On the Design of a Flexible Stimulator for Animal Studies in Auditory Prostheses

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***Abstract*—The present paper describes the design of two stimulators (bench-top and portable) which can be used for animal studies in cochlear implants. The bench-top stimulator is controlled by a high-speed digital output board manufactured by National Instruments and is electrically isolated. The portable stimulator is controlled by a personal digital assistant (PDA) and is based on a custom interface board that communicates with the signal processor in the PDA through the secure digital IO (SDIO) slot. Both stimulators can provide 8 charge-balanced, bipolar channels of pulsatile and analog-like electrical stimulation, delivered simultaneously, interleaved or using a combination of both modes. Flexibility is provided into the construction of arbitrary, but charge-balanced, pulse shapes, which can be either symmetric or asymmetric.**

I. Introduction

The field of cochlear implants has experienced a considerable growth in the last few years. The growth and progress in cochlear implant technology is largely stimulated and driven by research with both human subjects and animals. Having access to a flexible research platform is critical for the advancement of cochlear implants. While most implant manufacturers provide research speech processors which allow researchers to develop and test new signal processing algorithms, most research labs are unable to use them due to limited technical resources. Of those research processors, only the one made by CRC/Hearworks (SPEAR3 processor) is portable and wearable. The research processors provided by the other manufacturers are constrained for use in the laboratory environment.

The main drawback of laboratory research processors is that they do not allow for investigation of novel algorithms after long-term use. Given that the performance of CI users may improve or change within a period of a few months, it is necessary that novel algorithms are evaluated after long-term use of the device. Such evaluations would give us a more realistic assessment of the performance of new algorithms and new experimental methods. In addition to being portable, the research processor needs to be flexible and easy to use. While the SPEAR3 research processor is portable, it is not easy to program as it requires a skilled software engineer to implement the algorithms in assembly language. The processor needs to be flexible so that it can be used by both clinicians and researchers without requiring advanced programming skills. Such a processor would also be valuable in animal studies assessing long-term effects of electrical stimulation, and it would therefore bridge the gap and speed up the transition from animal studies to clinical applications. To achieve the above goals we sought for a research platform which required minimal investment in hardware development. For that reason, we opted for a research platform that is more software driven and that is nearly hardware independent. Changing the software to accommodate new technologies is much easier than replacing existing hardware.

In [1], we proposed the use of Personal Digital Assistants (PDAs) as a research platform for both human and animal studies in cochlear implants. This research platform includes a stimulator unit which can be used for electrical stimulation in animal studies, a recording unit for collecting evoked potentials from human subjects and a portable processor for implementing and evaluating novel speech processing algorithms after long-term use. In the present paper, we describe the development of a bench-top stimulator designed for neurophysiological studies with animals (further details regarding the development of the portable speech processor designed for human studies can be found on our website[1]). We also describe ongoing work with a portable stimulator, which can be used for chronic animal studies. This PDA-based stimulator can allow the animals to roam freely in a laboratory environment without being tethered or confined in any way.

II. Bench-top Stimulator: System Overview

The bench top, bipolar stimulator or BT-BiSTM is a multichannel bipolar current source designed for percutaneous, animal cochlear implant systems. The BT-BiSTM is a highly versatile platform capable of generating up to 8 simultaneous channels over a wide array of excitation patterns including both pulsitile and analogue-like, or combinations of both. Built around the 9-bit configurable current source chip [2], the BT-BiSTM platform possesses the following specifications:

- 8 electrically isolated, charge-balanced, simultaneous bipolar channels
- 5V compliance voltage
- 1mA maximum current amplitude per channel
- 9-bit current amplitude resolution per channel

[1] http://www.utdallas.edu/∼loizou/cimplants/PDA/

- 4μs minimum pulse width per channel
- 4μs minimum interphase gap per channel
- 4μs minimum interstimulus interval per channel
- 83.3kHz maximum pulse rate per channel
- $>$50MΩ output resistance per channel

With this platform, many stimulation techniques for cochlear implants can be tested for use on animals. By varying parameters such as current amplitude, pulse width, interphase gap, inter-stimulus interval (ISI) and pulse rate, a multitude of stimulation combinations can be created both in phase (simultaneous) or interleaved across multiple channels.

In addition to the 8-channel current source BT-BiSTM board shown in Fig. 1, the software needed to control the board is also available in an easy to use and user-friendly graphical user interface (GUI) built on top of the National Instruments (NI) graphical programming environment, LabVIEW. When combined with NI's 32 channel, high speed digital output board, the PCI-6534[2], which serves as the hardware control interface between any PC equipped with a standard PCI slot and the BT-BiSTM board, the BT-BiSTM GUI greatly simplifies the task of designing a desired set of electrical stimulation patterns by eliminating the need of users to program the board. Waveform parameters such as pulse rate or pulse width may simply be entered into the GUI for a desired set of stimuli without knowledge of the underlying sequence of control signals needed to control the BT-BiSTM, thus reducing the time required in learning how to use the platform and allowing researchers to focus their efforts on conducting animal experiments.

III. BT-BiSTM Hardware Architecture

Shown in Fig. 1 is a photograph of the BT-BiSTM board. At the core of the board is the 9-bit configurable current source chip, simply referred to as the BiSTM chip. Each of its 8 bipolar outputs are electrically isolated from the line power supplying the board in order to avoid problems incurred by ground loops and voltage spikes. Electrical isolation is achieved with use of the NMXS0505UC isolated DC-to-DC converter made by Murata and the IL711 optocoupler made by NVE.

The NMXS0505UC divides the 5V input supply voltage into two separate power/ground planes: 1) tied to line power or that of the electrical circuit within a building and 2) one apart from line power, having no direct electrical connection to the 5V input supply. Once sufficiently isolated, the BiSTM current output signals no longer share a common reference with any other electrical equipment which may be attached to a test animal such as neural recording systems, thereby eliminating the formation of potential ground loops between various devices and further eliminating the risk of physically harming the animal or incurring distortions associated with electrical artifacts during recordings. In addition to the electrical isolation through the BT-BiSTM power supply circuit provided by the NMXS0505UC, the Murata IL711 optocouplers further isolate the 30 digital control signals entering the 68-pin Dsub connector at the base of the circuit board. Thus, all sources of electricity attached to the board, both for power and control, are isolated from the BiSTM outputs.

[2] http://sine.ni.com/nips/cds/view/p/lang/en/nid/13505

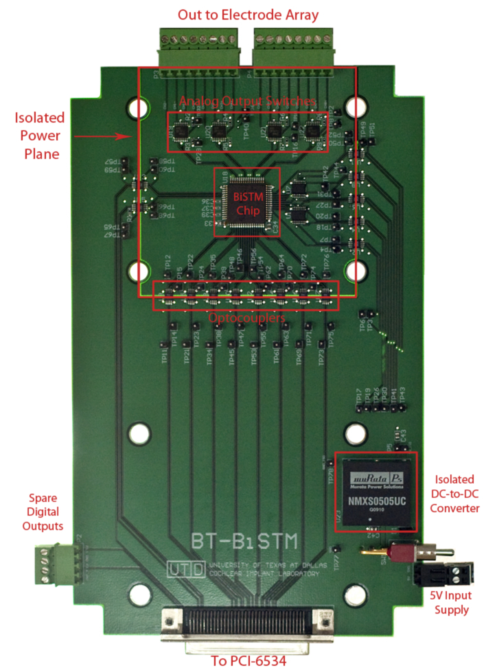

Fig. 1. BT-BiSTM 8 channel bipolar current source.

The BiSTM chip has at each of its 8 bipolar outputs a constant compliance voltage of 5V when actively generating a signal or when at rest with no current flow. Depending upon the application, the 5V found at each of the 8 bipolar outputs of the chip may be either disconnected or left attached from the output connectors located on the top of the board when in rest, and of course, attached when active. Achieved by passing each of the 8 BiSTM outputs through a single-pole-single-throw (SPST) switch, the 5V compliance voltage may be applied or removed from the implanted electrode array when needed.

Also available on the BT-BiSTM board are 2 spare digital control signals. Chosen to control the BT-BiSTM board is the PCI-6534 made by NI. Equipped with 32 high- speed digital output signals, two of the PCI-6534 outputs are unused and routed out to the left-most connector of the board - made available to the user if needed.

IV. PCI-6534 Control Interface

Attached through a cable to the 68-pin Dsub connector located at the base of the BT-BiSTM board is the PCI-6534 digital output card shown in Fig. 2. The PCI-6534 is equipped with 32 high speed digital output signals which serve as the input control signals to the BT-BiSTM board, though only 30 are needed, where each channel has a maximum data rate of 20 Mbits/s. To ensure accurate generation of waveform stimuli, all the necessary control signals for a given set of stimulation parameters are first stored onto the PCI-6534 64 MBytes of

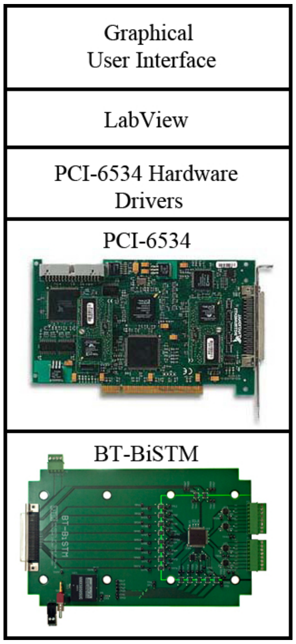

Fig. 2. BT-BiSTM stimulation platform control stack.

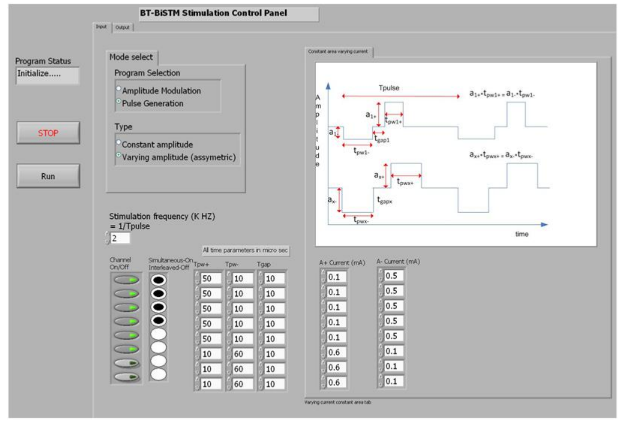

Fig. 3. LabVIEW GUI used for specifying and changing stimulation parameters.

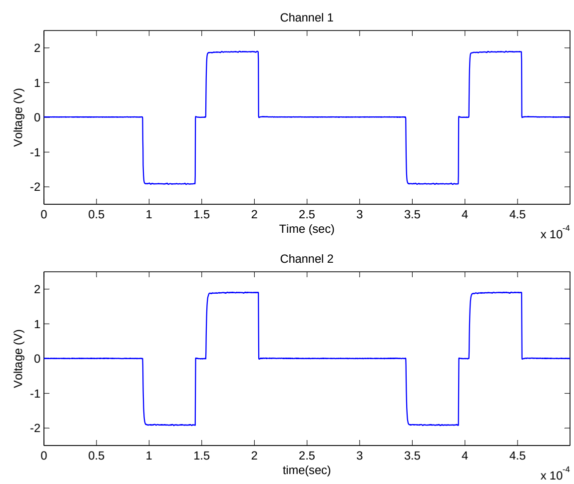

Fig. 4. Pulsatile simultaneous stimulation measured over 2kΩ loads.

onboard memory and then transmitted to the BT-BiSTM in a repeated pattern at a data rate based upon the onboard 20 MHz clock. Doing so guarantees that the desired timing parameters such as pulse width or inter-stimulus interval are maintained at the outputs with high precision.

A LabVIEW GUI has been created to simplify the task of controlling the BT-BiSTM board by allowing the user to simply specify a set of desired stimulation parameters, without concern of how the underlying 30 digital control signals function to control the board. Essentially, the user is only required to learn how to use the LabView GUI with only minimal knowledge of how the lower levels of the control stack operate (Fig. 2). Fig. 3 shows a snapshot of the LabVIEW GUI. As can be seen, the user can easily change the stimulation rate, the pulse width, pulse amplitude and can also select individual channels to be stimulated simultaneously or interleaved.

However, if needed, users are able to create custom applications that control the BT-BiSTM board in programming environments other than LabVIEW. By using the C/C++ library of hardware drivers provided with the PCI-6534 and the BiSTM *User's Guide*, which describes in full detail the function of each of the chip's 30 control signals (available upon request), users may create custom applications to control the board in order to better integrate it into their existing test setups. Moreover, taking advantage of the BT-BiSTM open control interface, digital output boards other than the PCI-6534 may also be used to control the BT-BiSTM given that these boards have a minimum of 30 outputs, each 5V TTL compatible.

V. Evaluation

The following sample waveforms are provided as examples of the BT-BiSTM capabilities. Beginning with the two simultaneous charge-balanced bipolar signals shown in Fig. 4 where channels 1 and 2 generate identical signals locked in phase with pulse widths of 50μs, interphase gaps of 10μs, ISI of 140μs, and current amplitudes of 965μA. Measurements are taken over 2kΩ loads. Note, that although only 2 channels are displayed in this example, the BT-BiSTM is capable of generating simultaneous signals over all 8 channels.

To further demonstrate the BT-BiSTM's ability to generate nearly any arbitrary waveform patterns, two more phase locked signals are shown in Fig. 5 where channel 1 generates an *asymmetric* bipolar signal with equal charge over cathodic and anodic pulses, while channel 2 generates a *symmetric* bipolar signal also equal in total charge over both cathodic and anodic pulses. 765μA are applied at each cathodic/anodic pulse of

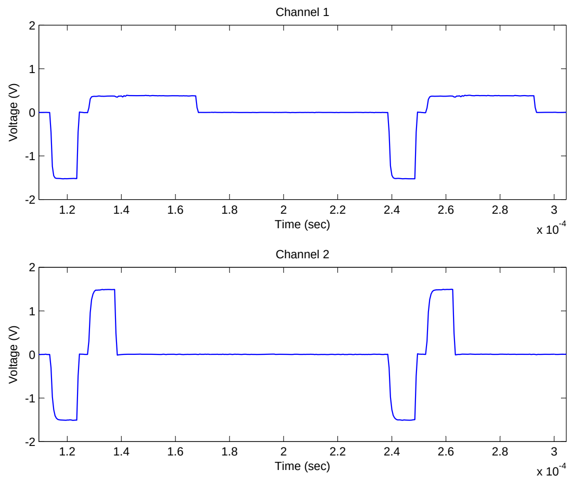

Fig. 5. Symmetric/asymmetric simultaneous stimulation measured over 2kΩ loads.

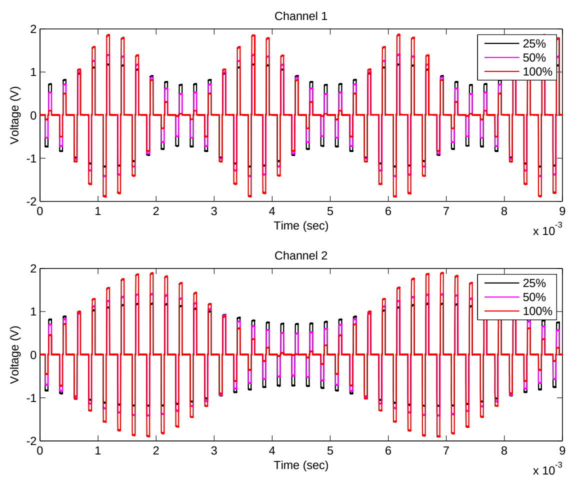

Fig. 6. Simultaneous amplitude modulation stimulation measured over 2kΩ loads.

channel 2 and also to each cathodic pulse of channel 1 over 10μs, while only 191μA is applied to each anodic pulse in channel 1 over 40μs. Measurements are taken over 2kΩ loads.

Lastly, as a demonstration of the BT-BiSTM's ability to generate amplitude modulated (AM) signals, displayed in Fig. 6 are three sets of AM signals, each corresponding to a modulation depth of 25%, 50%, and 100%. The modulation frequency of channel 1 is 400Hz and for channel 2 is 200Hz. Both channels have equal pulse rates. Also note that both channels are again locked in phase (i.e., stimulated simultaneously).

VI. Portable Stimulator: SDIO-BiSTM System Overview

Presently under development is a portable adaptation of the bipolar stimulation platform. Referred to as the SDIO-BiSTM, the portable stimulation platform is based upon the open interface cochlear implant research platform in [3]. Similar to the open interface research platform, the SDIO-BiSTM takes the mobile processing capabilities of a personal digital assistant (PDA) and combines it with a custom made interface card that communicates to the CPU found in the PDA through a secure digital IO (SDIO) slot, hence the SDIO prefix in the name of the portable stimulation platform. In the case of the SDIO-BiSTM, the interface board consists primarily of the BiSTM chip.

The SDIO-BiSTM is comprised of a main board and a daughter board shown in Figures 7 and 8, respectively. Listed below are the main circuit elements of the main board and their respective functions.

- Xilinx Spartan FPGA: Accepts desired output waveform parameters from a GUI application running on the PDA and controls the BiSTM chip accordingly in a way similar to that of the PCI-6534 in the case of the BT-BiSTM platform.
- Arasan SDIO interface controller: Controls communication between the PDA and FPGA.
- 80-pin board-to-board connector: Routes various control/power signals to the BiSTM chip located on the daughter board.
- Miscellaneous power circuitry: Converts 6V of battery supply power to the various voltage levels needed to power the board.

The daughter board circuit elements and respective functions are as follows:

- BiSTM chip: 8 channel configurable bipolar current source.
- Analog output switches: Disconnects the 5V compliance voltage from the test subject when the BiSTM chip is in reset.
- 5V low drop-out regulator (LDO): Converts/regulates 6V battery power down to the 5V BiSTM chip supply power.
- Voltage level shifters: Translates the FPGA's 3.3V digital signal to the required 5V level of the BiSTM chip.
- 16-pin output connector: Routes the 8 bipolar signals to the implanted Cochlear electrode array.

The SDIO-BiSTM board design was divided into two separate boards in order to minimize the overall size of the board. Combining both boards into a single board would have been many times larger and impractical. Also, in anticipation of the eventual release of the monopolar stimulator chip, the modular design of the daughter board system requires the design of just one other daughter board that can also be controlled by the same SDIO-BiSTM main board. This eliminates the need to redesign two additional circuit boards.

It should be noted that since the SDIO-BiSTM board operates on battery power to facilitate mobility, the 8 BiSTM bipolar outputs are electrically isolated from any other elec-

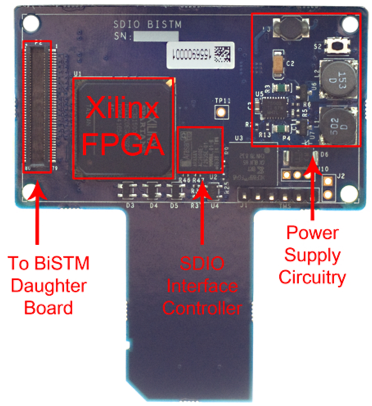

Fig. 7. SDIO-BiSTM main board prototype.

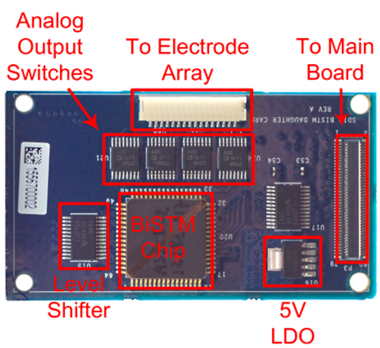

Fig. 8. SDIO-BiSTM daughter board prototype.

trical devices that may be attached to a test animal.

VII. Acknowledgments

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