Some tips on how to design the EEG Virtual Acquisition Chain

Introduction

In this guide, we present a case study based on an electroencephalograph (EEG) to show the use of our acquisition chain. An overview of the major parameters that can be tuned and their impact on the chain will be provided. One of the major goals will be to enhance signal quality measured by the signal to noise ration (SNR).

The SNR chosen here is equal to the power of the signal divided by the power of the error. The error is defined as the instantaneous difference of the ideal signal and the non-ideal signal.

The examples provided here are not extensive and you will certainly be able to learn a lot more by yourself. However this approach provides a good starting point.

Both the EEG virtual chain and its user guide can be downloaded at:
http://beams.ulb.ac.be/beams/research/all/virtualchain.html.

The EEG chain in its default configuration

Start the chain to get its default configuration (see Figure 1). The signal being quite large (200µVpp), the SNR is good until the end of the chain (28~29dB). The acquisition chain is fairly well designed.

Fig1 – The chain in its default configuration.

Another EEG and a smaller signal

Through this manual we will focus on another acquisition chain that is slightly modified: the filter and the amplifier are now noisier. To do so, increase the order of the high-pass filter from 1 to 2, the noise of the filter module from 75µVpp to 200µVpp and the one of the amplifier from 3µVpp to 5µVpp. We can now see if this chain is adequate to amplify a smaller signal and how it can be enhanced. Changing the signal amplitude from 200µVpp to 50µVpp and switching it from 'Stylized SW' to 'Illustration' gives quite another picture than for the previous acquisition chain (see Figure 2). The noise, much more visible, comes from the electrode, the cable, the amplifier, the filter and the ADC, which damages the signal.

The resulting SNR at the output of each element is the following:

- Electrode output: 26 dB (because of the 5µVpp noise of the electrode).
- Cable output: remains at 26 dB (because no noise or 50Hz hum is present).
- Amplifier output: drops to 13 dB (because of the 5µVpp amplifier's noise).
- Filter output: still decreases a bit to 12 dB (because of the filter's noise).
- ADC's output: remains at about 12 dB.

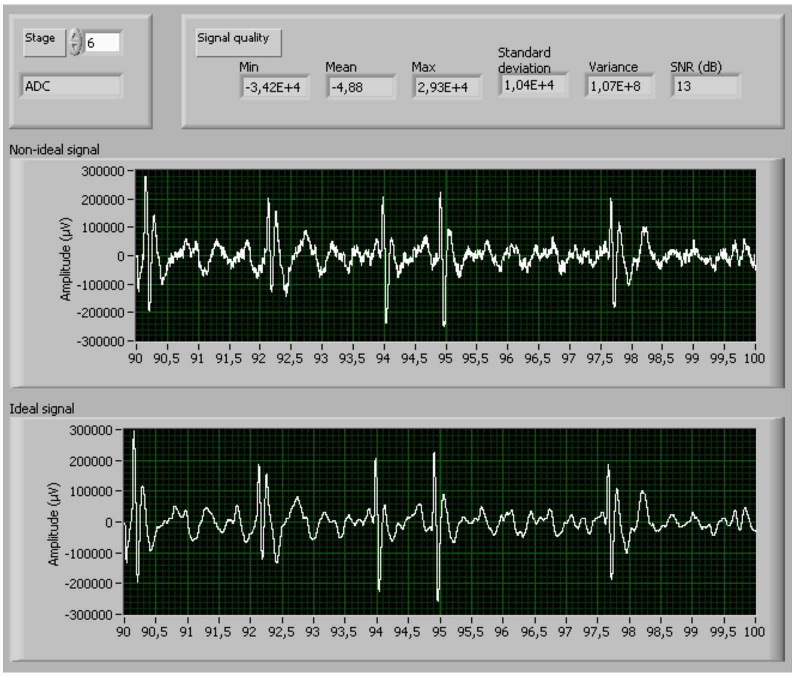

Fig 2 – The noise is more visible than in the previous case.

Even if the signal is noisier, the digital signal processing, which objective is to spot the spikes, can still provide adequate identification. However, the peak amplitudes are not only dependant on the spike shapes, but also vary due to noise. This makes the automatic spike detection more problematic because it is difficult to adjust a threshold (see Figure 3).

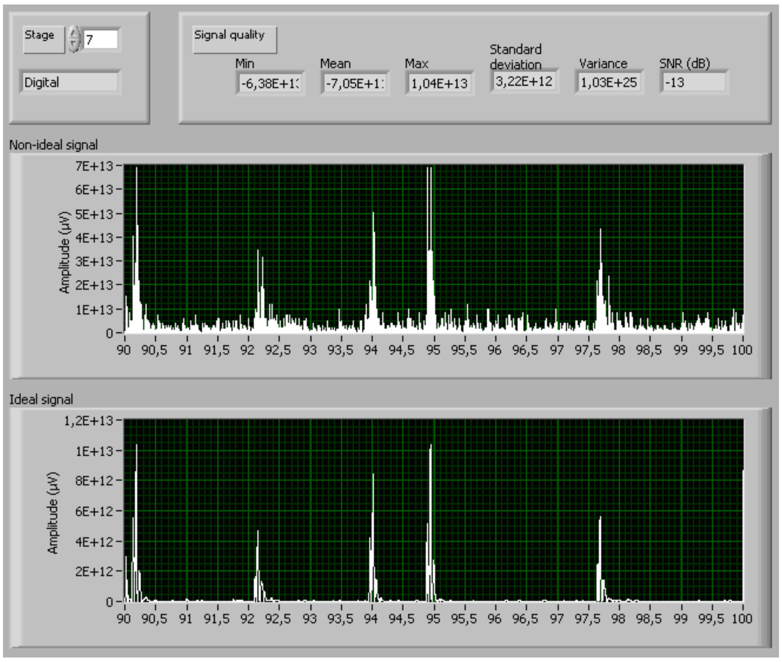

Fig 3 – Signal processing stage.

Increasing the amplifier's gain

Increasing the amplifier's gain helps to reduce the noise of the filter and the AD because the signal is already stronger when it reaches those components. For example, increasing the gain from 10 to 100 leads to a SNR of 18 dB at the ADC's output, compared to the previous 12 dB. The major source of noise now originates from the amplifier.

However, this increase leads us to a problem: the signal dynamic has been reduced by a factor 10. Increasing the signal amplitude to 1mV leads to the saturation of the filter (see Figure 4). This is because the overall gain of the chain must be lower than the power voltage divided by the maximum input signal (so equal to 5V/1mV = 5000) in order to be able to handle a 1mV signal. Otherwise, the signal clips at the output of the filter.

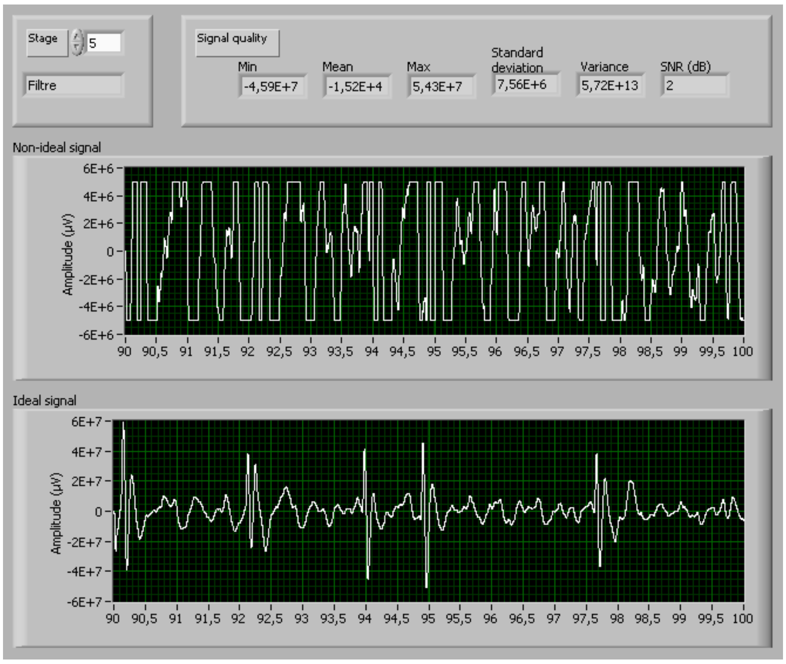

Fig 4 – The signal clips at the filter's output

This saturation problem can be readily resolved by decreasing the filter gain to 50. The SNR at the ADC's output and at the filter's output is still in the range of 18 dB, and the signal handled is in the range of 1 mV. (Note: the amplitude of the signal must be reduced again to 50µV in order to maintain the comparison. Otherwise, the SNR increase is only due to the signal amplitude increase.)

But now, the chain does not handle a 300mV offset (see Figure 5), again because the signal saturates. The gain of the chain must be 5V / 300mV = 16 maximum before the signal goes through the high pass filter that gets rid of the offset. Starting from that point we can calculate the filter gain (5000/16 = 312). This is the optimum between the signal robustness after the amp and the offset handle. The SNR at the output of the filter drops to 15dB but is however higher than the initial SNR of 12dB.

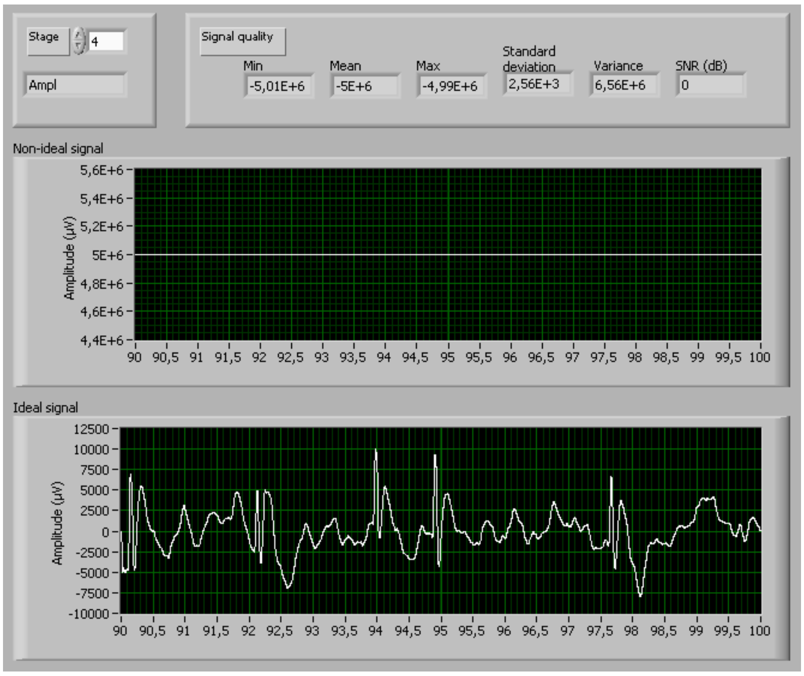

Fig 5 - A 300mV offset makes the chain saturate.

Looking at the bandpass of the chain

Lowering the bandpass also lowers the noise. This result is illustrated by the fact that the SNR at the output of the filter is higher than the one at the output of the amplifier (even if the filter induces an additional 200µVpp noise), because it cuts off the noise out of the bandpass (it equals 13 dB at the amplifier's output and rises to 15 dB at the filter's output). Lowering the signal bandpass, for example, from 0.16~70Hz to 0.16~40Hz increases the SNR from 15 dB to 17~18 dB. Lowering it below 50Hz also clears the signal of the 50Hz hum.

However, higher frequency content of the signal is not preserved which is often not considered acceptable. Lowering the signal bandpass to an extremely low level (for example to a 0.16~4Hz) totally destroys the signal shape (see Figure 6), although the SNR continues to rise[1].

[1] Note here that we decided to define the 'ideal signal' as noiseless, free of parasites but filtered. Defining the 'ideal signal' as non-filtered would have significantly reduced the SNR.

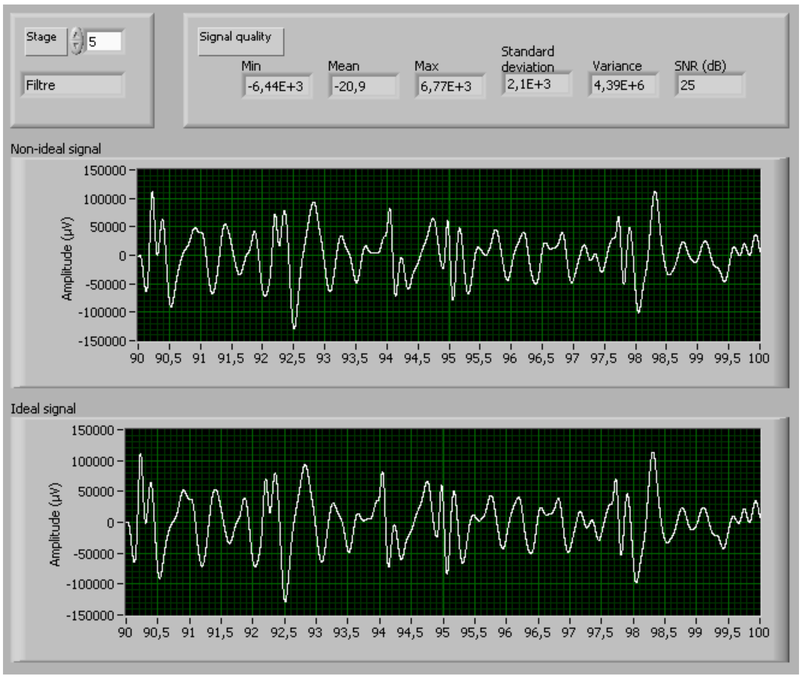

Fig 6 - The small bandpass destroys the signal shape.

The ADC

The ADC can reduce the signal quality through its imperfections mostly in two ways: the quantification noise and the sampling period.

Again, this distortion depends on the definition of the 'ideal' signal. In its default configuration, the ideal ADC is identical to the non-ideal ADC (modelled by the quantification and sampling period). This way, if the input signal is the same, the SNR is infinite.

Lowering the ADC number of bits excessively gives a good idea of its imperfections. For example, a 6 bit ADC simply destroys the signal shape (see Figure 7).

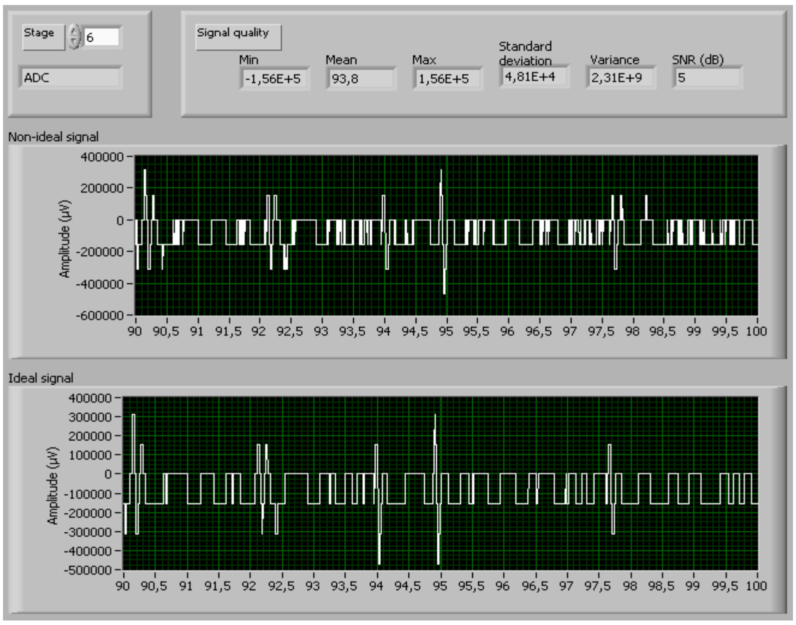

Fig 7 - The signal shape is destroyed by the 6 bit ADC.

It is possible to change the model of the ideal ADC into a simple wire to further quantify its impact on the signal change. To do so, simply delete the implementation of the 'ADC Level 1 Ideal.vi', except for the input and output signals (see Figure 8). The SNR at the output of the ADC is now in the range of 14 dB.

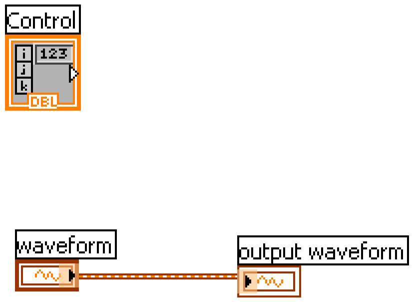

Fig 8 - The ADC modelled as a simple wire

Increasing the sampling frequency of the ADC from 200Hz to about 400Hz results in an increasing SNR until it reaches 15 dB (the filter's output SNR), at which time a levelling out occurs at steady-state. This shows that it is not worth increasing the sampling frequency beyond that limit because the sampling period is low enough not to distort the signal.

With the same approach, increasing the number of bits of the ADC, increases the SNR until it reaches 15 dB (the filter's output SNR), at which time steady-state is also attainted. This result shows that it is not worth increasing the number of bits beyond that limit (~11 bits) because the quantification noise is low enough.

Thanks to those parameter changes, the peaks amplitude variation is much smaller than in the case of the initial setup, which, in turn, makes automatic spike detection much easier.