Electroencephalography instrumentation

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***Abstract*—Electroencephalography (EEG) belongs to the field of electrobiological measuring and it has been an important tool in neuroscience and neural engineering as a tool to measure the neuronal activity. The consistent measurement of the electric waves has important clinical value and can be used to evaluate the sleeping patterns and more complex disorders such as epilepsy and schizophrenia. In order to perform an accurate analysis of the brain waves, an acquisition system must be developed with the right amplification, filtering, and protection. This report provides a review of the basic concepts of the EEG, and presents an acquisition system composed of an instrumentation amplifier, a band-pass filter, and a common mode rejection circuit. In order to test its performance, the circuit simulation and real-time EEG measurements were implemented.**

1. Introduction

The electroencephalogram (EEG) is a medical imaging technique that measures the electrical potential created by the neural activity and the characteristics of the neural waves, during the different cognitive and mental processes [1]. Electroencephalography (EEG) can provide an insightful view of brain processes and circuitry in a non-invasive, affordable, fast, and accurate manner, thus positing an essential and inevitable tool for diagnosing mental disorders. The EEG has been involved in research and clinical applications both in humans and animals not only to study brain development but also to monitor alertness, coma, and brain death [2]. Additionally, it has been used to locate damaged areas following head injury, stroke, and tumours.

The procedures that allow the creation of neural waves, can be described in two different ways [1]. The first consists of the rapid depolarization and polarization of the superficial membrane of the neurons caused by the flux of K^+ and Na^+ ions. These fluxes have different directions and are responsible to generate action potentials in axons and dendrites, which in turn, generate brief electrical fields that can be captured by the electrodes on the scalp. The second process is based on the synaptic activation mediated by the neurotransmitters and the Ca^{2+} ion. However, the electric field generated by this process is weaker and slower [1].

However, not all brain activity can be captured by an EEG. In general, only the synchronized activity of pyramidal neurons, oriented parallel to each other, allows the generation of electrical fields intense enough to be detected by electrodes on the surface of the head [3]. Neurons in deeper parts of the brain, such as the cerebellum, are not arranged parallel to each other, giving rise to electrical fields that cancel each other [4]. The same effect occurs in sulci (depressions or grooves in the brain).

In addition to the advantages mentioned previously, the EEG allows the identification of cognitive processes at the speed of cognition, with temporal precision in the order of milliseconds [4]. In contrast, its main disadvantage is that it provides functional rather than structural information. In other words, the EEG does not provide high spatial resolution, having to be complemented with other imaging techniques such as Magnetic Resonance Imaging (MRI), in situations where it is necessary to accurately locate the source of electrical activity [3]. However, with current technological and electrode system advancements, it has become possible to overcome this disadvantage.

The brain is one of the most complex systems in the universe. Inevitably, the biosignal captured by the EEG is highly non-linear and non-stationary with quasi-stationary segments (250ms) [5]. An EEG signal generally presents amplitudes and frequencies ranging from 0.5 μV to 100 μV and from 0.1 Hz to 80Hz, respectively [4], with frequencies above 50Hz being rarely relevant [3]. Through methods of decomposing signals in their frequencies, namely the Fourier transform, it is possible to identify five groups of waves, each relevant to a specific mental state in which low frequencies are associated with reduced responsiveness to stimuli [3]: *Delta* (0.1-4 Hz), *Theta* (4-7 Hz), *Alpha* (8-12 Hz), *Beta* (12-30 Hz), and *Gamma* (above 30 Hz).

The analysis and interpretation of the signal bands is indispensable for a correct evaluation of the brain state and generally the patient, as the frequency of a determined wave differs from a healthy and a sick patient. In fact, in the case of papers regarding patients with Schizophrenia it has been proved that the power of the delta and theta band frequency increased, and the alpha band power decreased, compared with a group of healthy patients. However, the results previously described were only valid if the group subjects kept their eyes closed. The studies where the patients kept their eyes opened, the schizophrenic patients also had an increase in the band power beta, it should also be noted that, as formerly stated the local of measurement had a key role in the final results [6].

To accurately study the brain waves acquired from the electrodes in the scalp, the right circuit instrumentation must be developed. This work focused on developing a low-cost and simple circuit to acquire the EEG signal from 1 electrode.

2. Methodology

This chapter presents the materials and methods used in this work, including the circuit components used, the electrodes, and the software used to design the circuits and to concomitantly acquire and process the signal. In order to project and calculate the circuit, the Multisim Software was used.

2.1. The acquisition circuit

With the EEG signal being very weak in amplitude, one of the most important sections of the circuit is the amplification. Albeit constituting a very important role in signal acquisition, meeting the right amplification requirements is not the only factor when considering an amplifier. The first amplification must also offer very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances [7]. For this reason, the INA128P was chosen as the instrumentation amplifier and first component of the circuit, providing a very low offset voltage of 0.5µV and a common mode ratio up to 120dB [8]. From the equation: $G = 1 + \frac{50k\Omega}{Rg}$, the projected gain was of $G = 1 + \frac{50k\Omega}{47\Omega+47\Omega} = 532{,}9$.

After the amplification, the next stage in almost every biosignal acquisition system is the filtering to obtain the desired frequency bandwidth.

Regarding the low-frequency components, the amplifier output was directed to a 4th order Sallen Key-High pass filter with a cut-off frequency of 0.1Hz. In addition to cutting off all frequency components below 0.1 Hz, the active filter was used to remove the DC voltage offsets, which originate, for example, from the accumulated electric charge in polarizable electrodes.

Following the high-pass filter, the signal was subjected to a 4th order Sallen Key Low-Pass filter with a cut-off frequency of 45Hz. With this cut-off frequency, the inclusion of a notch-filter at 50Hz becomes unnecessary, simplifying the circuit. Pictures 1 and 2 represent the bandwidth and frequency response provided by the circuit when acquiring the EEG.

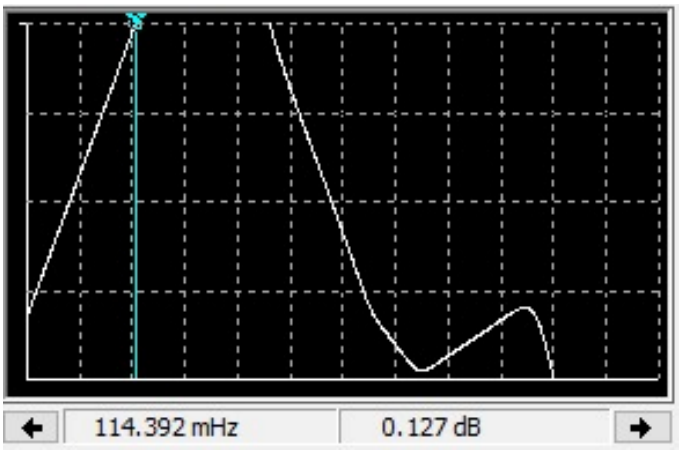

Figure 1 - Plot of the lower limit of the bandwidth created by the Low-Pass Filter designed to have a cutoff frequency of 0.1Hz.

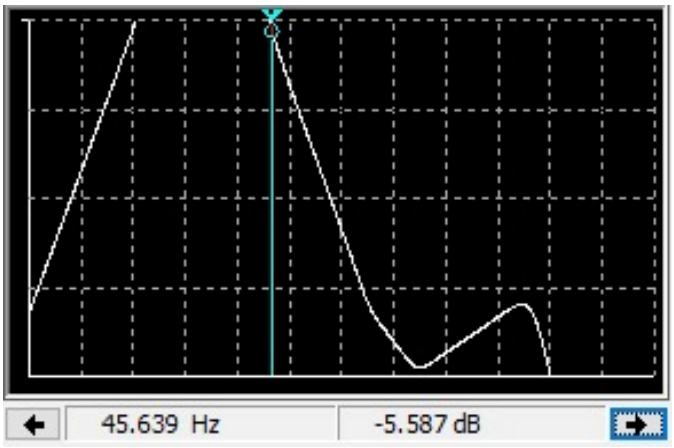

Figure 2 - Plot of the upper limit of the bandwidth created by the High-Pass Filter designed to have a cutoff frequency of 45 Hz.

The amplification and filtering circuit is illustrated in Figure 3. It is important to note that Multisim does not offer a model of the INA128P and in order to simulate the amplification, a INA126 was used, where the resistor was adjusted to obtain the same gain of 500.

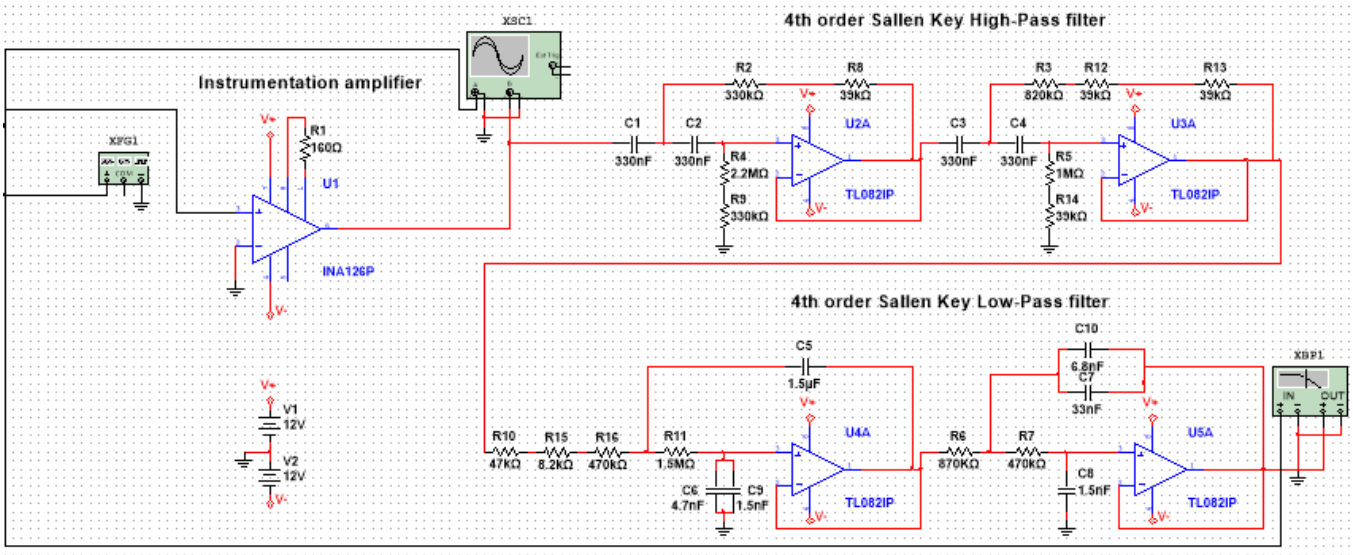

Figure 3 - EEG acquisition system simulated on Multisim, composing the amplification and filtering components.

It should be noted that in these systems that measure biometric signals like the EEG, a safety system is required. For that purpose, the right leg drive circuit could be used. This circuit is extremely relevant as it protects the user from an electrical discharge and permits the evasion of unbalanced currents and compensates for the common-mode noise problems that arise in the differential input for the instrumentation amplifier, *i.e.*, noise that is common to both electrodes such as power line 50Hz frequencies [9-10]. The right leg drive circuit was not simulated but implemented in the acquisition system following the scheme below, built specifically for the INA128P instrumentation amplifier [8].

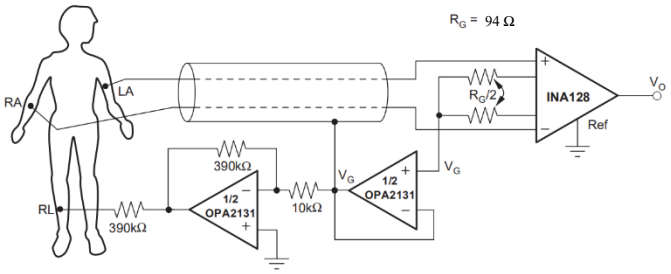

Figure 4 – Amplification with Right-Leg Drive.

2.2. Signal acquisition and processing

In order to process the signal and divide the different frequency wave bands, the LabVIEW software was used. In order to test the pipeline, the biomedical toolkit was used to simulate an EEG signal with the desired parameters, namely, the power distribution of each band and power noise. The sampling frequency used was of 256 Hz, similar to currently used EEG acquisition systems such as the openBCI Cyton board (250 Hz). Furthermore, a sampling frequency that is a power of 2 enables more efficient computations when calculating the spectrum through the Fast Fourier Transform (FFT) algorithm, which can be an important factor when designing systems that perform signal processing in real-time. Additionally, we simulated blocks of 2s of data or, in other words, 512 samples, into the pipeline to have a frequency resolution of 0.5, providing a smooth estimation of the frequency spectrum. Before inputting the data into the FFT function in LabView, the signal was tapered in the edges by a Hamming window to zero-out the boundaries and thus, preventing the formation of edge artifacts. After converting the complex coefficients of the FFT to polar form, the spectrum was divided into the positive and negative frequencies, eliminating the latter which is the mirrored image of the former. With Nyquist's theorem stating that a periodic signal must be sampled at more than twice the highest frequency component of the signal and because our signal has a sampling rate of 256Hz, we further divided the spectrum by 2. However, in order to keep a resolution of 0.5 and a smooth spectrum, we mapped the values from 0 to 128 with 256 values with the ramp function. With the frequency indexes corresponding to the real frequencies of the signal, the division of the spectrum into the target frequency bands, alpha, beta, and gamma could finally be done. The signal processing pipeline developed in *LabView* is depicted in Figure 4.

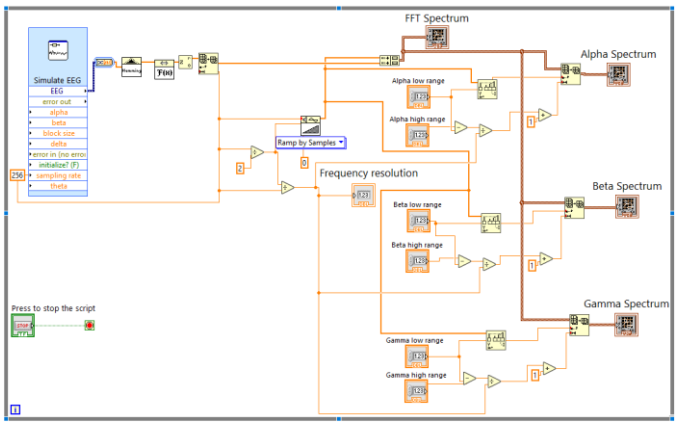

Figure 4 – Representation of the signal processing pipeline using the *LabView* software.

Transitioning to the EEG acquisition, the Analog to Digital Conversion was performed by the NI USB-6221 M SERIES DAQ DEVICE, providing an input resolution of 16 bits. The same rationale was applied for the acquisition, *i.e.*, from DAQ board, we read 2s of EEG data at a sampling frequency of 256 Hz for 1 channel at the F8 position. The reference electrode was placed at the F7 position while the RLD in the left arm.

3. Results and discussion

As mentioned previously, in order to test the signal processing pipeline, the EEG signal was simulated in LabView. The parameters selected to test the simulated pipeline are depicted in Figure 5. This resulting frequency spectrum divided into the three bands specified from simulated data is illustrated in Figure 6. The simulated alpha peak can be seen in the alpha spectrum. The same process was then tested while acquiring the EEG in real-time. While the simulated pipeline run smoothly and as intended, the live acquisition did not work properly. Albeit the code functioned as designed insofar as calculating and separating the frequency spectrum into the alpha, beta, and gamma bands, the data acquired was impossible to interpret from the electroencephalographic point of view and was mostly noise. This is most likely due to the circuit not providing enough amplification. Despite the amplification deficit, the rest of the circuit worked properly with the function generating as it filtered the signal as projected.

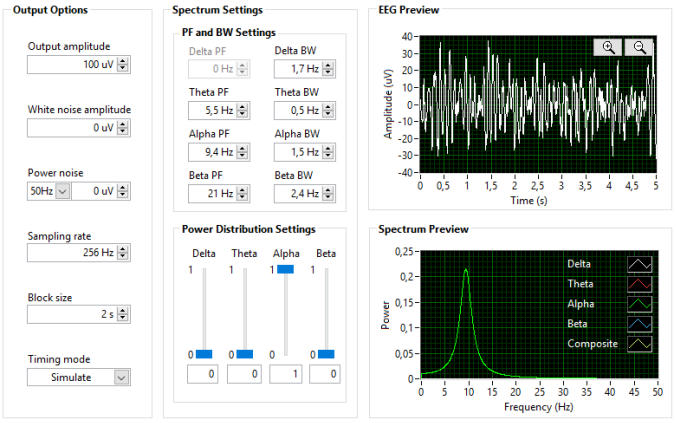

Figure 5 – Parameters of the simulated EEG signal.

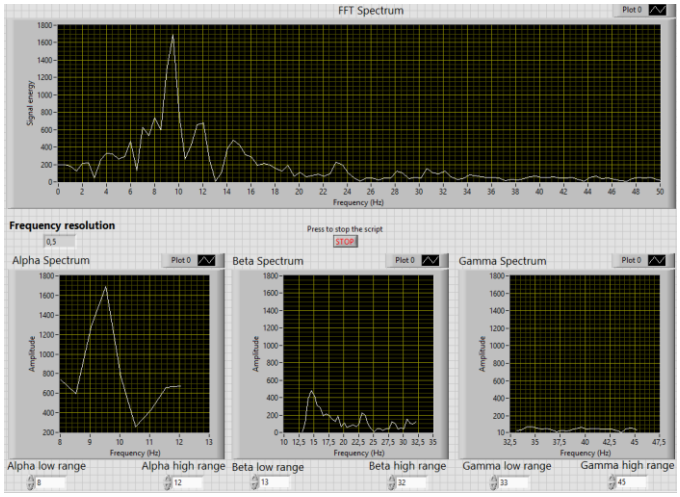

Figure 6 - Separation of the frequency spectrum into the alpha, beta, and gamma bands.

4. Conclusion

The objective of this work was to develop a circuit capable of acquiring the EEG biosignal. By providing the right instrumentation and thus acquiring the signal properly, doctors or even algorithms can better analyze the biosignal. Separating the different frequency bands in the EEG can provide information to diagnose certain disorders. Albeit the signal processing pipeline worked as intended, as shown with the simulation, the circuit did not provide enough amplification.

5. References

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