Optical Sensors - Transmissive

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. Both types detect the presence of an object without any mechanical or electrical contact. The output signal of the sensor is used to control various functions of an application.

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 light energy reaching the detector changes. 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 transmissive sensors. It describes several factors that must be considered when using a transmissive sensor. Vishay has a broad portfolio of transmissive sensors in leaded and surface mount packages with various gap and aperture sizes. One is just right for your application. Should you have any design questions, Vishay's Application Engineers are ready to assist you.

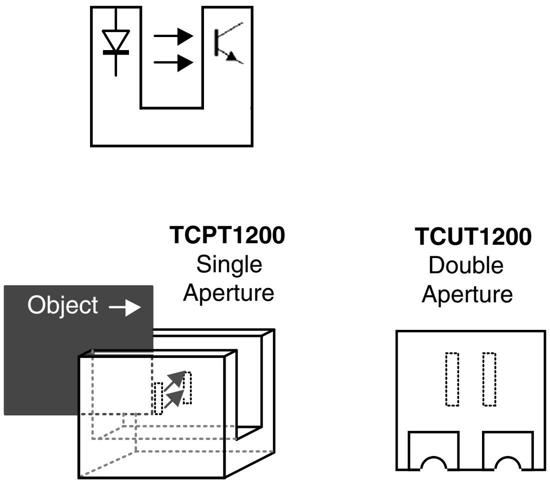

Figure 1.

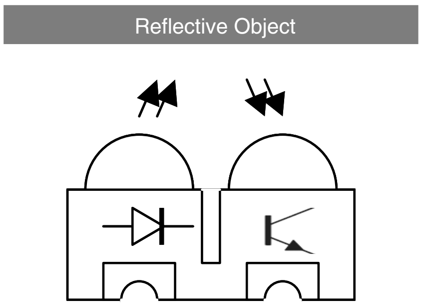

Figure 2.

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 transmissive 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 transmissive sensor datasheets.

Collector Current

If an object is moving towards the aperture, the light will be blocked and the collector current decreases, Figure 3. If the object is moving away from the aperture, the light will not be blocked and the collector current increases. Both scenarios are commonly found in transmissive sensor applications. The resolution of the transmissive sensor depends on the aperture, the light sensitive area of the detector and the direction of movement. To increase the performance of the sensor, the object should not be infrared translucent. For linear position sensing applications, only the collector current range from 90 % to 10 % can be used to avoid false detects.

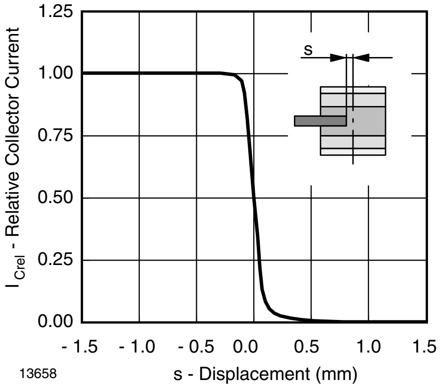

Figure 3.

Aperture, Gap Size

Most of Vishay's transmissive sensors use an aperture to focus the light onto a single plain and direction. Smaller apertures are intended to give better resolution which will result in a steeper sloped Ic. A single channel transmissive sensor has one emitter and detector pointing at each other while a dual channel sensor will have one emitter and two detectors, and apertures, Figure 4, 5, 6. Single channel sensors are used to detect the presence or absence of an object and to detect speed. Dual channel sensors are commonly used to detect direction and speed using quadrature encoding.

The medium or object to be sensed plus its tolerances normally defines the minimum gap size. Assembly tolerances and other factors relating to the type of medium will add to this gap size. The ideal gap size accounts for all of these factors and is no larger than necessary. This ensures the optimum current transfer ratio for the system. If the gap size is too big, stray ambient light may interfere with the signal, emitted light will diffuse and the current transfer ratio will not be optimum.

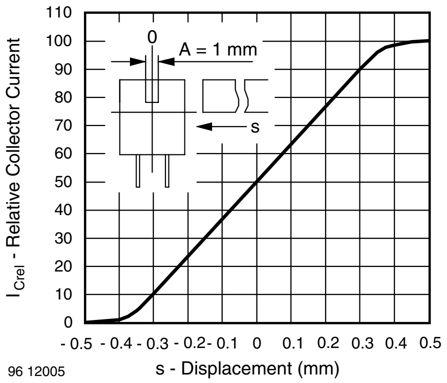

Figure 4. Rel.Rel. Collector Current vs. Displacement

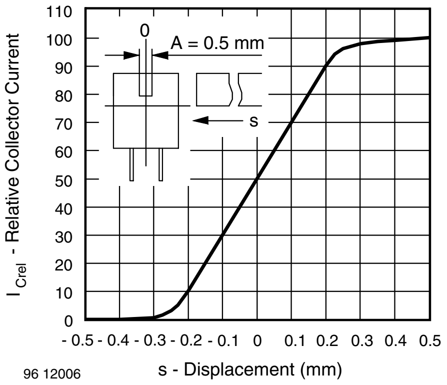

Figure 5. Rel. Rel. Collector Current vs. Displacement

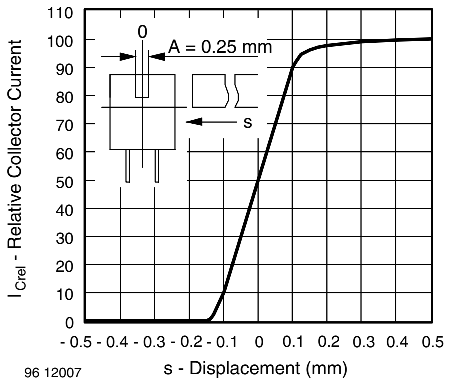

Figure 6. Rel. Collector Current vs. Displacement

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 7.

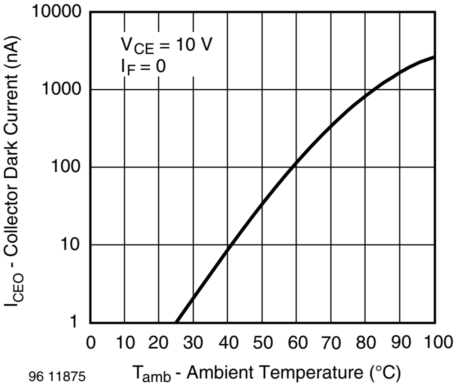

Figure 7. Collector Dark Current vs. Ambient Temperature

Temperature

Photo transistors and infrared emitting diodes are temperature dependent. As temperature increases, the light and dark current increases while emitter output decreases. Radiant intensity of the emitter decreases by - 0.7 %/°C while the sensitivity of the phototransistor increases by + 1 %/°C. So, an increase in the light current of the phototransistor is off-set by a decrease in the output of the emitter, Figure 8 and 9. Consequently, the change in the output of transmissive sensors due to temperature change is comparatively small at less than 10 % from - 25 °C to + 70 °C, Figure 10. Because of this, it is not recommended or necessary to try to compensate for changes in temperature in the design of transmissive sensor circuit.

Temperature also plays an important role in determining the emitter forward current in the application. As an example, if the maximum forward current at an ambient temperature of 25 °C is 50 mA. As shown in Figure 11, as power dissipation decreases the forward current must be reduced according to changes in the ambient temperature. At an ambient temperature is 85 °C, the maximum current is roughly 20 % of the value at 25 °C. In practice, the actual current should include a large safety margin and the lowest possible current should be used.

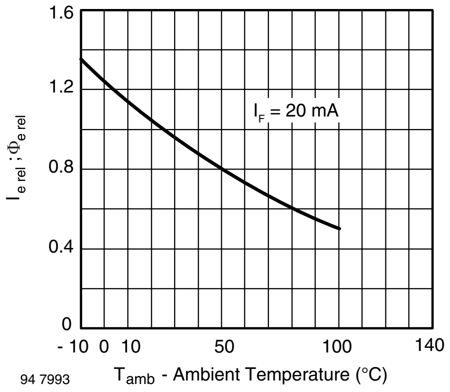

Figure 8. Rel. Radiant Intensity/Power vs. Ambient Temperature

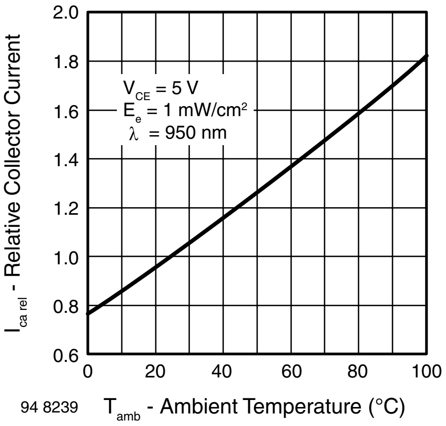

Figure 9. Rel. Collector Current vs. Ambient Temperature

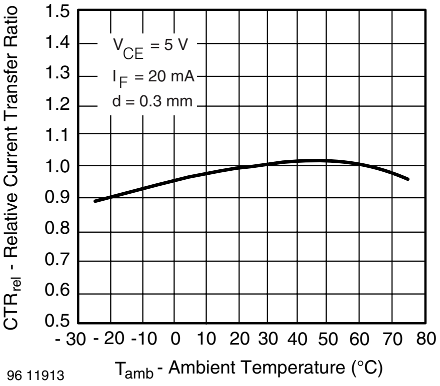

Figure 10. Rel. Current Transfer Ratio vs. Ambient Temperature

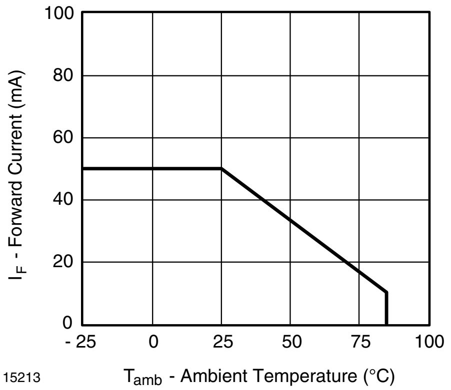

Figure 11. Forward Current vs. Ambient Temperature

Ambient Light

Ambient light can impair the sensitivity of the transmissive sensor though its effect is reduced compared to reflective sensors because of relative small gap sizes and the in-line nature of the emitter and detector. Steady light falling directly on the detector may saturate the phototransistor. If an object intended to block the light path does not block the direct ambient light, the phototransistor may remain saturated and no signal will be generated. Varying ambient light results in incorrect signals and missed detections. In many applications, it is difficult to precisely determine the ambient light and its effects. Therefore, the influence of ambient light must be minimized by using optical filters, inspired mechanical design and, if necessary, AC operation. Most of Vishay's transmissive 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. The absolute maximum forward current is found in the datasheet. For some of Vishay's transmissive sensors, the maximum forward current is 25 mA at an ambient temperature of 25°C. 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 1.2 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. Intensities that are too high will reduce response time and potentially accelerate degradation. However, since the emitter points directly at the detector over a small gap, forward currents for transmissive sensors are typically low.

Switching Times

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. If 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. Transmissive sensors are generally saturated when an object is not present so fall time is 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 may result in a faster response time at the expense of a smaller voltage signal.

Degradation

End-users purchasing a transmissive 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 12. Therefore the useful life of a transmissive 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.

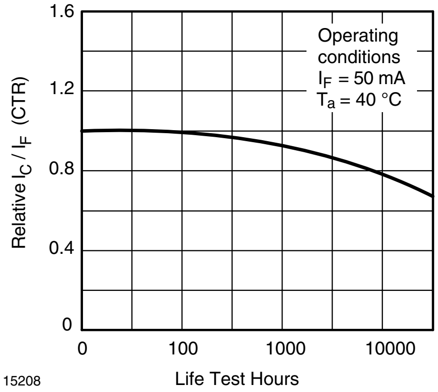

Figure 12.

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 GaAIAs Double Hetero (DH) technologies result in lower rates, while GaAIAs and GaAIAs/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 11. This is especially important since degradation due to mechanical stress and delamination is potentially greater in epoxy-based sensors. Transmissive 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
	Gap	Distance from emitter face (or post) to detector face
	Aperture	The opening in the detector post that admits light
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
TJ	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
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