A retinal prosthetic device using a CMOS image sensor employed with modified pulse frequency modulation

J. Ohta, T. Furumiya, David C. Ng, A. Uehara, K. Kagawa, T. Tokuda, and M. Nunoshita
Nara Institute of Science and Technology, 8916-5 Ikoma, Nara 630-0101, Japan
Tel: +81-743-72-6051, Fax: +81-743-72-6059, Email: ohta@ms.aist-nara.ac.jp

Abstract

This paper describes a retinal prosthetic device using a modified pulse frequency modulation (PFM) based photosensor with a standard CMOS technology. The output waveform of the PFM based photosensor is modified to stimulate retinal cells effectively. Two improvements are achieved. First modification is to restrict the maximum output pulse frequency to protect cells and also to shift photosensitivity curve adaptively. By introducing the adaptation, we almost keep an input light dynamic range of 5-Log. Second, biphasic current pulses are introduced to alleviate the fatigue of retinal cells as well as to keep injected charges constant irrespective to impedance change. A 32x32-pixel PFM photosensor array chip is fabricated using 0.6 μm CMOS technology and demonstrated the improved functions.

1. Introduction

We have proposed that pulse frequency modulation (PFM) is applied to a photosensor of a CMOS image sensor to use as a subretinal implanted device of a retinal prosthesis [1], [2]. A PFM photosensor converts input light intensity into output pulse train whose frequency is proportional to the light intensity [3]. Such a pulse output is suitable to stimulating retinal cells effectively. The other features are robust against noise and compatible with digital circuits.

In this abstract, we modify output characteristics of a PFM photosensor to adapt for retinal prosthesis more effectively. Based on the modifications, a 32x32-pixel array chip employed with improved PFM photosensor is fabricated. The chip is demonstrated to display its output pulse pattern on 32x32 LED array panel.

2. Modification of PFM for retinal prosthesis

We modified the function of PFM to adapt the retinal prosthetic device as follows. First, Output from a PFM photosensor is voltage pulse waveform, but current output is more preferable to inject charges into retinal cells constantly even if the contact resistances between the electrodes and the cells are changed. Second, biphasic output, that is positive and negative pulses, is preferable for charge balance. Third, output frequency limitation is needed, because too high frequency may cause damage against retinal cells. The output pulse frequency of original PFM is generally too high (around 1MHz) for stimulating retinal cells.

The frequency limitation, however, causes to reduce a range of input light intensity. We have alleviated this problem by introducing a variable sensitivity: the output frequency is divided into 2^{-n} with a frequency divider. It is noted that digital output of PFM is suitable to introducing such a logic function of the frequency divider Table 1 summarizes the comparison of a photosensor for requirement in retinal prosthesis.

Based on the above modifications, we have designed and fabricated a pixel circuitry using standard 0.6μm CMOS technology. Figure 2 shows the block diagram of the pixel. The microphotograph of the fabricated chip is shown in Fig. 3. The frequency limitation is achieved by a switched capacitor filter (SCF) for a low pass filtering. Figure 4 demonstrates the experimental result of the variable photosensitivity using the chip. The original output curve has a dynamic range of over 6-Log (6-order range of input light intensity) while it reduces to around 2-Log to be limited at 250 Hz when the low pass filter is turn on. By introducing the variable sensitivity, the total coverage of input light intensity becomes 5-Log between n=0 and n=7, where n is a division number. The other functions in Table 1 also have been demonstrated. Figure 5 shows an oscilloscope traces and demonstrates the biphasic current pulse, which is generated from original PFM output pulse.

3. 32x32-pixel array

A 32x32-pixel array chip using standard 0.6 μm CMOS technology has been designed and fabricated to demonstrate the function and to use for *in vitro* experiment. Figure 6 shows a schematic of the pixel circuit. The pixel consists of a pulse generator of PFM with an upper limiter, a pulse shaper and an amplifier which is current source and sink, and a stimulus electrode which is the interface to retinal cells. The electrode can be coated with Pt for biocompatibility. The pixel layout and a microphotograph of the fabricated chip are shown in Fig. 7. The chip specifications are listed in Table 2.

The output pattern from the chip is visualized in a 32x32-LED array display as shown in Fig. 8. Each LED is blinking according to the output pulse frequency from the corresponding pixel. You can directly experience the stimulation of retinal cells through this blinking of the LED array.

4. Conclusion

We have improved a PFM photosensor to adapt for retinal prosthesis. 32x32-pixel array chip has been demonstrated the improved functions. The variable sensitivity is also demonstrated.

Acknowledgement

This work was supported by the New Energy Development Organization (NEDO), Japan.

References

1 .J. Ohta *et al.*, Jpn. J. Appl. Phys. **41**, 2322 (2002).
2. T. Furumiya *et al.*, Proc. SPIE **4829**, 969 (2002).
3. W. Yang, *IEEE Int'l Solid State Circuits Conf.*, p.230 (1994).

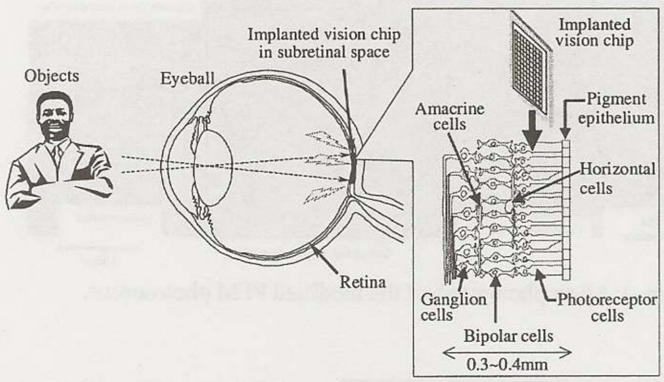


Figure 1: Subretinal approach of retinal prosthesis.

Table 1: Comparison of photosensor in retinal prosthesis

Photosensor	Photodiode	Original PFM	Improved PFM
Sensitivity	Low	High	High
Stimulation	Current	Voltage	Current
	Continuous	Pulsed	Pulsed
	Monophasic	Monophasic	Biphasic
Frequency	DC	> 100 kHz	< a few 100 Hz
Power supply	Not required	Required	Required
Injection charge	Insufficient	Sufficient	Sufficient

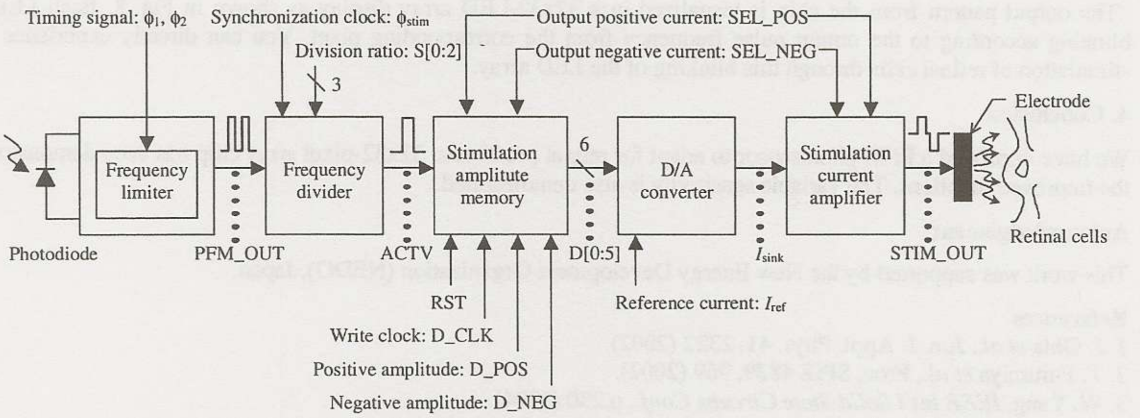


Figure 2: Block diagram of a PFM photosensor modified for a retinal prosthetic device.

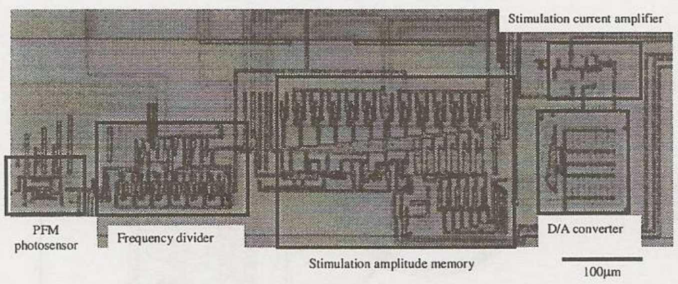


Figure 3: Microphotograph of the modified PFM photosensor.

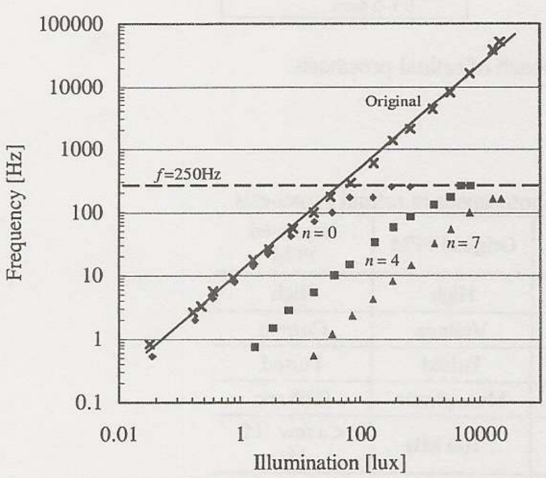


Figure 4: Experimental results of output pulse frequency as a function of illumination. n is a division number

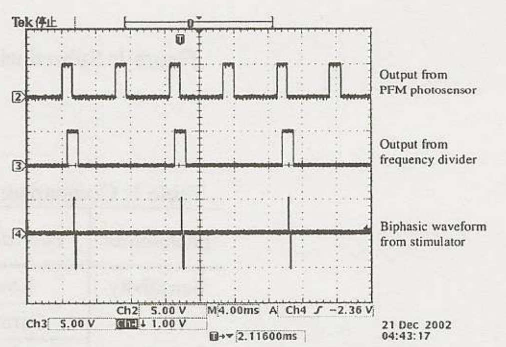


Figure 5: Oscilloscope traces of output pulses. Upper: original PFM pulses, Middle: Output pulses from frequency divider (n=1), Lower: Biphasic current pulses.

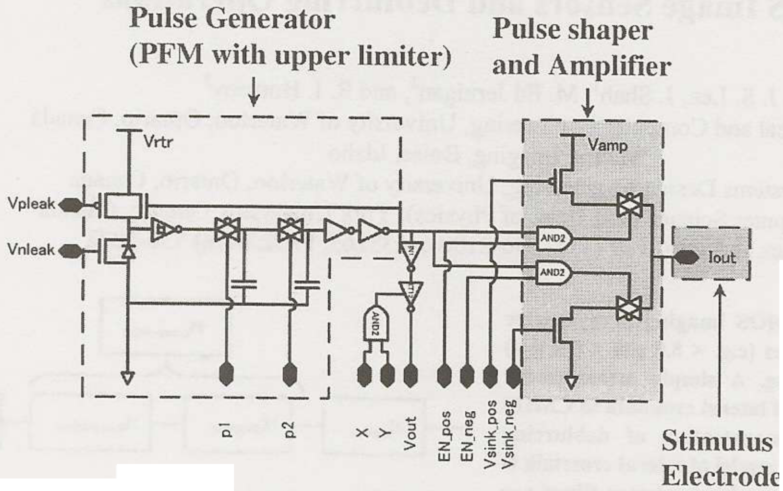
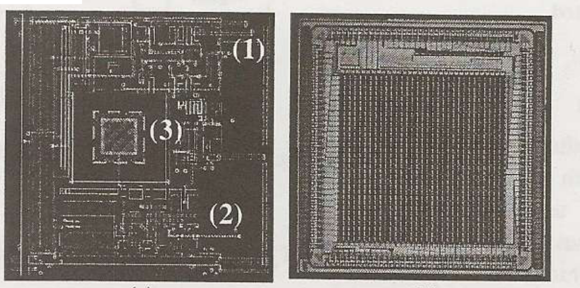


Figure 6: Schematic of pixel

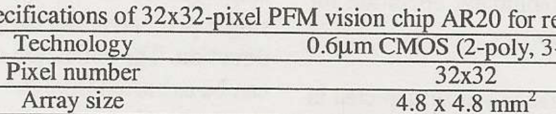


(a) (b)

Figure 7: (a) pixel layout; (1) pulse generator, (2) pulse shaper and amplifier, (3) stimulus electrode, (b) microphotograph of fabricated chip.

Table 2: Specifications of 32x32-pixel PFM vision chip AR20 for retinal prosthesis.

Technology	0.6μm CMOS (2-poly, 3-metal)
Pixel number	32x32
Array size	4.8 x 4.8 mm^2
Pixel size	150 x 150 μm^2
PD size	15 x 15 μm^2
Electrode size	15 x 15 μm^2
Max. output current	30μA@10k Ωload
Photosensitivity	1.91 Hz/lux



(a) (b) (c)

Figure 5: Displayed images of (c) a hand, (d) Chinese character, and (e) a figure of “Maneki-Neko”.