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A Multifunctional Neural Electrode Stimulation ASIC using NeuroTalk™ Interface

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***Abstract*—The NeuroTalk™ inteface, described in a companion paper allows for a standardized method of communication with implanted modules that contain custom application specific integrated circuits (ASIC). Here, we describe an example of one such ASIC that has been designed for use in a visual prosthesis. The ASIC is small enough to be incorporated within a 16-channel multielectrode stimulation array implanted in the cortex. In this paper we describe a version designed to operate over a 4-wire buss called NeuroTalk 2. Other versions of the ASIC operate using a single coil input for power and data, over a transcutaneous magnetic link.**

I. Introduction

As part of our development [1] of an intracortical visual prosthesis, we have developed an electrode/stimulator module for chronic implantation in the visual cortex. This module will eventually take the form of being completely wireless, using transcutaneous magnetic power and data transmission for operation. For preliminary animal experiments that investigate visual prosthesis stimulation strategies, we have developed a wired version of the electrode stimulator module that requires only 4-wires to power and control in implanted stimulator ASIC. Shown conceptually in Figure 1, this stimulation module incorporates the ASIC on the backside of a substrate that contains the activated iridium oxide film (AIROF) stimulating electrodes. Here, we describe the functionality and operation of the stimulator ASIC.

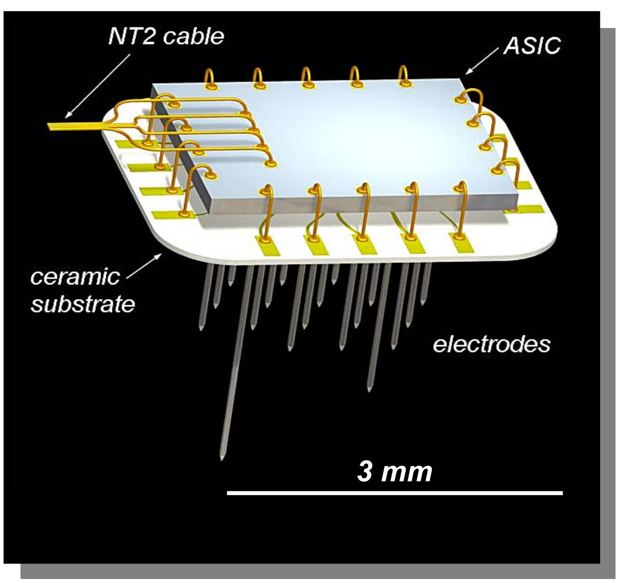

Figure 1 – 3D rendering of the implantable stimulation module showing the stimulation ASIC and electrodes mounted on a common substrate.

II. ASIC Functional Description

A. General Description

The stimulator ASIC uses the 4-wire NeuroTalk-2 (NT2) interface for power and digital data commands [see Troyk, et. al, EMBS 2006] with the NT2 interface cable leading to the animal's head connector. Using the NT2 protocol, the ASIC can be commanded to perform a range of channel-based, and global-based stimulation functions. Each of the 16 microelectrodes can be connected, disconnected, specified with respect to stimulation parameters, and connected to a global voltage monitor. Each microelectrode has a dedicated driver.

B. ASIC Block Diagram

A functional block diagram of the ASIC is shown in Figure 2. Each of the 16 stimulator channels contains a dedicated constant-current, monophasic, charge-balanced electrode driver. Stimulation of each electrode is provided by true potentiostatic control using a common reference electrode and a common counter electrode. The method of charge recovery for each microelectrode is controlled by a sophisticated compliance supply regulator that uses the voltage on the reference electrode to limit the voltages on the microelectrode to be within the "water window" [2]. The normal anodic and cathodic compliance supply limits are +0.6V and –0.6V with-respect-to (WRT) Ag|AgCl.

C. ASIC Command Set

An internal state machine receives the commands from the NT interface and converts them into channel commands. A common on-chip parallel interface buss controls each channel uniquely by gating each channel driver as needed and as determined by the channel address within the interface command.

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The basic instruction set for the stimulator ASIC is shown in Figure 3. To command a single channel, using a 5-MHz system clock, typically takes 10 µsec. The ASIC is controlled by the NT2 interface to provide the following modes of operation:

channels could be controlled through one NT2 4-wire interface.

Independent Channel Operation Each stimulator ASIC controls 16 independent electrode channels. Every channel can be programmed with its own stimulation parameters.

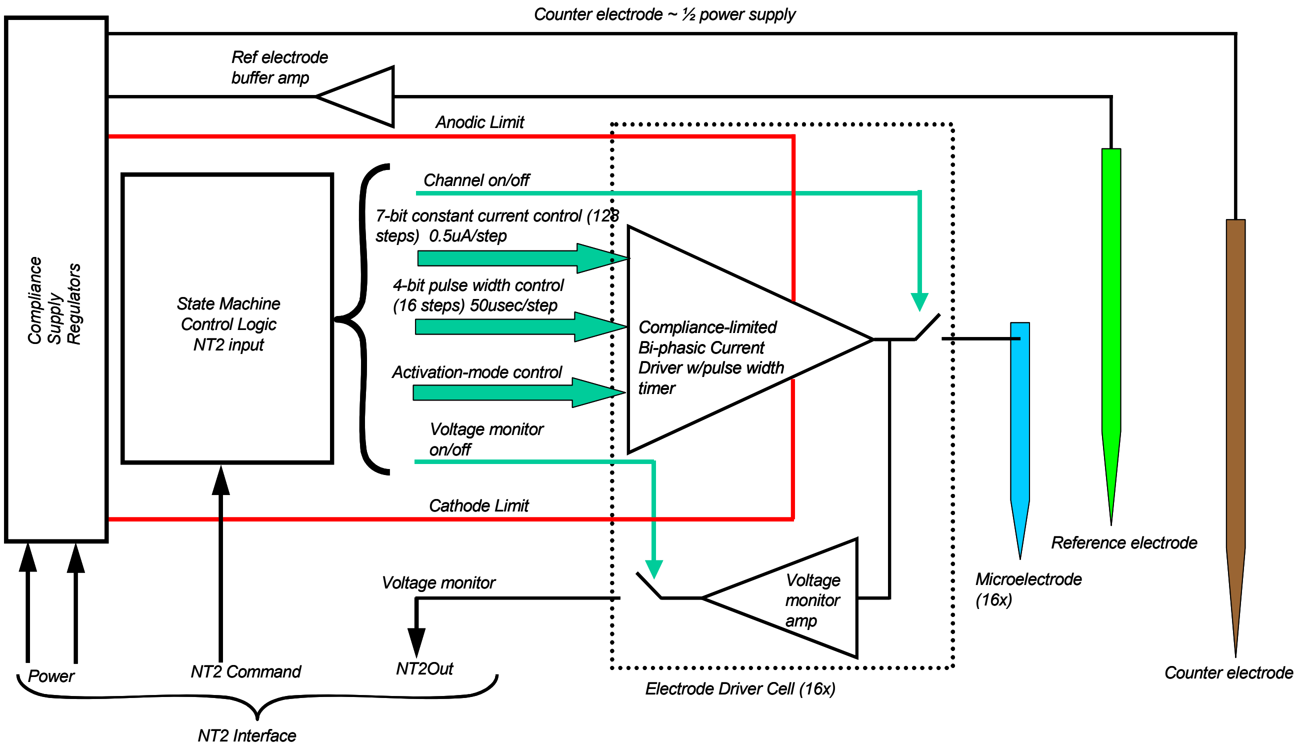

Figure 2 – Block diagram of the 16-channel stimulator ASIC

Instruction
Stimulate all channels with current parameters
Stimulate a single channel with current parameters
Load a single channel with new amp data
Load a single channel with amp data them stimulate
Load a single channel with amp and pw data
Load a single channel with amp and pw data and stimulate
Connect a channel to the Monitor
Connect core reference to the Monitor
Enter Activation Mode
Enter Condition Mode
Return to Normal Mode
Send Telemetry
Reset Cells
Generate single Tclk Pulse

Cathodic-first Amplitude	**Min** 0uA	**Max** 63.5uA	**Step** 0.5uA
Pulse Width	**Min** 0uSec	**Max** 750uSec	**Step** 50uSec

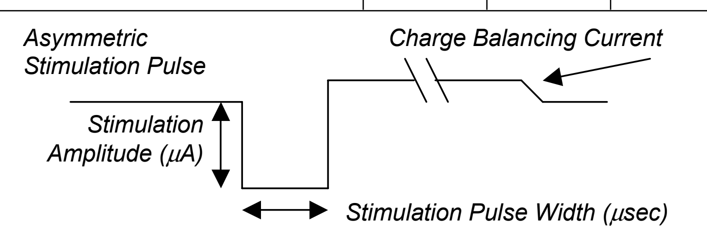

Figure 3 – Stimulator command set

System, Module, or Channel-Based Addressing Each stimulator ASIC has a 7-bit hardwired system address with a value from 0x00 to 0x7E with 0x7F being reserved for Broadcast Address (to all system ASICs at once) commands. A stimulator ASIC will respond only to instructions that contain its native address or the universal system wide command address. The address is programmed at the time of incorporation into the module by laser cutting of on-chip metal links. Conceptually, 128 stimulators, each with 16

Stimulation parameters include pulse amplitude and pulse width and are stored in the electrode cells.

Multiple Operating Modes Each stimulator ASIC can be set to operate in three different modes: Normal, Electrode Conditioning, and Electrode Activation. In normal mode the pulse width of stimulation is derived from a pulse width timer contained within each electrode cell, and is controlled by the NT2 system clock. In conditioning mode and activation mode, the pulse width channel counters are disconnected from the system clock and require specialized

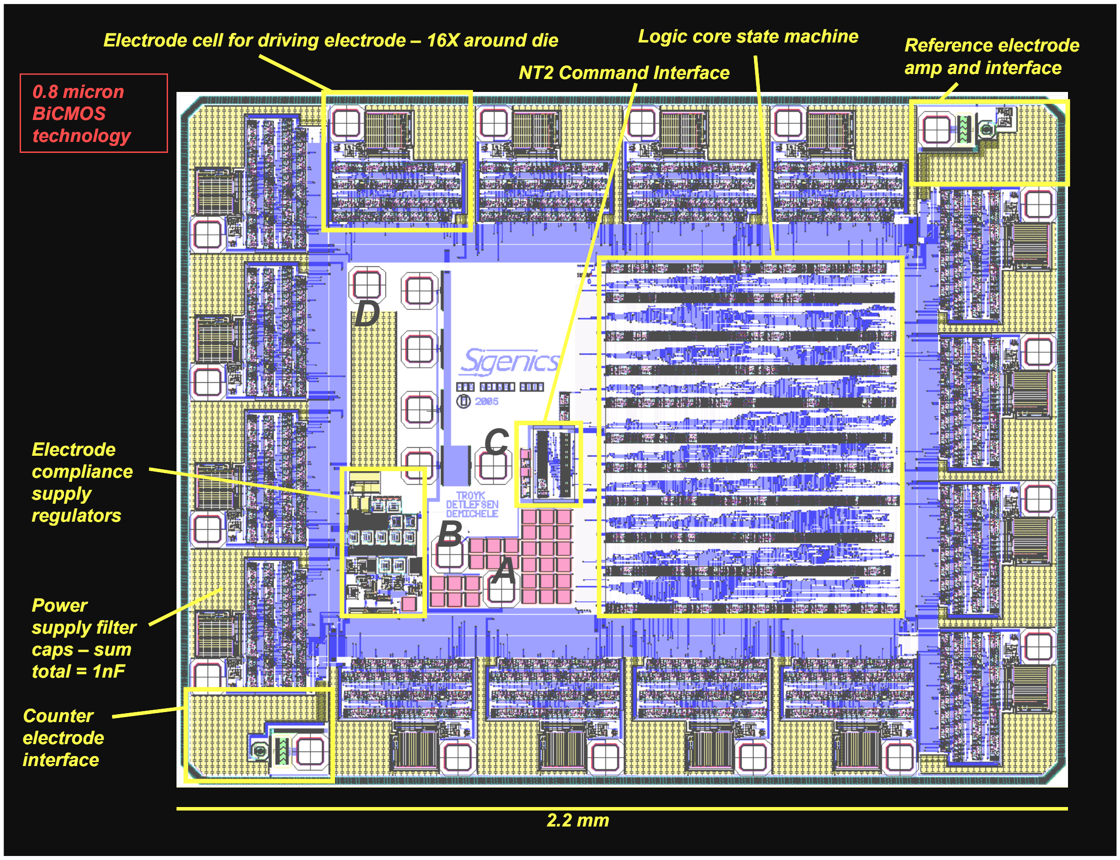

Figure 4 – Layout of the prototype stimulator ASIC

instructions to step through a stimulation pulse. In conditioning mode, electrodes are connected to the normal anodic supply. In Activation mode, the electrodes are connected to the high anodic supply. Conditioning mode was built into the design to allow for manipulation of the tissue/electrode interface by slowly cycling the electrode voltage between an anodic and cathodic limit. In a similar manner, Activation mode was built into the design to allow the stimulator to activate AIROF electrodes after all high-temperature operations of the encapsulation packing have been performed (AIROF is not tolerant of dry elevated temperatures).

Channel Monitoring A single channel from every stimulator ASIC can be dynamically connected to a read-back signal, on the NT2Out line, to monitor the performance of an electrode channel by observing the electrode potential excursion during stimulation.

Multiple Compliance Supplies Every Stimulator ASIC module has a normal +0.6V WRT ref, and high anodic limit +0.85V WRT ref, (used for Activation mode). Either one of these supplies can be connected to the electrode channels by changing the operating mode of the Stimulator ASIC. When the stimulator ASIC chip is powered up or after a reset condition, all current drivers are initially disconnected. Before stimulation can be produced the desired channel's current drivers must be connected and is accomplished by sending a special coded command. After a channel's current drivers are brought on-line, that channel is available to produce stimulation pulses. Certain serial instructions produce stimulation on a single specific channel, while others produce stimulation on all available channels simultaneously. In each case, the stimulation produced is characterized by each channel's amplitude and pulse width values that have been previously set and stored within the electrode-driver cell. Each instruction triggers a single stimulation pulse. A pattern of stimulation is produced by sending a sequence of channel stimulation commands. True simultaneous stimulation can also be produced on predefined channels. Since the stimulation parameters, for any channel, can also be altered during a stimulation pulse, complex and innovative stimulation sequences can be produced within the surrounding neurons.

III. ASIC LAYOUT

A CAD layout of the stimulator ASIC is shown in Figure 4. Around the periphery of the die, the 16 electrode driver cells are placed. The bonding pads are strategically placed so as to facilitate the wire-bonding to the electrode array substrate as shown in Figure 1. The 4-wire NT2 interface lines are marked as ABCD. Each electrode driver contains a poly-poly-substrate power supply filter capacitor to prevent digital power supply noise from invading the stimulus output currents. A total of 1 nF of capacitance is on the die. The Reference electrode input cell includes a high-impedance buffer amplifier whose output is used by the compliance supply regulators. The logic core state machine occupies a major portion of the central die area.

IV. ASIC Stimulus waveshape

Once stimulus parameters are loaded into an electrode driver, a short command can be used to repeatedly output a single stimulus pulse on that channel. Once pulse is produced for each command, and the interpulse interval is controlled by varying the time between commands. Using the global stimulation command, all channels can be simultaneous stimulated. A typical stimulation waveform in which the normally-constant cathodic-first current pulse is "cut-back" to prevent electrode damage is shown in Figure 5. More details can be found in [2], as space does not allow for a detailed description of the compliance-supply limited driving strategy here.

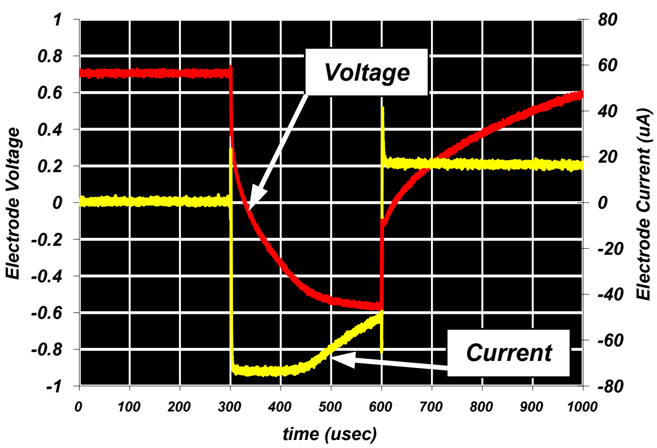

Figure 5 - Oscilloscope waveforms for an AIROF electrode driven from the stimulator ASIC with the cathodic cutback method. Note that as the electrode voltage, shown in red, approaches the –0.6V limit, the current is reduced. The cathodic injected charge density is 1.86mC/cm^2.

V. Discussion

Although we have designed the stimulator ASIC for use in our specific multielectrode array, its operation is general enough that it might be used in other neural prosthesis stimulation systems. The present limitation in stimulus current amplitude of 63.5 µA is only a function of the area restriction for use within the multielectrode array. It would be relatively easy to increase the size of the output transistors used for the electrode driving circuitry to obtain any desired maximum current.

The Activation and Conditioning modes of the ASIC are unique. For use of AIROF electrodes, it is important to be able to activate the electrodes only after all of the elevated temperature assembly operations are completed. This is because the AIROF can be damaged by the higher temperatures. For AIROF activation ones needs to control the dwell time at a cathodic and anodic potential, and the ASIC command set allows for arbitrary control of both the anodic and cathodic dwell time durations. Conditioning mode is a related form of operation. It is well known that electrode tissue interfaces can become affected by invasion of biomolecules and glial cells. It has been suggested that some sort of slow cyclic voltage waveform, applied to the electrodes, may help to condition or restore the integrity of the artificial neural interface.

The single NT2Out interface line is used for monitoring the voltage on a selected electrode. Although the current waveform does not have a similar output, analysis of the voltage waveshape allows one to infer what the general shape of the stimulus current would be. As long as the voltage waveform is not limited by the compliance supply, the stimulus current will be constant due to the wide range of compliance supply operation of the current drivers. When the voltage excursion approaches the preset compliance limit, the current waveform will naturally cutback.

This ASIC is one example of a family of chips that we are designing for use with the NeuroTalk interface. The extreme flexibility of this interface allows for device specific sophisticated functions.

References

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[2] Srivastava, N.R., Troyk, P.R., Cogan, S.F., "A laboratory testing and driving system for AIROF microelectrodes," Proc. 26th IEEE EMBS, San Francisco, CA, Sept 1-5, pp. 4271 – 4274, 2004.