An Electromyography Signal Conditioning Circuit Simulation Experience

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Abstract - **This paper deals with concepts about the electromyography signal (EMG), which is a record of action potentials presented by muscles, and presents the software simulation of a low-cost conditioning circuit for electromyography signals including component blocks capable of signal processing and adaptation for micro-controlling devices. The low cost and high sensitivity make the developed EMG, a good choice in medical applications, such as sleep disorders.**

Keywords — *EMG; Conditioning Circuit for EMG Signals; Circuit Simulation; Instrumentation.*

I.   INTRODUCTION

The EMG spectrum includes signals with frequencies varying from 10 Hz to 1 kHz, primarily between 50 and 150 Hz, and voltage peaks going from 1 µV to 100 mV, mainly between 50 µV and 9 mV. While acquiring an EMG signal, some high levels of interference and noise can be noted, requiring a carefully projected conditioning circuit to enable the signal's analysis. The main noise sources involved in this analysis are the environmental noise and the transducer noise, even though the noise from other sources can not be discarded. The environmental noise results from electromagnetic wave generators present, mainly, the frequency of 60 Hz (line frequency). It should be noted that the 60 Hz frequency is part of the EMG spectrum and should not be ruled out of the analysis. The transducer noise, on the other hand, results from the electrode-skin junction during the conversion of ionic current to electrical current, presenting DC portion (from the impedance gradient present between the skin and the electrode) and an AC portion (impedance fluctuations). Finally, there are other noises involved in the analysis, such as electromagnetic interference and cardiac noise.

Each muscle's EMG signal involves many action potentials resulting in the various MUAP (Motor Unit Action Potential) of each motor unit. In this way, it is possible to distinguish the muscle's spectrum in function of the distance between the electrodes and the contractions intensity level. The whole process involves some challenges surrounding signal processing and noise treatment, with the intention of allowing a more accurate measure and a greater sensitivity level, considering the kind of application given to the EMG [2][3][4][6].

In this paper, the surface EMG's development process is described with a special emphasis on noise treatment. The simulation analysis involves the inputs signal's processing and amplification, verifying the signal's accuracy for frequencies of 10 Hz, 250 Hz, 600 Hz and 10 kHz.

II.   THE ELECTROMYOGRAPHIC SIGNAL

The electromyography signal is a small amplitude signal, with high noise levels and frequencies ranging between ± 50 and ± 500 Hz. In order to allow this signal to be interpreted by a micro-controlling device, it must be amplified, filtered and rectified, as well as the noise levels must be reduced.

The first amplification stage requires the use of an instrumentation amplifier. This amplifier is specifically made for noise attenuation at small amplitudes. For this work, and bench experiments, we used the instrumentation amplifier INA129 [1], whose details will be described in the following sections. The instrumentation amplifier works according to the principles of a differential amplifier, involving the CMRR (Common Mode Rejection Rate) properties [1]. The rejection rate, in general, is the amplification of a potential difference, which, in this case, is the difference between the two electrodes positioned over the muscle surface. Considering that the existing level of noise in both electrodes is similar, a fact that results from their similar exposure conditions, the amplification of the potential difference would eliminate much of the external noise [1].

III.   THE AMPLIFIER'S DETAILS

The instrument amplifier (INA129) is a variable gain and high precision amplifier, especially designed for low voltages. With a resistor in the input, the unit gain can vary from 1 to 10,000 approximately: the output voltage can be from 1 to 10,000 times the input voltage. The internal circuitry is designed to withstand voltages up to ± 40V without damage in operation. The operation can be made with feeds of at least ± 2.25 V, with a quiescent current of only 700µA, making it suitable for battery powered systems (Figure 1).
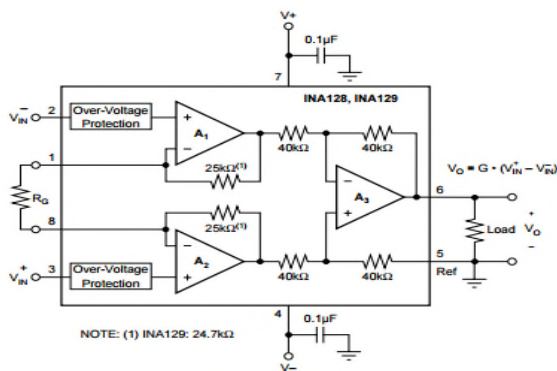
Figure 1: INA129 Instrumentation Amplifier's Internal Circuit

The internal circuitry of the instrumentation amplifier involves three amplifiers and a combination of resistors, so the total gain obeys equation (1). Using a resistor of 240Ω, for example, the circuit obtains a gain of 206.83 (With 200Ω, it obtains a gain of 248). It is noteworthy that the main function of this amplifier, however, is to ensure a significant reduction in the input noise of the electromyography signal.

$$G = 1\frac{49.9\Omega}{R_G} \qquad (1)$$

After the first amplification, the signal is filtered using initially a high-pass filter with a cutoff frequency of 500 Hz. Then, the signal travels through (with) a low-pass filter with a cutoff frequency of 50 Hz. Therefore, the most significant part of the EMG signal proceeds to the rectification stage, in order to achieve the appropriate values for the microcontroller.

Upon conclusion of the simulation, using the National Instruments software Multisim, the circuit is printed in a PCB, substituting the equivalent circuit for SMD components.

IV.   SIMULATION AND EXPERIMENTS

The first circuit consists of four functional blocks: a) the primary amplifier, b) filter, c) rectifier and d) smoother. Using a sinusoidal signal as input (assuming that the signal has a frequency within the filter passband), the wave output is rectified and smoothed. In other words, the signal is adjusted to positive, the negative portions are kept in amplitude but are transformed into positive portions and then the signal peaks are used as DC stretches. Thus, the DC output is proportional to the amplitude of input signal: by increasing the intensity of the muscle contractions detected by surface electrodes, the circuit's output signal is higher (Figure 2).

The circuit, in this way, fulfills the objective of detecting the muscle contraction at different intensity levels and condition the detected signal to an electrical signal that is compatible with a microcontroller device, so that the final output is between 0 and 5V. Thus, the simulation circuit is shown in Figure 3.
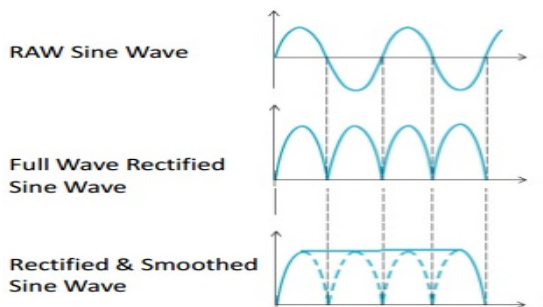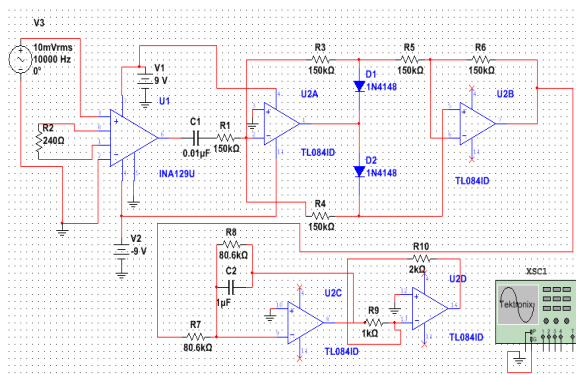

Figure 2: Circuit 1 Input Signal

Figure 3: Simulation Circuit Configuration

The sinusoidal signal generator is used as the input of the circuit and an oscilloscope (Tektronix brand) is used at the output. Thus, in order to confirm the basic operation of the circuit, the simulation should provide four measurements: the initial amplification (made by INA129U), the filtering (attenuation of signals outside the range 50-500Hz), the rectification (final results entirely positive) and the smoothing of the output waveform. Only the noise reduction can't be verified by simulation with sine waves, since the generated signal is ideal.

Firstly, the circuit is mounted in a way of analyzing the instrumentation amplifier, as shown in Figure 4 and viewed on an oscilloscope (Figure 5):
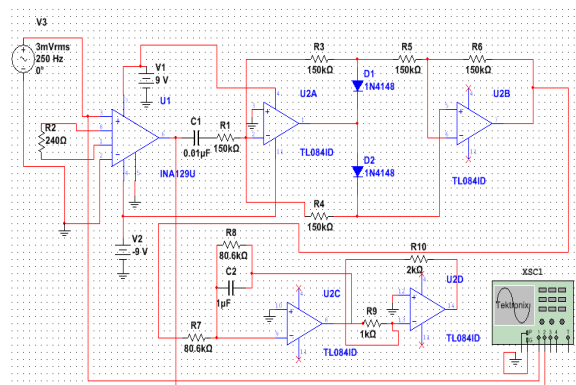

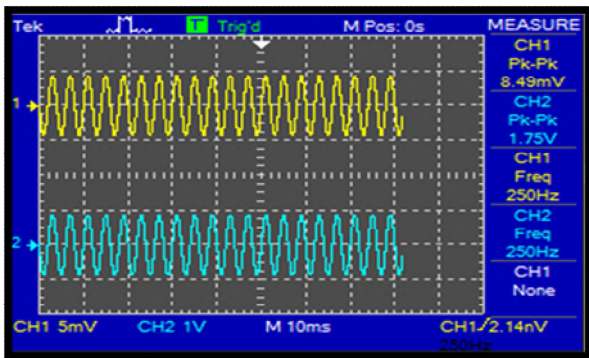Figure 4: Simulation Circuit Configuration for Instrumentation Amplifier Analysis

Figure 5: Results of Instrumentation Amplifier Analysis

Analyzing the results, there was a gain of nearly 206, as expected for a resistor of 240Ω. It is noteworthy that the input signal has 3mVrms, a value compatible with the EMG signal. It can also be inferred that there were no changes regarding the input signal's frequency or phase.

After checking the operation of INA129U, the filter must be analyzed. The circuit's final output must be checked for four input frequencies: 10Hz, 250Hz, 600Hz and 10 kHz. The analysis will be done by checking a possible output signal attenuation (the signal's amplitude values will be checked). It is important or remarkable that the signal frequency is changed in the rectification and smoothing process, as the negative portion of the signal is bounced to the positive voltage range, amplifying or magnifying the signal repetition (doubling its frequency). Figure 6 displays the oscilloscope positioning.
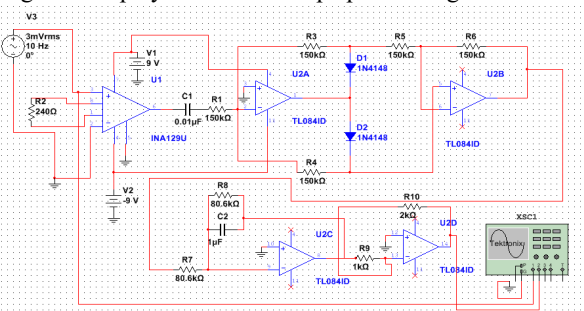

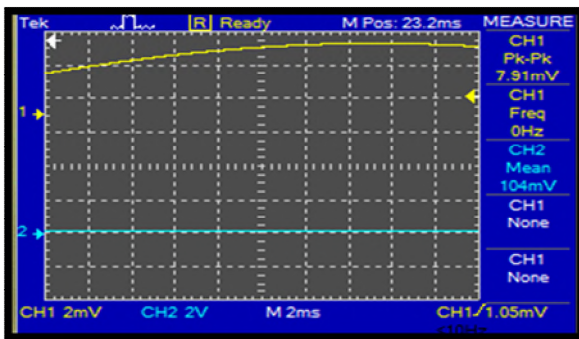Figure 6: Simulation Circuit Configuration for Filter Analysis

Figure 7: Results for 10 Hz input

For an input frequency of 10 Hz (Figure 7), it appears that the oscilloscope shows only a portion of the signal

(the rising of the sinusoid), since the sample period chosen is too large. The circuit's output, on the other hand, has a very low value (within the range of 0 to 5V). Then, the signal, despite of being amplified, was attenuated in the circuit, since the frequency is not suitable for an EMG signal. In other words: the signal which was not detected, as an EMG signal, was filtered by the conditioning circuit.

For an input of 250Hz (Figure 8), with an amplitude close to the maximum of a typical EMG signal, a 2.39V output can be seen. As such, voltage values within 0 to 5V are proportional to the input value, so, it could be concluded that the signal is not attenuated, i.e., was not filtered. In fact, as the frequency is in the appropriate range for electromyography signal, the circuit must keep the amplifications and let the signal passes to the exit without suffering attenuation.
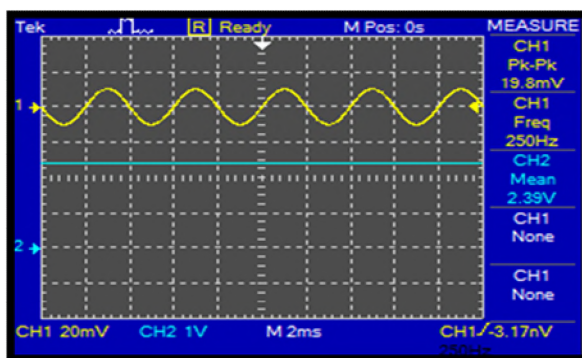

Figure 8: Results for 250 Hz input

For an input of 600 Hz (Figure 9), the attenuation is still unclear, although the frequency is already outside the range of the EMG signal. Because the value is close to the 500Hz filter cutoff frequency, the signal is not intensely attenuated. In practice, it is impossible to design a filter able to fully attenuate signals above 500Hz, as signals near cut-off frequency will continue passing through to the circuit output. However, the actual spectrum of an EMG signal is not that precisely located in the pass band mentioned above (50 to 500Hz) and, in addition, signals near to 500Hz are not very common. Thus, it is not expected or required for the circuit to be able to filter signals with frequencies that close to the cutoff frequency.
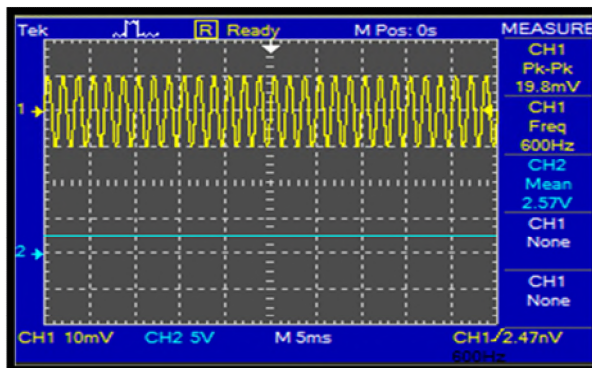

Figure 9: Results for 600 Hz Input

For an input signal of 10 kHz (Figure 10), the attenuation becomes evident. The output signal, in this case, has zero amplitude, illustrating a signal completely filtered. Unlike the previous case, the frequency of 10 kHz is distant from the circuit's cut-off frequency (500 Hz) and therefore, in a real situation, would not be part of the EMG. That frequency represents only noise, featuring as an unwanted signal. Then, the complete attenuation of the signal is indicative of a good filtering performed by the circuit.
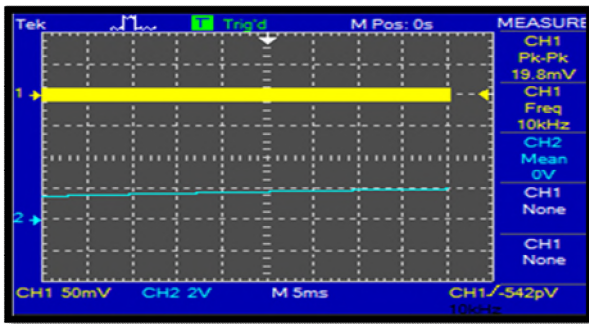

Figure 10: Results for 10 kHz input

After the filtering, the rectification and the smoothing must be verified. For that, the oscilloscope is positioned, both before and after the rectification circuit, as shown below (Figures 11-12):
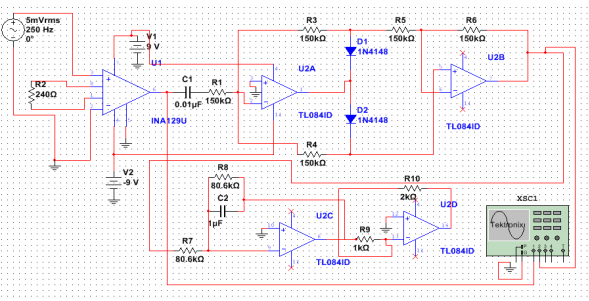

Figure. 11: Simulation Circuit Configuration for Rectification Analysis
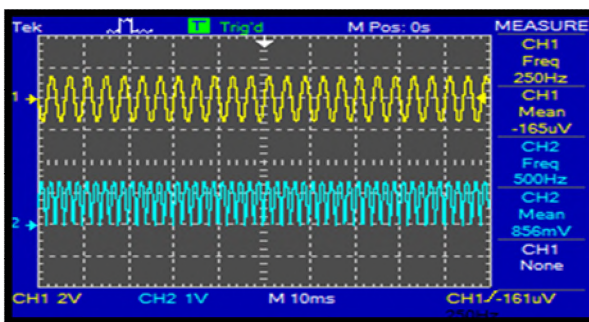

Figure 12: Results for Rectification Circuit

V. CONCLUSION AND FUTURE WORKS

The result observed on the oscilloscope evidence the frequency amplification is double and the signal's average value's rise. In fact, the full-bridge rectification results in a modular signal of the input; thus, the output presents, for a sinusoidal input, a signal with the double of the frequency and a "displacement" of the average value for a positive portion of the signal, since the negative portions were reflected upside.

The filters used in these experiments present cutoff frequencies of 50Hz and 500Hz. Using sinusoidal inputs of 10Hz, 250Hz, 600Hz and 10kHz, it could be noted the good functioning of the filters. It was observed that the circuit is able to attenuate completely the signals with 10Hz and 10 kHz (signals with frequencies too distant of the EMG spectrum), attenuate partially the input signals with 600Hz (uncommon frequency for the EMG spectrum) and not attenuate signals of 250Hz (typical frequency of the EMG spectrum).

Besides that, it should be noted that the amplified signals did not exceed 5V, such as they did not assume negative values. In this way, it can be concluded that the circuit is able to meet the conditions imposed by a micro-controlling device, which operate with input signals between 0 and 5V.

Finally, the signal's smoothing was verified. For that, it was sufficient to insert a typical signal as the input and verify the aspect of the output signal. The smoothing of an infinite sinusoidal signal is a DC voltage, since all the peaks are the same (it can be seen that the DC voltage is equal to the maximum peak value of the sinusoidal signal, already amplified, filtered and rectified).

The high sensitivity of the EMG may allow its use in several medical applications, such as studies of sleep disorders, specifically bruxism [7], even considering its low manufacturing cost.

REFERENCES

[1] Burr-Brown Corporation. Datasheet: "Precision, Low Power Instrumentation Amplifiers ". Access: http://instrumentation.obs.carnegiescience.edu/ccd/parts/INA128.pdf , Feb. 2017.

[2] J.D. Geyer, P. R. Carney, and T. Payne, "Atlas of Polysomnography," Lippincott Williams and Wilkins, 2009.

[3] S. Devuyst *et al*., "Automatic Sleep Spindle Detection in Patients with Sleep Disorders," *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*, New York, NY, 2006, pp. 3883-3886.

[4] J.F. Gagnon, R. B. Postuma, and J. Montplaisir, "Update on the pharmacology of REM sleep behavior disorder," Neurology, vol. 67, no. 5, pp. 742–747, 2006.

[5] A. Siddiqi, D. Kumar and S. Arjunan, "Surface EMG model for Tibialis Anterior muscle with experimentally based simulation parameters," *5th*

ISSNIP-IEEE Biosignals and Biorobotics Conference (2014): Biosignals and Robotics for Better and Safer Living (BRC), Salvador, 2014, pp. 1-5.

[6] M. E. G. Bigelow *et al*., "Point-of-Care Technologies for the Advancement of Precision Medicine in Heart, Lung, Blood, and Sleep Disorders," in *IEEE Journal of Translational Engineering in Health and Medicine*, vol. 4, no., pp. 1-10, 2016.

[7] N. Jirakittayakorn and Y. Wongsawat, "An EMG instrument designed for bruxism detection on masseter muscle," *The 7th 2014 Biomedical Engineering International Conference*, Fukuoka, 2014, pp. 1-5.