

in-vivo Wireless Communication System for Bio MEMS Sensors

Kenichi Okada¹, Tomohiro Yamada¹, Takumi Uezono¹, Kazuya Masu¹, Akio Oki², and Yasuhiro Horiike²

¹Precision and Intelligence Laboratory, Tokyo Institute of Technology

4259-R2-17 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan

Phone & Fax: +81-45-924-5031 E-mail: okada@pi.titech.ac.jp

²Biomaterials Center, National Institute for Materials Science

1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan

1. Introduction

Bio sensors have been developed using bio MEMS technology as a key device of μ -TAS (micro-Total Analytical System) [1]. This paper proposes an *in-vivo* wireless communication system to extend an application of the μ -TAS. The proposed system provides a small-size and *battery-less* wireless communication through human body as shown in Fig.1. It was implemented into 1.8mm² chip, and it can realize an interactive sensing of everywhere in human body by swallowing or implanting into human body.

The crucial problem of the *in-vivo* wireless communication is very large attenuation of human body. In this paper, we report measured attenuation characteristics of human body and an antenna coil structure for the wireless communication chip.

2. Wireless Communication System

Figure 2 shows electromagnetic transmission types of electromagnetic wave and electromagnetic coupling. Attenuation characteristics through 15cm thickness of human body equivalent are measured at 2.45GHz [2], which is transmitted as electromagnetic wave. Table 1 shows measured attenuation of 300kHz, 1MHz, 3.5MHz, 13.56MHz, and 35MHz for 15cm thickness of human body equivalent, which are measured by the outside and inside inductors as shown in Fig.3. At these frequencies, a signal is transmitted by inductive coupling as a near-field communication. For permeation characteristics, the electromagnetic coupling transmission is advantageous to the electromagnetic wave transmission in Fig.2. We therefore use 13.56MHz for the proposed system because it is an ISM band and we can use the electromagnetic coupling transmission.

It is difficult to use usual modulations, because the attenuation is often varied by the moving of human body. Thus, Pulse Interval Modulation (PIM) is employed in our system [3]. PIM uses pulse interval for data transmission. The feature is that data transmission does not depend on the human body attenuation, so PIM at 13.56MHz is suitable for the proposed system.

S/N ratio is important issue for battery-less wireless communication, so the transmitting sequence is separated into two phases. In the first phase, inside device is charged up from outside coil to inside coil using inductive coupling. In the second phase, the inside device transmits medical information to the outside coil. At this time, charging from outside coil is stopped to avoid insensitiveness. Figure 4 shows block diagram of the designed system. The value k is coupling factor [3].

Figures 5, 6 and 7 show time domain simulated results of the proposed system at $k = 0.5$. Figure 5 shows capacitor voltage at charging time. In the first phase, capacitor is charged by the outside coil. Figure 7 shows voltage at the outside coil. In the second phase, interval time between the first and second pulses is determined according to measured medical informa-

tion. Table 2 shows simulated peak-to-peak voltage of first pulse as a function of coupling factor k .

Figure 8 shows the designed layout using 0.35 μ m Si CMOS process, and core size is 1.8mm square. In this time, we implemented the proposed system without control circuit.

3. Coupling Factor

From the result of Table 2, to improve S/N ratio, coupling factor k should be large. We hence investigate coupling factor between outside coil in Fig. 3 and inside coil. Figure 9(a) shows tablet structure, and the size is 9mm in diameter and 4mm in height. Figure 9(b) shows capsule structure, and the size is 5mm in diameter and 15mm in length. Both sizes are common in usual medicines. Magnetic flux density at the center of outside coil in Fig. 3 is given by Biot-Savart law.

$$B = (\mu I / \pi r) \cdot N_1 \cdot 2 \quad (1)$$

where μ is permeability, I is current of outside coil, r is length between line of coil and center of coil, and N_1 is turn number of outside coil. Mutual inductance is calculated by

$$M = \sum_{a=0}^{N_2} B \cdot S_a \quad (2)$$

where S_a is inside coil area of the a -th turn, and N_2 is turn number of inside coil. Coupling factor is calculated by

$$k = M / \sqrt{L_1 \cdot L_2} \quad (3)$$

where L_1 is self inductance of outside coil, and L_2 is self inductance of inside coil.

Table 3 shows calculated result of coupling factor and simulated result of $v_{outside}$ peak-to-peak. Coupling factor is calculated in both structures with or without ferrite core. Outer shapes of both cases are the same, and ferrite area can be used for coil line in case without the ferrite core. In this result, tablet structure is suitable for the proposed system, and coupling factor with ferrite is better than that without ferrite.

4. Summary

We propose the battery-less wireless communication system through human body. This paper investigates carrier frequency and antenna structure, and reports attenuation and coupling factor. The results show that 13.56MHz and tablet structure are suitable for the proposed system.

Acknowledgment

This work is partially supported by Grant-Aid for a Scientific Research Project on Priority Area from the Ministry of Education, Culture, Sports, Science and Technology, and VLSI Design and Education Center(VDEC), the University of Tokyo in collaboration with Cadence Design Systems, Inc.

References

- [1] A. Oki, et. al., IEICE Trans. on Electron. **E84-C-12**(2001) 1801.
 [2] T. Yamada, et. al., Proc. SSDM (2003) 366.
 [3] T. Yamada, et. al., to be presented at IEEE WoWCAS (2004).

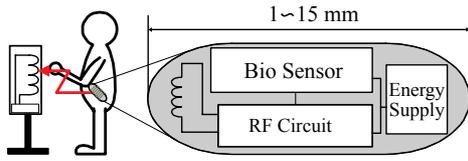


Fig. 1: Schematic of “in-vivo” wireless communication system

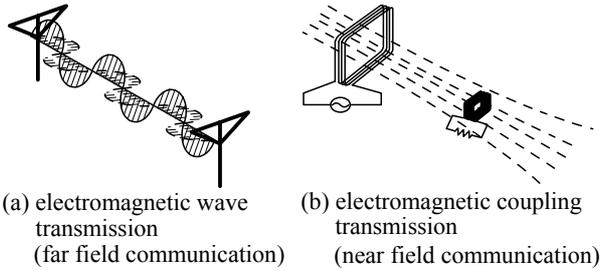


Fig. 2: Transmission Types

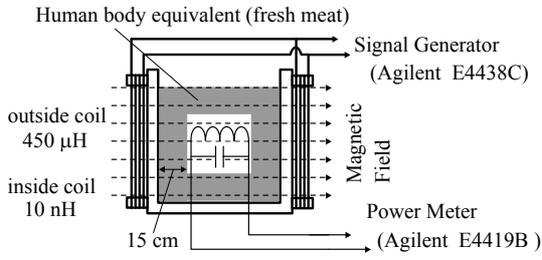


Fig. 3: Measuring Equipment

Table 1: Attenuation characteristics through 15 cm thickness of human body equivalent. (Average value)

300kHz	1.00MHz	3.50MHz	13.5MHz	35.0MHz
45 dB	51 dB	54 dB	47 dB	39 dB

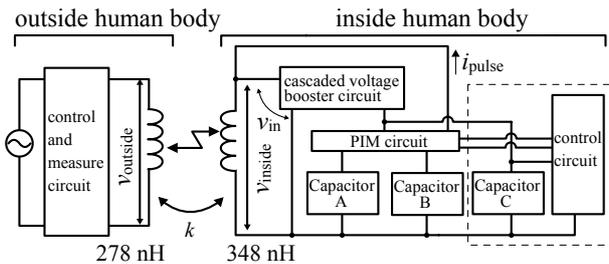


Fig. 4: Block diagram of wireless communication circuit

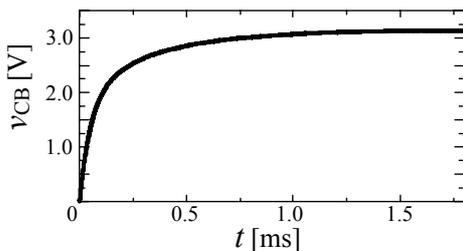


Fig. 5: Simulated voltage at capacitor C_B at $k = 0.5$

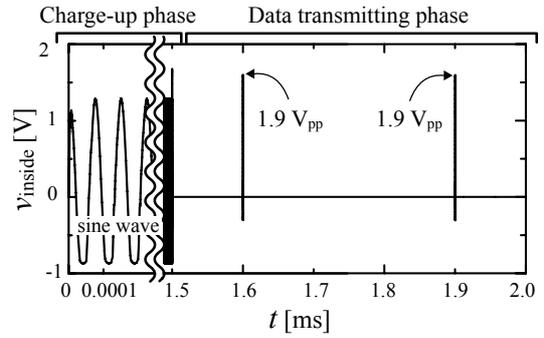


Fig. 6: Simulated voltage at the inside coil at $k = 0.5$

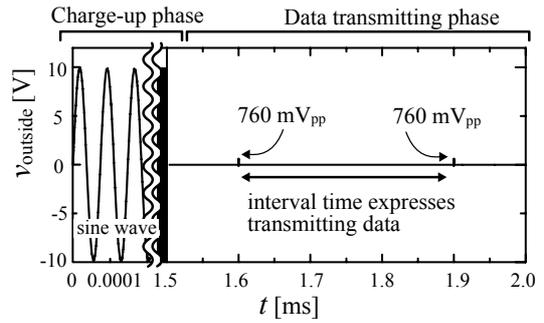


Fig. 7: Simulated voltage at the outside coil at $k = 0.5$

Table 2: Simulated peak-to-peak voltage of first pulse

coupling factor k	0.1	0.2	0.5	1.0
$v_{outside\ pp}$	16 mV	340 mV	760 mV	2.3 V

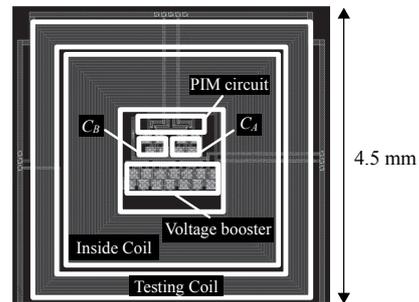


Fig. 8: Layout of TEG

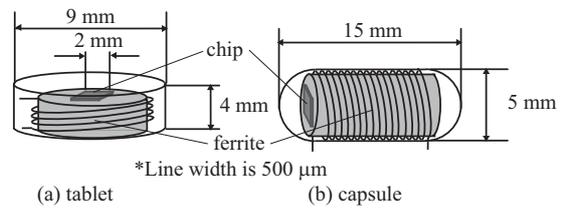


Fig. 9: Antenna structures

Table 3: Calculated result for each antenna structure in Fig. 9

core structure	without ferrite core		with ferrite core	
	tablet	capsule	tablet	capsule
self inductance	304 nH	343 nH	142 μH	243 μH
k	0.0032	0.0019	0.095	0.066
$v_{outside\ pp}$	120 mV	75 mV	230 mV	125 mV