ELECTROCARDIOGRAM PCB DESIGN

PROJECT REPORT

This project aims to demonstrate the functioning and principles of an electrocardiogram and design its PCB using KiCad.

An electrocardiogram (ECG) is a medical test to check the functioning of the heart. The beats of the heart generate electrical impulses which are detected by electrodes connected to a person's arms and legs. These pulses are then visualized on a computer to help doctors diagnose any underlying diseases or malfunctions of the heart.

The characteristics, design and working of the system is explained below.

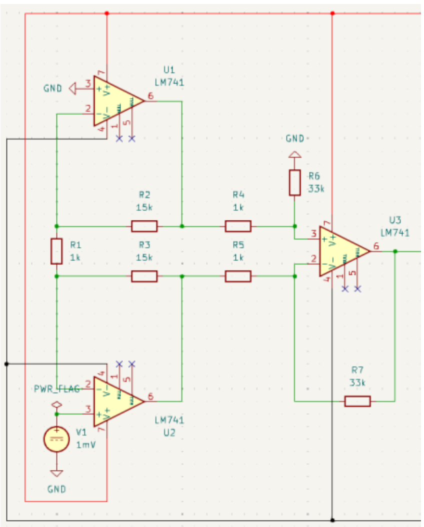
a) **Desired Characteristics and Functionalities**

Differential Amplifier – It should amplify the small electrical impulses from the heart so that they can be processed without getting attenuated in the process.
Notch Filter – The electrical wiring of a building carries AC power at 50 Hz which produces significant noise in the readings. To specifically filter this out, a band-stop filter has to be used.
Low Pass Filter – Other interferences from various sources have to be filtered out and signals relevant to the reading should be retained. As relevant readings have low frequencies, a low-pass filter must be used.

b) **Schematic Diagram**

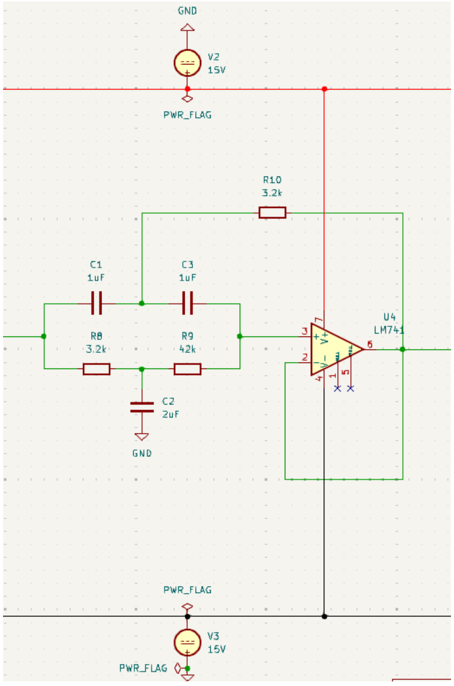
The three components of the circuit as described above were drawn and cascaded as shown below:

<u>Differential Amplifier</u>



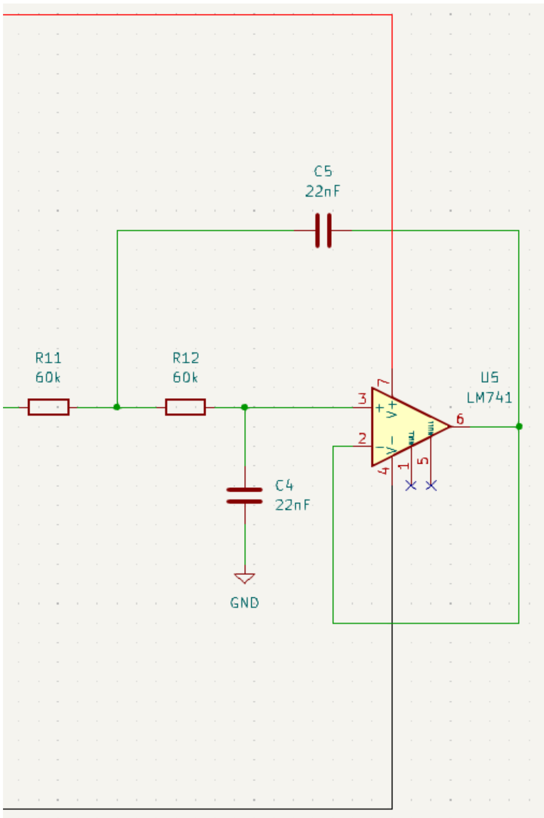
3 electrodes are attached to the patient's body. Op-Amps U1 and U2 are the input buffers and U3 amplifies the signal. All three are LM741 Operational Amplifier ICs. PIN 3 of U1 and U2 receive two electrode inputs from the patient. The third electrode is connected to ground. The outputs of U1 and U2 are passed to U3 which amplifies the inputs. For the purpose of drawing this schematic in KiCad, the PIN 3 of U1 was grounded and PIN 3 of U2 was provided an offset of 1mV to simulate the small difference in the input signals. Note that the red wires are connected to +15V and black wires are connected to -15V.

Notch Filter



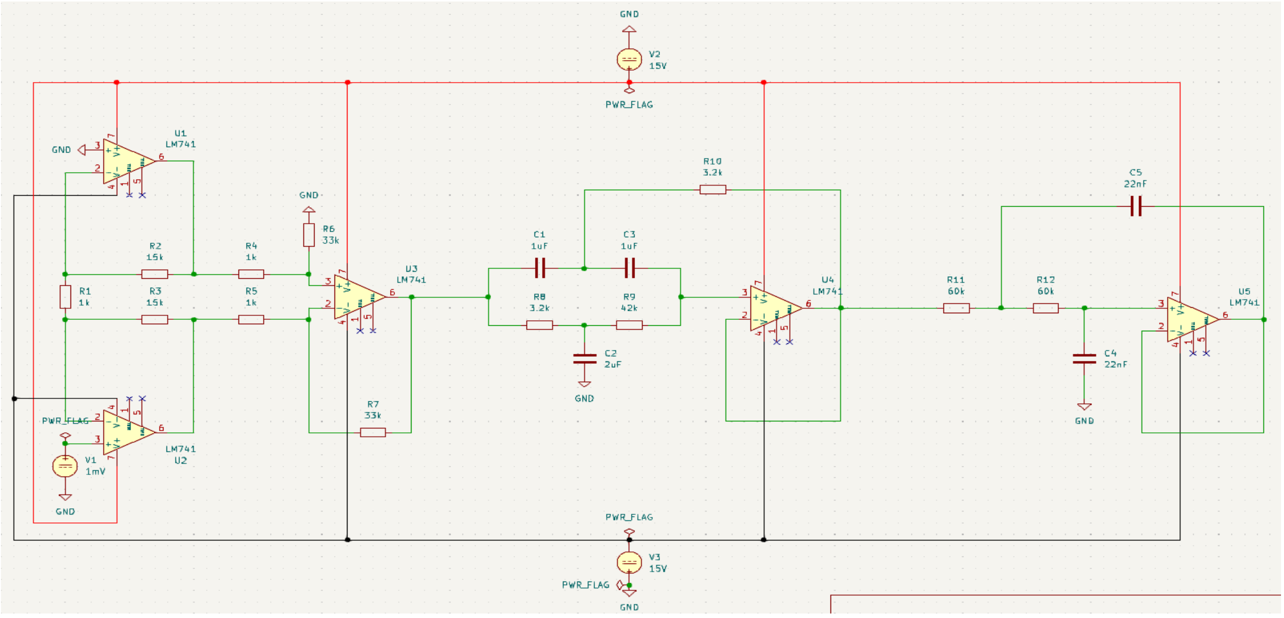
This is the schematic of the Notch Filter. The input is taken from PIN 6 (output pin) of U3 in the differential amplifier. The notch filter is designed to filter out electrical grid noise of 50 Hz frequency and amplify the remaining signals. The output contains the filtered signals and is passed to the low-pass filter.

Low-Pass Filter



The low-pass filter takes the filtered signal from the Notch filter and further removes high frequency noise from the signal. It is a second-order active low-pass filter that uses the LM741 IC as its op-amp. The output signal is through PIN 6 (output pin) of the IC.

The complete circuit is provided below.



c) **Working of the System**

<u>Differential Amplifier</u>

The ECG gets its input through electrodes attached to the body, which are small electrical impulses. These are amplified by a differential amplifier that amplifies these signals. The differential amplifier comprises of 3 operational amplifiers (LM741) two of which take in the inputs from the electrodes and act as input buffers (have a gain of 1 but increase the power of the signals). The third op-amp is the differential amplifier which amplifies the signals due to the small difference between them and rejects any common signals.

<u>Notch Filter</u>

A Notch Filter is a band-stop filter, a filter that allows frequencies outside a certain range to pass. It is created using twin T configuration (involves 2 'T's built using resistors and capacitors). Here, it is required to filter out the 50 Hz frequency, which acts as noise (or a "hum") in the signal. This noise is generated because the electrical grid of the room where the readings are being taken carries AC current at 50 Hz frequency, which causes significant effects in the readings, which are also of low frequencies. The output signal is again amplified by another op-amp with a resistor.

<u>Low-Pass Filter</u>

The third stage contains a low pass filter. A low-pass filter is a filter that allows frequencies below a certain value to pass and attenuates higher frequencies. The type of low-pass filter used here is a second order active low-pass filter that uses an op-amp. Our heart beats at around 72 beats per minute which is 1.2 Hz. However, the ECG signal is composed of several waveforms:

1. P-Wave: Represents atrial depolarization, has low frequency (5 – 30 Hz)
2. QRS Complex: Represents ventricular depolarization, has comparatively higher frequency (up to or sometimes greater than 100 Hz)
3. T-Wave: Represents ventricular repolarization (0 – 10 Hz)

As a result, we cannot directly apply a low pass filter of cutoff around 1.2 Hz since we need to let the other essential signals pass through. Therefore, a low pass filter of around 120 Hz is created to allow for abnormalities.

Frequencies higher than this are most likely noise, such as electromagnetic interference by radios or muscle noise and can be filtered out.

d) Power Rating

To estimate the power consumption of the circuit, we need to consider the power-consumption of the operational amplifiers used. The datasheet of LM741 mentions that in our operating conditions ($V_s = \pm 15\text{V}$, Temp 25C), the power consumption is typically 50mW and maximum is 85mW.

Therefore, since there are 5 op-amps, the average power consumption would be around 0.25 W, with maximum of 0.425 W.
The power consumption of the resistors would be negligible because of the current flowing would be very small in this application of measuring heart rates. Even after amplification, the current would not be significant enough to affect power consumption.

Capacitors do not consume power, they either store it (for DC inputs) or have charge and discharge cycles (for AC inputs). In our case the DC inputs are only provided to the op-amps for amplification, so we can consider the pulses to be a form of AC.

The thicknesses of the wire during PCB design were decided by considering the power consumption to be 0.5W, which provides a sufficient buffer for unprecedented fluctuations.