Universidade do Minho
Escola de Engenharia

Instrumentation Amplifier for measuring bio-potentials generated by human body

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Report prepared by Diogo Gomes Rodrigues

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Summary

This practical work aims to study the acquisition and amplification of differential signals using an instrumentation amplifier. The focus is on measuring biopotentials generated by the human body, such as EMG (electromyogram), EOG (electro-oculogram), EEG (electroencephalogram) and ECG (electrocardiogram).

The practical experiment will focus on ECG measurement as it is one of the easiest signals to observe. For this, three electrodes will be used: two to capture the differential signal from the heart and one as a reference. The instrumentation amplifier will be responsible for amplifying and filtering the signal before processing.

1. Introduction

There are several signals with very low amplitudes that can be significantly affected by noise or interference, external or internal to the acquisition system. Furthermore, in many situations, instead of intending to make the acquisition in relation to potential land, GND, it is possible and/or desirable to make the acquisition in a differential manner, that is, to make the acquisition and amplification of a signal relative to a reference point, which does not have to be GND. This can make the system more immune to noise and interference. There are several examples, from Wheatstone bridges to differential system outputs. A very amplifier commonly used in this type of acquisition is the instrumentation amplifier. In this work practical, the use of this amplifier will be studied, as we will need a signal differential to amplify and filter.

A “simple” way to obtain such signals in the laboratory is to acquire them and see the effect of an instrumentation amplifier, is to resort to one of the biopotentials generated by the human body. Among them we have the EMG (electromyogram), the EOG (electro-oculogram), the EEG (electroencephalogram) and ECG (echocardiogram). To measure this type of signals, in addition to the instrumentation amplifier, it will be necessary to use at least one pair of electrodes that

connects to the input of an instrumentation amplifier and then to the acquisition electronics and processing.

Of those mentioned, the most difficult signal to measure is the EEG and the easiest is usually the EMG. Ease of reading is associated with amplitude, which is greater for EMG. However, his waveform does not allow any relevant characteristics to be observed with the naked eye. From this group, one of the best known signs is the ECG, which is also relatively easy to observe with a appropriate but simple circuit. This experiment aims to measure your ECG. For the effect it is necessary to use two electrodes (which allow measuring an ECG derivation) that connect to the input of an instrumentation amplifier, as well as a third that serves as reference electrode.

2. Material used

Material used:

- ECG electrodes (provided after instrumentation amplifier is up and running)

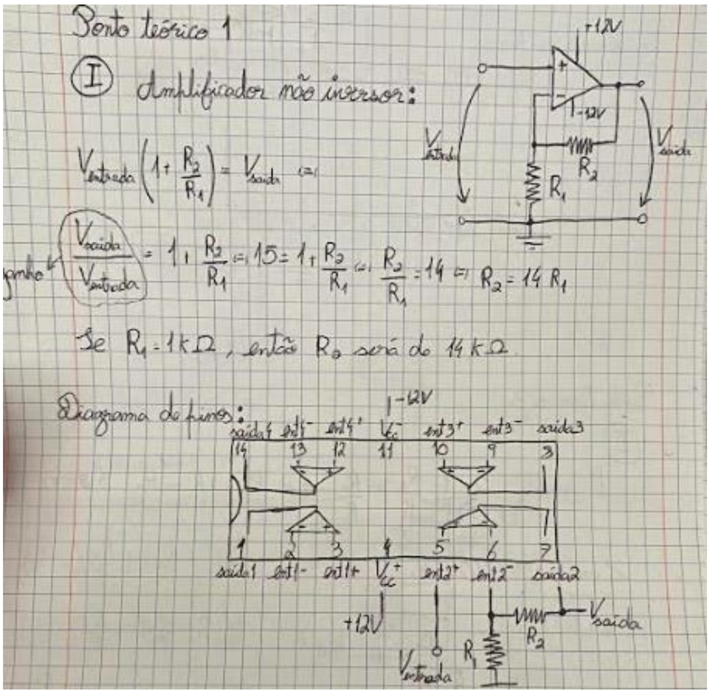
- Digital Lab, BreadBoard, Digital Multimeter, Oscilloscope
- Operational amplifier (LM324 or TL084)
- Resistances;
- Capacitor;
- AC/DC source;
- Connection wires;

3. Procedure

3.1. Cascade amplifiers

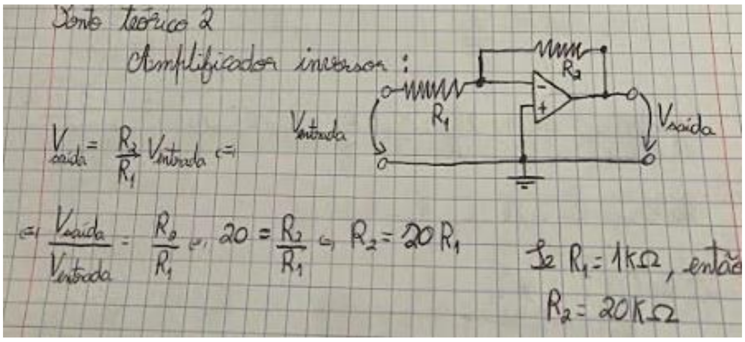
It is intended to use the TL084 (or LM324) (4 AmpOps) to build a two-stage amplifier. This amplifier should allow a biopotential (μV-mV) to control an LED (4-5 V). In this particular case, the ECG should allow the activation of an LED with each heartbeat. All OpAmps are powered with +-/12V.

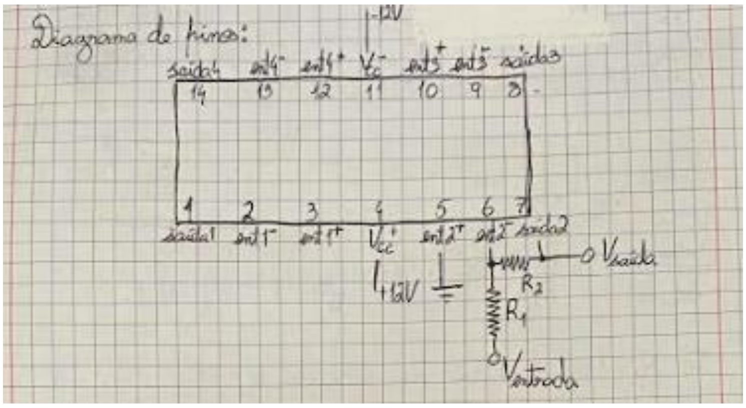
First we use one of the OpAmps to obtain a non-inverting amplifier assembly with a gain of ~15.



Its gain is $gain = \frac{7.5}{0.5} = 15$ and its bandwidth is [0,fc], where $fc = \frac{S.R.}{2\pi V_m} = 16kHz$ wich is the frequency where the wave starts to become a triangle.

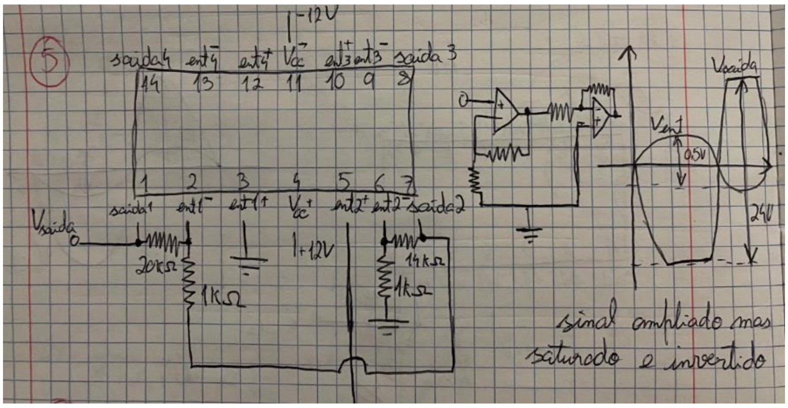
Then we use another OpAmp to obtain an inverting amplifier assembly with gain of ~20.





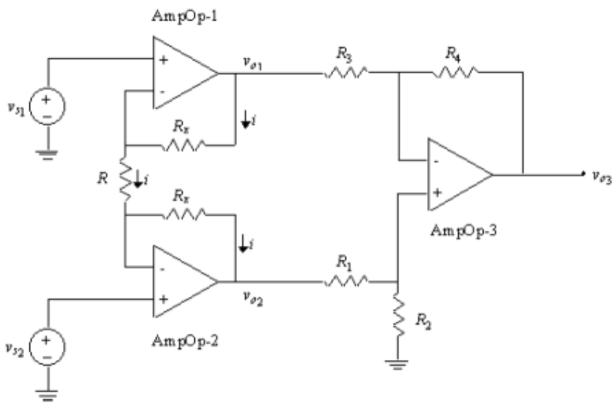
The bandwidth is expected to be smaller since the amplifier gain is inversely proportional to the bandwidth.

If we now connect the output of the first assembly to the input of the second, we know that the set of a series association of amplifiers has a gain equal to the product of the gains of each one and a bandwidth corresponding to the intersection of the bandwidth of the two, that is, the smallest of them. In this case the set would have a gain of $gain = 15 * 20 = 300$, but if we put, for example, a sinusoidal wave with 0.5 Vpp at the input and 1kHz the wave would come out amplified but saturated, cutting at 12V due to the limitation introduced by the amplifiers' supply voltage, the bandwidth would be practically equal to the smallest bandwidth of the 2 amplifiers which is the inverting amplifier.

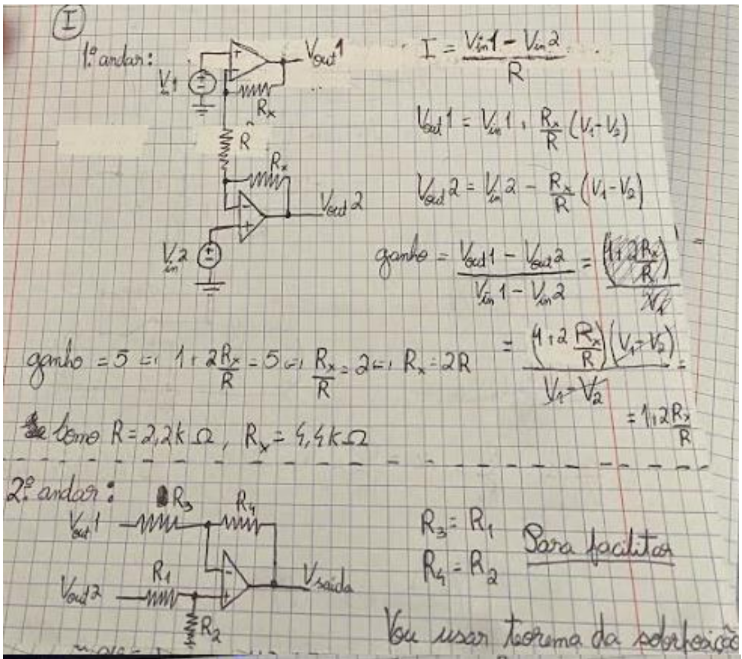


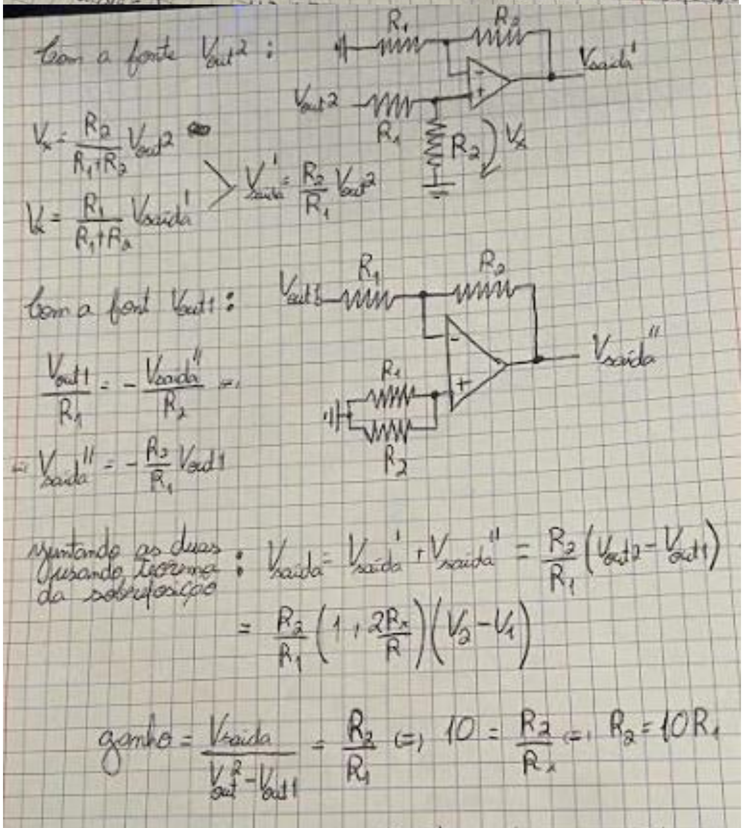
The great advantage of using amplifiers in series instead of using a single amplifier with high gain is that we can achieve these gains with a larger bandwidth (equal to the smallest of them all), which would not be possible in a single amplifier with high gain because the bandwidth is inversely proportional to the amplifier gain. If the amplifier is connected to a LED which needs about 2 V and a few milliamps the LED would light up even with the amplifier input being 0 because a signal with a few millivolts amplified 300 times would exceed 2V, that is, it would have an output voltage greater than the LED's cut-off voltage, causing it to conduct, and the current that passes through it is supplied by the amplifier's power supply.

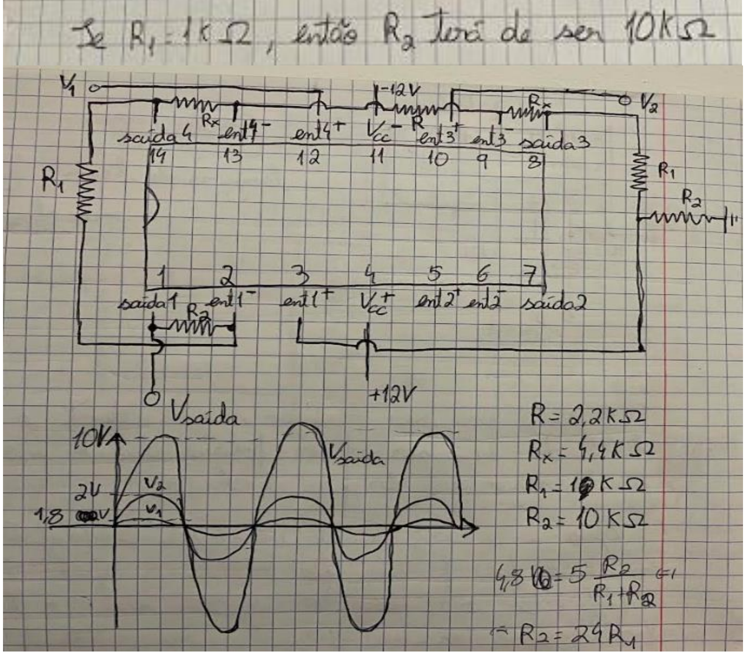
3.2. Instrumentation amplifier



The idea now is to apply the knowledge from the previous point to build an instrumentation amplifier with R = 2.2 kΩ, so that the gain of the 1st stage is ~5 and in the 2nd stage ~10.

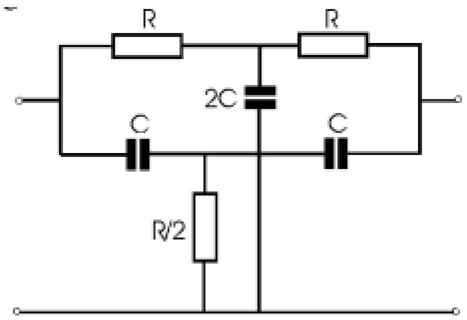




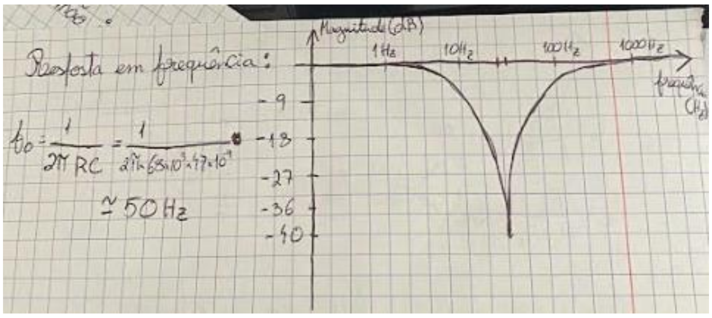


3.3. Acquisition and processing of an ECG

Now I need to implement a band-reject filter that allows us to eliminate interference whose frequency is 50 Hz. To do this, we use a notch filter, that does not allow voltage to pass for signals with a frequency around a central station and allows others to pass without attenuating anything,based on the Twin-T configuration, as shown in the following image:

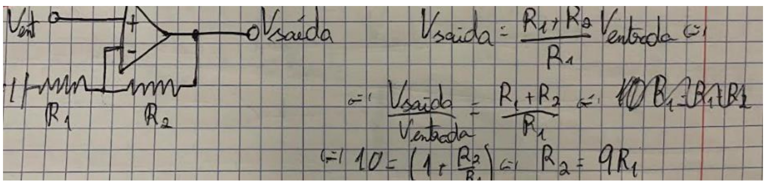


Using the capacitor I have (C=47nF), I obtained a resistance value of 68 kΩ through a simulator, so I will use a C=47nF, 2C=94nF (2 of 47nF in parallel), R=68 kΩ, R/2=34 kΩ.

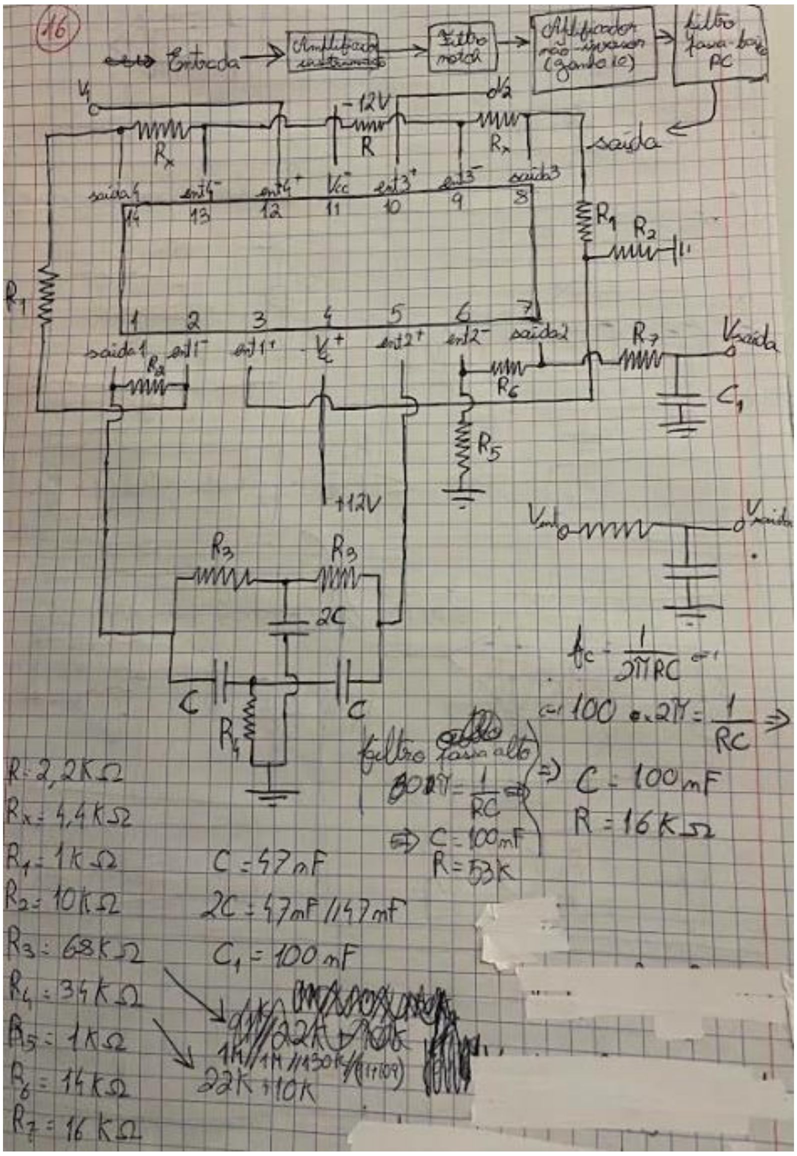


To test if it is working correctly we can place a 50Hz sinusoid and check that the output is 0V and if we place another it is 10V.

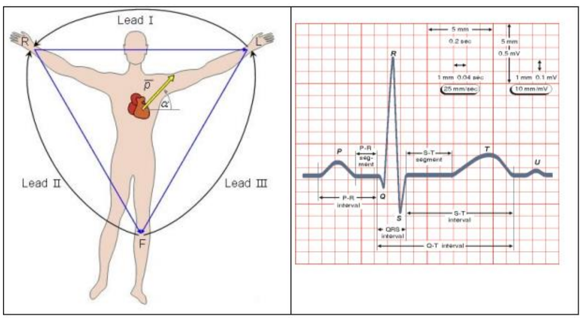
With the last remaining amplifier, I implemented a non-inverting amplifier with gain ~10 and connect to the output of the notch filter.



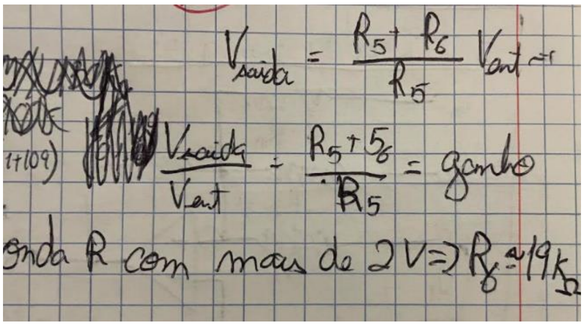
Finally, I placed an RC low-pass filter on the output of the entire system. The bandwidth should be between 30 and 100 Hz.



Now let's finally test the circuit and measure lead I of the ECG (figure below). Now you should connect the electrodes to the AI input and observe your ECG on the oscilloscope.

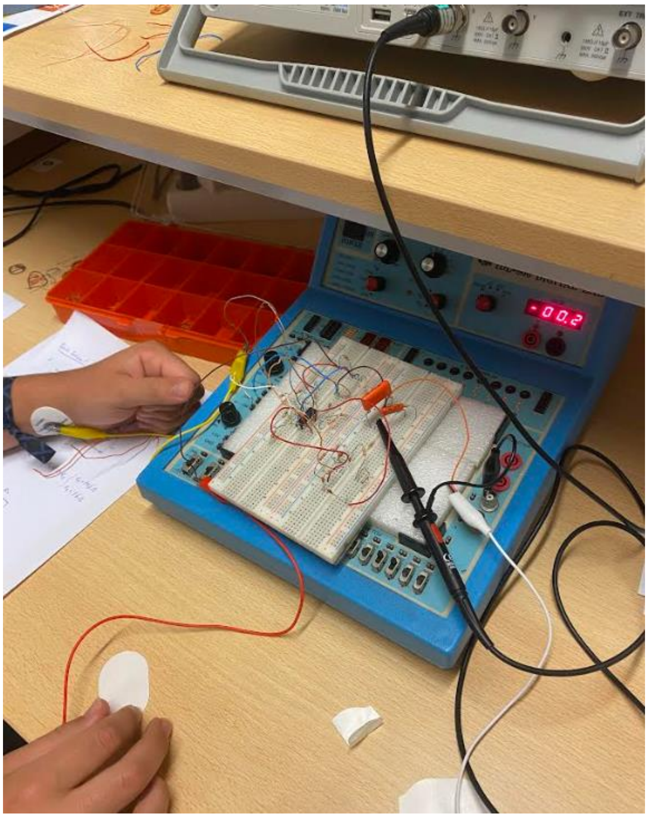


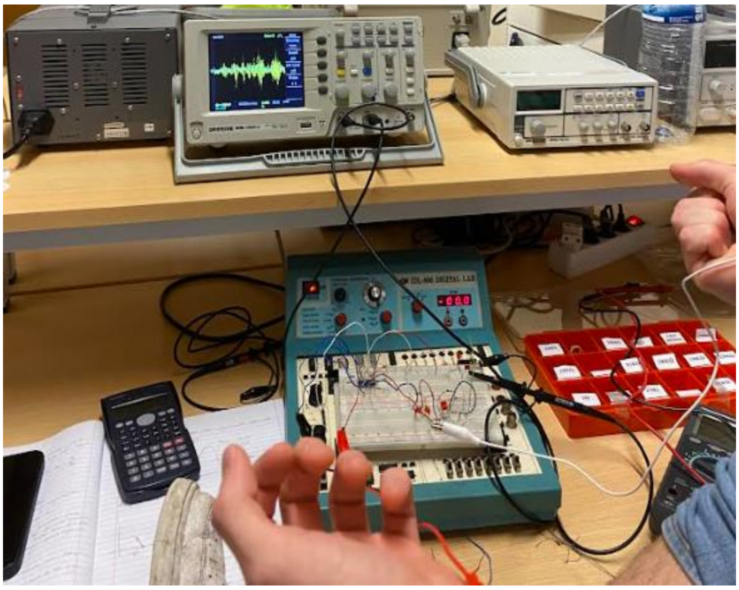
I also calculated the gain of the non-inverting assembly to amplify the signal if I wanted the ECG signal to light up an LED whenever an R wave appeared.



4. Discussion of results and conclusion

The ECG signal obtained was as follows:





As we can see, the ECG signal has a lot of noise, which can be caused by several factors such as:

- **Poor Electrode Contact:**

  - Electrodes not properly attached to the skin or dried out.

  - Skin not properly prepared (not cleaned or oily).

  - Use of low-quality or worn-out electrodes.

- **Power Line Interference:**

- Lack of shielding in electrode cables.
- Excessive cable length, picking up environmental noise.

- Presence of nearby electrical equipment generating electromagnetic interference.

- **Muscle Noise (Involuntary EMG):**

- Person moving during measurement.

- Involuntary muscle contractions near the electrodes.

- **Instrumentation Amplifier Issues):**

- Gain too high, amplifying noise like as well.

- **Electronic Circuit Issues:**

- Poorly made or loose connections (without welding).

- Poor Breadboard layout, with no proper separation of sensitive signal traces.

- Shared power supply with other noisy devices.

Bibliography

[1] Work guide.

[2] Notes from Electronics Complements classes.

[3] Previous support texts on assemblies with operational amplifiers.