A highly parallelizable signal conditioning module dedicated to cortical implantable monitoring devices

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Abstract

We present a low-power analog signal conditioning system intended for cortical data recording. Using Chopper modulation enhances recording quality and decreases integrated devices sizes, making this implementation suitable for highly parallelized monitoring systems. Low-power design techniques allows the proposed conditioning module to acquire neural signals from a few Hz to 7kHz while meeting power consumption and input noise requirements. The proposed signals acquisition module, implemented in 0.18µm CMOS process, achieves power consumption below 20µW and occupies only 0.0705 mm² of chip area.

1 Introduction

Neurophysiology has explored multiunit recording since a few years in accordance with neural assemblies coding assumptions. Researchers have combined electronic circuits with micromachined multielectrodes arrays to increase the recording quality, the spatial resolution of measurements and the experimental apparatus stability. The needs for new experimentations and novel prosthetic devices, as Brain Computer Interface (BCI), is now carrying out researches towards the implementation of more recording channels, leading to more power efficient and smaller circuits. However, recording quality is of major concerns for neural recording and must not be neglected. Most neural recording systems are composed of a single high gain amplifier prior to analog-to-digital (A/D) conversion. This approach may be too sensitive to electromagnetic interference (EMI) and may have poor signal-to-noise ratio (SNR). We present a complete analog conditioning module suitable for highly parallel integration into an implantable multichannel system, which could be used for simultaneous monitoring of several cells in the visual cortex areas, as depicted on figure 1. The conditioning path includes a preamplifier, filters and a gain amplifier.

Figure 1: Implantable recording devices for simultaneous monitoring in several cortex areas.

2 Methods

CMOS process is well suited for implantable medical instrumentation devices such as cortex monitoring systems because of high input impedance of MOSFETs and their low power consumption. However, CMOS suffer from higher inherent noise than other processes as bipolar. Thermal noise and low frequency noise are dominant noise sources in MOS transistors. The $1/f$ noise in transistors is mostly related to their sizes. Thus, area consuming devices must be used to implement the input stage of low-noise amplifiers. Consequently, this imposes serious limits on the number of channels that could be integrated for recording. The Thermal noise must also be carefully considered since higher DC bias currents must be used to keep it low, draining an important amount of power. The trade off between noise, power consumption and circuits sizes is efficiently addressed in this design by usage of Chopper modulation [1]. This method is used to reduce low frequency noise inherent to CMOS devices and decrease the circuits size, as it will be shown later.
3 Chopper modulated conditioning devices

Figure 2 shows a block diagram of the Chopper modulated conditioning module. Fig. 3 presents the output signal of each block when a low amplitude sine wave is conditioned by the module. The Chopper frequency ($f_{chop}$) is set to 20kHz. A More detailed description of each block can be found in [1].

4 Highly parallelized monitoring devices

A complete multichannel monitoring device is depicted on figure 4. The performances reached by the conditioning module allow 32 channels devices, consuming less than 1mW and stand within 2.5mm$^2$ of chip area. The neural signals are transferred from the implantable device using percutaneous hard wired connections or Radio Frequency (RF). Additional circuits as voltage rectifier and regulators are required for RF energy transfer. Bidirectional transmission is desirable for system configuration, to set analog parameters, as gain or bandwidth, and digital parameters, as transfer rate, sampling frequency or channel activation/deactivation. A serial data transfer link is used to decrease the number of percutaneous wires, requiring fast serial bus connection. The Universal Serial Bus (USB) is efficient and convenient for serial data transfer. A transfer rate of 1Mbytes/s is allowed with USB1.0 and may be extend to more than 20Mbyte/s with USB2.0. USB also provides the whole acquisition system to be portable. USB1.0 allows 32 channels with 30kHz sampling rate per port.

5 Acquisition software

Custom software is used for data storage management and visualisation. Data analysis and signal processing methods may be embedded in the software or done with dedicated Matlab toolboxes such as presented in [2]. Signal processing needed prior to analysis may involve tasks such as spikes sorting and denoising. Its goal is to construct reliable spikes trains for further analysis. Also, the software must manage bidirectional data transfer. Multiport data transfer is supported by the software. The transferred data may then be distributed over a few USB ports to increase the throughput. The software under development allow data visualization, data reconstruction and data storage. The neural data can be saved to ASCII format or to Matlab format for further processing and analysis. Fig. 5 shows the graphical user interface of the implemented software.
6 Results

Figure 6 shows the Chopper modulated module efficiency to reduce $1/f$ noise induced in the preamplifier from a Power Spectral Density (PSD) perspective.

Figure 5: Low frequency Noise removal (PSD).

Also, results shown on fig. 7 are in accordance with the theoretical analysis made in [3]. Chopper modulation does not increase the input thermal noise, which can come from the microprobe itself or the biological environment, as sampling circuit does.

Figure 6: Input and output thermal noise.

Tables 1, 2, 3, 4 and 5 summarise the main characteristics of the analog conditioning modules. Two channels of the system have been implemented with CMOS 0.18µm process for testing and characterization. The size of a conditioning channel is 0.0705mm$^2$, which is smaller than other known implementations (Table 6).

7 Discussion and Conclusions

A complete low-power neural signal conditioning module has been presented. The module meets the requirements for massive parallelization needed to implement multichannel monitoring devices. Having fully implantable monitoring systems would be of great help for in-vivo experimentations and the presented module is suitable for such application. However, the bit rate reached by actual Radio Frequency (RF) data transfer systems is one important bottleneck encountered for implementation of such devices. Load Shift Keying (LSK) used for several biotelemetry applications now enable transfer rates ranging from 1 to 2Mbps, limiting simultaneous recording to a few channels with sufficient sampling rate. Being able to send only useful data, based on on-chip event detection could be an interesting approach for bandwidth enhancement.

References


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