Designing the VCNT2025X01 Into an Application

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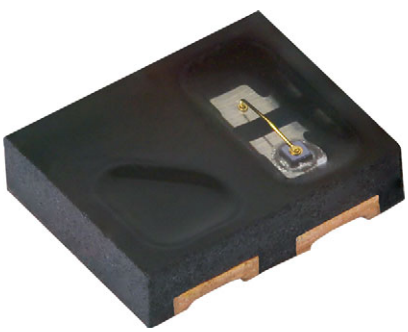
INTRODUCTION AND BASIC OPERATION

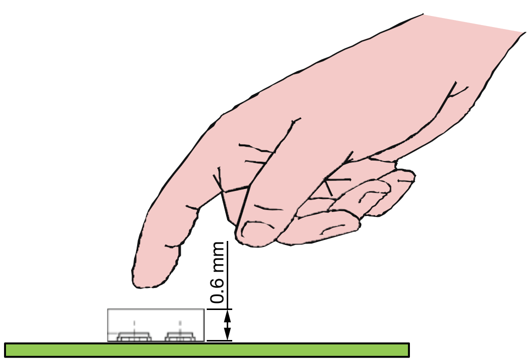
The VCNT2025X01 is a reflective sensor in a miniature SMD package with dimensions of 2.5 x 2 x 0.6 (L x W x H in mm). The emitting light source and the detector are arranged in the same plane, but the crosstalk from the IRED towards the detector is almost zero. The operating infrared wavelength is 940 nm. The detector consists of a silicon phototransistor. The sensor's analog output signal (photocurrent) is triggered by the detection of reflected infrared light from a near by object. The sensor has a built-in daylight blocking filter, which greatly suppresses disturbing ambient light and therefore increases the signal to noise ratio.

Typical applications are:

- Position sensor
- Optical switch
- Optical encoder
- Object detection (e.g. paper presence in printer and copy machines)

Due to its high sensitivity, the VCNT2025X01 can be used for detection distances up to 5 mm. At this distance, a highly reflective object will still generate a current at the detector of about 0.5 mA.





Smallest Possible Reflector Sensor

DATASHEET PARAMETER VALUES

The datasheet provides information about the absolute maximum ratings and the basic electrical and optical characteristics of the sensor, as shown in the two tables below.

The sensor must be operated inside the limits given in the absolute maximum ratings table for reverse and forward voltage, collector current, power dissipation, and ambient and storage temperature. In practice, applications should be designed so that a large safety margin between the operating conditions and the absolute maximum ratings is achieved.

The electrical and optical characteristics that are given in the basic characteristics table indicate the performance of the sensor under specific operating conditions. The given min. / max. values are guaranteed and are tested during the manufacturing of the sensor. Typical values should only be used as a guide in the design process.

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ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
INPUT (EMITTER)				
Reverse voltage		V_R	5	V
Forward current		I_F	65	mA
Forward surge current	$t_p \leq 100$ μs	I_{FSM}	200	mA
Junction temperature		T_J	120	°C
Thermal resistance junction to ambient	JESD 51	R_{thJA}	380	K/W
OUTPUT (DETECTOR)				
Collector emitter breakdown voltage		$V_{(BR)CEO}$	20	V
Emitter collector voltage		V_{ECO}	7	V
Collector current		I_C	50	mA
SENSOR				
Total power dissipation	$T_{amb} \leq 25$ °C	P_{tot}	107	mW
Ambient temperature range		T_{amb}	-40 to +110	°C
Storage temperature range		T_{stg}	-40 to +110	°C
Soldering temperature		T_{sd}	260	°C

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)						
PARAMETER	**TEST CONDITION**	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
INPUT (EMITTER)						
Forward voltage	I_F = 20 mA	V_F	1.0	1.25	1.4	V
	I_F = 65 mA		-	1.47	-	
Temperature coefficient of V_F	I_F = 20 mA	TKV_F	-	-1.0	-	mV/K
Peak wavelength	I_F = 65 mA	λ_P	-	940	-	nm
Reverse current	V_R = 5 V	I_R	-	-	10	μA
OUTPUT (DETECTOR)						
Collector emitter breakdown voltage	I_C = 0.1 mA, E = 0	$V_{(BR)CEO}$	20	-	-	V
Emitter collector voltage	I_E = 100 μA, E = 0	V_{ECO}	7	-	-	V
Collector emitter dark current	V_{CE} = 5 V, E = 0	I_{CEO}	-	1	100	nA
SENSOR						
Collector current	V_{CE} = 5 V, I_F = 20 mA, d = 1 mm	I_C	3.5	6.6	10.5	mA
Current transfer ratio	I_C/I_F, d = 1 mm, V_{CE} = 5 V	CTR	-	33	-	%
Rise time	I_C = 0.8 mA, V_{CE} = 5 V, R_L = 100 Ω	t_r	-	10	-	μs
Fall time	I_C = 0.8 mA, V_{CE} = 5 V, R_L = 100 Ω	t_f	-	15	-	μs

The basic characteristics for the sensor are only valid for a standard test setup, as it is described in Fig. 1.

This standard setup includes a flat mirror on top of the sensor at a distance of 1 mm.

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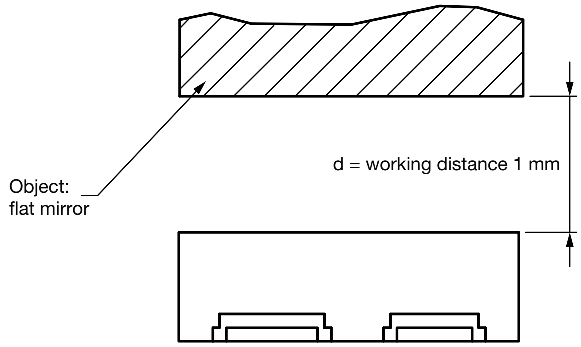

Fig. 1 - Test Setup

DISTANCE BETWEEN SENSOR AND OBJECT

The VCNT2025X01 is a reflective proximity sensor with an analog transistor output. The emitter sends out infrared light. A near by object will subsequently reflect part of that light back towards the sensor. The reflected signal induces a photocurrent that is amplified at the detector. The amplitude of the output current correlates directly and proportionally to the amount of the received IR irradiation. On the other hand, the amount of radiation that is reflected back depends on various factors, the most prominent of which are the distance between the sensor and the reflective object and the reflectivity of the object. This leads to a dependance of the output current on the distance to a reflective object, as shown in Fig. 2 and Fig. 3.

The following distance curves were recorded using a Kodak neutral card (white side) that has a calibrated, diffuse reflecting surface of 90 %. The distance is measured from the top of the sensor. The emitter current I_F was held constant.

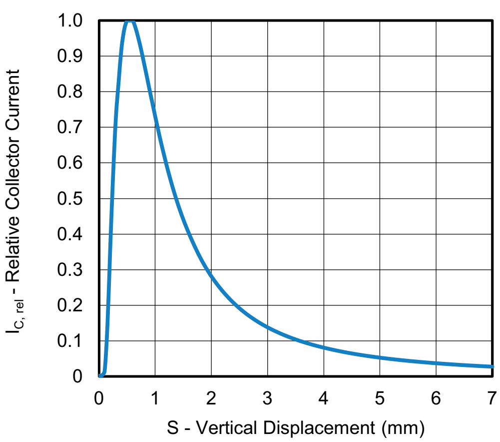

Fig. 2 - Relative Collector Current vs. Distance

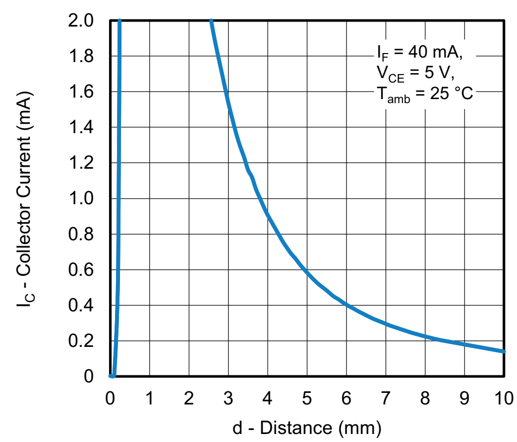

Fig. 3 - Collector Current vs. Distance for $I_C \leq 2$ mA

The distance curves of all reflective sensors have a peak at a certain distance that is determined mechanically by the position of the emitter and detector. The relative distance curve of the VCNT2025X01 has its peak at about 0.5 mm. The sensor is particularly sensitive for any approaching object in this area.

The distance curve is an important input to a reflective circuit design. Choosing an operating distance at or near the sensor's maximum sensitivity will provide greater design flexibility.

The second graph (Fig. 3) shows a distance curve in absolute values. It shows that at a distance of 5 mm, the VCNT2025X01 still puts out more than 0.5 mA.

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REFLECTION INDEX OF VARIOUS MATERIALS / COLORS			
Kodak Neutral Card		**Plastics, Glass**	
White side (reference medium)	100 %	White PVC	90 %
Gray side	20 %	Gray PVC	11 %
Paper		Blue, green, yellow, red PVC	40 % to 80 %
Typewriting paper	94 %	White polyethylene	90 %
Drawing card, white (Schoeller Durex)	100 %	White polystyrene	120 %
Card, light gray	67 %	Gray partinax	9 %
Envelope (beige)	100 %	**Fiber Glass Board Material**	
Packing card (light brown)	84 %	Without copper coating	12 % to 19 %
Newspaper paper	97 %	With copper coating on the reverse side	30 %
Pergament paper	30 % to 42 %	Glass, 1 mm thick	9 %
Black or White Typewriting Paper		Plexiglass, 1 mm thick	10 %
Drawing ink (Higgins, Pelikan, Rotring)	4 % to 6 %	**Metals**	
Foil ink (Rotring)	50 %	Aluminum, bright	110 %
Fiber-tip pen (Edding 400)	10 %	Aluminum, black anodized	60 %
Fiber-tip pen, black (Stabilo)	76 %	Cast aluminum, matt	45 %
Photocopy	7 %	Copper, matt (not oxidized)	110 %
Plotter Pen		Brass, bright	160 %
HP fiber-tip pen (0.3 mm)	84 %	Gold plating, matt	150 %
Black 24 needle printer (EPSON LQ-500)	28 %	**Textiles**	
Ink (Pelikan)	100 %	White cotton	110 %
Pencil, HB	26 %	Black velvet	1.5 %

Note

- Relative collector current (or coupling factor) of the reflex 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

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APPLICATION CIRCUITS

This paragraph covers three application examples that show how the circuitry around the VCNT2025X01 can be laid out and designed to suit several situations. The underlying circuit in Fig. 4, and the procedure for designing the circuit, always remains similar and can be summarized in five points.

Assumptions that define the scenario:

1. Define the sensing distance
2. Estimate the expected worst-case reflectivity of the object to detect

Calculation steps:

3. Estimate the corresponding minimum current transfer ratio ($CTR_{min.}$) from the distance curve
4. Choose a suitable forward current I_F and calculate the minimum output current I_C
5. Calculate the emitter resistor R_E and load resistor R_L

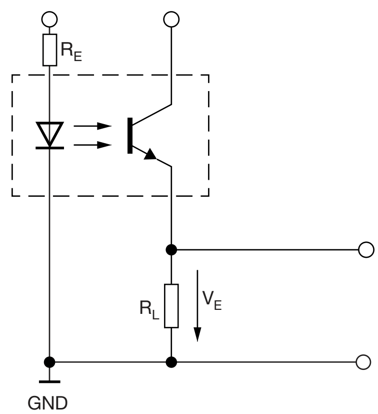

Fig. 4 - Application Circuit

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EXAMPLE CALCULATION 1 - CLOSE DISTANCE, HIGH REFLECTIVITY

Assumptions:

1. The sensing distance is 2 mm from the sensor
2. The reflectivity of the object is greater than 90 %

Calculation steps:

3. At first, the $CTR_{min.}$ will be estimated. It is vital to take a worst-case scenario into account, since even the sensor with the poorest sensitivity due to part to part tolerances must be capable of triggering a detection.

   From the basic characteristics table in the datasheet, the minimum collector current $I_{C,\ min.,\ datasheet}$ is given as 3.5 mA (at d = 1 mm and I_F = 20 mA). This corresponds to a $CTR_{min.}$ of $\frac{3.5\ mA}{20\ mA} = 0.175$.

   However, this $CTR_{min.}$ only applies for an object at 1 mm and therefore has to be further reduced since the assumed distance from the sensor is 2 mm. From the distance curve in Fig. 5, the relative collector current at a distance of 2 mm is estimated as just $I_{C,\ rel.}$ (2 mm) = 0.3 times the maximum collector current (marking II). Compared with the green marked point I in the figure, this leads to a further reduction factor of the $CTR_{min.}$ of $\frac{0.3}{0.7} = 0.43$.

   Taking the reflectivity of the object into account, the final $CTR_{min.}$ can be calculated as:

   $$CTR_{min.} = \frac{I_{C,\ min.,\ datasheet}}{I_F} \times \frac{I_{C,\ rel.}\ (2\ mm)}{I_{C,\ rel.}\ (1\ mm)} \times \text{reflectivity} = 0.175 \times 0.43 \times 0.9 = 0.068$$

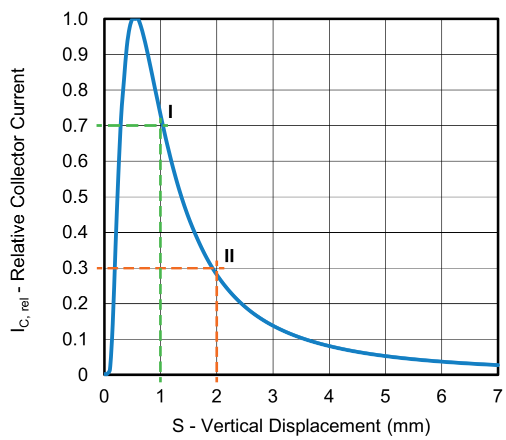

Fig. 5 - Relative Distance Curve of the VCNT2025X01

4. I_F is set to 20 mA. With $CTR_{min.}$ follows the equation above, the minimum collector current $I_{C,\ min.}$ that can be expected is:

   $I_{C,\ min.}$ = 20 mA x 0.068 = 1.36 mA

5. Calculation of the resistors:

   Assuming a supply voltage of 5 V, the emitter resistor R_E calculates to

   $$R_E = \frac{5\ V - 1.25\ V}{20\ mA} = 187.5\ \Omega \rightarrow 180\ \Omega$$

   The corresponding load resistor can be calculated as

   $$R_L = \frac{5\ V - 0.4\ V}{1.36\ mA} = 3382\ \Omega \rightarrow 3.9\ k\Omega$$

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EXAMPLE CALCULATION - HIGHER DISTANCE, HIGH REFLECTIVITY

Assumptions:

1. The sensing distance is 6 mm from the sensor
2. The reflectivity of the object is greater than 90 %

Calculation steps:

3. Calculating $CTR_{min.}$:

$$CTR_{min.} = \frac{I_{C,\ min.,\ datasheet}}{I_F} \times \frac{I_{C,\ rel.}\ (6\ mm)}{I_{C,\ rel.}\ (1\ mm)} \times \text{reflectivity} = 0.175 \times \frac{0.03}{0.7} \times 0.9 = 0.0068$$

4. Calculating the minimum collector current that can be expected:
   I_F is set to 40 mA. With $CTR_{min.}$ follows:

$$I_{C,\ min.} = 40\ mA \times 0.0068 = 0.27\ mA$$

5. Calculation of the resistors:
   Assuming a supply voltage of 5 V, the emitter resistor R_E calculates to

$$R_E = \frac{5\ V - 1.25\ V}{40\ mA} = 93.8\ \Omega \rightarrow 82\ \Omega$$

   The corresponding load resistor can be calculated as

$$R_L = \frac{5\ V - 0.4\ V}{0.27\ mA} = 17\ 037\ \Omega \rightarrow 18\ k\Omega$$

In this case, the load resistor R_L is already quite highly ohmic. The issue that comes with high load resistors is that the circuit gets more sensitive, and subsequently even small photocurrents will lead to a relevant output voltage. Consequently, the sensor must be protected from light sources with a high IR component, which interfere with the reflected signal and cause false detection.

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EXAMPLE CALCULATION - HIGHER DISTANCE, LOWER REFLECTIVITY

Assumptions:

1. The sensing distance is 4 mm from the sensor
2. Human skin with 40 % reflectivity shall be detected

Calculation steps:

3. Calculating $CTR_{min.}$:

$$CTR_{min.} = \frac{I_{C,\ min.}}{I_F} \times \frac{I_{C,\ rel.}\ (4\ mm)}{I_{C,\ rel.}\ (1\ mm)} \times \text{reflectivity} = 0.175 \times \frac{0.08}{0.7} \times 0.4 = 0.008$$

4. I_F is set to 40 mA. With $CTR_{min.}$ yields

$$I_{C,\ min.} = 40\ mA \times 0.008 = 0.32\ mA$$

5. Calculation of the resistors:
Assuming a supply voltage of 5 V, the emitter resistor R_E calculates to

$$R_E = \frac{5\ V - 1.25\ V}{40\ mA} = 93.8\ \Omega \rightarrow 82\ \Omega$$

The corresponding load resistor can be calculated as

$$R_L = \frac{5\ V - 0.4\ V}{0.32\ mA} = 14\ 375\ \Omega \rightarrow 15\ k\Omega$$

Similar to the previous example, the load resistor R_L again is quite highly ohmic, and the sensor has to be protected from disturbing external light sources with high IR components.

ALTERNATIVE CIRCUITRY – ADDITIONAL TRANSISTOR FOR AN INCREASED SWITCHING TIME

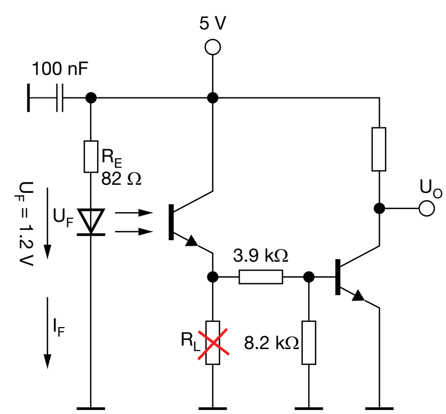

Fig. 6 - Alternative Circuitry for the VCNT2025X01 With an External Transistor

As shown in Fig. 6, the circuitry around the VCNT2025X01 can be adapted to ensure higher detection speeds compared to the circuitry shown for the previous examples. The smaller load at the detector's collector in the adapted circuitry causes the sensor system to be less sensitive; however, the threshold for triggering a detection can be fine-tuned with the resistor divider at the base of an external transistor.

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DERATING AND TEMPERATURE BEHAVIOR

The VCNT2025X01 is specified for a temperature range of -40 °C up to 110 °C. However, following Fig. 8, the emitter current has to be decreased accordingly for operation above 76 °C ambient temperature. Otherwise the internal heat dissipation will lead to a junction temperature that exceeds the absolute maximum limit of T_J.

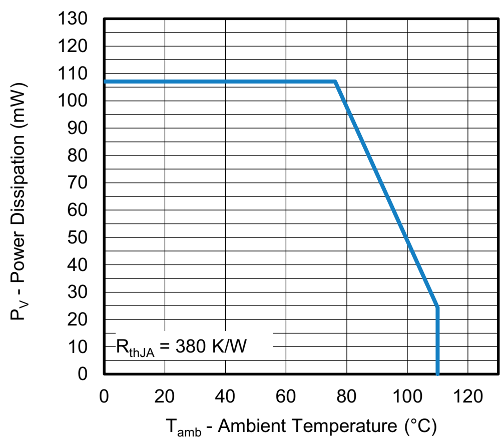

Fig. 7 - Power Dissipation vs. Ambient Temperature

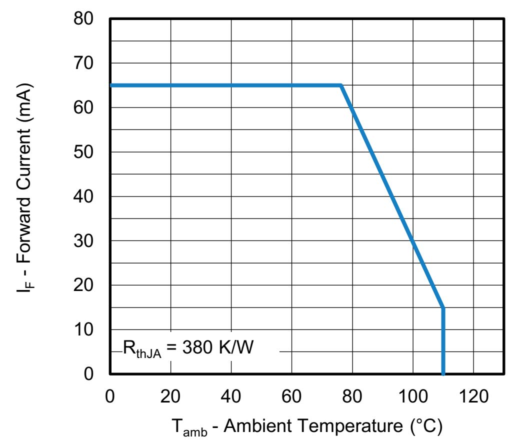

Fig. 8 - Forward Current vs. Ambient Temperature

The collector current behavior vs. ambient temperature shows about a 25 % lower current for -40 °C, where for higher temperatures only a small increase is seen.

For higher temperatures the dark current increases. This may end up at about 2 μA at 100 °C. This needs to be kept in mind when choosing a high load resistor.

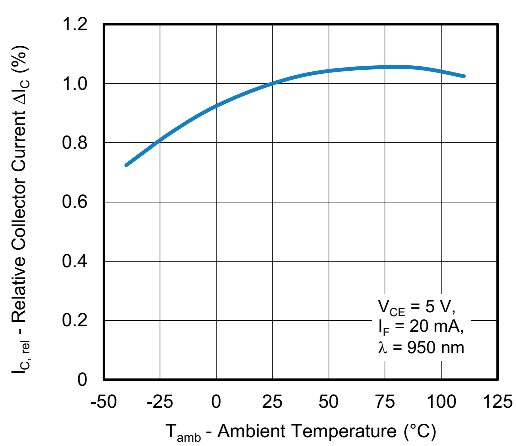

Fig. 9 - Relative Collector Current vs. Ambient Temperature

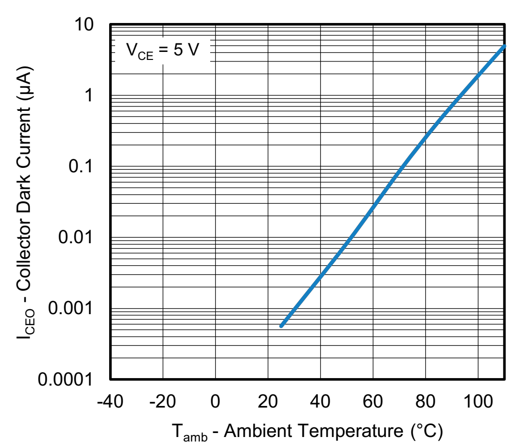

Fig. 10 - Collector Dark Current vs. Ambient Temperature

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SWITCHING TIMES

Rise and fall times are defined as t_r = 10 µs and t_f = 15 µs. However, these were measured with small load resistors of 100 Ω.

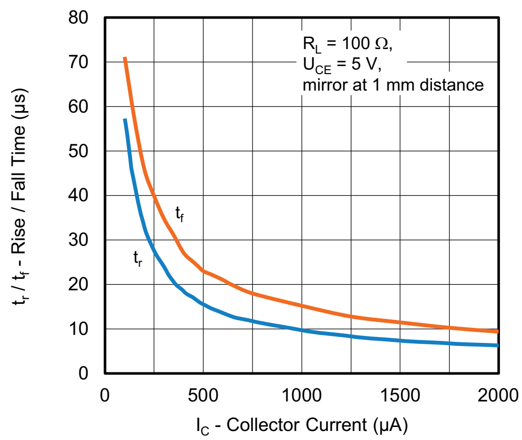

Fig. 11 - Rise / Fall Time vs. Collector Current

SENSITIVITY TO DISTURBING LIGHT SOURCES

Although the sensor has a built-in daylight blocking filter, which greatly suppresses disturbing ambient light and therefore increases the signal to noise ratio, bright sunlight will influence the sensor.

A higher forward current plus a lower collector load resistor will help here, but it may not for very strong light sources also containing high infrared signals.

A possible solution could be to not operate the emitter continuously, but pulsed.

Also having a DC-decoupling amplification at the collector side would eliminate this more steady signal.

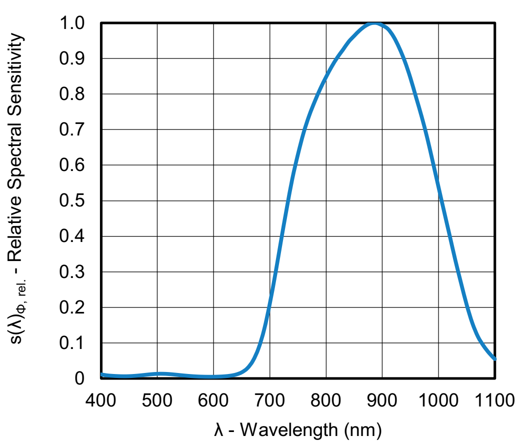

Fig. 12 - Relative Spectral Sensitivity vs. Wavelength

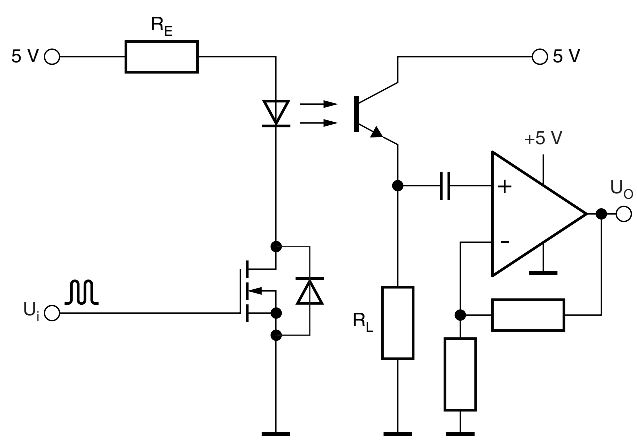

Fig. 13 - Application Example With Added AC-Coupled Amplification

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MECHANICAL CONSIDERATIONS

Fig. 2 shows that the sensor’s highest sensitivity is at about 0.5 mm. Any cover at close distances in this range will cause a very high offset current at the detector.

So, it is preferred that the cover is > 2 mm away from the sensor, as this is not within the highest sensitivity range. In order to achieve the highest possible signal amplitude, it is recommended to keep the cover thinner than 1 mm, or as thin as possible.

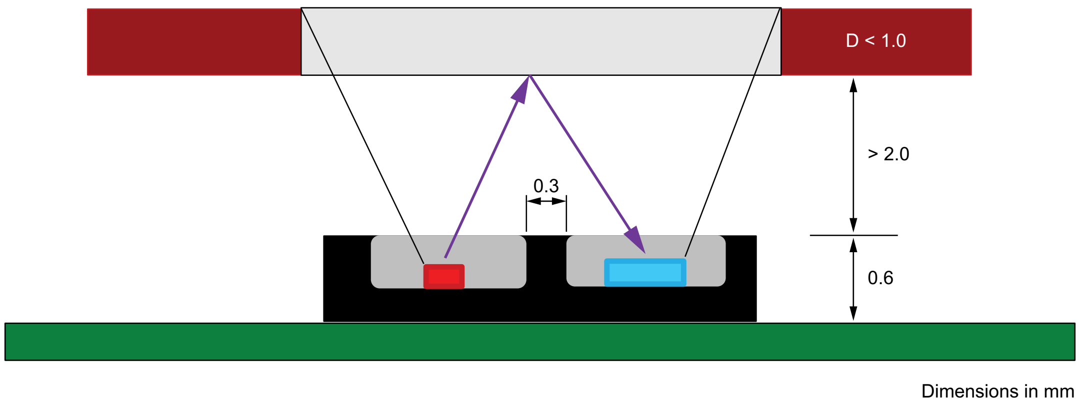

Fig. 14 - Recommended Cover Distance From the Sensor

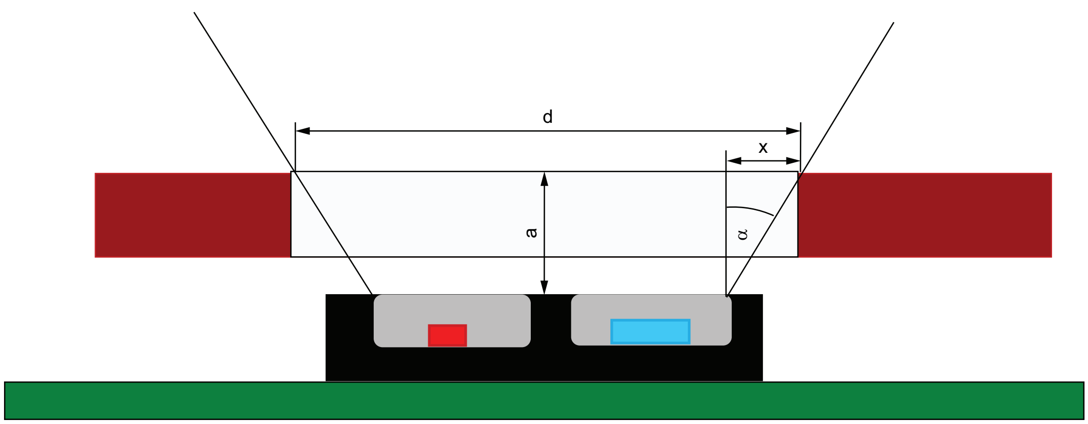

Fig. 15 - Estimate of the Size of a Cover Window

The angle of half intensity of the emitter is about ± 65° and the viewing angle of the phototransistor is characterized as ± 55°. These angles should be considered during the design of a window on top of the sensor. The window diameter must not be too small to avoid limiting the viewing angle of the detector nor blocking the emitter’s signal. In either case, the signal's amplitude will get reduced critically. The following calculation example provides a good estimate for the necessary window sizes to guarantee a viewing / emission angle alpha of at least 65°, as indicated in Fig. 15.

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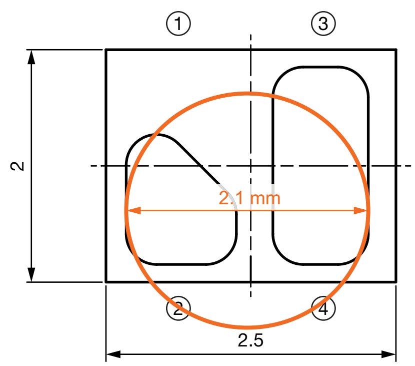

Fig. 16 - Minimum Diameter of a Cover Window

The circular window size comprises a minimum width $d_{min.}$ of 2.1 mm that arises from the distance between the emitter and detector (see Fig. 16), and a component “x” that increases with the distance “a” of the cover from the sensor. If the cover is placed further away from the sensor, the diameter of the window has to be increased accordingly. From the drawing in Fig. 15, the window diameter can be calculated as:

$$d = d_{min.} + 2 \times x = d_{min.} + 2 \times \tan(\alpha) \times a$$

The width calculation for distances from 0 mm to 3.0 mm yields:

d = 0.0 mm → x = 0.0 mm → d = 2.1 mm + 0.0 mm = 2.1 mm
d = 0.5 mm → x = 1.1 mm → d = 2.1 mm + 1.1 mm = 4.3 mm
d = 1.0 mm → x = 2.1 mm → d = 2.1 mm + 2.1 mm = 6.3 mm
d = 1.5 mm → x = 3.2 mm → d = 2.1 mm + 3.2 mm = 8.5 mm
d = 2.0 mm → x = 4.3 mm → d = 2.1 mm + 4.3 mm = 10.7 mm
d = 2.5 mm → x = 5.4 mm → d = 2.1 mm + 5.4 mm = 12.9 mm
d = 3.0 mm → x = 6.4 mm → d = 2.1 mm + 6.4 mm = 14.9 mm

EXPLANATION FOR DISPLACEMENT

Fig. 17 shows the relative collector current versus displacement for both directions an object may occur above the sensor. Since the emitter and detector are aligned in the x-direction, the curve for the x-direction is not as steep as the curve for the y-direction. In the y-direction, both the emitter and detector are being covered simultaneously, which is causing the y-curve to be steeper. This fact is of major importance when it comes to finding the smallest necessary width of an object that is still capable of covering the sensor totally and producing a full signal amplitude. In the y- and x-direction, the width of an object has to be at least 1 mm (10 % to 90 %) and 1.5 mm (10 % to 90 %), respectively.

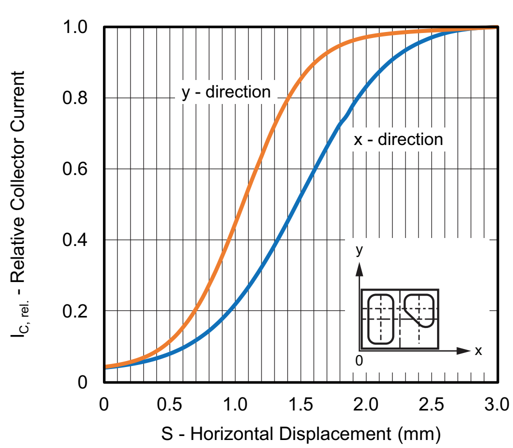

Fig. 17 - Relative Collector Current vs. Displacement

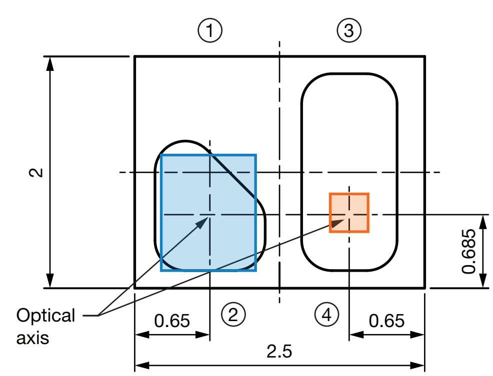

Fig. 18 - Dimensions of the VCNT2025X01

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Designing the VCNT2025X01 Into an Application

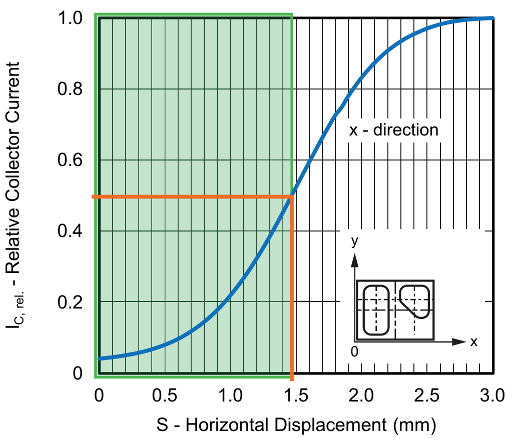

Fig. 19 - Relative Collector Current vs. Displacement

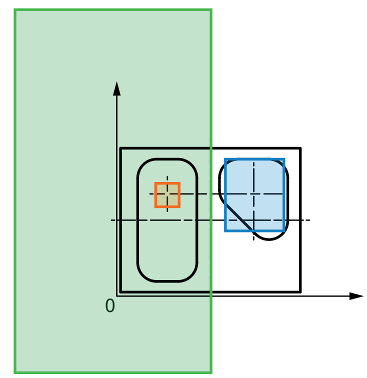

Fig. 20 - Displacement in x-Direction

About half of the collector current will be seen when the object is shifted 1.5 mm from the left edge of the component; so, a bit beyond midway (of 2.5 mm side, see Fig. 19).

And about half of the collector current will be seen when the object is shifted 1.05 mm from the bottom of the component; so a bit beyond midway (of 2 mm side, see Fig. 21).

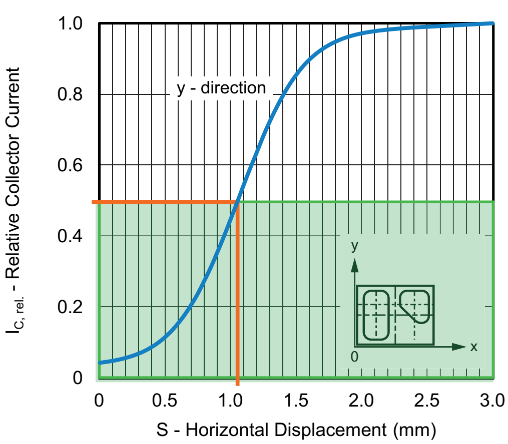

Fig. 21 - Relative Collector Current vs. Displacement

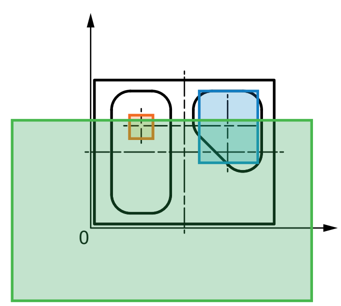

Fig. 22 - Displacement in y-Direction

SUMMARY

This application note covers the key characteristics of the VCNT2025X01 for typical applications. Key dependencies on tolerances, window design and the distance curve was covered as well as typical circuitries were discussed. Depending on the application, further specifics such as switching times, mechanical placement tolerances, degradation of the emitter, amongst other things, may need to be taken into consideration. This is however out of the scope of this application note.

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