An Implantable Retinal Stimulator Design for Long-term Animal Experiments

J. A. Zhou, S. I. Park, J. M. Seo, S. W. Lee, E. T. Kim, H. Chung and S. J. Kim

Abstract— **this article reports on an electrical retinal stimulation system for use in long-term animal electrical stimulation experiments. The presented system consists of an implantable stimulator, which provides continuous electrical stimulation and an external component, which provides preset stimulation parameters and power to the implanted stimulator *via* a paired RF (radio frequency) coil. A rechargeable internal battery and a parameter memory part were introduced to the implantable stimulator to avoid use of the external component during the stimulation cycles. The same inductive coil pair was used to pass the parameter data and to recharge the battery. To separate the stimulation mode and the battery recharging mode, a switch circuit is used. The implantable stimulator was implemented with IC chips and the electronics except the stimulation electrodes were hermetically packaged in a biocompatible metal case.**

Index Terms—**electrical neural stimulation, neural prosthesis, long-term animal experiment, neural implant system, RF telemetry**

I. Introduction

Retinal prostheses are under investigation by several groups [1], and some preclinical and clinical trials have been reported [2]-[5]. Preclinical experiments are intended to estimate the stimulation parameters and to evaluate the efficacy and the safety of the devices while the clinical trials are aimed at demonstrating the feasibility of the prosthesis. Although the electrical stimulation of the retina in preliminary clinical study showed encouraging results such as the patient's perception of a small spot of light or basic shapes according to the stimulation pattern [3], there is much to be investigated and revised.

Before the implantation of the retinal prosthesis into the eye of the real patient, the electrical stimulation conditions, the long-term stability and durability of the retinal prosthesis *in vivo* should be verified. Previous reports showed either long-term biocompatibility of various electrodes without stimuli [6]-[9] or a safety threshold of electrical stimulation in acute experiments [10]-[12]. In the previous studies, electrical stimulation systems needed a wired or a wireless external component to provide parameters and power to the internal electrodes. When using these systems for long-term electrical stimulation tests in animals [13, 14], some difficulties arose. Systems with a percutaneous connection restricted the test animal's movement and sometimes posed an infection risk. In transcutaneously connected systems, the external controller was worn by the test animal and usually came off the test animal or was damaged by the animal.

In this article, an implantable retinal prosthesis system is proposed for a chronic electrical stimulation test in an animal model. For this purpose, a small rechargeable battery and a parameter memory were introduced into the implanted stimulator so the external power supply and control part could be removed during a chronic stimulation experiment. The external unit is needed for two purposes only: parameter passing and battery charging.

II. Method

The implantable retinal prosthesis system for a chronic animal experiment consists of an external unit for stimulation control and battery charging, and an internal unit for retinal stimulation (figure 1). A paired RF coil links these two units for data and power transmission.

The external unit has a stimulation waveform parameter selector to control the channel selection, amplitude, duration and rate of stimulation. This parameter selector generates a parameter data frame and was implemented using a commercially available digital signal processing chip, and the control codes, which were implemented in-house using the C programming language. The parameter data frame consists of 22-bit. To transmit this parameter data into the internal stimulator, pulse width modulation (PWM) encoding method is

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used. Logic ‘1’ and ‘0’ are encoded to have a duty cycle of 75% and 25%, respectively, and ‘end-of-frame (EOF)’ bit has a 50% duty cycle [15]. Such an encoding method enables easier synchronization and decoding because each bit has a uniform rising edge at its beginning. The transmission data rate is 125 kbps. For transmission of PWM encoded data, a class-E tuned power amplifier (data/power transmitter) is used with amplitude shifted keying (ASK) modulation. The carrier frequency is 2.5 MHz.

The transmitted data are received by the internal coil and then an envelope is extracted through a half-wave rectifier and a low-pass filter. Using this envelope signal, a data decoder in data/power receiver chip recovers the parameter data and saves it to the parameter memory chip. Using the same envelope signal, a voltage regulator generates power to be consumed by the data/power receiver chip (figure 1).

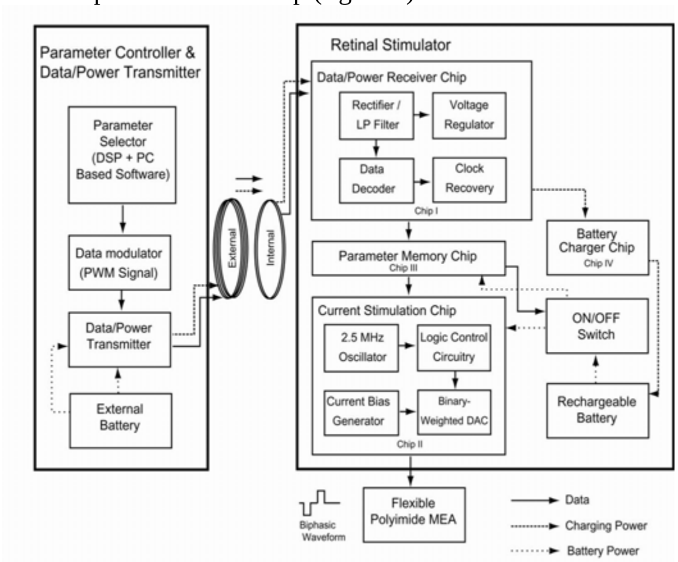

Fig. 1 System block diagram

The internal unit, *i.e.* the retinal stimulator, was implemented with a rechargeable battery and IC (integrated circuit) chips: the data/power receiver chip, including data decoding and voltage regulation functions, and current stimulation chip are custom IC’s designed by our laboratory (0.8 ㎛ CMOS (complementary metal-oxide semiconductor) technology), and the parameter memory chips and battery charging chip are off-the-shelf commercial chips (figure 1). Except for data/power receiver chip, the other chips in the stimulator are powered by a rechargeable battery. Therefore, once the parameters are passed to the parameter memory, the external unit can be removed from the animal during the electrical stimulation test. The retinal stimulator has two modes of function: a stimulation mode and a battery recharging mode.

In stimulation mode, the saved parameter data in the parameter memory part are provided to the current stimulation chip. The parameter data do not change unless a new parameter is transmitted from the external part. The current stimulation chip consists of current generator circuitry and timing logic circuitry. The current generator circuitry has current bias circuitry (8 ㎂) and an 8-bit binary current-weighted DAC (digital-to-analog converter). The timing logic circuitry has a 2.5 ㎒ oscillator and switch control logic circuitry for controlling the current stimulation waveform.

In the battery recharging mode, 2.5 ㎒ sinusoidal waves were transmitted with no data. A rechargeable coin-type lithium ion battery is used as the power source for the internal implant. A charging chip is used to control the battery recharging.

In this work, only one inductive coupling was used for data transmission and battery charging. Simultaneous transmission of the stimulation parameter and charging power is difficult because the battery charger circuit affects the precisely designed load value of the data/power receiving circuit and can induce the failure of data reception. To separate the stimulation mode and battery charging mode, a switch circuit was positioned between the voltage regulator in Data/power Receiver Chip and the Battery Charge Chip to control the recharging of the battery. The introduced switch circuit consists of two p-MOS transistors, one capacitor and one resistor (figure 2). The resistor and capacitor comprise a parallel connection with an RC time constant of 100 ms, which is very long compared to the 8 us period of the clock of Data/power Receiver Chip. Therefore, the voltage of the ‘a’ node is higher than the threshold of the Q2 switch when a data signal (PWM) is applied causing the Q2 to turn off. The data decoding can therefore be successfully carried out with no load effect. However, when only a sinusoidal wave without data is applied to the retinal stimulator through the inductive link, the level of CLK is logic high. In this case, Q1 will be turned off and the voltage of node ‘a’ will be logic low, so Q2 will be turned on. Therefore, the battery can be recharged.

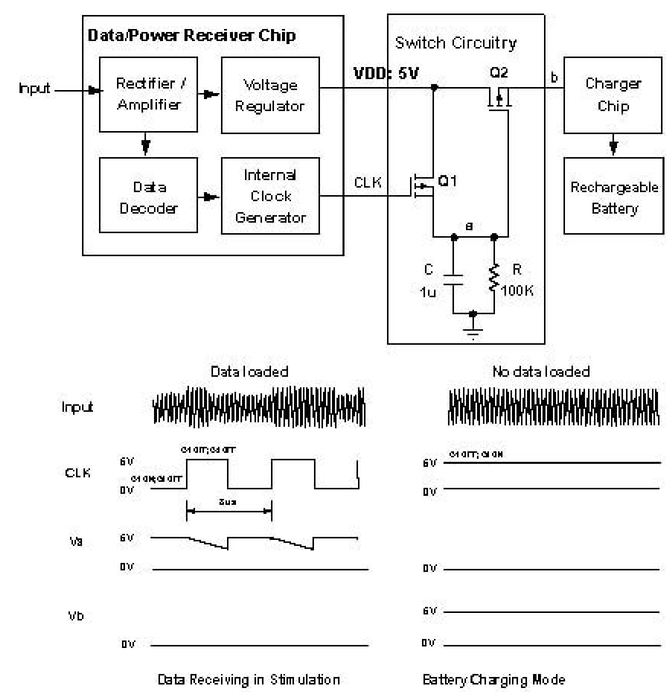

Fig. 2 Operation of switch circuitry in stimulation and battery charging modes

To protect the ICs from body fluids and mechanical forces, the electronics of the stimulator were hermetically housed in a metal package which consists of biocompatible titanium housing, platinum feedthroughs, and a ceramic plate. The feedthroughs connect the electrode array and receiver coil to the retinal stimulator. A ceramic sintering process is used to fix the feedthroughs in the ceramic plate that provides electrical isolation. Brazing and laser welding techniques were employed to achieve hermetic sealing of titanium housing.

A polyimide-based seven-channel, strip-shaped (750 x 300 μm) gold electrode array was used. The stimulating sites were constructed in a 4 ㎜ x 4 ㎜ area [14]. One side of this array was lengthened and connected to the stimulator *via* feedthroughs.

III. Results

A current mode, charge-balanced, cathodic first-biphasic stimulation waveform was generated in the stimulation mode and provided to a stimulation electrode array. The current stimulation chip can simultaneously deliver a stable current from 8 ㎂ to 2 ㎃ to all channels. The pulse width and the interphase delay can be changed up to 3 ㎳. The interphase delay was designed to have the same time duration with the pulse width.

The fabricated polyimide electrode array was checked for electrode impedance. Impedance for the electrode site (750 ㎛ x 300 ㎛) was typically 1.3 ㏀ in phosphate buffered solution (pH 7.4) measured at 1 ㎑ with a potentiostat (Zahner Elektrik IM6e, Germany).

The stimulator consumed around 2.35 mA current when delivering 520-uA biphasic current pulsed of 1-ms pulse width at a stimulation rate of 10.4 Hz to all seven channels.

The capacity of the battery was 75 ㎃h (4.2 V) and the battery could supply the power to the internal circuitries for over 30 hours under the 520-㎂ amplitude, 1-ms stimulation condition. The battery was fully recharged within 3 hours with 25 ㎃ charging current through the RF inductive link when in the battery recharging mode.

IV. Discussion

In the retinal prosthesis research, long-term animal electrical stimulation experiment is needed to verify the long-term stability and durability of the system before clinical use. Retinal systems using an electrical stimulation test usually consist of external and internal units [13]. The external unit is a necessary to change the stimulation parameters and to provide power for the implanted stimulator, but it is also burdensome especially in long-term animal electrical stimulation experiments.

The stimulation system presented in this paper is intended to provide a useful tool for long-term animal experiments on retinal prostheses. To remove the external connection or the external unit from the animal during electrical stimulation, we used a small rechargeable battery in the implantable stimulator. This battery can be simply recharged using an RF inductive link while the system is idle. This system makes it possible to conduct the chronic electrical stimulation tests in such a way that the animal can move and act freely without any external unit during the stimulation test. Therefore, there is no need to anesthetize the test animal and the stimulation system is also protected from the animal's claws and teeth.

The implantable retinal stimulator was built using IC chips and discrete elements for this proof-of-concept. An integrated IC chip can be developed to reduce power consumption and further miniaturize the implanted component of the device.

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