Miniaturized Implantable Multichannel Neural Stimulator

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Abstract

A miniaturized implantable neural stimulator has been set up solely using commercially available electronic components. Despite its conservative and thus cheap construction it is considerably small in size although it features six independently programmable current sources, versatile stimulation patterns such as n-let and round-about stimulation and passive inductive powering plus a bi-directional inductive communication link.

Keywords: Neural Stimulator, Inductive Link, FES, Stimulation, Implant

1. Introduction

Miniaturization of electronic devices and micro-technologies enables the development of implants small enough to be located near recording or stimulation sites. Therefore, the trend in the design of implant electronics directs to using highly integrated and specialized ASICs (e.g. [1], [2]). Though, their design and fabrication are extremely time consuming and costly. In many cases it is more desirable to use conventional technologies, especially when more flexibility is required as is the case in basic investigations. The miniaturized stimulator presented here will be used for evaluating the new multipolar cuff electrodes, recently developed at IBMT [4], in long term experiments. Another intention of the system is to provide a powerful means of investigating new neural stimulation patterns for fatigueless peripheral nerve stimulation in acute and long term animal tests.

2. Methods

A miniaturized implantable neural stimulator with six independently current controlled channels has been set up. This stimulator is controlled by an external unit by means of an inductive bi-directional communication link. The externally applied magnetic field is also used to power the implant electronics. An overview of the system is given in Fig. 1.

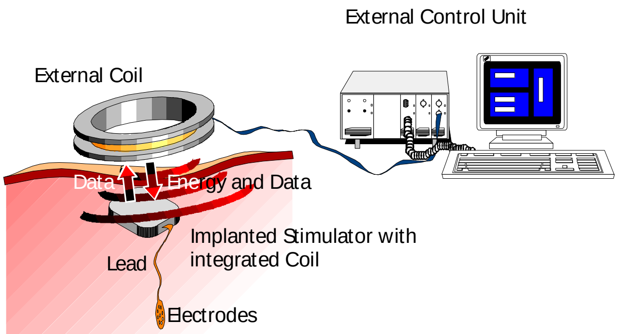

Fig. 1: Overall stimulator system

The external control unit is realized as an embedded Intel 486 DX processor system that contains the necessary circuitry for receiving and transmitting the inductive signals. With the help of a graphical user interface, the operator can easily modify system settings and control the implantable stimulator via the wireless link.

In Fig. 2 a block diagram of the stimulator is depicted.

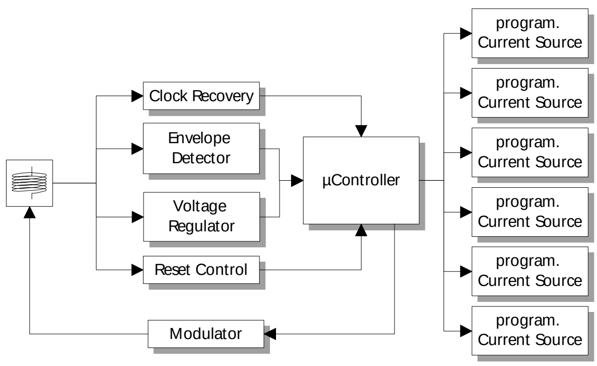

Fig. 2: Block diagram of implantable stimulator

The core of the implant is Arizona Microchip's PIC 16C71 microcontroller which in first place is responsible for controlling each of the six stimulation channels. In addition, its responsibilities comprise the coding and decoding of the wireless inductive communication data exchanged with the external telemetric unit. The controller's A/D-converter monitors the unregulated dc-supply. This digitized voltage value may be viewed on the screen of the external control unit in a graphical representation. By searching the maximum voltage, this helps to optimize coil placement. A clock recovery circuit supplies the controller with the required logic clock derived from the carrier frequency of the alternating magnetic field. In this way, a bulky quartz crystal is omissible. The voltage regulator is required to limit the supply voltage of the electronics to 3.3 V. As soon as the supply drops below 3.0 V, the reset supervisory circuit will generate a reset to avoid logic hook-up of the controller.

Current Sources

The current sources are implemented by a single transistor emitter follower for each of the channels.

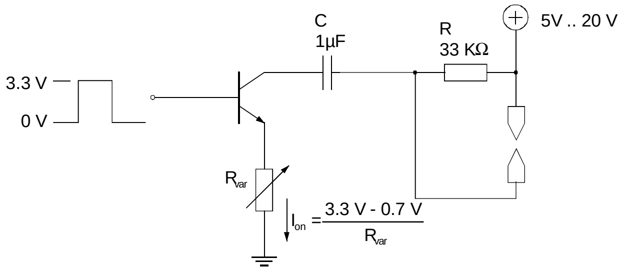

Fig. 3: Schematic of current sources

A digital potentiometer R_{var} is used to program the emitter resistor and thus the collector current. The cathode of each electrode is connected to the collector branch of its corresponding transistor. The anodes are connected to the positive unregulated power supply. Capacitively implemented charge compensation avoids electrochemical corrosion and other irreversible processes at the electrodes. The shunting resistor R will not degrade the current through the electrodes if their impedance is much smaller than R. The stimulator is designed for rectangular pulses with stimulation currents up to 1 mA. Using short pulses (< 250 µs) on one single channel only, stimulation currents of slightly more than 4 mA can be reached (s. also Fig. 5).

Communications

Incoming data are implemented by amplitude shift keying the electromagnetic field applied by the external transmitter coil. An additional reverse communication channel is implemented via load shift keying. This channel is used to control the data flow and to provide information on the status of the implant, e.g. power supply. The carrier frequency is 4 MHz, but can be adjusted between 3 MHz and 5 MHz. The coils are designed for transmission distances of up to 25 mm and a maximum diameter of the implant coil of 20 mm.

Communications are half-duplex at 9.600 bits/s. A modified Manchester code is used in order to guarantee bit synchronization and a dc-free modulation signal. An 8 bit cyclic redundancy check block at the end of each transmitted frame secures safe operation and prevents unintentional stimulation.

After applying the magnetic field, the storage capacitor on board of the stimulator will charge and the supply voltage will start to build up. As soon as the minimum voltage of 3.0 V has been reached, the supervisory circuit will start the controller. The latter monitors the supply and transmits a reset notification frame to the external controlling unit. This frame also includes the implant's specific ID and the digitized supply voltage value. Now, the µ-controller is in idle mode and waits for a command frame to be transmitted by the external controller.

At present, three different commands have been implemented:

- The *status inquiry* command asks the implant to return its ID and the level of supply voltage.
- The *n-let stimulation* command initiates the stimulation of n-lets with specified parameters (current amplitudes, pulse width, number of pulses in one burst, the distance between pulses, the number of bursts and the time between bursts).
- The *round-about* command starts a stimulation program stimulating a sequence of channels with specified parameters (see above including the sequence period and the sequence itself).

Stimulation patterns

The stimulator is designed for rectangular shaped current pulses, only. The parameters of stimulation for both, n-let and round-about stimulation are shown in Fig. 4 and are specified as follows.

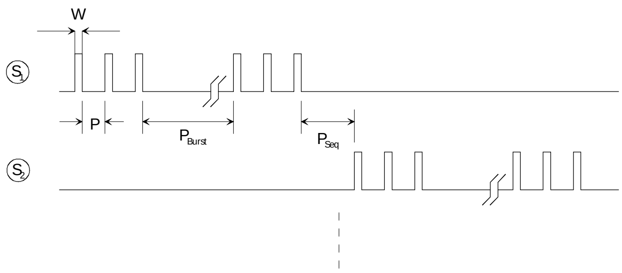

Fig. 4: Definition of stimulation parameters

The amplitude of stimulation currents can be programmed individually for each channel in 64 unequally spaced steps, ranging from 53 µA to 4.5 mA as can bee seen in Fig. 5. The pulse width W is quantized using 8 bit with a resolution of 6 µs. N-lets can be set in bursts of 1 to 256 pulses with a time spacing P from 16 µs to 4.1 ms. The spacing between two bursts P_{Burst} is configurable from 292 µs to 65.6 ms. The number of bursts which are to be generated can be preset as well, starting from 1 burst to up to 65536 successive bursts. In continuos mode, the stimulator will stimulate until the remote control unit terminates stimulation. Round-about stimulation is additionally characterized by the time between two successive sequences (P_{Seq}). Up to six sequences may programmed which are defined by any combination of the six output channels. After all sequences have been processed, the stimulation cycle will start at sequence S_1 again.

As the parameters are determined by software in the first place, they can easily be adapted if necessary.

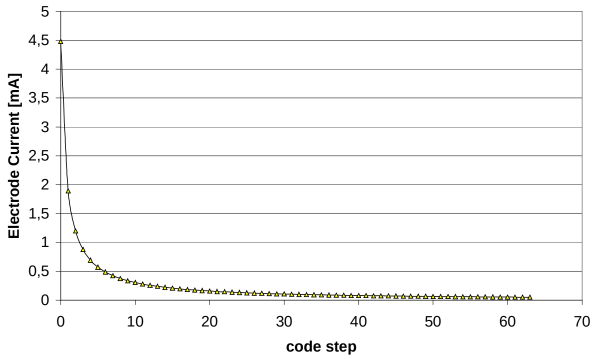

Fig. 5: Programming steps of pulse amplitudes

3. Results

So far, a prototype version of the implant has been set up. It has been constructed of off-the-shelf electronic components using surface mount technology on double sided standard FR4 printed board. It measures 24 x 26 x 6 mm³ not encapsulated, not including the coil for the inductive link. The top and bottom view is shown in Fig. 6 and Fig. 7, respectively.

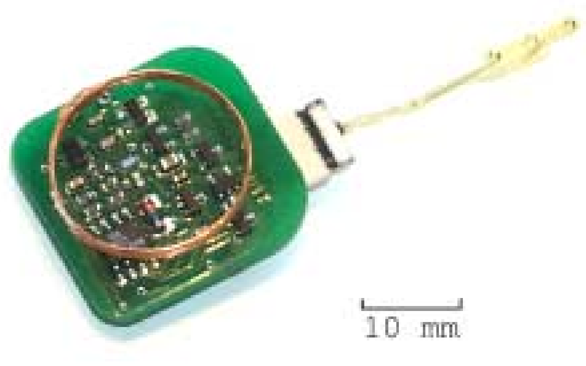

Fig. 6: Top view of stimulator with 3polar cuff-electrode

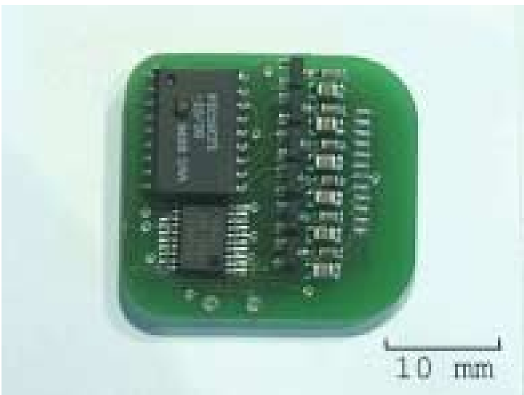

Fig. 7: Bottom view of stimulator

Fig. 8 depicts voltage and current curves recorded during in vitro tests of the stimulator connected to a 12polar cuff-electrode [3] in physiological saline solution (0.9 % NaCl). Rectangular pulse trains at approx. 20 Hz were used. The electrode areas are made of platinum and are 1 mm in diameter. The recordings were done in tripolar configuration using one channel, only. The coil separation was 1 cm.

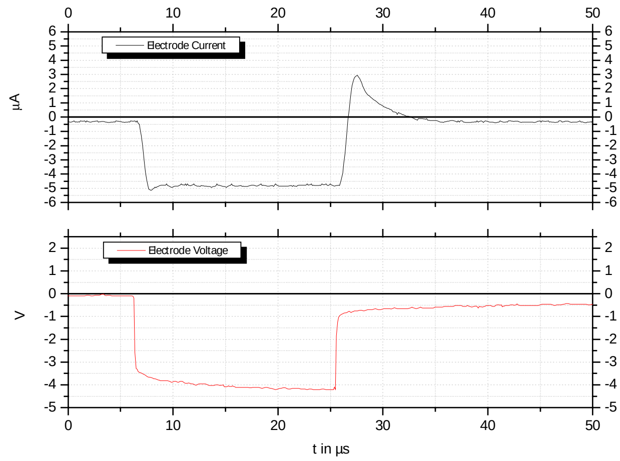

Fig. 8: Stimulation current and voltage across electrode

In idle-mode (no stimulation), the implant draws 2.8 mA. Although no implantation has been carried out yet, the inductive link proved to be not affected by biological tissue between transmitter and receiver coil. This was shown by placing a hand between the coils.

4. Conclusions

A quite powerful neural stimulator has been designed and constructed using off-the-shelf electronic components, only. Although no ASIC has been implemented, the size of the laboratory version is considerably small and would not restrict implantation. In small animal models however, it is desirable to reduce the size of the implant electronics even more. Future activities will concentrate on further miniaturization by using bare dice and mounting the electronics on a flex substrate. First results from stimulation of sacral roots and peripheral nerves in acute and chronic animal studies are hoped to be gathered until the date of the conference.

5. References

[1] Boyer S. et al, „New Integrated Miniaturized Neuromuscular Stimulator to Enhance Bladder Voiding“, in Proc. IV Intern IFESS Conf, Sendai, August 1999.

[2] Nardin M. et al, „A Multichannel Neuromuscular Microstimulator with Bi-Directional Telemetry“, in Proc. IIX Intern Solid-State Sensors and Actuators Conf, and Eurosensors IX, Stockholm, June 1995.

[3] Schuettler M. et. al, „A Multipolar Precision Hybrid Cuff Electrode for FES on Large Peripheral Nerves“, in Proc. 21th Intern IEEE EMBS Conf, Atlanta, October 1999.

[4] Schuettler M. et. al, „18polar Hybrid Cuff Electrodes for Stimulation of Peripheral Nerves“. To be published in Proc. V Intern IFESS Conf, Aalborg, June 2000.