DOI 10.5162/sensor2015/C5.2

Implantable EMG measuring system

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Abstract

The development of a multi-channel, implantable EMG measuring system is presented. The system integrates an application specific integrated circuit for EMG acquisition. Inductive coupling is used to supply the ASIC, an ARM Cortex-M4 microcontroller and a wireless data transmission in conformity with the medical implant communication service. Additional monitoring functions like electrode resistance, temperature and humidity measurement are implemented to monitor the reliability of the system. The implant is projected to control hand prostheses by EMG monitoring.

Key words: Application specific integrated circuit (ASIC), Electromyography (EMG), Implantable device, Prostheses

Introduction

Cosmetic or active replacementes are crucial for patients to overcome their trauma and to restore some of the funtionalities after the loss of the natural hand.

Conventional active hand prostheses are typically controlled by electromyogenic signals recorded with surface electrodes from the residual limb muscles. These artificial hands provide only one or two degrees of freedom (DoFs) and, therefore, a limited functionality and dexterity. The patients learn rapidly to generate efferent motor commands and the decoding works with an acceptable accuracy and reliability. Despite these efforts, the control of the system does not reflect the original movement patterns and, therefore, does not act in a physiological way.

The development of a new generation of intuitively mind-controlled prostheses is an ongoing field of research. This approach allows improving the control interface towards the behavior of a real part of the body by two major strategies: i) Extracting a higher functional density by increasing the number as well as the selectivity of the recording electrodes. ii) Integrating a sensory feedback as a sensation to the user that gives him a natural perception when touching or grasping objects with his artificial hand.

This research direction is inspired by bionic approaches and was followed in several recent projects. [1] describes the first long-term human application (26 days) of four electrodes systems for bidirectional control of a hand prosthesis system, including sensory feedback. The system recorded the motor information with thin film microelectrodes, longitudinally implanted in peripheral nerves. The sensory feedback was applied as an electrical stimulation of the nerves as well. Other electrode gemometries and implantation methods were successfully evaluated in the meantime [2].

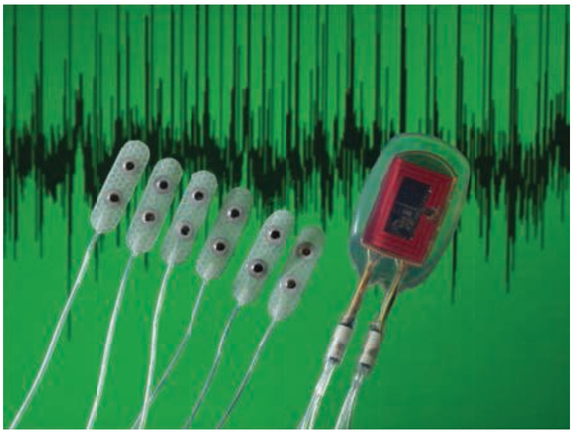

Fig. 1. Fully implantable multichannel prosthesis control with intramuscular recording electrodes (© Fraunhofer IBMT)

Further approaches use invasively recorded myogenic activity to extract the motor intention. These signals have a lower selectivity but a higher signal-to-noise ratio in comparison to the nerve signal. In [3], flexible electrodes were fixed sub-epimysially in a primate on the delta, triceps and biceps muscles. An active intelligent implant, as shown in Fig. 1, processed 4 channels of raw data by an integrated amplifer and transferred the information wirelessly using the medical implant communication service (MICS) band. Reliable recognition of a set of arm movements was achieved and it was shown that this system is suitable for applications requiring continuous force decoding such as advanced forelimb prosthetic devices with multiple degrees of freedom [4].

This paper presents a new approach of a multi channel, fully implantable recording system to detect and process muscle activity in order to intuetively control prostheses with a higher number of DoFs.

Material and Methods

The design and development of an implantable system has to include many different aspects. The limited space and low-power consumption requirements force to co-engineer the package, the printed circuit board (PCB), the interconnections, power supply and the measurement application specific integrated circuit (ASIC). The PCB has to be adapted for round corners and mill outs in order to fit into the bio-compatible titan package. An 8-layer PCB with micro vias, below 100 µm line spacing and an overall thickness of only 800µm is required to integrate all components. Chip size packages and chip-on-board mounting technology are two additional ways, which are applied to save board space.

Results

System architecture

The electronic heart of the implantable device is a printed circuit board, which carries and interconnects the different components. The main devices and interconnections are shown in Fig. 2.

Eight differential recording channels are used for EMG measurement, which are connected to an ASIC. The ASIC includes the analog pre-processing and passes the analog sampled data in a time-multiplexed fashion to an analog to digital converter (ADC). The ADC is integrated with the microcontroller.

This approach allows implementing an energy efficient acquisition system as the integrated ADC can be served by a direct memory access (DMA) controller. An RF transmitter, which is conform to the medical implant communication service is used for data transmission. The transmission bandwidth is limited to approx. 600 kbits/s, which forces the implementation of signal processing within the microcontroller unit (MCU). Therefore, a cortex-M4 MCU, which provides DSP functionality is selected for this development. The latency of the EMG monitoring system, consisting of analog signal procession, conversion, digital signal processing, data transmission and prosthesis action has to be limited to approx. 120 ms to allow interaction like a real hand.

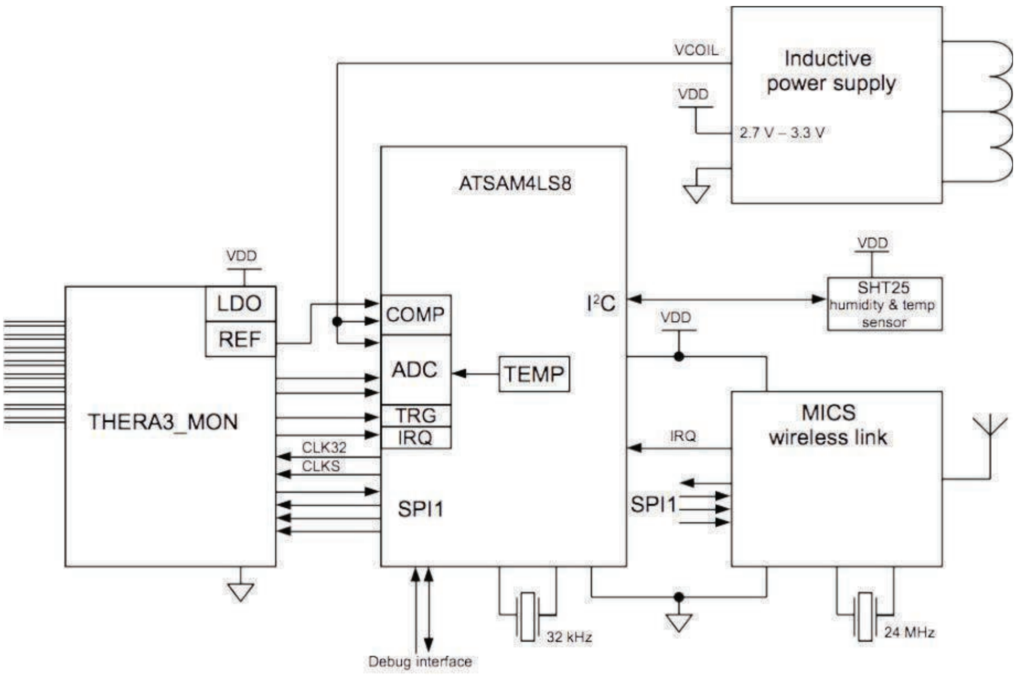

Fig.2. Simplified schematic of the implantable system

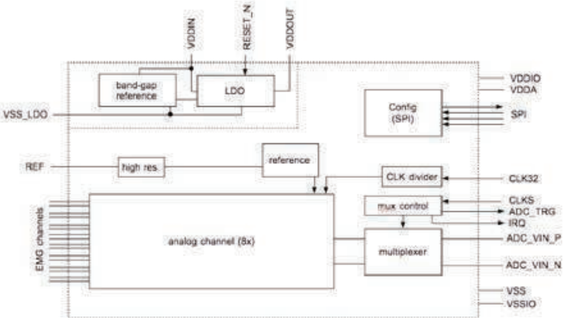

Fig. 3. Block diagram of the EMG monitoring ASIC

An external unit, which is embedded in the prosthesis, supplies the power across an inductive link. The power consumption of the internal device has to be minimized to extent the battery lifetime of the system. On one hand, the system is designed to monitor the current coil voltage. This allows the adaptation of the transmitted energy of the external unit to the current power consumption of the implantable device. On the other hand, the power consumption of the RF communication is the major contributor within this implantable device. Therefore, one focus of the development is to reduce the amount of data, which need to be transmitted. Different data compression algorithm will be evaluated for EMG data within the project.

EMG monitoring ASIC

The ASIC includes the analog frontend of eight differential EMG channels. The configuration interface and a linear voltage regulator are integrated. The block diagram of this circuit is shown in Fig. 3.

The analog channel consists of several amplification and filtering stages as shown in Fig. 4. The first stage implements a capacitive coupled feedback amplifier. The high pass frequency response of this stage exhibits a mid frequency gain of 34 dB relieving noise requirements of the following stages and hence reducing the power consumption. The lower cut-off frequency of the amplifier is set to 1 Hz and can be switched to 1 kHz for fast recovery. The low pass filter following the first stage provides selectable gain and limits the frontend bandwidth to 1 kHz, thus avoiding noise folding at subsequent sampling stages. The feedback of the first order filter is realized with a switched capacitor (SC) pseudo resistor and an integration capacitor. Therefore, the cut-off frequency is defined by capacitor ratios. The full-scale input range can vary from tens of millivolts to hundreds of microvolts. Convenient additional gain risks to saturate the frontend as the signal spectrum may contain power line interferences at 50 Hz or 60 Hz. The SC band pass filter isolates the power line interferences components. The last stage of the frontend consists of a SC adder (not shown in Fig. 4) with selectable gain, which is used to time multiplex the eight analog channels. The multiplexer combines the outputs of the band pass and low pass thus realizing a notch filter.

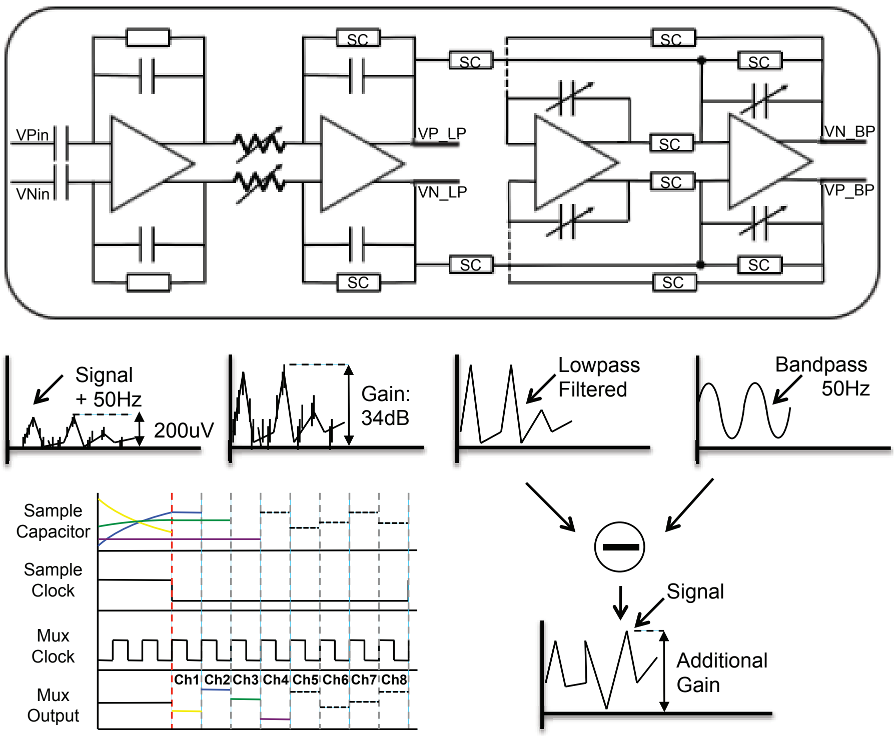

Fig. 4. Integrated analog EMG signal processing

The time multiplexed differential output signal, as shown in Fig. 4, is passed to the MCU together with an ADC trigger signal.

The performance parameters of the EMG monitoring ASIC are listed in Table 1.

Tab. 1: ASIC performance parameter

Symbol	Description	Value
f_{C_LOW}	Lower cut-off freq.	<1 Hz
f_{C_UP}	Upper cut-off freq.	1 kHz
f_{SAMPLE}	Sampling rate	5 kS/s
V_{N_RMS}	Input referred noise	<2 µV_{RMS}
A	System gain (programmable)	50 – 1000
CMRR	Common mode rejection ratio	120 dB
f_{NOTCH}	Notch filter frequency (programmable)	50 Hz 60 Hz

Monitoring the reliability

On one hand, monitoring the reliability of an implantable system is important to prevent any risk for the user. On the other hand, as the replacement of an implantable device should be avoided, it is required to detect the current functional status from external.

The presented device includes temperature and humidity sensors. The temperature sensor allows the adaption of the processing power of the device and to monitor the injection of heat due to the energy transmission. In this way, a temperature increase on more than 2 °C is prevented. The humidity sensor is added to the system to monitor the state of the encapsulation. Any increase of humidity during storage or after implantation is detected and countermeasures will be started to avoid risks for the user.

Beside these essential protection functions, the system includes also electrode resistance monitoring. This allows detecting the current electrode status after implantation as well as to adapt the system configuration during the time of use.

Summary and outlook

This paper presented an implantable EMG acquisition system, which is intended to control hand prostheses. An application specific integrated circuit is designed for this purpose, which interacts closely with the microcontroller unit. Additional monitoring functions are provided to ensure safety. The integrated voltage monitoring of the power supplying inductive link allows the adaption of the external power transmission unit. The current measurement data are transmitted to an external receiver using the MICS band.

The used platform approach enables the fast adaption of the system to other signal characteristics and extended functionality like integrated digital signal processing, additional sensors, and alternative wireless transmission interfaces.

As a further improvement, a four channel integrated stimulator will supplement the system in order to provide a sensory feedback to the patient by stimulating the amputee’s afferent pathways. After the integration into a hermetic encapsulation, a closed-loop controlled prosthesis system will be achieved for the first time as single integrated active implanted device.

Acknowledgment

This work is supported by the Fraunhofer Leitprojekt “Theranostische Implantate”

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