Two Channel Electronic Device for Cortical Stimulations by Microampere DC Currents

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Abstract— **A new realized current stimulation device, capable to simultaneously drive two independent channels, is presented in the paper. Device is battery powered and microprocessor controlled. Ultra small current from 30 μA to 2 mA DC current could be applied to both channels independently. Applied current could be set by front panel as well as application time. During the stimulation applied currents on both channels are monitored. Internal software PI current regulators are implemented into the system providing 5% accuracy of applied current. Realized currents during the stimulation are presented onto the separated LED displays for both channels. System is capable to be connected to the remote supervision system (PC, or Human machine interface) by USB cable.**

Keywords-component; stimulation, ultra small DC current, regulation, battery power, robust PI regulator.

I. INTRODUCTION

Stimulation of constant current is widely used in the field of non-invasive brain stimulation, with particular interest directed towards research related to the recovery of motor function after stroke, treatment of depression, chronic pain, and several neurological and psychiatric condition, as well as modulation of various cognitive function (e.g. attention, working memory) [1]. A special problem during electrical stimulation is the current regulation. During laboratory tests on the given subjects and patients battery power is one of the special technical requirements which is not so easy to preserve. It is necessary to ensure long-term battery power as well as the constant current control. A particular problem during the current stimulation is the high output resistance of the subjects. During the electrical stimulation at the beginning of the stimulation the load resistance reaches up to 100 a kΩ and during long-term stimulation the load resistance fell down to 3 kΩ. Therefore, it is necessary to implement robust current controller that can preserve the wide range of output load resistance as well as the required current precision. It should be noted that during the experimental session duration of stimulation varies from a few minutes to a few hours. The device should be adaptive to such a wide range of stimulation time and should be robust enough to continuously achieve the desired precision of electrical stimulation in a long period of time. The battery power supply is another problem because the battery must ensure the durability and consistency of power during the stimulation. Most commercial stimulators have the power regulation in the range of 0.5 mA – 2 mA. Special type of devices who have a range from a few tens of μA until 2000 μA, suitable for animal experiments are very rare [2]. The number of such devices who has required characteristics on the market is limited with very high price. It should be also noted that all such commercial stimulators of the desired current range have one stimulation channel. Modern medical laboratory usually needs two or more channels during one laboratory experiment.

II. SYSTEM DESIGN

The presented developed device enables two independent channels for subject stimulation using micro amp currents for medical laboratory test purposes. The parameters of electrical current stimulation can be set using local display and this can be done independently for both channels (Figure 1). Current intensity and stimulation duration can be set for both channels. During the stimulation device regulates stimulated current using the local software implemented PI current controller. The device is a micro-processor controlled by ARDUINO DUE micro-controller board [3] that possess ATMEL MEGA ARM Cortex microcontroller. The device is battery operated according to the rules of safety electrical stimulation of subjects in medical research. Implemented software PI regulator provides 5% accuracy of regulated current which is monitored at all times during the stimulation on both channels. Specially designed electronic provides the safe stimulation and secure environment.

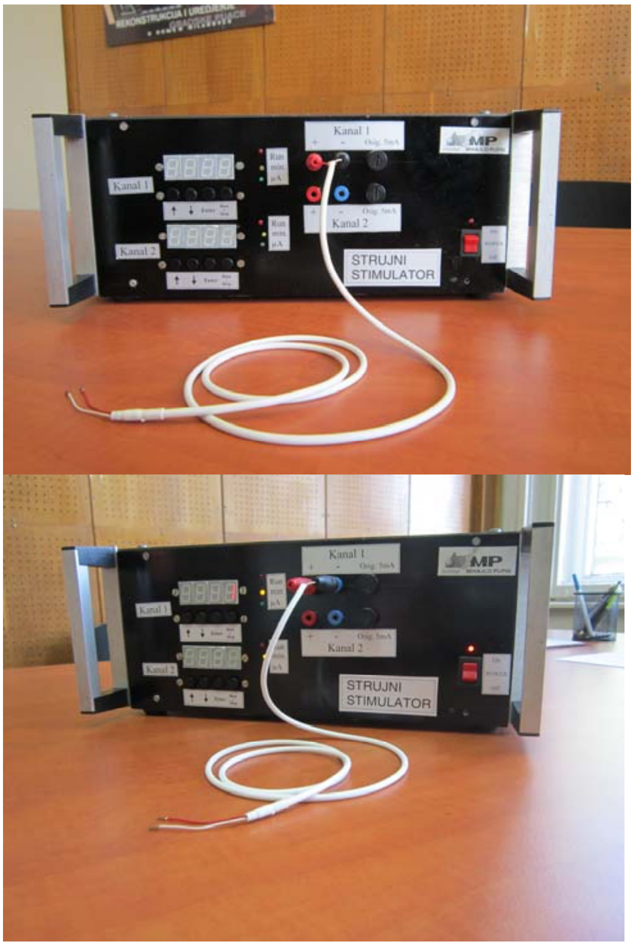

Figure 1. *Device view together with the micro probes. The connected micro probes are specially designed for micro ampere stimulation for the rats.*

Figure 2. *ARDUINO DUE microprocessor bnoard[3].*

III. TECHNICAL DESCRIPTION

As it is already mentioned, the electronic circuit of the device is based on ARDUINO DUE [3] microcontroller board. This platform becomes more popular, because it is inexpensive and relatively easy to be programmed in his own environment, based on C/C++ program language. The controller board is based on the ATMEL ARM SAM3X8E 32-bit microcontroller running at 84 MHz, and it has 54 digital input-output (I/O) pins (7 can be PWM programmed, 12 pins are basically analogue input pins and 2 pins serve as analogue outputs (Figure 2). Realized external keypad and LED display allows the setting current stimulation in μA and stimulus length in minutes for both channels independently. Each channel has its own keyboard. The keypad consists of four keys each of which has its own function. The buttons are labelled with the ↑ (UP), ↓ (DOWN), ENTER and RUN / STOP. These keys are directly connected to one of the input-output pins ARDUINO DUE controller board.

Electrical schematic of the keyboard is shown in Figure 3. Each key output is connected to an appropriate input pin of the controller board ARDUINO DUE. Appropriate reading algorithm together with the software filtering detects which key is pressed and according to key press appropriate program action occurred. By pressing the ↑(UP) key, which can be readable only if parameter selection mode is active, it is possible to increase current stimulation parameter or duration time parameter. Increasing could be made for an appropriate amount. Current parameter stimulation could be increased in steps of 10 μA while increasing of time duration parameter could be done in steps of 1 minute. By pressing the ↓ (DOWN) key, which can be readable only if parameter selection mode is active, it is possible to decrease current stimulation parameter or duration time parameter. Decreasing could be made for an appropriate amount. Current parameter stimulation could be decrease in steps of 10 μA while decreasing of time duration parameter could be done in steps of 1 minute. By pressing ENTER key it can be performs the selection of parameters. The first press to the ENTER key achieved input parameters selection for stimulation current. This is manifested by flashing green LED labelled μA on the front panel, indicating that selection of current stimulation on the specific channel is in progress. The second press to the ENTER key memorize the last selected intensity of current and achieve input parameters selection for time of stimulation. Now this is manifested by blinking yellow LED marked MIN. Third press to the ENTER key memorize the last selected time of stimulation. By pressing the RUN/STOP key the beginning of stimulation for the selected channel is realized. During the stimulation of red LED which is marked RUN is blinking. Interruption of the stimulation could be done by pressing the RUN/STOP key. During the stimulation while led RUN is blinking, on the 7 segment LED display it is presented remaining time of stimulation and realized stimulation current simultaneously. This is done for each channel separately.

This is possible because on the front panel, next to the local keyboard, an 8 digit 7 segment LED display is realized. Electrical schematic of 7 segment LED display is shown in Figure 4. It can be observed that driving of this 7 segment LED displays should be made by 30 ms software timer. Each 7 segment LED digit is common cathode. Each digit common cathode is connected to the separate input-output port ARDUINO DUE controller board. Segments of all digits are connected together to is connected to the separate input-output port ARDUINO DUE controller board. Especially implemented software driver with a cycle of 30 milliseconds provides continually data presentation to the display (Figure 4).

IV. CURRENT STIMULATION CONTROL

Electrical schematics of the power section stimulator, which enables direct electrical stimulation is given in Figure 5. It is a simple inexpensive but effective realization of constant energy micro amp current from a battery source. 300 V battery section is realized by simple serial connection of 34 single 8.2V NiMH standard rechargeable batteries. The total capacity of the battery section is 240 mAh. This allows continuously power for electrical stimulation on both channels for more than 10 hours. The required maximum stimulation time is 240 minutes or 4 hours for both channels. Such realized energy section in addition to its simplicity and functionality provide currant control stimulation using software PI controller for both channels. Implemented software PI controller achieves current regulation trough to appropriate analogue inputs and outputs of ARDUINO DUE controller board.

The corresponding analogue output drives high voltage optocoupler TLP-627 [4] (Figure 5). Such realized current stimulation is directly measured and reversed into the PI controller via high gain optocoupler IL300 [5]. In this way, by simple realization, a reliable current control for both channels is achieved. Powering and global activation of current stimulation is achieved by special digital signal that activate high-voltage relay (Figure 5) connecting drive unit to the high voltage battery pack. If any error occurs during the stimulation microcontroller immediately disconnect relay and interrupts stimulation. Using precise melted fuse of 5mA it is realized a physical protection during the stimulation (Figure 5), so that in any case current stimulation can never exceed 5 mA per channel. All digital and analogue inputs and outputs are connected to the corresponding I/O pins ARDUINO boards to achieve stimulation.

Software implemented PI regulator is responsible for current stimulation control. Parameters of PI regulator are obtained by the simulation of the systems and further adjustments are made manually [6-8]. For the purpose of the simulation a detailed model of the energetic system are developed. For the primary modelling a battery pack are modelled as ideally one. Using high voltage TLP-627 optocoupler (figure 5) it is provided controlled current stimulation. This optocoupler is highly nonlinear element transfer parameter ration If/Ic is directly implemented into the model from the catalogue [5]. Another important element into the feedback loop is wide bandwidth high gain stability servo optocoupler IL300 [5]. It is used into the servo loop (figure 5) to measure realized current into the system. The servo gain of this optocoupler represents the ratio between realized current and measured voltage. Block diagram of the realized software PI regulator are presented onto the Figure 6. Simulation diagram of the realized model with simulated currents are presented onto the Figure 7, while measured realized stimulated current are presented onto the Figure 8.

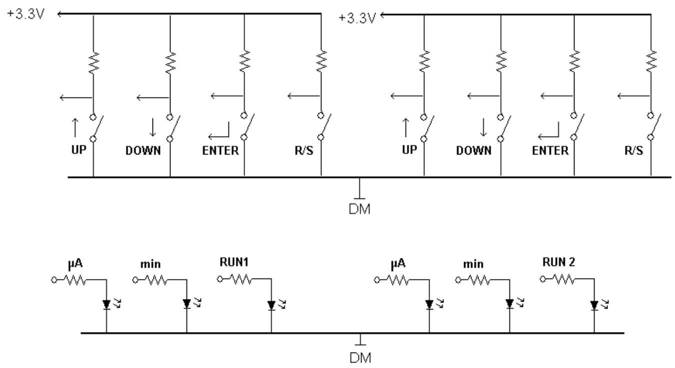

Figure 3. *Electrical schematics of the front pannel keyboard.*

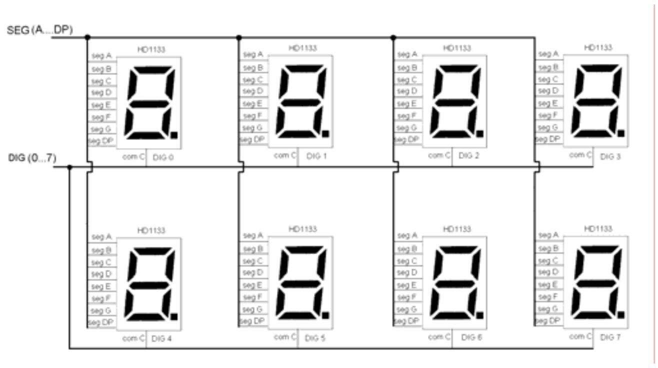

Figure 4. *Electrical schematics of the front pannel 7 segment LED display.*

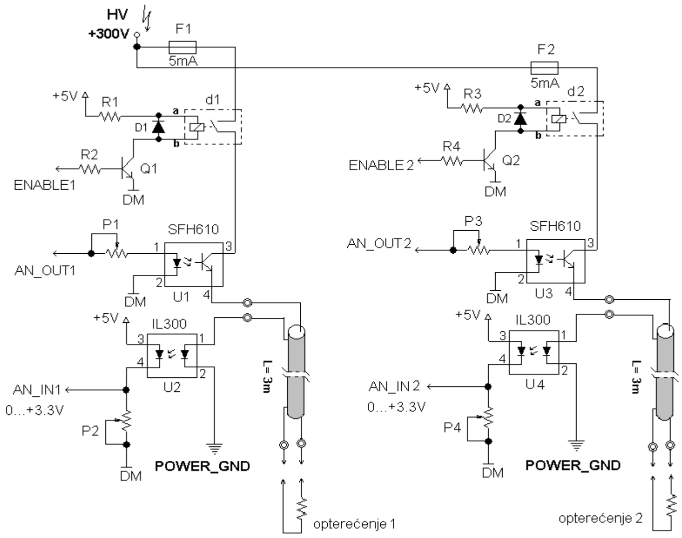

Figure 5. *Electrical schematics of the high voltage power stage.*

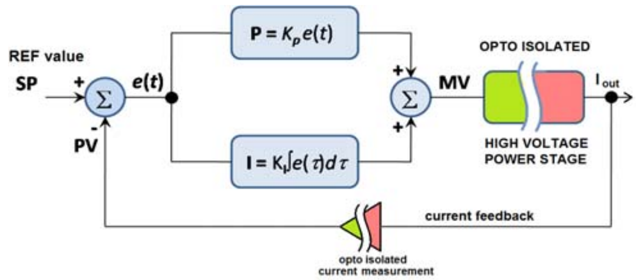

Figure 6. *Block diagram of the software implemented PI regulator.*

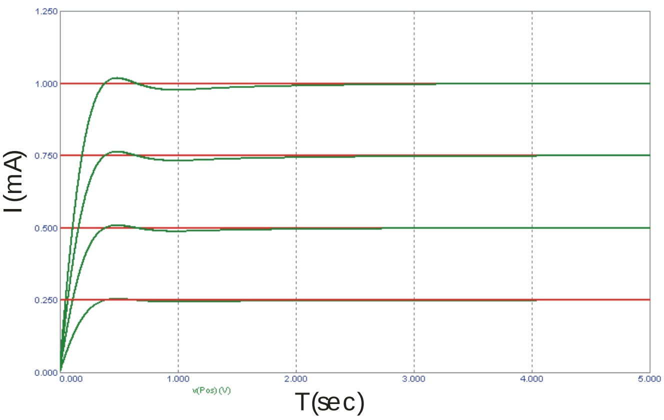

Figure 7. *Simulated output currents using PI current control at load R=50 KΩ*

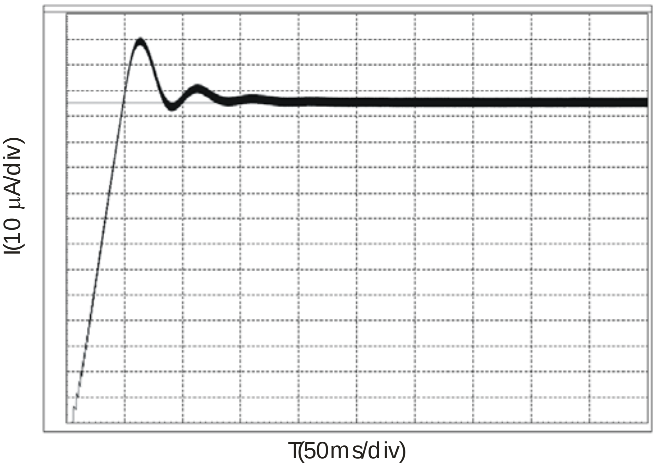

Figure 8. *Measured really output current using realised PI current control at load R=50 KΩ*

V. Conclusion and Further Improvement

A new, low price and useful battery powered microampere current stimulation is presented. This new realized current stimulation device capable to simultaneously drive two independent channels. Device is battery powered and microprocessor controlled. Ultra small current from 30 µA to 2 mA DC current could be applied to both channels independently. Applied current could be set by front panel as well as application time. During the stimulation applied currents on both channels are monitored. Internal software PI current regulators are implemented into the system providing 5% accuracy of applied current. Realized currents during the stimulation are presented onto the separated LED displays for both channels. System is capable to be connected to the remote supervision system (PC, or Human machine interface) by USB cable. Further improvement would be implemented especially to realize more robust PID controller as well as safety improvement and efficient battery charger capable for fast charging and discharging. Remote controlled GUI should be realized to provide PC control and monitoring of stimulate parameters during the stimulation.

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