Technical Description of the EEG Acquisition Pipeline

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Electronic Hardware - Technical file

The end goal of the project is to design and conceive an acquisition board able to acquire, process and display an electroencephalogram signal (EEG). The PCB presented is adapted to filter and amplify EEG signals. The analogic signal is converted and processed with a Raspberry Pi to display temporal and frequential domains at a data rate of 215 Hz for each electrode. The printed circuit board model (PCB) is versatile and could be adapted to different bio-signals such as ECG, EOG and EMG. The topography of each circuit is the same, however the values of the respective components in the filters can be varied to respond to the specified frequency range of the biosignal.

Acquisition Circuit

The circuit includes 4 channels, one for each electrode. Five electrodes are used, one of which is used for a common reference used by all four channels. The EEG is the result of the difference between a given electrode and the reference. The reference is usually connected to the earlobe of the subject. A bias electrode is often used in EEG measurement. This electrode has the role to limit the impact of interference and noise. On the board, the reference and the bias electrodes are connected. The acquisition board is composed of nine main levels:

Considering the maximum amplitude of EEG measured on the scalp is around 100 µV and the frequency range is from 0.5 to 40 Hz [1], targeted frenquencies and gains were chosen and adapted to the supply voltage used of 5V provided by the Raspberry Pi. The operational amplifiers (LM324) have a saturation gain of V^{+}-1.5V. The signal displayed is included in the 0 to 3.5V range. This implies that the output signal is centered in 2.5V (see section Power Supply and Virtual Ground), because the op-amps use the virtual ground as reference. Considering a net gain of 18 337 and a maximal amplitude of 100 µV, a signal with an amplitude under 1.83 V is expected.

Table 1. Frequency Range & Gain at every level of the board

Signal	Frequency Range (Hz)	Instru. Amplifier	High-pass filter (0.5 Hz)	Low-pass filter (35 Hz)	Notch filter (60Hz)	Non-inverter amplifier	Net gain
EEG	0.5 - 35	883	1	1	0.74	28	18 296

The following sections will detail each level that composes the acquisition circuit.

1. Power Supply and Virtual Ground

The circuit is powered directly by a 5V supply from the Raspberry Pi, itself supplied by a power outlet. The Raspberry Pi could also be supplied by a batterie which would make it portable. The amplification and the filters use multiple op-amps which must be powered by a differential supply. A virtual ground is used to reproduce the differential power supply (± 2.5 V) with the single 5V supply. The design used is a tension divider splitting the 5V power in two. The virtual ground is stabilised by a follower op-amp. The reference used for the whole circuit is then the 2.5 V corresponding to the virtual ground (VGND). This way the op-amps are all supplied with the 5V, but the positive terminals of the op-amps are connected to the virtual ground instead of the ground. Compared to the 2.5V reference, the supply is more or less 2.5V which reproduces the differential power supply.

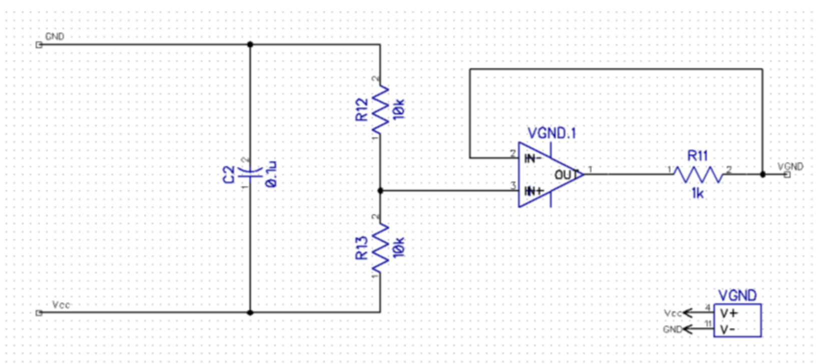


Figure 1: Virtual ground for a 5V single supply

The consequence of using the design of virtual ground presented at figure 2, is that the signals become centered in 2.5V. This implies that the reference electrode has to be connected to the virtual ground to have a common reference.

2. Protection circuit

The protection circuit works as a current sink from the electrodes to the circuit and from the circuit to the electrodes, thus protecting the circuit as well as the user from high currents in both directions. Fast switching diodes are often implemented in protection circuits as they prevent current flow in one direction above a given voltage threshold. A 4-Channel Ultra Low Leakage ESD (Electrostatic Discharge) protection circuit is used to implement back to back diode array to accommodate bi-directional signaling between –5.5 V and 5.5 V, part TPD4E1B06. Below is a figure of the protection circuit.

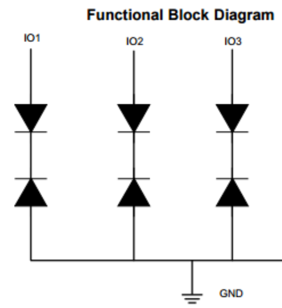


Figure 2: Protection circuit, part #TPD4E1B06, illustration of diode configuration inside the ESD protection circuit.

3. Instrumentation Amplifier

The second level consists of a high gain, low noise instrumentation amplifier (AD620AR). Instrumentation amplifiers use three integrated op-amps. The two input-differential op-amps reduce the common noise between the inputs. They also insure a minimum of tension division due to the high input impedance (*Figure 3*). A non-inverting op-amp amplifies with a total gain of 883.

$$G = 1 + \frac{49400}{R_G} = 1 + \frac{49400}{56} = 883$$

The positive input represents one of the 4 electrodes and the negative input is connected to the reference electrode. The signals of interest are the difference of a selected electrode and the reference electrode placed on the earlobe of the subject.

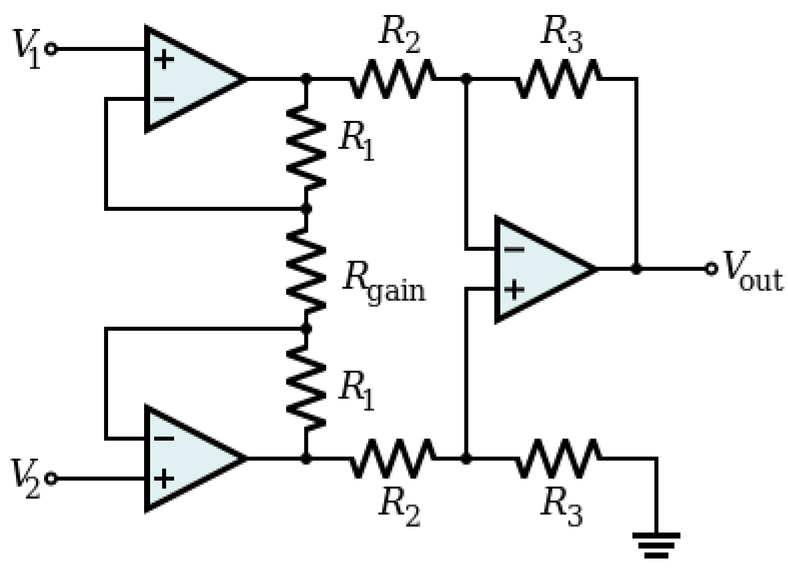


Figure 3: Instrumentation amplifier

4. High-Pass Filter

The EEG signal contains frequencies ranging from 0.5 to 35 Hz. The signal must be filtered. The first level of filtration is a second order unity gain Sallen-Key high-pass filter at to eliminate frequencies beneath 0.3 Hz. The Sallen-Key filter was chosen for its lower ripple voltage properties. The second order provides an acceptable steep in the Bode diagram to cut the low frequencies.

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$f_{coupure} = \frac{1}{2\pi \times \sqrt{60\,400 \times 75\,000 \ \times (10 \times 10^{-6})^2}} = 0.3\ Hz$$

The cut-off frequency is confirmed on the Bode diagram on *Figure 5*.

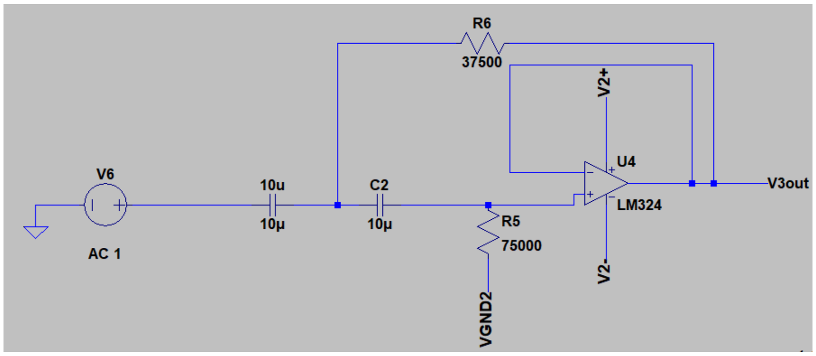


Figure 4: High-pass unity gain Sallen-Key filter (LTspice)

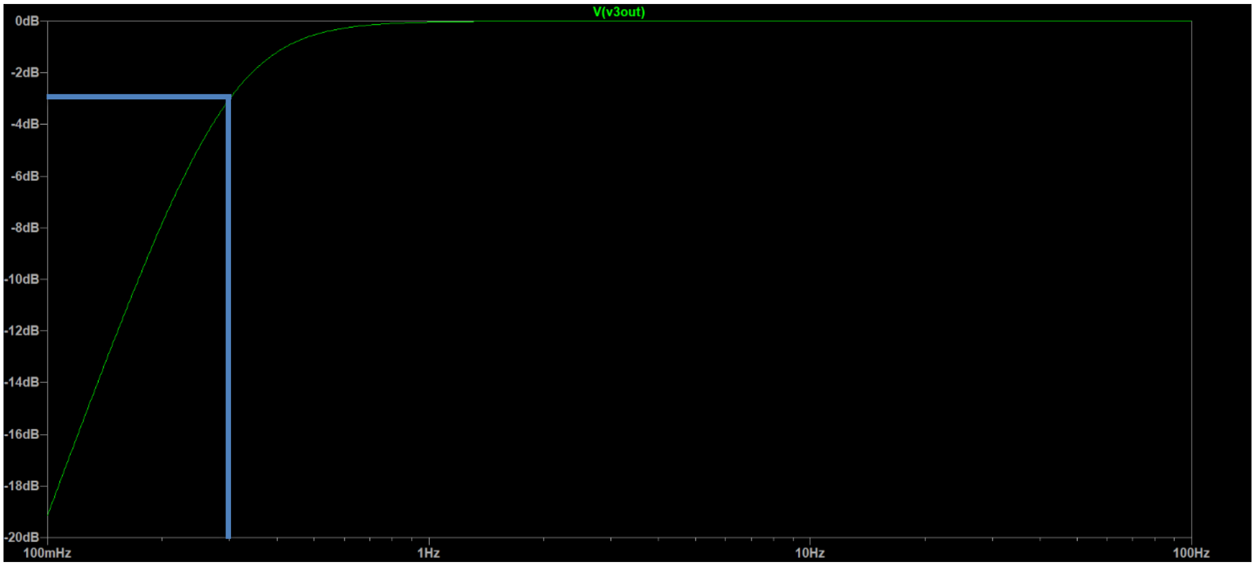


Figure 5: Bode Diagram of a high-pass filter unity gain Sallen-Key filter simulated with LTspice.

5. Low-Pass Filter

The low-pass filtering level is used to reject the unwanted high frequencies. The second level of filtration is a second order unity gain Sallen-Key low-pass filter at to eliminate frequencies above 35 Hz. The Sallen-Key filter was chosen for its lower ripple voltage properties. The second order provides an acceptable steep in the Bode diagram to cut the low frequencies.

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$f_{coupure} = \frac{1}{2\pi \times \sqrt{3400 \times 60\,400\ \times 10^{-6} \times 0.1 \times 10^{-6}}} = 35.1\ Hz$$

The cut-off frequency is confirmed on the Bode diagram on *Figure 7*.

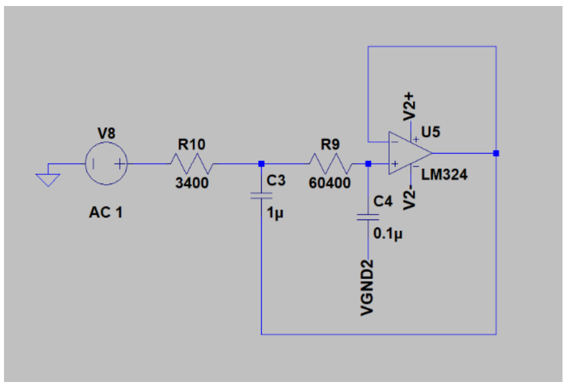


Figure 6: High-pass unity gain Sallen-Key filter (LTspice)

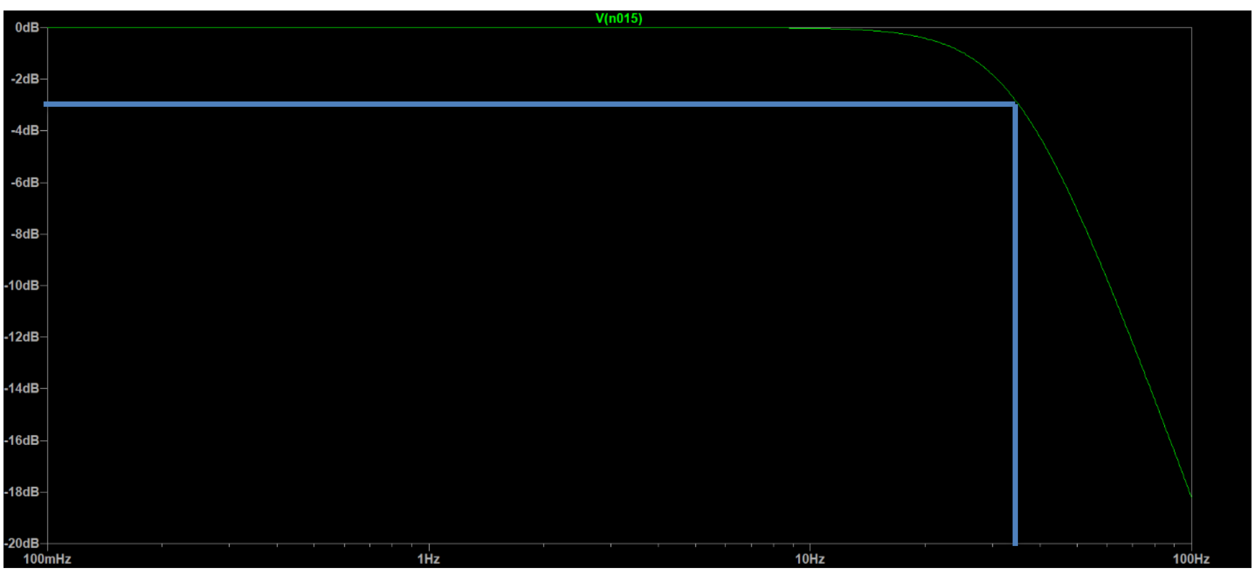


Figure 7: Bode Diagram of a low-pass filter unity gain Sallen-Key filter simulated with LTspice

6. Notch Filter

A notch filter was implemented to reduce the 60 Hz interference caused by the power line. A notch filter is a band-stop filter with a narrow stopband. Therefore, it allows most frequencies to pass unaltered but attenuates a certain range of frequencies to a very low level, in our case 60 Hz. A quality factor of 74% (100% being very specific to 60 Hz and 0% being the largest frequency cut-off), was selected. The 60 Hz-frequency is attenuated by about -26 dB.

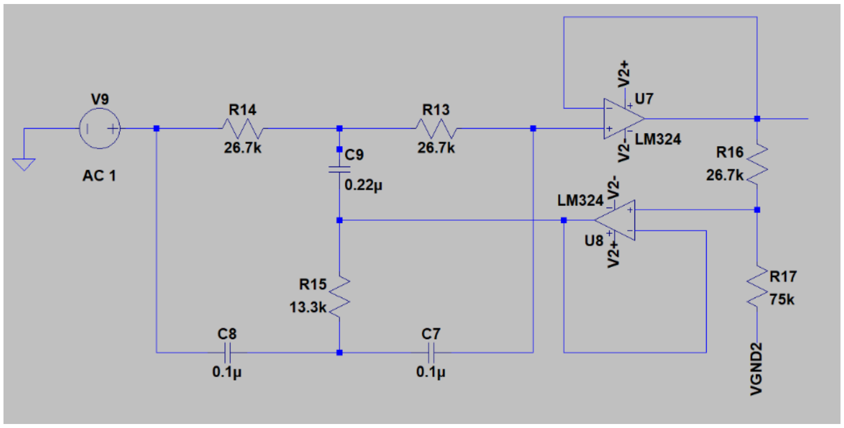


Figure 8: 60 Hz Notch filter (LTspice)

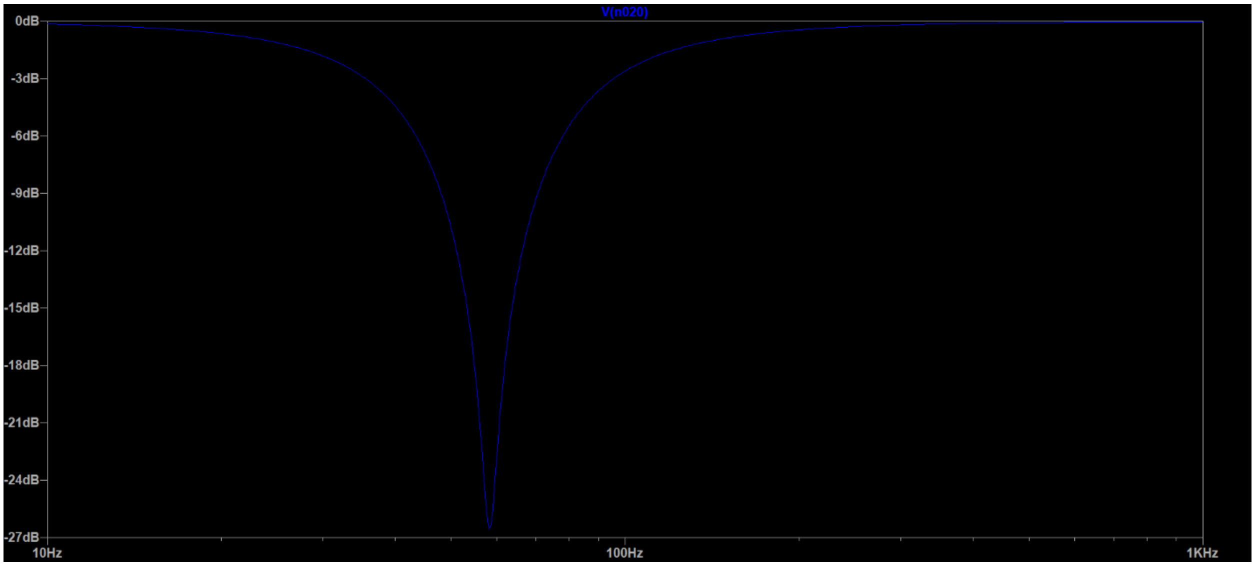
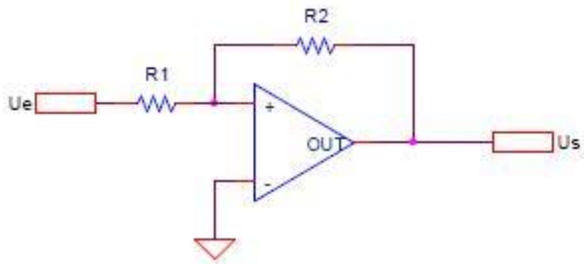


Figure 9: Bode diagram of the 60 Hz Notch filter (simulated with LTspice).

7. Non-inverter amplifier

A final operational amplifier was implemented to increase the net gain of the signals. This way the EEG can be in an acceptable detection range. The gain of the non-inverter is at 28 for a total gain of around 18 300.



$$G = 1 + \frac{R_2}{R_1} = 1 + \frac{26.7}{1} = 28$$

8. ADC

The analog-digital converter used to transmit the data to the Raspberry Pi is the ADS1115. The component uses an I^2C communication protocol. The data are transmitted serially at a frequency of 860 Hz, because the ADS1115 have 4 channels the data rate for one signal is then 215 Hz. The data circulates through the Serail Data Line (SDA) at a certain frequency defined by the Serial Clock Line (SCL). The ADC sends numbers between -32768 to 32767, corresponding to the voltage value (0 corresponding to 0V and 32767 corresponding to 4.096V). The precision of the ADC is 16 bits. The signals are centered in 2.5 V, because of the virtual ground, the values sent to the Raspberry Pi is then never underneath 0V. The voltage measured ranges from 0.5 to 3.8 V due to the limitation of the op-amps supplied at 5V (saturation).

9. Raspberry Pi

The data is sent through a program on the Raspberry Pi, which treat (FFT) and plots the temporal and spectral domains of the signals. The four electrodes can be plotted at the same time and both domains can be visualised simultaneously on the interface. The graphs replot every second to approach a real-time plotting.

References

[1] Biomedical Engineering Education Portal - National Instruments. *Ni.com*. N.p., 2016. Web. 2 Oct. 2016.