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Proposal of Application of Pulsed Vision Chip to Retinal Prosthesis

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1. Introduction

In this paper, we propose and discuss an application of a CMOS vision chip using pulse frequency modulation to sub-retinal implantation to partially recover human vision. In sub-retinal approaches, a photo-sensor buried underneath the retina converts light distribution of the image projected on a retina surface to electric signals, and stimulates the horizontal cells or neurons behind them [1], [2]. So far in the sub-retinal approach, a simple photodiode array without any bias voltage has been used as a photo-sensor mainly due to its simple configuration [2]. The photocurrent is directly used as injection current into cells. However, the amount of the photocurrent is so small not to stimulate cells due to its low photosensitivity.

To increase the sensitivity it is effective to integrate the photo-generated charge in a capacitor, and this technique, integration mode, is commonly used in conventional image sensors. We use a pulse frequency modulation (PFM) [3], [4] instead of this conventional integration method as following reasons. First, PFM operates asynchronously and independently, and thus each pixel could be separated each other in space. This makes it easy to flow nutrition penetrating the chip. On the contrary, a conventional integration mode requires timing sequence for reset and read-out. Second, PFM outputs pulse streams, which would be suitable to stimulate the cells. In addition, PFM can operate in a very low voltage without decreasing signal-to-noise ratio. Finally, its dynamic range is relatively large, which is very effective to replacement of photoreceptors.

We have designed and fabricated PFM pixel circuits using standard CMOS technology and demonstrated its fundamental characteristics. In addition, we discuss future issues to apply the PFM to retinal prosthesis device.

2. Operation Principle

A PFM is an output representation that an analog output is converted into pulse frequency, and is used in the output from the nerve cells as spikes [5]. To employ a PFM in a vision chip, relaxation oscillation circuits are constructed as shown in Fig.1 [6]. The photodiode PD acts as a variable current source controlled by the input light intensity and is charged through the reset transistor

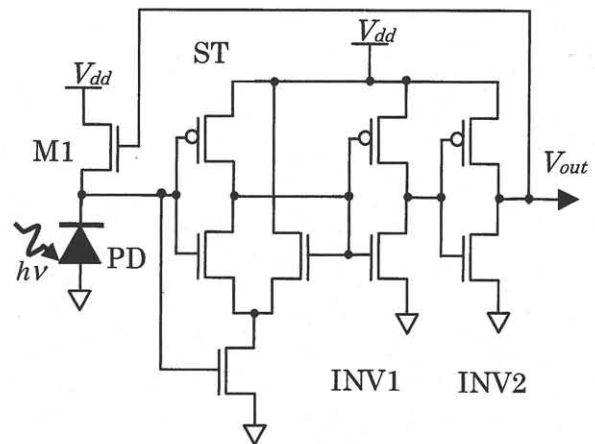


Fig1: Pixel circuits of PFM

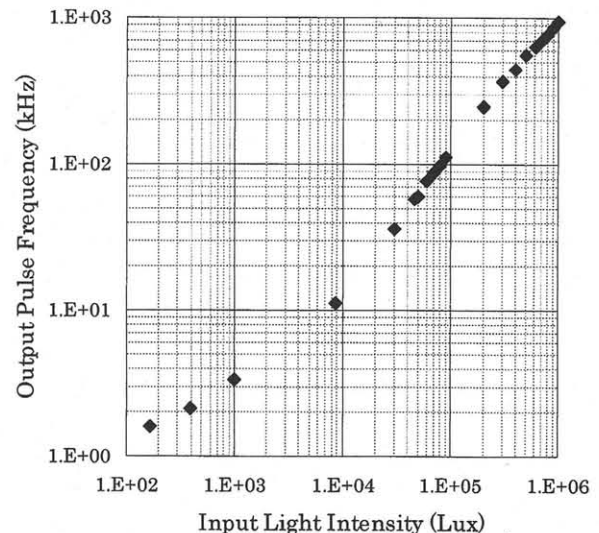


Fig.2: Dependence of output pulse frequency on input light intensity

M1. The gate of M1 is switched by the feedback from the Schmitt trigger ST and the two inverters INV1 and INV2. In such configuration the stronger the light intensity is, the higher the pulse frequency is. The analog value of the light intensity is consequently converted into a pulse train as digital signal naturally.

To confirm fundamental characteristics of the PFM circuits, a test chip was designed using triple-metal double-poly 0.35 μm CMOS process. The photodiode consists of a parasitic pn junction diode between N-diffusion and P-substrate. To demonstrate the size

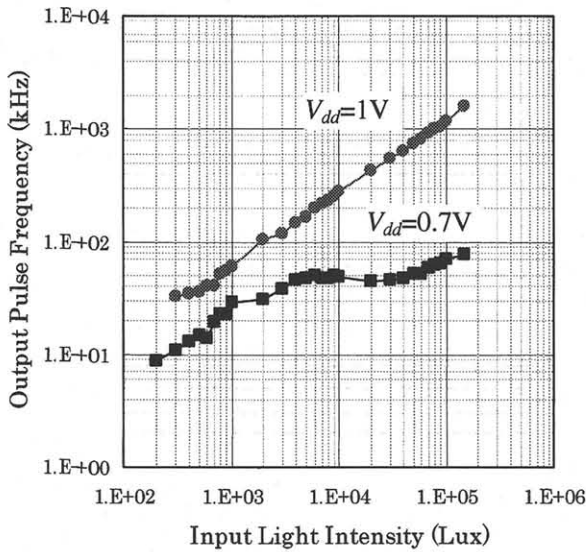


Fig. 3: Dependence of output pulse frequency on input light intensity. The power supply voltage V_{dd} is a parameter.

effect of the photodiode, only $1\mu\text{m}$ square hole is opened on the top of the shield metal of the photodiode with the size of $2\mu\text{m}$ square. The capacitance is estimated around 1fF . All of the transistors have the minimum L/W in the process technology used here.

3. Results and Discussions

Figure 2 shows the dynamic range characteristics of the fabricated PFM chip. A metal-halide lamp is used as an input light source because of its strong light intensity. The dynamic range is obtained around 40dB with $V_{dd}=1\text{V}$. The maximum detectable light intensity is restricted by the intensity of the used light source, and thus the dynamic range could be larger than this value. It is noted that the chip works well with such a large dynamic range only in a low power supply voltage of 1V , which shows great advantage when the chip operates in implantation. Lower light intensity could be detected if the photodiode size becomes larger.

Next, we demonstrate the low voltage operation characteristics of the PFM chip. Figure 3 shows the dependence of the output frequency on the input light intensity with two different power supply voltages, $V_{dd}=1\text{V}$ and 0.7V . A halogen lamp is used for the input light. While in $V_{dd}=1\text{V}$ the output pulse frequency linearly increases according to the input light intensity, in $V_{dd}=0.7\text{V}$ the output frequency seems to saturate. The reason the output saturates is that when the light intensity is large, that is the photocurrent is large, it requires longer time to charge the parasitic capacitance of the photodiode if the power supply voltage is low. Thus for low voltage operation a small capacitance is required, and this could be conflicted with the sensitivity. This is the next issue to be studied.

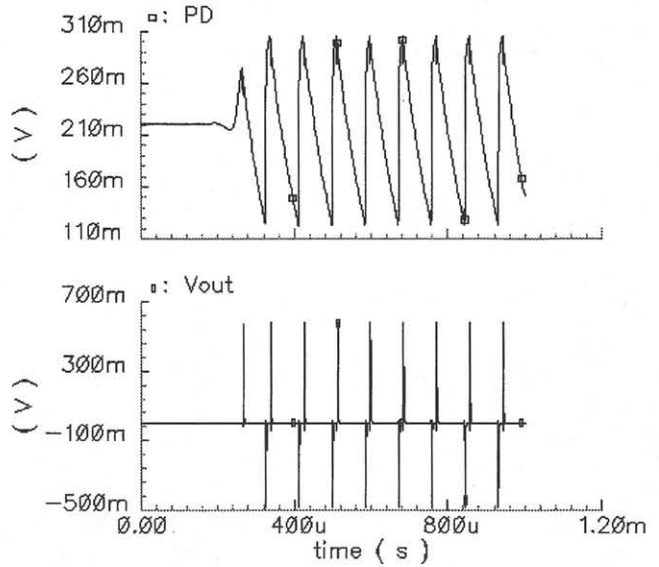


Fig. 4: Spice simulation results of bipolar output pulse. The upper trace shows the voltage of PD and the lower the output.

To emulate the retinal signal more precisely, we have a plan to introduce a bi-phasic output circuits in the PFM circuits, which is required to alleviate fatigue of cells and/or extract excess charge from cells. We have confirmed proper operation using SPICE simulation. Figure 4 shows the simulation results of the bipolar output. The RC constant is set $1\mu\text{s}$, which is much faster than the pulse frequency.

We are now designing an array chip based on the PFM, and also preparing *in vitro* tests by using the fabricated chip.

4. Conclusions

We propose that PFM is applied to a sub-retinal stimulation for retinal prosthesis. The fundamental characteristics of the PFM are demonstrated for the fabricated chip.

Acknowledgments

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