Optical Sensors - Reflective

Vishay is a leading manufacturer of optical sensors. These sensors integrate an infrared emitter and photo detector in a single package. The most common types of optical sensors are transmissive and reflective sensors.

Transmissive sensors, also called interrupter sensors, incorporate an infrared emitter and photo detector that face each other as shown in Figure 1. When an object is located between the emitter and detector in the sensing path, it interrupts or breaks the optical beam of the emitter. The amount of light energy reaching the detector is reduced. This change in light energy or photo current is used to affect an event in the application.

Reflective sensors incorporate an infrared emitter and photo detector adjacent to each other as shown in Figure 2. When an object is in the sensing area, the emitted light is reflected back towards the photo detector, the amount of light energy reaching the detector increases. This change in light energy or photo current is similarly used an input signal in the application.

This application note describes the proper use of Vishay's reflective sensors. It describes several factors that must be considered when using a reflective sensor. Vishay manufactures many reflective sensors in leaded and surface mount packages. One is just right for your application. Should you have any design questions, Vishay's Application Engineers are ready to assist you.

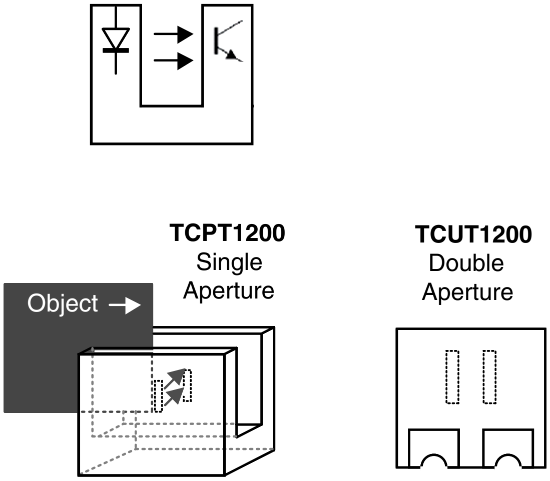

Figure 1.

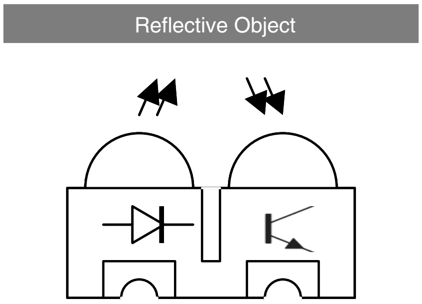

Figure 2.

Datasheet Parameter Values

The datasheets of each sensor include the absolute maximum ratings, and electrical and optical characteristics. The absolute maximum ratings of the emitter, detector and the sensor combined are provided. Maximum values for parameters like reverse and forward voltage, collector current, power dissipation, and ambient and storage temperatures are defined. The reflective sensors must be operated within these limits. In practice, applications should be designed so that there is large margin between the operating conditions and the absolute maximum ratings. The electrical and optical characteristics indicate the performance of the sensor under specific operating conditions. Generally, the minimum and/or maximum values are provided. These values are guaranteed and are tested during the manufacture of the sensor. Typical values, while sometimes provided, should only be used as a guide in the design process. They may or may not be tested during the manufacturing process and are not guaranteed. Table 2 at the end of this note provides the symbol, parameter and definition of data found in reflective sensor datasheets.

Reflective Materials

The reflective sensor parameter values are measured using a metal mirror or an industry-standard reference surface called the Kodak neutral card also known as the gray or white card. The white side of the card has a reflection factor of 90 % while the gray side has a factor of 18 %. To learn more about the Kodak neutral card refer to Kodak's publication No. Q-13, CAT 1527654. Table 1 shows the relative values of measured reflection of a number of materials. They were measured with the TCRT1000, with a forward current of 20 mA, at distance where the collector current was highest and with a wavelength of 950 nm. While the TCRT1000 was used, these values apply to all reflective sensors under the same operating conditions. These measurements have important practical use when designing a reflective sensor application. The reflection of surfaces in the infrared range can vary significantly from that in the visible range.

Table 1. Relative collector current (or coupling factor) of thereflex sensors for reflection on various materials. Reference is the white side of the Kodak neutral card. The sensor is positioned perpendicular to the surface. The wavelength is 950 nm

Kodak neutral card	
White side (reference medium)	100 %
Gray side	20 %
Paper	
Typewriting paper	94 %
Drawing card, white (Schoeller Durex)	100 %
Card, light gray	67 %
Envelope (beige)	100 %
Packing card (light brown)	84 %
Newspaper paper	97 %
Pergament paper	30 - 42 %
Black on white typewriting paper	
Drawing ink (Higgins, Pelikan, Rotring)	4 - 6 %
Foil ink (Rotring)	50 %
Fiber-tip pen (Edding 400)	10 %
Fiber-tip pen, black (Stabilo)	76 %
Photocopy	7 %
Plotter pen	
HP fiber-tip pen (0.3 mm)	84 %
Black 24 needle printer (EPSON LQ-500)	28 %
Ink (Pelikan)	100 %
Pencil, HB	26 %

Plastics, glass	
White PVC	90 %
Gray PVC	11 %
Blue, green, yellow, red PVC	40 - 80 %
White polyethylene	90 %
White polystyrene	120 %
Gray partinax	9 %
Fiber glass board material	
Without copper coating	12 - 19 %
With copper coating on the reverse side	30 %
Glass, 1 mm thick	9 %
Plexiglass, 1 mm thick	10%
Metals	
Aluminum, bright	110 %
Aluminum, black anodized	60 %
Cast aluminum, matt	45 %
Copper, matt (not oxidized)	110 %
Brass, bright	160 %
Gold plating, matt	150 %
Textiles	
White cotton	110 %
Black velvet	1.5 %

Operating Range and Peak Operating Distance

The phototransistor collector current is also dependent on the distance of the reflecting material from the sensor. Figure 3 shows the relative collector current versus the distance of the material from the sensor for the TCRT1000. This curve is included in each reflective sensor datasheet. The data was recorded using the Kodak neutral card's 90 % diffuse reflecting surface. The distance was measured from the surface of the sensor. The emitter current, I_F, was held constant during the measurement. This curve is called the working diagram. The working diagram of all reflective sensors shows a maximum collector current at a certain distance. For greater distances, collector current decreases. The working diagram is an important input to the reflective sensor circuit design. Choosing an operating distance at or near the sensors maximum collector current will provide greater design flexibility.

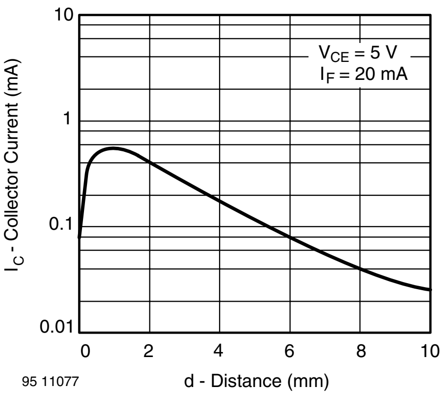

Figure 3. Collector Current vs. Distance

Switching Distance and Resolution

As an object moves over a reflective sensor the radiation reflected back to the detector changes gradually. For example, imagine a surface with an area high reflectivity and low reflectivity. As it moves over the sensor, Figure 4, the emitted radiation is reflected back to the detector. As the low-reflective surface moves into the sensing area of the detector, the collector current begins to drop-off. As this motion continues, a point is reached where the low-reflective surface completely envelops the detectors field of view. The edge of a sheet of paper, a black line on a shaft or the gaps in an encoding wheel will all see this gradual rise and fall in collector current. The switching distance, X_d, is the displacement relating to the width from 90 % I_{c1} to 10 % of I_{c2}. This distance is predominantly dependent on the mechanical and optical design of the sensor, and the distance to the reflecting surface. The resolution of the sensor is the capability to recognize a change in reflectivity. If the width of a black line on a spinning shaft is less than X_d, then the change in collector current may not be large enough and recognition by the sensor uncertain. The shorter the switching distance, the higher the sensors resolution.

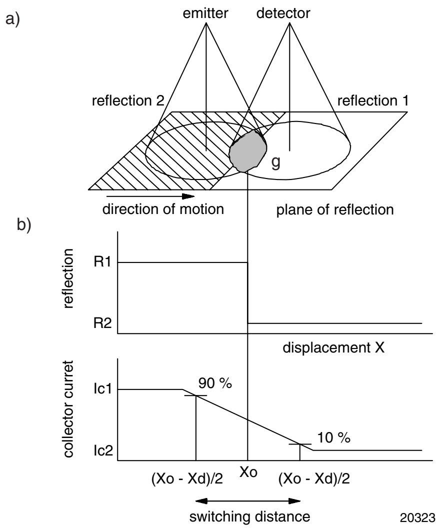

Figure 4. Abrupt reflection change with associated I_C curve

Cross Talk

The lowest light current that can be processed as a useful signal in the sensor's detector determines the weakest useable reflection and defines the sensitivity of the reflective sensor. This light current is determined by two parameters: cross talk and dark current. Whether the reflective sensor is lead-frame or PCB based, some of the emitted light will be internally reflected or channeled within the package to the detector. This is called optical cross talk. It is measured by operating the sensor without a reflective medium. While Vishay's sensors are designed to minimize crosstalk, the current must be considered when defining the circuit. The maximum cross talk current for each of Vishay's reflective sensors is specified in data sheets.

Reflection of the emitted light off of windows or surfaces surrounding the sensor is another source of cross talk to account for in the application design. In many applications this ambient crosstalk will be much higher than internal crosstalk of the sensor components and will determine signal to noise ratio or operating distance.

Dark Current

When a phototransistor is placed in the dark, or zero ambient illumination, and a voltage is applied from collector to emitter, a certain amount of current will flow. This current is called the dark current. It consists of the leakage current of the collector-base junction multiplied by the DC current gain of the transistor. The presence of this current prevents the phototransistor from being considered completely "off" or being an ideal "open switch". In datasheets, the dark current is described as being the maximum collector current permitted to flow at a given collector-emitter voltage. The dark current is a function of this voltage and temperature, Figure 5. Vishay phototransistors are tested at a V_{CE} applied voltage of 20 V. All reflective sensors which use a phototransistor specify a maximum dark current of 200 nA at 25 °C (typical 1 nA).

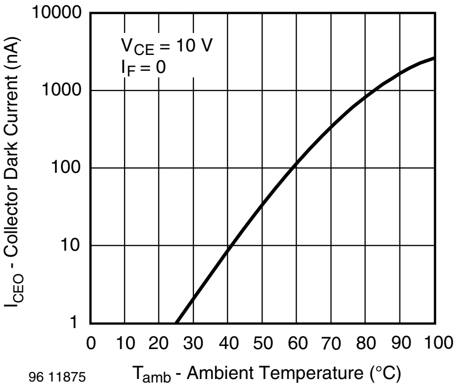

Figure 5. Collector Dark Current vs. Ambient Temperature

Temperature

Photo transistors and infrared emitting diodes are temperature dependent. As temperature increases, the light and dark current increases while emitter output decreases. An increase in the light current of the phototransistor is off-set by a decrease in the output of the emitter, Figure 6 and 7. Consequently, the change in the output of reflective sensors due to temperature change is comparatively small at less than 10 % from - 10 °C to + 70 °C, Figure 8. Because of this, it is not recommended to try to compensate for changes in temperature in the design of reflective sensor circuit.

Temperature also plays an important role in determining the emitter forward current in the application. As an example, for the TCRT1000, the maximum forward current at an ambient temperature of 25 °C is 50 mA. As shown in Figure 9, the forward current must be reduced according to changes in the ambient temperature. If the ambient temperature is 60 °C, the maximum current is 25 mA. This means a current exceeding 25 mA must not flow into the emitter. In practice, the actual current should include a large safety margin and the lowest possible current should be used.

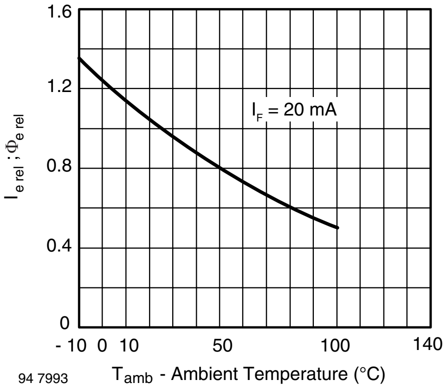

Figure 6. Rel. Radiant Intensity/Power vs. Ambient Temperature

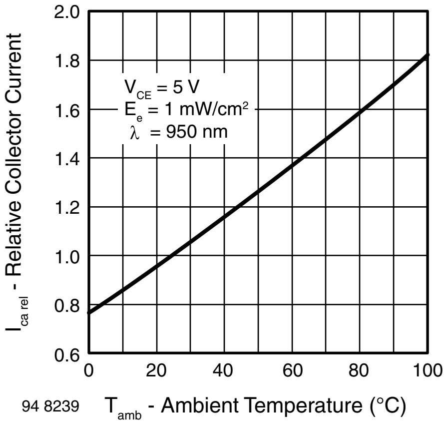

Figure 7. Rel. Collector Current vs. Ambient Temperature

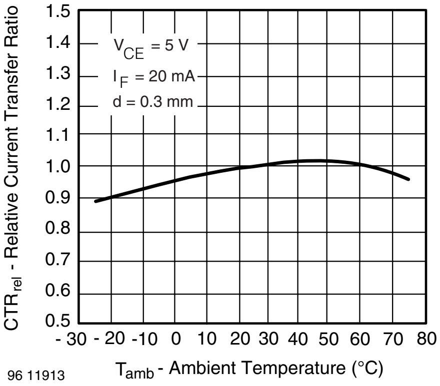

Figure 8. Rel. Current Transfer Ratio vs. Ambient Temperature

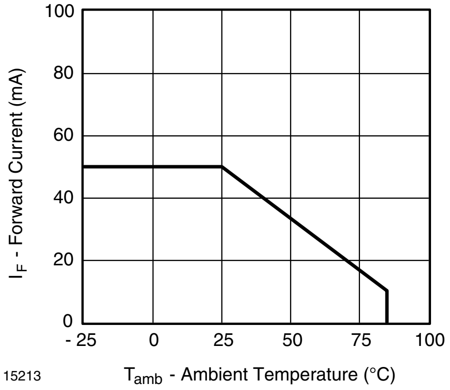

Figure 9. Forward Current vs. Ambient Temperature

Ambient Light

Ambient light can impair the sensitivity of the reflective sensor. Steady light falling directly on the detector reduces the sensor's sensitivity. Strong light can saturate the phototransistor and, in this condition, the sensor is blind. Varying ambient light results in incorrect signals and non-existent reflection changes. In applications where the ambient light source is known and relatively weak, in most cases it is enough to estimate the expected power of this light on the detector and to consider the result when defining the circuit. However, in many applications, it is difficult to precisely determine the ambient light and its effects. Ambient light is not only a problem when falling on the detector but can also be a problem when falling on the reflective surface. If the ambient light affects the object's and background's reflective factor in the same way, the ambient light effect can be ignored for low intensities. On the other hand, the object and background's reflective factor can differ. The background may reflect ambient light much more than the object. In this case, ambient light may reduce the contrast between the object and the background and the object may not be detected. Conversely, the sensor may detect a non-targeted feature because it reflects the ambient light much more than the surroundings.
Therefore, the influence of ambient light must be minimized by using optical filters, inspired mechanical design and, if necessary, AC operation. Vishay's reflective sensors are molded from epoxy that blocks visible light. Still, a large portion of sunlight is in the infrared. Locate or house the sensor so it is recessed to eliminate direct light. Pulsed operation can be helpful in some applications. AC operation is the most effective protection against ambient light.

Emitter Intensity

Emitter intensity depends largely on the forward current, I_F, optical efficiency of the lens and an internal reflector cup if included. The absolute maximum forward current of Vishay's TCRT1000, TCRT5000 and CNY70 is 50 mA, while the TCND5000 is 100 mA at an ambient temperature of 25 °C. The lower limit of the forward current of the emitter of any reflective sensor must be 5 mA minimum. If the forward current is too low, the optical output of the emitter will not be stable. A current limiting resistor is required. Without it, the current of the diode is theoretically limitless and the diode will burn out. The value of the current limiting resistor is calculated using the formula

$$R_L = (V_{CC} - V_F) / I_F$$

where the forward voltage of the emitter, V_F, typically 1.25 V, is subtracted from the supply voltage, V_{CC}, and divided by the forward current. Again, design in safety margin between actual operating conditions and the absolute maximum ratings. The external current limiting resistor defines the light intensity of the emitter. Driving the emitter with higher forward current to obtain larger reflected signal strength is not always be the best solution.

Response Time and Load Resistor

The speed of response of a phototransistor is dominated by the capacitance of the collector-base junction and the value of the load resistance. A phototransistor takes a certain amount of time to respond to sudden changes in light intensity. The response time is usually expressed by the rise time and fall time of the detector. As long as the light source driving the phototransistor is not intense enough to cause optical saturation, characterized by the storage of excess amounts of charge carriers in the base region, rise time equals fall time. If optical saturation occurs, fall time can become much larger than rise time. The selection of the load resistor, R_L, will also determine the amount of current-to-voltage conversion in the circuit. Reducing the value of R_L will result in a faster response time at the expense of a smaller voltage signal.

Degradation

End-users purchasing a reflective sensor want an accurate estimate of how long the sensor will last. Many will have minimum life requirements. Unlike most traditional light sources, infrared emitting diodes do not fail catastrophically. Instead, the light output degrades over time, Figure 10. Therefore the useful life of a reflective sensor can be defined by the time when it fails to provide sufficient light for the intended application. Infrared and visible light emitting diode life is often quoted to be 100000 hours but this is based on the average life span of a single, 5 mm epoxy encapsulated emitter. Vishay's reflective sensors also have a single emitter that is epoxy encapsulated. With some similarity, average life span can be considered comparable. As a rule-of-thumb, plan for 30 % degradation of the emitter over the life time of the sensor.

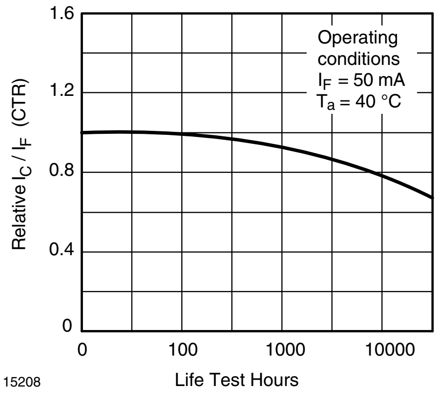

Figure 10.

The three main causes of degradation are:

- A loss of efficiency caused by mechanical stress deforming the crystal structure
- A loss of optical coupling caused by delamination between epoxy and chip
- A loss of efficiency caused by thermal stress on the crystal structure

The rate of degradation or aging is affected by:

- Chip technology: GaAs and GaAlAs Double Hetero (DH) technologies result in lower rates, while GaAlAs and GaAlAs/GaAs technologies result in higher rates of aging
- Package technology: metal can packaging technologies result in lower rates, and epoxy packaging technologies result in higher rates of aging
- Chip size: The smaller the chip, the higher the current density. A higher current density results in faster aging

There are a number of ways to minimize emitter degradation or aging. First, minimize the junction temperature. As long as the junction temperature, T_J, is kept below 100 °C, heating of the pn-junction will cause no significant degradation. To reduce junction temperature, minimize the forward current and the ambient temperature. Second, in applications where there is temperature cycling, keep the forward current for the corresponding temperature well below that shown in Figure 9. This is especially important since degradation due to mechanical stress and delamination is potentially greater in epoxy-based sensors. Third, in applications where response time is not critical, pulse the emitter instead of constant current operation. Reflective sensor datasheets include a curve showing Total Power Dissipation versus Ambient Temperature. Use this curve as a guide to minimize degradation.

Vishay features state-of-the-art chip technologies and high quality standards in the assembly process resulting in low degradation rate of our sensor components.

Table 2.

Parameter	Symbol	Definition
V_R	Reverse voltage	The maximum permissible applied voltage to the anode of the LED such that the current flows in the reverse direction
I_F	Forward Current	The direct or continuous current flowing in the forward direction of a diode, from the anode to the cathode
I_{FSM}	Forward surge current	The maximum permissible surge or pulse current allowed for a specified temperature and period in the forward direction
P_V	Power dissipation	The maximum power that is consumed by the collector junction of a phototransistor
T_J	Junction temperature	The spatial mean value of the collector junction temperature during operation
V_{CEO}	Collector emitter voltage	The positive voltage applied to the collector of a phototransistor with the emitter at a reference potential and open base
V_{ECO}	Emitter collector voltage	The positive voltage applied to the emitter of a phototransistor with the collector at a reference potential and open base
I_C	Collector current	The current that flows to the collector junction of a phototransistor
T_{amb}	Ambient Temperature	The maximum permissible ambient temperature
T_{stg}	Storage Temperature	The maximum permissible storage temperature without an applied voltage
V_F	Forward voltage	The voltage drop across the diode in the forward direction when a specified forward current is applied
I_{CEO}	Collector dark current	The current leakage of the phototransistor when a specified bias voltage is applied so that the polarity of the collector is positive and that of the emitter is negative on condition that the illumination of the sensor is zero
I_{CX}	Cross talk current	The output current measured at a specified voltage and forward current when there is no reflective medium
V_{CEsat}	Collector emitter saturation voltage	The continuous voltage between the collector and emitter when the detector is in its "ON" state as measured with the Kodak neutral test card, white side
t_r	Rise time	Amount of time it takes the output voltage to go from 10 % of the lower specified value to 90 % of the upper specified value
t_f	Fall time	The time required for the output voltage to go from 90 % of the upper specified value to 10 % of the lower specified value