Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp820-821

Wireless Data Transmission in a Brain Tissue with Intra-Body Communication by a Micro-Sized Image Sensor

Hajime Hayami, Kengo Nagata, Makito Haruta, Hiroaki Takehara,
Toshihiko Noda, Kiyotaka Sasagawa, Takashi Tokuda and Jun Ohta

Nara Institute of Science and Technology
8916-5 Takayama, Ikoma, Nara, 630-0192 Japan
Phone: +81-743-72-6054 E-mail: ohta@ms.naist.jp

Abstract

Intra-body communication technology can make the size of an implantable device compact and its power consumption less than that of an RF wireless technology. In this paper, we report an implantable device with a micro-sized image sensor of 625-μm-width and 830-μm-length and demonstrate wireless data transmission in a brain tissue of a living mouse. The sensor transmits an output signal as a pulse width modulation (PWM). The PWM signals from the sensor are detected by a receiver electrode through a brain tissue. We have successfully demonstrated wireless data transmission in a mouse brain with intra-body communication.

1. Introduction

A fully implantable CMOS imaging device with wireless communication enables real-time monitoring with high spatiotemporal resolution and low invasiveness, and reduces the risk of infection through the interface boundary at the skin [1]. We have succeeded imaging a mouse brain using an implantable CMOS image sensor which was connected to a control board with wires [2]. However, to measure cooperative neural activities in the brain, multiple sensors need to be implanted into the brain without complicated wires.

To connect each sensor without any wires, we have proposed to apply an intra-body communication to our implantable imaging system [3, 4]. Intra-body communication is a wireless data transmission approach, in which an implanted device transmits electric signals through biological tissue as a conductive medium by capacitive coupling. This technique can reduce power consumption and minimizing device size [5, 6].

In this paper, we demonstrate an *in-vivo* transmission experiment with a pulse width modulation (PWM) image sensor in a living mouse brain.

2. *Methods*

All experimental protocols were approved by the Animal Experiment Committee of Nara Institute of Science and Technology.

2.1 Design and fabrication of the PWM image sensor

Figure 1a shows a photograph of the PWM image sensor chip fabricated by 0.35-μm CMOS technology. The image data is transmitted based on the body channel communication technique. The image sensor has 60 × 60 pixels based on three-transistor active pixel sensor (3-Tr APS) technology. PWM output signal is generated by comparing the voltages of the pixel output and the triangle wave. More details are described in the literature [7].

2.2 Design and fabrication of the implantable device

As shown in Figs. 1b and c, the PWM image sensor was mounted on a flexible printed circuit (FPC). Two bonding pads (VDD and GND) of the PWM image sensor chip were connected to the FPC via Al wires. The FPC can be connected to a 3-V battery for power supply. The PWM image sensor chip also has a pad for PWM signal output. The implantable device was entirely coated with a Parylene film for waterproofing to implant into a mouse brain.

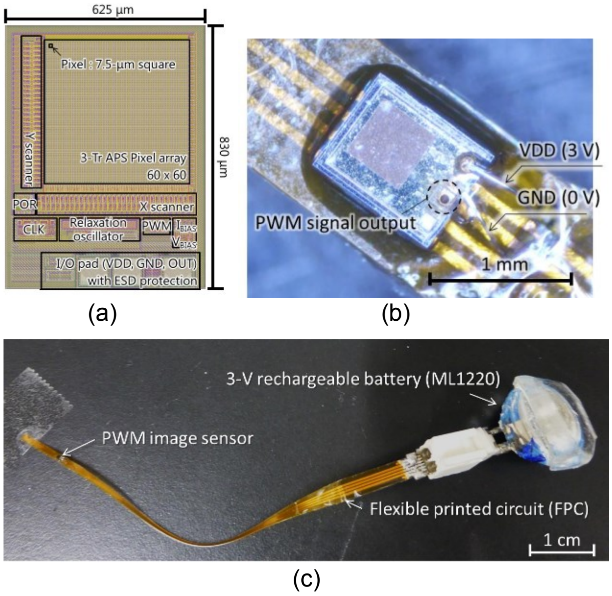

Fig. 1 The implantable imaging device with the PWM mage sensor. (a) A chip layout of the implantable PWM image sensor. (b) A close-up photograph of the implantable imaging device for wireless signal transmission. (c) Photograph of the fabricated device.

2.3 Experimental setup of data transmission in brain tissue with intra-body communication

Figure 2 shows a photograph of an experimental setup for signal transmission through a living mouse brain using the PWM image sensor. The implantable device with the

PWM image sensor was placed on the surface of a mouse's brain. The sensor was powered by a 3-V rechargeable battery (ML1220) to isolate the sensor ground from the receiver circuit.

An electrode for PWM output was formed on the output pad of the image sensor by a gold ball bump with a diameter of about 100 µm. A tungsten needle electrode was placed on the surface of a mouse brain and connected to a receiver. The electrode on the image sensor and the tungsten needle electrode were placed with 2-mm separation. Received waveforms were monitored using an oscilloscope (MSO2024).

2.4 Receiver Circuit for reconstruction of attenuated signals in the brain tissue

Figure 3 shows a schematic of the receiver circuit. The receiver circuit was designed to reconstruct the PWM signal from the received waveforms. In the received waveforms, edges of the output signal appear as spike pulses, because DC component of the sensor output is attenuated through the brain tissue. The receiver has two functions. The first function is detecting the pulse edge. The second function is reforming the PWM signal.

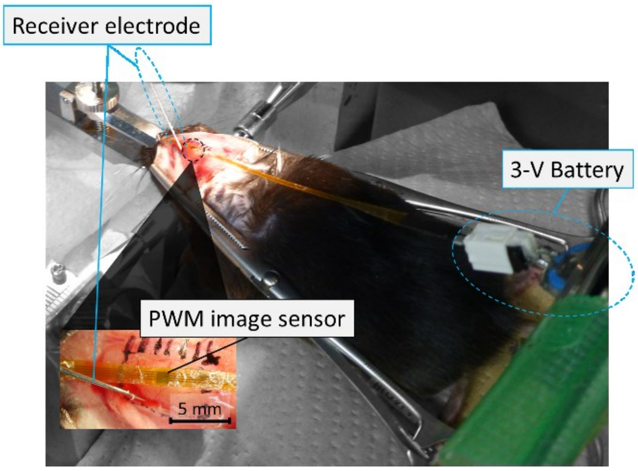

Fig. 2 An experimental setup of data transmission in a brain tissue using the PWM image sensor.

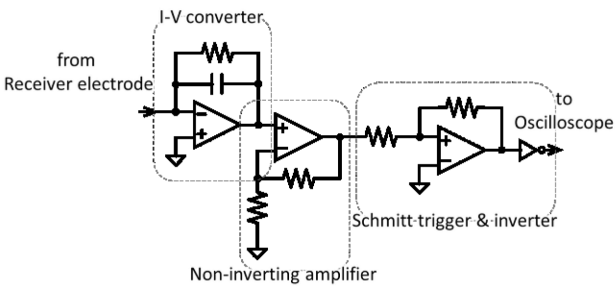

Fig. 3 Schematic of the receiver circuit. The spikes are amplified with an I-V converter and a non-inverting amplifier. A Schmitt trigger and an inverter reconstruct block pulses from detected edge pulses. The reference voltage of the I-V converter and Schmitt triggers were set to circuit ground.

3. Results and Discussion

We successfully detected transmitted signals from the image sensor by the electrode at the surface of the brain and reconstructed the PWM waveforms. As shown in Fig. 4 (solid-line), the received signal had positive and negative spikes, because low frequency components were attenuated by the brain tissue. Those spikes were originated from the edges of the output signals from the image sensor. Hence, the received signal was reconstructed to the PWM signal by the receiver circuit, as shown in Fig. 4 (dot-line). On the sensor output waveform, the relatively long pulses correspond to the edge of column in the pixel array of the image sensor. Through the receiver circuit, the PWM waveform of the sensor output was successfully recovered.

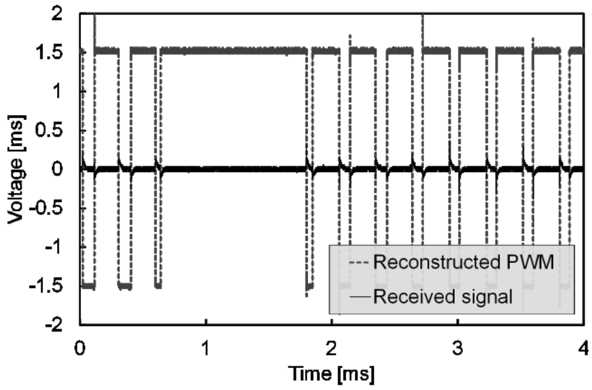

Fig. 4 Demonstration of signal transmission in a mouse brain. Received signal waveform by the electrode at the surface of the brain (solid-line) and reconstructed PWM waveform (dot-line).

4. Conclusions

We developed implantable imaging device with PWM mage sensor and demonstrated wireless data transmission in a mouse brain with intra-body communication. Intra-body communication is a promising approach for signal transmission between implanted sensors.

Acknowledgements

This work is supported by Grants-in-Aid for Scientific Research (26249051, 15K01289, and 15K21164) from Japan Society for the Promotion of Science (JSPS) of Japan, Tateishi Science and Technology Foundation, and VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Cadence Design Systems, Inc.

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