A Passive Multi-Channel Brain Implant for Wireless Neuropotential Monitoring

Wei-Chuan Chen*, Asimina Kiourti
Electrocience Laboratory, Electrical and Computer Eng. Dept.
The Ohio State University
Columbus, OH, 43212
chen.5825@osu.edu, kiourti.1@osu.edu

John L. Volakis
College of Engineering and Computung
Florida International University
Miami, FL, 33199
jvolakis@fiu.edu

***Abstract*—A passive, wireless and batteryless multi-channel (8 channels) brain implant is proposed with the following unique features: a) 28 times better sensitivity, b) 2 times smaller footprint, and c) scalability to 100s or even 1000s of channels. To verify the operation within biological tissues, *in-vitro* measurements are presented using fresh pig skin. Experimental results show that the proposed neuro-sensing system exhibits $20\mu V_{pp}$ sensivity at all channels. That is, it can record any signal generated by the human brain. Overall, this technology brings forward transformational opportunities for patients with epilepsy, Alzheimer's and Parkinson's disease.**

I. Introduction

Deep brain neuropotential monitoring can significantly improve the physical and mental well-being of humans. Examples include detection and interruption of early epileptic seizures, understanding for brain functionality for patients [1], [2]. However, state-of-the-art brain implants are limited by: 1) presence of intra-cranial wires that are obtrusive to the patients and restrict long-term brain clinical research, 2) excessive heat generation from the complex electronics, with possible damage to brain tissue, 3) presence of implanted batteries that limit comfort and increase infection risks.

To address the above concerns, a new class of wireless and batteryless brain implants are recently introduced by our group [3], [4], [5]. These single-channel implants can be as small as 8.7 mm $\times$ 10 mm [5], and exhibit sensitivity as high as $20\mu V_{pp}$. That is, they can detect all signals generated by the human brain [6]. However, their single-channel operation is not suited for 100+ concurrent recordings required in realistic clinical applications.

[1] In this paper, we present a new class of passive and wireless multi-channel brain implants with the following unique features: 1) concurrent recording from 8 channels by using an infrared transceiver/receiver, scalable to 100s and up to 1000s channels, 2) neuropotential detection as low as $20\mu V_{pp}$ per channel, and 3) validation using fresh pig skin to emulate human skin properties at RF and infrared bands.

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II. Operation Principle

A. Transceiver Overview

The block diagram of the proposed multi-channel neurosensing system is shown in Fig. 1. The set-up consists of 1) an implanted recorder placed just under the scalp with the recording electrodes protruding through the bone into the brain, and 2) an external interrogator placed outside the scalp. Its operation entails two processes: 1) wireless transmission of the neural signal using a process similar to RFIDs, and 2) selection of the different channels via an infrared-enabled implanted multiplexer.

The process for wireless and batteryless neural signal collection/transmission can be summarized as follows. First, the interrogator sends a 2.4GHz carrier signal to turn on the implanted recorder. The mixer in the implanted device uses this 2.4 GHz signal to generate a $4.8GHz \pm f_{neuro}$ modulated signal that is eventually transmitted back to the interrogator. For this case, f_{neuro} refers to the frequency of the signal. For recording at multiple brain locations, several probes are connected to the wireless recorder. These channels are turned on/off with an infrared controlled switch. Specifically, the channels are toggled using infrared signals transmitted through the scalp. These infrared signals turn on/off sequentially the channels of an extremely/low-power commercial multiplexer (Analog Devices, ADG708). For our particular design, the 8 channels are selected via an on-off scheme that employed 3 implanted photodiodes (Vishay, VEMD2000). These photodiodes can be individually turned on and off via the external infrared emitters to generate 8 different optical combinations. This scheme can be employed to toggle 100s or even 1000s of channels. The power consumption of the implant is mostly caused by the resistance of the photodiodes. Of importance is that the power can be reduced to trivial levels ($16\mu W$, -18dBm) by choosing high-value resistors (R = $1.5M\Omega$) and high-sensitivity photodiodes.

To guarantee a minimum detectable signal of $20\mu V_{pp}$ (or -90dBm), and considering a -120dBm sensitivity for the employed interrogator [4], the system loss (L_{sys}) must be smaller than 30 dB. The latter can be divided into three major

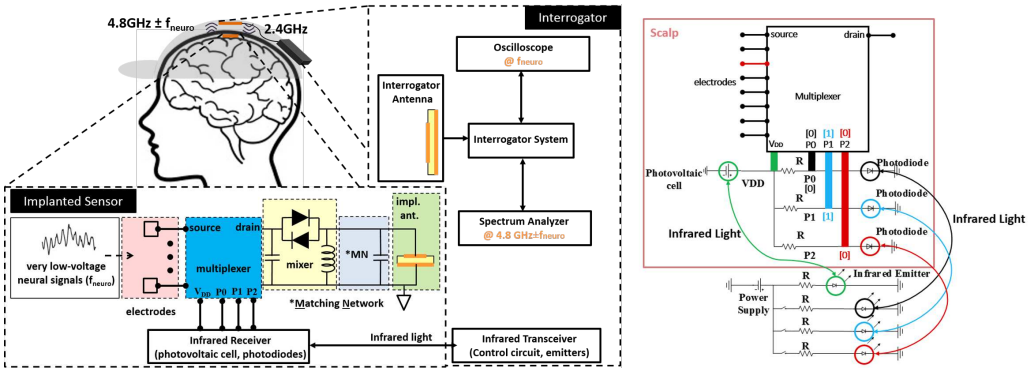


Fig. 1. Block diagram of the proposed mulitchannel neurosensing system. The infrared transceiver employs 3 photodiodes to form a 3 digit code for selecting each of the 8 channels. As an example of the three digit code is 0,1,0 then channel 3 is selected.

components as expressed in

$$L_{sys}[dB] = L_{prop}[dB] + L_{conv}[dB] + L_{match}[dB] \quad (1)$$

In this, L_{prop} = propagation loss between the implanted and interrogator antenna, L_{conv} = conversion loss at the implanted mixer, and L_{match} = impedance mismatch losses between the antenna and the mixer in the implanted device.

III. *IN-VITRO* VALIDATION

The fabricated brain implant is shown in Fig. 2. For this proof-of-concept demonstration, it occupies 40 mm × 40 mm. It was fabricated on Rogers RO4003C substrate ($\epsilon_r = 3.38$, $tan\delta = 0.0021$), 40 mils-thick (1.016cm). To ensure biocompatibility, the implant was coated with a 0.7mm-thick layer of Polydimethylsiloxane ($\epsilon_r = 2.8$, $tan\delta = 0.001$ [4]).

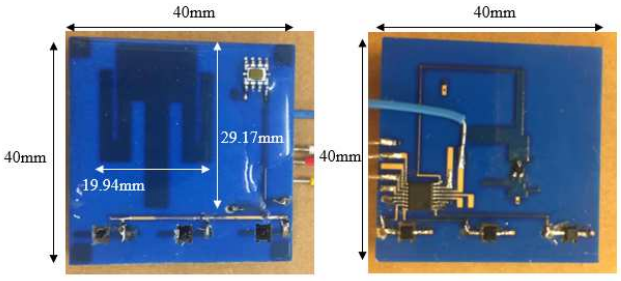


Fig. 2. Fabricated brain implant prototypes

Our measurements using a pig skin indicated that L_{sys} = -25dB. Although this measured L_{sys} is 7dB larger than simulations, it still meets the system loss design criterion of $L_{sys} < 30$dB. Fig. 3 provides example demodulated backscattered signals received at the interrogator. For these example signals, the emulated neuropotentials were as low as $20\mu V_{pp}$.

IV. CONCLUSION

We proposed and demonstrated the first-ever passive and wireless brain implant, scalable to 100s and even 1000s channels. To do so, RF backscattering techniques were employed

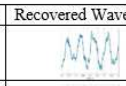
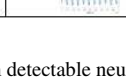
f_{neuro} (Hz)	Recovered Waveform	Minimum Detectable Signal Level
10		$20\mu V_{pp}$
50		$20\mu V_{pp}$
100		$20\mu V_{pp}$
500		$20\mu V_{pp}$
1000		$20\mu V_{pp}$
5000		$20\mu V_{pp}$

Fig. 3. Minimum detectable neural signals (MDS_{neuro}) and their recovered time-domain waveform at different neuropotential frequencies (f_{neuro})

along with an implanted infrared-activated multiplexer used to toggle among different channels connected to specify brain probes. For demonstration, an 8-channel prototype was fabricated and demonstrated to achieve $20\mu V_{pp}$ sensitivity in all channels under *in-vitro* conditions. Such excellent sensitivity implies that most neural signals generated by the human brain can be detected across all 8 channels in a passive and wireless manner. This is a game-changing capability for a very wide range of applications.

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