An Electrochemical Amperometric Sensing Circuit with Wireless Interface for Detection of Neural Signals

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I. INTRODUCTION

Bio-Chemical sensors are devices that detect physiological change or changes in the chemical/biological composition of materials in the environment. They usually consist of a sensitive layer or coating and a transducer. We quote from Dr. Jiri Janata’s work [1] at Georgia Tech, “Upon interaction with a chemical species (absorption, chemical reaction, charge transfer, etc.), the physiochemical properties of the coating, such as its mass, volume, optical properties, or resistance, etc. reversibly change. These changes in the sensitive layer are detected by the respective transducer and translated into an electrical signal such as frequency, current, or voltage, which is then read out and subjected to further data treatment and processing.”

In accordance with the principles laid out by Dr. Janata [2], chemical sensors can be classified into four principle namely Chemomechanical, Thermal sensors, Optical sensors and Electrochemical sensors.

Understanding brain functionality on a fundamental level requires measurements of both electrical and chemical neural activity. Implantable, bio-compatible, robust, multi-functional micro-probes capable of electro-physiological and chemical sensing in the brain are becoming available. These sensors detect electro-physiological phenomenon that generate current in order of a few pico-amperes. Thus mandating a low-noise, highly sensitive measurement of electrical action potentials and neuro-chemical signals. We propose a low-power microsystem with a small form-factor detection circuit that measures these variations reliably.

II. ANALOG FRONT END

One of the standard methods for interfacing, biological recognition elements (BRE) to electronics utilizes amperometric approach. The key electronic component for electrochemical measurement is a potentiostat which can be configured for potentiometric (apply fixed current and measure output voltage) or amperometric (apply fixed voltage and measure output current) readout. In this approach, sensitivities in the range of a few pico-amperes to nanoamperes is required. Thus mandating a low-noise, highly sensitive measurement of electrical action potentials and neuro-chemical signals. We propose a low-power microsystem with a small form-factor detection circuit that measures these variations reliably.

![Figure 1: Model of 1st order Sigma-Delta Modulator [13]](image)

Since the sensitivity of the entire system is depends directly on the AFE’s ability to sense and amplify the transducer output, we will evaluate more than one scheme here. One possible approach would be using Sigma-delta based AFE which can reliably converts very small currents into digital data directly [12].

A delta sigma based ADC enables noise shaping of the input signal. The $\Delta \Sigma$ operates at frequencies higher than Nyquist rates and enables shifting of the low frequency noise component to higher frequencies. A standard first-order $\Delta \Sigma$ implementation is shown in Figure 1.

This has the advantage of removing unwanted coupling from various noise sources in the vicinity of the system. 1-bit, Sigma Delta ADC offers a SNR better than alternate implementations for every quadrupling of sampling rate.
III. The Sensor Sub-system

In this work we explore a sensor interface for Electrochemical Amperometric Sensing [14] of extra-cellular concentration variations of neurotransmitters. Figure 2 shows Block diagram explaining our proposed system. The dashed block indicates elements of the proposed implementation:

The proposed AFE is shown in Figure. 3. In this implementation, the digital filtering and decimation is performed off-chip. This approach has been adopted to minimize the die area and power consumption.

A△Σ: BGR, Calibration loop, I→V
Aman △Σ: Modeling of ΔΣ, Current Ref, Calibration loop, Encoder
Abhilash △Σ: I→V, Comparator, Encoder
Saravanan RF Transmitter

IV. Work Allocation

The noise shaping characteristics of the modulator and hence the sensitivity of the whole system. [15]

2. Current Calibration Loop

The current-input ΔΣ Modulator that lies at the core of the neurochemical sensing circuitry as well as the front-end voltage-to-current (V/I) converter with DC baseline stabilization used to reconfigure the modulator for electrophysiological studies. This imposes stringent requirements on the current reference circuits that control the feedback gain of ΔΣ stage. This also mandates a current calibration scheme that will cater to system sensitivity variations and input dynamic range. Since the system clock/data rate is a constant, any variation in reference currents will include calibration of the integrating capacitor as well. A hybrid of analog feedback and digital control can be utilized to accomplish calibration with minimal impact on the system performance.

The design of these current sources also entails best practices in analog layouts for current matching as well as noise-reduction.

3. Digital Encoder and RF Transmitter

a) Digital Encoder

The Digital encoder, maps the Sigma-Delta output bit-stream to contain frequent level transitions which allow the receiver to extract the clock signal using a Digital Phase Locked Loop (DPLL) and correctly decode the value and timing of each bit. To allow reliable operation using a DPLL, the transmitted bit stream must contain a high density of bit transitions.

b) RF Transmitter [19]
REFERENCES