

High integrated analog front-end device for measurement of evoked myoelectric signals during electrical stimulation

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Abstract

During FES myoelectric signals (M-wave) are often used for muscle monitoring. Usually sophisticated multi-stage amplifier circuitry is used to measure the small electric muscle signals in the presence of the strong stimulation pulses.

A new approach from the point of circuit design is offered by the new highly integrated, especially for bio signals developed analogue front-end device ADS1298 of Texas Instruments Inc. (Dallas TX, USA). This integrated circuit includes all analogue components and a 24 bit analog to digital converter. The major advantages of the device low analogue amplification and high resolution A/D conversion are that neither amplifier saturation occurs due to stimulation artifacts nor due to electrode potential. Hence full DC coupling is possible.

An EMG amplifier was designed, built and tested when measuring the electrically evoked myoelectric signals of the anterior thigh muscles.

The front-end device is capable of measuring M-wave following electric stimuli without disturbance of the stimulation artifact. This high resolution bio-signal front end offers new possibilities in detection of electric muscle activity even in the presence of high voltage stimulation impulses. The ADS1298 is especially suitable for battery powered portable devices because of low power consumption and small package size.

Keywords: M-wave, EMG, amplifier, biomedical instrumentation, stimulation artifact

Introduction

The detection of surface myoelectric signals during electrical stimulation allows assessment of the peripheral properties of the neuromuscular system [1]. Common acquisition systems of myoelectric signals are based on a differential amplifier, a filter chain and an analog-digital converter [2]. Texas Instruments Inc. (Dallas TX, USA) introduced the ADS1298 [3], a fully integrated eight channel analog front-end device for bio-electrical signal acquisition. In a basic EMG detection application the ADS1298 is tested during surface measurements of electrically evoked myoelectric signals (M-wave).

Material and Method

Front-end device

The ADS1298 chip is capable to convert eight input channels simultaneously up to 32 000 samples per second (S/s) for each channel. Every channel has 24 bit resolution and an individual gain setting, ranging from 1 to 12. The highest resolution is only provided up to a sampling frequency of 8 kS/s per channel, it decreases to 17 bit at 16 kS/s and 32 kS/s. The chip requires a

single supply voltage, ranging from 2.8V to 5.25V, whereas the common-mode rejection ratio of 115dB is guaranteed for input signals by 300mV reduced supply range. Using a serial peripheral interface bus (SPI) the device can be configured by a microcontroller [4]. The bandwidth of the acquired data has, according to Nyquist-Shannon theorem a range from DC to half of the sampling frequency.

Hardware design

The new designed bio-signal amplifier was based on three main elements - a microcontroller, digital isolators and the front-end device (Fig. 1). A PIC24F microcontroller (Microchip Technology Inc., Chandler, AZ, USA) was connected with a SPI to the ADS1298. The main task of the

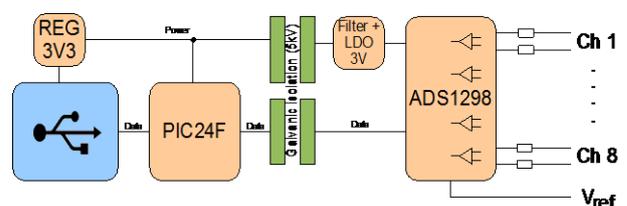


Figure 1: Simplified schematic of the biosignal-amplifier.

microcontroller was to configure the AD1298 and to transmit the sampled values to a personal computer via the universal serial bus (USB) data link. The USB connection additionally provides the power supply for the whole printed circuit board. For patient safety and to avoid ground loops, the AD1298 and all related peripherals were galvanic decoupled according to the safety and regulatory requirements for medical devices by a circuitry with 5kV isolation voltage.

ADS1298 test measurement set up

All input channels were shorted and grounded during noise and power measurements. Different settings of the ADS1298 were chosen by the microcontroller firmware.

M-wave measurement set up

Healthy subjects received electrical stimulation of the anterior thigh muscle group via large stimulation electrodes (STIMEX self-adhesive electrodes, 80 x 130 mm). Single biphasic, charge balanced stimulation impulses with a width of $2 \times 500 \mu\text{s}$ were used to evoke muscle twitch and related M-wave response. The evoked myoelectric signal was measured at the rectus femoris with EMG electrodes (SKINTACT FS-50 electrodes, Pre-Gel Ag/AgCl, round, 50mm). Those electrodes were placed between the stimulation electrodes, transversally oriented in respect to the stimulation electrodes and the fiber orientation of the rectus femoris muscle to minimize stimulation artifacts.

The ADS1298 was set to a gain of 12 and a sampling rate of 8 kS/s. Hence, the full-scale input range was $\pm 200\text{mV}$. No additional filters were applied.

Data acquisition

PC-Software was used to receive the binary data stream from USB and wrote it in a Matlab (MathWorks, Natick, MA, USA) compatible

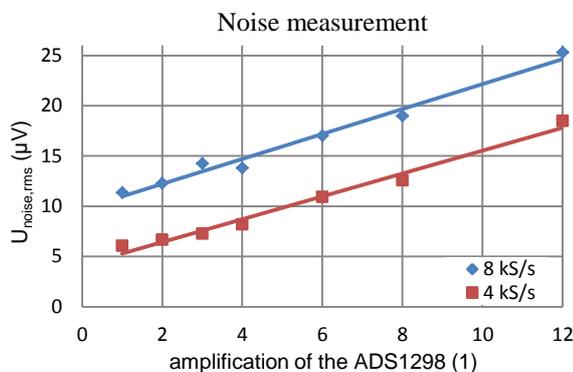


Figure 2: Root mean square value of the amplifier noise. ($U_{\text{noise,rms}}$) at different gain settings and sampling frequency.

format to a file. Matlab was finally used for data post-processing and visualization.

Results

ADS1298 test results

The ADS1298 had an average base power consumption of 3.27 mW. When the input channels were enabled the consumption increased by 0.95 mW per channel up to 10.95 mW with all channels activated (Tab. 1)

Table 1: Supply power at 3.3V supply voltage

Number of channels	Sampling rate		
	4 kS/s	8 kS/s	16 kS/s
0	3,27 mW	3,27 mW	3,30 mW
1	4,26 mW	4,26 mW	4,26 mW
2	5,18 mW	5,18 mW	5,18 mW
4	7,10 mW	7,13 mW	7,13 mW
8	10,86 mW	10,89 mW	10,92 mW

Due to the internal operation of the ADS1298, the desired sample frequency had nearly no influence on the total power consumption. It varied less than 3% from 500 Hz (10.69 mW) to 32 kHz (10.96 mW) with all channels enabled.

The sampling frequency had an influence on the

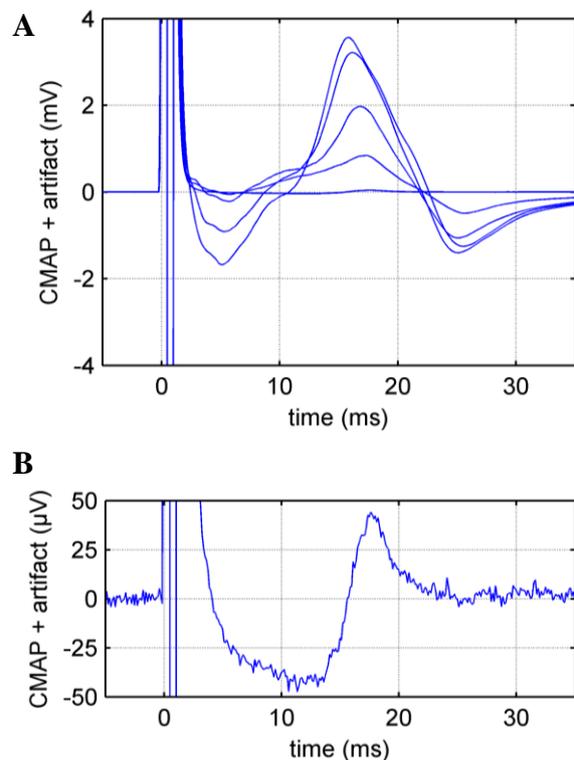


Figure 3: (A) Compound muscle action potential (CMAP) at different biphasic stimulation amplitudes ($\pm 10\text{V}$, $\pm 15\text{V}$, $\pm 20\text{V}$, $\pm 25\text{V}$ and $\pm 30\text{V}$), pulse width = $2 \times 500 \mu\text{s}$. Sampling rate: 8kS/s, gain = 12; (B) CMAP at a stimulation amplitude of $\pm 10\text{V}$

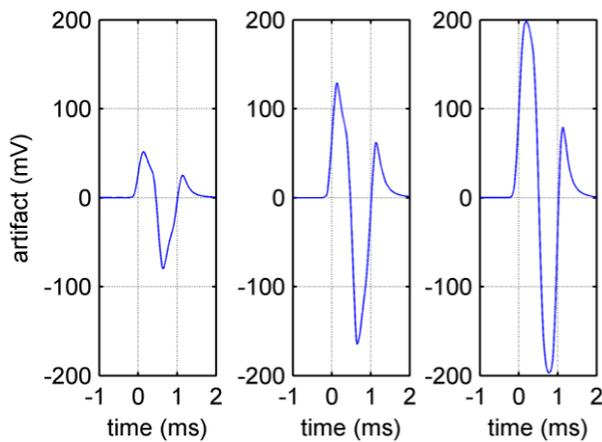


Figure 4: Stimulation artifact @ stimulation amplitudes of $\pm 10\text{V}$ (left), $\pm 30\text{V}$ (middle) and $\pm 50\text{V}$ (right). Pulse width = $2 \times 500\mu\text{s}$

measured noise floor. The root mean square of the noise ($U_{\text{noise,rms}}$) increased with the sampling frequency and also with higher amplifications (Fig. 2).

Evoked myoelectric signals

The results of Figure 3 showed M-waves at different stimulation amplitudes, from ± 10 to $\pm 30\text{V}$, in 5V steps. Even evoked potentials caused by small activation levels can be recognized (Fig. 3B).

Stimulation artifact

The stimulation artifact was a large interference to M-wave measurements and can cause latch-up effects in the analog front-end. The used setting allows the measurement of the complete stimulation artifact, up to $\pm 50\text{V}$ stimulation impulses without any saturation effects. (Figure 4)

Discussion

The ADS1298 is a high integrated front-end device with a small package size down to $8 \times 8\text{ mm}$. It is designed especially to measure bioelectric-signals and has additional built in modules specially designed for measurements of the ECG and EEG [5]. A very handy feature is that not properly attached electrodes and leads can be detected.

The high resolution of 24bits ($\sim 300\text{nV/LSB}$) and the wide full-scale range of $\pm 2.4\text{V}$ provide the possibility to omit multiple amplifier stages and analogue filter and keep the circuitry small.

The ADS1298 has low power consumption (up to 12mW) at high sampling rates. The largest part of the overall power consumption of the introduced device is from the PIC24F (60 to 80mW).

The analogue front-end (ADS 1298) must be configured by a microcontroller which additionally provides an interface to a PC via USB. At the highest full resolution sample-rate (8 kS/s) the data-rates increase to 187.5 kByte/sec . The computation of such a large amount of data has to be handled by an adequate microcontroller resulting in the mentioned power consumption of 80 mW .

The presented circuit is powered from the PC's USB port and has no need for an external medical power supply due to the galvanic decoupling circuitry. In the used configuration, the EMG sensing leads can be directly attached to the stimulator output without causing any device damage because an external series resistor of $20\text{ k}\Omega$ extends the ADS1298 internal protection circuitry beyond stimulation levels.

Conclusions

The presented front-end device, ADS1298, is a versatile component for M-wave acquisition. The small size of the chip, the low supply voltage and low power consumption make it especially suitable for small, battery powered, portable solutions.

References

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