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Design Considerations for Improved Noise Rejection in Surface EMG Systems

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Abstract*: *Bioelectric signals are distorted by unwanted electric noise interference. This paper focuses on techniques that can be applied to surface electromyographic systems design to improve the signal-to-noise ratio. Three case studies are presented in this manuscript: Effects of the front-end instrumentation amplifier gain, use of dc-dc converters for single-supply operation, and dedicated hardware for 60 Hz power line noise rejection. Results show that the quality of the signal is highly improved when the suggested techniques are applied.

Index Terms*: *Electromyography, gain effects, noise rejection, portable.

I. INTRODUCTION

The electronic acquisition of a biomedical surface electromyographic (EMG) signal is contaminated with noise that modifies the information of interest. The real shape of the signal is altered and therefore it is necessary to use signal conditioning electronics to remove interference. A literature review shows that some authors recommend noise reduction at the source via skin preparation and the use of active electrodes. Some noise is always present for which other signal processing techniques such as filtering, noise cancelation and advanced signal processes should be used. Active electrodes reduce the problem of interference pickup of the cables by impedance transformation directly on the electrodes. The output impedance is reduced to less than 1 Ohm, which makes the signal insensitive to interference. High skin-electrode impedance will be prone to power line interference, while the use of very stable electrically Ag-AgCl electrodes are recommended [1].

The electrocardiogram signal (ECG) is considered a noise for myoelectric activity (EMG) and can be cancelled with a Butterworth filter, while another main noise that disturbs the EMG signal is the power line interference (PLI) which is removed with a notch filter. The performance evaluation of the suppression techniques can be done in terms of the signal-to-noise ratio or the mean square error [2].

Characteristics of signal conditioning electronics, such as amplifiers and filters, determine the quality of EMG signals, and capturing the features of these signals for the intended application is a challenge. Studies made of commonly used methodologies for EMG signal processing show that second-order high-pass filters can suppress low frequency noises, and that notch-filters used for the power line interference may cause the loss of useful signal components and degrade the signal-to-noise ratio [3].

As electromyography signals are becoming important in a variety of applications, detection, processing and classification analyses is a necessity. The process of acquisition of EMG signals is prone to background noises received from the presence of electronic equipment and physiological factors. To remove completely the noise is a difficult task, even employing advanced techniques such as the wavelet transform [4].

Software-based filtering techniques are commonly used to clean EMG signals, and although these procedures minimize the interference, they distort the useful components of the target signal. However, hardware-based methods that use shielded drive circuits effectively suppress power line noise and eliminate electrode lead jitter interference [5].

Although the literature analysis shows many noise filtering techniques, improved circuit designs are needed for accurate and reliable EMG signal driven systems.

II. METHODOLOGY

The works reported in this manuscript emphasize three concepts related to EMG signal processing: Gain of the front-end instrumentation amplifier, on-chip dedicated filtering electronics, and dc-dc voltage converters for single supply operation. The instrumentation amplifier INA114 was used at the front-end circuitry and was tested for low and high voltage gains. The power line noise filtering stage was implemented with an Analog Devices LTC1060, which has configurable filter blocks capable of tuning the center frequency with an external clock. For single supply operation, a switched capacitor voltage converter with regulator and optimized efficiency over a wide range of output currents, Linear Technology LT1054, was used. Three Ag/AgCl electrodes were located on the lower arm for differential voltage measurement according to Fig. 1.

An electronic data acquisition system was used to record the signal. A National Instruments USB 6000 in conjunction with a program developed in LabVIEW were employed to save data and display the information.

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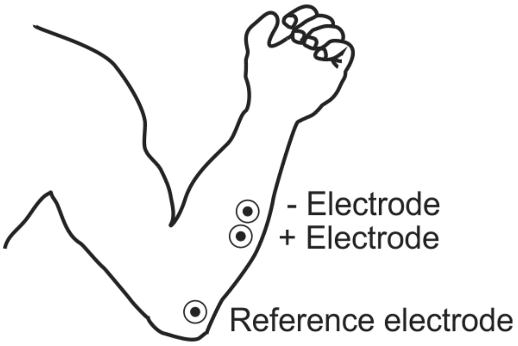

Fig. 1 Electrodes location for surface EMG measurement.

III. ANALYSIS AND DISCUSSION OF RESULTS

A. Front-end instrumentation amplifier gain

Front-end electronics was implemented with Texas Instruments INA114 which amplification gain is controlled with a single external resistor. For this test, electronics consisted of the instrumentation amplifier, a low-pass filter and an output amplification stage. Two cases were studied: a) Low voltage gain value of 51 for the INA114, b) High voltage gain value of 610 for the INA114. Figs. (2), (3) show that interference noise is more evident for low voltage gains, making difficult to recognize the EMG signal. The signal in these figures corresponds to the hand opening and closing actions.

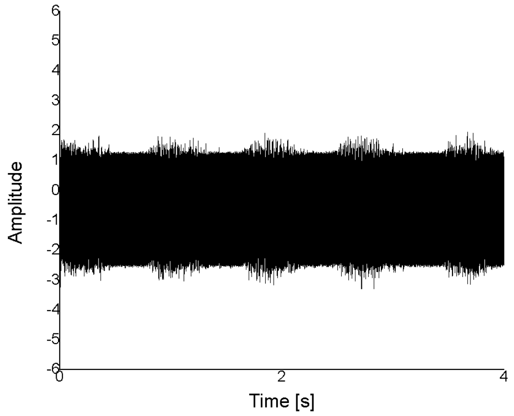

Fig. 2 Noisy signal for low-gain front-end amplification.

B. Power-line noise rejection with on-chip filter blocks

Dedicated signal filtering electronics is available for various applications. For this project the LTC1060 was selected, since it has built-in filter blocks with a center frequency that is tuned with an external clock. Fig. 4 shows the design implemented as a notch filter tuned to a frequency of 60 Hz.

After this stage was added to the design, the signal was recorded and processed. Fig. 5 shows the signal spectrum where the power line interference noise is clearly present. In contrast, the spectrum of the signal after the notch filter is shown in Fig. 6, where the interference noise is unrecognizable in the EMG power spectrum.

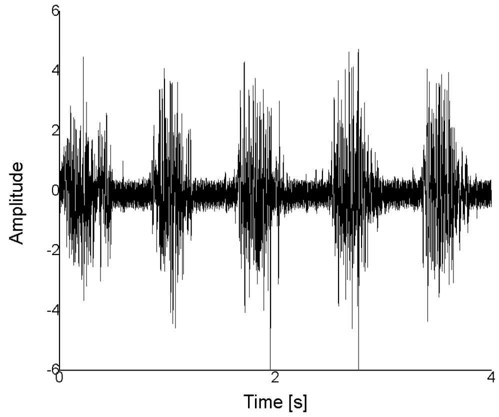

Fig. 3 Signal improvement with high-gain front-end instrumentation amplifier.

An anti-alias filter is necessary because the DC-DC conversion circuit is a switched capacitor converter, that in combination with the analog to digital conversion process, produces a signal spectrum rich in high frequency alias components as shown in Fig. 7.

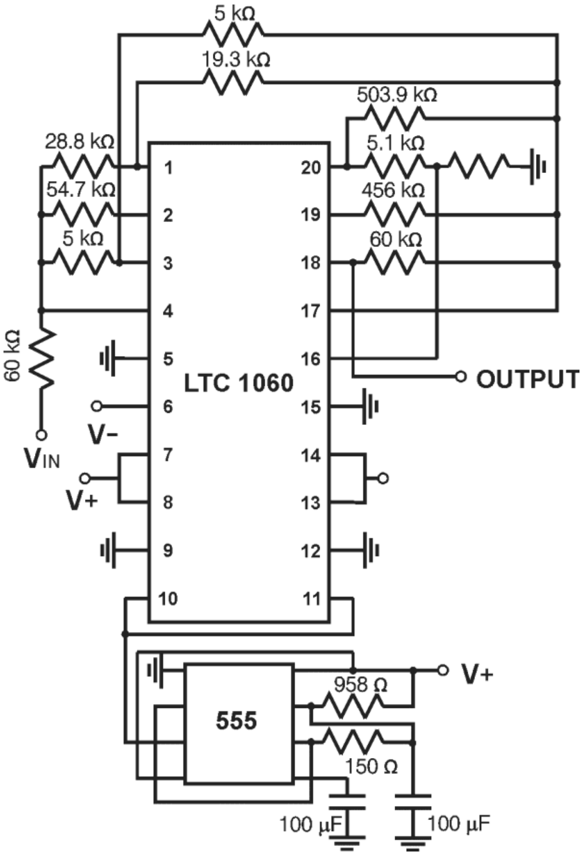

Fig. 4 On-chip configurable filter blocks

C. Optimized EMG system

Fig. 8 shows the signal obtained with the optimized design. Two patterns can be identified. The first pattern, from 0-3 seconds, characterized by discrete rhythmic positive and negative spikes, corresponds to the heartbeat.

The second pattern, from 3-6 seconds, corresponds to the surface EMG signal obtained when opening and closing the hand.

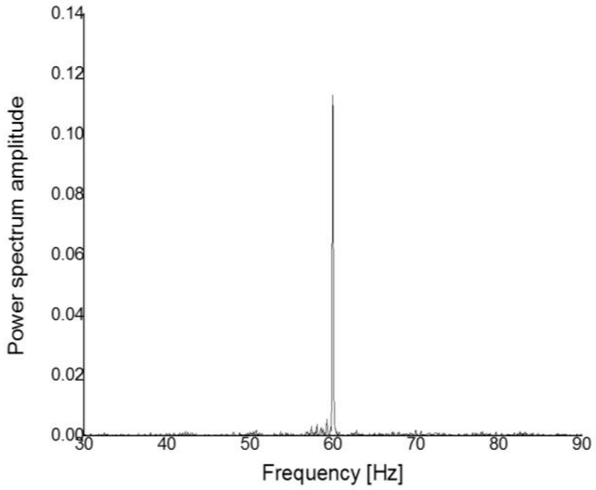

Fig. 5 Power line signal interference.

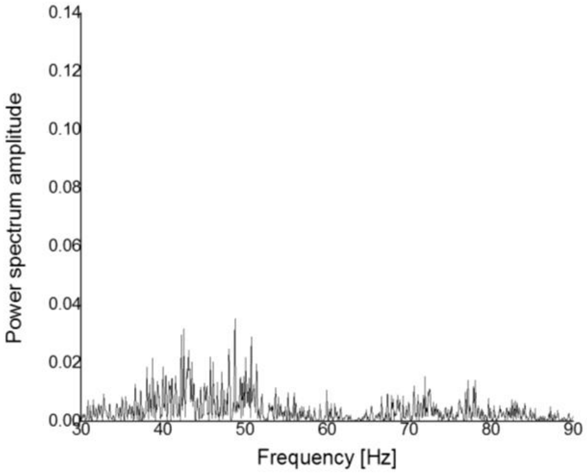

Fig. 6 EMG signal with power-line noise suppressed.

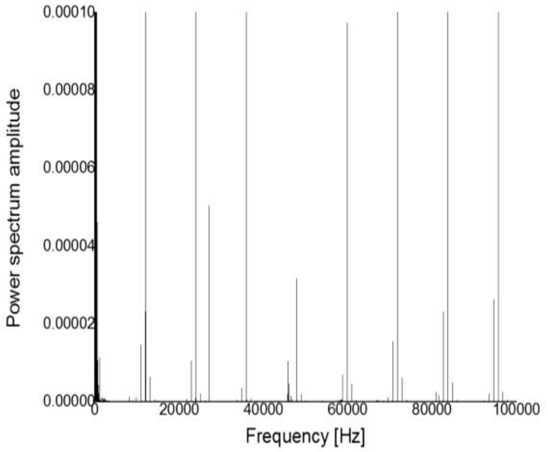

Fig. 7 EMG signal with aliasing.

A few reports in the literature make reference to the appearance of the heart signal from EMG surface measurements.

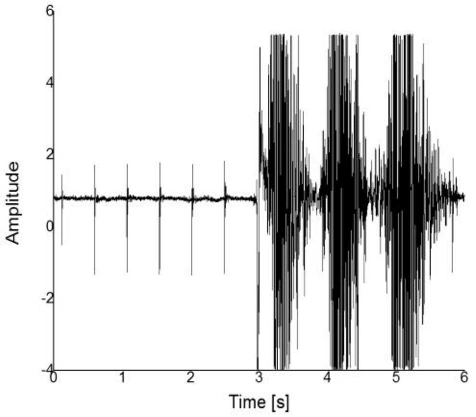

Fig. 8 Signals recorded with the optimized system where EMG and ECG biopotentials are present.

The schematics of the design for the optimized noise rejection system is shown in Fig. 9. The differential output voltage of the electrodes is connected to a high-gain instrumentation amplifier, followed by a high-pass RC filter and a second amplifying stage. The output is then coupled to the notch filter, with the center frequency tuned by an astable 555 timer. The output of this circuit is then connected to an anti-alias filter. Single supply operation is accomplished with a DC-DC converter that inverts the positive supply voltage and provides the negative voltages necessary for the correct operation of the circuits.

IV. CONCLUSION

Engineers have the option of using specialized chips in biomedical electronics design or implementing the functional blocks of the design from basic conditioning components such as operational amplifiers. This paper reported the application of specialized on-chip electronics for power line noise filtering with improved results.

On the other hand, it was found that the voltage gain of the front-end instrumentation amplifier plays an important role in obtaining a signal with attenuated interference. Additionally, when using DC-DC converters for single supply operation, a spectrum rich in high frequency components is obtained, for which the anti-alias filter is mandatory. Finally, the proposed design was able to detect the heart beat signal, which is similar to an ECG biopotential.

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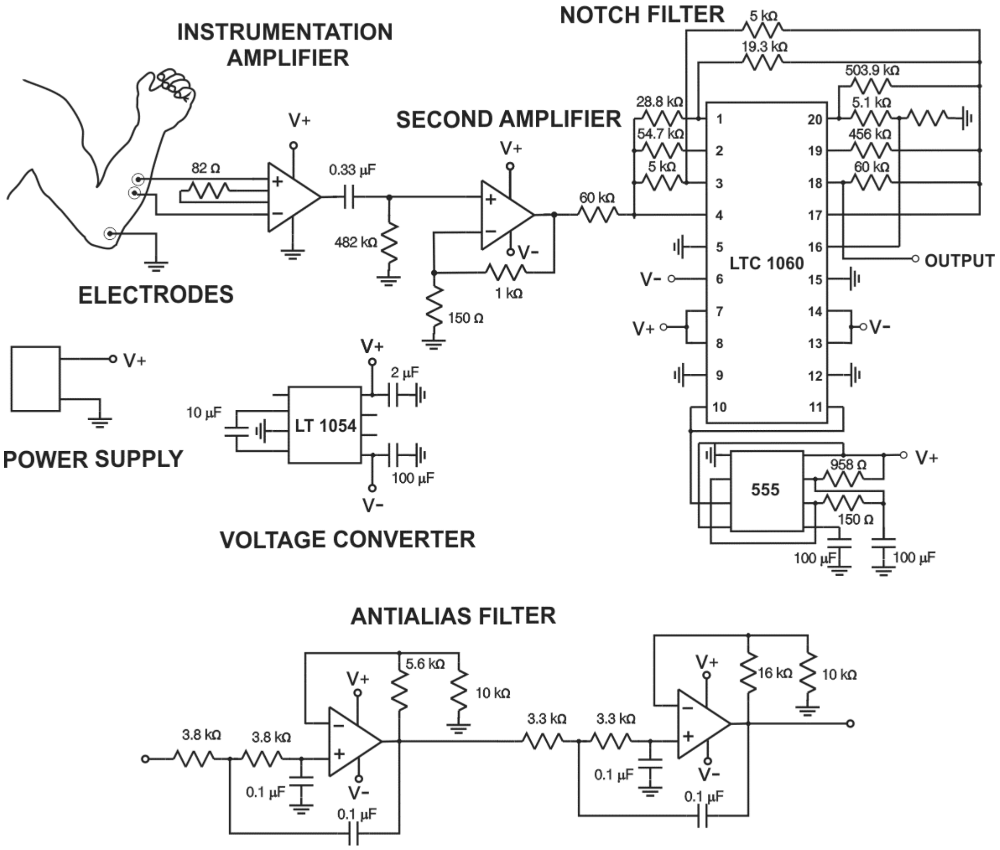

Fig. 9 Schematic circuit of the improved EMG system.

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Eduardo Rubio received his PhD and MS degrees in Energy from the Universidad Nacional Autónoma de México (UNAM) in 2002 and 1996 respectively, and Engineering degree in Communications and Electronics from the Instituto Politécnico Nacional (IPN) in 1996. Currently, he is a research professor at the Universidad Autónoma de Aguascalientes (UAA). His current interests include basic research in solar thermal systems, and technology research for industry.

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