Fourteenth Quarterly Progress Report

NIH-NO1-DC-6-0002

Open Architecture Research Interface for Cochlear Implants

Douglas Kim, Vanishree Gopalakrishna, Song Guo, Hoi Lee, Murat Torlak, Nasser Ketharnavaz, Arthur Lobo[†] and Philipos Loizou

Department of Electrical Engineering
University of Texas-Dallas
Richardson, TX 75080
Email: loizou@utdallas.edu

[†] Signals and Sensors Research, Inc, McKinney, TX

July 1, 2009 – September 30, 2009

1. Introduction

The main aim of this project is to develop a research interface platform which can be used by researchers interested in exploring new ideas to improve cochlear implant devices. 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. The research platform chosen for this project is the personal digital assistant (PDA).

2. Summary of activities for the quarter

Work in this quarter focused on the development of a benchtop stimulator designed for neurophysiological studies with animals. We also describe ongoing work with a portable stimulator, which can be used for chronic animal studies.

3. BENCHTOP 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 analoguelike, 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, chargebalanced, simultaneous bipolar channels

- 5V compliance voltage
- 1mA maximum current amplitude per channel
- 9bit current amplitude resolution per channel
- 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, interstimulus interval (ISI) and pulse rate, a multitude of stimulation combinations can be created both in phase (simultaneous) or interleaved stimulation modes across multiple channels.

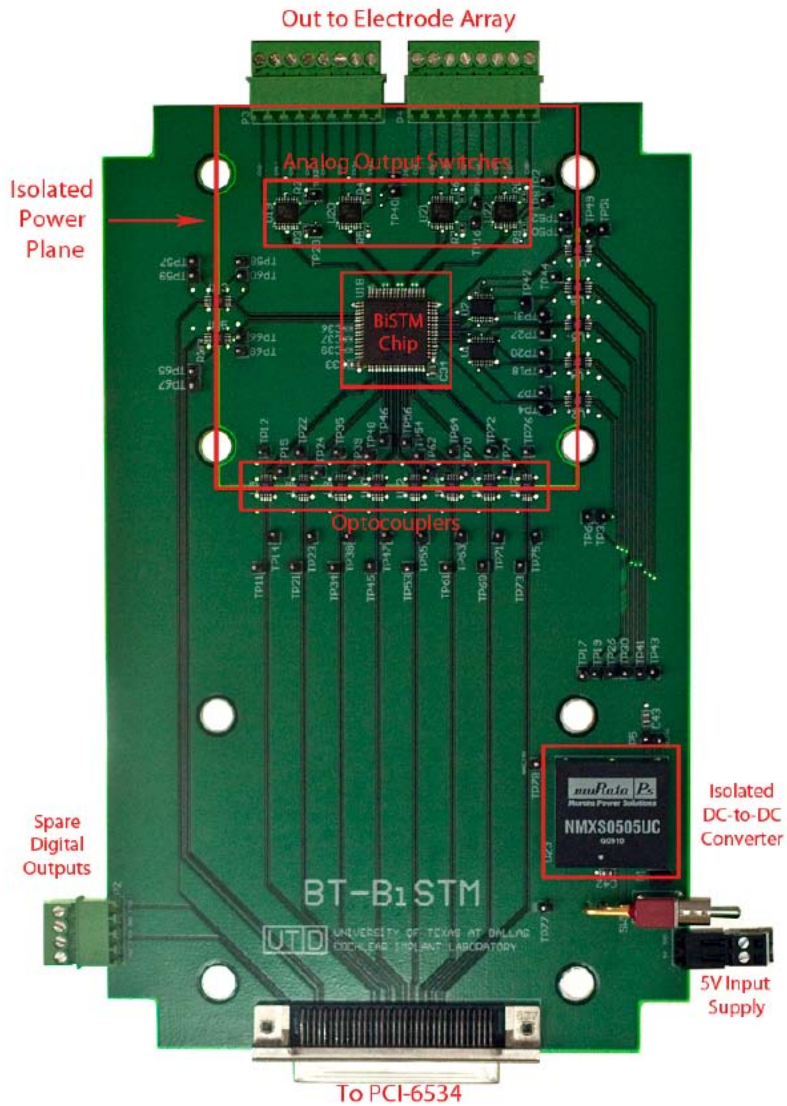

Fig. 1. BT-BiSTM 8 channel bipolar current source.

In addition to the 8channel 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 userfriendly 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 PCI6534[1], which serves as the hardware control interface between any PC equipped with a standard PCI slot

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

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.

4. BT-BiSTM HARDWARE ARCHITECTURE

Shown in Fig. 1 is a photograph of the BT-BiSTM board. At the core of the board is the 9bit configurable current source chip, simply referred to as the BiSTM chip. Each of its 8 bipolar outputs is 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 DCtoDC 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 68pin 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.

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 PCI6534 made by NI. Equipped with 32 high-speed digital output signals, two of the PCI6534 outputs are unused and routed out to the leftmost connector of the board made available to the user if needed.

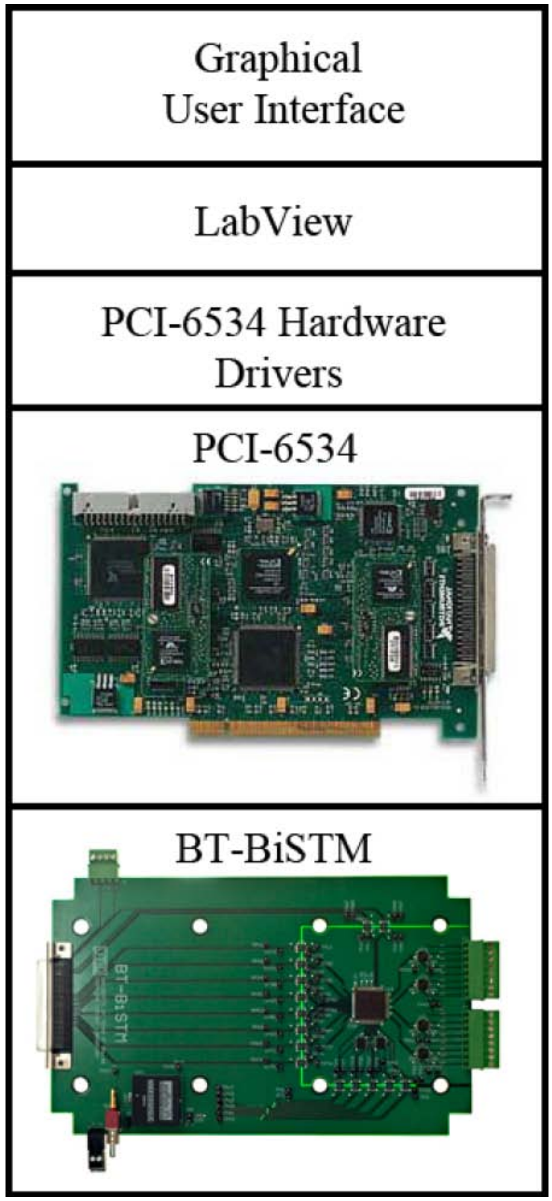

Fig. 2. BT-BiSTM stimulation platform control stack.

5. PCI6534 CONTROL INTERFACE

Attached through a cable to the 68pin Dsub connector located at the base of the BT-BiSTM board is the PCI6534 digital output card shown in Fig. 2. The PCI6534 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 PCI6534 64 MBytes of 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 interstimulus 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.

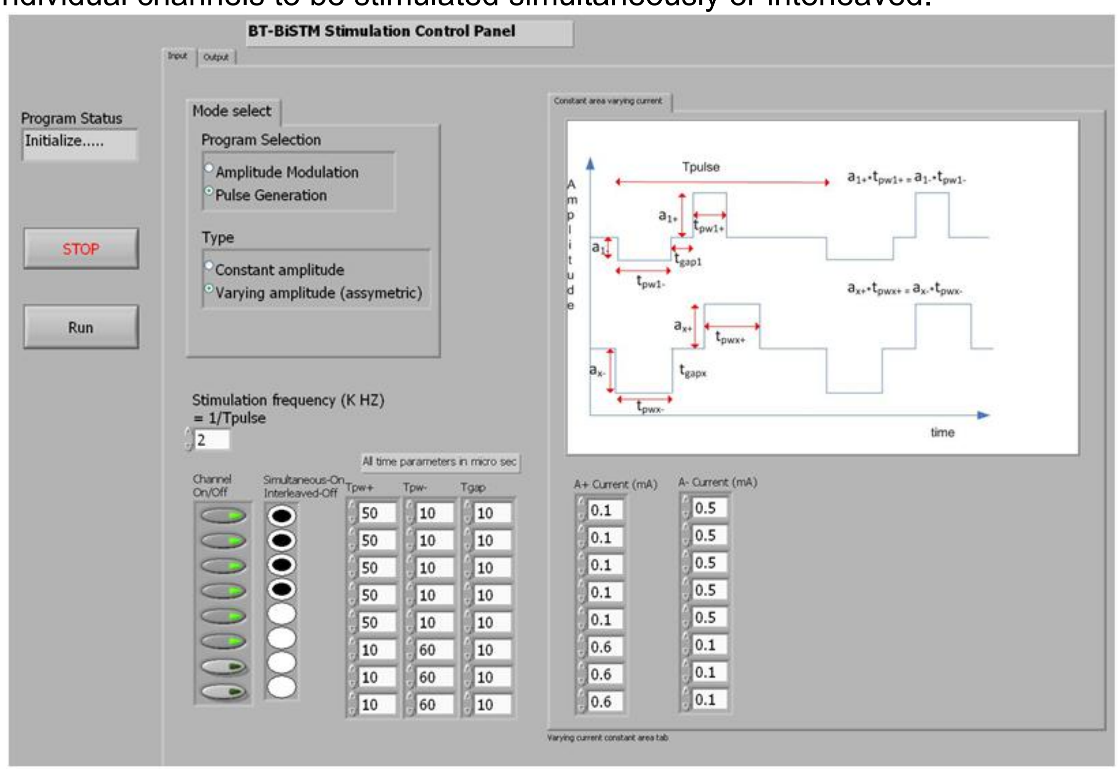

Fig. 3 LabVIEW GUI used for specifying and changing stimulation parameters.

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 PCI6534 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 PCI6534 may also be used to control the BT-BiSTM given that these boards have a minimum of 30 outputs, each 5V TTL compatible.

6. EVALUATION

The following sample waveforms are provided as examples of the BT-BiSTM capabilities. Beginning with the two simultaneous chargebalanced 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 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.

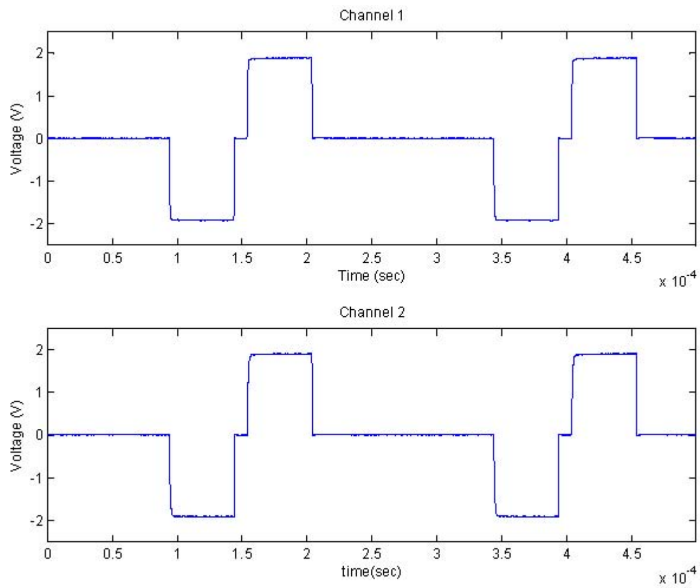

Fig. 4. Pulsatile simultaneous stimulation measured over 2 kΩ loads.

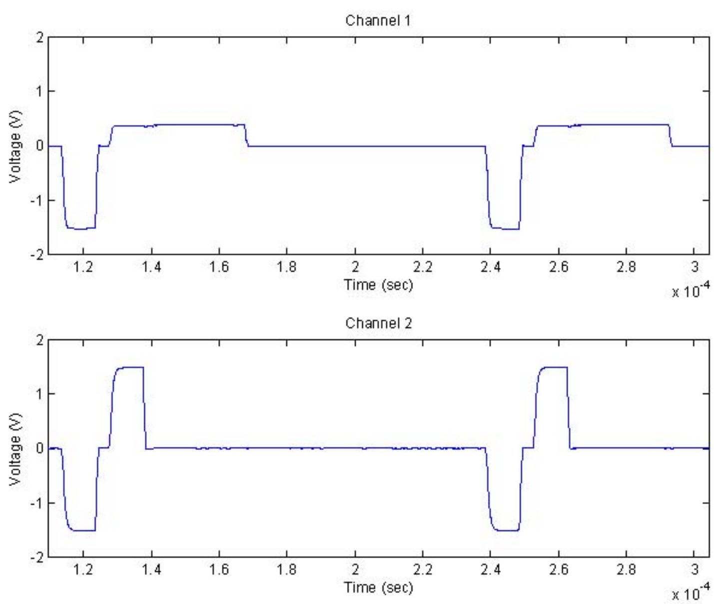

Fig. 5. Symmetric/asymmetric simultaneous stimulation measured over 2 kΩ loads.

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%.

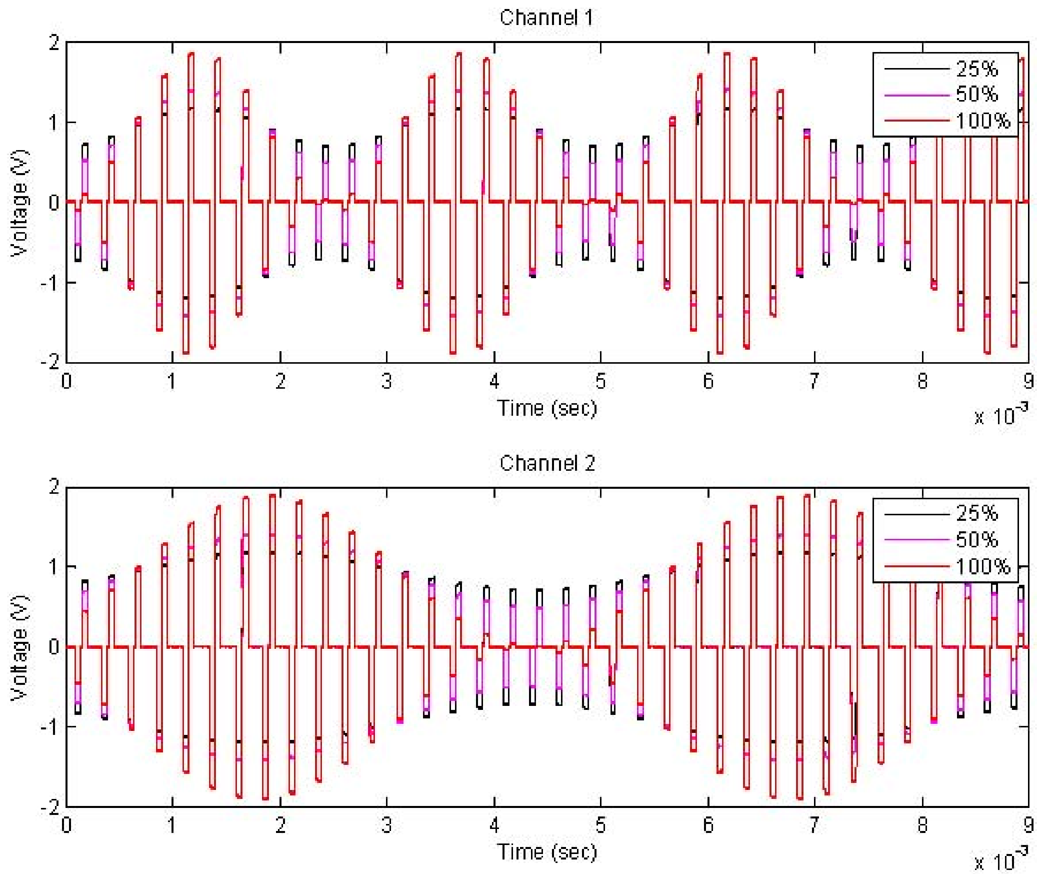

Fig. 6. Simultaneous amplitude modulation stimulation measured over 2kΩ loads.

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).

7. 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. 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 PCI6534 in the case of the BT-BiSTM platform.
- Arasan SDIO interface controller: Controls communication between the PDA and FPGA.
- 80pin 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 mode.
- 5V low dropout 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.

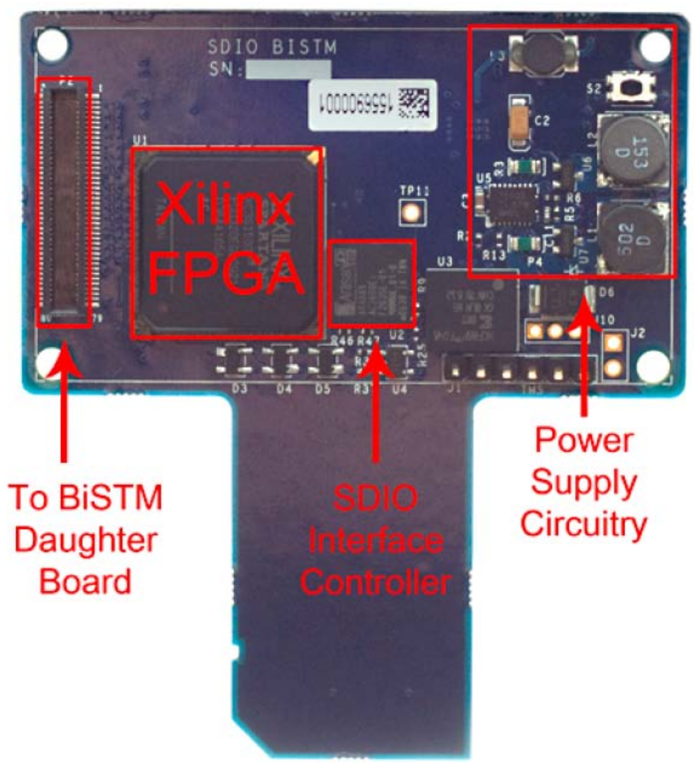

Fig. 7. SDIO-BiSTM main board prototype.

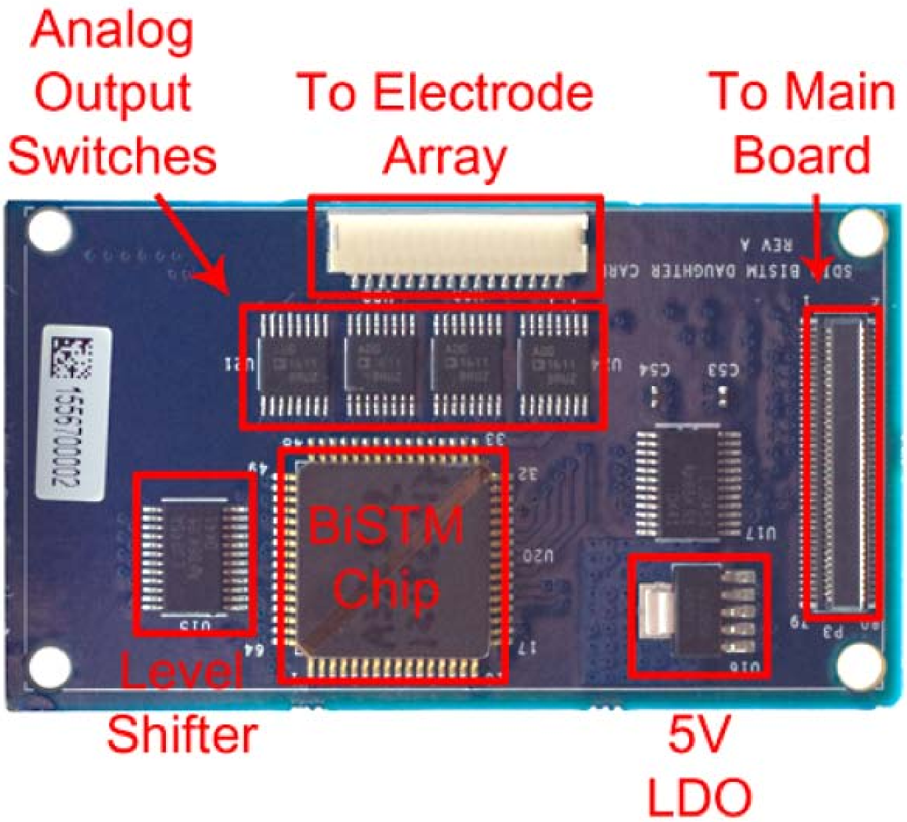

Fig. 8. SDIO-BiSTM daughter board prototype.

REFERENCES

[1] A. Lobo, P. Loizou, N. Kehtarnavaz, M. Torlak, H. Lee, A. Sharma, P. Gilley, V. Peddigari, and L. Ramanna, "A PDA-based research platform for cochlear implants," in 3rd *International EMBS Conference on Neuroengineering*, Hawaii, May 2007, pp. 28–31.

[2] S. Guo, H. Lee, and P. Loizou, "A 9bit configurable current source with enhanced output resistance for cochlear stimulators," in *Proc.of IEEE Custom Integrated Circuits Conf*., San Jose, CA, Sep. 2008, pp. 511–514.

[3] D. Kim, R. Ramachandran, N. R. Gunupudi, K. Kokkinakis, V. Gopalakrishna, N. Kehtarnavaz, M. Torlak, L. Ramanna, A. Lobo, and P. C. Loizou, "Final PDA prototype, beamforming implementation for bilateral studies, FFT code optimization," in *Ninth Quarterly Progress Report*, NIHNO1DC60002, Apr. 2008.