CHAPTER 03

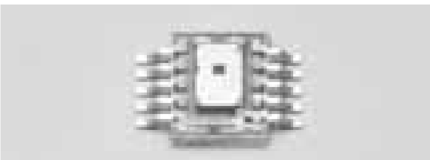
Photo IC

Photo IC

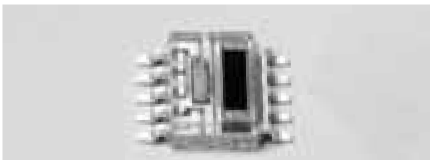
Photo ICs are optical devices that combine a photosensitive section and a signal processing circuit into one package. These devices possess versatile functions according to their particular product applications. Photo ICs offer the following features compared to devices made up of discrete parts on a circuit board.

· Small and lightweight
· Resistant to electromagnetic induction noise
· High reliability
· Ideal for mass production
· High cost performance

Photo ICs can be broadly grouped into monolithic types and hybrid types. The monolithic type contains a photosensor and a signal processing IC formed on the same chip. This type is extremely resistant to electromagnetic induction noise because there is no wiring between the photosensor and signal processing circuit. In the hybrid type, however, the photosensor and the signal processing IC are formed on separate chips and connected to each other within one package. The hybrid type offers the advantage that specifications such as the photosensor shape and spectral response characteristics are easy to change. When designing a photo IC to custom specifications, it is important to select the photo IC type while seeking a balance between performance and cost.
HAMAMATSU offers photo ICs that are optimized for a wide range of applications such as brightness and color sensing, optical links using POF (plastic optical fiber), and synchronous detection for laser printers, etc. HAMAMATSU has made intensive R&D efforts over the years to create various types of opto-semiconductor processes and unique IC processes to meet the product specifications needed by our customers. We have established a comprehensive production system ranging from photo IC design to wafer processing, assembly, and inspection processes. We also offer our strong support system for device analysis and evaluation including reliability testing. Feel free to consult with us about photo ICs that match your custom specifications.



Monolithic type example



Hybrid type example

HAMAMATSU Photo ICs

Application	Product name	Monolithic/hybrid	Output
Illuminance sensor	Photo IC diode	Monolithic	Analog
	Light-to-frequency converter photo IC	Hybrid	Digital
	I^2C compatible illuminance sensor	Monolithic	Digital
Optical link	Transmitter/receiver photo IC for optical link (For MOST network and AMI-C 1394 network)	Monolithic or hybrid	Digital
Displacement/rotation sensor	Encoder module	Hybrid	Digital
Color sensor	Digital color sensor, I^2C compatible color sensor	Monolithic	
Optical switch	Light modulation photo IC, photo IC for optical switch	Monolithic	
Print start timing detection in laser printer, etc.	Photo IC for laser beam synchronous detection	Hybrid	

1. Illuminance sensors

1 - 1 Photo IC diodes

Photo IC diodes are monolithic ICs consisting of photodiodes that generate electrical current from incident light and a circuit section that amplifies the current by several tens of thousands of times. Photo IC diodes provide a current output and can be used in the same way as a photodiode applied with a reverse voltage. Photo IC diodes include visual-sensitive compensation types and infrared types with sensitivity extending to the infrared range. Packages available include SIP (single inline package), DIP (dual inline package), COB (chip on board), and head-on types. The IC and the package can be customized to match customer needs, ranging from consumer electronics to in-vehicle use.

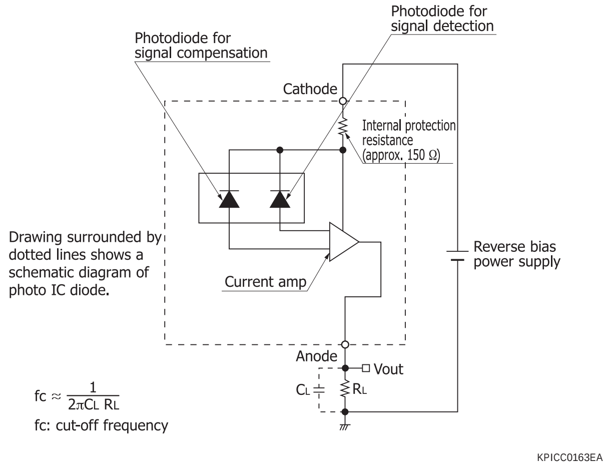
Features

- Just as easy to use as photodiodes
- Large output equivalent to phototransistors
- Excellent linearity

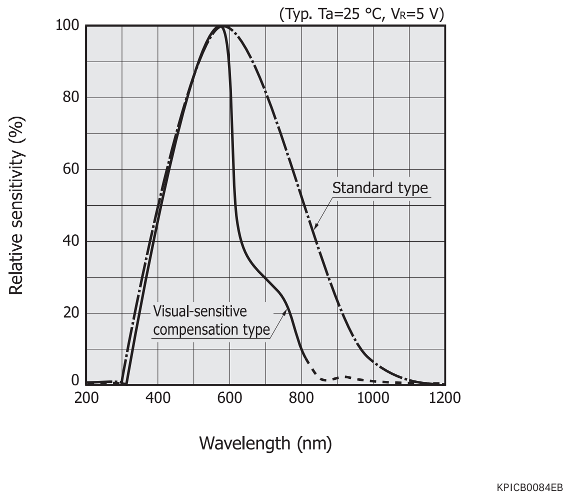
Operating principle and characteristics

Here we describe the operating principle of visual-sensitive compensation type photo IC diodes. The photosensitive section of visual-sensitive compensation types is made up of a photodiode for the main signal and a secondary photodiode for signal compensation. An internal arithmetic circuit subtracts the photocurrent generated in the photodiode for signal compensation from the photocurrent of the photodiode for signal detection, in order to obtain spectral response characteristics that block out the infrared range. The signal is then amplified by a current amplifier and is output.

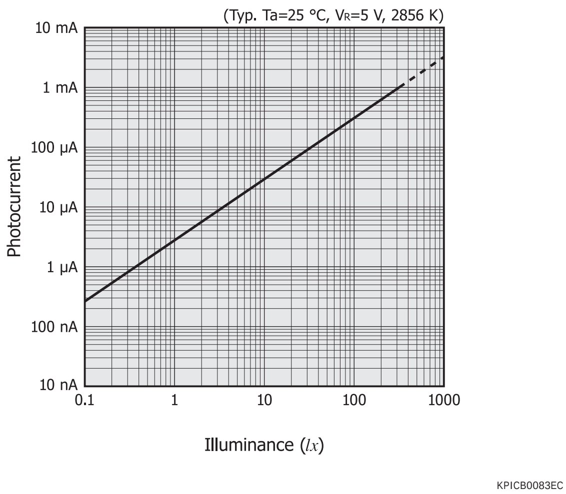
[Figure 1-1] Block diagram (visual-sensitive compensation type)



[Figure 1-2] Spectral response



[Figure 1-3] Linearity (visual-sensitive compensation type)



[Table 1-1] Electrical and optical characteristics (visual-sensitive compensation type S9648-100)

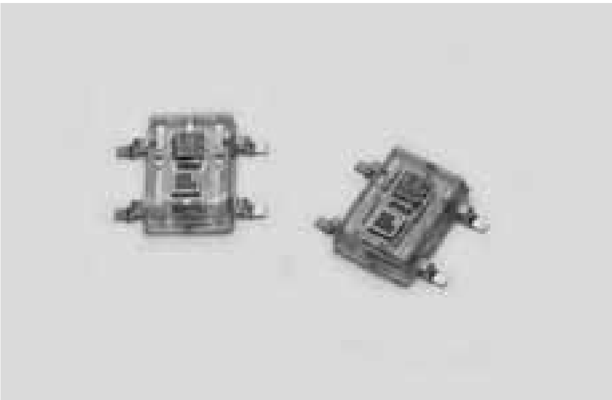
Parameter	Symbol	Condition	Min.	Typ.	Max.	Unit
Spectral response range	λ		-	300 to 820	-	nm
Peak sensitivity wavelength	λp		-	560	-	nm
Dark current	I_D	V_R=5 V	-	1.0	50	nA
Photocurrent	I_L	V_R=5 V, 2856K, 100 *lx*	0.18	0.26	0.34	mA
Rise time	tr	10 to 90%, V_R=7.5 V R_L=10 kΩ, λ=560 nm	-	6.0	-	ms
Fall time	tf	90 to 10%, V_R=7.5 V R_L=10 kΩ, λ=560 nm	-	2.5	-	ms

Usage

Apply a voltage so that a positive potential is applied to the cathode. If the high-frequency components must be removed, then connect a capacitive load (C_L) as a low-pass filter in parallel with the load resistance (R_L).
The cut-off frequency (fc) is expressed as shown in equation (1).

$$fc \approx \frac{1}{2\pi C_L R_L} \cdots\cdots\cdots (1)$$

1 - 2 Light-to-frequency converter photo IC



The light-to-frequency converter photo IC is a CMOS photo IC combining a photodiode with a current-to-frequency converter. This photo IC outputs digital pulses supporting CMOS logic, and the output frequency is proportional to the incident light level. This photo IC can be used in various types of light- level sensors.

Features

- Wide dynamic range

Ordinary voltage-to-current converter circuits usually have a limited dynamic range due to the noise and supply voltage. This light-to-frequency converter photo IC employs a circuit that converts current directly to a pulse frequency. So the photocurrent of the photodiode is converted to a frequency with no loss in the wide dynamic range. This photo IC therefore achieves a dynamic range of five figures or more.

- Spectral response close to human eye sensitivity

Spectral response characteristics of the photodiode used in the light-to-frequency converter photo IC are close to human eye sensitivity. The IC output nearly matches human eye sensitivity because color temperature errors are minimal.

- Low dark output

The photodiode in the light-to-frequency converter photo IC is driven under conditions where the bias voltage between the anode and cathode is near zero. This minimizes the dark current and allows higher sensitivity.

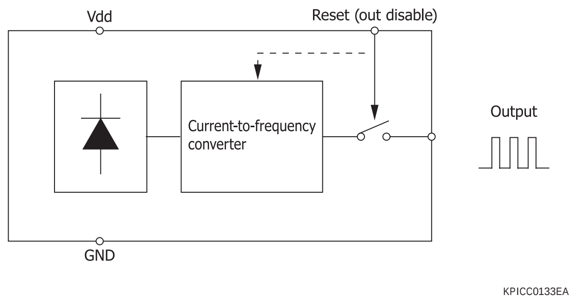
- Digital output

Output is in digital pulses so no troublesome analog processing is required.

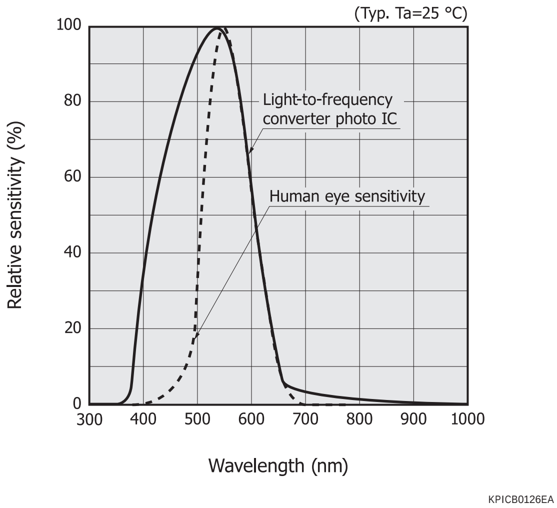
Operating principle and characteristics

The light-to-frequency converter photo IC is made up of a photodiode and current-to-frequency converter. It outputs a pulse frequency proportional to the illuminance. Output is released during the high period of the reset pulse. The output pulse phase is initialized when the reset pulse is changed from high to low.

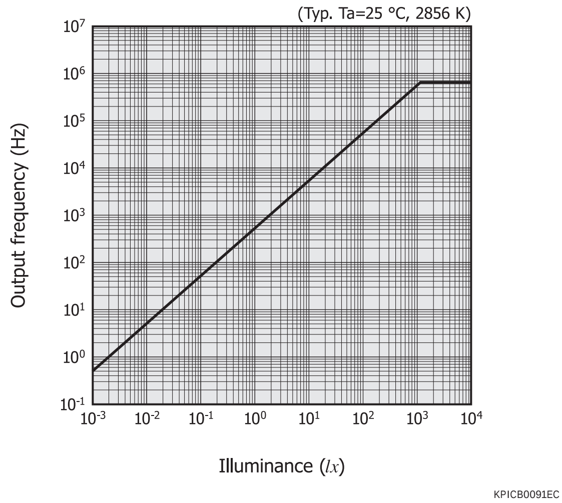
[Figure 1-4] Block diagram



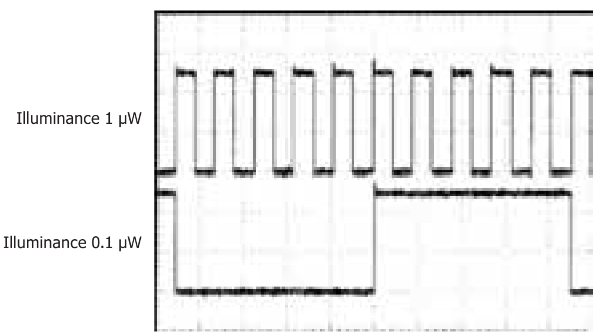
[Figure 1-5] Spectral response



[Figure 1-6] Output frequency vs. illuminance



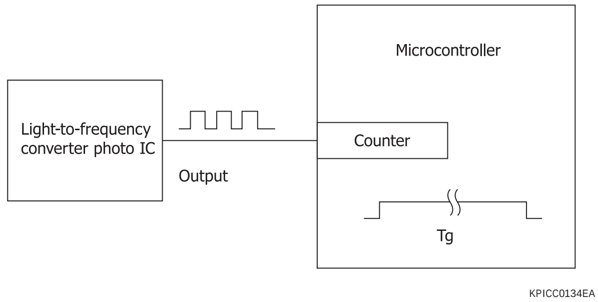
[Figure 1-7] Output waveform example



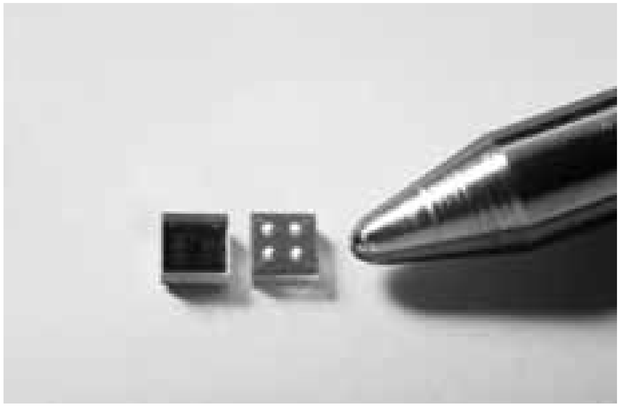
Usage

To detect illuminance by using the light-to-frequency converter photo IC, find the output frequency by counting the number of pulses in a specified period (Tg). The illuminance can also be detected by finding the half-cycle time of the output. This method is effective when detecting low illuminance or, in other words, during output of a low frequency.

[Figure 1-8] Connection example



1 - 3 I^{2}C compatible illuminance sensor



This illuminance sensor contains an I^{2}C (inter-integrated circuit; pronounced "I-square-C") interface. Illuminance data converted to digital signals is serially output. Ordinary illuminance sensors that provide an analog signal output require an A/D converter on the microcontroller, but this I^{2}C compatible illuminance sensor provides a digital signal that can be directly connected to a microcontroller supporting an I^{2}C interface. This illuminance sensor uses a chip size package (CSP) to meet needs in space-constraint applications such as cell phones.

Features

- Supports I^{2}C

I^{2}C is a serial interface developed by the Phillips Corporation. Two signal lines consisting of a SCL (serial clock) line and a SDA (serial data) line convey data between ICs. The I^{2}C interface is used to connect a microcontroller to a low-speed peripheral device operating at a few hundred kilohertz, such as in cell phones.

- Gain switching, dynamic range (integration time), and standby function are settable from the microcontroller.

- Spectral response characteristics are close to human eye sensitivity.

An infrared-cut filter is attached to the light receiving area to provide spectral response characteristics close to human eye sensitivity.

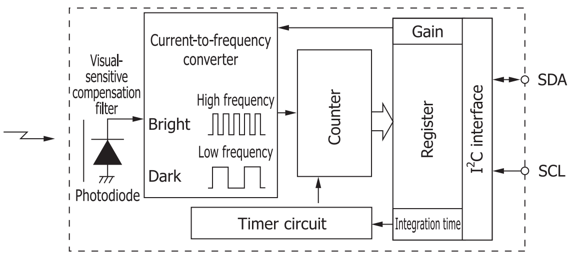
- Compact, thin package

A WL-CSP (wafer level - chip size package) is used to ensure a small size.

Structure

This I^2C compatible illuminance sensor is made up of a visual-sensitive compensation filter, photodiode, current-to-frequency converter, counter, timer circuit, register, I^2C interface circuit, etc. The visual-sensitive compensation filter provides human eye sensitivity by blocking out infrared components and allowing only visible light to pass through the filter. The photodiode converts the light to electrical current, and the current-to-frequency converter converts the electrical current to a pulse frequency. Under low light levels the frequency is low, and under high light levels the frequency becomes higher (maximum of approx. 1 MHz). In this point, this sensor functions the same as a light-to-frequency converter photo IC. Illuminance data can be obtained by counting the pulses output from the current-to-frequency converter with the counter for a certain period of time (integration time). The timer circuit generates signals to set this integration time. The digital data obtained from the counter is then accumulated in the register and sent via the I^2C interface to the microcontroller, etc.

[Figure 1-9] Block diagram



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Characteristics

The sensitivity of the I^2C compatible illuminance sensor can be adjusted by setting the integration time and gain. The sensitivity (S) is proportional to the integration time and gain.

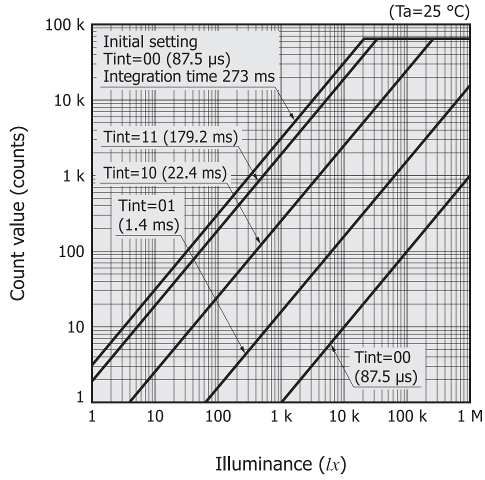
$$S = \text{Tint} \times \text{Gain}\ [\text{counts}/lx] \quad \cdots\cdots\cdots\cdots (2)$$

Tint : integration time

The percent of surface area used on the photodiode is different between high gain and low gain operation. The ratio of high-gain to low-gain surface area usage is 10 to 1. Integration time is selectable from four preset types (64 µs, 1 ms, 16 ms, and 128 ms). If even higher sensitivity is needed, the integration time can be set to a constant multiple [1 to 65535 (16 bits or less)] of these four types of integration times.

[Figure 1-10] Count value vs. illuminance (typical example)

(a) Low gain mode



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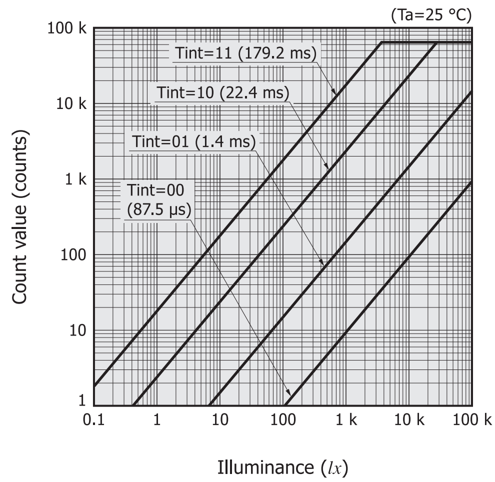
(b) High gain mode



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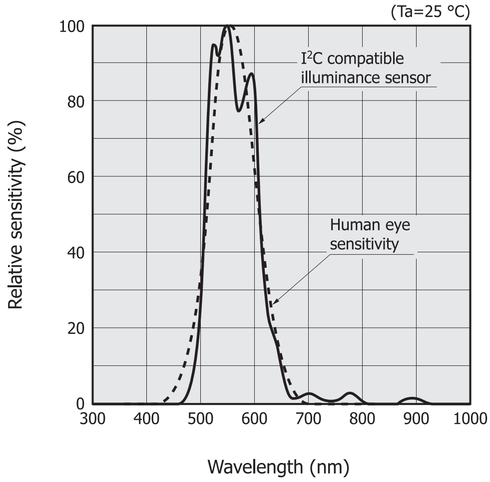
[Figure 1-11] Spectral response (typical example)



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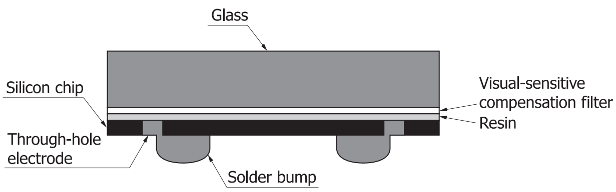
Package

The I^{2}C compatible illuminance sensor uses a WL-CSP (wafer level - chip size package). In conventional packages, the silicon chip is mounted on a lead frame or a substrate, and pads on the chip upper surface are connected to the lead frame or the electrodes on the substrate by wire bonding. In contrast to this, WL-CSP utilizes MEMS technology to connect pads on the chip upper surface with solder bumps on the chip backside by through-hole electrodes formed in the chip. This allows even further miniaturization.

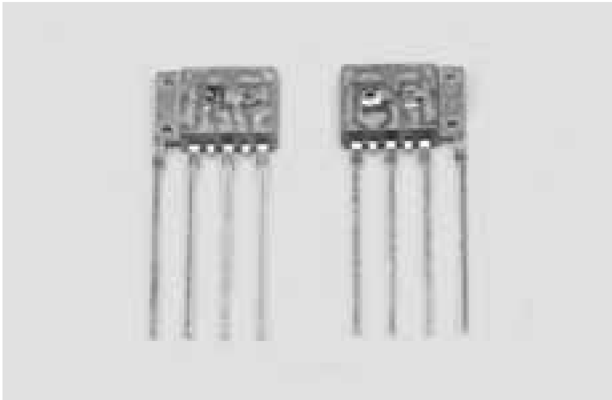
[Figure 1-12] WL-CSP cross section



2. Transmitter/receiver photo IC for optical link

In-vehicle networks can be classified into those for an automotive body system, driving control system, and information system. Information system networks require higher speed and higher quality due to widespread use of digital devices. The vehicle has many noise sources, so information system networks use optical fiber communications that are not affected by external noise. Information system network standards include the MOST (Media Oriented Systems Transport) network which is widespread in Europe, and the AMI-C (Automotive Multimedia Interface Collaboration) 1394 network which is being evaluated in the United States, Japan, France, and other countries.

2 - 1 For MOST networks



MOST networks utilize a ring topology that features simple node connections, easily expandable network, few connection cables, etc. Here we introduce fiber optical transceivers (FOT) for MOST networks. To meet demands for MOST networks using FOT, we provide transmitter photo ICs that output digital pulsed light and receiver photo ICs that convert the optical signals to a digital output.

Features

- High-speed response

Data transmission speed in MOST networks is 25 Mbps, but in order to utilize high-redundancy bi-phase signals, our photo ICs achieve a physical speed of 50 Mbps which is doubled in terms of NRZ (non-return-to-zero) conversion.

- Digital input (transmitter photo IC)

Transmitter photo ICs are digital input light-emitting devices that emit light at 650 nm which is the low-loss wavelength for POF. These photo ICs use a high-reliability LED with high emission efficiency.

- Monolithic structure (receiver photo IC)

Receiver photo ICs integrate the photodiode and signal processor into a monolithic structure to reduce effects from external electromagnetic noise. HAMAMATSU uses a unique PIN bipolar process to form the monolithic structure. This PIN bipolar process allows manufacturing photo ICs with high speed up to 250 Mbps.

- Standby function (receiver photo IC)

In-vehicle networks require a standby function for temporarily shutting down the network except when needed in order to lower battery consumption. The standby function shifts from operating mode to standby mode when light is no longer input to the photo IC. The receiver photo IC incorporates a light-level monitor to activate the standby function.

- High reliability

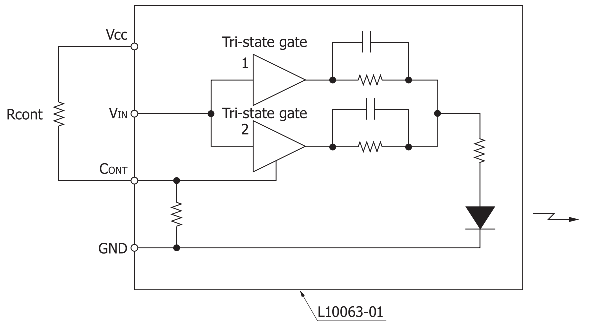
HAMAMATSU FOTs ensure the high reliability needed for in-vehicle use while housed in plastic packages which are easy to mass-produce. This allows use at operating temperatures from -40 to +105 °C.

- Low voltage drive

Besides the standard type using an operating voltage of 4.75 to 5.25 V, HAMAMATSU also provides a low voltage type operating at 3.135 to 3.465 V.

Configuration

[Figure 2-1] Block diagram (transmitter photo IC: L10063-01)



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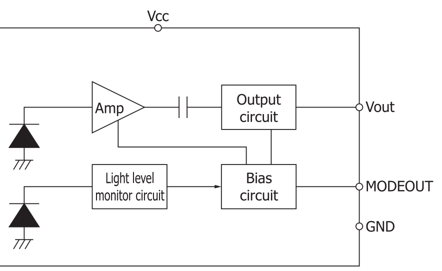
[Figure 2-2] Block diagram (receiver photo IC: S10064-01B)



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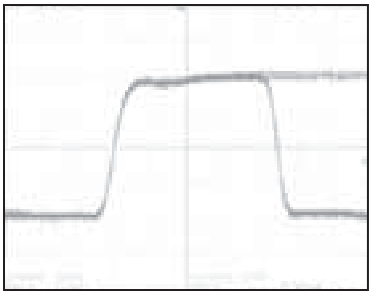
Characteristics

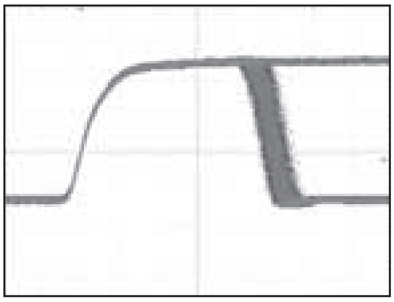
[Figure 2-3] Output waveforms

(a) Transmitter photo IC: L10063-01



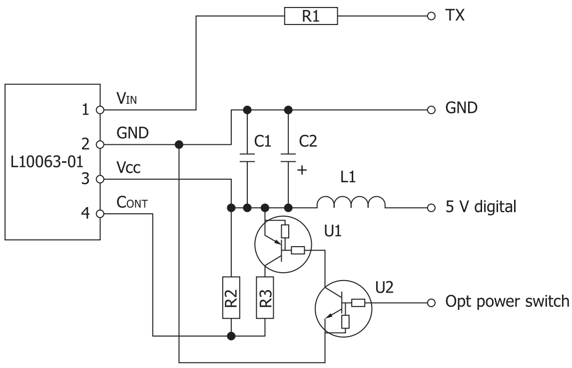
Horizontal axis: 5 ns/div.
MOST stream data, 45.2 Mbps

(b) Receiver photo IC: S10064-01B



Horizontal axis: 5 ns/div., vertical axis: 1 V/div.
MOST stream data, 45.2 Mbps

[Figure 2-4] Connection example (transmitter photo IC: L10063-01)



Symbol	Part	Constant	Remark
R1	Resistor	50 Ω to 150 Ω	For excessive current prevention
R2	Resistor	27 kΩ	For light output adjustment
R3	Resistor	27 kΩ	For light output adjustment
L1	Inductance	0.1 μH	For noise suppression
C1	Capacitor	0.1 μF	Bypass capacitor for noise suppression
C2	Capacitor	10 μF	Bypass capacitor for noise suppression
U1	Digital transistor	DTA144EKA	
U2	Digital transistor	DTC144EKA	

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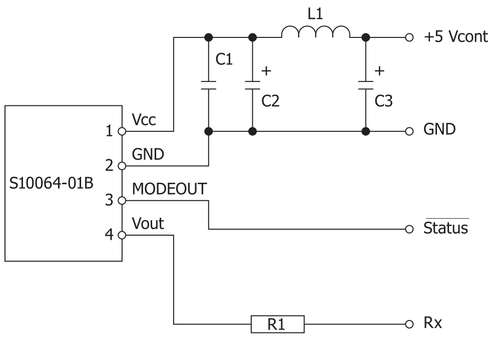
[Figure 2-5] Application circuit example
(receiver photo IC: S10064-01B)



Symbol	Part	Constant	Remark
R1	Resistor	50 Ω to 150 Ω	For excessive current protection
L1	Inductance	0.1 µH	
C1	Capacitor	0.1 µF	Bypass capacitor for noise suppression
C2	Capacitor	10 µF	Bypass capacitor for noise suppression
C3	Capacitor	10 µF	Bypass capacitor for noise suppression

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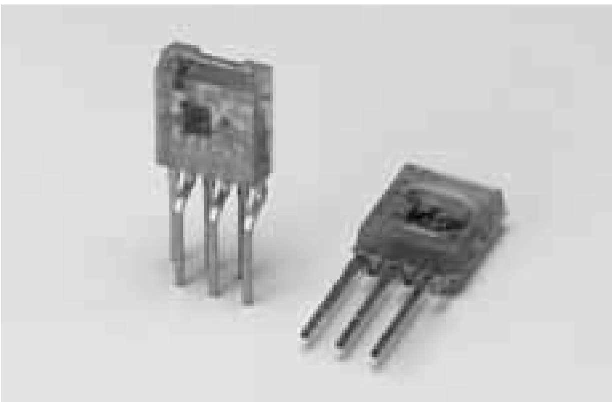
2 - 2 For AMI-C 1394 networks



AMI-C 1394 networks use a star topology that offers fast communication speeds along with high network efficiency and connectivity to IEEE 1394 devices such as the iPod®. Here we introduce FOT for the AMI-C 1394 network S200 (250 Mbps). These products offer a high-speed response of 250 Mbps and the high reliability needed for in-vehicle use at temperatures from -40 to 85 °C. They contain an LVDS input/output interface and can also be used for home LAN or FA (factory automation) LAN, as they send and receive the IEEE 1394 S200 data.

Features

- Uses high-speed LED (transmitter photo IC)

The transmitter photo IC employs a high-speed, high-power LED with a peak emission wavelength of 650 nm. The drive IC contains an internal temperature-compensation circuit that suppresses optical output fluctuations caused by changes in the ambient temperature.

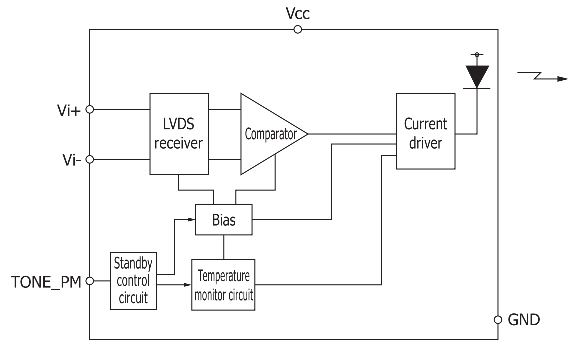
- Wide dynamic range and standby mode (receiver photo IC)

The receiver photo IC is a hybrid structure integrating a PIN photodiode and CMOS IC, which delivers high-speed operation. It has a wide dynamic range of -2 to -22 dBm and includes a standby function that switches to power-saving mode when no light is input.

Configuration

Figure 2-6 shows a block diagram of the transmitter photo IC. Operation shifts from standby mode to operation mode when an electrical signal is input to the input terminal, and the LED then emits light. A temperature monitor circuit senses the ambient temperature and adjusts the LED drive current.
Figure 2-7 shows a block diagram of the receiver photo IC. When the light level exceeding a preset level enters the photodiode, operation shifts from standby mode to operation mode, then the amplifier and LVDS output circuit start operating to output an LVDS signal.

[Figure 2-6] Block diagram (transmitter photo IC: L10061)



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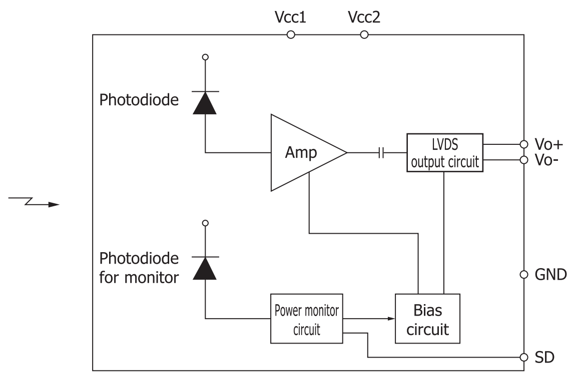
[Figure 2-7] Block diagram (receiver photo IC: S10062)



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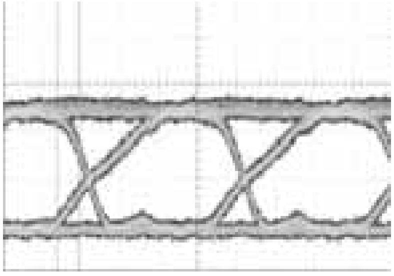
Characteristics

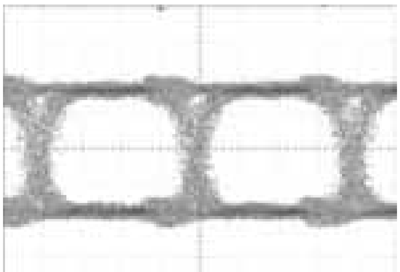
[Figure 2-8] Optical output waveforms

(a) Transmitter photo IC: L10061



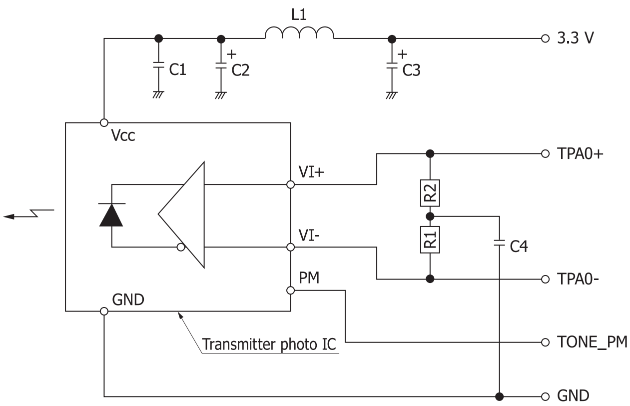
fD=250 Mbps, PN2^7-1, Vcc=3.3 V, Ta=25 °C

(b) Receiver photo IC: S10062



fD=250 Mbps, PN2^7-1, Vcc=3.3 V, Ta=25 °C, Pin=-22 dBm

[Figure 2-9] Connection example (transmitter photo IC: L10061)



Symbol	Part	Constant	Remark
R1	Resistor	56 Ω	
R2	Resistor	56 Ω	
L1	Inductance	0.1 µH	
C1	Capacitor	0.1 µF	Bypass capacitor for noise suppression
C2	Capacitor	10 µF	Bypass capacitor for noise suppression
C3	Capacitor	10 µF	Bypass capacitor for noise suppression
C4	Capacitor	270 pF	Bypass capacitor for noise suppression

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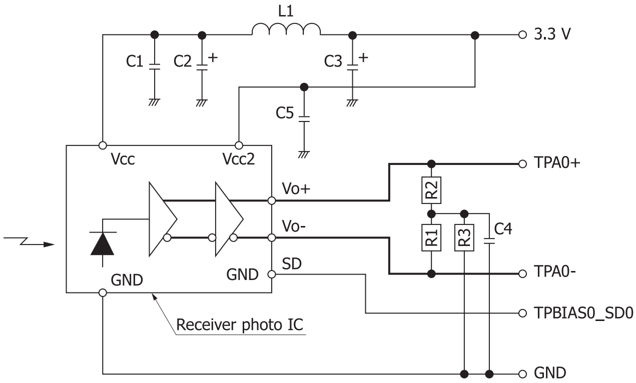
[Figure 2-10] Connection example (receiver photo IC: S10062)



Thick line: 50 Ω strip line

Symbol	Part	Constant	Remark
R1	Resistor	50 Ω	
R2	Resistor	50 Ω	
R3	Resistor	5 kΩ	
L1	Inductance	0.1 µH	
C1	Capacitor	0.1 µF	Bypass capacitor for noise suppression
C2	Capacitor	10 µF	Bypass capacitor for noise suppression
C3	Capacitor	10 µF	Bypass capacitor for noise suppression
C4	Capacitor	270 pF	Bypass capacitor for noise suppression
C5	Capacitor	0.1 µF	Bypass capacitor for noise suppression

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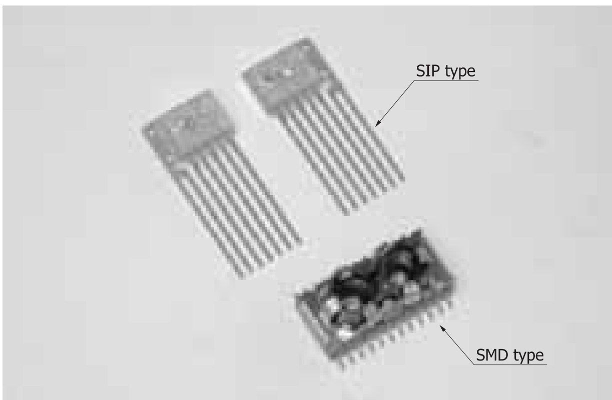
2 - 3 New approaches

We are currently developing new FOTs for MOST 150 which will be the next-generation MOST for attaining even faster in-vehicle networks. These FOTs will offer stable transmission at a data rate of 150 Mbps and also ensure highly reliable operation over a wide temperature range. In addition to SIP type, we will provide a SMD (surface mount device) type suitable for solder reflow mounting by assembling the transmitter/receiver chips in a single package.

[Figure 2-11] FOTs for MOST 150



3. Encoder modules (displacement/rotation sensors)

This is an encoder module that incorporates a red LED and a photo IC designed specifically for optical encoders. This encoder module detects the displacement or rotation angle of the object. When the slit optical pattern attached to the object moves between the LED and photo IC, the 4-element photodiode in the photo IC reads the slit optical pattern, and then outputs the pattern signals (phase A and phase B).

Features

• High resolution and high accuracy

Incremental optical encoders require two LED-photodiode pairs in order to detect the position and direction of movement of the object. Using multiple discrete LED-photodiode pairs has the disadvantage that characteristics vary between components. However, this encoder module incorporates one LED and a single-chip 4-element photodiode, so there are no problems due to variations in characteristics between components. Moreover, element position accuracy is high, so both high resolution and high accuracy are ensured.

• Low current consumption

Incorporates one red LED and one photo IC which are built into a single module to ensure low current consumption.

• Small size

Uses a small package with positioning pins.

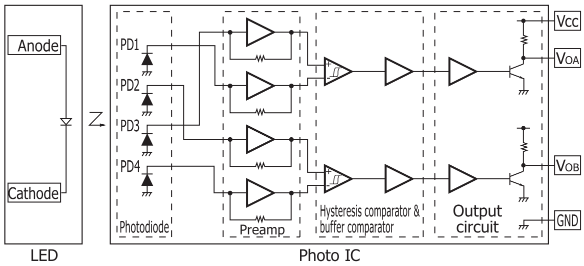
Operating principle and usage

A block diagram of this encoder module is shown in Figure 3-1. A light beam emitted from the LED is transformed into light/dark patterns via the slits and projected onto the 4-element photodiode. Figure 3-3 shows recommended slit sizes in the slit plate for this encoder module.

The 4-element photodiode has four active areas which are PD1, PD2, PD3, and PD4. The photo IC output is a 2-phase digital output (TTL compatible) consisting of phase A and phase B. Phase A (V_{OA}) shows which of PD1 or PD3 is receiving more light, and phase B (V_{OB}) shows which of PD2 or PD4 is receiving more light.

Figure 3-4 shows changes in the signal amount that was input to PD1 to PD4 when there was movement of the light/dark pattern created by the slits, along with results obtained when the electrical current from that input signal was converted into a 2-phase digital signal via the preamp, comparator, and output circuit.

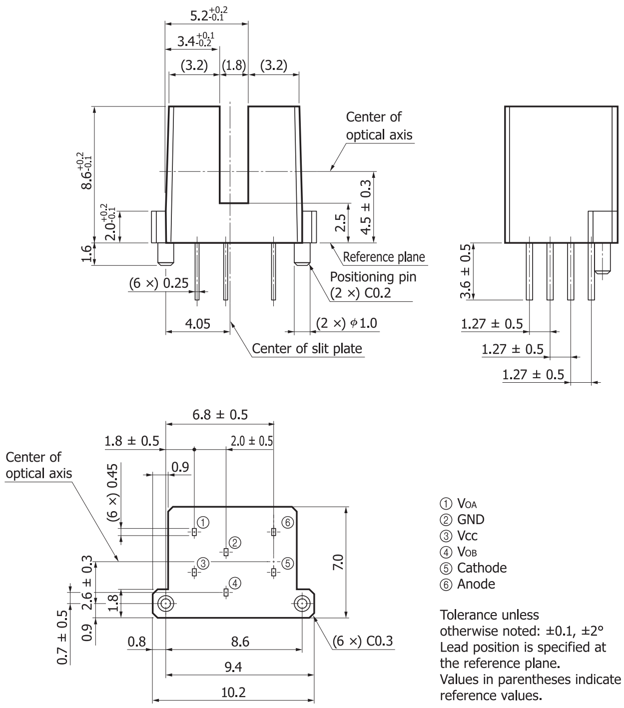
[Figure 3-1] Block diagram and truth table



Input		Output	
		V_{OA}	V_{OB}
$P_1 < P_3$	$P_2 > P_4$	Low	Low
$P_1 < P_3$	$P_2 < P_4$	Low	High
$P_1 > P_3$	$P_2 > P_4$	High	Low
$P_1 > P_3$	$P_2 < P_4$	High	High

KPCC0011EC

[Figure 3-2] Dimensional outline (unit: mm)



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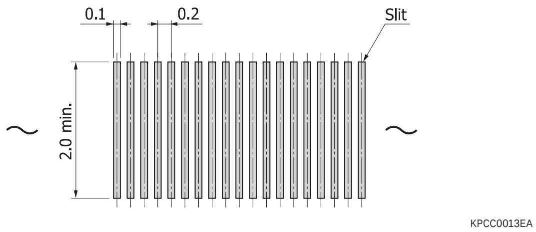
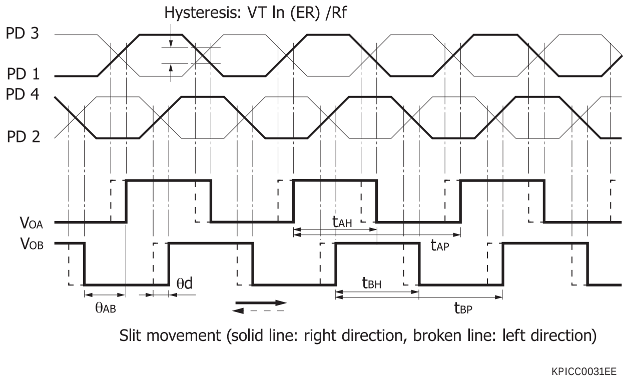
3 ▼ Photo IC

[Figure 3-3] Recommended slit dimension (unit: mm, t=0.1)
(See "Dimensional outline in Figure 3-2" for the center position of slit plate.)



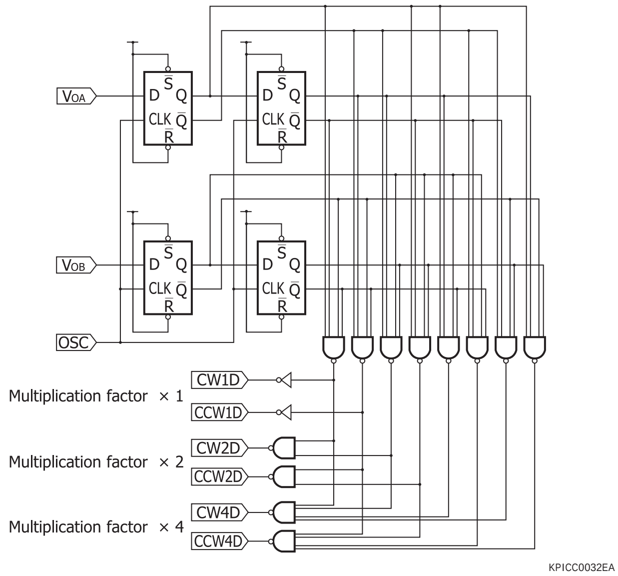
[Figure 3-4] Timing chart



The incremental encoder module detects the distance and direction that the slit optical pattern moves, but it cannot detect the position of the slit optical pattern itself. To detect the slit optical pattern position, the origin point of the slit plate must be specified, and the amount of movement from the origin point then detected. To do this, a device is needed for calculating the encoder module's output change count from the origin point. Additions to the output change count are judged as movement farther from the origin point, while subtractions are viewed as movement nearer the origin point. This judgment is made by the 2-phase digital output (V_{OA}, V_{OB}) making either of the following transitions.

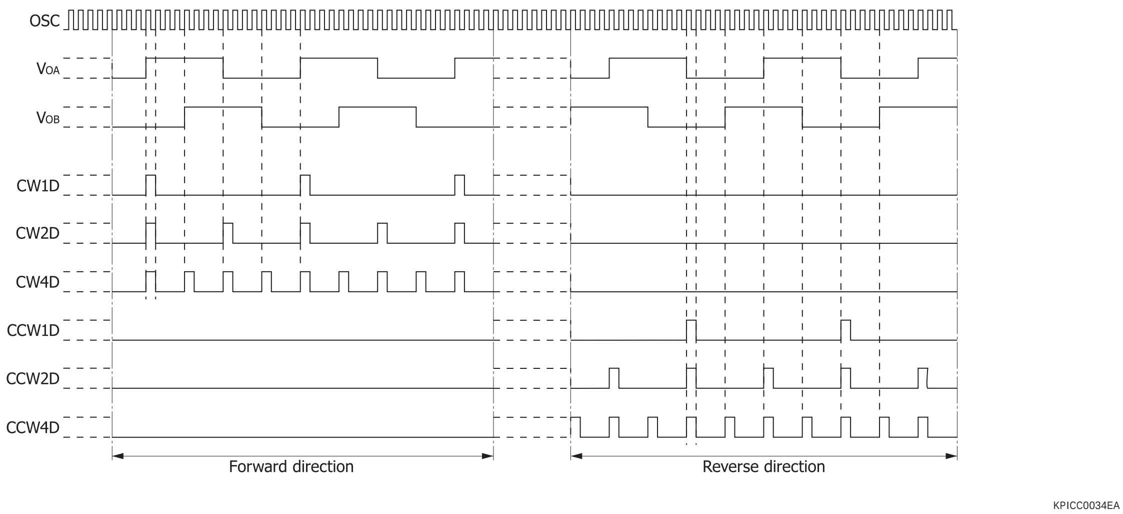
(L, L) → (L, H) → (H, H) → (H, L) → (L, L)
(L, L) → (H, L) → (H, H) → (L, H) → (L, L)

[Figure 3-5] Application circuit example
(CW/CCW pulse signal generator circuit)



The circuit in Figure 3-5 is a CW (forward direction)/CCW (reverse direction) pulse signal generator circuit that generates up-count signals and down-count signals for counting movement distance and rotation angles. This circuit detects the order of state transitions in V_{OA} and V_{OB} at the OSC signal timing which is used as the sampling signal, and generates pulse signals to the CWnD terminal in response to state transitions in the forward direction and to the CCWnD terminal in response to state transitions in the reverse direction (CWnD/CCWnD are output terminals for the multiplication factor × n). These CWnD/CCWnD terminals generate "n" number of pulses per one state transition period of V_{OA} and V_{OB}. This pulse width is equal to one period of the sampling signal. Figure 3-6 shows pulse signals appearing at the output terminal in response to state transitions of OSC, V_{OA}, and V_{OB}.

[Figure 3-6] Decoder output timing chart (when used with circuit shown in Figure 3-5)

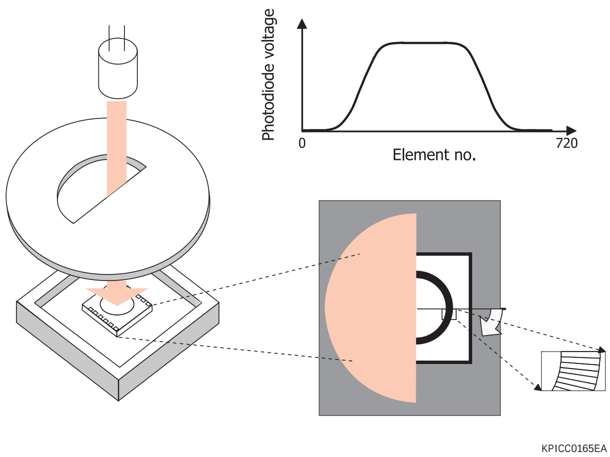


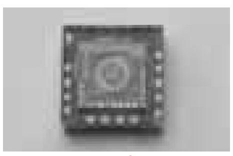
A suitable sampling signal frequency is 40 or more times larger than the maximum frequency of one period of the V_{OA} and V_{OB} state transitions (in Figure 3-6 this is 16 times for purposes of simplicity). Pulses appearing at each terminal are generated with a slight delay from the instant that the defined state transition occurs [maximum theoretical delay time = 1/[2 × OSC frequency (unit: cycles)]. Each of these signals is input to the up-count terminal and down-count terminal of the up/down counter. The amount of movement from the origin point can then be detected with a circuit that clears the up/down counter at origin position.

New approaches

We are developing a rotation angle sensor that directly processes absolute angle information into digital data. This rotation angle sensor consists of an annular array of 720-element fan-shaped photodiodes and a signal processing circuit. To detect a rotation angle, this sensor is combined with a light source (LED) and a rotating plate with a semicircular slit to configure an encoder. Light emitted from the light source passes through the semicircular slit and strikes the annular photodiode array. The signal processing circuit converts the light quantity incident on each element to a voltage and compares the voltage with a threshold level to obtain binary data which shows boundary positions of dark and bright sections on the annular photodiode area and is serially output. By calculating this output with an external device, the absolute angle of the rotating plate can be found. Applications of this rotation angle sensor include vehicle steering angle sensors, tilt detection in digital cameras, machine tool and FA equipment encoders, and operating sensors in game machines, etc. (patent pending).

[Figure 3-7] Encoder configuration example using rotation angle sensor

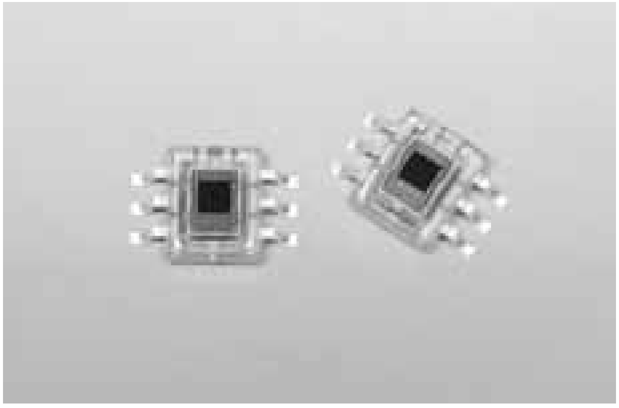




Rotation angle sensor

4. Color sensors

4 - 1 Digital color sensors



This digital color sensor converts the RGB components of light into 12-bit digital signals for output as serial data. The digital output makes handling the data very simple.
One typical application for this digital color sensor is adjusting the backlighting for RGB-LED back-lit liquid crystal displays. To handle deterioration that occurs in LED over time, the digital color sensor monitors the LED brightness and feeds back that information to the LED driver to stabilize the color tint and brightness of the liquid crystal display. This digital color sensor is also widely used to make various color measurements.

Features

- 9 × 9 element photodiode

This digital color sensor is a monolithic photo IC that integrates a photodiode and analog/digital circuits. The photodiode consists of 9 × 9 elements arranged in a mosaic pattern. Each element is sensitive to one of three colors which are red (λp=610 nm), green (λp=540 nm), and blue (λp=465 nm). The mosaic pattern of the 9 × 9 elements helps reduce effects due to variations in brightness.

- 2-step sensitivity setting

Sensitivity can be selected from 2-step settings (high-sensitivity mode and low-sensitivity mode) to measure light over a wide illuminance range. The active area varies depending on whether high-sensitivity or low-sensitivity mode is used. (High-sensitivity mode uses 9 × 9 elements, and low-sensitivity mode uses only 3 × 3 elements in the center.)

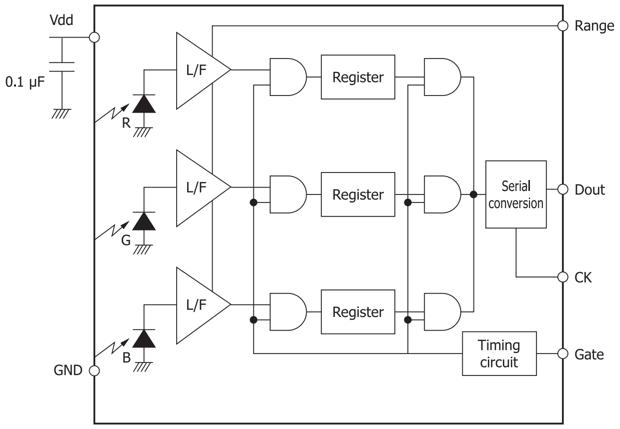
- 12-bit digital output

The light signal measured by the photodiodes is amplified and converted into a 12-bit digital signal.
Each of the RGB photodiodes arranged in a mosaic pattern has an internal amplifier, so the RGB components of the incident light can be simultaneously measured with high accuracy.

Structure and operating principle

The amplifiers in this digital color sensor utilize a light-to-frequency converter. The output from the light-to-frequency converter is a square wave (digital signal), and its frequency is proportional to the incident light level.
Outputs from each light-to-frequency converter are counted during the high period of the Gate terminal, and the count value is held in a register. This count value is then serially output from the Dout terminal according to the color in synchronization with pulses that are fed to the CK terminal. The colors are output in the sequence “red” → “green” → “blue,” and each color output is 12 bits.

[Figure 4-1] Block diagram



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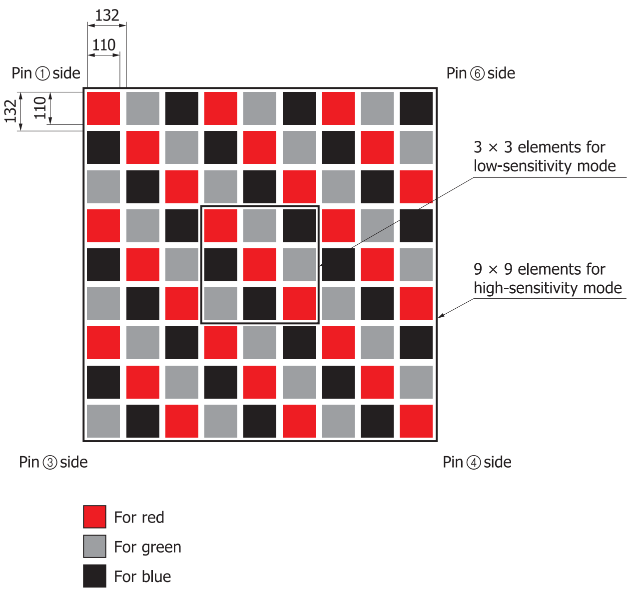
[Figure 4-2] Enlarged view of active area (unit: μm)



Note: Gaps between elements are light-shielded.

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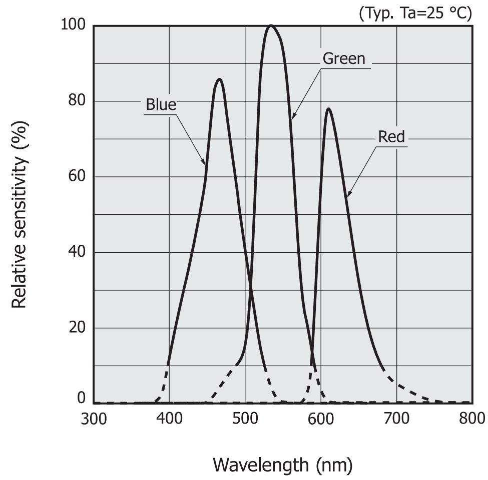
[Table 4-1] Sensitivity setting

Range	Mode	Effective active area
High	High sensitivity	9 × 9 elements
Low	Low sensitivity	3 × 3 elements

Characteristics

[Figure 4-3] Spectral response



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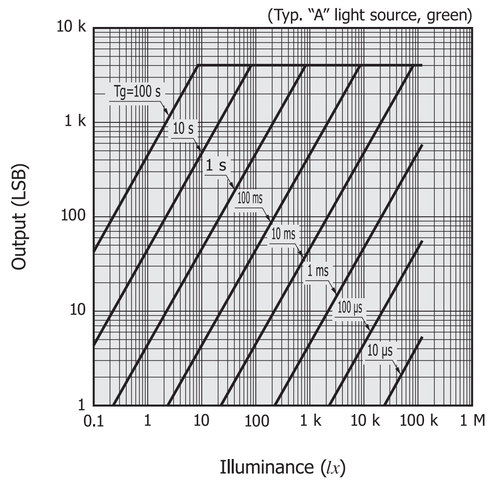
[Figure 4-4] Output vs. illuminance
(a) Low range



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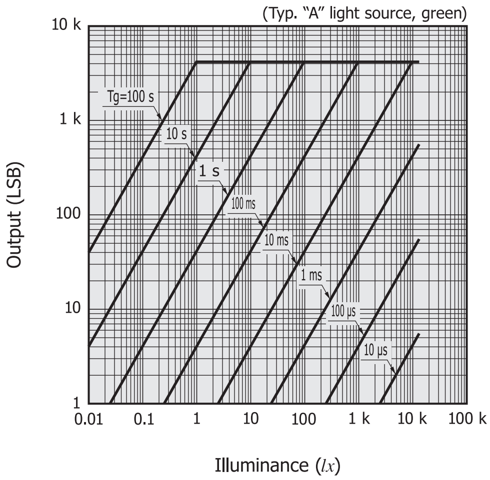
(b) High range



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Usage

The only input signals required by the digital color sensor are a "Range" signal for setting the sensitivity, a "Gate" signal for setting the light integration time, and a "CK" signal for extracting the 12-bit digital data measured from the light [Figure 4-5]. The input and output for digital color sensors are both digital signals and so can be directly connected to the microcontroller and easily used. The only required external component is a bypass capacitor (0.1 µF) that should be inserted between the power supply and the ground.

An infrared cut-off filter is attached to the top surface of the package of the digital color sensor to remove infrared light. However, light from the side of the package does not pass through the infrared cut-off filter. Some countermeasure such as using an aperture is needed to remove infrared light that may enter the sensor without passing through the infrared cut-off filter.

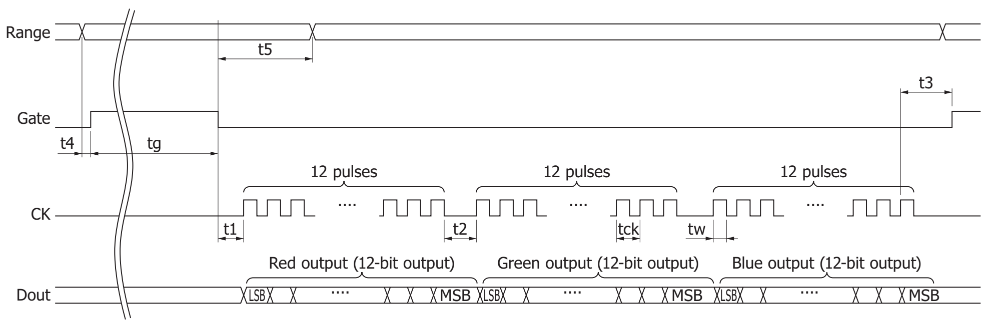
4 - 2 I²C compatible color sensor

This color sensor incorporates an I²C interface. It is sensitive to red (λp=615 nm), green (λp=530 nm), blue (λp=460 nm), and infrared (λp=855 nm) light, and outputs detected results as 16-bit digital data for each color. Four 16-bit registers are also included to measure RGB and infrared light sequentially. The sensitivity and integration time are adjustable so that light measurements can be performed over a wide dynamic range.

Features

- Supports I²C
- Sequential measurements of RGB and infrared light
- 2-step sensitivity switching (sensitivity ratio 1:10)
- Adjustable sensitivity (1 to 65535 times) by setting the integration time
- Low voltage (2.5 V, 3.3 V) operation
- Low current consumption (75 µA typ.)
- Subminiature package (WL-CSP)

[Figure 4-5] Timing chart (digital color sensor)



Operating sequence
(1) Set the Gate terminal and CK terminal to low.
(2) Select the desired sensitivity with the Range terminal.
(3) Set the Gate terminal from low to high to start integrating the light level.
(4) After the desired integration time (tg) has passed, set the Gate terminal from high to low to end the light level integration.
(5) Measurement data is output from the Dout terminal by inputting 36 CK pulses to the CK terminal.

Note 1: A total of 36 CK pulses are required to read out 3-color measurement data. Red data is output by the first 12 pulses, green data by the next 12 pulses, and blue data by the last 12 pulses. Measurement data is output from the LSB side.
Note 2: Measurement data changes at the CK pulse rising edge.
Note 3: Do not switch the Range terminal during integration time (tg).

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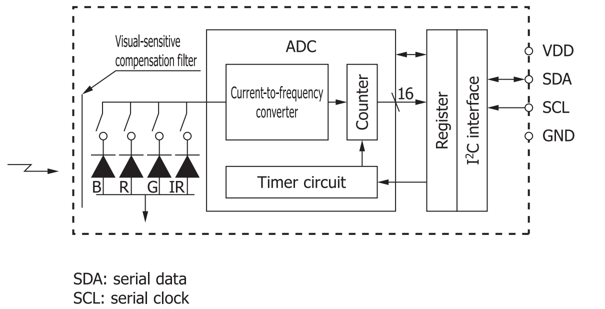
Configuration and operating principle

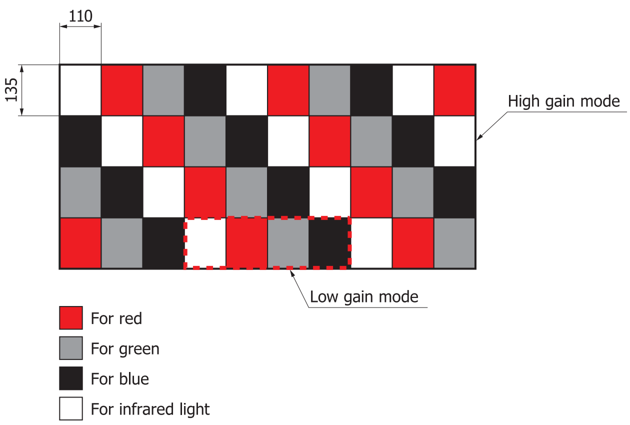
The basic configuration of this I²C compatible color sensor is identical to that of I²C compatible illuminance sensors. This sensor is comprised of a visual-sensitive compensation filter, photodiode, current-to-frequency converter, counter, timer circuit, register, and I²C interface circuit, etc. [Figure 4-6]. The photodiode consists of 4 × 10 elements arranged in a mosaic pattern [Figure 4-7], and the size of each element is 110 × 135 μm. In ordinary color sensors, strong infrared light such as from remote controls might cause errors in color detection. This I²C compatible color sensor, however, prevents such detection errors using its infrared detection function.

The colors being measured are automatically selected by a switch, so they are sequentially measured in the order of red, green, blue, and infrared. The gain and integration time can be set the same as in I²C compatible illuminance sensors. The 16-bit data for each color stored in the registers can be read out through the I²C interface.

[Figure 4-6] Block diagram



[Figure 4-7] Enlarged view of active area (unit: μm)

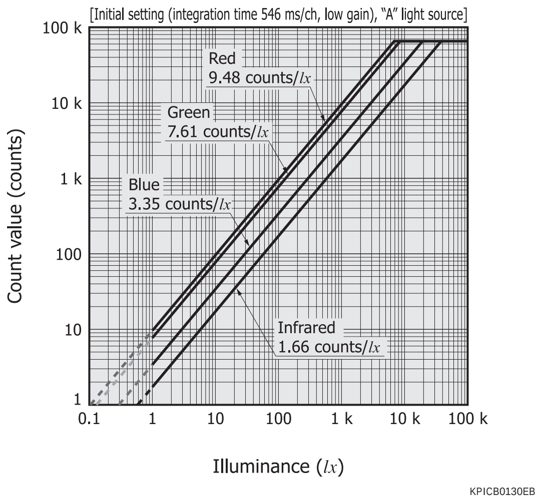


Characteristics

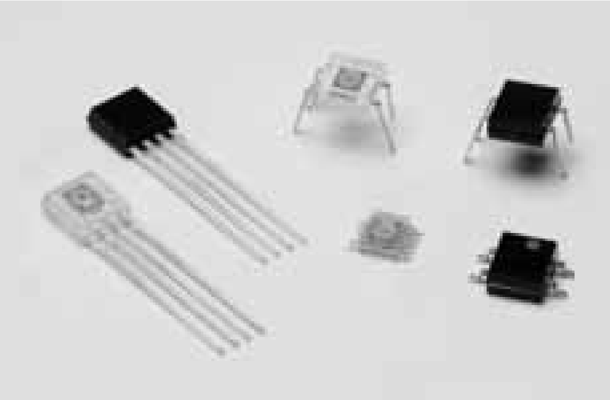
In low gain mode, a single-element photodiode in the bottom center is used to measure each color. In high gain mode, however, a 10-element photodiode is used for each color. The gain switching sensitivity ratio is therefore 1 to 10. Integration time (Tint) is selectable from four preset types (64 μs, 1 ms, 16 ms, and 128 ms). If even higher sensitivity is needed, the integration time can be set to a constant multiple [1 to 65535 (16 bits or less)] of these four types of integration times.

The default is set to low-gain mode at an integration time of 574 ms (3120 times 184 μs).

[Figure 4-8] Count value vs. illuminance (typical example)



5. Light modulation photo IC (for optical switch)



Light modulation photo ICs were developed to optically detect objects. Optical detection of objects usually uses a photosensor/light emitter pair, like a photointerrupter and photoreflector which detect an object when it interrupts or reflects light. However, detection errors might occur if fluctuating background light such as room lighting strikes the photosensor. To prevent these detection errors, one typical method uses optical filters by utilizing the difference in wavelengths between the signal light and background light. However, these methods do not work if the background light level is too strong. Light modulation photo ICs deal with this problem by using a synchronous detection method to reduce detection errors and ensure a stable output even if fluctuating background light strikes the photosensor. This synchronous detection method pulse-modulates the signal light and detects it in synchronization with the modulation timing to reduce effects from "noise light" that enters the photosensor asynchronously.

Features

- Fewer detection errors even if fluctuating background light hits the photosensor

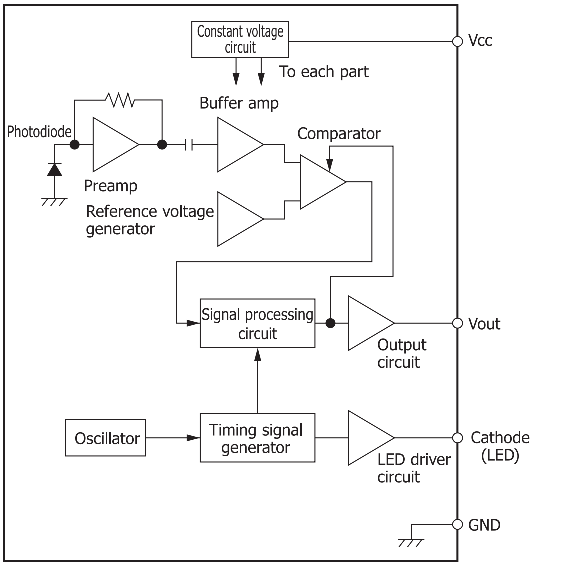
A typical light modulation photo IC consists of an oscillator, a timing signal generator, an LED driver circuit, a photodiode, a preamp, a comparator, a signal processing circuit, and an output circuit, which are all integrated on a monolithic chip. Connecting an external LED to this photo IC allows optical synchronous detection.

- Various types are available for handling higher background light levels or offering higher sensitivity.

HAMAMATSU provides types usable even under higher background light levels (10000 *lx* typ.), as well as high sensitivity types (lower detection level: 0.2 μW/mm^2 typ.), and asynchronous type that does not require wiring to a light emitter. These are supplied in various packages (DIP, SIP, and surface mount type).

Types for higher background light level (S4282-51, S6986) have a preamp with special measures added to deal with DC light input. This ensures reliable detection of signal light even under high-illuminance DC background light. On the other hand, high-sensitivity types (S6846, S7136) allow making the detection distance even longer.

[Figure 5-1] Block diagram and truth table



Truth table

Input	Output level
Light ON	Low
Light OFF	High

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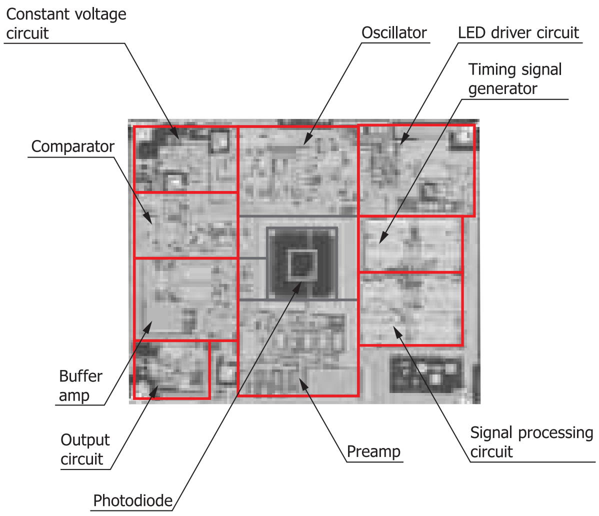
[Figure 5-2] Enlarged photograph of chip and block layout



Configuration

Circuit block configurations of a light modulation photo IC are described below.

(1) Oscillator and timing signal generator

The oscillator produces a reference oscillation output by charging and discharging the internal capacitor at a constant current. The oscillation output is fed to the timing signal generator, which then generates LED drive pulses and other timing pulses for digital signal processing.

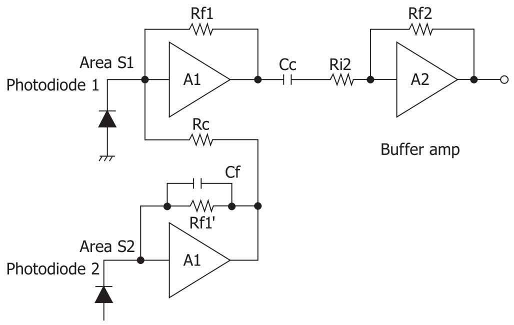
(2) LED driver circuit

This circuit drives an externally connected LED using the LED drive pulses generated by the timing signal generator. The duty cycle is 1/16. The S4282-51 and S6986 use a constant current drive, while the S6846 and S7136 use an open collector drive.

(3) Photodiode and preamp

Photocurrent generated in the photodiode is converted to a voltage via the preamp. The preamp in the S4282-51 and S6986, which are usable at high background light levels, uses an AC amplifier circuit to expand the dynamic range versus DC or low-frequency fluctuating background light without impairing signal detection sensitivity.

[Figure 5-3] Preamp block diagram (S4282-51, S6986)



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(4) Capacitive coupling, buffer amp, and reference voltage generator

Capacitive coupling removes low-frequency noise and also cancels the DC offset in the preamp. The buffer amp amplifies the signal up to the comparator level, and the reference voltage generator generates a comparator level signal.

(5) Comparator

The comparator has a hysteresis function that prevents chattering caused by small fluctuations in the incident light.

(6) Signal processing circuit

The signal processing circuit consists of a gate circuit and a digital integration circuit. The gate circuit discriminates the comparator output to prevent possible detection errors caused by asynchronous background light. Background light that enters at the same timing as the signal detection cannot be eliminated by the gate circuit. The digital integration circuit in a subsequent stage cancels out this background light.

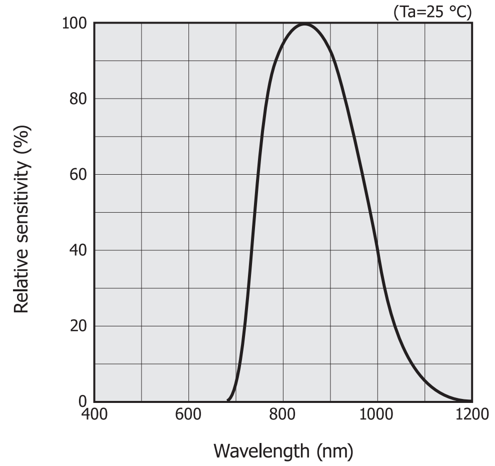
(7) Output circuit

This circuit serves as an output buffer for the signal processing circuit and outputs the signal to an external circuit.

Characteristics

[Figure 5-4] Spectral response

(a) S6846, S7136



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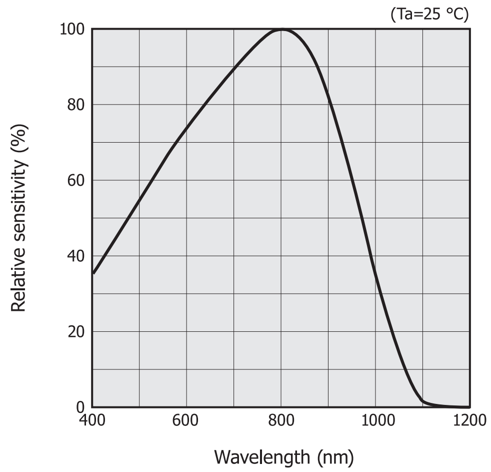
(b) S4282-51, S6986



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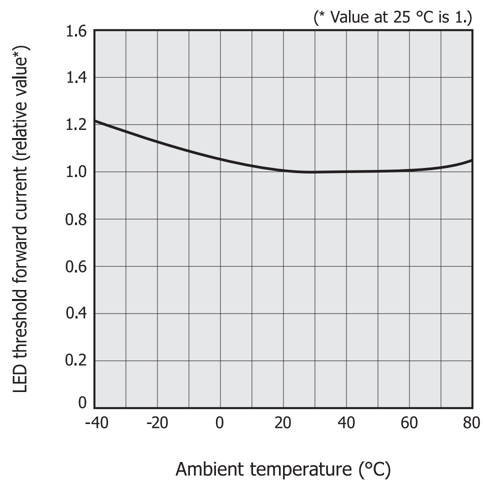
[Figure 5-5] Sensitivity temperature characteristics

(a) When used with HAMAMATSU LED (λp=890 nm)



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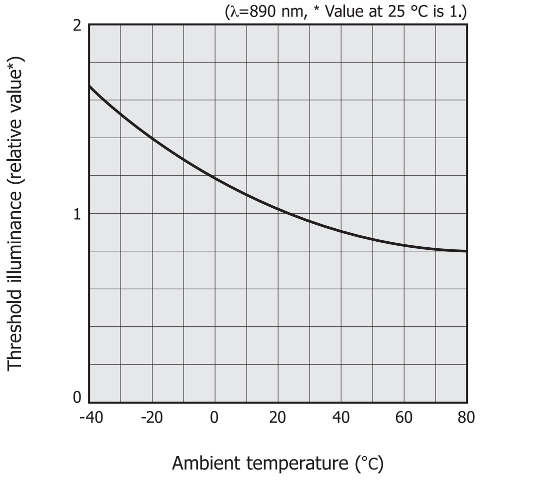
(b) Light modulation photo IC only



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Usage

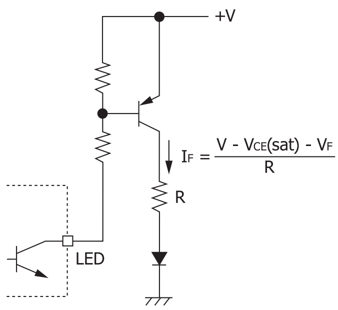
Optical synchronous detection type photoreflectors and photointerrupters can be easily made by connecting an infrared LED to a light modulation photo IC, which are less affected by fluctuating background light. The light modulation photo IC is used in reflection type sensors that detect an object or proximity to an object by detecting the infrared LED light reflected from the object; and also used in transmission type sensors that detect an object or a passing object by detecting whether the infrared LED light beam is interrupted by the object.
An infrared LED must be connected to the light modulation photo IC in order to perform synchronous detection. In some applications, however, connecting an LED may not be possible. In those cases, asynchronous type photo ICs are used. Asynchronous photo ICs cannot remove fluctuating background light as efficiently as the synchronous type, but they offer the advantage that they can be used without connecting to an infrared LED.

(1) LED drive current enhancement

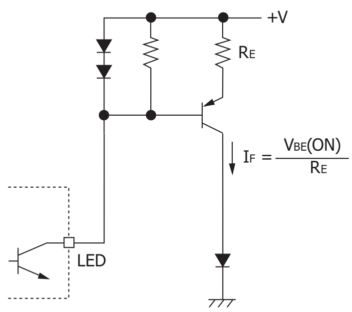
Detecting light over longer distances requires enhancing the LED drive current. This means that an external driver circuit must be added. Figure 5-6 shows simple external circuits using a PNP transistor to enhance the LED drive current. Another method uses a pull-up resistor connected to the LED terminal to convert LED drive pulses to logic signals before inputting the signals to the external LED driver circuit. If the photo IC and the LED drive current operate from the same power supply line, then the supply voltage may fluctuate due to the LED drive current and cause erroneous operation. If this happens, take measures to stabilize the photo IC power terminal.

[Figure 5-6] LED drive current enhancing method

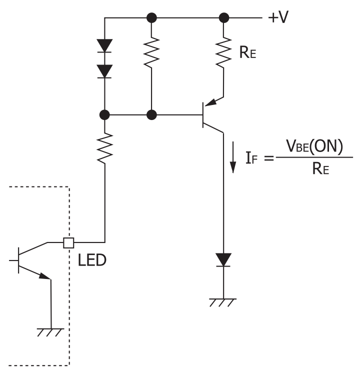
(a) All types



(b) S4282-51, S6986



(c) S6846, S7136



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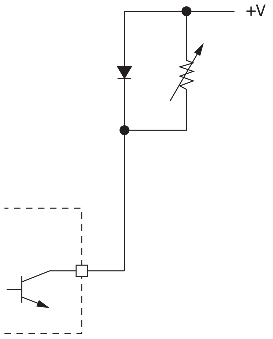
(2) Sensitivity adjustment

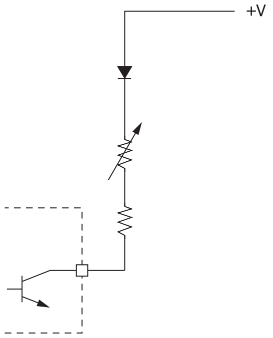
There is no special terminal for adjusting the sensitivity of light modulation photo ICs. If sensitivity must be adjusted, then change the LED drive current. To do this, connect a variable resistor in parallel with the LED for the S4282-51 and S6986; and connect a variable resistor in series with the LED for the S6846 and S7136. If using an external circuit to drive the LED, adjust the external circuit constant.

[Figure 5-7] LED drive current adjusting method

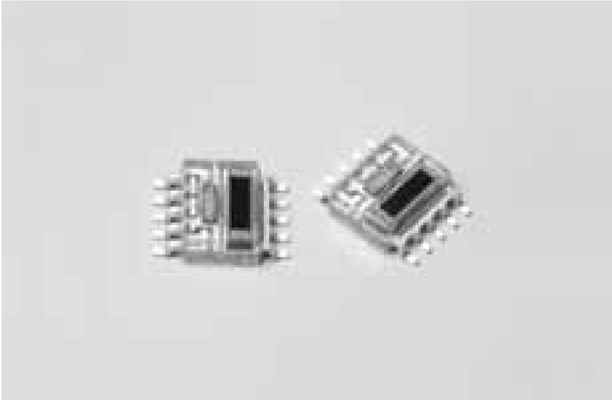
(a) S4282-51, S6986



(b) S6846, S7136



6. Photo IC for laser beam synchronous detection



This photo IC detects the print start timing such as for laser printers. It contains a high-speed PIN photodiode and a high-speed signal processing circuit. When the laser beam passes over the photodiode, the photo IC outputs a digital signal to show the laser beam timing.

Features

- Available in high-accuracy type (dual-element photodiode) and general-purpose type (single-element photodiode)

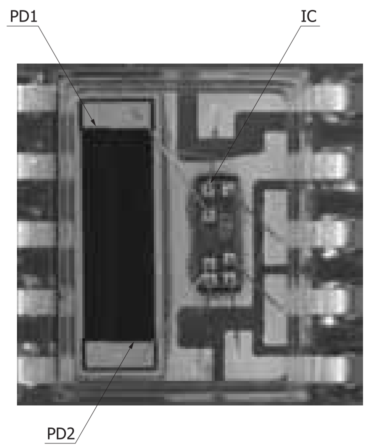
- Compatible with a wide range of input laser power

Internal current amplifiers are available in a 6 × type and 20 × type. The dual-element photodiode type delivers a stable output even if the ambient temperature or input laser power fluctuates, by comparing the outputs from the two elements. The single-element photodiode type is available with different lengths of the photodiode.

- Hybrid structure

The photo IC for laser beam synchronous detection uses a hybrid structure to make use of the features of both photodiodes and amplifiers [Figure 6-1].

[Figure 6-1] Enlarged photo (dual-element photodiode type S9684)



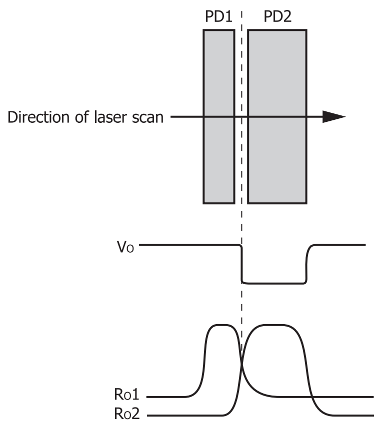
Operating principle

Figure 6-2 shows a block diagram of the S9684 dual-element photodiode type. When PD1 and PD2 are irradiated with a laser beam, the respective photocurrents Ipd1 and Ipd2 flow. These photocurrents are amplified by the current amplifiers and flow as source currents Io1 and Io2 to the Ro1 and Ro2 terminals. Gain resistors R1 and R2 are externally connected between the Ro1, Ro2 terminals and GND terminal, so the voltage potential of R1 and R2 rises when the source current flows. The voltage difference between the Ro1 and Ro2 terminals is detected by a comparator and a signal then output [Figure 6-3].

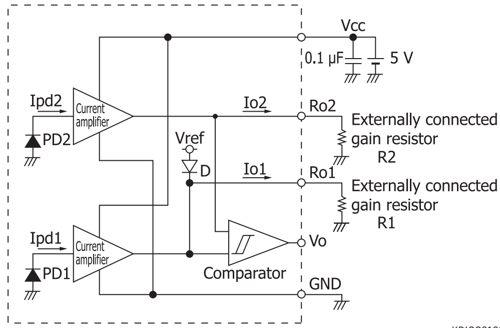
If no laser beam is irradiated on PD1 and PD2, then the comparator output cannot be determined just by comparing the voltages at the Ro1 and Ro2 terminals. The comparator output must therefore be clamped at high level if no beam is irradiated on PD1 and PD2. However, just setting a voltage difference between the Ro1 and Ro2 terminals will cause a shift in the output timing if the input power fluctuates. To cope with this, a limit circuit made up of a bias circuit and diode D is used to clamp the upper limit of the Ro1 terminal voltage [Figure 6-3].

Propagation delay time variation indicates how stable output timing can be obtained with respect to fluctuations in the laser power. Dual-element photodiode types have good characteristics for this propagation delay time variation. Among those types, the S10456 is particularly excellent. The S10456 achieves a propagation delay time variation of only a few nanoseconds over a wide range of laser input power.

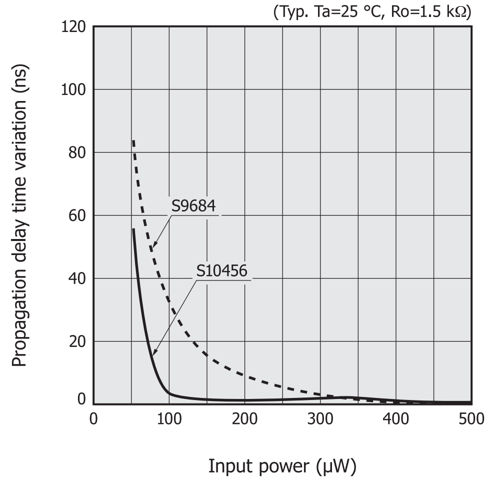
[Figure 6-2] Terminal waveforms (S9684)



[Figure 6-3] Block diagram (S9684)



[Figure 6-4] Propagation delay time variation vs. input power

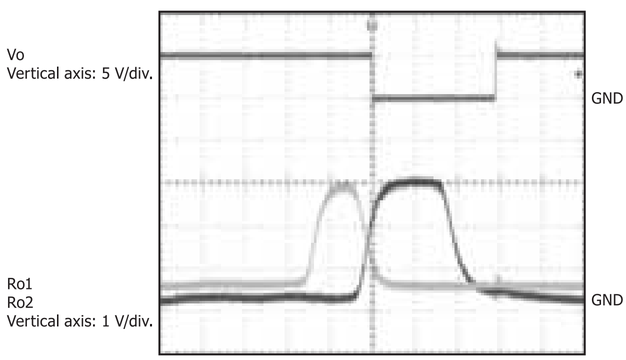


Usage

Connect an external gain resistor (10 kΩ max.) between Ro1 and GND (or Vcc on some products) and also between Ro2 and GND (or Vcc on some products) [Figure 6-3]. When a laser beam is scanned over PD1 and PD2, analog waveforms such as shown in Figure 6-5 are observed at the Ro1 and Ro2 terminals. The beam is scanned from PD1 toward PD2. This allows the steep falling edge to be used as a timing signal.

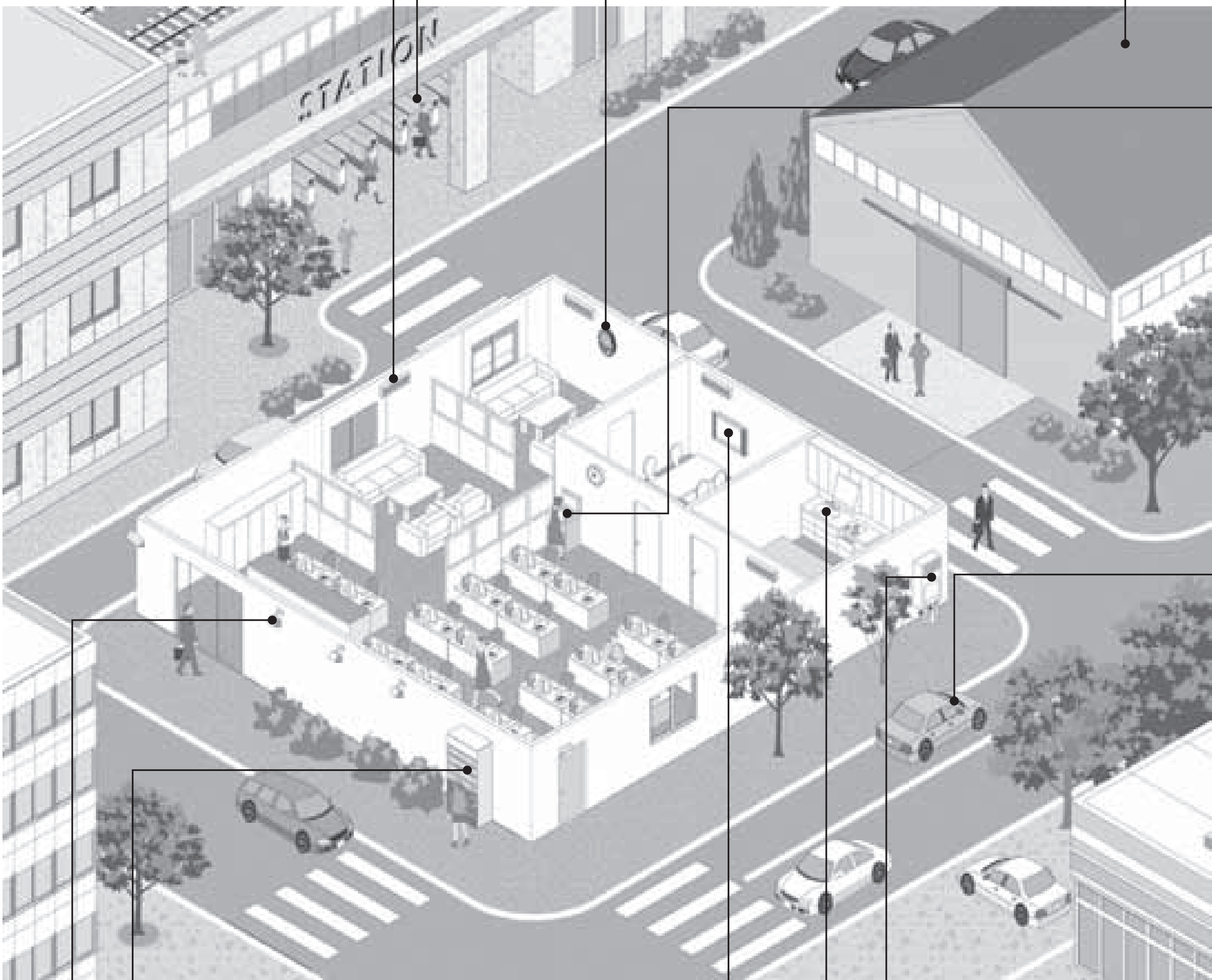
To ensure that the output timing is stable, the input laser power and the gain resistance must be set so that the analog waveform amplitude of Ro1 and Ro2 is 2 to 3 V.

[Figure 6-5] Waveform example (S9684)

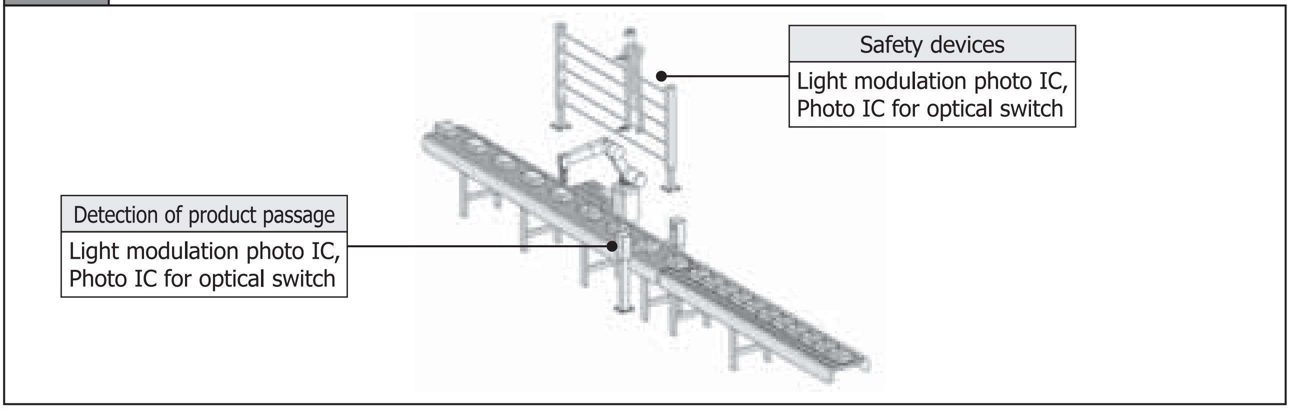


7. Applications

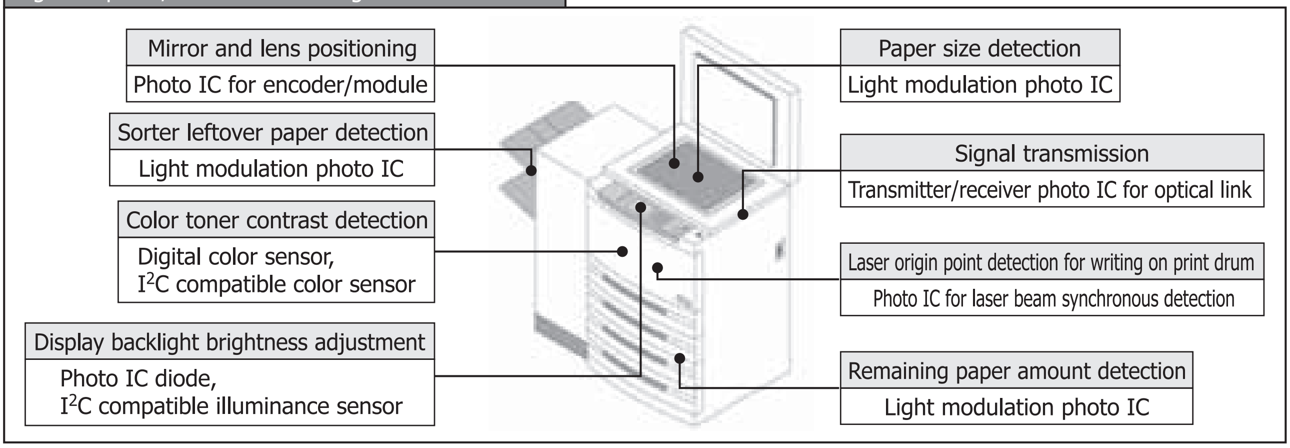
HAMAMATSU photo ICs are widely used for many different applications.



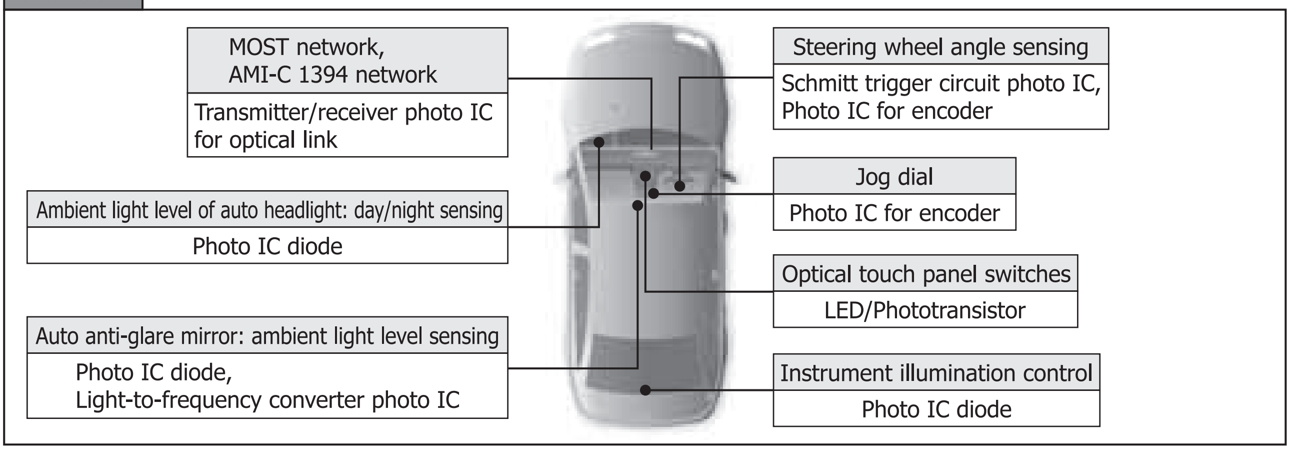
Factories



Digital copiers / Multifunctional digital office machines



Automobiles



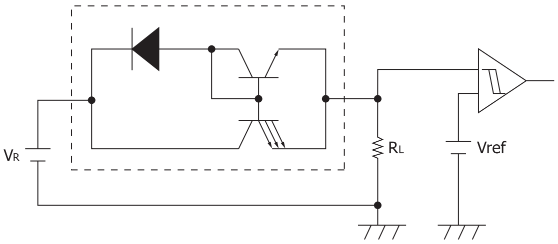
7 - 1 Simple illuminometers

Application example of photo IC diode

Here we show a simple illuminometer made from a photo IC diode and a comparator. A simple illuminometer can be made by utilizing the features of photo IC diodes (good linearity and small variations in output current). This meter can be turned on at a specified illuminance level as shown in the connection example in Figure 7-1 by inputting the voltage generated across load resistor R_L into the comparison terminals on the comparator (LM111, etc.).
Photo IC diodes with spectral response characteristics near human eye sensitivity are used in the following applications.

· Energy-saving sensors on TV and other appliances
· Backlight adjustment on cell phones
· Brightness adjustment on LCD panels
· Ambient light level sensing on vehicle anti-glare mirrors
· Automatic lighting sensors

[Figure 7-1] Connection example (photo IC diode)



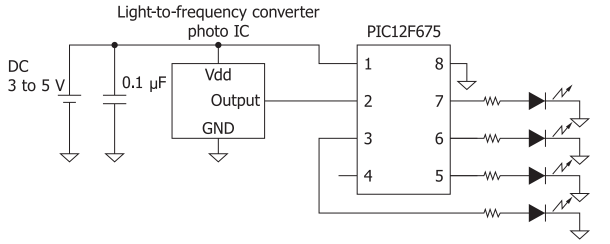
Note: Drawing surrounded by dotted lines shows a schematic diagram of photo IC diode.

KPICC0100EB

Application example of light-to-frequency converter photo IC

This is a simple illuminometer made from a light-to-frequency converter photo IC and a single-chip microcontroller PIC12F675 (made by Microchip Technology Inc.). The internal 16-bit timer of PIC12F675 is used. The light-to-frequency converter photo IC and microcontroller are connected to the same power supply, and the photo IC output is connected to the timer input pin (no. 2) on the microcontroller. The illuminance level appears on the LEDs. Figure 7-3 shows a program example. The output appears in binary, and when the number increases by 1, then the brightness doubles. The logarithmic display is close to that of human eye sensitivity.

[Figure 7-2] Connection example (light-to-frequency converter photo IC)



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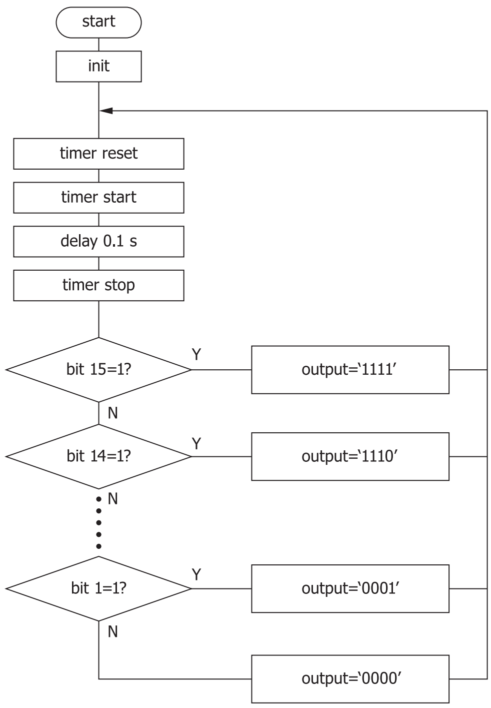
[Figure 7-3] Program example

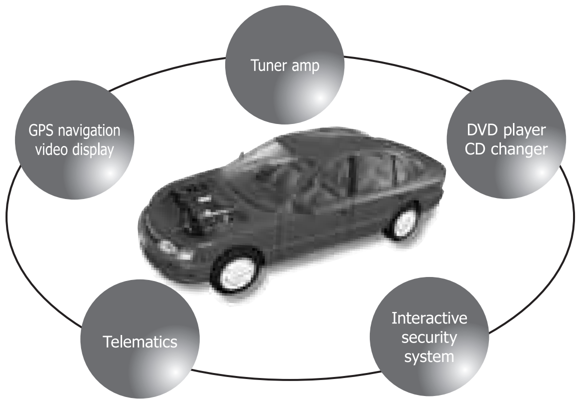


KPICC0102EA

7 - 2 High-speed digital transmission (application example of photo IC for optical link)

High-speed digital transmission has become an essential part of digital media and equipment in recent years. Metal cables have the problem that they require some means to reduce external noise to ensure high transmission quality. In contrast, plastic optical fibers (POF) are unaffected by the noise and so are ideal for use in extremely noisy environments. HAMAMATSU offers a wide lineup of photo ICs for optical link ranging from those for digital audio equipment up to 250 Mbps LAN. These photo ICs are utilizable in consumer electronics, FA (factory automation), OA (office automation) equipment, in-vehicle networks, and home networks, etc.

[Figure 7-4] In-vehicle network (MOST)

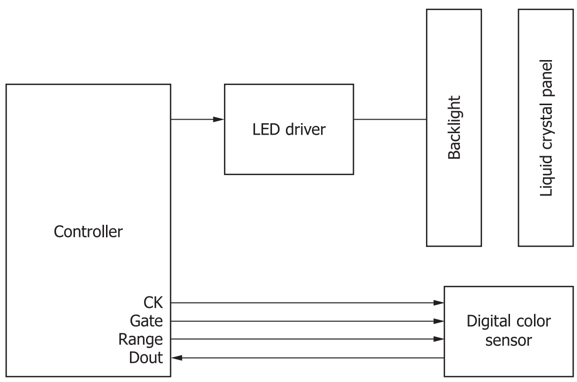


KPICC0107EA

7-3 LED backlight LCD display color adjustment (application example of digital color sensor)

The backlight brightness on LCD displays using RGB-LED backlighting is usually regulated by a microcontroller. Since the backlight deteriorates over time, the color sensor is used to monitor the backlight level. The brightness information is fed back to the microcontroller, which then adjusts the backlight brightness to maintain a stable display. Digital color sensors provide digital input/output signals that can be directly connected to the microcontroller.

[Figure 7-5] Connection example (digital color sensor)



KPICC0148EA

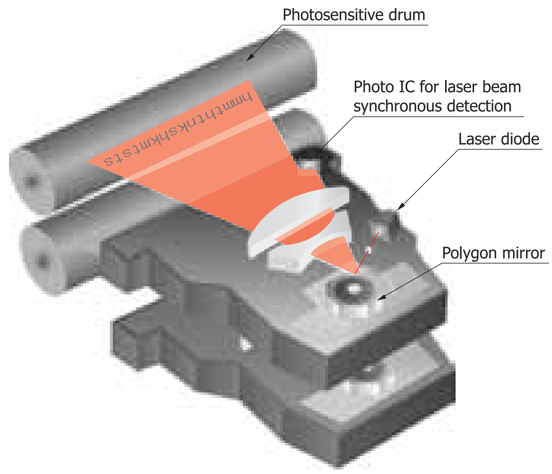
7-4 Print start timing signal output for digital copiers and laser printers (application example of photo IC for laser beam synchronous detection)

Digital copiers and laser printers record an electrostatic latent image on a photosensitive medium by scanning with an intensity-modulated laser beam. In this type of raster scanning, it is essential to synchronize the scanning signal. To do this, a photosensor is mounted at the position where the main scanning starts, in order to generate a synchronization signal by utilizing the received light signal from the photosensor.

The photo IC for laser beam synchronous detection outputs a print start timing signal. A timing signal is then generated when the laser beam passes the position where this detection photo IC is mounted and the signal sent to the phase control circuit. The phase control circuit then uses this timing signal to set the timing for writing the raster information from the laser intensity modulator circuit.

HAMAMATSU offers two types of photo ICs for laser beam synchronous detection. One is a high-precision type (dual-element photodiode) and the other is a general-purpose type (single-element photodiode).

[Figure 7-6] Schematic of laser printer



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3 ▶ Photo IC

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