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Battery-less Telemetry System with a Closed-loop Power Control for Bio-Implantable Applications

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1. Introduction

Biomedical implants, such as the vital signal sensors [1] [2], use wireless interface, which can only be activated when placed near the interrogator. The operation of these systems is based on the telemetry inductive link without an embedded battery. To keep a supply voltage constant in such systems, an excessive energy is usually disposed as thermal energy at clamp circuit. It becomes, however, serious problem for the human body to make a heat spot higher than 42 degrees centigrade in any tissue. At frequencies higher than 100 kHz, international standards for electromagnetic safety identify limits of power dissipated in the human body in terms of specific absorption rate (SAR), expressed in W/kg. For example, the radio regulation law of Japan prescribes an acceptable maximum 1-kg average SAR of 0.08 W/kg. A 10-g in the case, an acceptable SAR was considerably lower than 0.8mW.

To realize a safe biomedical implantable device, we have proposed a closed-loop power control function to keep the temperature (i.e. power dissipation) within the allowable level. In this paper, the system design and experimental results of the proposed battery-less telemetry interface system are described.

2. Vital signal monitoring System

A simplified block diagram of the body-implanted vital signal monitoring system is outlined in Figure 1. It can be divided into the following two major functional blocks:

- *Transponder (implantable unit)*

The vital signal is sensed and digitized by Delta-Sigma modulator (ΔΣ ADC). An inductive link system consists of load modulation circuit (Load Mod.) and a resonant circuit (L2 and C2).

- *Interrogator (External unit)*

Supply of electric power to the implanted chip and communication between an external controller and the implanted chip are preformed via coupled coils. The external controller consists of a power controller to keep the power dissipation of the transponder, a demodulator (De-Mod.), and a microcontroller with decimation filter for the Delta-Sigma modulator.

3. Design considerations and Implementation

A block diagram of the proposed battery-less telemetry communication system is depicted in Figure 1. In the transponder, a RF signal is induced by the electromagnetic field and boosted by the resonant circuit. The rectifier converts a part of the incoming RF signal power to DC voltage. The closer the distance of coupled coils is, the higher DC voltages become. The DC voltage higher than the maximum rating damages the transponder chip. To avoid this situation, the voltage clamp circuit limits the voltage to a safe level. The Clock Gen is a comparator to detect the zero-cross point of the RF signal and generates the system clock. Load modulation method is utilized to send data back to the interrogator. The voltage regulator generates the supply voltage for these circuits. If the implantable device uses a telemetry inductive link to transmit power, electromagnetic field impinging on the human body could lead to dissipated power in the tissue and, in turn, increase in temperature. The interrogator coil moving closer toward the transponder coil will result in dissipation of additional power in the tissue. This cause of heat is the amount of the clamped current for the voltage clamp. To overcome this problem, we have implemented the closed-loop power control function using the telemetry inductive link. Figure 2 shows the transponder block for closed-loop power control system which detects both the amount of clamped current and dissipation current of the load circuit. The CMP compares the clamp current in the voltage clamp circuit with the source current of the voltage regulator. In this system, we control that the amount of clamped current (I_{C-DET}) is less than load dissipation current (I_{L-DET}). The equation is expressed as

$$I_{C-DET} < I_{L-DET} \qquad (1)$$

To reduce the power dissipation of the circuit, the current of I_{C-DET} and I_{L-DET} are scaled down to *S'* and *S*.

By the reverse telemetry link, the current level of the transponder is continuously transmitting to the interrogator as a 1-bit digital data. The interrogator decodes this data and controls the transmitted power. Figure 3 shows the data receiver and power transmitter with the power control circuit.

The interrogator and the transponder are able to communicate with the coupling coil via a telemetry inductive link where the carrier frequency 13.56MHz (= Industrial Scientific Medical band) is loaded to generate a sub-carrier with frequency of 847.5 kHz. The packets of 8-bit are transmitted from the transponder to the interrogator. The bit arrangement of the packet is as follows,

bit 1~4: 0	synchronous bit
bit 5 : 1	start bit
bit 6 :OVR	excessive current information
bit 7 :AD	A/D signal of vital signal
bit 8 :OP	option bit

The bits 1~4 are assigned as 0 (Low). Whenever the interrogator receives a start bit (bit 5), it starts reading each of the subsequent bit (bit 6~8). The bit 6 is an observed current level of Eq. (1), i.e. 1 (High) when the amount of current I_{C-DET} is larger than I_{L-DET}, otherwise 0 (Low). The bit 7 is the output signal of Delta-Sigma modulator.

4. Experimental result

Figure 4 shows the results of total verification test of the proposed system with the closed-loop power control function when the coils are placed at 10mm apart. The upper signal is start bit, the middle is data, and the lower is received voltage VDDC, as shown in Figure 2. The transponder sends 8-bit data within 75.2μs (=1/106 kHz x 8 bits). The right side of this figure shows allowable energy level because of bit 6 indicates 0 (Low). The time constant to change the power transmitter is chosen to be 10ms not to oscillate the VDDC. The power dissipation in the clamp circuit can be reduced to 56% from 367μW to 160μW. As results, the system keeps the same power dissipation and prevents the clamp circuit from heating up.

5. Conclusions

We proposed a battery-less telemetry communication system with a closed-loop power control function for bio-medical applications. Stable power supply has been obtained by the closed-loop power control function, which keeps the power dissipation of implantable chip within the allowable level for human body.

Acknowledgements

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The LSI chip used in this study has been fabricated in the academy chip fabrication program of TSMC Cybershuttle service.

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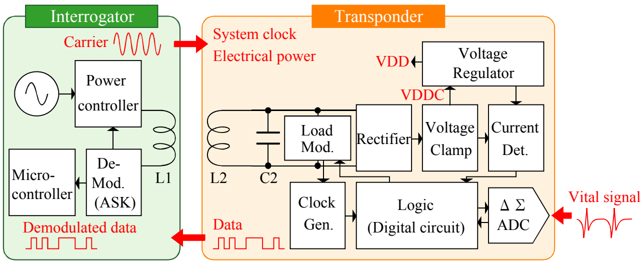


Fig. 1 Overview of the proposed vital signal monitoring system

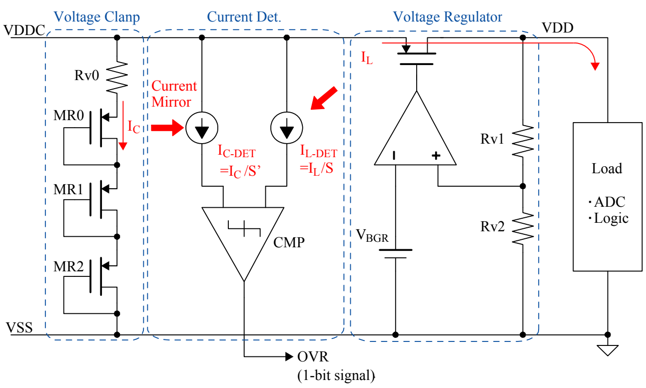


Fig. 2 Simplified excessive current detector of the transponder

Table I Characteristics of the transponder circuit

Technology	TSMC CMOS 0.18-μm
Operating voltage range	1.2 - 1.8 V
Power consumption	350 μW @ 1.8V
Carrier frequency	13.56 MHz
Sub-carrier frequency	847.5 kHz
Bit representation	NRZ
Data rate	106 kbps
Core area	330 μm × 420 μm (0.139 mm^2)

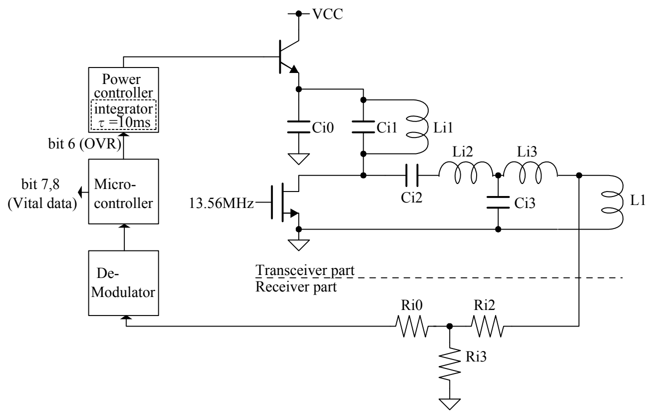
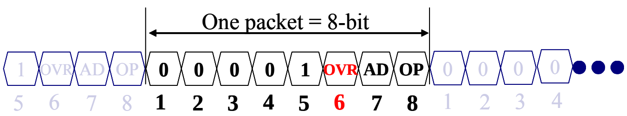
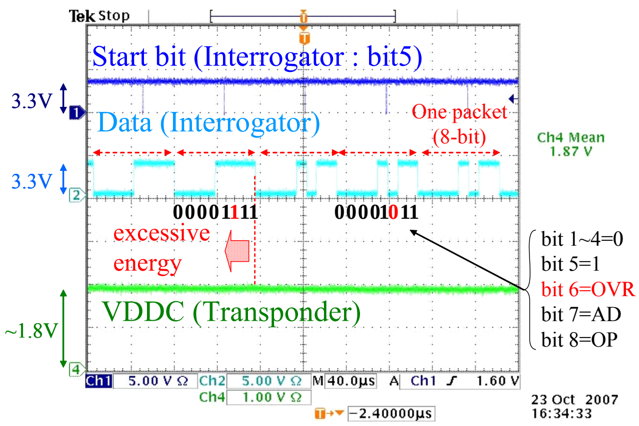


Fig. 3 Simplified interrogator system



(a) Bit arrangement (Data signal)



(b) A screen shot of oscilloscope

Fig. 4 Measurement result with closed-loop power control function