Telemetry Unit for a Neuro-prosthesis Stimulation Chip

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The combined expertise of micro-/nano-technology and neuroscience opens new opportunities in the development of neuro-prostheses, i.e. devices designed to restore sensory and motor functions after injury or disease to the nervous system. The SpineRepair project, involving a multidisciplinary consortium of experts, aims at developing a miniaturized spinal cord neuro-prosthesis in the hope of someday offering a solution to paraplegics.

The SpineRepair project proposes to optimize, manufacture, assemble and validate a fundamentally different technology to produce an electrical stimulation of the spinal cord via a neuro-prosthetic system based on ultra-compliant microelectrode arrays, embedded ultra-low-power analog electronics and an efficient telemetry unit. This type of device could also be applied to epilepsy, Parkinson's disease or pain management.

Spinal cord injury causes a loss of function below the level of the lesion. The goal of the neuro-prosthesis is to restore motor function and potentially to provide sensory feedback. Stretchable and flexible electrodes are connected to a stimulator chip which generates epidural current pulses to stimulate the spinal cord below the point of injury. The micro-electrode array and the flexible electrodes must withstand demanding mechanical loading and yet present low resistivity.

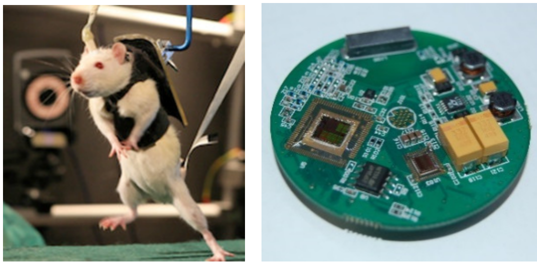

Figure 2: Left: rat walking with electrical stimulations on spinal cord (EPFL [1]). Right: First version of PCB for neuro-prosthesis.

The SpineRepair implantable device addresses important technical challenges: ultra-low-power consumption, miniaturization and bio-compatible encapsulation to cite a few. The neuro-prosthesis is composed of electrodes, a stimulation chip, an ultra-low power microcontroller with radio transceiver, and a rechargeable battery.

For the purposes of the project, the neuro-prosthesis is driven by a lab computer. A radio link between the PC and the prosthesis relays commands to the stimulation chip to test different forms of stimulation patterns on the spinal cord.

The stimulation chip was developed by Prof. Hierlemann's group [2] at ETHZ and drives 15 independent channels which can generate monophasic or biphasic current pulses with up to 3 mA amplitude at up to ±6 V each. CSEM too has proven experience in designing similar neural stimulation and sensing chips, e.g. collaborations with Nano Retina [3] (retinal implant), the Wyss Center for Bio- and Neuro-engineering [4] (brain implant) and 3Brain (in vitro monitoring).

A state of the art ultra-low power 868-915 MHz radio link is provided by CSEM's icycom [5] system-on-chip which provides a radio transceiver (4 mW at 1 V), local processing capability with the icyflex1 processor and SPI connectivity to the stimulation chip (on the neuro-prosthesis side) or an Ethernet interface (on the PC side of the radio link).

A simple software API was defined for the host PC to send commands to the stimulator. The icyflex1 processor on the icycom SoC then parses the UDP command strings, recodes them in the form of stimulation commands and transmits them over-the-air to the implantable receiver. The radio on the receiver node continuously listens for commands and sends them to the stimulation chip.

In terms of power budget, the receiver system-on-chip consumes less than 2.5 mA in continuous-receive mode (on a 3 V battery), which is on the same order as the average power consumption of the stimulation chip (typically 4 mA). However, the impulsive nature of the current delivered and drawn by the stimulation chip (up to ~50 mA peaks on ±6 V) implies important constraints on the power management. Large capacitors are coupled to the +6 V and +12 V step-up converters to avoid large peak currents on the 3 V battery.

Transmission delays are also very important for an efficient use of the system. The overall delay from commands on the host PC to the resulting stimulation spikes is currently around 10 ms. Whereas the timing on the icycom controller depends essentially on the processing done on the icyflex1 CPU, the time from host PC to the icycom radio varies more as it is dependent on the host hardware and its operating system (MS Windows) which is not a real time OS.

An antenna was designed specifically for the radio link and the wireless charging of the battery. Its operation on or under the skin poses specific challenges. Experiments with bio-compatible packaging (silicone rubber) were carried out at EPFL on an antenna module. CSEM characterized the antenna properties of this packaged version, connected to the 868 MHz radio. The dielectric packaging impacts the matching of the antenna. Additional experimentation will be undertaken to model the effects of surrounding tissues and to fine tune the antenna circuits before the finalization of the device.

The electronics for the neuro-prosthesis have been validated in the lab, with the stimulation channels connected to a load. A first in-vivo test is planned for Nov 2015 on a rat to validate the whole command chain from the host PC to the spinal cord.

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[1] cnp.epfl.ch, Center for Neuroprosthetics, EPFL

[2] www.bsse.ethz.ch/bel, Bio Engineering Laboratory, ETHZ

[3] www.nano-retina.com, Nano Retina, Inc.

[4] www.wysscenter.ch, Wyss Center for Bio- and Neuro- engineering

[5] www.csem.ch/docs/Show.aspx/12228, icycom flyer