch Filter**. This is used to eliminate the line frequency and is generally superimposed on the ECG signal.

The entire setup with the values various components is given below. The calculations for the values is not given here.

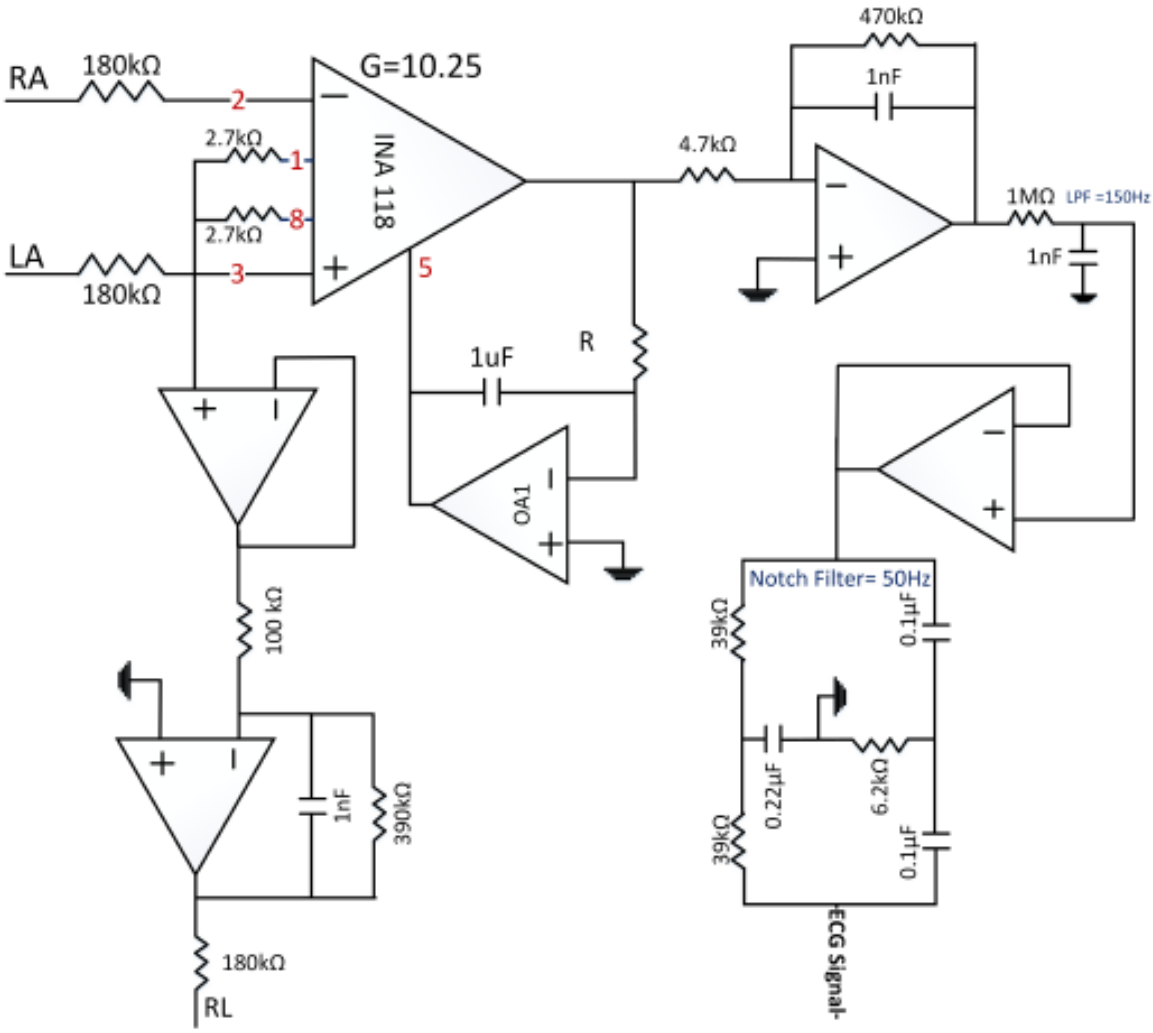

Figure 6: The complete circuit for the ECG Amplifier

Figure 7: The ECG signal obtained

8 Improvements

- We can improve the low pass filter by increasing the rate of fall of the bode plot after the cut of frequency. This can be achieved by having square terms in the denominator of the transfer function. Better yet, we can use higher order filters.
- Instead of having two same resistors in the notch filter we can fix one of the resistor and put a rheostat (pot) in place of the other. We can then tune the pot for a better output.

9 Conclusion

We successfully built the front end for the ECG Amplifier while taking into consideration many factors that arise in bio-potential measurements. We ensured highest safety standards for the subject and kept that as the first and foremost priority.