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Implantable Image Sensor Based on Intra-Brain Image Transmission

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***Abstract*— We developed and fabricated a micro-imager based on wireless intra-brain communication using conductive property of living tissues. An pixel array, analog-to-digital converter and transmitter are integrated on a single chip. The dimensions of the chip are 1 mm × 1mm × 0.15 mm. We demonstrate wireless image transmission through phosphate buffer saline as a brain phantom.**

I. Introduction

Optical imaging techniques enable the observation of neural activities in a brain. By imaging intrinsic optical signals or fluorescence of functional dyes in the brain, several types of activities have been studied. [1]–[3]. To perform optical imaging, an optical microscope is usually used. Thus, the observation targets have to be secured. To overcome this issue, novel devices for observation under freely moving conditions have been studied recently [4]–[11]. Our implantable micro-imagers expand the application area of the optical imaging methods from not only the surface but also to cross-section of the brain. Due to their small dimensions, e.g. $<$ 1 mm^2, this architecture realizes deep brain imaging with low invasiveness. Also, neural activity observation of a freely behaving mouse has been demonstrated [7].

Our goal is multi-area imaging of a brain by using the micro-imagers [12]. (Fig. 1) In order to implant many chips, it is important to transmit power and signals wirelessly because completely free motion is not allowed and the behaviour of the mouse is significantly limited by wires to the chips. Conventional wireless communication techniques such as Bluetooth or Zigbee are not suitable Their power consumption and circuit dimensions are too large for our purpose.

To overcome these issues, we are developing an approach based on short range communication. Our strategy is to use the conductive properties of living tissue to realize low power communication [13]. It is similar to communication techniques through animal or human bodies [14]–[20]. In our previous work, we showed that it is possible to transmit imaging signal through a brain phantom without additional signal carrier. This technique has advantages with respect to circuit area and power consumption because the baseband digital signal is directly transmitted and no oscillator and modulator is required. However, the image sensor and the output circuits were separated.

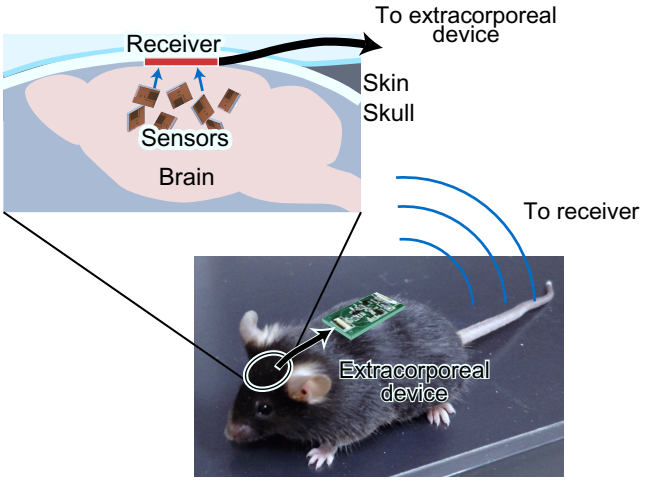

Fig. 1. Concept of distributed implantable CMOS image sensor system.

In this paper, we integrated the image sensor and the output circuits, developed in the previous work, on a single chip with dimensions of 1 mm × 1 mm. By using the device, we demonstrate feasibility of wireless image transmission with a tiny image sensor.

II. Micro-imager Chip for Digital Intra-Brain Transmission

We designed and fabricated a micro-imager integrated with an analog-to-digital converter (ADC) and an output circuit. The photograph of the micro-imager is shown in Fig. 2. Figure 3 and Table I show the block diagram and the specification the micro-imager, respectively. The imager is designed for implantation into a mouse brain and fabricated in 0.35-μm 2-poly 4-metal standard CMOS technology. The area of the imager is 1.0 mm × 1.0 mm and the thickness is 0.15 mm. The pixels are based 3-transistor active pixel sensor architecture. The output from the pixel is amplified by 2-stage source followers (n-type and p-type) and fed into the ADC based on successive approximation technique. Its resolution is 10 bits and the input voltage is 1 to 3 V. The output signal from the ADC is converted to a serial signal by a parallel-to-serial converter. The image signal is output

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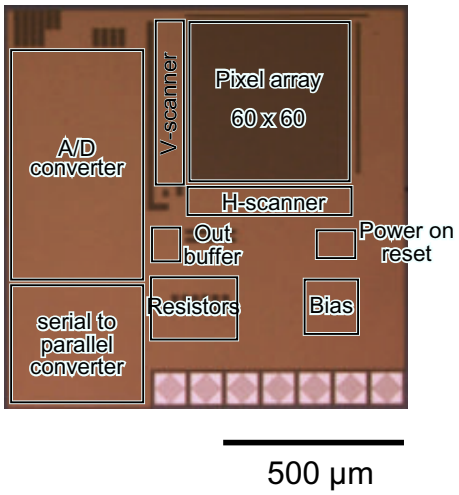

Fig. 2. Photograph of the micro-imager.

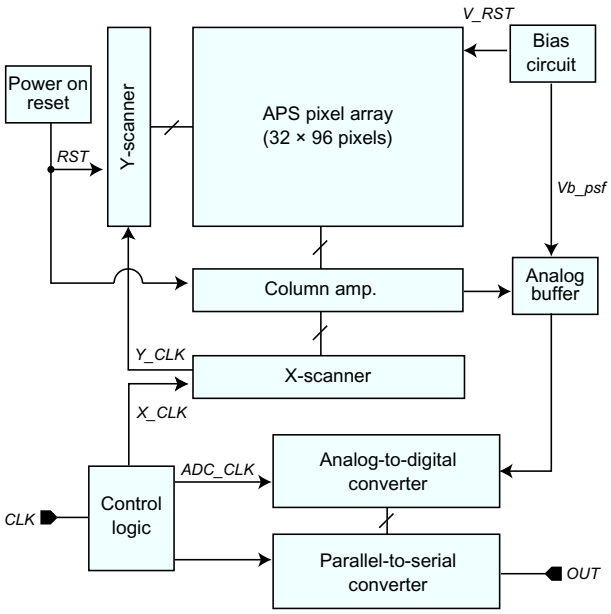

Fig. 3. Block diagram of the micro-imager.

TABLE I
SPECIFICATION OF THE MICRO-IMAGER

Technology		0.35 μm 2-poly 4-metal standard CMOS process
Supply voltage		3.3 V
Chip size		1.0 mm × 1.0 mm
Pixel	Type	3-transistor active pixel sensor
	Size	7.5 μm × 7.5 μm
	Fill factor	30 %
	Photodiode	Nwell-Psub
Pixel array size		60 × 60
A/D converter	Type	Successive approximation
	Resolution	10-bit
Load resistor		0, 1k, 5k, 10k Ω

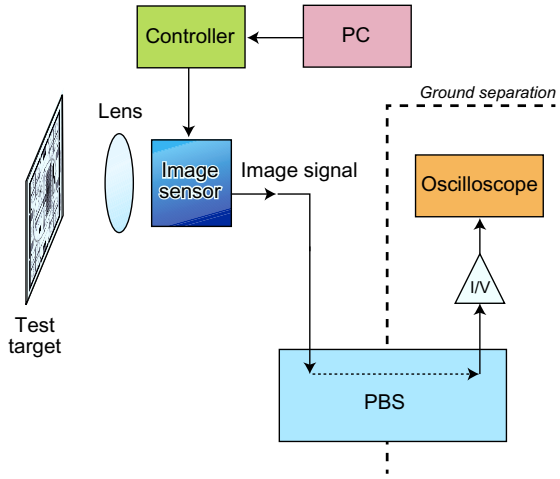

Fig. 4. Experimental setup for image signal transmission through phosphate-buffered saline (PBS).

through a resistor that can be selected from 0, 1k, 5k, 10k Ω. The capacitive coupling of clock signal between the chip and the brain would increase noise level. To reduce it, the top metal layer is used as a shield layer.

In the present device, the power of 3.3 V and the clock signal (CLK) are supplied with wires. In the future, the device should be powered without wires and the clock signal should be provided from an internal oscillator or an external RF signal in order to realize a wireless micro-imager system.

III. Signal Transmission Experiments

The experimental setup to demonstrate image signal transmission is shown in Fig. 4. The chip is mounted on a printed circuit board (PCB) for testing. The image is formed on the pixel array of the imager by using a focusing lens although contact imaging is performed in brain imaging. The phosphate-buffered saline (PBS)is used as transmission media where transmission efficiency was similar to the real mouse brain in our prior work [12]. Here, the micro-imager was placed outside of the PBS, and the signal from the imager was launched into the PBS by using a Au electrode on PCB. The areas of the both electrodes are 0.5 mm × 0.5 mm. The thickness of the substrate is 0.6 mm.

The received signal through the PBS was amplified using a current-to-voltage (I/V) converter composed of an operational amplifier (Analog Devices, AD8616) . The output voltage signal waveform was captured by using an oscilloscope (Tektronix, MSO2024). Here, the grounds of the equipment were isolated and the transmitter and receiver systems were only connected with the ground electrodes inserted in the PBS. The captured image signal from the micro-imager was processed by using MATLAB (The MathWorks, Inc.).

The waveforms received and processed are shown in Figs. 5. The operation clock input into the sensor was set to 1.67

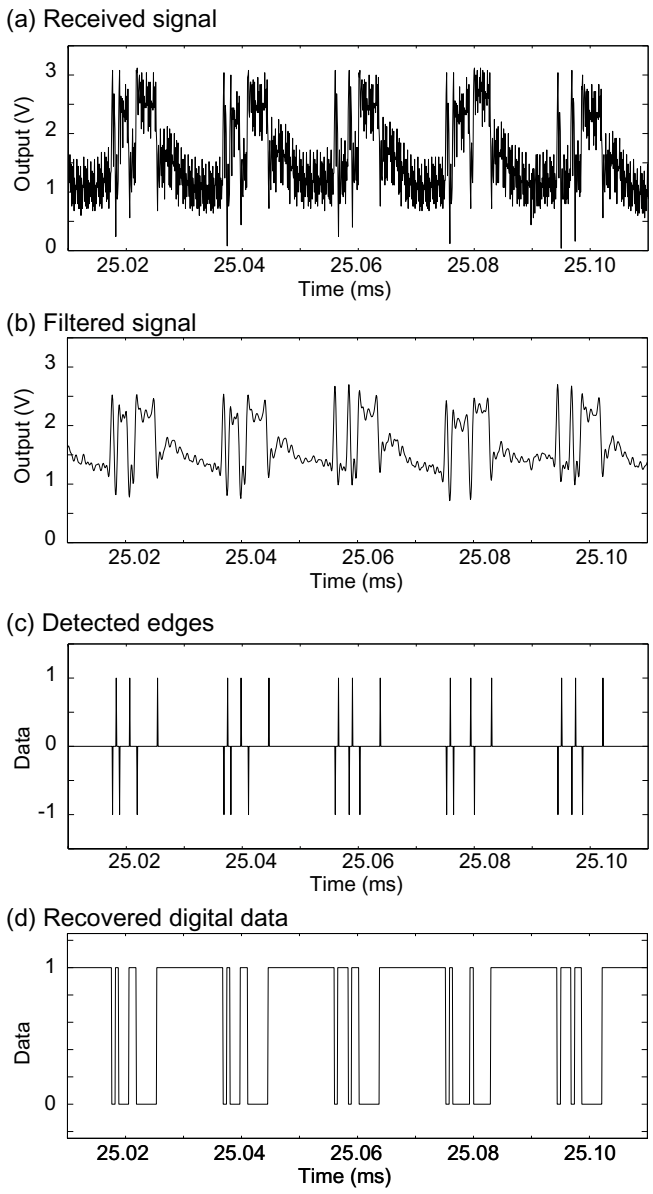

Fig. 5. Received and processed waveforms of the image data. (a) raw signal waveform through PBS. (b) waveform after low pass filtering for high frequency noise reduction. (c) waveform of detected rising and falling edges. (d) digital data recovered as a result of signal processing.

MHz. Figure 5(a) is a typical raw received waveform. The data of 5 pixels are included in the waveform. Due to the ground separation, the output level is not stable. However, weak connection through the PBS reduces the fluctuation amplitude within a few volts.

The high frequency noises in the raw received signal was filtered out by low pass filter processing. The result is shown in Fig 5(b). Although some fluctuations remain, edges of digital data can be clearly observed. The edges were detected as shown in Fig. 5(c). Here, the rising and falling edges correspond to -1 and 1, respectively. From this result, the digital data from the sensor was recovered as shown in Fig. 5(d), where the positive and the negative pulses are converted

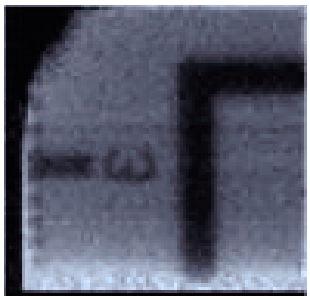

Fig. 6. Example of the image reconstructed from a received signal after transmission through the PBS.

to falling and rising edges, respectively. In this experiment, all the data recovery process was performed by the software. However, they can be implemented by using a filter circuit.

The example of the reconstructed image from the received data is shown in Fig. 6. To reduce the fixed pattern noise of the image sensor, the image under dark condition was subtracted. If some errors are included in the recovered data, gap or black/white pixel appears. In the present image, such errors are not observed.

The data format of the digital output was modified universal asynchronous receiver/transmitter (UART) format to send 10-bit ADC output. The output spectrum is relatively wide. Because transmission efficiency through the living tissue depends on frequencies, transmission with narrower spectrum format improve stability.

IV. Conclusion

We designed and fabricated a micro-imager integrated with wireless transmission function through living tissue. The output was directly connected to the Au electrode. The images were successfully reconstructed from the signal received through the PBS. This method is very simple and expected to have low power consumption because no RF oscillator or modulator is required. By integrating with wireless power supply, it is expected that an implantable wireless imager can be realized.

Acknowledgements

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