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RF Propagation Characteristics and pH Measurement for *in vivo* Wireless Healthcare Chip

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1. Introduction

Small size RF communication systems have been proposed for communicating medical image and data through the human body [1][2]. Our study aims at developing small *in vivo* wireless communication chips as shown in (Fig. 1). The medical data measured is pH in the digestive organs of the body[3]. The data is communicated between the inside and the outside of the human body. This paper reports measurements of propagation characteristics of 2.45GHz RF signal through human body equivalent, and measurement of medical data such as pH.

2. *in vivo* pH sensor chip with communication

Power dissipation of the wireless chip should be reduced as low as possible. From the viewpoint of medical safety to the body, NiH or Li ion battery can't be used. One solution is the use of charging energy at the capacitor, which is integrated on the chip. The capacitor can be charged before or after the chip is ingested. Transmission power from the *in vivo* chip is supplied from the charged battery and the charging energy is limited by the volume of the chip, so that, in order to estimate the available transmission power or available capacitor size, the propagation characteristics of electromagnetic (EM) waves through the human body is one of the most fundamental data for *in vivo* chip. In the following section, the propagation characteristics of 2.45GHz signal through the human body equivalent is described and the available capacitor size for the *in vivo* wireless communication chip is discussed.

3. Propagation measurement

Figure 2 shows a measurement system. Transmitting and receiving antennas are non-directional dielectric chip-antennas: the commercially available 9×3×2mm^3 chip antenna (Murata, ANCM12G45SAA072TT1). The center frequency and the bandwidth are 2.45GHz and 100MHz, respectively. The human body is modeled by a 30cm×30cm×***D*** [cm] rectangular parallelepiped, which is filled with physiological saline or pieces of meat. ***D*** is the distance between transmitting and receiving antenna. Transmitted signal is 2.45GHz sinusoidal wave with 0dBm.

4. Results and Discussion

[Propagation characteristic] Figure 3 shows propagation characteristics as a function of the distance between antennas for air, a physiological saline, and stacked pieces of meat. The distance will be ***D***=10-20cm in actual application. Attenuation of this distance is 80-110dB. The attenuation of the human body equivalent is found to be A_{body}=60-90dB, because the attenuation at ***D***=0cm is about 20dB.

We discuss the energy that is required to be stored in the capacitor as summarized in Table I. With the assumption of the minimum power at the receiving antenna of P_{rmin}= -90dBm, the transmission power of the chip becomes $P_t=P_{rmin}+A_{body}$ = -30 to 0dBm. Several hundred bits of data is assumed to be transmitted, and the transmission rate is assumed to be 10kbps. These assumption gives a transmission time of T_t=0.1sec. The total transmitted energy required is $W_t=P_t \times T_t$=100nJ-100μJ.

The minimum capacitance can then be estimated. The capacitance required is $C = 2P_t/V^2$ = 2nF-2μF@V=10V. If the capacitor is fabricated on Si chip with 5nm-thick SiO_2, the size of the parallel plate capacitor is $S_{pc} = Cd_{ox}/\varepsilon$ = 0.3-300mm^2, which is a little bit large in order to be embedded in the mm-cm order *in vivo* chip. As a more densely packed capacitor structure, the finger structure capacitor is proposed as shown in Fig. 4. Using an aspect ratio of about 50, the size of the capacitor can be reduced by about 100 times to $S_{fc} = S_{pc}/100$ =0.003-3mm^2. This size of capacitor can be embedded in a *in vivo* wireless chip.

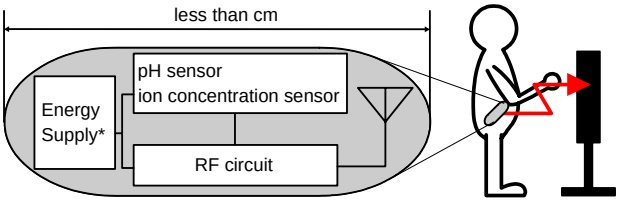
[Communication chip] As a small size communication chip, the chip with an active area of 150×150μm^2 (see Fig. 5) allowing kbps/Mbps has been developed[4]. The consumption power of several tens mW at the present time is required to be reduced.

[pH sensing result] For pH sensing, a plate-type 6×6mm^2 sensor has been developed. A micro channel with a cross section of 100×500μm^2 was fabricated on ISFET. As shown in Fig. 6(a), the dependence of the output signal of coated ISFET on pH varies by -0.04 mV/pH over the range from pH=0.7 to 10.0. Figure 6(b) shows the pH calibration curve obtained by the differential amplifier method. Figure 7

shows the pH calibration result measured over the pH range of 4 to 10. Medical data such as pH can be measured with a small size sensor chip.

5. Summary and Conclusion

We described the propagation characteristic of 2.45GHz signal through a human body equivalent. The attenuation is 60-90dB. The size of the capacitor in which the energy is charged and used for power supply is discussed from the measured data. For several hundreds bits communication, the capacitor size becomes several mm^2, which can be embedded in a mm-cm order *in vivo* chip. Furthermore, several mm^2 size pH sensor using ISFET were fabricated and evaluated. Components required for *in vivo* chip were presented: The work on further power reduction to be μW-nW level and implementation of these components are now progressing.



* Energy is supplied by charging energy of capacitor

Fig. 1. Schematic of "in-vivo" wireless communication chip.

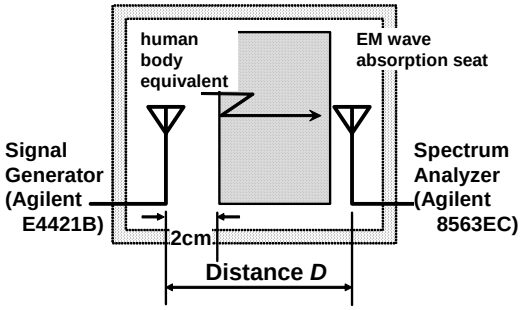


Fig. 2. Schematic of the experimental setup.

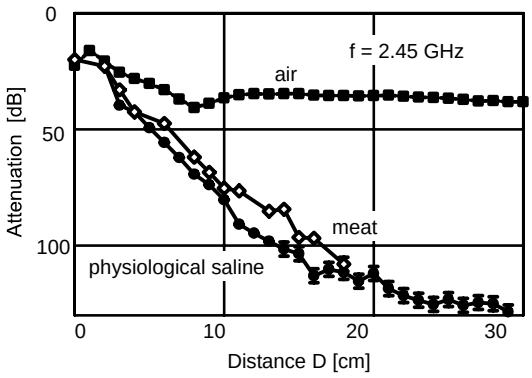


Fig. 3.
Propagation characteristics through a human body equivalent.

Table I. Estimation of the size of capacitor (electrostatic battery).

Human body width	W	10 cm – 20 cm
Attenuation	A_{body}	60 dB – 90 dB
Transmitting power	P_t = -90 dB + A_{body}	-30 dBm – 0 dBm
Expected transmitting time	T_t	0.1 sec
Transmitting energy	$W_t = P_t T_t$	100 nJ - 100μJ
Required capacitance	$C = 2 P_t / 10^2$	2 nF – 2 μF
SiO_2 thickness	d_{ox}	5 nm
Area of a parallel plate cap.	$S_{pc} = C d / \varepsilon$	0.3 mm^2 – 300 mm^2
Area of the finger structure cap.	$S_{fc} = S_{pc} / 100$	0.003 mm^2 – 3 mm^2

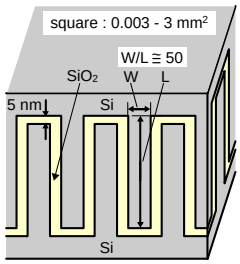


Fig. 4. Finger structure capacitor.

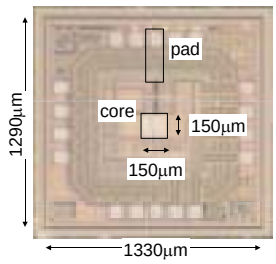


Fig. 5. A possible small size communication chip.

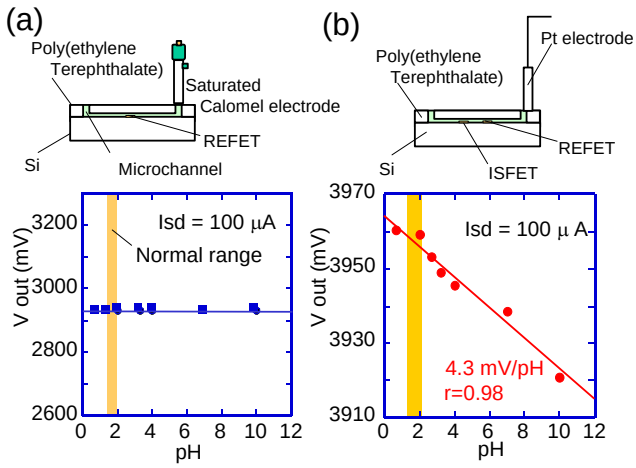


Fig. 6. Characteristics of (a) REFET and (b) REFET/ISFET

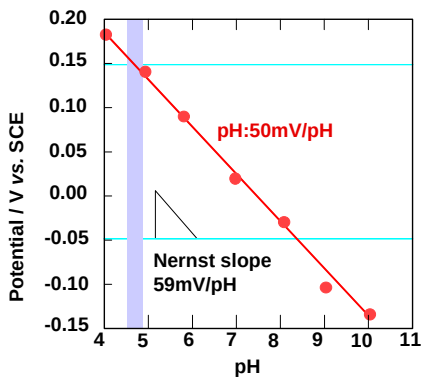


Fig. 7. Calibration curve of pH potentiometer sensor.

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