

# Technical Information

## Features of Photomicrosensors

The Photomicrosensor is a compact optical sensor that senses objects or object positions with an optical beam. The transmissive Photomicrosensor and reflective Photomicrosensor are typical Photomicrosensors.

The transmissive Photomicrosensor incorporates an emitter and a transmissive that face each other as shown in Figure 1. When an object is located in the sensing position between the emitter and the detector, the object intercepts the optical beam of the emitter, thus reducing the amount of optical energy reaching the detector.

The reflective Photomicrosensor incorporates an emitter and a detector as shown in Figure 2. When an object is located in the sensing area of the reflective Photomicrosensor, the object reflects the optical beam of the emitter, thus changing the amount of optical energy reaching the detector. "Photomicrosensor" is an OMRON product name. Generally, the Photomicrosensor is called a photointerrupter.

Figure 1. Transmissive Photomicrosensor

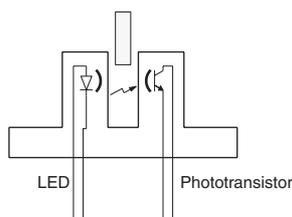
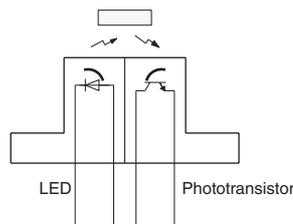


Figure 2. Reflective Photomicrosensor



## Datasheet

### ■ Absolute Maximum Ratings and Electrical and Optical Characteristics

The datasheets of Photomicrosensors include the absolute maximum ratings and electrical and optical characteristics of the Photomicrosensors as well as the datasheets of transistors and ICs. It is necessary to understand the difference between the absolute maximum ratings and electrical and optical characteristics of various Photomicrosensors.

### ■ Absolute Maximum Ratings

The absolute maximum ratings of Photomicrosensors and other products with semiconductors specify the permissible operating voltage, current, temperature, and power limits of these products. The products must be operated absolutely within these limits. Therefore, when using any Photomicrosensor, do not ignore the absolute maximum ratings of the Photomicrosensor, or the Photomicrosensor will not operate precisely. Furthermore, the Photomicrosensor may be deteriorate or become damaged, in which case OMRON will not be responsible. Practically, Photomicrosensors should be used so that there will be some margin between their absolute maximum ratings and actual operating conditions.

### ■ Electrical and Optical Characteristics

The electrical and optical characteristics of Photomicrosensors indicate the performance of Photomicrosensors under certain conditions. Most items of the electrical and optical characteristics are indicated by maximum or minimum values. OMRON usually sells Photomicrosensors with standard electrical and optical characteristics. The electrical and optical characteristics of Photomicrosensors sold to customers may be changed upon request. All electrical and optical characteristic items of Photomicrosensors indicated by maximum or minimum values are checked and those of the Photomicrosensors indicated by typical values are regularly checked before shipping so that OMRON can guarantee the performance of the Photomicrosensors.

**In short, the absolute maximum ratings indicate the permissible operating limits of the Photomicrosensors and the electrical and optical characteristics indicate the maximum performance of the Photomicrosensors.**

## Terminology

The terms used in the datasheet of each Photomicrosensor with a phototransistor output circuit or a photo IC output circuit are explained below.

### ■ Phototransistor Output Photomicrosensor

Symbol	Item	Definition
$I_{FP}$	<b>Pulse forward current</b>	The maximum pulse current that is allowed to flow continuously from the anode to cathode of an LED under a specified temperature, a repetition period, and a pulse width condition.
$I_C$	<b>Collector current</b>	The current that flows to the collector junction of a phototransistor.
$P_C$	<b>Collector dissipation</b>	The maximum power that is consumed by the collector junction of a phototransistor.
$I_D$	<b>Dark current</b>	The current leakage of the phototransistor when a specified bias voltage is imposed on the phototransistor so that the polarity of the collector is positive and that of the emitter is negative on condition that the illumination of the Photomicrosensor is 0 lx.
$I_L$	<b>Light current</b>	The collector current of a phototransistor under a specified input current condition and at a specified bias voltage.
$V_{CE(sat)}$	<b>Collector-emitter saturated voltage</b>	The ON-state voltage between the collector and emitter of a phototransistor under a specified bias current condition.
$I_{LEAK}$	<b>Leakage current</b>	The collector current of a phototransistor under a specified input current condition and at a specified bias voltage when the phototransistor is not exposed to light.
$t_r$	<b>Rising time</b>	The time required for the leading edge of an output waveform of a phototransistor to rise from 10% to 90% of its final value when a specified input current and bias condition is given to the phototransistor.
$t_f$	<b>Falling time</b>	The time required for the trailing edge of an output waveform of a phototransistor to decrease from 90% to 10% of its final value when a specified input current and bias condition is given to the phototransistor.
$V_{CEO}$	<b>Collector-emitter voltage</b>	The maximum positive voltage that can be applied to the collector of a phototransistor with the emitter at reference potential.
$V_{ECO}$	<b>Emitter-collector voltage</b>	The maximum positive voltage that can be applied to the emitter of a phototransistor with the collector at reference potential.

### ■ Phototransistor/Photo IC Output Photomicrosensor

Symbol	Item	Definition
$I_F$	<b>Forward current</b>	The maximum DC current that is allowed to flow continuously from the anode of the LED to the cathode of the LED under a specified temperature condition.
$V_R$	<b>Reverse voltage</b>	The maximum negative voltage that can be applied to the anode of the LED with the cathode at reference potential.
$V_{CC}$	<b>Supply voltage</b>	The maximum positive voltage that can be applied to the voltage terminals of the photo IC with the ground terminal at reference potential.
$V_{OUT}$	<b>Output voltage</b>	The maximum positive voltage that can be applied to the output terminal with the ground terminal of the photo IC at reference potential.
$I_{OUT}$	<b>Output current</b>	The maximum current that is allowed to flow in the collector junction of the output transistor of the photo IC.
$P_{OUT}$	<b>Output permissible dissipation</b>	The maximum power that is consumed by the collector junction of the output transistor of the photo IC.
$V_F$	<b>Forward voltage</b>	The voltage drop across the LED in the forward direction when a specified bias current is applied to the photo IC.
$I_R$	<b>Reverse current</b>	The reverse leakage current across the LED when a specified negative bias is applied to the anode with the cathode at reference potential.
$V_{OL}$	<b>Output low voltage</b>	The voltage drop in the output of the photo IC when the IC output is turned ON under a specified voltage and output current applied to the photo IC.
$V_{OH}$	<b>Output high voltage</b>	The voltage output by the photo IC when the IC output is turned OFF under a specified supply voltage and bias condition given to the photo IC.
$I_{CC}$	<b>Current consumption</b>	The current that will flow into the sensor when a specified positive bias voltage is applied from the power source with the ground of the photo IC at reference potential.
$I_{FT(I_{FT OFF})}$	<b>LED current when output is turned OFF</b>	The forward LED current value that turns OFF the output of the photo IC when the forward current to the LED is increased under a specified voltage applied to the photo IC.
$I_{FT(I_{FT ON})}$	<b>LED current when output is turned ON</b>	The forward LED current value that turns ON the output of the photo IC when the forward current to the LED is increased under a specified voltage applied to the photo IC.
$\Delta H$	<b>Hysteresis</b>	The difference in forward LED current value, expressed in percentage, calculated from the respective forward LED currents when the photo IC is turned ON and when the photo IC is turned OFF.
$f$	<b>Response frequency</b>	The number of revolutions of a disk with a specified shape rotating in the light path, expressed by the number of pulse strings during which the output logic of the photo IC can be obtained under a specified bias condition given to the LED and photo IC (the number of pulse strings to which the photo IC can respond in a second).

## Design

The following explains how systems using Photomicrosensors must be designed.

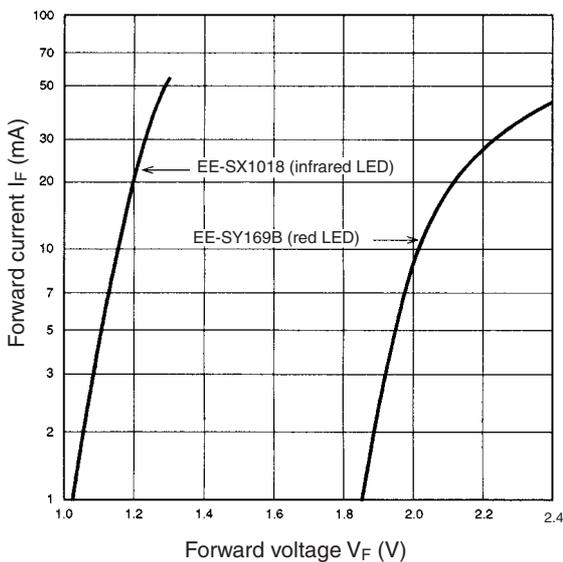
### ■ Emitter

#### Characteristics of Emitter

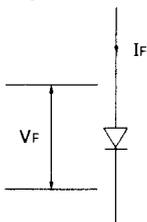
The emitter of each Photomicrosensor has an infrared LED or red LED. Figure 3 shows how the LED forward current characteristics of the EE-SX1018, which has an emitter with an infrared LED, and those of the EE-SY169B, which has an emitter with a red LED, are changed by the voltages imposed on the EE-SX1018 and EE-SY169B. As shown in this figure, the LED forward current characteristics of the EE-SX1018 greatly differ from those of the EE-SY169B. The LED forward current characteristics of any Photomicrosensor indicate how the voltage drop of the LED incorporated by the emitter of the Photomicrosensor is changed by the LED's forward current ( $I_F$ ) flowing from the anode to cathode. Figure 3 shows that the forward voltage ( $V_F$ ) of the red LED is higher than that of the infrared LED.

The forward voltage ( $V_F$ ) of the infrared LED is approximately 1.2 V and that of the red LED is approximately 2 V provided that the practical current required by the infrared LED and that required by the red LED flow into these LEDs respectively.

Figure 3. LED Forward Current vs. Forward Voltage Characteristics (Typical)



Forward Voltage  $V_F$



## Driving Current Level

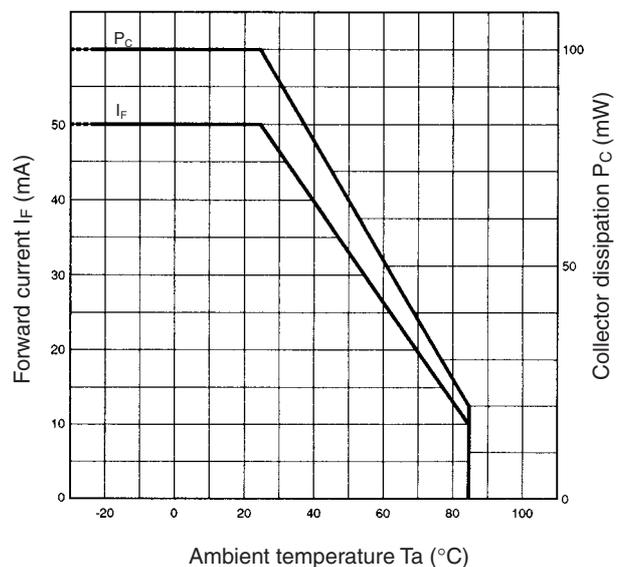
It is especially important to decide the level of the forward current ( $I_F$ ) of the emitter incorporated by any Photomicrosensor. The forward current must not be too large or too small.

Before using any Photomicrosensor, refer to the absolute maximum ratings in the datasheet of the Photomicrosensor to find the emitter's forward current upper limit. For example, the first item in the absolute maximum ratings in the datasheet of the EE-SX1018 shows that the forward current ( $I_F$ ) of its emitter is 50 mA at a  $T_a$  (ambient temperature) of 25°C. This means the forward current ( $I_F$ ) of the emitter is 50 mA maximum at a  $T_a$  of 25°C. As shown in Figure 4, the forward current must be reduced according to changes in the ambient temperature.

Figure 4 indicates that the forward current ( $I_F$ ) is approximately 27 mA maximum if the EE-SX1018 is used at a  $T_a$  of 60°C. This means that a current exceeding 27 mA must not flow into the emitter incorporated by the EE-SX1018 at a  $T_a$  of 60°C.

As for the lower limit, a small amount of forward current will be required because the LED will not give any output if the forward current  $I_F$  is zero.

Figure 4. Temperature Characteristics (EE-SX1018)



In short, the forward current lower limit of the emitter of any Photomicrosensor must be 5 mA minimum if the emitter has an infrared LED and 2 mA minimum if the emitter has a red LED. If the forward current of the emitter is too low, the optical output of the emitter will not be stable. To find the ideal forward current value of the Photomicrosensor, refer to the light current ( $I_L$ ) shown in the datasheet of the Photomicrosensor. The light current ( $I_L$ ) indicates the relationship between the forward current ( $I_F$ ) of the LED incorporated by the Photomicrosensor and the output of the LED. The light current ( $I_L$ ) is one of the most important characteristics. If the forward current specified by the light current ( $I_L$ ) flows into the emitter, even though there is no theoretical ground, the output of the emitter will be stable. This characteristic makes it possible to design the output circuits of the Photomicrosensor easily. For example, the datasheet of EE-SX1018 indicates that a forward current ( $I_F$ ) of 20 mA is required.

## Design Method

The following explains how the constants of a Photomicrosensor must be determined. Figure 5 shows a basic circuit that drives the LED incorporated by a Photomicrosensor.

The basic circuit absolutely requires a limiting resistor (R). If the LED is imposed with a forward bias voltage without the limiting resistor, the current of the LED is theoretically limitless because the forward impedance of the LED is low. As a result the LED will burn out. Users often ask OMRON about the appropriate forward voltage to be imposed on the LED incorporated by each Photomicrosensor model that they use. There is no upper limit of the forward voltage imposed on the LED provided that an appropriate limiting resistor is connected to the LED. There is, however, the lower limit of the forward voltage imposed on the LED. As shown in Figure 3, the lower limit of the forward voltage imposed on the LED must be at least 1.2 to 2 V, or no forward current will flow into the LED. The supply voltage of a standard electronic circuit is 5 V minimum. Therefore, a minimum of 5 V should be imposed on the LED. A system incorporating any Photomicrosensor must be designed by considering the following.

1. Forward current ( $I_F$ )
2. Limiting resistor (R) (refer to Figure 5)

As explained above, determine the optimum level of the forward current ( $I_F$ ) of the LED. The forward current ( $I_F$ ) of the EE-SX1018, for example, is 20 mA. Therefore, the resistance of the limiting resistor connected to the LED must be decided so that the forward current of the LED will be approximately 20 mA. The resistance of the limiting resistor is obtained from the following.

$$R = \frac{V_{CC} - V_F}{I_F}$$

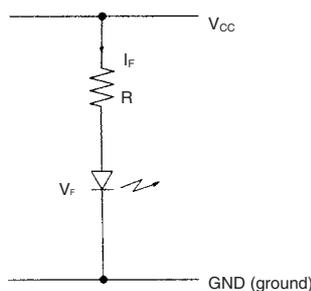
In this case 5 V must be substituted for the supply voltage ( $V_{CC}$ ). The forward voltage ( $V_F$ ) obtained from Figure 3 is approximately 1.2 V when the forward current ( $I_F$ ) of the LED is 20 mA. Therefore, the following resistance is obtained.

$$R = \frac{V_{CC} - V_F}{I_F} = \frac{5 - 1.2 \text{ V}}{20 \text{ mA}} = 190 \Omega$$

= approx. 180 to 220  $\Omega$

The forward current ( $I_F$ ) varies with changes in the supply voltage ( $V_{CC}$ ), forward voltage ( $V_F$ ), or resistance. Therefore, make sure that there is some margin between the absolute maximum ratings and the actual operating conditions of the Photomicrosensor.

Figure 5. Basic Circuit



The positions of the limiting resistor (R) and the LED in Figure 5 are interchangeable. If the LED is imposed with reverse voltages including noise and surge voltages, add a rectifier diode to the circuit as shown in Figure 6. LEDs can be driven by pulse voltages, the method of which is, however, rarely applied to Photomicrosensors. In short, the following are important points required to operate any Photomicrosensor.

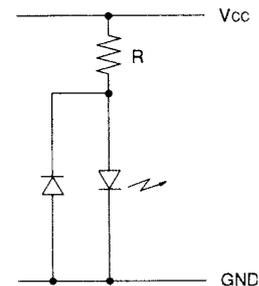
A forward voltage ( $V_F$ ) of approximately 1.2 V is required if the Photomicrosensor has an infrared LED and a forward voltage ( $V_F$ ) of approximately 2 V is required if the Photomicrosensor has a red LED.

The most ideal level of the forward current ( $I_F$ ) must flow into the LED incorporated by the Photomicrosensor.

Decide the resistance of the limiting resistor connected to the LED after deciding the value of the forward current ( $I_F$ ).

If the LED is imposed with a reverse voltage, connect a rectifier diode to the LED in parallel with and in the direction opposite to the direction of the LED.

Figure 6. Reverse Voltage Protection Circuit



## ■ Design of Systems Incorporating Photomicrosensors (1)

### Phototransistor Output

#### Characteristics of Detector Element

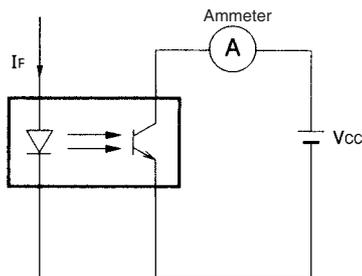
The changes in the current flow of the detector element with and without an optical input are important characteristics of a detector element. Figure 7 shows a circuit used to check how the current flow of the phototransistor incorporated by a Photomicrosensor is changed by the LED with or without an appropriate forward current ( $I_F$ ) flow, provided that the ambient illumination of the Photomicrosensor is ideal (i.e., 0 lx). When there is no forward current ( $I_F$ ) flowing into the LED or the optical beam emitted from the LED is intercepted by an opaque object, the ammeter indicates several nanoamperes due to a current leaking from the phototransistor. This current is called the dark current ( $I_D$ ). When the forward current ( $I_F$ ) flows into the LED with no object intercepting the optical beam emitted from the LED, the ammeter indicates several milliamperes. This current is called the light current ( $I_L$ ).

The difference between the dark current and light current is  $10^6$  times larger as shown below.

- When optical beam to the phototransistor is interrupted  
Dark current  $I_D$ :  $10^{-9}$  A
- When optical beam to the phototransistor is not interrupted  
Light current  $I_L$ :  $10^{-3}$  A

The standard light current of a phototransistor is  $10^6$  times as large as the dark current of the phototransistor. This difference in current can be applied to the sensing of a variety of objects.

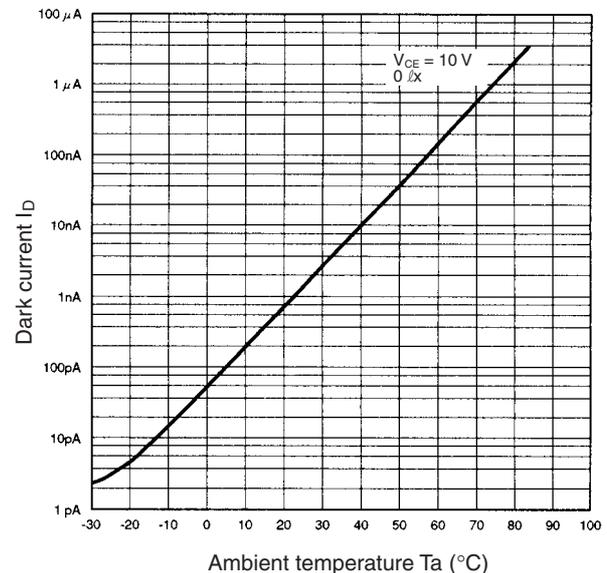
Figure 7. Measuring Circuit



The ambient illumination of the LED and phototransistor incorporated by the Photomicrosensor in actual operation is not 0 lx. Therefore, a current larger than the dark current of the phototransistor will flow into the phototransistor when the optical beam emitted from the LED is interrupted. This current is rather large and must not be ignored if the Photomicrosensor has a photoelectric Darlington transistor, which is highly sensitive, as the detector element of the Photomicrosensor. The dark current of the phototransistor incorporated by any reflective Photomicrosensor flows if there is no reflective object in the sensing area of the reflective Photomicrosensor. Furthermore, due to the structure of the reflective Photomicrosensor, a small portion of the optical beam emitted from the LED reaches the phototransistor after it is reflected inside the reflective Photomicrosensor. Therefore, the dark current and an additional current will flow into the phototransistor if there is no sensing object in the sensing area. This additional current is called leakage current ( $I_{LEAK}$ ). The leakage current of the phototransistor is several hundred nanoamperes and the dark current of the phototransistor is several nanoamperes.

The dark current temperature and light current temperature dependencies of the phototransistor incorporated by any Photomicrosensor must not be ignored. The dark current temperature dependency of the phototransistor increases when the ambient temperature of the Photomicrosensor in operation is high or the Photomicrosensor has a photoelectric Darlington transistor as the detector element of the Photomicrosensor. Figure 8 shows the dark current temperature dependency of the phototransistor incorporated by the EE-SX1018.

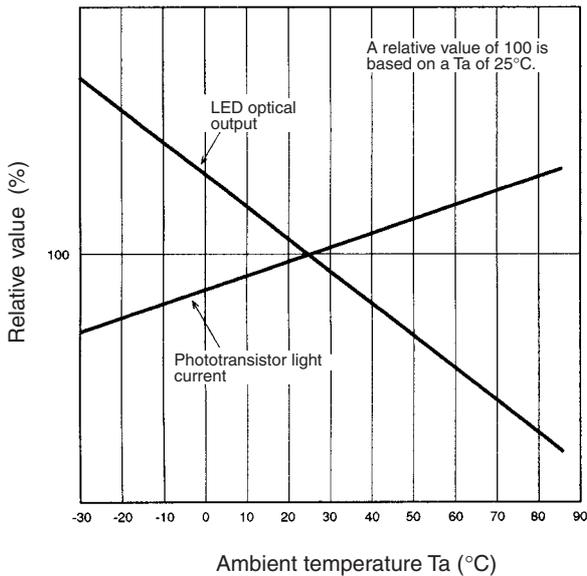
Figure 8. Dark Current vs. Ambient Temperature Characteristics (Typical) (EE-SX1018)



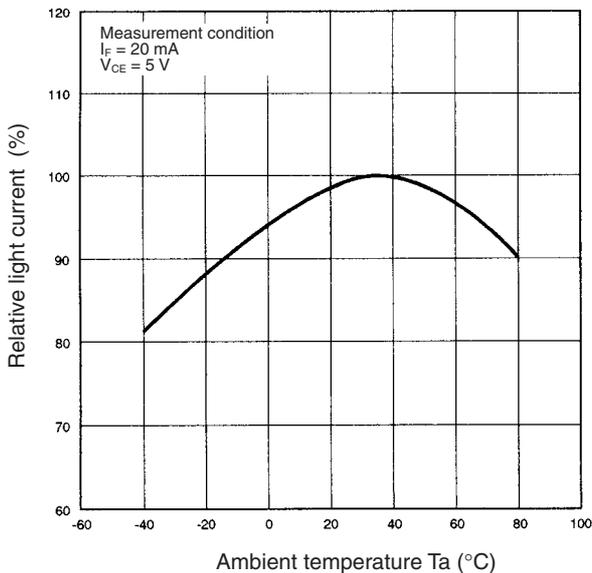
Due to the temperature dependency of the phototransistor, the light current ( $I_L$ ) of the phototransistor as the detector element of the Photomicrosensor increases according to a rise in the ambient temperature. As shown in Figure 9, however, the output of the LED decreases according to a rise in the ambient temperature due to the temperature dependency of the LED. An increase in the light current of the phototransistor is set off against a decrease in the output of the LED and consequently the change of the output of the Photomicrosensor according to the ambient temperature is comparatively small. Refer to Figure 10 for the light current temperature dependency of the phototransistor incorporated by the EE-SX1018.

The light current temperature dependency shown in Figure 10 is, however, a typical example. The tendency of the light current temperature dependency of each phototransistor is indefinite. This means the temperature compensation of any Photomicrosensor is difficult.

**Figure 9. LED and Phototransistor Temperature Characteristics (Typical)**



**Figure 10. Relative Light Current vs. Ambient Temperature Characteristics (EE-SX1018)**



## Changes in Characteristics

The following explains the important points required for the designing of systems incorporating Photomicrosensors by considering worst case design technique. Worst case design technique is a method to design systems so that the Photomicrosensors will operate normally even if the characteristics of the Photomicrosensors are at their worst. A system incorporating any Photomicrosensor must be designed so that they will operate even if the light current ( $I_L$ ) of the phototransistor is minimal and the dark current ( $I_D$ ) and leakage current of the phototransistor are maximal. This means that the system must be designed so that it will operate even if the difference in the current flow of the phototransistor between the time that the Photomicrosensor senses an object and the time that the Photomicrosensor does not sense the object is minimal.

The worst light current ( $I_L$ ) and dark current ( $I_D$ ) values of the phototransistor incorporated by any Photomicrosensor is specified in the datasheet of the Photomicrosensor. (These values are specified in the specifications either as the minimum value or maximum value.)

Table 1 shows the dark current ( $I_D$ ) upper limit and light current ( $I_L$ ) lower limit values of the phototransistors incorporated by a variety of Photomicrosensors.

Systems must be designed by considering the dark current ( $I_D$ ) upper limit and light current ( $I_L$ ) lower limit values of the phototransistors. Not only these values but also the following factors must be taken into calculation to determine the upper limit of the dark current ( $I_D$ ) of each of the phototransistors.

- External light interference
- Temperature rise
- Power supply voltage
- Leakage current caused by internal light reflection if the systems use reflective Photomicrosensors.

The above factors increase the dark current ( $I_D$ ) of each phototransistor.

As for the light current ( $I_L$ ) lower limit of each phototransistor, the following factors must be taken into calculation.

- Temperature change
- Secular change

The above factors decrease the light current ( $I_L$ ) of each phototransistor.

Table 2 shows the increments of the dark current ( $I_D$ ) and the decrements of the light current ( $I_L$ ) of the phototransistors. Therefore, if the EE-SX1018 is operated at a  $T_a$  of 60°C maximum and a  $V_{CC}$  of 10 V for approximately 50,000 hours, for example, the dark current ( $I_D$ ) of the phototransistor incorporated by the EE-SX1018 will be approximately 4  $\mu$ A and the light current ( $I_L$ ) of the phototransistor will be approximately 0.5 mA because the dark current ( $I_D$ ) of the phototransistor at a  $T_a$  of 25°C is 200 nanoamperes maximum and the light current ( $I_L$ ) of the phototransistor at a  $T_a$  of 25°C is 0.5 mA minimum.

Table 3 shows the estimated worst values of a variety of Photomicrosensors, which must be considered when designing systems using these Photomicrosensors.

The dispersion of the characteristics of the Photomicrosensors must be also considered, which is explained in detail later. The light current ( $I_L$ ) of the phototransistor incorporated by each reflective Photomicrosensor shown in its datasheet was measured under the standard conditions specified by OMRON for its reflective Photomicrosensors. The light current ( $I_L$ ) of any reflective Photomicrosensor greatly varies with its sensing object and sensing distance.

**Table 1. Rated Dark Current ( $I_D$ ) and Light Current ( $I_L$ ) Values**

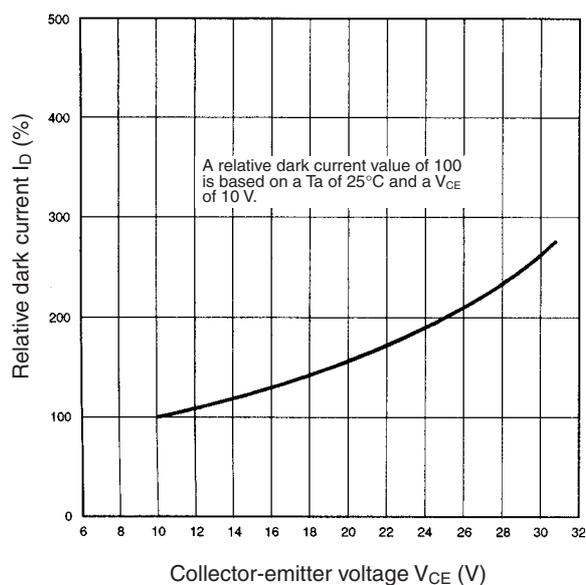
Model	Upper limit ( $I_D$ )	Lower limit ( $I_L$ )	Condition
EE-SG3(-B)	200 nA	2 mA	$I_F = 15$ mA
EE-SX1018, -SX1055 EE-SX1041, -SX1042 EE-SX1070, -SX1071 EE-SX198, -SX199	200 nA	0.5 mA	$I_F = 20$ mA
EE-SB5(-B) EE-SF5(-B) EE-SY110	200 nA	0.2 mA	$I_F = 20$ mA (see note)
Condition	$V_{CE} = 10$ V, $0 \text{ } \mu\text{x}$ $T_a = 25^\circ\text{C}$	$V_{CE} = 10$ V $T_a = 25^\circ\text{C}$	---

**Note:** These values were measured under the standard conditions specified by OMRON for the corresponding Photomicrosensors.

**Table 2. Dependency of Detector Elements on Various Factors**

Elements		Phototransistor	Photo-Darlington transistor
Dark current $I_D$	External light interference	To be checked using experiment	To be checked using experiment
	Temperature rise	Increased by approximately 10 times with a temperature rise of $25^\circ\text{C}$ .	Increased by approximately 28 times with a temperature rise of $25^\circ\text{C}$ .
	Supply voltage	See Figure 11.	See Figure 12.
Light current $I_L$	Temperature change	Approximately $-20\%$ to $10\%$	Approximately $-20\%$ to $10\%$
	Secular change (20,000 to 50,000 hours) <b>Note:</b> For an infrared LED.	Decreased to approximately one-half of the initial value considering the temperature changes of the element.	Decreased to approximately one-half of the initial value considering the temperature changes of the element.

**Figure 11. Dark Current Imposed Voltage Dependency (Typical) (EE-SX1018)**



**Table 3. Estimated Worst Values of a Variety of Photomicrosensors**

Model	Estimated worst value ( $I_D$ )	Estimated worst value ( $I_L$ )	Condition
EE-SG3(-B)	4 nA	1 mA	$I_F = 15$ mA
EE-SX1018, -SX1055 EE-SX1041, -SX1042 EE-SX1070, -SX1071 EE-SX198, -SX199	4 nA	0.25 mA	$I_F = 20$ mA
EE-SB5(-B) EE-SF5(-B) EE-SY110	4 nA	0.1 mA	$I_F = 20$ mA (see note)
Condition	$V_{CE} = 10$ V, $0 \mu\text{x}$ $T_a = 60^\circ\text{C}$	$V_{CE} = 10$ V, Operating hours = 50,000 to 100,000 hrs $T_a = T_{opr}$	---

**Note:** These values were measured under the standard conditions specified by OMRON for the corresponding Photomicrosensors with an Infrared LED.

### Design of Basic Circuitry

The following explains the basic circuit incorporated by a typical Photomicrosensor and the important points required for the basic circuit.

The flowing currents (i.e.,  $I_L$  and  $I_D$ ) of the phototransistor incorporated by the Photomicrosensor must be processed to obtain the output of the Photomicrosensor. Refer to Figure 13 for the basic circuit. The light current ( $I_L$ ) of the phototransistor will flow into the resistor ( $R_L$ ) if the phototransistor receives an optical input and the dark current ( $I_D$ ) and leakage current of the phototransistor will flow into the resistor ( $R_L$ ) if the phototransistor does not receive any optical input. Therefore, if the phototransistor receives an optical input, the output voltage imposed on the resistor ( $R_L$ ) will be obtained from the following.

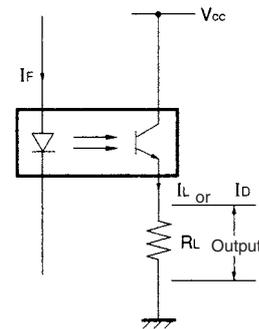
$$I_L \times R_L$$

If the phototransistor does not receive any optical input, the output voltage imposed on the resistor ( $R_L$ ) will be obtained from the following.

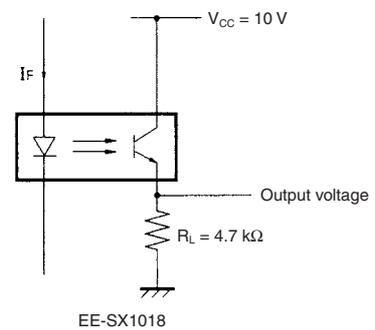
$$(I_D + \text{leakage current}) \times R_L$$

The output voltage of the phototransistor is obtained by simply connecting the resistor ( $R_L$ ) to the phototransistor. For example, to obtain an output of 4 V minimum from the phototransistor when it is ON and an output of 1 V maximum when the phototransistor is OFF on condition that the light current ( $I_L$ ) of the phototransistor is 1 mA and the leakage current of the phototransistor is 0.1 mA, and these are the worst light current and leakage current values of the phototransistor, the resistance of the resistor ( $R_L$ ) must be approximately 4.7 k $\Omega$ . Then, an output of 4.7 V (i.e., 1 mA x 4.7 k $\Omega$ ) will be obtained when the phototransistor is ON and an output of 0.47 V (i.e., 0.1 mA x 4.7 k $\Omega$ ) will be obtained when the phototransistor is OFF. Practically, the output voltage of the phototransistor will be more than 4.7 V when the phototransistor is ON and less than 0.47 V when the phototransistor is OFF because the above voltage values are based on the worst light current and leakage current values of the phototransistor. The outputs obtained from the phototransistor are amplified and input to ICs to make practical use of the Photomicrosensor.

**Figure 13. Basic Circuit**



**Figure 14. Output Example**



## Design of Applied Circuit

The following explains the designing of the applied circuit shown in Figure 15.

The light current ( $I_L$ ) of the phototransistor flows into  $R_1$  and  $R_2$  when the phototransistor receives the optical beam emitted from the LED. Part of the light current ( $I_L$ ) will flow into the base and emitter of  $Q_1$  when the voltage imposed on  $R_2$  exceeds the bias voltage (i.e., approximately 0.6 to 0.9 V) imposed between the base and emitter of the transistor ( $Q_1$ ). The light current flowing into the base turns  $Q_1$  ON. A current will flow into the collector of  $Q_1$  through  $R_3$  when  $Q_1$  is ON. Then, the electric potential of the collector will drop to a low logic level. The dark current and leakage current of the phototransistor flow when the optical beam emitted from the LED is intercepted. The electric potential of the output of the phototransistor (i.e.,  $(I_D + \text{leakage current}) \times R_2$ ) is, however, lower than the bias voltage between the base and emitter of  $Q_1$ . Therefore, no current will flow into the base of  $Q_1$  and  $Q_1$  will be OFF. The output of  $Q_1$  will be at a high level. As shown in Figure 16, when the phototransistor is ON, the phototransistor will be seemingly short-circuited through the base and emitter of the  $Q_1$ , which is equivalent to a diode, and if the light current ( $I_L$ ) of the phototransistor is large and  $R_1$  is not connected to the phototransistor, the light current ( $I_L$ ) will flow into  $Q_1$  and the collector dissipation of the phototransistor will be excessively large.

The following items are important when designing the above applied circuit:

- The voltage output (i.e.,  $I_L \times R_2$ ) of the phototransistor receiving the optical beam emitted from the LED must be much higher than the bias voltage between the base and emitter of  $Q_1$ .
- The voltage output (i.e.,  $(I_D + \text{leakage current}) \times R_2$ ) of the phototransistor not receiving the optical beam emitted from the LED must be much lower than the bias voltage between the base and emitter of  $Q_1$ .

Therefore, it is important to determine the resistance of  $R_2$ . Figure 17 shows a practical applied circuit example using the EE-SX1018 Photomicrosensor at a supply voltage ( $V_{CC}$ ) of 5V to drive a 74-series TTL IC. This applied circuit example uses  $R_1$  and  $R_2$  with appropriate resistance values.

Figure 15. Applied Circuit

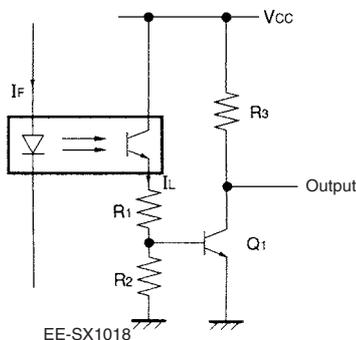


Figure 16. Equivalent Circuit

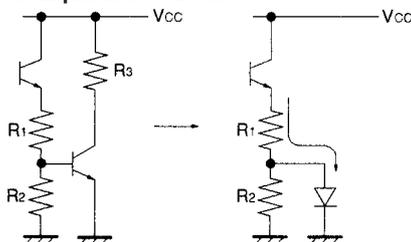
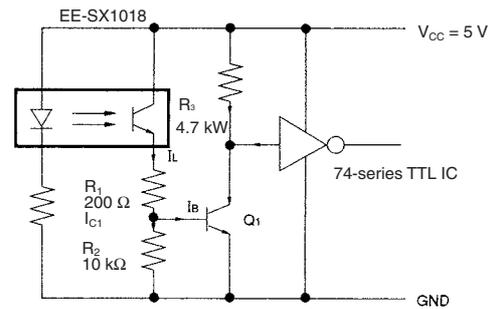


Figure 17. Applied Circuit Example



## Calculation of $R_2$

The resistance of  $R_2$  should be decided using the following so that the appropriate bias voltage ( $V_{BE(ON)}$ ) between the base and emitter of the transistor ( $Q_1$ ) to turn  $Q_1$  ON will be obtained.

$$I_{C1} \times R_2 > V_{BE(ON)}$$

$$I_{C1} = I_L - I_B$$

$$\therefore (I_L - I_B) \times R_2 > V_{BE(ON)}$$

$$\therefore R_2 > \frac{V_{BE(ON)}}{I_L - I_B}$$

The bias voltage ( $V_{BE(ON)}$ ) between the base and emitter of  $Q_1$  is approximately 0.8 V and the base current ( $I_B$ ) of  $Q_1$  is approximately 20  $\mu$ A if  $Q_1$  is a standard transistor controlling small signals. The estimated worst value of the light current ( $I_L$ ) of the phototransistor is 0.25 mA according to Table 3.

Therefore, the following is obtained.

$$R_2 > \frac{0.8 \text{ V}}{0.25 \text{ mA} - 20 \text{ } \mu\text{A}} = \text{approx. } 3.48 \text{ k}\Omega$$

$R_2$  must be larger than the above result. Therefore, the actual resistance of  $R_2$  must be two to three times as large as the above result. In the above applied circuit example, the resistance of  $R_2$  is 10 k $\Omega$ .

## Verification of $R_2$ Value

The resistance of  $R_2$  obtained from the above turns  $Q_1$  ON. The following explains the way to confirm whether the resistance of  $R_2$  obtained from the above can turn  $Q_1$  OFF as well. The condition required to turn  $Q_1$  OFF is obtained from the following.

$$(I_D + \alpha) \times R_2 < V_{BE(OFF)}$$

Substitute 10 k $\Omega$  for  $R_2$ , 4  $\mu$ A for the dark current ( $I_D$ ) according to Table 3, and 10  $\mu$ A for the leakage current on the assumption that the leakage current is 10  $\mu$ A in formula 3. The following is obtained.

$$(I_D + \alpha) \times R_2 > V_{BE(ON)}$$

$$(4 \text{ } \mu\text{A} + 10 \text{ } \mu\text{A}) \times 10 \text{ k}\Omega = 0.140 \text{ V}$$

$$V_{BE(OFF)} = 0.4 \text{ V}$$

$$\therefore 0.140 \text{ V} < 0.4 \text{ V}$$

The above result verifies that the resistance of  $R_2$  satisfies the condition required to turn  $Q_1$  OFF.

If the appropriateness of the resistance of  $R_2$  has been verified, the design of the circuit is almost complete.

**R<sub>1</sub>**

As shown in Figure 16, when the phototransistor is ON, the phototransistor will be seemingly short-circuited through the base and emitter of the Q<sub>1</sub>, and if the light current (I<sub>L</sub>) of the phototransistor is large and R<sub>1</sub> is not connected to the phototransistor, the light current will flow into Q<sub>1</sub> and the collector dissipation of the phototransistor will be excessively large. The resistance of R<sub>1</sub> depends on the maximum permissible collector dissipation (P<sub>C</sub>) of the phototransistor, which can be obtained from the datasheet of the Photomicrosensor. The resistance of R<sub>1</sub> of a phototransistor is several hundred ohms. In the above applied circuit example, the resistance of R<sub>1</sub> is 200 Ω.

If the resistance of R<sub>1</sub> is determined, the design of the circuit is complete.

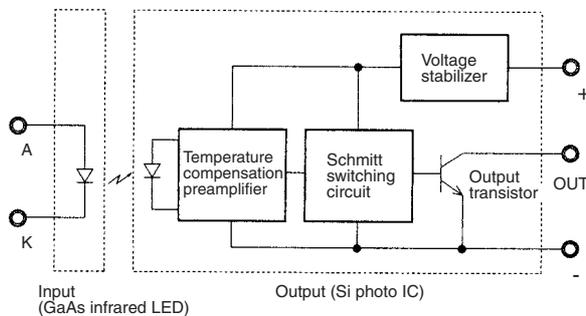
It is important to connect a transistor to the phototransistor incorporated by the Photomicrosensor to amplify the output of the phototransistor, which increases the reliability and stability of the Photomicrosensor. Such reliability and stability of the Photomicrosensor cannot be achieved if the output of the phototransistor is not amplified. The response speed and other performance characteristics of the circuit shown in Figure 15 are far superior to those of the circuit shown in Figure 13 because the apparent impedance (i.e., load resistance) of the Photomicrosensor is determined by R<sub>1</sub>, the resistance of which is comparatively small. Recently, Photomicrosensors that have photo IC amplifier circuits are increasing in number because they are easy to use and make it possible to design systems using Photomicrosensors without problem.

**■ Design of Systems Incorporating Photomicrosensors (2)**

**Photo IC Output**

Figure 18 shows the circuit configuration of the EE-SX301 or EE-SX401 Photomicrosensor incorporating a photo IC output circuit. The following explains the structure of a typical Photomicrosensor with a photo IC output circuit.

**Figure 18. Circuit Configuration**



**LED Forward Current (I<sub>F</sub>) Supply Circuit**

The LED in the above circuitry is an independent component, to which an appropriate current must be supplied from an external power supply. This is the most important item required by the Photomicrosensor.

It is necessary to determine the appropriate forward current (I<sub>F</sub>) of the LED that turns the photo IC ON. If the appropriate forward current is determined, the Photomicrosensor can be easily used by simply supplying power to the detector circuitry (i.e., the photo IC). Refer to the datasheet of the Photomicrosensor to find the current of the LED turning the photo IC ON. Table 4 is an extract of the datasheet of the EE-SX301/EE-SX401.

**Table 4. Abstract of Characteristics**

Item	Symbol	EE-SX301, -SX401	
		Value	Condition
LED current when output is turned OFF (EE-SX301)	I <sub>FTOFF</sub>	8 mA max.	V <sub>CC</sub> = 4.5 to 16 V Ta = 25°C
LED current when output is turned ON (EE-SX401)	I <sub>FTON</sub>		

To design systems incorporating EE-SX301 or EE-SX401 Photomicrosensors, the following are important points.

- A forward current equivalent to or exceeding the I<sub>FTOFF</sub> value must flow into the LED incorporated by each EE-SX301 Photomicrosensors.
- A forward current equivalent to or exceeding the I<sub>FTON</sub> value must flow into the LED incorporated by the EE-SX401 Photomicrosensors.

The I<sub>FTON</sub> value of the EE-SX301 is 8 mA maximum and so is the I<sub>FON</sub> value of the EE-SX401. The forward current (I<sub>F</sub>) of LED incorporated by the EE-SX301 in actual operation must be 8 mA or more and so must the actual forward current of (I<sub>F</sub>) the LED incorporated by the EE-SX401 in actual operation. The actual forward currents of the LEDs incorporated by the EE-SX301 and EE-SX401 are limited by their absolute maximum forward currents respectively. The upper limit of the actual forward current of the LED incorporated by the EE-SX301 and that of the LED incorporated by the EE-SX401 must be decided according Figure 19, which shows the temperature characteristics of the EE-SX301 and EE-SX401. The forward current (I<sub>F</sub>) of the EE-SX301 must be as large as possible within the absolute maximum forward current and maximum ambient temperature shown in Figure 19 and so must be the forward current (I<sub>F</sub>) of the EE-SX401. The forward current (I<sub>F</sub>) of the EE-SX301 or that of the EE-SX401 must not be close to 8 mA, otherwise the photo IC of the EE-SX301 or that of the EE-SX401 may not operate if there is any ambient temperature change, secular change that reduces the optical output of the LED, or dust sticking to the LED. The forward current (I<sub>F</sub>) values of the EE-SX301 and the EE-SX401 in actual operation must be twice as large as the I<sub>FTOFF</sub> values of the EE-SX301 and EE-SX401 respectively. Figure 20 shows the basic circuit of a typical Photomicrosensor with a photo IC output circuit.

If the Photomicrosensor with a photo IC output circuit is used to drive a relay, be sure to connect a reverse voltage absorption diode (D) to the relay in parallel as shown in Figure 21.

When using the transmissive Photomicrosensor to sense any object that vibrates, moves slowly, or has highly reflective edges, make sure to connect a proper circuit which processes the output of the transmissive Photomicrosensor so that the transmissive Photomicrosensor can operate properly, otherwise the transmissive Photomicrosensor may have a chattering output signal as shown in Figure 24. If this signal is input to a counter, the counter will have a counting error or operate improperly. To protect against this, connect a 0.01- to 0.02- $\mu\text{F}$  capacitor to the circuit as shown in Figure 25 or connect a Schmitt trigger circuit to the circuit as shown in Figure 26.

Figure 24. Chattering Output Signal

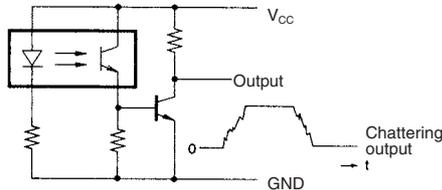


Figure 25. Chattering Prevention (1)

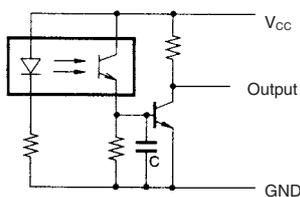
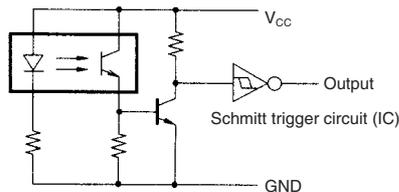


Figure 26. Chattering Prevention (2)



## ■ Reflective Photomicrosensor Incorporating Phototransistor Output Circuit

When using a reflective Photomicrosensor to sense objects, pay attention to the following so that the reflective Photomicrosensor operates properly.

- External light interference
- Background condition of sensing objects
- Output level of the LED

The reflective Photomicrosensor incorporates a detector element in the direction shown in Figure 27. Therefore, it is apt to be affected by external light interference. The reflective Photomicrosensor, therefore, incorporates a filter to intercept any light, the wavelength of which is shorter than a certain wavelength, to prevent external light interference. The filter does not, however, perfectly intercept the light. Refer to Figure 28 for the light interception characteristics of filters. A location with minimal external light interference is best suited for the reflective Photomicrosensor.

Figure 27. Configuration of Reflective Photomicrosensor

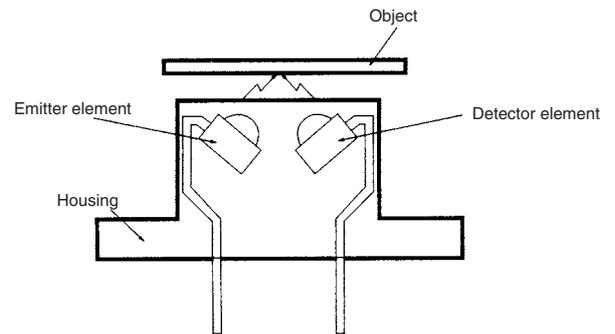


Figure 28. Light Interception Characteristics of Filters

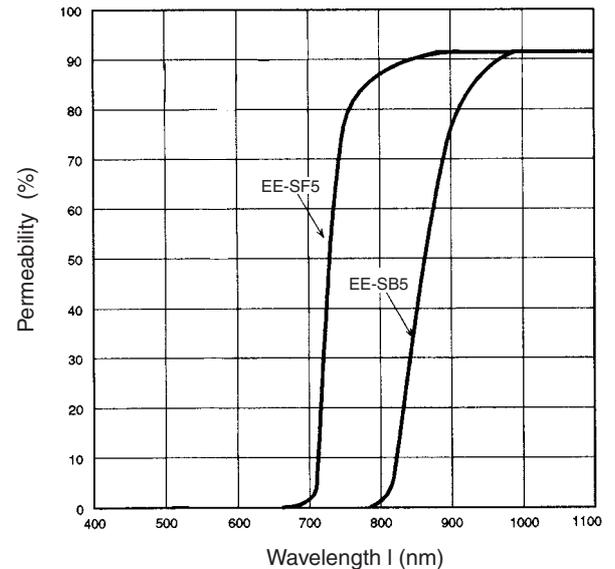
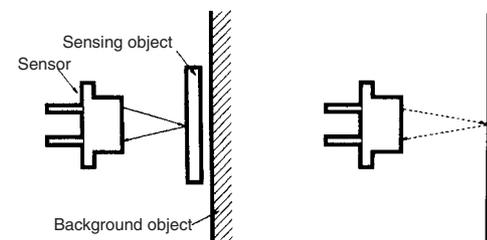


Figure 29. Influence of Background Object



With regard to the background conditions, the following description is based on the assumption that the background is totally dark.

Figure 29 shows that the optical beam emitted from the LED incorporated by a reflective Photomicrosensor is reflected by a sensing object and background object. The optical beam reflected by the background object and received by the phototransistor incorporated by the detector is considered noise that lowers the signal-noise ratio of the phototransistor. If any reflective Photomicrosensor is used to sense paper passing through the sensing area of the reflective Photomicrosensor on condition that there is a stainless steel or zinc-plated object behind the paper, the light current ( $I_L(N)$ ) of the phototransistor not sensing the paper may be larger than the light current ( $I_L(S)$ ) of phototransistor sensing the paper, in which case remove the background object, make a hole larger than the area of the sensor surface in the background object as shown in Figure 30, coat the surface of the background object with black lusterless paint, or roughen the surface of the background. Most malfunctions of a reflective Photomicrosensor are caused by an object located behind the sensing objects of the reflective Photomicrosensor.

Unlike the output (i.e.,  $I_L$ ) of any transmissive Photomicrosensor, the

### Detector Circuit

Supply a voltage within the absolute maximum supply voltage to the positive and negative terminals of the photo IC circuit shown in Figure 18 and obtain a current within the  $I_{OUT}$  value of the output transistor incorporated by the photo IC circuit.

Figure 19. Forward Current vs. Ambient Temperature Characteristics (EE-SX301/-SX401)

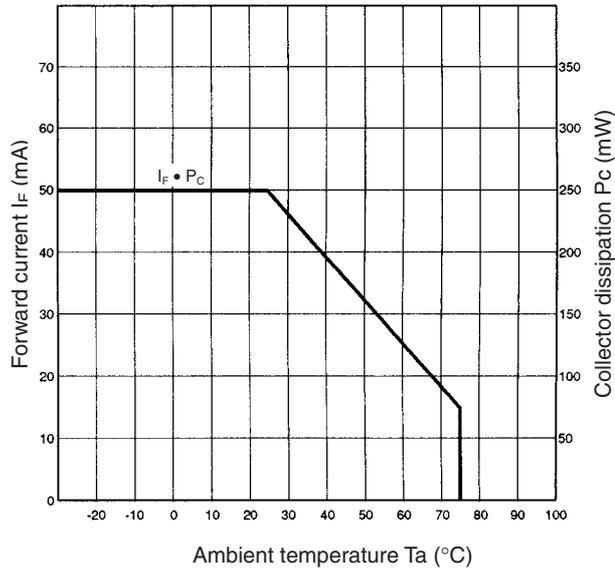


Figure 20. Basic Circuit

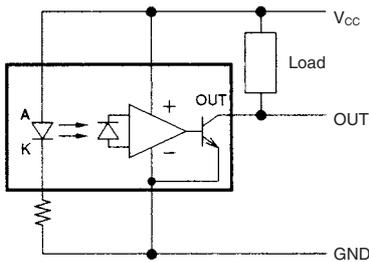
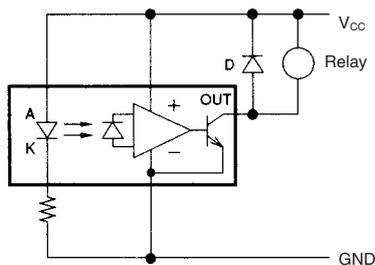


Figure 21. Connected to Inductive Load



### Precautions

The following provides the instructions required for the operation of Photomicrosensors.

#### ■ Transmissive Photomicrosensor Incorporating Phototransistor Output Circuit

When using a transmissive Photomicrosensor to sense the following objects, make sure that the transmissive Photomicrosensor operates properly.

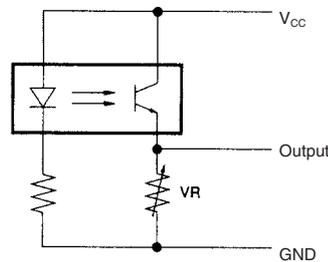
- Highly permeable objects such as paper, film, and plastic
- Objects smaller than the size of the optical beam emitted by the LED or the size of the aperture of the detector.

The above objects do not fully intercept the optical beam emitted by the LED. Therefore, some part of the optical beam, which is considered noise, reaches the detector and a current flows from the phototransistor incorporated by the detector. Before sensing such type of objects, it is necessary to measure the light currents of the phototransistor with and without an object to make sure that the transmissive Photomicrosensor can sense objects without being interfered by noise. If the light current of the phototransistor sensing any one of the objects is  $I_L(S)$  and that of the phototransistor sensing none of the objects is  $I_L(N)$ , the signal-noise ratio of the phototransistor due to the object is obtained from the following.

$$S/N = I_L(S)/I_L(N)$$

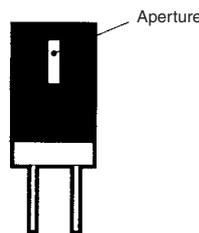
The light current ( $I_L$ ) of the phototransistor varies with the ambient temperature and secular changes. Therefore, if the signal-noise ratio of the phototransistor is 4 maximum, it is necessary to pay utmost attention to the circuit connected to the transmissive Photomicrosensor so that the transmissive Photomicrosensor can sense the object without problem. The light currents of phototransistors are different to one another. Therefore, when multiple transmissive Photomicrosensors are required, a variable resistor must be connected to each transmissive Photomicrosensor as shown in Figure 22 if the light currents of the phototransistors greatly differ from one another.

Figure 22. Sensitivity Adjustment



The optical beam of the emitter and the aperture of the detector must be as narrow as possible. An aperture each can be attached to the emitter and detector to make the optical beam of the emitter and the aperture of the detector narrower. If apertures are attached to both the emitter and detector, however, the light current ( $I_L$ ) of the phototransistor incorporated by the detector will decrease. It is desirable to attach apertures to both the emitter and detector. If an aperture is attached to the detector only, the transmissive Photomicrosensor will have trouble sensing the above objects when they pass near the emitter.

Figure 23. Aperture Example



light current ( $I_L$ ) of a reflective Photomicrosensor greatly varies according to sensing object type, sensing distance, and sensing object size.

Figure 30. Example of Countermeasure

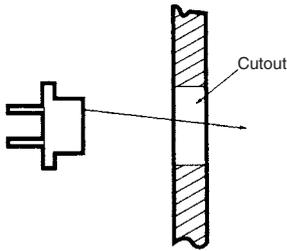
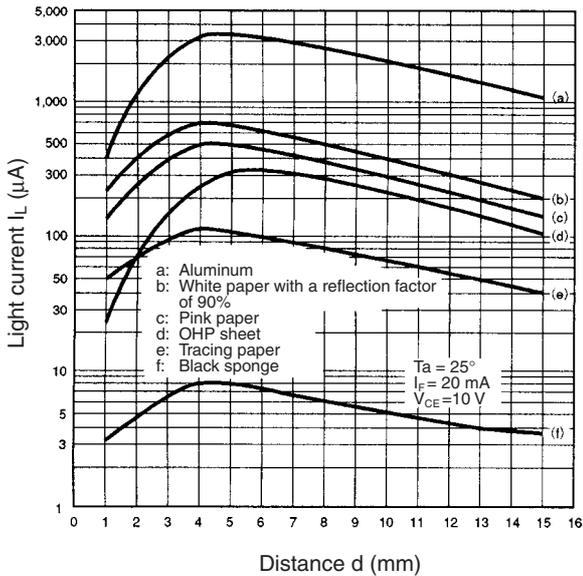


Figure 31. Sensing Distance Characteristics (EE-SF5)



The light current ( $I_L$ ) of the phototransistor incorporated by the transmissive Photomicrosensor is output when there is no sensing object in the sensing groove of the transmissive Photomicrosensor. On the other hand, the light current ( $I_L$ ) of the phototransistor incorporated by the reflective Photomicrosensor is output when there is a standard object specified by OMRON located in the standard sensing distance of the reflective Photomicrosensor. The light current ( $I_L$ ) of the phototransistor incorporated by the reflective Photomicrosensor varies when the reflective Photomicrosensor senses any other type of sensing object located at a sensing distance other than the standard sensing distance. Figure 31 shows how the output of the phototransistor incorporated by the EE-SF5(-B) varies according to varieties of sensing objects and sensing distances. Before using the EE-SF5(-B) to sense any other type of sensing objects, measure the light currents of the phototransistor in actual operation with and without one of the sensing objects as shown in Figure 32. After measuring the light currents, calculate the signal-noise ratio of the EE-SF5(-B) due to the sensing object to make sure if the sensing objects can be sensed smoothly. The light current of the reflective Photomicrosensor is, however, several tens to hundreds of microamperes. This means that the absolute signal levels of the reflective Photomicrosensor are low. Even if the reflective Photomicrosensor in operation is not interfered by external light, the dark current ( $I_D$ ) and leakage current ( $I_{LEAK}$ ) of the reflective Photomicrosensor, which are considered noise, may amount to several to ten-odd microamperes due to a rise in the ambient temperature. This noise cannot be ignored. As a result, the signal-noise ratio of the reflective Photomicrosensor will be extremely low if the reflective Photomicrosensor senses any object with a low reflection ratio.

Pay utmost attention when applying the reflective Photomicrosensor to the sensing of the following.

- Marked objects (e.g., White objects with a black mark each)
- Minute objects

The above objects can be sensed if the signal-noise ratio of the reflective Photomicrosensor is not too low.

The reflective Photomicrosensor must be used with great care, otherwise it will not operate properly.

Figure 32. Output Current Measurement

