# IMPORTANT ASPECTS ASSOCIATED WITH THE DESIGN OF SUPERFICIAL EMG SIGNAL CONDICIONING CIRCUIT

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**Abstract:** This paper presents the design of a surface Electromyographic (sEMG) data acquisition circuit, with emphasis in the stages of amplification and filtering. A detailed design guideline for the system is exposed, providing the means for the correct choice of the circuit components. In order to validate the design, the results obtained from the system simulation and also from a prototype built in printed circuit board are provided, which prove that the system has a good accuracy. The system accuracy is limited to the tolerance of commercial components and devices. Lastly, it is proposed an improvement of the circuit for next processing stages, dependent on the application, which the system is intended to be used.
**Keywords:** Surface EMG Acquisition Circuit; Amplification; Filtering; Biomedical Instrumentation.

## Introduction

The Electromyography (EMG) can be defined as a technique of detection, analysis and recording, with interpretation, of the electric signals obtained from the muscular contractions. This technique can be used with diagnosis purposes, such as the analysis of a motor system of a determinate muscle or monitoring of rehabilitation, as well as a tool for realization of the control of movements, using concepts linked to biomechanical and robotic systems [1-3]. Among the EMG techniques, there is the Surface EMG, a non-invasive technique where the signals are obtained by the skin [4].

The origin of the electromyographic signals is in the Motor Unity (MU), present in the muscle fibers. When a muscle is moved, the brains sends an ionic current that creates an Action Potential (AP) to reaches the MU in the cellular membrane. A muscle has many UMs and a move generates some APs. The sum of these potentials is the Motor Unity Action Potential (MUAP), and these signals are read in the EMG [1, 5, 6].

In this paper, a surface electromyographic data acquisition circuit is presented and regarding the aforementioned circuit can be constructed in amplification and filtering stages. The reason of this paper is presenting the main aspects to construction of a reliable system, which captures the signal to be processed by the aforementioned circuit, in order to be applied in electromechanical drives or robotics, benefiting individuals with physical disabilities, focusing on accessibility. Moreover, this circuit presents designed stages to auxiliary the posterior signal processing for the desire application, allowing the final software to be faster and more efficient. Lastly, for the verification of the system, it is inserted sinusoidal waves of different frequencies and simulated sEMG signals.

## Materials and methods

**Isolation from the supply mains** – Before being used in a person, a circuit that does acquisition of bio-signals must be isolated from the electric power-line supply. The protection of the individual is the main basis that is going to be used by system, ensuring it does not suffer any physiological disturbs (electrical shock) or hazards. [7]. Considering that the threshold of perception ranges to 0.6 to 7 mA, the current used in the circuit and electrodes has a lower value [8].

Thus, letting the system isolate from the power supply, all the circuit is fed by 9V-batteries, connected in symmetric form, providing the same magnitude, both positive and negative. This value was chosen due to the ease of obtainment, it is inside of the range of maintenance of the employed devices, and does not allow the circulation of a current with a dangerous magnitude.

**Amplification** –The first stage of the system is the amplification, which consists in capturing the signal and raising its amplitude proportionality through a gain. Furthermore, the surface EMG bipotencials have amplitudes in order of ranges 20 to 2 mV or 0 to 6 mV peak-to-peak, very small to work with this real value [1, 9, 10]. Usually, differential amplifiers are used to the fulfillment of the technique, since these amplifiers reject signals with equal properties, amplifying different signals [11]. Therefore, the instrumentation amplifiers are appropriated to this application. They present: high input impedance reducing the current in electrode-skin interface, noises and voltages-drops; a low output impedance; the output voltage is independent of the load connected to the output; a high Common-Mode Rejection Ratio - CMRR, to attenuate signals which are common to both signals inputs, as 60 Hz noise; and present to a high gain (ratio between the output by the input) [12].

For the amplification circuit, it is used an integrated circuit (IC) INA128 (Instrumentation Amplifier), which is presented in Figure 1. The gain amplifier chosen is 400, and this value was choose because posteriorly, the signal is going to go to an embedded system, which has a voltage limit to analog-digital converter. Considering the value of the signal amplitude, the maximum peak-to-peak voltage for this stage is 1.6V to 2.5 V [1, 9, 10]. The gain has been calculated by [13].

$$G = 1 + 50k\Omega/Rg \therefore Rg = 50k\Omega/(G-1) \quad (1)$$

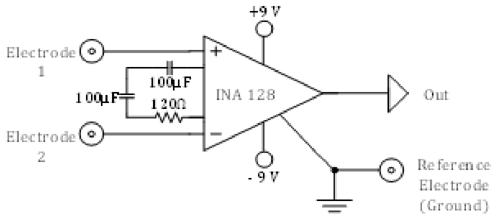


Figure 1: Circuit of Amplification System

In equation (1), G refers to the gain of the amplifier, and Rg is the resistance of gain in Ω. The constant of 50 kΩ is due to internal resistances of the IC and the constant 1 is due to the simplification of the equation. In order to achieve a gain of 400, it would be necessary a resistor with 125.31 Ω. As the value is unviable for that precision, it was used a commercial value of 120 Ω, increasing the gain to 417.67. For eliminate the noise made by the movement of the electrodes and the cables when the measurement are been made, a high-pass filter is used [4]. The capacitors connected together with the gain resistor make the amplifier assume a high-pass filter characteristic, with a cutoff frequency given by

$$f_c = 1/(2\pi RgC) \therefore C = 1/(2\pi Rgfc) \quad (2)$$

In equation (2), $f_c$ corresponds to the cutoff frequency (in Hz) and C to the capacitance value (in F). Among the properties of the signal, a cutoff frequency of 20 Hz is specified, leading to a capacitance value of 66.31 μF. [4] Due to the unavailability, it is used two capacitors of 100 μF in series, resulting in 50 μF, resulting in a cutoff frequency of 26.52 Hz, that due to the precision of the components, does not show significant changes.

**Filtering** –As well as any signal, the sEMG signal also has noises, and filters are used to eliminate them. The filters are designed to the band of frequency with more power to the sEMG signal, which is about 50 Hz until about 500 Hz [6,14,15]. It is designed a low-pass active filter (both with unitary gain to better analysis of filtering system) with cutoff frequency of 500 Hz and a band-stop filter of 60 Hz, due to the electromagnetic interference generated by the power supply system and also by the lighting system near the place of signal capturing [16]. The Figure 2 presents these used stages. The first stage of the filtering consists in a fourth- order-active low-pass filter (compound by two stages of second order in cascade) with cutoff frequency of 500 Hz in Sallen and Key's topology (VCVS, Voltage Controlled Voltage Source) [17-18], using the IC OPA4131 as operational amplifier, with unitary gain and Butterworth approximation. The filter order was chosen to provide a response flatter than a second order filter.

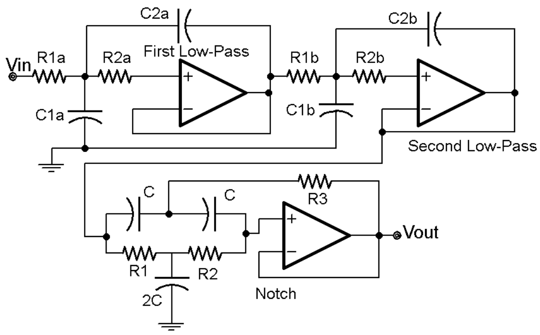


Figure 2: Electronic circuit of filtering stages

The first dimensioned component is the capacitor C2, using the following criteria: a commercial value in µF near the ratio of 10 by the cutoff frequency in Hz. After this, in order to guarantee unitary gain, the components C1, R1 and R2 are given by

$$C_1 \leq a^2 C_2/4b \quad (3)$$

$$R_1 = 2\bigg/\left[aC_2 + \sqrt{a^2C_2^2 - 4bC_1C_2}\right]\omega_c \quad (4)$$

$$R_2 = 1/(bC_1C_2R_1\omega_c^2) \quad (5)$$

In which the values of a (0.7654 and 1.8478 for the first and second stage, respectively) and b (1 for both stages) are parameters that provide the Butterworth approximation, found in tables, and $\omega_c$ corresponds to the angular cut frequency (in rad/s) [19]. This sequence of dimensioning is followed: with the chosen commercially value of $C_2$, it is calculated $C_1$, which then is set to a commercially value; from that, the values of resistance were calculated from the commercially available values of the capacitors. The values found for these components are provided in Table 1.

Table 1: Value of components, calculated and commercial, of the Low Pass Filter

| Component | Calculated | Commercial Used |
|---|---|---|
| $R_{1a}$ | 16.75 kΩ | 18 kΩ ± 5% |
| $R_{1b}$ | 7.97 kΩ | 8.2 kΩ ± 5% |
| $R_{2a}$ | 2.42 MΩ | 2.4 MΩ ± 5% |
| $R_{2b}$ | 49.42 kΩ | 47 kΩ ± 5% |
| $C_{1a}$ | ≤ 2.93 nF | 100 pF ± 10% |
| $C_{1b}$ | ≤17.07 nF | 10 nF ± 10% |
| $C_{2a}$ | ≈20 nF | 25 nF ± 10% |
| $C_{2b}$ | ≈20 nF | 25 nF ± 10% |

The second stage of filtering matches the 60 Hz-band-stop filter, being this also a Sallen and Key's topology. This filter is proposed because the components of 60 Hz of power-line supply influence in to measurement, even the frequency of 60 Hz also is a real part of sEMG signal [20]. Firstly, it is established a quality factor ($Q_o$) that denotes the precision of the filter, in which case, match the attenuation in the band of 50 to 70 Hz, where the parameter $f_o$ is found, which corresponds to the central frequency among the cutoff band, as given by (6). Hence, it is possible to calculate the quality factor by (7) and $R_1$, $R_2$ and $R_3$ by (8), (9) and

(10), respectively, knowing that the criteria used to C is the same to $C_2$ from the previously filter (using fc) and that 2C is the double value of C.

$$f_o = \sqrt{f_{c2} \times f_{c1}} \quad (6)$$

$$Q_o = f_o/(f_{c2} - f_{c1}) \quad (7)$$

$$R_1 = 1/2Q_o\omega_o C \quad (8)$$

$$R_2 = 2Q_o/(\omega_o C) \quad (9)$$

$$R_3 = R_1R_2/(R_1 + R_2) \quad (10)$$

In which $f_{c1}$ is the lower limit of the frequency band (50 Hz), $f_{c2}$ is the upper limit of the frequency band (70 Hz), and $\omega_o$ is the value of the angular frequency of the value of $f_o$ Table 2 presents the results obtained to the calculated and commercially available values.

Table 2: Value of the components, calculated and commercial, of the Band-Stop Filter

| Component | Calculated | Commercial Used |
|---|---|---|
| C | ≤169 nF | 100 nF ± 10% |
| $R_1$ | 4.53 kΩ | 4.7 kΩ ± 5% |
| $R_2$ | 159.16 kΩ | 160 kΩ ± 5% |
| $R_3$ | 4.53 kΩ | 4.7 kΩ ± 5% |

**Methodology** – In order to test the performance of the circuit, the aforementioned circuit is subjected, firstly, to a simulation by the software Orcad®/Pspice®. It was defined a frequency range to the analysis: of 1 to 1.3 kHz. The data of simulation is taken from Orcad® and subject to another software for construction of graphs.

Thereon, the circuit was construct in a printed circuit board and subject to a sinusoidal wave of 20 mV, with variation of this frequency, respecting the same limits previously imposed, to frequency domain analysis. It was calculated the gain in dB of each stage: needing, for the stage of filtering, the measurement of the output of the amplification stage. The second test consisted in the injection of simulated EMG signal obtained by a database, in view of the waiting of acceptance of the project in Ethics Committee, with the CAAE number 30162814.5.0000.5547 [21]. The used signal was obtained by PhysioNet, project with a database of physiological signals. This signal contains 0.5 seconds, belonging a healthy person, presented in Figure 3. It was simulated in LabView® and sent in a Data Acquisition Board. After, a noise of 60 Hz was only inserted in the original wave - the AD conversion inserted the high frequencies in the signal - and the result was amplified by 10, for approximate to a sEMG signal.

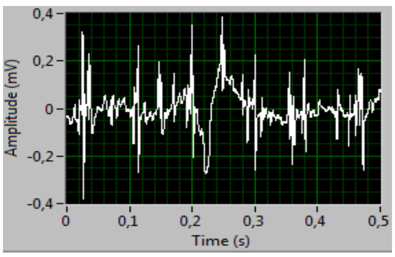


Figure 3: EMG used signal to simulation.

## Results

The measurement results of the circuit can be seen in Figures 4, 5, and 6. Figure 4 presents the Bode diagram of the magnitude regarding the complete circuit, proving that the simulated values match the real values. The gain is crescent from 1 Hz, stabilizing to reach 100 Hz, with a peak of 52,4 dB, equivalent to a value of gain of 416, very close to the calculated value. When it approaches 50 Hz, there is an attenuation, caused by the band-stop filter action, which persists until about 70Hz. As simulated, the maximum attenuation is -32 dB occurring at 57.2 Hz, and although the practice and the simulation have differences, the attenuation value at the frequency of 60 Hz is about 10 dB, approaching the situation of the simulated system.

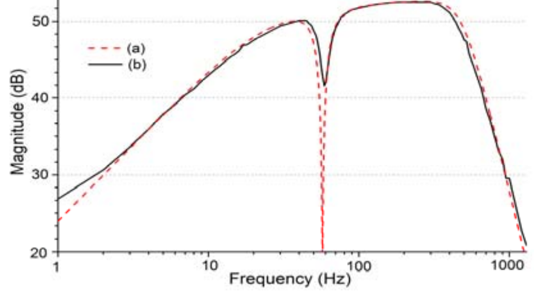


Figure 4: Bode Diagram of Magnitude of Complete System with simulated (a) and real (b) values.

Figure 5 presents the simulated signal in the amplification and filtering outputs and Figure 6 presents the frequency response for the two signals. The amplitude of the signals are for amplification and filtering systems are approximately 4V. In the frequency response, for comparison with the signal obtained by the Fast-Fourier-Transformer (FFT) of LabView®, the signal filtered exhibits a considerable attenuation from 500 Hz for high frequencies, and the frequency spectrum concentrated to 200 Hz, as a sEMG signal.

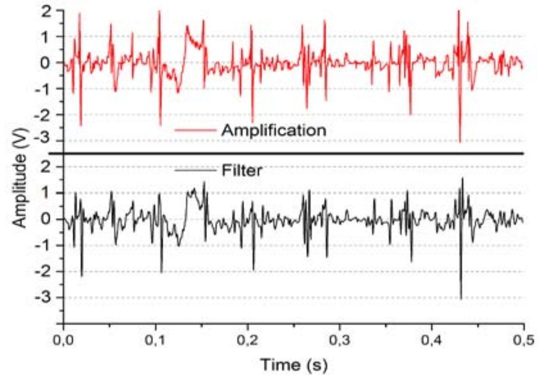


Figure 5: Simulated EMG signal in amplification and filtering stages.

## Discussion

With the results, the circuit fulfills its function as data acquisition, as well as the stages to construction of one. The precision and the tolerance of the components are some factors that influence these results. Thereon, for more precision, the data acquisition can be made by dedicated filters or/and the use of precision components.

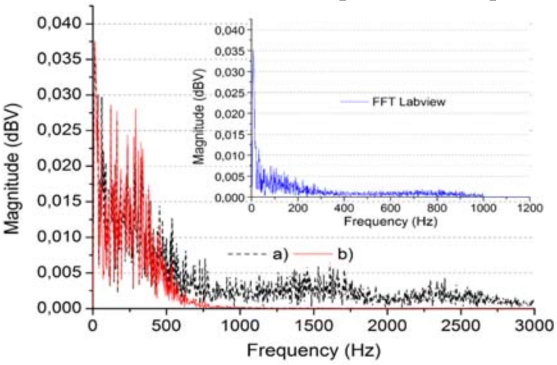


Figure 6: Frequency Response of a) amplification and b) filtering output systems and simulated signal in LabView.

## Conclusion

The system presented an acceptable behavior, as it has been proved to work properly. Even with its accuracy, the major problem in the measurement of sEMG is the precision of the parameters that changes for each person, due to individual factors. Nevertheless, it has some similar characteristics that can be obtained from the signal and used for different applications, especially robotic. Therefore, it proposes an improvement through the components of higher precision, as well as the construction of the system of signal processing for the same data, that can be treated for the application that is desired to be constructed.

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