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The challenge of analog mix-mode integrated circuit design for brain computer interface

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Abstract —*The requirement of IC for the brain computer interface (BCI) is discussed. An analog-digital mixmode IC used for cochlear implant is designed using CMOS process*[1].

Index Terms — low power IC, brain computer interface, brain machine interface.

I. INTRODUCTION

The technical system that provides real-time direct communication between brain and electronic or mechanical devices is addressed as brain computer interface (BCI). In this case the traditional ways of communication such as speech and motoric output are not used, instead, signal from the brain activity itself is directly transmitted from the brain to the external world. BCI one day will be used to restore sensory and motor functions lost through injury or disease. A BCI also have the potential to enhance human perceptual, motor and cognitive capabilities by revolutionizing the way we use computers and interact with remote environments [1].

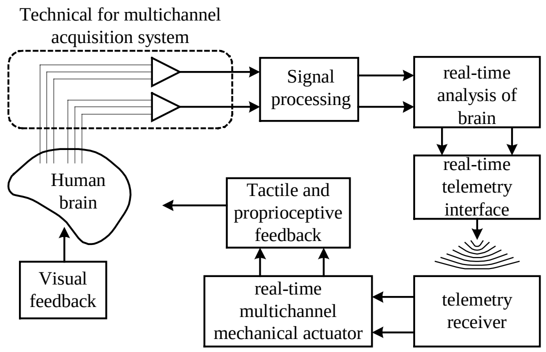

Figure 1 Schematic description of the organization of a BCI

There are two types of BCIs based on two main types of application. The first type of BCI can artificially generate electrical signal to stimulate brain tissue in order to transmit some particular type of sensory information or to mimic a particular neurological function, for example, an auditory prosthesis. The future applications will aim at restoring other sensory functions, such as vision, by stimulating at specific brain areas. To alleviate pain, to control motor disorders such as Parkinson 's disease, and to reduce epileptic activity by stimulation of cranial nerves also belong to the fist type of BCI. The second type of BCI relies on the real-time sampling and processing of large-scale brain activity to control artificial devices. An example of this application would be the use of neural signals derived from the motor cortex to control the movements of a prosthetic robotic arm in real time. Figure 1 is the schematic description of the organization of a BCI with the application to restore different aspects of motor function in patients with severe body paralysis. Obviously, clinical applications that require reciprocal interaction between the brain and artificial devices will combine both types of BCIs.

II. THE IMPLEMENTATION OF BCI

The implementation of a BCI will involve the combined efforts of many areas of research, such as neuroscience, computer science, biomedical engineering, VLSI design and robotics. From the viewpoint of IC design, when design a BCI illustrated in Figure 1, the first step involves the selection of a technique that yields reliable, stable and long-term recordings of brain activity that can be used as control signals to drive an artificial device. The applications of such BCI will probably require sampling of large numbers of neurons (in the order of hundreds or thousands) with a temporal resolution of 10–100 ms[2,3]. This require an advanced MEMS and IC technologies for the design and fabrication of multielectrode array and neural signal instrumentation to increase the number of neurons that can be recorded simultaneously. Figure 2 is a demonstration of an active probe that integrates stimulating/recoding sites and signal processing circuits on a single subtract.

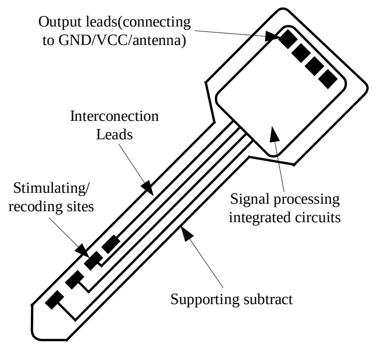

Figure 2 An active probe using MEMS/IC technologies

Another important issue is to achieve a seamless interaction between the prosthetic devices and the brain. Patients will have to receive sensory feedback information (for example visual or tactile signals) from the prosthetic limbs. These feedback signals will establish a closed control loop between the brain and artificial devices and will probably help patients learn how to operate BCI. The building blocks to set up a communication channel between the brain and the prosthetic device is sketched in Figure 3.

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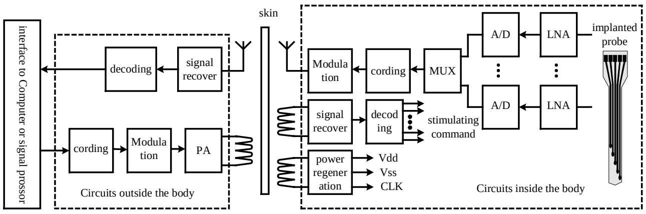


Figure 2 Schematic description of the components interface between the prosthetic devices and the brain

The research topic for the communication between brain and external world include theory and design technologies for the very low power CMOS integrated circuits(E.g. Adiabatic CMOS circuit), low voltage and low power amplifier, low voltage and low power A/D convertor, low voltage and low power RF IC

RF transceiver, digital communication in the biologic environment inside creature tissue, wireless power transmission, etc.

III. AUDITORY PROSTHESES

Auditory prosthesis [4], which is considered as the first BCI, works by converting features of acoustic signals, such as speech, into patterns of electrical stimuli that are then delivered through an array of chronically implanted electrodes to auditory nerve fibres lying on the basilar membrane of the cochlea. As the basilar membrane contains a representation of sound frequencies, known as a tonotopic map, auditory prostheses deliver high-frequency information to the basal region of the cochlea, and low-frequency signals to the apical region, to mimic normal auditory processing.

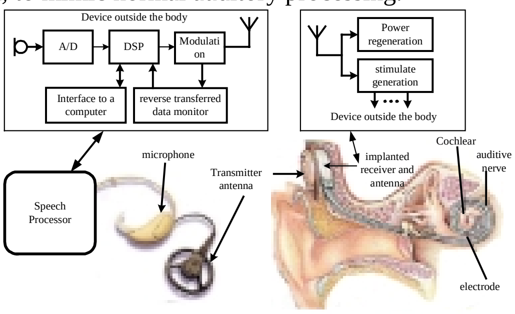


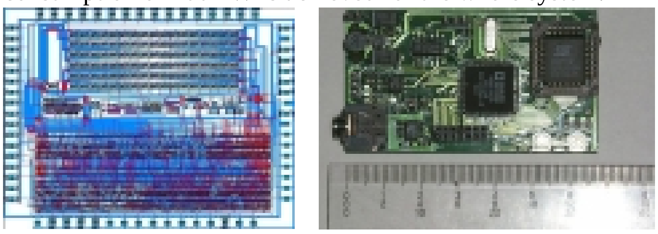
Figure 3 *cochlear implants* - example of the first type of BCI

The key elements in the auditory prosthesis are illustrated in Figure 3. Acoustic signal is picked up by a microphone, which converts it into electric signal. The processor divides the signal into multiple components using filters or other electronic processors and sends each component to a separate output channel. The electrical signal must be compressed to conform to the dynamic range of electrical hearing. The signal must then be sent to the implanted electrodes. Batteries are used to provide power for the signal processor. A receiver-stimulator which is implanted under the skin behind the external ear and lead wires from it to the electrode array that implanted in or near auditory neurons. Instructions and power are then transmitted to the implanted receiver-stimulator by an antenna placed on the skin overlying the implanted receiver.

IV. A COCHLEAR IMPLANT SYSTEM DEVELOPED BY TSINGHUA UNIVERSITY

A cochlear implant system was development based on the continuous-interleaved-sampling (CIS) processing strategy [5]. A modification to CIS was carried out and the computation cost was reduced to about 20% of the original CIS strategy. The core component of the system is an integrated circuit used in the implanted receiver-stimulator. The IC is an analog digital mixmode chip with 16 channels and supports 4 stimulus modes. It provides a highest stimulus rate of 18k pulses per second per channel, and a highest dynamic range of 60dB with the 10 bit D/A convertor. A reverse data transfer methodology is designed for the IC, so it can be used in the experimental studies.

The processor is realized based on a fixed-point low power general purpose DSP chip and different processing strategies can be download to the board to investigate processing strategy. A high efficiency class-E power amplifier is used and an anti-jamming architecture is adopted, so the low power consumption of 100mW is achieved for the whole system.



Layout of IC for Cochlear implants   Prototype for the speech processor

Figure 4 IC for cochlear implant and the speech processor

The layout of the chip and the photo of the prototype of the speech processor were illustrated on Figure 4. The chip area including pads is 3.56mm×3.67mm with 1.2μm CMOS process. The measured static and peak power consumption are 8 mW and 35 mW respectively.

V. CONCLUSION

The requirement of IC for BCI is reviewed. The design methodologies for the very low power CMOS integrated circuits and the compatibility of analog digital mixmode IC process with others, e.g. MEMS, processes will be the important challenge for the design of BCI. An analog-digital mixmode IC used for cochlear implant, which is considered as the first BCI, is designed using 1.2μ CMOS process. The performance of this IC and its application is demonstrated.

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