Technical note

Photo IC for rangefinder

Contents

1. Overview

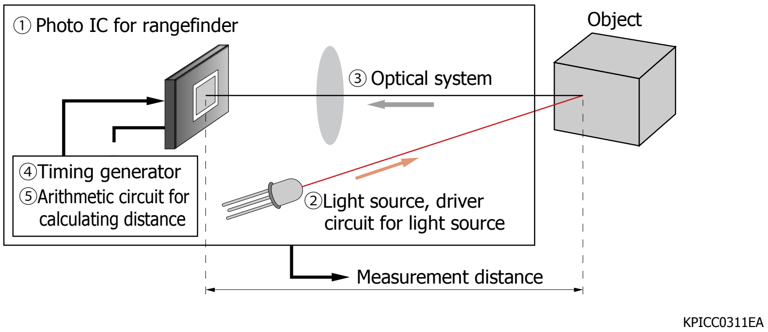
The photo IC for rangefinder is a distance measurement device using the indirect TOF method. It integrates a photosensitive area and signal processing circuit. The sensor outputs signals proportional to the time for the pulse-modulated light to reflect by the target object and return. The output value can be used to calculate the distance to the target object. The photo IC for rangefinder runs on low voltage (3.3 V) and supports I2C interface and SPI.
Typically, a high-speed response, high output LED or LD is used for the light source. An external light source driver connected to an I^2C timing circuit built into the photo IC for rangefinder is used to synchronize the light emission from the light source. The photo IC for rangefinder performs a charge-to-voltage conversion on the information that corresponds to the time (delay time) for the light from the light source to reflect off the target object and reach the photo IC for rangefinder and outputs the result. From the output voltage that corresponds to the delay time and the light of speed ($c=3 \times 10^8$ m/s), the external distance arithmetic circuit calculates the distance to the target object.

2. How to use

2-1. Configuration example

A configuration example of a distance measurement system using the photo IC for rangefinder is shown in Figure 2-1. The system consists of the photo IC for rangefinder, light source and its driver circuit, light emitting/receiving optical system, timing generator, and arithmetic circuit for calculating distance. The distance accuracy depends greatly on the light source emission level and the light emitting/receiving optical system.

[Figure 2-1] Configuration example of distance measurement system



3. Operating principle

3-1. Phase difference (indirect) TOF (time-of-flight)

The timing chart of the photosensitive area of the distance image sensor is shown in Figure 3-1. Output voltages Vout1 and Vout2 obtained by applying charge-to-voltage conversion on accumulated charges Q1 and Q2 based on their integration capacitances Cfd1 and Cfd2 are expressed by equations (3-1) and (3-2).

$$Vout1 = Q1/Cfd1 = N \times Iph \times \{(T_0 - Td)/Cfd1\} \quad \dots (3\text{-}1)$$
$$Vout2 = Q2/Cfd2 = N \times Iph \times (Td/Cfd2) \quad \dots (3\text{-}2)$$

Cfd1, Cfd2: integration capacitance of each output
N: charge transfer clock count
Iph: photocurrent
T_0: pulse width
Td: delay time

Delay time Td when Cfd1=Cfd2 in equations (3-1) and (3-2) is expressed by equation (3-3).

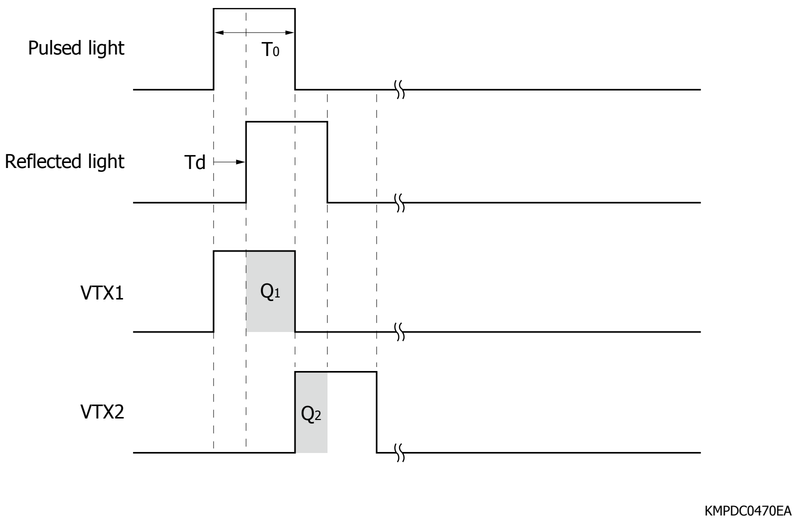
$$Td = \{Vout2/(Vout1 + Vout2)\} \times T_0 \quad \dots (3\text{-}3)$$

Using the values (Vout1, Vout2) output according to the distance, distance (L) is expressed by equation (3-4).

$$L = 1/2 \times c \times Td = 1/2 \times c \times \{Vout2/(Vout1 + Vout2)\} \times T_0 \quad \cdots (3\text{-}4)$$

c: speed of light (3×10^8 m/s)

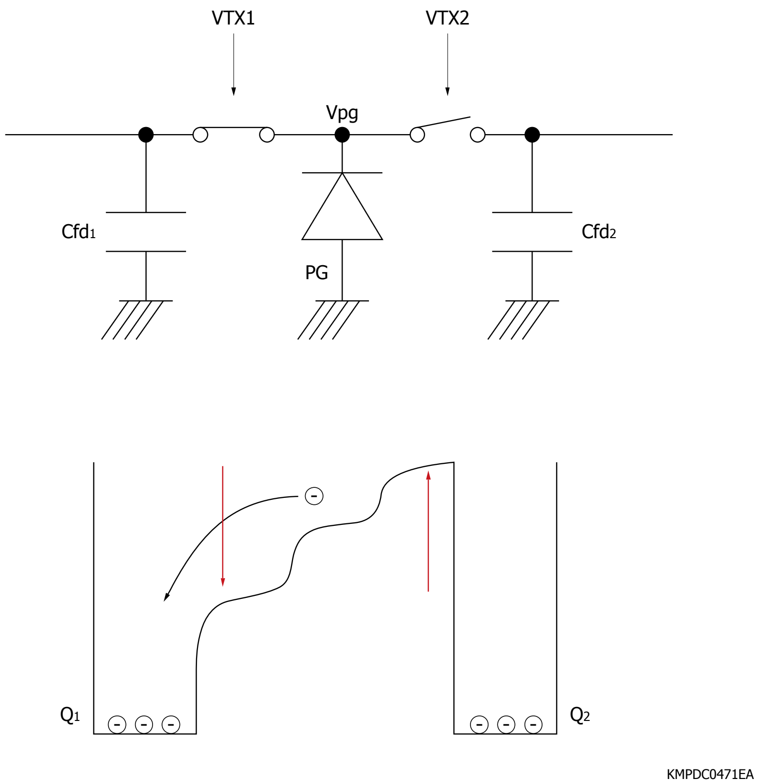
[Figure 3-1] Timing chart of photosensitive area



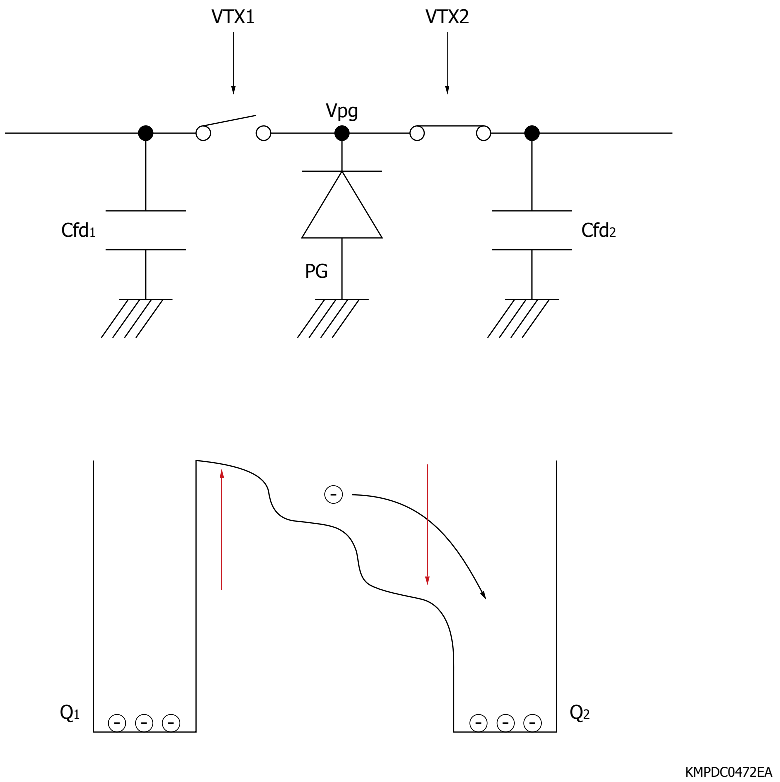
The structure and surface potential of the photosensitive area of the photo IC for rangefinder are shown in Figure 3-2. Typical CMOS image sensors can be driven with a single power supply, but the transfer time needed for the charge to move from the photosensitive area to the integration area is in the microsecond order. On the other hand, high-speed charge transfer (nanosecond order) is possible on CCD image sensors, but they require multiple voltage inputs including high voltage.
To achieve the high-speed charge transfer (several tens of nanoseconds) needed to acquire distance information, we have developed a pixel structure that enables high-speed charge transfer like the CCDs in the CMOS process. This has allowed photo ICs for rangefinder to achieve the high-speed charge transfer needed for distance measurement.
The number of electrons generated in each pulse emission is several e-. Therefore, the operation shown in Figure 3-2 is repeated several thousand to several tens of thousands of times, and then the accumulated charge is read out. The number of repetitions varies depending on the incident light level and the required accuracy of distance measurement.

[Figure 3-2] Structure and surface potential of photosensitive area

(a) VTX1: on, VTX2: off (in the case of Figure 3-1①)



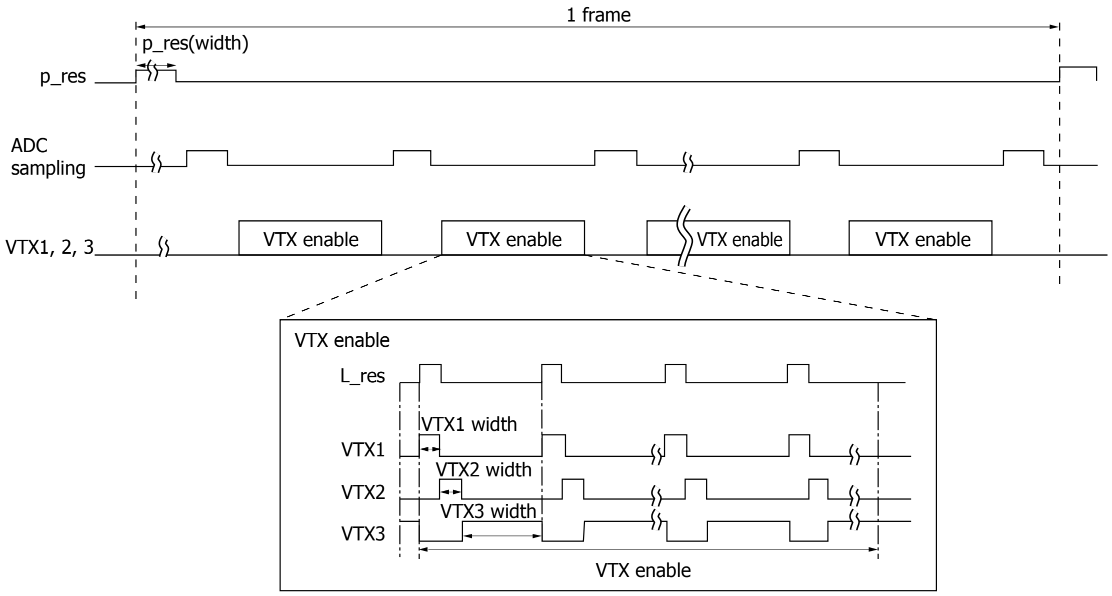
(b) VTX1: off, VTX2: on (in the case of Figure 3-1②)



3-2. Timing chart

Figure 3-3 shows the timing chart when a signal is read out twice in a frame. The first time, the signal immediately after a pixel reset is read out, and the second time, the signal after signal integration is read out. Pulse emission, signal integration, and pixel charge transfer are executed repeatedly within the frame period. Note that the number of pulse emissions needs to be changed according to the required distance accuracy. If you want to perform non-destructive readout, repeat pulse emission, signal integration, and signal readout after reading out the integrated signal. In this case, pixel reset and reset level readout are not performed.

[Figure 3-3] Timing chart



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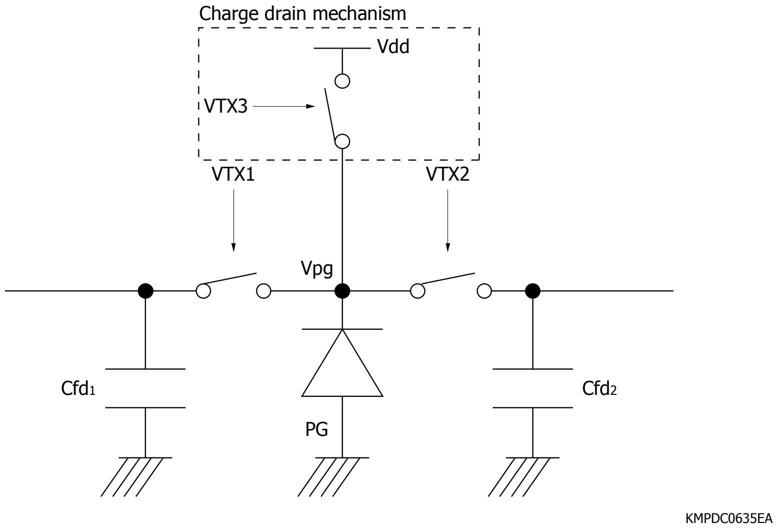
3-3. Charge drain function

A photo IC for rangefinder has charge transfer gates (VTX1, VTX2), which transfer the charges that are generated at the photosensitive area, and a charge drain gate (VTX3), which discharges unneeded charges. When VTX1 and VTX2 are off and VTX3 is on, the charge drain function is turned on without the accumulation of signal charges. This makes it possible to drain unneeded charges caused by ambient light during the non-emission period. The charge drain function enables the following:

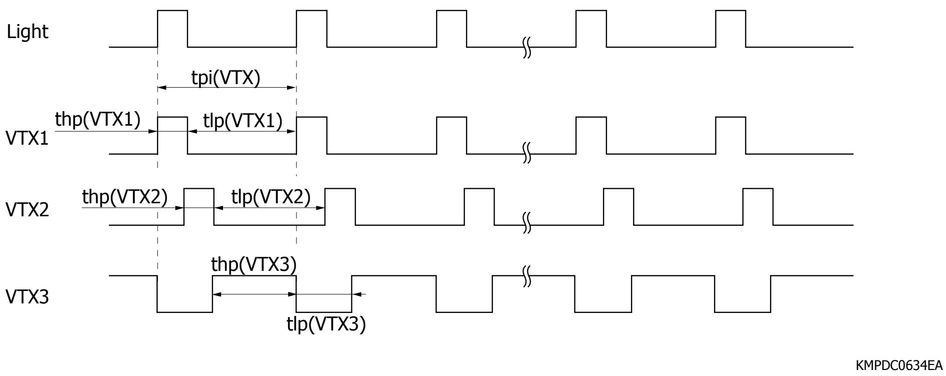
① Detection of high-speed pulses
Signal charges from pulse laser diodes and other high-speed pulse light sources can be integrated efficiently.

② Shutter operation

[Figure 3-4] Structure of photosensitive area



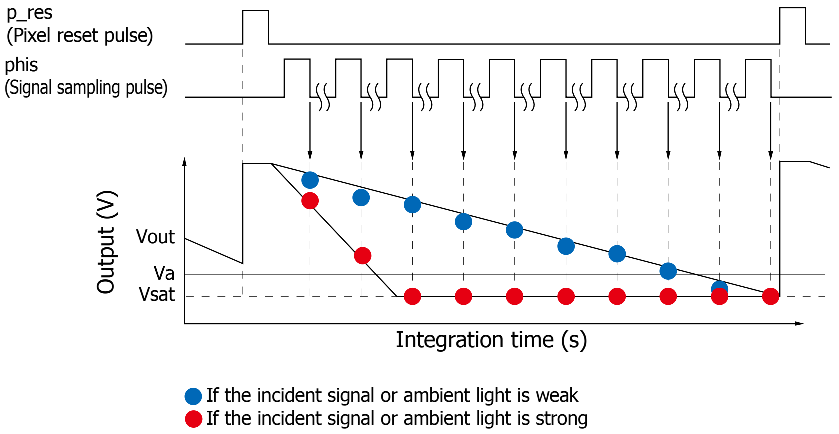
[Figure 3-5] Timing chart of photosensitive area



3-4. Non-destructive readout

If the incident signal is strong (the object is close and has high reflectance) or if the ambient light is strong, the photo IC for rangefinder saturates easily, so the integration time must be reduced. If the incident signal or ambient light is weak, the integration time must be increased.
These issues can be solved by using non-destructive readout. With non-destructive readout, signals with different integration times in a frame can be read out. Wide dynamic range is achieved by selecting the signal with the optimal integration time.
Note that the reset noise that occurs within a pixel can be canceled by computing the difference between two specific signals obtained by non-destructive readout.
An even wider dynamic range can be achieved in non-destructive readout by setting a threshold voltage (Va) [Figure 3-6] and selecting a signal that does not exceed the threshold. To do this, however, a signal processing circuit must be attached externally.

[Figure 3-6] Non-destructive readout



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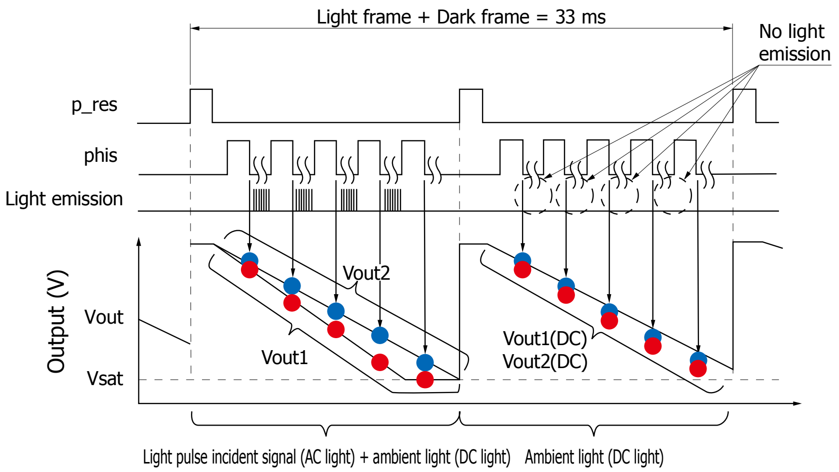
3-5. Subtracting signals caused by ambient light

The charge drain function allows draining of unneeded charges accumulated during the light emission period. However, unneeded charges caused by ambient light and the like are also accumulated during the non-emission period (VTX1 and VTX2 are on). The way to eliminate these unneeded charges is to calculate the difference between the light frame and dark frame data and extract only the AC signal component. In light frames, since the LED emits light, the light that is incident on the photosensitive area contains light pulse (AC light) and ambient light (DC light). In dark frames, since the LED does not emit light, the light that is incident on the photosensitive area contains only ambient light.

[Figure 3-7] Function for subtracting signals caused by ambient light



$L \propto (1/2) \times c \times To \times [\{Vout2 - Vout2(DC)\}/\{Vout1 - Vout1(DC)\} + \{Vout2 - Vout2(DC)\}]$

L: distance to the target object
c: speed of light
To: pulse width
Vout1, Vout 2: output generated from signal light
Vout1(DC), Vout2(DC): output generated from ambient light

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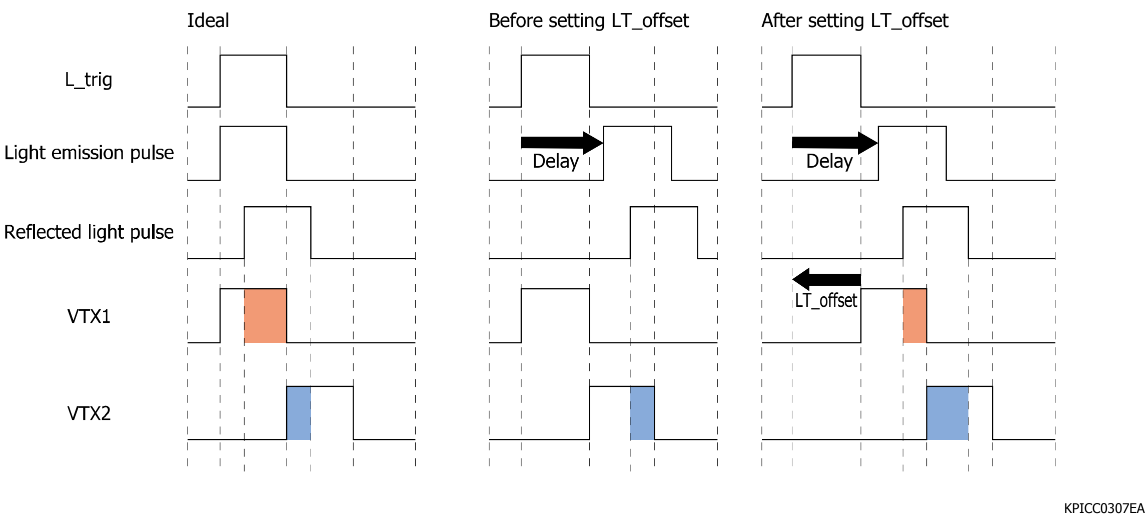
3-6. LED light emission pulse timing

Connect the L_trig (light pulse trigger) terminal of the photo IC for rangefinder to the LED driver circuit to make the LED emit light. It would be ideal for VTX1, light emission pulse, and L_trig to be synchronized (left of Figure 1-8), but in reality, the light emission pulse is delayed due to the following factors.

- Wiring
- Response speed of the LED driver circuit
- Response speed of the LED

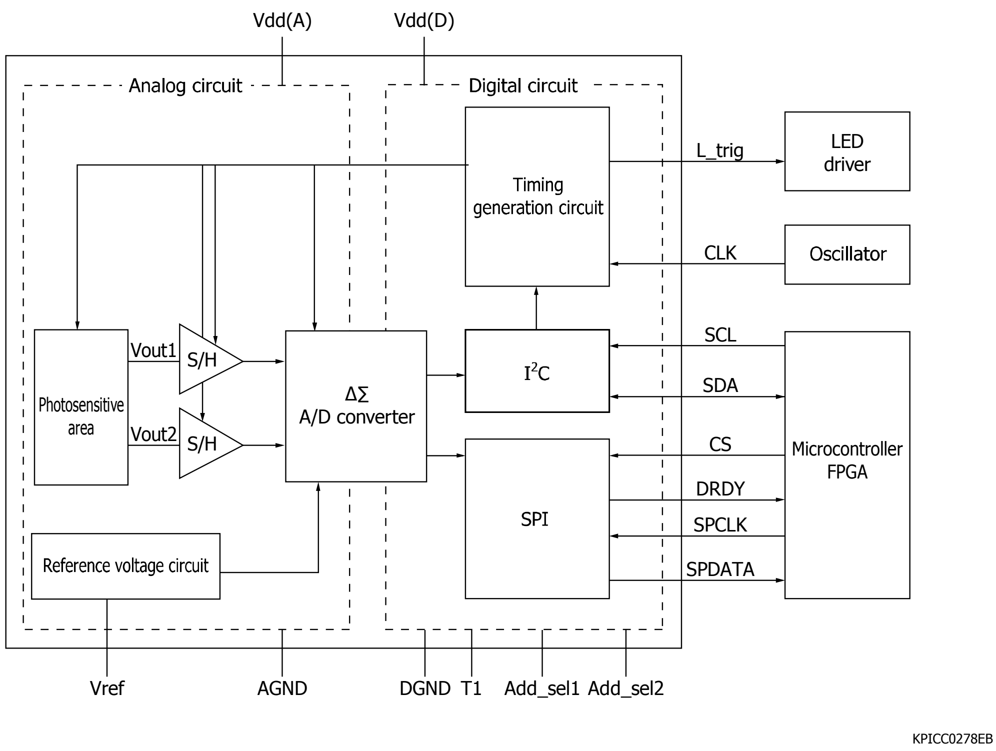
If the delay of the light emission pulse is large as shown in the center of Figure 3-8, the reflected light signal falls outside VTX1, and distance calculation becomes impossible. To handle this issue, there is a method in which L_trig is generated earlier than VTX1 so that the reflected light signal is included in VTX1 (right of Figure 3-8). To do this, set LT_offset of the I2C register. When LT_offset is set to the default value of 1, L_trig and VTX1 are generated at the same time. For every 1 increase in LT_offset, L_trig is shifted earlier by 20 ns.

[Figure 3-8] Detection of reflected light pulse based on LT_offset setting



4. Structure

[Figure 4-1] Block diagram

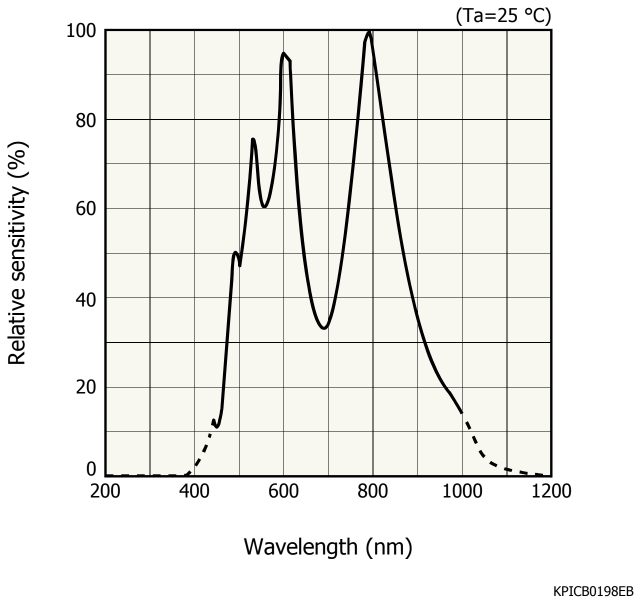


[Figure 4-1] Structure

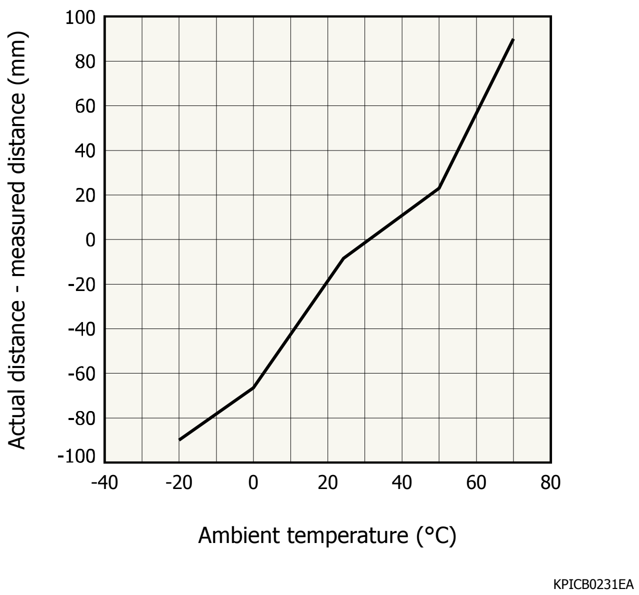
Component	Description
Photosensitive area	Receives reflected light in sync with LED light emission and outputs voltage Vout1 and Vout2, which are proportional to the delay of the reflected light.
S/H	Sample-and-hold circuit. Holds Vout1 and Vout2.
ΔΣADC	Performs A/D conversion sequentially on Vout1 and Vout2 held in S/H.
I^2C	Performs data communication with external devices. It has read and write functions.
SPI	Performs data communication with external devices. It only has a readout function for Vout1 and Vout2.
Timing generation circuit	Generates signals needed for synchronizing the photosensitive area, S/H, ADC, and LED light emission. An LED and LED driver must be provided separately and connected.
Reference voltage circuit	Generates the reference voltage for the ADC. Connect a noise filtering capacitor to the Vref terminal.

5. Characteristics

[Figure 5-1] Spectral response

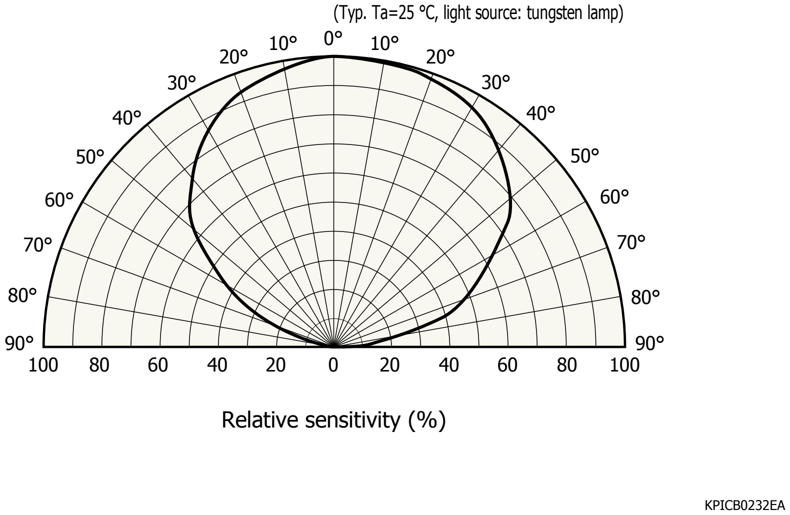


[Figure 5-2] Distance drift vs. temperature

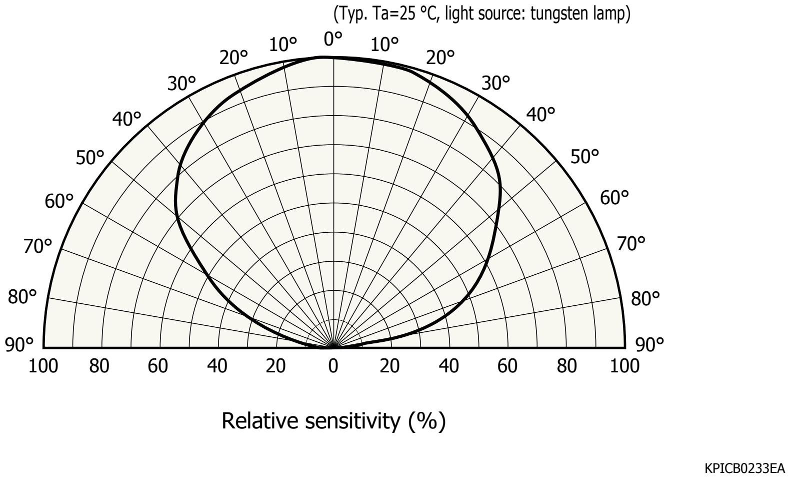


[Figure 5-3] Directivity

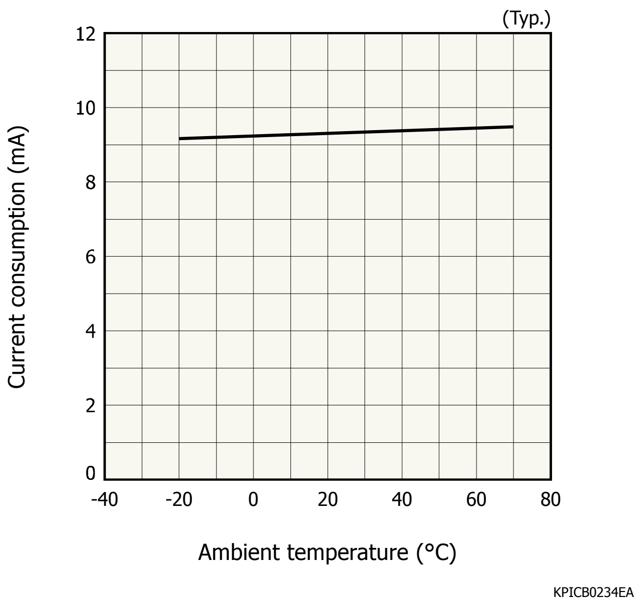
(a) X direction



(b) Y direction



[Figure 5-4] Current consumption vs. ambient temperature



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HAMAMATSU PHOTONICS K.K., Solid State Division
1126-1 Ichino-cho, Higashi-ku, Hamamatsu City, 435-8558 Japan, Telephone: (81) 53-434-3311, Fax: (81) 53-434-5184
U.S.A.: Hamamatsu Corporation: 360 Foothill Road, Bridgewater, N.J. 08807, U.S.A., Telephone: (1) 908-231-0960, Fax: (1) 908-231-1218
Germany: Hamamatsu Photonics Deutschland GmbH: Arzbergerstr. 10, D-82211 Herrsching am Ammersee, Germany, Telephone: (49) 8152-375-0, Fax: (49) 8152-265-8
France: Hamamatsu Photonics France S.A.R.L.: 19, Rue du Saule Trapu, Parc du Moulin de Massy, 91882 Massy Cedex, France, Telephone: 33-(1) 69 53 71 00, Fax: 33-(1) 69 53 71 10
United Kingdom: Hamamatsu Photonics UK Limited: 2 Howard Court, 10 Tewin Road, Welwyn Garden City, Hertfordshire AL7 1BW, United Kingdom, Telephone: (44) 1707-294888, Fax: (44) 1707-325777
North Europe: Hamamatsu Photonics Norden AB: Torshamnsgatan 35 16440 Kista, Sweden, Telephone: (46) 8-509-031-00, Fax: (46) 8-509-031-01
Italy: Hamamatsu Photonics Italia S.r.l.: Strada della Moia, 1 int. 6, 20020 Arese (Milano), Italy, Telephone: (39) 02-93581733, Fax: (39) 02-93581741
China: Hamamatsu Photonics (China) Co., Ltd.: B1201, Jiaming Center, No.27 Dongsanhuan Beilu, Chaoyang District, Beijing 100020, China, Telephone: (86) 10-6586-6006, Fax: (86) 10-6586-2866

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