Extended Abstracts of the 2004 International Conference on Solid State Devices and Materials, Tokyo, 2004, pp. 350-351

H-5-1

Retinal Prosthesis System with Telemetry Circuit Controlled by Human Eyelid Movement

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1. Introduction

There has been a growing interest in visual prostheses by electrically stimulating the retinas of blind patients suffering from end-stage photoreceptor degenerative diseases [1-6]. Depending on the degree of damage in a patient's retina, medical doctors must be able to tune the electrical stimulus current waveform parameters such as frequency, amplitude, pulse width and interphase delay [1, 2]. Based on this discussion, we have proposed a retinal prosthesis chip with three-dimensional (3D) structure, which is a one-piece implantable device with the function of photodetection, image processing, stimulus current generation, and an electrode array on one LSI chip [7, 8].

We will tune the stimulus current waveform parameters using stimulus current generator circuits to which we will transmit power and data signals from the outside of eyeballs via a telemetric inductive link. Therefore, in this paper, we propose a retinal prosthesis system with a novel telemetry circuit controlled by human eyelid movement with keeping low power consumption. In addition, we evaluate the function of the stimulus current generator circuits, which are implemented in a prototype chip.

2. Overview of Retinal Prosthesis System

The conceptual diagram and the block diagram of the retinal prosthesis system are shown in Fig. 1, 2. The system is composed of extraocular and intraocular units which are connected by a telemetric inductive link. The extraocular unit consists of a transmitter with a primary coil. The intraocular unit is composed of a secondary coil, a telemetry circuit controlled by human eyelid movement, a bias controller, pixel circuits which include stimulus current generator circuits. The intraocular unit is strongly required to keep the power consumption as low as possible in consideration of the power transmission and heat generation. In order to meet this requirement, there are two states in the itraocular unit: "EDIT" and "RUN" states. Since the stimulus current generator circuits hardly generate stimulus current pulses while the patients are closing their eyelids, the power consumption of the intraocular unit becomes low and the intraocular unit is moved to "EDIT" state. The telemetry circuit is invoked to receive data signals from the transmitter in "EDIT" state. Therefore, the telemetry circuit never operates concurrently with the stimulus current generator circuits. The details of these circuits are described in section 3, 4.

The bias controller consists of a main controller, a synchronization circuit, bias reference registers, a constant bias generator circuit and digital-to-analog converters (DACs) as shown in Fig. 3. In order to tune the stimulus current waveform parameters by controlling bias voltages supplied for the stimulus current generator circuit, the DACs provide the bias voltages according to the bit data which are transmitted from the outside of eyeballs and are stored in the bias reference registers.

3. Features of Telemetry Circuit

In this section, we propose a novel telemetry circuit controlled by human eyelid movement, which consists of power and clock/data recovery circuits and a detector of human eyelid movement (DHEM) as shown in Fig. 4. Since the stimulus current generator circuits hardly generate the stimulus current pulses while the patients are closing their eyelids, the power consumption of the intraocular unit becomes low so that the clock/data recovery circuit should receive clock signals and bit data, followed by writing the bit data in the bias reference registers during this "EDIT" state. On the other hand, the stimulus current generator circuits, which are composed of analog asynchronous circuits and are controlled by the bit data stored in the bias reference resisters, generates the stimulus current pulses without clock signals while the patients keep their eyelids open. Therefore, we can reduce the power consumption of the intraocular unit by cutting off the power supplied for the clock/data recovery circuit during this "RUN" state.

The DHEM, which is shown in Fig. 5, detects the human eyelid movement by sensing the incident light intensity to the retinal prosthesis chip, and controls the "EDIT" and "RUN" states. The time constant of DHEM is larger than the time of eye blinks (approximately 100ms) in order to prevent the DHEM from confusing the state of eyelid closure with that of eye blinks.

4. Evaluation of Stimulus Current Generator Circuit

In order to evaluate the basic function of the stimulus current generator circuit, we fabricated a prototype chip using 0.35μm double poly-Si and triple metal standard CMOS technology. Figure 6 shows the pixel circuit diagram of the stimulus current generator with the function of light detection. As the measurement results of this chip, we confirmed that this circuit could detect the incident light and convert it into the biphasic stimulus current pulses without clock signals as shown in Fig. 7. In addition, the cathodic pulse width could be tuned from about 0.5ms to 5ms by controlling bias voltages (BIAS2) as shown in Fig. 8. We also confirmed that the anodic pulse width and the interphase delay could be tuned from about 0.5ms to 5ms by controlling the bias voltage (BIAS5, BIAS4) as with the cathodic pulse width.

5. Conclusions

We proposed a retinal prosthesis system with a novel telemetry circuit controlled by human eyelid movement, and described that we could reduce the power consumption of the intraocular unit by cutting off the power supplied for the telemetry circuit while the patients keep their eyelids open. In addition, we confirmed that the stimulus current generator circuit implemented in a prototype chip could generate the stimulus current pulses without clock signals, and the pulse widths and the interphase delay could be tuned from about 0.5ms to 5ms by controlling the bias voltages.

Acknowledgements

The VLSI circuit used in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo, in collaboration with Rohm Corporation and Toppan Printing Corporation.

References

[1] W. Liu, et al., IEEE J. Solid-State Circuits **35** (2000) 1487.
[2] M. S. Humayun, et al., Vision Res. **39** (1999) 2569.
[3] R. Eckmiller, Ophthalmic Res. **29** (1997) 281.
[4] Zrenner E, et al., Vision Res. (1999) 2555.
[5] Chow A.Y., et al., Ophthalmic Res. (1998) 195.
[6] M. S. Humayun, et al., Arch. Ophthalmol. **114** (1996) 40.
[7] J. Deguchi, et al., Extended Abstracts SSDM (2003) 402.
[8] J. Deguchi, et al., Jpn. J. Appl. Phys. **43** (2004) 1685.

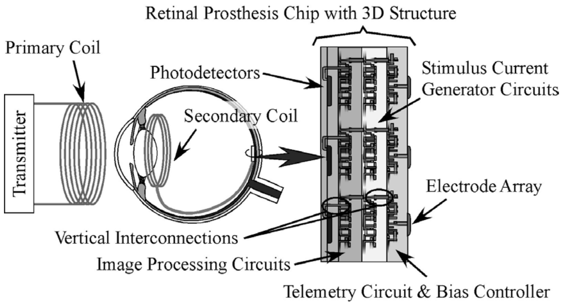

Fig. 1. Conceptual diagram of retinal prosthesis system.

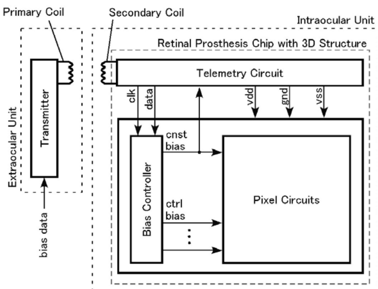

Fig. 2. Block diagram of retinal prosthesis system.

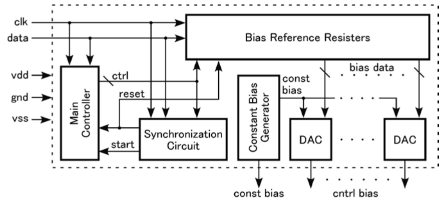

Fig. 3. Block diagram of bias controller.

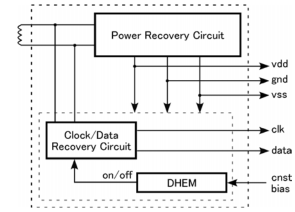

Fig. 4. Block diagram of telemetry circuit based on human eyelid movement.

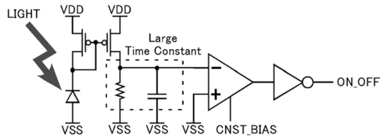

Fig. 5. Circuit Diagram of DHEM.

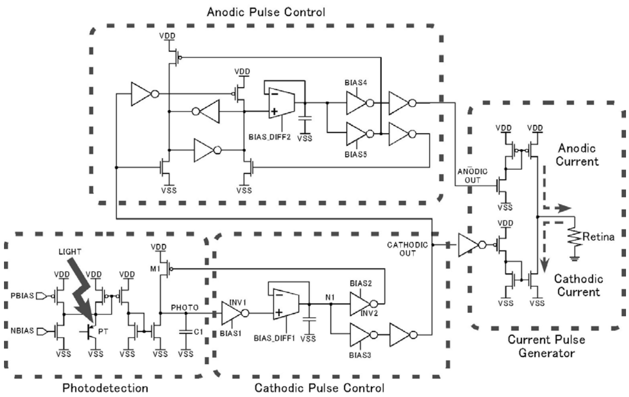

Fig. 6. Pixel circuit diagram of stimulus current generator.

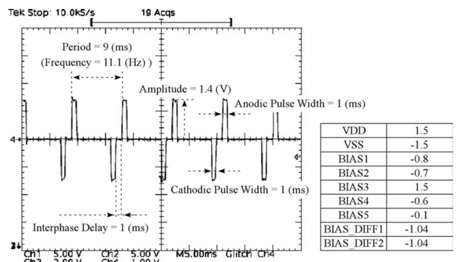

Fig. 7. Measurement result of generated stimulus current pulses from the designed stimulus current generator circuit.

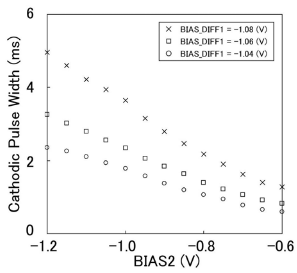

Fig. 8. Dependence of cathodic pulse width on bias voltage (BIAS2).