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# Wireless Intra-Brain Communication for Image Transmission through Mouse Brain

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***Abstract*— We demonstrate wireless image data transmission through a mouse brain. The transmission characteristics of mouse brain is measured. By inserting electrodes into the brain, the transmission efficiency is drastically increased. An AM signal modulated with the image data from an implantable image sensor was launched into the brain and the received signal was demodulated. The data was successfully transmitted through the brain and the image was reproduced.**

## I. Introduction

An implantable complementary-metal-oxide (CMOS) image sensor is expected to be a powerful tool to observe neural activities in the deep brain. By the virtue of advanced CMOS technology, very tiny image sensor can be designed and fabricated [1]–[5]. Such sensors are implantable even in a small mouse brain with low invasiveness and can take images while the mouse is moving [4]. The implantable sensors are useful to elucidate activities in the deep brain because fluorescent imaging techniques for neural activities are well developed [5].

Some experimental results using implantable image sensors have been reported [1]–[5]. However, the sensors were wired. In order to observe coordinated activities among brain functional blocks of a freely moving mouse, many sensor chips must be implanted with in the brain. Thus, wireless communication techniques are required.

We propose the distributed implantable image sensor system as shown in Fig. 1. By using conventional wireless technique, it is difficult to send imaging data directly from implantable sensors to an external receiver because of the limitation of power consumption and antenna size [6]. To solve this problem, an extracorporeal device is placed on the back of the mouse. The image data is sent as a wireless signal from the sensor to the extracorporeal device and from the extracorporeal device to the receiver system. The first step is more difficult and hence an important issue for research. A novel low power and high speed wireless communication technique is required. The technology should be suitable for transmission over short distances between the mouse deep brain and the brain surface.

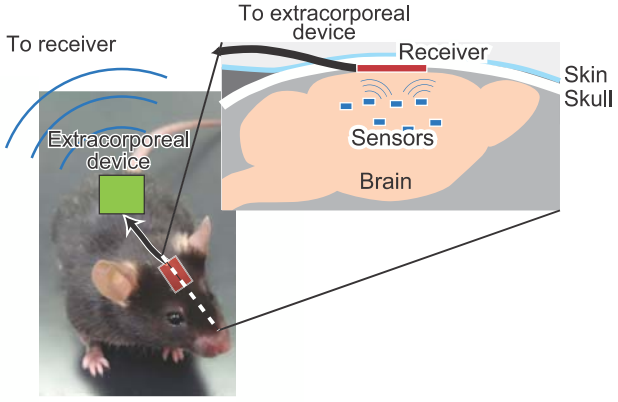


Fig. 1. Concept of distributed implantable CMOS image sensor system.

As one solution, we propose a wireless intra brain communication (WIBCOM) method. In this method, signals are directly transmitted from image sensors to the receiver placed on the brain surface through the brain [7]. It is known that living tissues have capability as transmission media [8]–[11]. It could be possible that the transmission characteristics of brain would be enough to send images from implantable image sensors. In this study, we measured transmission characteristics of a mouse brain and demonstrate that it is capable to communicate through a mouse brain with miniature electrodes. Al-Ashmouny et al. proposed the use of a similar method in an intra-brain communication microsystem for neural electric signal recording [12]. Their system uses frequencies from 100 to 400 kHz. However, the transmission window of living tissues is very wide and it has the potential to be applied for wide band communication such as imaging data transmission. We transmit AM modulated imaging data at 50 MHz from an image sensor through a mouse brain and demonstrate that the image can be successfully reproduced from the received signal.

## II. Transmission Characteristics through Mouse Brain

In order to realize implantation of many small image sensors, the sensors should be wireless because wired sensors would have high invasiveness and be difficult to deal with. In

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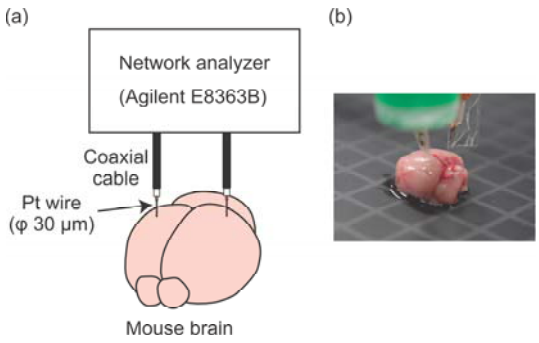


Fig. 2. (a) Schematic and (b) photograph of experimental setup.

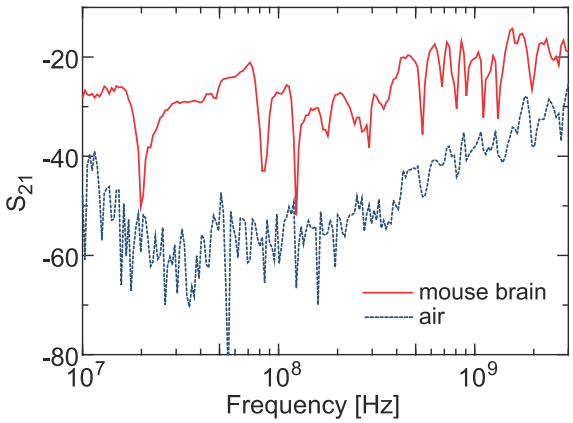


Fig. 3. Transmission characteristics of mouse brain with $\varphi 30 \mu$m Pt wire electrodes.

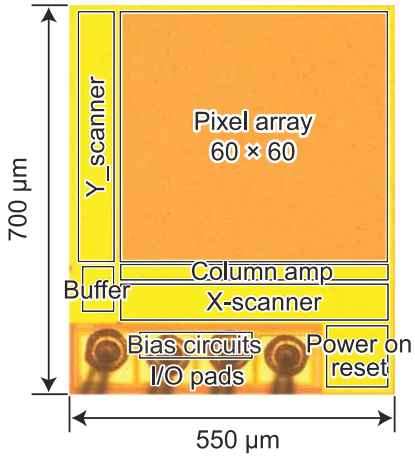


Fig. 4. Micrograph of the implantable CMOS image sensor.

TABLE I
SPECIFICATION OF IMPLANTABLE IMAGE SENSOR.

| | | |
|---|---|---|
| Technology | | 0.35 $\mu$m 2-poly 4-metal standard CMOS process |
| Supply voltage | | 3.3 V |
| Chip size | | 550 $\mu$m × 700 $\mu$m |
| Pixel | Type | 3-transistor active pixel sensor |
| | Size | 7.5 $\mu$m × 7.5 $\mu$m |
| Array size | | 60 × 60 |
| Photodiode type | | Nwell-Psub |
| Fill factor (%) | | 30 |

this study, a mouse brain is used as a transmission medium for wireless communications with low power. Electrodes are inserted into the brain tissue and signals are transmitted through the brain.

Figure 2 shows the experimental setup for the measurement of transmission characteristics. The brains of adult male mice were used in the present study. All animal procedures conformed to the animal care and experimentation guidelines of Nara Institute of Science and Technology and the National Institute of Health Guide for the Care and Use of Laboratory Animals. All efforts were made to minimize animal suffering and the number of animals used. The electrodes connected to a network analyzer (Agilent Technology, E8363B) were inserted to an isolated brain as shown in Fig. 2(b). To reduce electromagnetic coupling between the signal transmission paths, coaxial cables are used.

Pt wires with a diameter of 30 $\mu$m are soldered to the core of the cables and used as electrodes in order to suppress electrochemical reaction in the brain. The spacing between the electrodes was approximately 8 mm.

If an image sensor is implanted in a brain, it operates independently and the ground is separated from that of the receiver. To emulate this condition, we inserted baluns between the electrodes and the measurement equipment [11]. However, at frequencies higher than several tens of MHz, the effect of ground separation to transmission characteristics is low.

Figure 3 shows the transmission characteristics ($S_{21}$) through the brain. The red solid line shows when Pt wires are inserted by approximately 3 mm. The surface area of each inserted electrode is estimated to be lower than 1 mm$^2$. The blue dotted lines shows the characteristics for transmission through air where the gap between the wires is the same as in the mouse brain. Throughout the whole measured frequency range (from 10 MHz to 3 GHz), the transmission efficiency is improved when the electrodes are inserted into the brain. Especially around 50 MHz, improvement is more than 20 dB. These characteristics indicate that high speed and low power data transmission can be realized in the brain.

The improvement of transmission efficiency was observed only when both the electrodes were in contact with to the brain. Such characteristics are not achieved with the devices electrically isolated from the brain tissue. The present technique enables high speed data transmission without wires in the limited condition where the devices are implanted.

## III. Image Data Transmission through Mouse Brain

### A. Implantable CMOS image sensor

To demonstrate image data transmission through a mouse brain, we used a tiny CMOS image sensor, which was designed in our laboratory. It is fabricated using a 0.35 $\mu$m

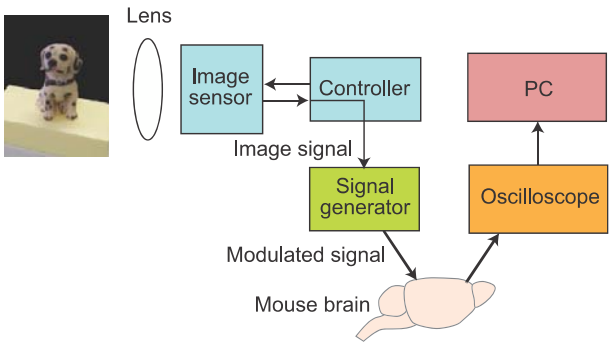


Fig. 5. Experimental setup of sensor image transmission in a mouse brain.

2-poly 4-metal standard CMOS process of Austria Micro Systems. A photograph of the image sensor chip and its specifications are shown in Fig. 4 and Table I, respectively. The sensor is based on a 3-transistor active pixel sensor. The pixel size is 7.5 $\mu$m $\times$ 7.5 $\mu$m and the number of pixels is 60 $\times$ 60, which corresponds to the imaging area of 450 $\mu$m $\times$ 450 $\mu$m.

In order to allow its implantation in a mouse brain, the chip was designed to be as small as possible. The bias circuits are fabricated below the I/O pads to reduce the chip area. The sensor size is 550 $\mu$m $\times$ 700 $\mu$m. The number of I/O pads is reduced to 4 by generating signals to drive the pixel array in the integrated circuit in the sensor chip. We have demonstrated in-vivo imaging of brain activities in a mouse brain using similar sensors [1]–[5].

In this experiment, the operation clock was set to 200 kHz. It corresponds to the frame rate of 32 frames per second.

### B. Experimental procedure

The experimental setup of image transmission through the mouse brain is shown in Fig. 5. The small image sensor is driven by a PC and a control circuit board. In this experiment, the sensor was not implanted and an image focused on the sensor was acquired. The output signal from the sensor was attenuated to the appropriate level by a variable attenuator and input into a signal generator (Agilent Technology E4432B/UN5, UND), where an AM modulated signal is generated. The carrier frequency was set to 50 MHz, which is one of the frequencies with high transmission characteristics. From Fig. 3, $S_{21}$ increases by approximately 25 dB at this frequency when the electrodes are inserted in the brain.

As in the experiment in Section II, the modulated signal were launched into the brain with a platinum electrode of diameter 30 $\mu$m at the end of a coaxial cable. The signal was received with an identical electrode and recorded by an oscilloscope (Tektronics, DPO4034). The sampling rate was set to 250 Msamples/sec. The sampling period was 40 msec which is enough to record 1 frame. The received signal was demodulated by a PC and the image from the sensor was displayed on the screen.

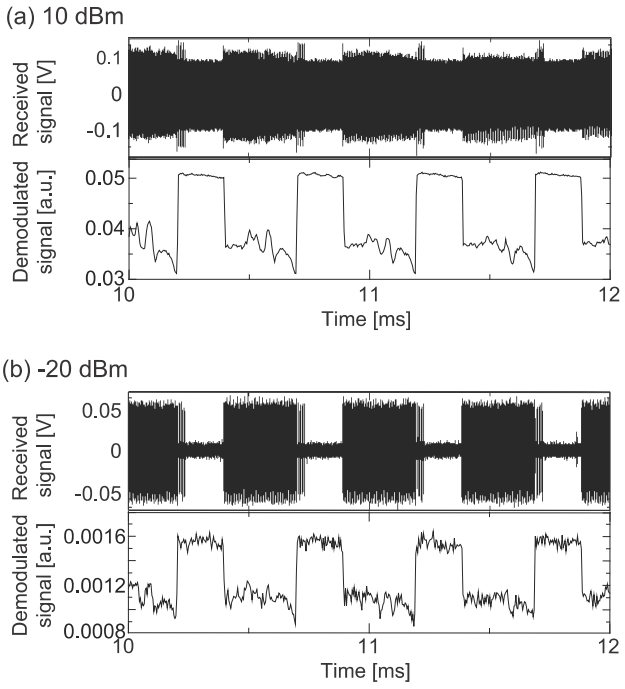


Fig. 6. Waveforms of the received and demodulated signals with the modulated RF power of (a) 10 dBm, and (b) -20 dBm, respectively.

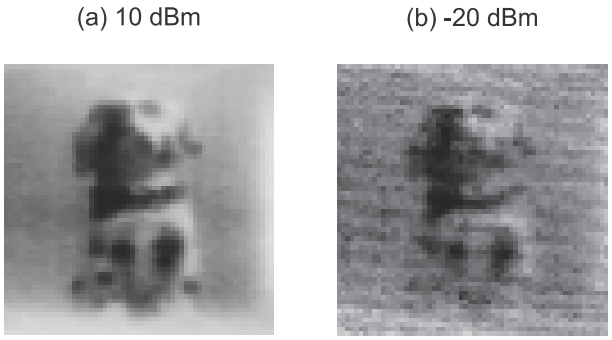


Fig. 7. Images generated from the data transmitted in the brain with the modulated RF power of (a)10 dBm and (b) -20 dBm.

### C. Imaging results

The received and demodulated signal waveforms are shown in Figs. 6. The output level of the signal generator was set to (a) 10 dBm and (b) -20 dBm, respectively. The period shown in the figures corresponds to a part of the image data corresponding to approximately 4 rows, that is 240 pixels.

The waveform of the received signal changes drastically with decrease of the output level from the signal generator. This indicates that the received signal includes not only the image data but also noises from other devices or equipment. Especially, in Fig. 6(b), the noise components emitted from the circuit board are dominant.

The lower traces of Figs. 6 (a) and (b) show the waveforms of the demodulated signals. As the output level decreases, the signal to noise ratio also decreases. However, the waveform of -20 dBm is similar to that of 10 dBm. This shows that the

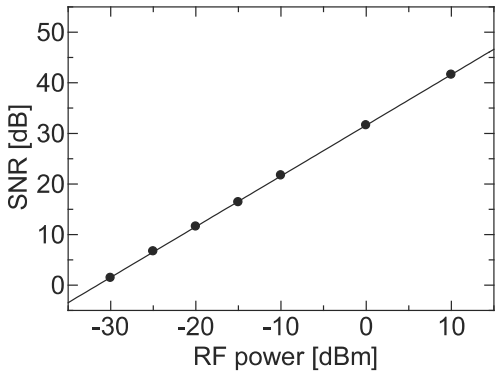


Fig. 8. Signal to noise ratio of demodulated signal from the image sensor.

image data was successfully transmitted through the brain. The relatively large unwanted components appearing in the raw signal at -20 dBm are not overlapped with the AM signal and are filtered out by demodulation process.

Figure 7 shows the images generated from the data transmitted in the brain. The output level was set to (a) 10 dBm and (b) -20 dBm. As predicted from the result of the demodulated signal waveforms, the images from the sensor were successfully transmitted in the mouse brain. Figure 8 shows the signal to noise ratio (SNR) of the demodulated signal. The signal level was estimated from the difference between bright and dark pixels. The noise level was obtained from a dark image. At the input power of -20 dBm, the SNR was 12 dB.

The carrier frequency used in this experiment was 50 MHz. However, the transmission characteristics shows the efficiency improvement by the electrodes insertion even at higher frequencies up to several GHz. Hence, with this method of wireless signal transmission the transmission window of the mouse brain is up to several GHz. To integrate an oscillator in a small CMOS chip, a higher frequency than several hundreds MHz might be used as a carrier.

Our results show that low power image transmission can be achieved by using the highly efficient propagation characteristics of living tissue. Thus, the distributed image sensor system for deep brain imaging shown in Fig. 1 can be realized.

## IV. Conclusions

We demonstrated high efficiency wireless image transmission through the mouse brain. The frequency of the input signal was set to 50 MHz and modulated with the signal from an image sensor. The result is consistent with the transmission characteristics of the brain, which shows that attenuation is drastically reduced by inserting electrodes into the brain tissue. The use of these characteristics makes it possible to reduce the signal level , which is very important for implantable devices, not only to realize wireless power supply but also to avoid thermal problems and electrochemical reaction on the electrodes. The image was successfully reproduced from the received signal even with input signal power of -20 dBm. The noise level was low enough and further reduction would be allowed.

For image data transmission, broader bandwidth is required than neural signal recording. The transmission bandwidth of the brain is broad enough to send image data simultaneously in many channels. We anticipate that the distributed implantable image sensor system integrated with power receiver can be realized based on this technique in the future.

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