A Low Cost Amplifier And Acquisition System For Cortical-Electroncephalography In Non-Human Applications

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Abstract **-** A simple circuit is described to make an AC-amplifier and an analog-to-digital converter in a single, compact solution, for use in basic research, but not on humans. The circuit sends data to and is powered from a common USB port of modern computers; using proper firmware and driver the communication with the device is an emulated RS232 serial port.

Keywords: amplifier, electrophysiology, data acquisition, cEEG, ECG, field potentials

I. INTRODUCTION

Extracellular electrophysiology consists of recording voltages over time between a couple of electrodes placed in extracellular fluids. Relevant signals of this kind comprise extracellular recording of action potentials from single neurons [1], post-synaptic potentials [2,3], electrocardiogram (ECG) [4,5], electromyogram (EMG) [6], cerebral cortical surface DC level [7], cerebral cortical surface electroencephalogram (cEEG) [8], or scalp electroencephalogram (EEG) [9]. The modern technique to record these kind of signals consists of a couple of metal electrodes, an amplifier, an analog-to-digital converter (ADC), and a computer with dedicated software. The electrodes are of variable dimensions (from less than 10 microns to some centimetres) and material (stainless steel, silver, chlorinated silver, gold, platinum, mercury) making contact with the living tissue directly or through a saline bridge. The amplifier usually provides a gain ranging from 10x to 10000x, depending on the amplitude of the signal (from some millivolts for ECG and EMG to some microvolts for EEG); other important features of the amplifier are the input impedance and the band-pass filtering. The input impedance must be greater (at least 10 times greater) than the electrodes impedance and is usually comprised from >1Mohm for surface macro-electrodes (e.g. ECG, cEEG) to >10 Mohm for extracellular microelectrodes (e.g. unit activity). For the band-pass frequencies, the high-pass frequency is usually comprised from DC level [7] to 1Hz for ECG or 10 Hz for EMG; the low-pass frequency is between 100 Hz for ECG to 500 Hz for EMG or some KHz for unit activity.

The ADC has to be able to connect to one of the standard input-output ports of modern computers, such as the PCI port or the USB port, and to send the digital reading of the amplified voltage with a reasonable digital resolution (usually 8 bits or more) and with a sample frequency greater than 2 times the low-pass frequency of the amplifying stage (i.e. >200 samples/s for ECG to >5000 samples/s for unit activity).

Specifications for the computer mainly depend on the software that will be used to acquire and record the signals from the ADC; actually, most modern low-cost consumer-level computers can do the job.

While sophisticated systems are needed to obtain the high security standards for use on humans, all the above depicted electrical specifications for electrophysiological recordings can be easily achieved with modern electronic components and integrated chips for basic research applications. Here a low-cost solution will be described to realize both an amplifier and an ADC in a single circuit that can be connected to the USB port of a modern computer to acquire the cortico-electroencephalogram signal (cEEG) from the cerebral cortical surface in basic, non-human studies.

II. METHODOLOGY

The circuit realized comprises an amplifying-filtering stage and an ADC stage (Figure 1). Amplification is obtained through three subsequent stages; the first stage comprises an integrated instrumental amplifier (INA126, Burr Brown, Texas, USA) which provides a gain of 5x and an input impedance of 10^9 ohm. The DC level of the input signal is zeroed by the active high-pass filter evidenced in box A of Figure 1; the cut-off frequency of this filter is given by the formula $Fc1 = 1/(2\pi \cdot R1 \cdot C1)$, meaning 1.59 Hz with the values shown in Figure 1. The second stage of amplification (Figure 1, box B) is obtained with an operational amplifier (MC33204, ON Semiconductor, Denver, Colorado, USA) configured as a classic inverting amplifier; this stage provides a gain of 100x and also a low-pass filter with a cut-off frequency given by the formula $Fc2 = 1/(2\pi \cdot R2 \cdot C2)$, meaning 99.5 Hz with the values shown in Figure 1; the output of this stage presents a total gain of 5x 100x = 500x, that is enough for seeing signals in the range of 1-10 mV (e.g. an ECG), and is connected to one of the analog inputs of the microprocessor PIC18F4550 (Microchip, Chandler, Arizona, USA). For smaller signals, there is another amplifying stage (Figure 1, box C) based on an operational amplifier (MC33204) configured as an AC-coupled (through C3) non-inverting amplifier, with a gain of 10x and a high-pass cut-off frequency given by the formula Fc3 = 1/(2π·R3·C3), meaning 1.59 Hz with the values shown in Figure 1. The output of this amplifier is connected to another analog input of the microprocessor PIC18F4550; this latter component provides the ADC function, with a resolution of 10 bits, and the link to the USB port of a PC. A software ("firmware") is loaded into the internal flash memory of the microprocessor to obtain the desired functions, like sampling frequency, number of channels to read, sending and receiving instructions through the USB port and so on. Classically, the firmware is created with dedicated software running on a PC (MPLAB, Microchip) and loaded through another USB-hardware (PICkit, Microchip) connected to the port named "programmer" in Figure 1. Another useful solution, for those familiar with the C language, is to load once, through the programmer, a firmware named "bootloader", freely available on the Internet; than, working firmware can be created with a more simple programming environment, named "Pinguino" (open source by Jean-Pierre Mandon), and loaded through the USB port; all this procedure is described at http://wiki.pinguino.cc/index.php/Main_Page. By this way a firmware was created that reads both signals on pins AN6 and AN7 with a sampling frequency of 1000samples/s and sends readings to the USB port; when connected to the USB port, the device is configured as a serial COM port, emulating the standard RS232 communication that is easy to implement in custom software. For the present application, a software was written with LabView (National Instruments, Austin, Texas, USA) to display real-time data and to record the signals (Figure 2).

III. RESULTS

The circuit described here is easy to realize, with a total cost for the materials below 100 euros. The noise amplitude is smaller than 30 μV (peak-to-peak); care must be taken to accurately shield all the instrumentation and the workstation to avoid noise coming from the power line (50 Hz or 60 Hz); to this end a metallic cage has been realized that covers both the circuitry and the site for the experiment (around 40cmx40cmx20cm) which was electrically connected to the point marked "shield" in Figure 1. The point marked "reference" in Figure 1 must be connected to a third macroscopic electrode (also known as "indifferent electrode") placed somewhere far from the exploring electrodes (e.g. the classic right leg electrode for ECG recording) to bring the mean DC level of the exploring points at a voltage level in the range comprised between the supplying voltages points of the circuitry (the +5V and the GND levels) to allow proper working of the first amplifying stage.

The device described here has been successfully used to record the cEEG on anesthetized rats in a study on epilepsy (work in progress); an exemplificative raw trace is shown in Figure 3.

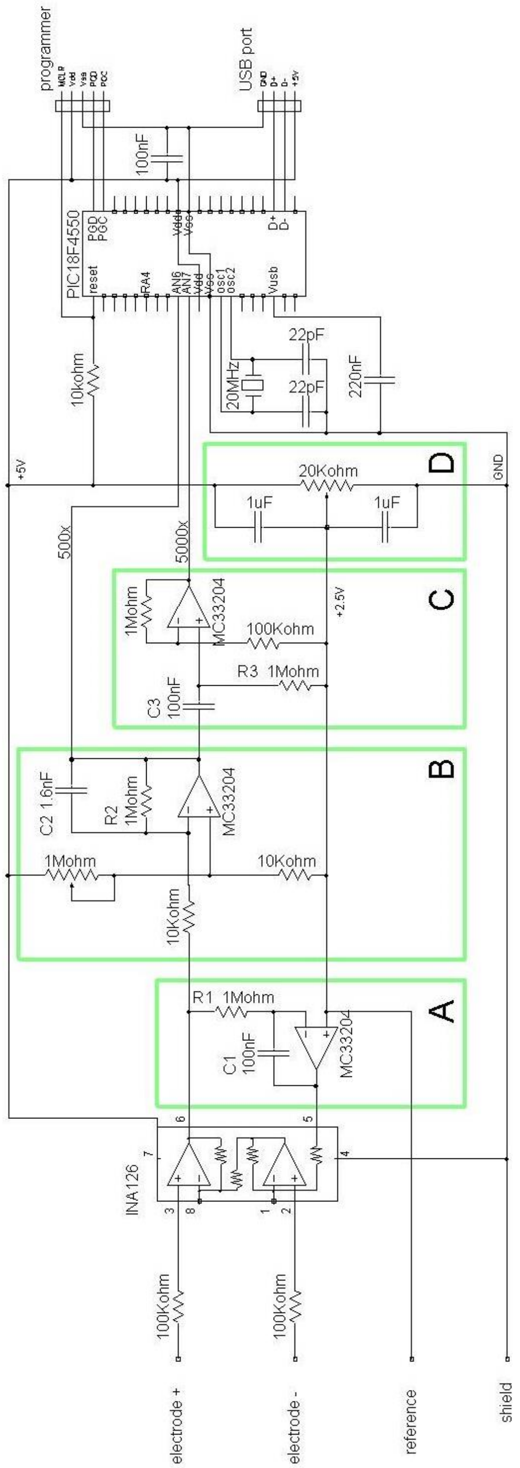

Fig. 1. Schematic of the amplifier/ADC circuit. The INA126 integrated circuit provides a first hi-impedance input with a 5x gain. Box A: zeroing of the DC level with a high-pass cut-off frequency of 1.6 Hz. Box B: second stage of amplification with 100x gain and a low-pass cut-off frequency of 99 Hz. Box C: AC-coupled third stage of amplification with 10x gain and a high pass cut-off frequency of 1.6 Hz. Box D: this voltage divider provides a reference voltage of 2.5V. The PIC18F4550

integrated microprocessor provides DAC function and link to a PC through a USB port. See text for other details.

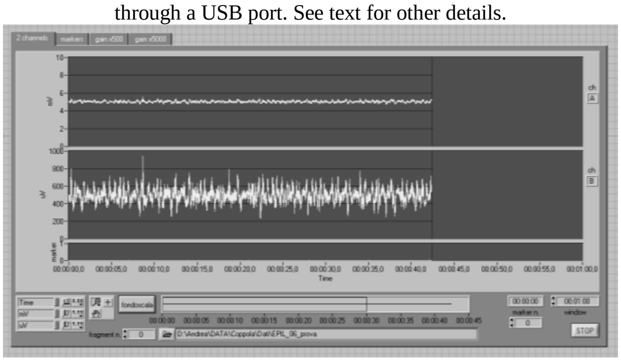

Fig. 2. Front panel of the software. The software realized with LabView displays incoming data from the circuitry; both the 500x and 5000x amplifications of the signal are displayed. When needed, a marker can be added for relevant events. Data are stored in a file selected when starting the software.

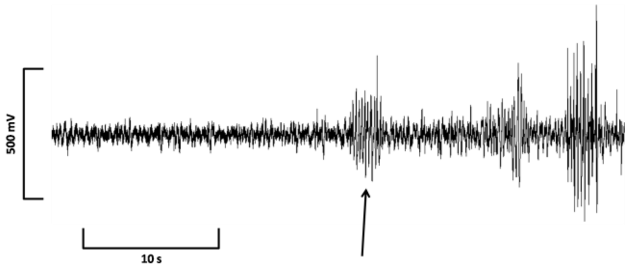

Fig. 3. Exemplificative cEEG. This trace has been recorded from the cortex surface of an anesthetized rat for a study on epilepsy; the epileptic discharge (arrow) is clearly discernable.

IV. DISCUSSION

The principal electric specifications of the circuit described in the present work fit many of the electrophysiological applications cited at the beginning of this dissertation, in particular to acquire cEEG or ECG signals: gain 500x and 5000x, input impedance greater than 10 Mohm, band-pass filtering 1.6-99 Hz, ADC sampling frequency 1000 samples/s, ADC resolution 10 bits. Some other low-cost amplifier circuits are described in scientific literature for similar purposes [10, 11, 12, 13]. Most of these papers only focus the attention on the analog amplifying part [10, 11, 12]; in the paper by Jain et al. [13] an integrated system is discussed, comprising both the analog amplifier and the analo-to-digital converter, which connects to a USB-port, but the full schematic of the circuit is not published and the figure of the prototype shows that the device is made with miniature surface-mount components which are hard to assemble for the "do-it-yourself" researcher. So, besides the principal electric characteristics of all these circuits, that are substantially similar, the main innovative characteristic of the present work is the description of a complete system, from the analog electrode input to computer recording, with a single circuit that is still simple to make with "hobby-level" tools. Moreover, the use of a PIC microprocessor with the "bootloader" firmware and the "Pinguino" user graphical interface makes it easy to re-program the functions of the ADC stage and the communication with the host computer to satisfy specific needs of the experimenter.

V. CONCLUSION

Overall, the hardware and software realized and described in the present work have satisfactory performance for the main goal, that was to record cEEG. The main limits of the present setup are the noise level and the sampling frequency. The noise amplitude was smaller than 30 μV (peak-to-peak), which is acceptable to record a cEEG, and in particular to reveal epileptic firing, whose expected amplitude is in the range 100-1000 μV; the ECG signal can also be well resolved (typical amplitude is in the range 1-10 mV). The sampling frequency of 1000 samples/s is good to record both a cEEG or an ECG signal, which have an high frequency limit of 100 Hz. Higher sampling frequency would be needed to record, for example, the shape of post-synaptic potentials; this could eventually be achieved with a different firmware loaded on the microprocessor. Future developments of the proposed methodology would include the acquisition of signals from more than one channel; to this end the circuitry would simply require to have as many amplifying lines (INA126, box A, box B and box C in fig. 1) as the desired number of channells and to connect the amplified signals to other analog inputs of the PIC18F4550; anyway, the number of analog signals to acquire is limited by the desired sampling frequency.

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