Wireless Integrated Voltametric and Amperometric Biosensing

[1]Mohsen Mollazadeh, [1]Kartikeya Murari,[1]Christian Sauer, [2]Milutin Stanaćevič, [1]Nitish Thakor,
[3]Gert Cauwenberghs
[1]Department of Biomedical Engineering, Johns Hopkins University, Baltimore.
[2]Department of Electrical Engineering, State University of New York, Stony Brook.
[3]Department of Neurobiology, University of California, San Diego.
mohsenm@jhu.edu, kartik@jhu.edu, csauer@jhu.edu, milutin@ece.sunysb.edu,
nitish@jhu.edu, gert@ucsd.edu

***Abstract*— Central Nervous System (CNS) uses the interplay between signals of different modalities to transfer and process information. Neurological events are characterized by changes in both neurochemical concentrations and the electrical activity of neurons. Here, We present a hardware implementation for wireless power & clock transfer *to* and serial transmission of digitized neurochemical and electropsysiological data *from* over one RF link. Electrophysiological and neurochemical events are highly corelated as one causes the other and *vice-versa*. The idea can be extended to sensors of different modalities having widely different data rates. Neurochemical data is acquired in real-time from a custom multichannel VLSI potentiostat chip at 5Hz. Field potential data was sampled at 400Hz. For the purpose of demonstration, it is generated from a memory at a rate matched to that of a custom multichannel VLSI field potential amplifier chip currently undergoing testing. The actual data rates depend on the number of channels and the resolution of the acquired data. The telemetry & powering module is a custom VLSI chip that performs LSK (load shift keying) modulation at 4kHz and can supply upto 6mW of power and control clocks to the sensor chips wirelessly using a RF link. All the chips were fabricated in AMI 3M-2P 0.5μ CMOS process.**

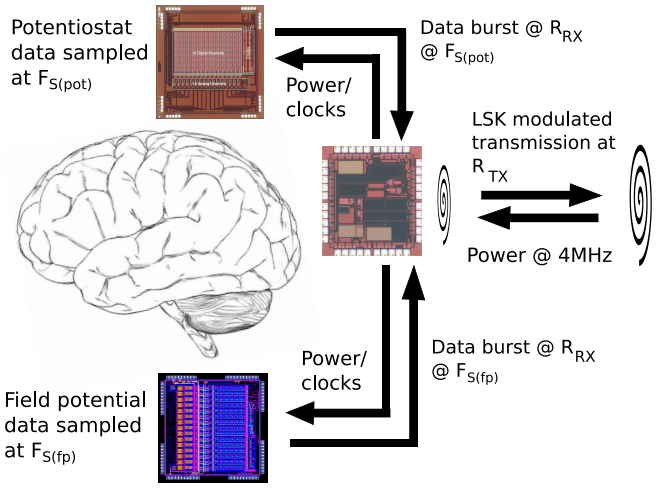


Fig. 1. System diagram showing the individual chips with variable data rates in an eventual implantable scenario. In this work the field potential data is played from a memory.

I. INTRODUCTION

Simultaneous detection and sensing of neurochemicals and electrophysiological field potentials would be very useful in studying the interaction between the chemical synaptic activity and the electrical neuronal activity. Communication and processing in the nervous system, for the most part, is by electrical signals travelling down neurons. At insulating gaps between two neurons (the synapse), the electrical activity in the pre-synaptic neuron causes the release of neurotransmitters into the synaptic cleft. Post-synaptic neurons sense these neurotransmitters and based on the specific chemical message initiate or supress the transmission of electrical activity through them. Thus, the electrical and chemical activities of neurons is highly corelated. To be able to monitor these related signals *in-vivo* is even more useful as it allows continuos sensing from awake and behaving animals. This could provide important imformation regarding neurological conditions where there is a imbalance between the chemical and electrical activity like epilepsy [1].

This work was supported by NIH MH062444 065296, DARPA, Army Research Office and the Whitaker Foundation. Chips were fabricated through the MOSIS foundry service.

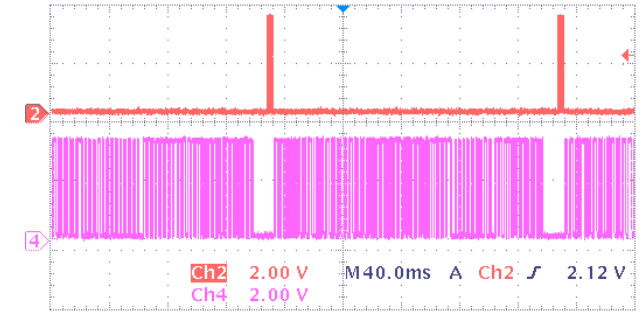
II. SYSTEM DESIGN AND DATA TIMING

A. VLSI Chips

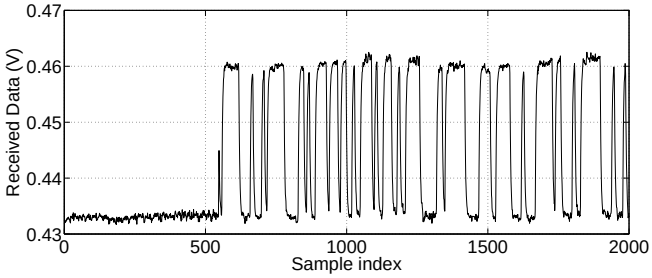
Our system consists of two custom designed and fabricated VLSI chips. A multichannel VLSI potentiostat [2] is used as a backend to an electrochemical neurotransmitter sensor that transduces concentrations into currents. The chip acquires 16 channels of currents potentiostatically and implements a configurable Δ-Σ analog-to-digital convertor (ADC) to convert them into a serial bitstream. The power harvesting and telemetry chip [3] uses a RF link to transfer power at a biologically optimum frequency of 4 MHz [4]. It has circuitry to generate a regulated power supply and recover clocks for the sensor chips. Data generated by the sensor chips is LSK modulated and transmited over the same link.

B. Timing

Neurochemical changes in general are on a very different time scale (on the order of several hundreds of milliseconds to seconds) than field potential events (on the order of a few tens of milliseconds). These are sampling rates in the sense of how frequently the measurement is made. For the VLSI potentiostat, sampling frequency depends on the



(a)



(b)

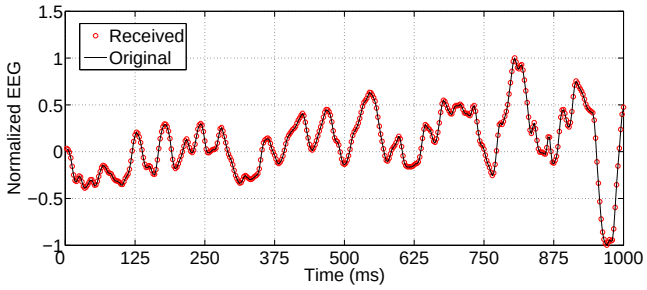
Fig. 2. (a) Scope plot showing the timing of our scheme. The top trace is the potentistat data burst. Lower trace shows the transmission of the multiplexed potentiostat and field potential data. (b) Shows a portion of the data recieved at the base station after demodulation with a peak follower.

concentration of the neurotransmitters being measured (lower concentrations need a longer conversion time which implies a lower sampling frequency). The chip digitizes 16 channels of the neurotranmitter concentration at 16 bits per channel 5 times every second and serially outputs the data at a burst rate of R_{RX}=64KHz. The field potential data is sampled at 400Hz and digitized to 12 bits per sample. The wireless data transfer chip has a bandwidth limitation because it utilizes the same link for power and data transmission. The constraining factor is the Q-factor of the coils used for transmission. A high Q benefits the power transmission system. However, it also curtails the bandwidth of the data transmission subsystem [3]. We choose a rate of 4 kbps. The timing diagram of our scheme is shown in Fig. 2. At a wireless transmission rate of 4 kbps, potentiostat data transmission takes $16 \times 16/4\text{k}$ = 64 ms. During this time, the field potential data is stored in a memory. Once the transmission of the potentiostat data is complete, we transmit the field potential data.

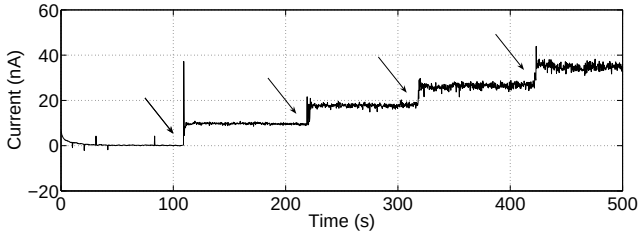
III. RESULTS

A modified class-E amplifier is used to drive the transmission coil and provide power for the system. A class E amplifier is used because of its high efficiency and low power supply voltage requirement [3]. System clock and supply voltages are recovered through the wireless chip.

Fig.2(b) shows the recovered data at the transmitter side. The current through the coil is converted to a voltage through a current sensing transformer. The voltage is then put through a rectifier and filtered to recover the envelope. A data



(a)



(b)

Fig. 3. (a) Original and demultiplexed LFP data shown for a 1 second window. (b) Demultiplxed output of one potentiostat channels showing response to the addition of the neurotranmitter dopamine to the test solution.

acquisition card samples the voltage at the output of the envelope detector for further processing. The amplifier and data recovery circuit were realized with discrete components on a board separate from the microchip test circuitry.

Fig.3 shows the decoded data for both modalities of the signal. The potentiostat was used to sense the neurotransmitter dopamine with a commercial electrode. The experimental protocol is described in [2]. Arrows denote times of dopamine addition to test solution. In order to show the feasibility of transmission, the LFP data was previously sampled at 400Hz from a human subject using a 10-20 electrode system, stored in a memory and multiplexed with the potentiostat data priot to transmission.

IV. CONCLUSIONS

We have presented a novel integrated system for simultaneous transmission of electrophysiological and neurochemical signals. The circuit consumes less than 4 mW of power when running from a 3.3V supply that is harvested through an inductively coupled link. In the near future, we plan to integrate all the systems on a standalone silicon die that can be used in a fully implantable system.

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