Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp604-605

An Implantable Subminiature PWM Image Sensor Based on Body Channel Communication

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Abstract

We demonstrate a pulse width modulation (PWM) image sensor as an implantable bio imaging device. The sensor transmits an electric signal without wiring through living body. By using PWM, the sensor can reduce its size and power in comparison with digital techniques. In this study, we obtained output signals of the sensor with an extracorporeal receiver through a phosphorous buffered solution (PBS) as a simulant body.

1. Introduction

Fully implantable CMOS imaging devices with wireless communicators enable not only real-time monitoring with high spatiotemporal resolution and low invasiveness to an animal's body, but also reducing the risk of infection through the interface boundary [1]. We have succeeded imaging of a part of mouse brain by an implantable CMOS image sensor connected with wires [2]. However, to measure cooperated neural activities in the brain, a lot of sensors should be implanted without complicated wires.

In previous work, we have applied a communication technique through a body to our implantable imaging system. In this technique, the internal body device transmits electric signals through biological tissue as a conductive medium by capacitive coupling. This technique allows reducing power consumption and minimizing device size [3, 4]. On the basis of these techniques, we have proposed a miniaturized implantable image sensor without wires for signal output [5-7].

In this work, we designed an ultra-small sensor based on a pulse width modulation (PWM) and demonstrate image signal transmission through a simulant body.

2. Implantable Imaging System

PWM Image Sensor

We designed a miniaturized PWM image sensor in 0.35-μm CMOS technology. The data is transmitted based on the body channel communication technique. In our previous work, we demonstrated signal transmission with an image sensor integrated with an analog-digital converter (ADC) [8]. However, the ADC occupies large area and consumes relatively high current (1.1 mA at 3 V). On the other hand, the PWM modulator consumes less power than the ADC because the PWM signal has less number of pulse transitions for each pixel data than digital signals.

Fig. 1(a) shows the layout of the sensor and components. Fig. 1(b) shows a system block diagram with the PWM image sensor. The image sensor has 60 × 60 pixels based on three-transistor active pixel sensor (3-Tr APS) technology. The chip size is 625 × 830 μm^2. Bias voltage and constant current source (VBIAS and IBIAS) circuits were designed with current mirror circuit and MOS diodes. A relaxation oscillator generates triangle wave by using clock (CLK) and IBIAS. The upper or lower limit of the triangle wave was defined by the voltages of VBIAS. The CLK signal is generated from the triangle wave. PWM output signal is generated by comparing the voltages of the pixel output and the triangle wave. The power consumption of the PWM image sensor (0.7 mA at 3 V) is lower than that of the ADC in our previous work.

Experimental Setup

We constructed a system for signal transmission through PBS using a PWM image sensor. Fig. 1(c) shows an experimental setup. A metal mesh was placed on the pixel array of the PWM image sensor for imaging test. The sensor was powered by a 3-V battery to isolate the sensor ground from the receiver. The sensor output port was connected to a circular Au electrode with a diameter of 2 mm. The receiver was connected another electrode with the same shape. The electrodes are submerged in PBS with 5-mm separation. The receiver circuit amplifies the signal pulses from the sensor.

Receiver circuit

Fig. 1(d) shows a schematic of the receiver circuit. The receiver has two functions. The first function is the pulse edge detector. Because the DC component of the sensor output is attenuated through PBS, the edges of the output signal appear as spike pulses. The spikes are amplified with an I-V converter. Next, a Schmitt trigger reconstructs block pulses from detected edge pulses. The second function is eliminating chattering by an envelope detector. And then, another Schmitt trigger inverter reforms pulse shape. The offset voltage of the I-V converter and Schmitt triggers were set to half the power-supply voltage.

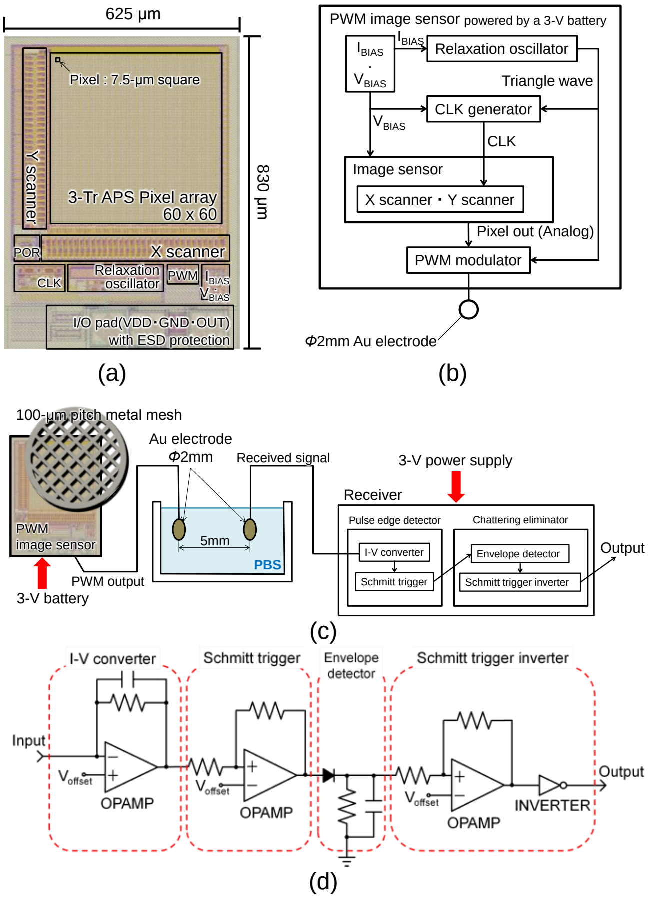

Fig. 1 (a) chip layout design of PWM image sensor, (b) block diagram of PWM image sensor, (c) experimental setup for signal transmission through simulant body and (d) receiver circuit.

3. Results and Discussion

Transmission of PWM Image Sensor Output through PBS

We succeeded to acquire PWM sensor output waveforms and receiver output waveforms as shown in Fig. 2. On the sensor output waveform, the relatively long pulses correspond to the edge of column in pixel array. Here, the sensor and receiver circuit grounds were isolated. If the sensor output voltage is constant, the sensor output in Fig. 2 is kept at the offset voltage input into the I-V converter. The pulse edges of the sensor output appear as spikes in the waveform of the sensor output (Fig. 2). Through a comparator, the PWM waveform of the sensor output was successfully recovered.

Imaging example

Figs. 3(a) and 3(b) show photographs obtained by a microscope and the image sensor, where the image signal was reconstructed from the received output signal through PBS. The metal mesh appears dark because it was placed on the imaging area. The result indicates that the image obtained by the sensor was successfully transmitted to the receiver.

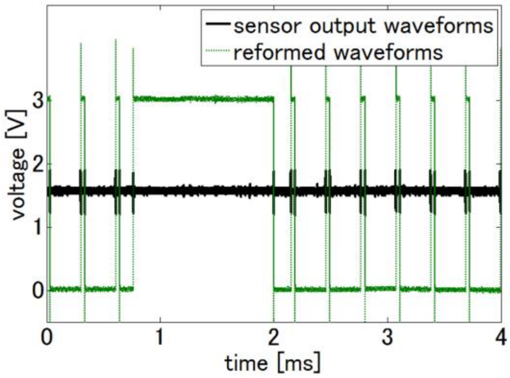

Fig. 2 PWM image sensor output in PBS and receiver output.

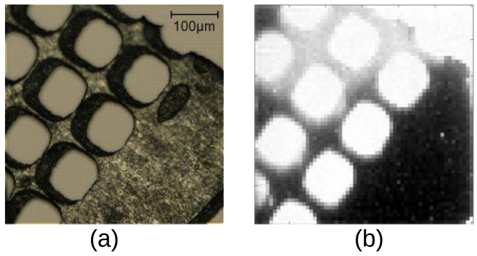

Fig. 3 (a) photograph by microscope, (b) reconstructed image from the received signal.

4. Conclusions

We designed a miniaturized and low power-consumed PWM image sensor, and succeeded to transmit a PWM image sensor output through PBS as a simulant body. The features of small size and low power consumption are suitable for *in-vivo* imaging.

Acknowledgements

This work was supported by KAKENHI (23246068).

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