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Design and Simulation of a New Electrical Device for EEG Signal Processing for Bio-Robotic Applications

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ABSTRACT

This paper presents an algorithm for acquiring and processing brain signals imported from the physionet.org. This data is then encoded in LVM data format for a sample size of n=91000 and fed into two National Instruments LabVIEW voltage generators for pre-amplification using the INA118P differential amplifier. Once this EEG signal is pre-amplified, it is buffered thanks to an operational amplifier OPA4277PA in order to allow a transmission of the EEG signal to the following circuit thanks to adaptation of its impedance. Once the impedance of circuit is adapted, it is introduced into a Notch filter having a central frequency approximately equal 60 Hz. This signal is then introduced into an active high-pass filter with a cut-off frequency of 1.079 Hz. Subsequently, the said EEG signals obtained will be transmitted to active low-pass filter with a cut-off frequency of 30.445 Hz. Subsequently, they will undergo a second amplification using an operational amplifier OPA4277PA. This signal will then be positively clamped. It will undergo a terminal amplification thanks to the operational amplifier OPA4277PA so that the imported EEG signals are exploitable, at the analog input of the Arduino microcontroller which is driving center of the human hand prosthesis.

Key words: EEG (ElectroEncephalogram), LVM (LabVIEW Measurement), Arduino, Differential amplifier, Active filter, Cut-off frequency, Center frequency, Clamp, Buffer

1. INTRODUCTION

Bionic prostheses are still in their infancy, but they have the potential to offer a very different life to amputees. Today, the challenge is not only to make hands and legs that are advanced and aesthetically pleasing, but also to improve the connection between the prosthesis and its wearer. In March 2020, neuroengineering scientist Cynthia Chestek presented in Science its important advances on this subject [1]. In May 2022 Kenyan engineers David Gathu and Moses Kinuya also presented in agence ecofin advances on this subject [2]. Today, in some countries of the world, prosthesis has been discovered that offers amputees the possibility to control their prosthetic hand simply by thinking about movements.

This innovation in the world, remains centered in 85% on the non-invasive method of surface electromyography which results from the contraction of residual muscles. Today only 15% research worldwide is focused on the non-invasive method of electroencephalography.

Faced with this reality in Cameroon, the control of hand prosthesis requires the definition of an algorithm to acquire and process the brain signal in order to make it usable by a microcontroller such as Arduino. To solve this problem, three hypotheses have been put forward:

- What is the algorithm to acquire and process EEG signals using the non-invasive method?
- What algorithm makes it possible to control this human hand prosthesis based on brain signals?
- What hardware tools can be used to implement this algorithm?

2. METHODS AND TOOLS

To answer the different hypotheses posed in the introduction, we first wanted to study the methods and tools required.

2.1. Methods

The methodology used here is that of computer simulation. This method is structured in two schemes, namely the block diagram and the operational diagram of the new proposed device for EEG signal processing.
As far as the block diagram is concerned, the device is as follows:

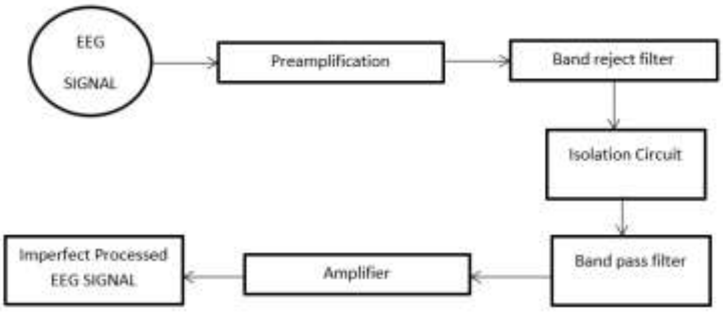


Fig. 1 Block diagram of the process of the EEG signal processing

And as for the operational diagram of our new EEG signal processing device, the device looks like this:

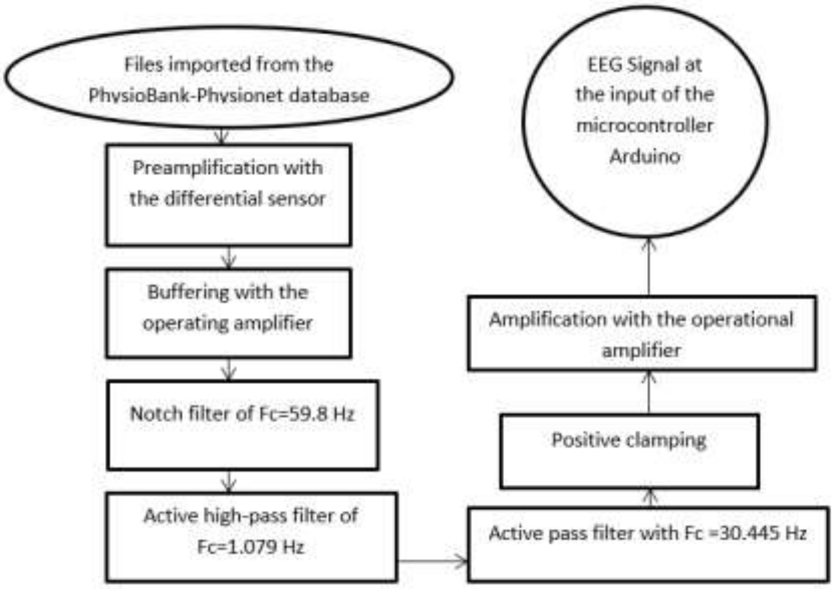


Fig.2 Operational diagram of the proposed new device for EEG signal processing

2.2. Tools Hardware and Software

2.2.1. Hardware tools

The material tools are summarized in Table -1.

Table -1 Hardware tools

Designations	**Specifications**
INA118P	High precision, low power instrumentation amplifier
OPA4277PA	High precision operational amplifier with low offset voltage ±50µV
TL081	High precision,low voltage operational amplifier
a_1kΩ	Resistors
aµF	Low capacity capacitor
V3 1Vpk0^0	AC voltage source
	Source of tension LabView biomedical
DELL LAPTOP E6540	Simulator

2.2.2. Software tools

The software tools are summarized in Table- 2.

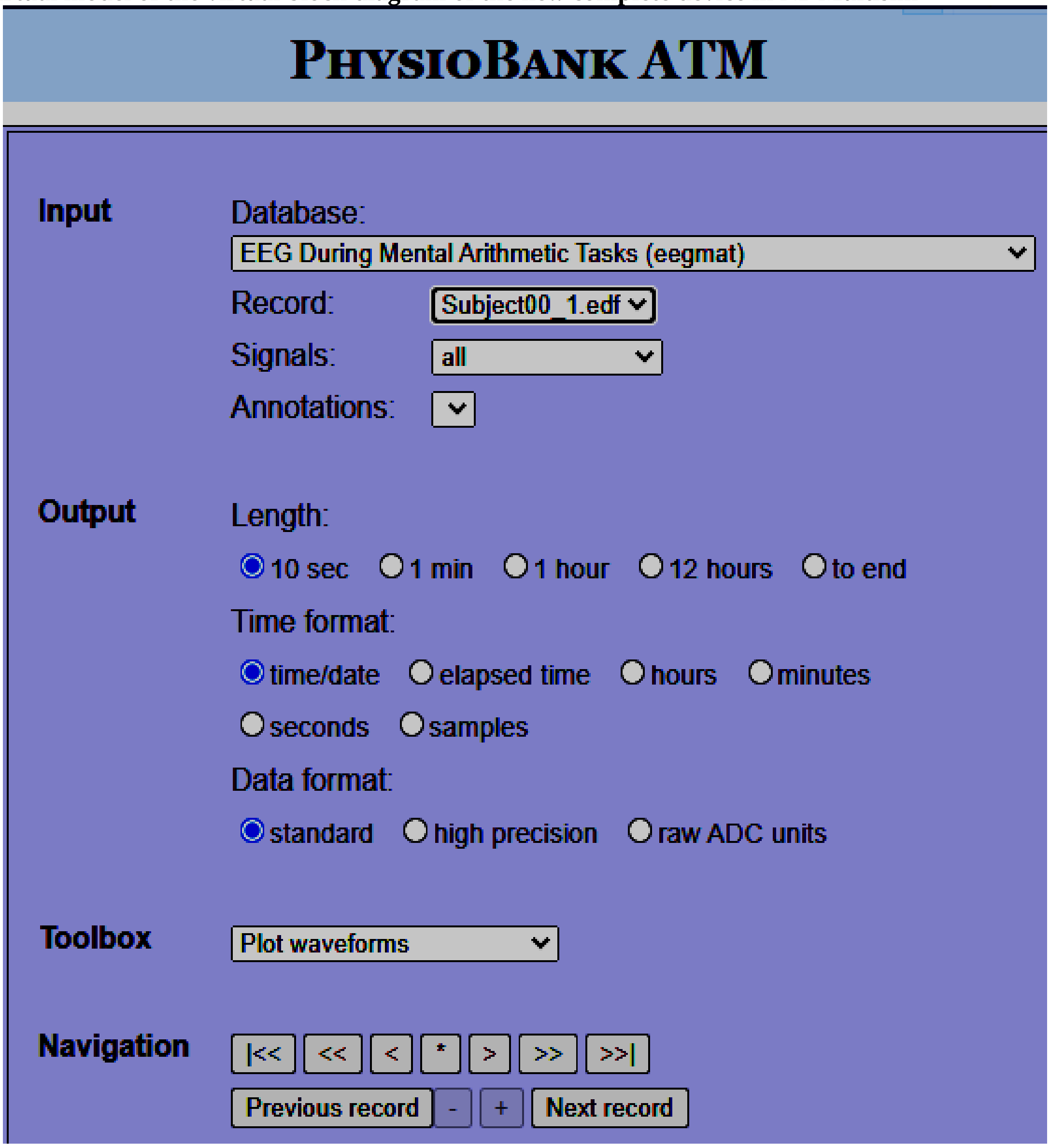
Table-2 Software tools

Designations	Specifications
NI-Multisim 14.2	Electronic schematic capture and simulation software
LabView 20.1	Graphical programming environment
PhysioBANK ATM	Physiological database online https://physionet.org
Arduino 1.8.10	Programming software for Arduino board
comOcom	Virtual serial port connection emulator
Proteus 8.13 SP0	Electronic schematic simulation software
Microsoft EXCEL	Application of calculation

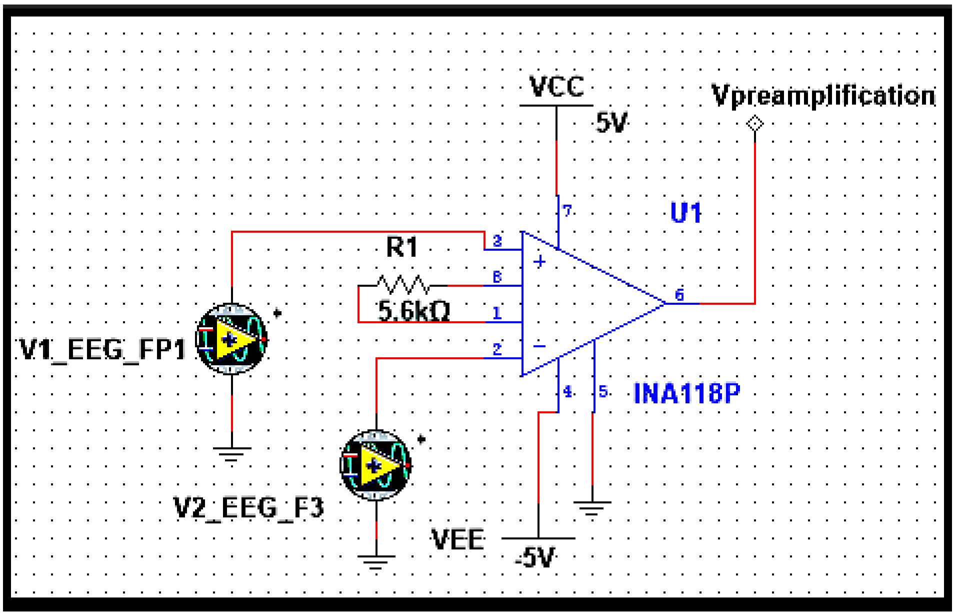
2.3. Implementation of Electronic Device

Following the synthesis of the schematic diagram in Figure 1, of tables 1 and 2 of the hardware and software specifications, and of the operational diagram in Figure 2, the last required conceptual element is established in subsection 2.3.1.

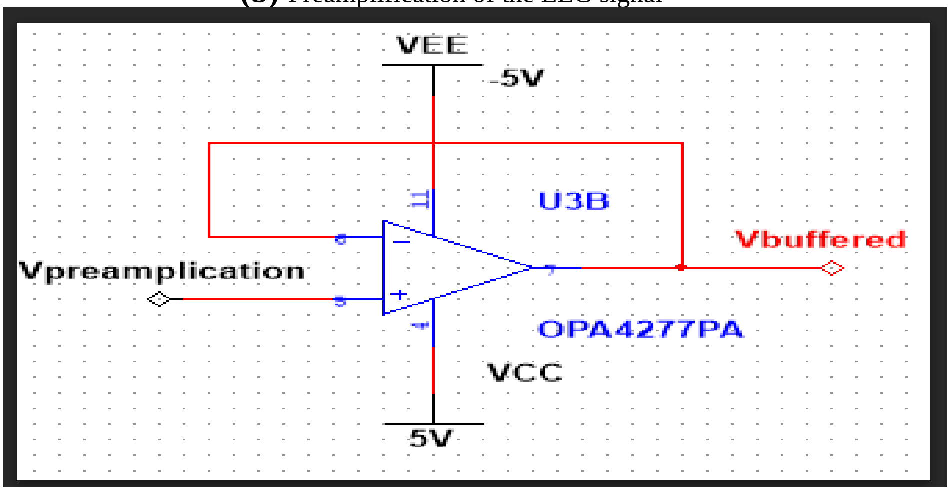
2.3.1 Virtual model of the virtual block diagram of the new complete device in NI-Multisim



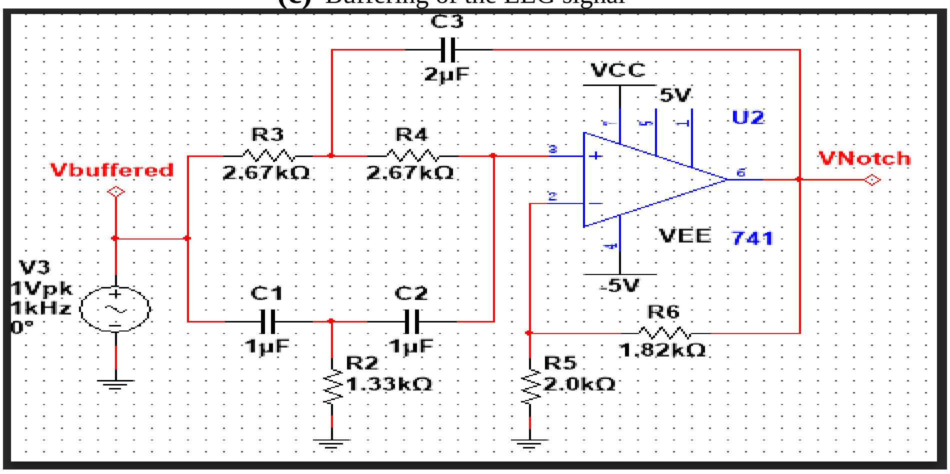
(a) Import of the .csv file into the PhysioBank-Physionet database



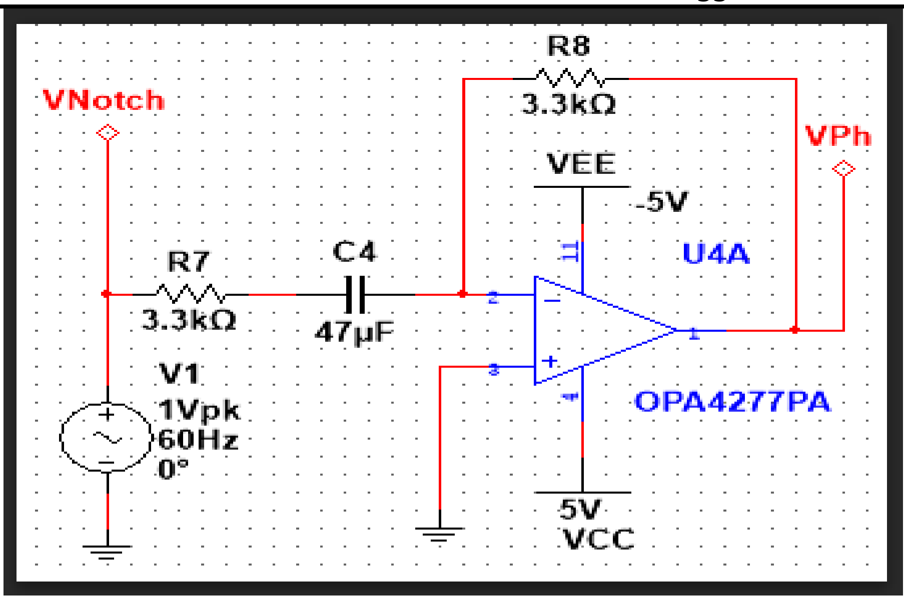
(b) Preamplification of the EEG signal



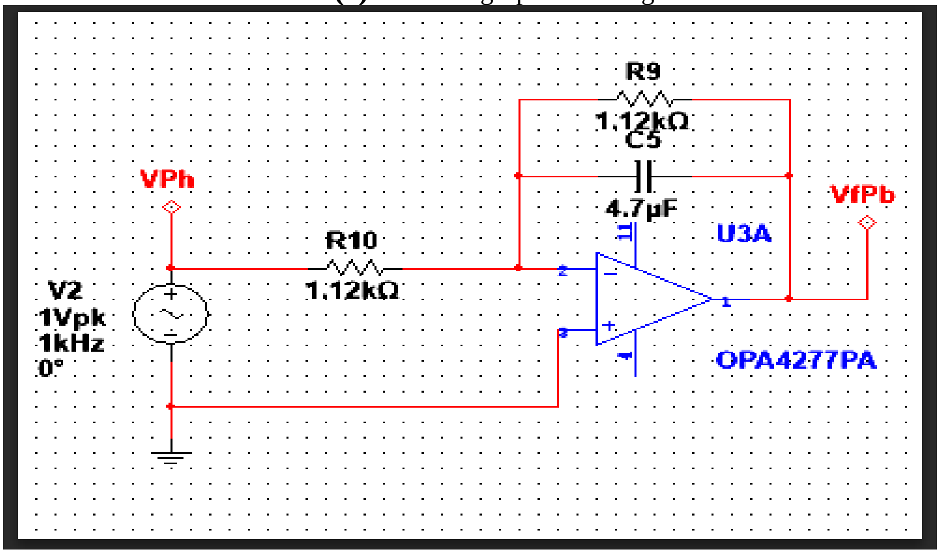
(c) Buffering of the EEG signal



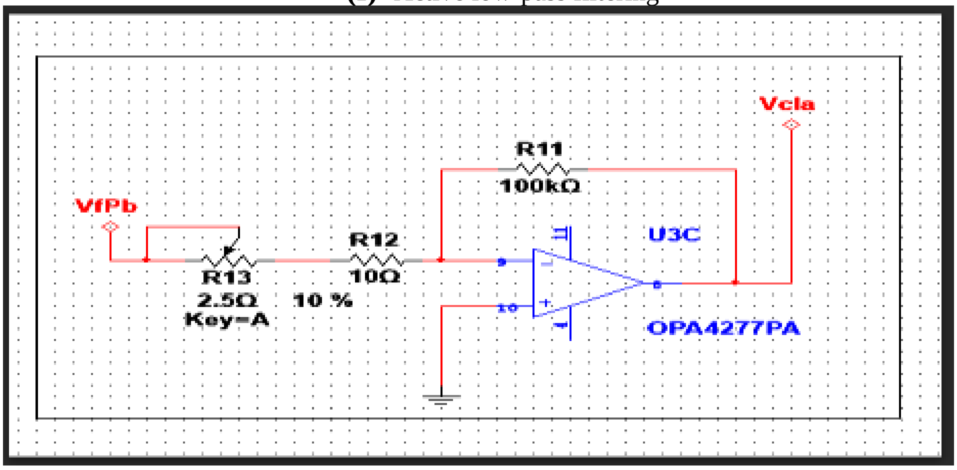
(d) Band rejection filter



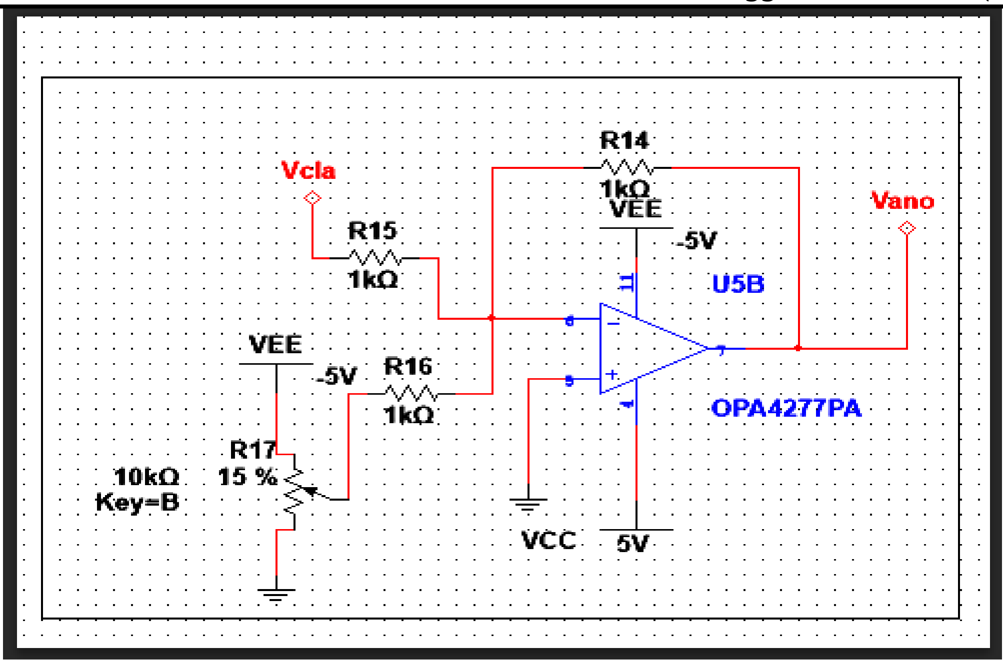
(e) Active high-pass filtering



(f) Active low-pass filtering



(g) EEG signal clamping



(h) Processed and imperfect analog EEG signal

Fig. 3 Virtual model of the virtual block diagram of the new complete device in NI-Multisim

2.3.2 Arduino-C++ application for digital acquisition with EEG signal monitoring

To simulate this model we have made an export to the Excel software of these data allowing to generate the analogical Signal in NI-Multisim thanks to the tab Export to Excel of NI-Multisim. These data were then processed in a text editor named Notepad. It is this file which was thereafter introduced in a file generator of the software proteus and thereafter wired to the analog input A0 of the Arduino microcontroller.

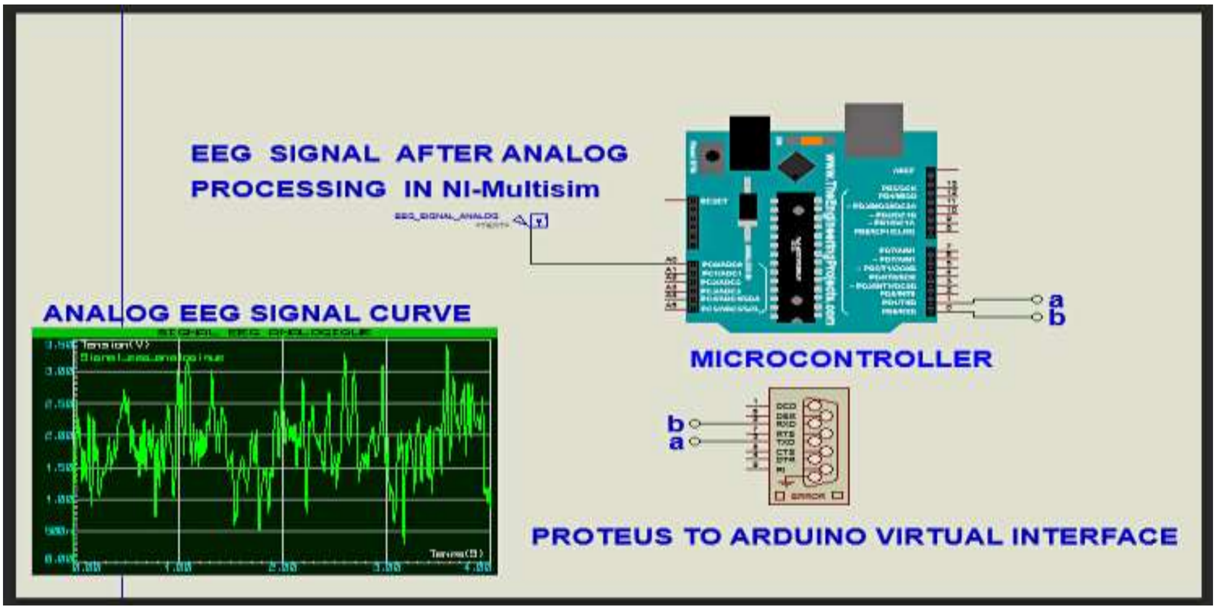


Fig. 4 Virtual model of the digital acquisition schematic with monitoring

3. RESULTS AND DISCUSSION

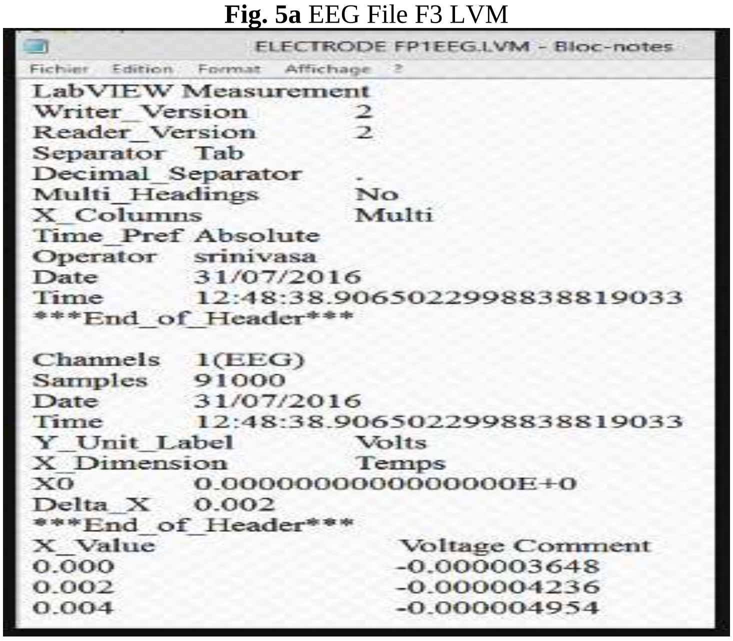
3.1. Result of the Analog Simulation of Device

The first step of our simulation consisted in downloading the .Csv file into the PhysioBANK ATM database, transforming it into two LVM files defining respectively the positive pole (FP1) and the negative pole (F3). These two LVM files that have been introduced into the LabVIEW voltage positive pole (FP1) and the negative pole (F3) generators are shown in Fig. 5:

ELECTRODE F3EEG.LVM - Bloc-notes
Fichier Edition Format Affichage ?
LabVIEW Measurement
Writer_Version 2
Reader_Version 2
Separator Tab
Decimal_Separator .
Multi_Headings No
X_Columns Multi
Time_Pref Absolute
Operator srinivasa
Date 01/01/2016
Time 12:48:38.9065022998838819033
End_of_Header

Channels 1(EEG)
Samples 91000
Date 01/01/2016
Time 12:48:38.9065022998838819033
Y_Unit_Label Volts
X_Dimension Temps
X0 0.0000000000000000E+0
Delta_X 0.002
End_of_Header
X_Value Voltage Comment
00.000 -4.082e-6
00.002 4.767e-6
00.004 5.784e-6

Fig. 5a EEG File F3 LVM



ELECTRODE FP1EEG.LVM - Bloc-notes
Fichier Edition Format Affichage ?
LabVIEW Measurement
Writer_Version 2
Reader_Version 2
Separator Tab
Decimal_Separator .
Multi_Headings No
X_Columns Multi
Time_Pref Absolute
Operator srinivasa
Date 31/07/2016
Time 12:48:38.9065022998838819033
End_of_Header

Channels 1(EEG)
Samples 91000
Date 31/07/2016
Time 12:48:38.9065022998838819033
Y_Unit_Label Volts
X_Dimension Temps
X0 0.0000000000000000E+0
Delta_X 0.002
End_of_Header
X_Value Voltage Comment
0.000 -0.000003648
0.002 -0.000004236
0.004 -0.000004954

Fig.5b EEG FP1 LVM file

Fig. 5 EEG data files of F3 and FP1 electrodes

The EEG signals being of very low voltage we proceeded to a pre-amplification and the result of this simulation is Fig. 6:

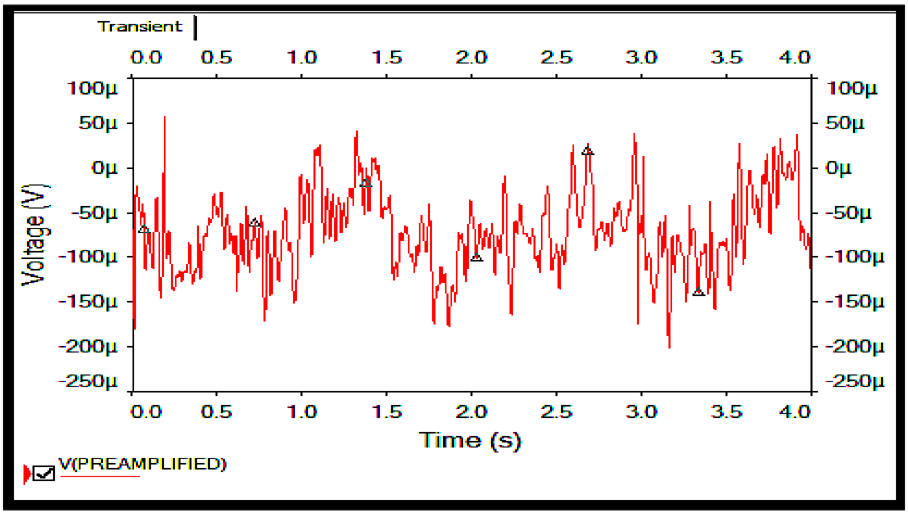


Fig. 6 Preamplified EEG signal

The result of this simulation shows us that the EEG signals with the following initial voltages: V_{EEG}(F3) € [-40 µV , 30 µV] et V_{EEG}(FP1) € [-30 µV , 25 µV],once introduced in an instrumentation amplifier have known a differential voltage of V_{EEG}(Pr) €[-250 µV , 100 µV].

After this operation to avoid a loss of signal we performed a buffering of this signal and the rendering of this simulation is Fig.7:

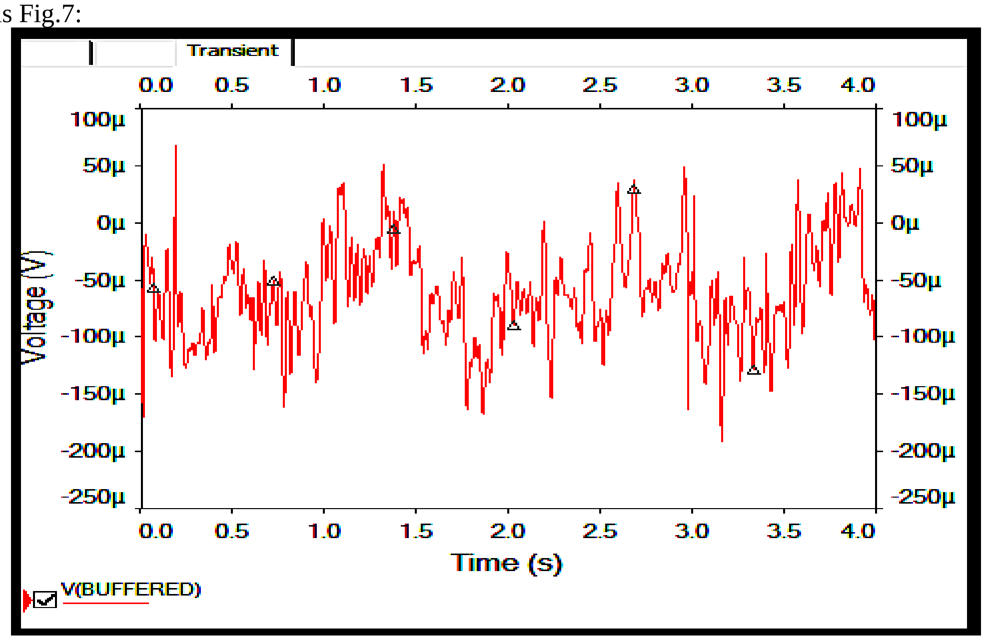


Fig. 7 Buffered EEG signal

Once this EEG signal was buffered, it was submitted to the input of a Notch filter with a cut-off frequency of 59.8 Hz in order to retain only EEG signals with a frequency lower than or equal to this one. To do this we determined this cut-off frequency by realizing on NI-Multisim a Bode diagram allowing us to confirm this said frequency. This Bode diagram on NI-Multisim is presented on Fig. 8:

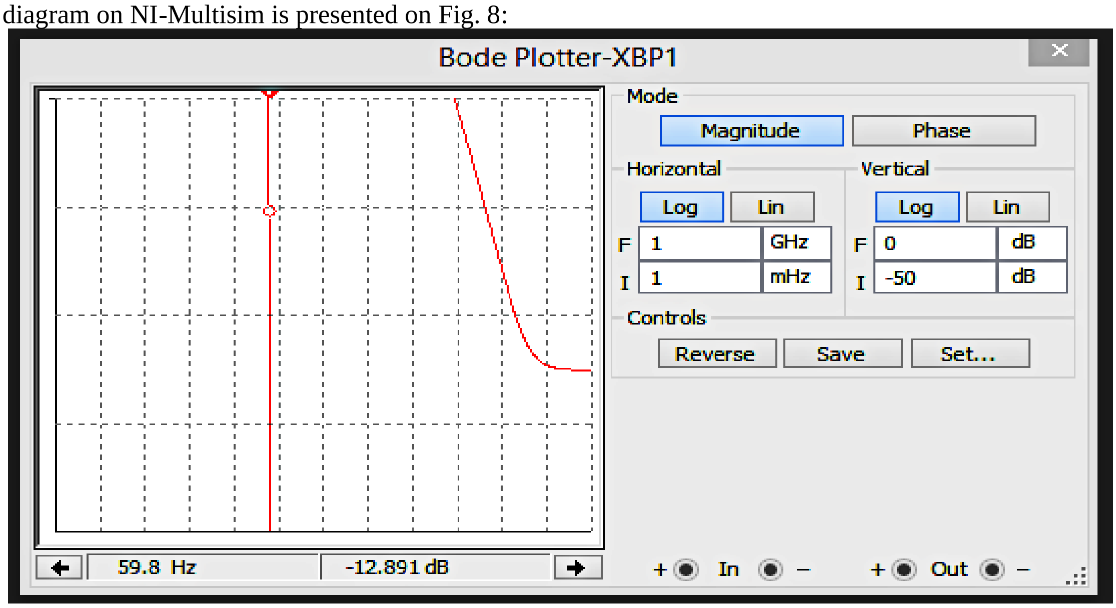


Fig. 8 Bode diagram of the EEG signal

The Bode diagram on this EEG signal shows us that the cut-off frequency is 59.8 Hz.

After this Notch filtering, our signal will now undergo a high-pass filtering and the result of the simulation is shown in Fig. 9:

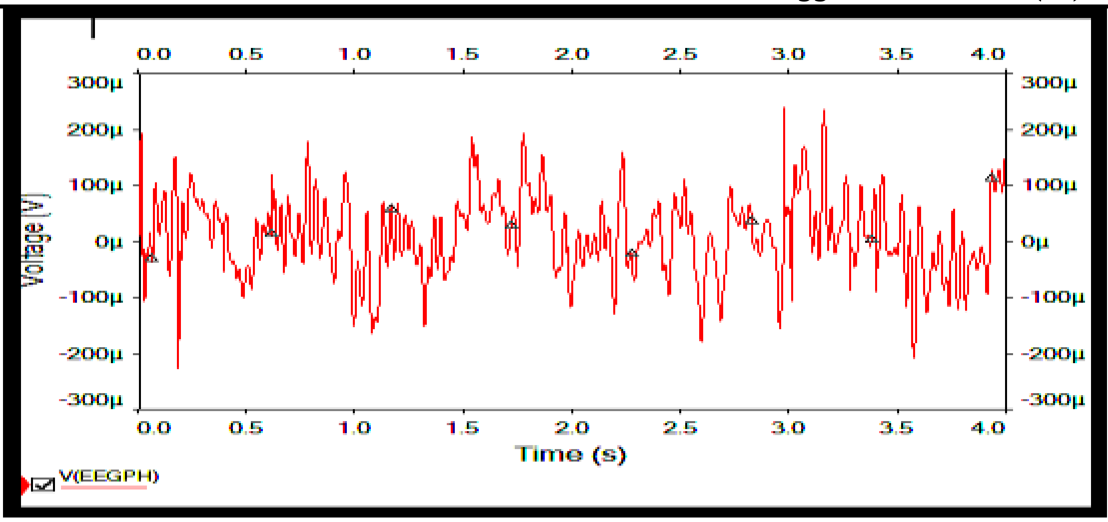


Fig. 9 Filtered EEG signal with Fc=1.079 Hz

This active high-pass filter, after having retained exclusively the EEG signals corresponding to a cut-off frequency of 1.079 Hz, allowed us to obtain after simulation a voltage of $V_{EEG}(f_{haut})$ €[-300 µV , 300 µV]. In addition to this active high-pass filtering, an active low-pass filtering was performed. The result of this simulation is shown in Fig. 10:

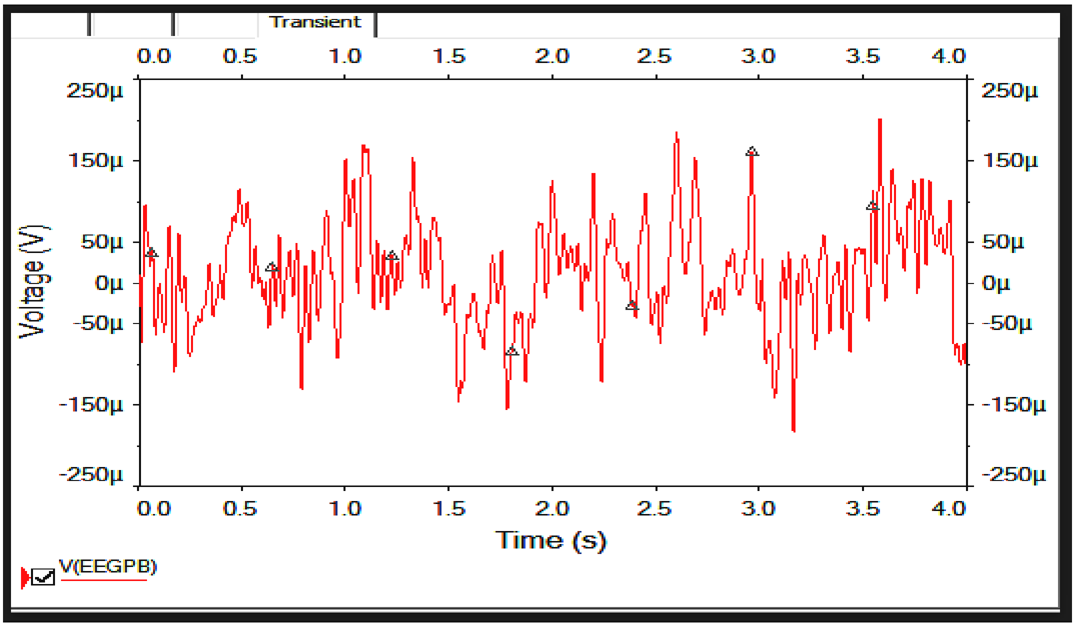


Fig. 10 Filtered EEG signal with Fc=30.445 Hz

After retaining only the EEG signals corresponding to a cut off frequency of 30.445 Hz, this active low-pass filter allowed us to obtain after simulation a voltage of $V_{EEG}(f_{bas})$ €[-250 µV, 250 µV].

Once the active pass-through filtering is completed, this resulting EEG signal will be positively clamped. The rendering of this simulation is Fig. 11:

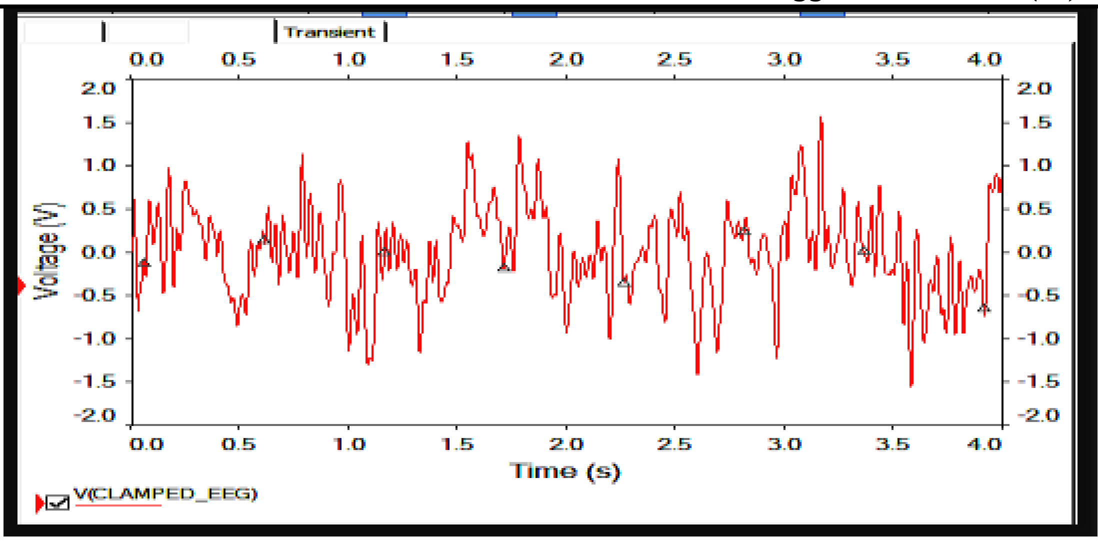


Fig. 11 Positively clamped EEG signal

This positive clamping of the EEG signal allowed us to obtain a voltage of V_{EEG}($f_{clamp)}$ €[-2 V , 2 V]. The EEG signal clamped positively before must be amplified again, in order to make possible the control of the said signal by the analog input of our Arduino microcontroller. To do this, the rendering of our simulation is shown in Figure 12:

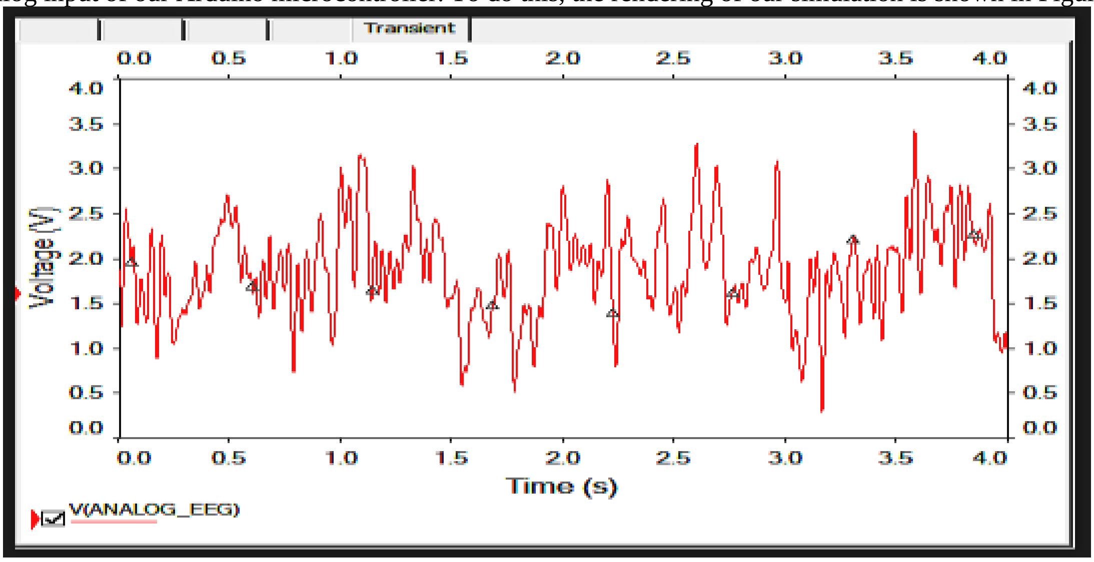


Fig. 12 Amplified EEG signal for the analog input of Arduino

This last amplification of the EEG signal allowed us to have a voltage of V_{EEG}($f_{\_amp)}$ €[0.0 V , 4.0 V]. After this operation we proceeded to import the data from this simulation on Microsoft Excel using the Export to Excel onget of the NI-Multisim 14.2 software. Then this file was processed on notepad, then introduced into a file generator of the NI-Multisim software as shown on our virtual model (Figure 4). To do this we introduced in this virtual model a virtual serial port interface (COMPIM) of Proteus modeling a physical serial port. This virtual interface buffers the serial communications and presents them as digital signals to the circuit. In order to implement this virtual model that we have presented in figure 4, we used the Null-modem emulator (com0com) that allows to link the Proteus software and the Arduino software. This emulator is shown in Fig. 13:

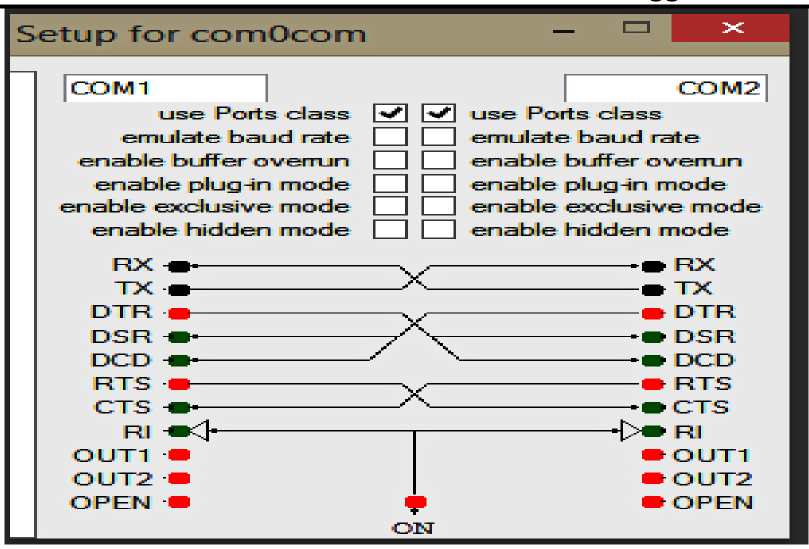


Fig. 13 Virtual serial link

In this virtual link COM1 represents the serial port of COMPIM of Proteus and COM2 the serial port of Arduino. For this data exchange to take place we had to define the same communication rate between the COM1 and COM2 serial ports, i.e. 9600 baud. Once this serial link was made we proceeded to a simulation and the rendering of this one is Fig.14:

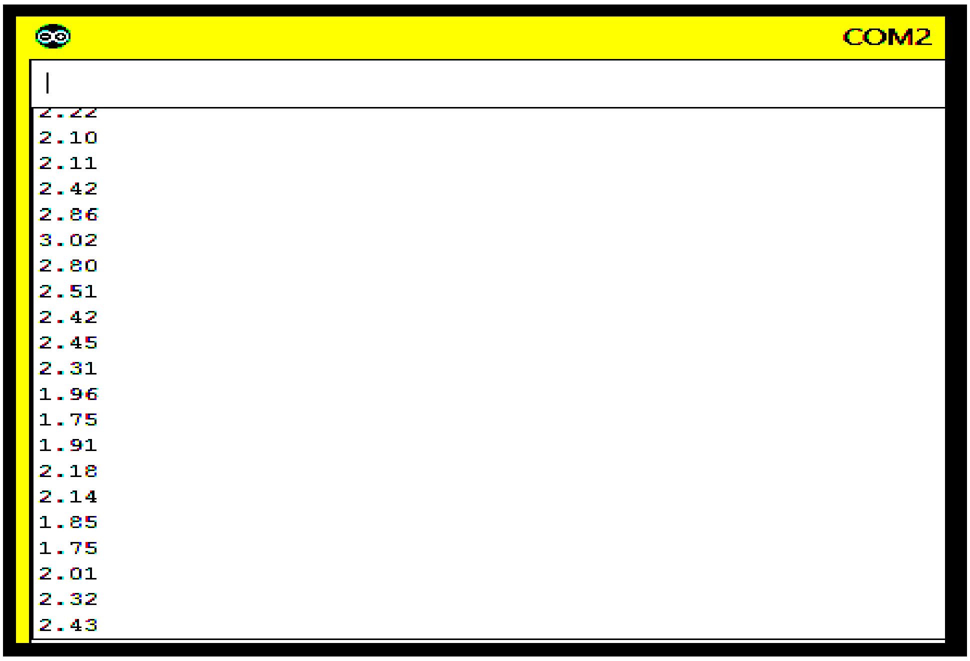


Fig. 14 Response of the analog-to-digital converter

After the rendering of this simulation we wanted to know the level of shaping of our current EEG signal using the serial tracer of the arduino software 1.8.10. The rendering of this simulation is Fig. 15:

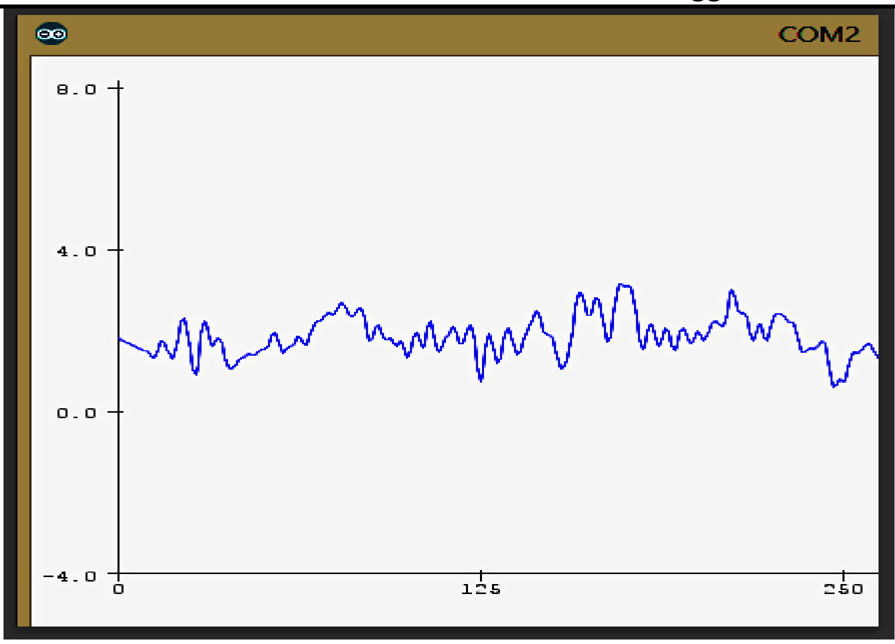


Fig. 15 Current shape of the EEG signal

4. CONCLUSION AND PERSPECTIVES

This article allowed us to perform a Markovian algorithm using the export of EEG data from the physioBANK ATM database. The results obtained by simulation allowed us to answer the three hypotheses posed in the introduction. This algorithm shows us how the EEG signal with an amplitude of the order of µV changes to an EEG signal of the order of V. The results were simulated mainly with the NI-Multisim 14.2 software in direct communication with the Arduino 1.8.10 and proteus 8.13 SP0 software simultaneously. With regard to our results, we can say that it is possible to really control our human hand prosthesis because the ranges of tensions that we obtained contain indeed the brain waves α, δ, θ, γ, β. But it would be necessary to define again a second Markovian algorithm to transform the digital signal obtained thanks to the analog converter of the Arduino microcontroller while taking into account this first algorithm. For this purpose we issue our perspectives in the form of new future research prospects derived from the results and established in this article. Namely:

What type of noise does this EEG signal generally contain?

Is it possible to control a human hand prosthesis with this imperfect EEG signal?

What filtering should be used for this EEG signal to improve its imperfection?

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