EMG FILTERING SYSTEM USING SWITCHED CAPACITOR MF10 AND ACTIVE FILTER UAF42 INTEGRATED CIRCUITS

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Abstract: This paper presents an Electromyography data filtering system with integrated circuits with switched capacitor MF10 and universal active UAF42 filters. The filters constructed are a Low Pass with cutoff frequency of 500Hz and Band Stop with cutoff central 60Hz employing components with commercial values. Its purpose is to show what are the major characteristics and functions for the construction of a system to filtering EMG signals for use in robotic applications. For analysis, the system is tested and compared with a surface Electromyography data acquisition with filters constructed by operational amplifiers. The results exhibit a good performance for the desired application.
Keywords: Switched capacitor filters; Universal Active Filters; surface Electromyography; instrumentation.

Introduction

Switched capacitor circuits are usual in systems of data sampling, that among their main applications, as comparators, analog-to-digital (AD) and digital-to-analog (DA) converters, highlight their uses as filters [1]. These circuits allow construction of time constant with accurate values without employ components of high precision and hard obtainment. This fact, associated to ease of construction of integrated circuits (IC) containing precision electronic components, renders simplification for the construction of systems employing filters with cutoff frequencies lower than 1 MHz, since capacitors with small values are used with transistorized switches (MOSFET technology) [2].

Among the main behavior conditions, there is the necessity for a switching frequency much higher than the cutoff frequency. As advantages, there are the facility of adjustment of the cutoff frequency by switching frequency, high reliability and stability – mainly against external factors as temperature – and represent lower costs of the circuit, because occupy small areas in an IC [3-4]. The obstacles that impede their implementation are related to the switched frequency, since the switched circuit introduces its frequency as noise, thus requiring a passive filter to attenuate these frequencies.

On the other hand, there are filters in IC that do not use switched principles but reactive components, mainly capacitors, with the semiconductor properties. One of these classes, there are active filters, where the response is not given by sampling but a continuous time signal [5].

Based on this knowledge, this paper proposes the construction of a surface Electromyography (sEMG) data filtering system using circuits compound by switched capacitors, in order to compare with other circuit employing active filters with similar specifications using operational amplifiers. The justification for this analysis is to find circuits that can be constructed for biomechanical and robotic applications that exhibit good performance and cost benefit for this way. It is noteworthy that the passband of frequencies for sEMG signals is within the range between 20 to 500 Hz, with signals of great power among the frequencies of 50 to 150 Hz [6-8]. In order to measure the signals by the active band, two filters are projected: a fourth order active low pass filter, with cutoff frequency of 500Hz; and a second order active band stop filter with central frequency of 60 Hz, due to the influence of the power supply of the instruments fed by the local electric grid [9]. Therefore, this work has as justification the assessment of using integrated filters in EMG data acquisition circuits, to demonstrate how a circuit with these components can be projected for EMG applications, and to identify their major characteristics.

Materials and methods

For constructing of the filters, two ICs are used, MF10 (for the Low Pass filter implementation), and UAF42 (for the Band Stop filter), due to their singular characteristics to the system, as proposal of comparison among its project and their characteristics.

MF10 – The IC MF10 contains two blocks of independent filters, each working with a clock – at the switched frequency – and with 3 to 4 external resistors (depending on the chosen configuration), allowing the realization of 2nd order functions from the Butterworth, Bessel, Chebyshev, and Cauer approximations. Their order can be raised by cascading filtering stages among the blocks of the MF10. There are three pins of output in each block, allowing the implementation of Low Pass, High Pass, Band Stop, Band Pass or All Pass filters. The cutoff frequencies can be configured to be dependents on both of the cutoff frequency as the association of the extern resistors; moreover, it has several operation modes due to their internal functionalities [10]. Among the operation modes, the third mode is chosen, as presented in the Figure 1, which allows to change the value of cutoff frequency through the ratio between the resistors R_2 and R_4 to values above or below the ratio of the clock frequency by 50 or 100 [11]. As for his approximation was chosen the Butterworth of second order. A clock frequency of 50 kHz is used for a cutoff frequency of 500 Hz, a clock frequency hundredfold, with an astable 555.

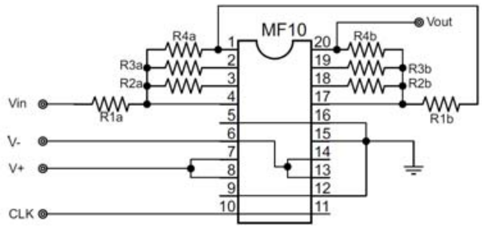

Figure 1: Third operation mode of MF10 as Low Pass Filter

The resistors R_1, R_2, R_3 and R_4 are chosen according to the specifications provided by the manufacturer, following these order of operation: select a value of R_2, between 10 kΩ to 100 kΩ; determine the value of R_4 by (1); determine the value of R_3 by (2); and determine R1 by the wanted gain using (3).

$$R_4 = R_2 {f_{CLK}}^2/(100f_o)^2 \quad (1)$$

$$R_3 = Q\sqrt{R_2 R_4} \quad (2)$$

$$R_1 = -R_4/H_{OLP} \quad (3)$$

In which R_1, R_2, R_3 and R_4 are the values of the respective resistors, f_{CLK} is the clock external frequency, f_o is the cutoff frequency, Q is the quality factor and H_{OLP} is the gain of the Low Pass Filter.

To dimension the quality factor of the filter, the values of the normalized square factors to filters with Butterworth approximation are used [11]. The values of Q are acquired by the components datasheet and adjusted – for the precision of the available components or necessity of the system – to form a filter of fourth order using two cascaded second order filters [11]. Table 1 presents the theoretical and real values of the quality factor, resistors and gains. The values with ‘a’ are related to the first stage, while ‘b’ refers to the second stage.

UAF42 – The UAF42 is an active universal filter, able to implement second-order filters based on several approximations (as Butterworth and Chebyshev) and of several functions (low pass, high pass, band pass). It contains internal capacitors of 1000 pF for achieving low loss active filters, and also provides an operational amplifier to implement additional stages, as band stop, inverted Chebyshev, among others [12].

Reference [13] presents a circuit able of reject the band of 60 Hz of external interference and its electronic schematic is shown in the Figure 2. This circuit exhibits a low sensibility on 60 Hz electric grid interference and a quality factor more stable under variations of external components value. Its response is (4), in which the rejected frequency can be modified by the change of the resistors R_{f1} and R_{f2} and and/or addition of external capacitors. Knowing that R_f is equal to R_{f1} and R_{f2}, and C refers to internal capacitances, on rearranging equation (4) leads it is possible to find (5), where the value of R_f can be determined.

Table 1: Value of the variables and components, calculated and commercial, regarding the Low Pass Filter for MF10 design.

Variable/ Component	Calculated Value	Commercial/ Real Used Value
Q_a	0.541	0.56
H_{OLPa}	1	-
R_{1a}	10kΩ	10kΩ ±5%
R_{2a}	10kΩ	10kΩ ±5%
R_{3a}	5.41kΩ	5.6kΩ ±5%
R_{4a}	10kΩ	10kΩ ±5%
Q_b	1.307	0.82
H_{OLPb}	1	-
R_{1b}	10kΩ	10kΩ ±5%
R_{2b}	10kΩ	10kΩ ±5%
R_{3b}	13.07kΩ	8.2kΩ ±5%
R_{4b}	10kΩ	10kΩ ±5%

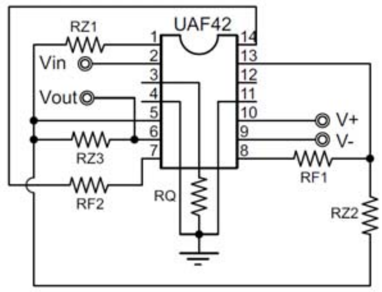

Figure 2: UAF42 as 60Hz-notch filter

In order to calculate Q (quality factor), the equation (6) is used with an adjustment in the resistor R_q, factor that influences the pass-band gain of the filter. This gain needs to be adapted due to the use of the feedback circuit in the amplifier, respecting the equation (7) [13]

$$f_O = 1/(2\pi C R_f) \quad (4)$$

$$R_f = 1/(2\pi C f_O) \quad (5)$$

$$R_Q = 25k\Omega/(Q-1) \quad (6)$$

$$Q = R_{Z3}/R_{Z1} = R_{Z3}/R_{Z2} \quad (7)$$

In which f_o is the value of the central cutoff frequency; R_f, R_q, and R_{zs} (R_{z1}, R_{z2}, and R_{z3}) are the resistors that adjust the cutoff frequency, quality factor and the gain, respectively; C is value of the internal capacitance of the IC and Q is the quality factor of the filter. The constants presented refer to the components of the IC internal circuit and simplifications of the expressions. The values, calculated and used, of the components and of the variables are provided in the Table 2.

Methodology – The circuit was constructed in a printed circuit board supply by 9 V batteries, isolated of the electric mains to avoid measurement interference. Meantime, it was used an acquisition stage consisted of instrumentation amplifier INA128, with gain of 416.67

Table 2: Values of the variable and components, calculated and commercial used, for the Band Stop Filter for UAF42 design.

Variable/ Component	Calculated Value	Commercial/ Real Used Value
Q	6.05	≈ 5.88
R_{f1}	2.65MΩ	2.7MΩ ±5%
R_{f2}	2.65MΩ	2.7MΩ ±5%
R_{z1}	2kΩ	2.2kΩ ±5%
R_{z2}	2kΩ	2.2kΩ ±5%
R_{z3}	12.1kΩ	12kΩ ±5%
R_q	4.99kΩ	4.7kΩ ±5%

with the electrodes in differential configuration. Furthermore, the acquisition stage employs a high pass filter with cutoff frequency of 26.51 Hz to delimit the EMG frequency band.

To perform the first test in the frequency domain, sinusoidal waves were used, with 20mV of amplitude with variation of their frequencies to 10 Hz to 1300 Hz. The points were made by steps of 5 Hz to 10 Hz to 200 Hz - except the range of 40 to 80 Hz, where it was used 1 Hz – and 20 Hz to 200 Hz to 1300 Hz – except the range of 450 Hz to 600 Hz, where it was used 5 Hz. The measurement of the values was done in the output of each filter, using the Agilent DSO-X-2012A oscilloscope.

The second test consisted to insert a simulated EMG signal, in view of the waiting of acceptance from Ethics Committee, with number of CAAE 30162814.5.0000.5547. The simulate signal was obtained by an EMG database [14], PhysioNet, project of physiological signals. This signal contains 0.5 seconds, belonging a healthy person, presented in Figure 3. For simulated, was used the software LabView® and a NIDaQ (Data Acquisition Board). For simulated some effects, the signal was amplified by 10 and was inserted a 60 Hz, corresponding the power-line noise.

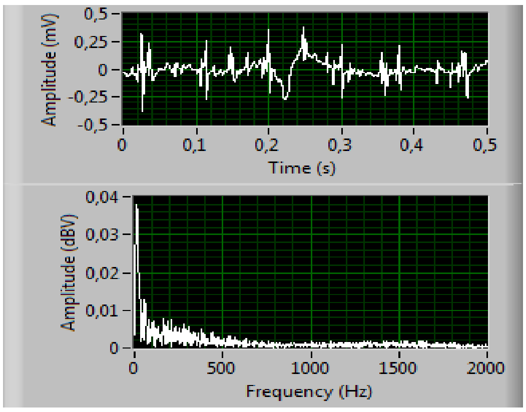

Figure 3: a) Simulated EMG used signal and b) its frequency response

Afterwards, the same test were done in the system presented in the Figure 4. This circuit is compound by three operational amplifiers OPA 4131, with the same amplification system [15].

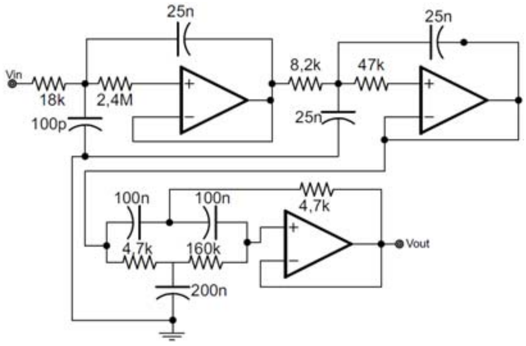

Figure 4: Filtered System for EMG Acquisition

Results

Firstly, Figure 5 exposes the comparison of the responses in frequency domain between the circuit made by operational amplifiers, (dashed curve); and made with IC filters (continuous curve). There are some considerations about them: the circuit using IC has, in the final output, a less attenuation than the (a) in the areas where do not have cutoff frequencies (due to the internal circuits loss), but is more effective than (a) in reaching the cutoff frequency. This fact is linked with the precision of the components. While the components of the circuit in (a) are commercial – and appear to be have good accuracy in the 500 Hz-low-pass filter – its cutoff frequency is in 450 Hz decade, due to the precision of the commercial components; in 500Hz, this system has a gain of -5,1dB.

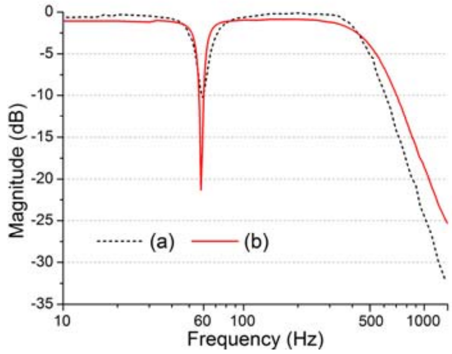

Figure 5: Frequency response by (a) operational amplifiers and (b) IC filtering systems.

In Figure 6, the simulated EMG signal is presented by the outputs of each systems, a) for operational amplifiers and b) for IC filters. The result in Figure 6.b) is inverted in compare to Figure 6.a) due to the inverted output of UAF 42. The amplitude of whole signal for both is 2 V. It is very difficult to see any alterations by this figure, but in Figure 7 is presented the Frequency Response for: a) operational amplifiers and b) IC filters systems. In Figure 7-I, can be seen the attenuation of the high frequencies, above 500 Hz. For the analysis of band stop filter, can be seen in Figure 7-II the attenuation of the signals near the 60 Hz frequency, where the IC filter shows a greater attenuation than operational amplifier filter.

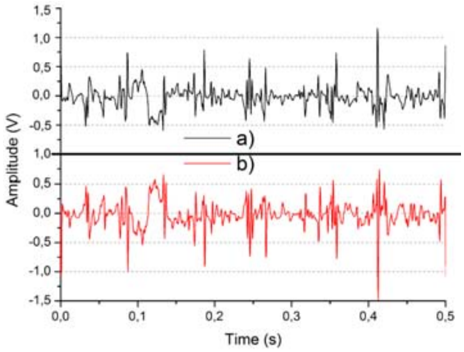

Figure 6: Simulated EMG signal for a) operational amplifiers circuit and b) IC filters.

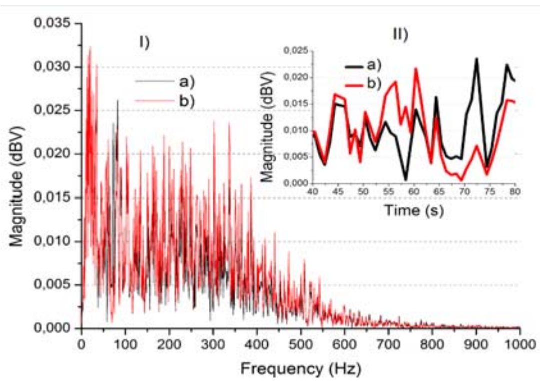

Figure 7: Frequency Response for simulated EMG signal with a) operational amplifiers and b) IC filters systems for I) from 1 to 1 kHz and II) from 40 to 80 Hz.

Discussion

As seen throughout this paper, the system with IC filters shows ease of construction; because, different of the circuit made by operational amplifiers, there are no external passive components, such as capacitors, with regular precision, for this application and commercially. The proposed system can be more accurate if trimpots are used instead of resistors, but it would disperse the proposition of the application. Hence, for the good behavior of these systems, an oscillator circuit must be designed and built. Depending on the frequency, oscillators can be complex, occupying more space on the board and/or injecting noise in the signal. For this circuit, the switching noise is 50 kHz. However, it does not harm the signal as a whole.

Conclusion

Therefore, the circuit presets a good behavior for the application, attenuating the signals for a sEMG conditioning. Future projects will be able to use this filtering circuit in a robotic arm controlled by EMG signals, enabling the accessibility to prostheses in order to help people with special needs.

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