INTRODUCTION
The VCNL4000 is a proximity sensor with an integrated ambient light sensor. It is the industry’s first optical sensor to combine an infrared emitter, PIN photodiode, ambient light sensor and signal processing in a single package with a 16-bit ADC for proximity measurement as well as ambient light measurement. The device provides ambient light sensing to support conventional backlight and display brightness adjustment, and proximity sensing for object and motion detection. With a range of up to 20 cm (7.9”), this stand-alone, single component greatly simplifies the use and design-in of a proximity sensor in consumer and industrial applications. The VCNL4000 features a miniature leadless package ( LLP) for surface mounting in a 3.95 mm x 3.95 mm package with a low profile of 0.75 mm designed specifically for the low height requirements of smart phone, mobile phone, digital camera, and tablet PC applications. Through its standard I2C bus serial digital interface, it allows easy access to a “Proximity Signal” and “Light intensity” measurement without complex calculations or programming.

COMPONENTS (BLOCK DIAGRAM)
The major components of the VCNL4000 are shown in the block diagram.
The integrated **infrared emitter** has a peak wavelength of 890 nm. It emits light that reflects off an object within 20 cm of the sensor. The infrared emitter spectrum is shown as a solid line. The infrared emitter has a programmable drive current from 10 mA to 200 mA in 10 mA steps. The infrared light emitted is modulated at one of four user defined carrier frequencies: 390.625 kHz, 781.25 kHz, 1.5625 MHz, or 3.125 MHz.

The **PIN photodiode** receives the light that is reflected off the object and converts it to a current. It has a peak sensitivity of 890 nm, matching the peak wavelength of the emitter. It is insensitive to ambient light. It ignores the DC component of light and “looks for” the pulsed light at one of the four frequencies used by the emitter. **Using a modulated signal for proximity provides distinct advantages over other sensors on the market.**

The **ambient light sensor** receives the visible light and converts it to a current. The human eye can see light of wavelengths from 400 nm to 700 nm with a peak of 560 nm. Vishay’s ambient light sensor closely matches this range of sensitivity. It has peak sensitivity at 540 nm and a bandwidth from 430 nm to 610 nm.

The application specific integrated circuit or **ASIC** includes an LED driver, I²C bus interface, amplifier, integrating analog to digital converter, oscillator, and Vishay’s secret sauce signal processor. For proximity, it converts the current from the PIN photodiode to a 16-bit digital data output value. For ambient light sensing, it converts the current from the ambient light detector, amplifies it and converts it to a 16-bit digital output stream.

**PIN CONNECTIONS**

Figure 4 shows the pin assignments of the VCNL4000. Only six of these pins need to be electrically connected while the remainder should be solder pad connections. The six connections include:

- Pin 1 - IR anode to the power supply
- Pin 4 - SDA to microcontroller
- Pin 5 - SCL to microcontroller
- Pin 7 - VDD to the power supply
- Pin 6, pin 12 - connect to ground
- Pin 2, pin 3 - IR cathode, no connect
- Pins 8 thru 11 - must not be connected

The power supply for the ASIC (VDD) and infrared emitter has a defined range from 2.5 V to 3.6 V. It is best if VDD is connected to a regulated power supply and pin 1, IR_Anode, is connected directly to the battery. This eliminates any influence of the high infrared emitter current pulses on the VDD supply line. The ground pins 6 and 12 are electrically the same. They both use the bottom metal case and may be routed to the same stable ground plane. The power supply decoupling components shown in fig. 4 are strongly recommended to isolate the sensor from other possible noise on the same power rail. The 100 nF capacitor should be placed close to the VDD pin. The SCL and SDA lines need a pull-up resistor. The resistor values depend on the application and on the I²C bus speed.
MECHANICAL DESIGN CONSIDERATIONS

The VCNL4000 is a fully integrated proximity and ambient light sensor. Competing sensors use a discrete infrared emitter which leads to complex geometrical calculations to determine the position of the emitter. Competing sensors also require a mechanical barrier between the emitter and detectors to eliminate crosstalk; light reflecting off the inside of the window cover which can produce false proximity readings. The VCNL4000 does not require a mechanical barrier. The signal processor continuously compensates for the light reflected from windows ensuring a proper proximity reading. As a fully integrated sensor, the design process is greatly simplified.

The only dimensions that the design engineer needs to consider are the distance from the top surface of the sensor to the outside surface of the window and the size of the window. These dimensions will determine the size of the detection zone.

The angle of half intensity of the emitter and the angle of half sensitivity of the PIN photodiode are ± 55° as shown in fig. 5 and fig. 6.

First, the center of the sensor and center of the window should be aligned. With the assumption that the detection zone is a cone shaped region with an angle of ± 40°, the following are dimensions for the distance from the top surface of the sensor to the outside surface of the glass, d, and the width of the window, w. The distance from the center of the infrared emitter to the center of the PIN photodiode is 2.47 mm.

The results above represent the ideal width of the window. The mechanical design of the device may not allow for this size. The sensor will function properly in less than ideal conditions. Performance testing is recommended in either case.
**PROXIMITY SENSOR**

The main DC light sources found in the environment are sunlight and tungsten (incandescent) bulbs. These kinds of disturbance sources will cause a DC current in the detector inside the sensor, which in turn will produce noise in the receiver circuit. The negative influence of such DC light can be reduced by optical filtering. Light in the visible range, 400 nm to 700 nm, is completely removed by the use of an optical cut-off filter at 800 nm. With filtering, only longer wavelength radiation above 800 nm can be detected. The PIN photodiode therefore receives only a limited band from the original spectrum of these DC light sources as shown in fig. 9.

As mentioned earlier, the proximity sensor uses a modulated carrier signal on one of four user selected frequencies. These frequencies are far from the ballast frequencies of fluorescent lights ensuring that the sensor is unaffected by them. The infrared emitter sends out a series of pulses, a burst, at the selected frequency and the PIN photodiode which features a band pass filter set to this same frequency, receives the reflected pulses, fig. 10.

In addition to DC light source noise, there is some reflection of the infrared emitted light off the surfaces which surround the VCNL4000. The distance to the cover, proximity of surrounding components, the tolerances of the sensor, the defined IRED current, the ambient temperature, and the type of material used all contribute to this reflection. The result of the reflection and DC noise yields a total offset count.

In addition to the offset, there is also a small noise floor during the proximity measurement which comes from the dc light suppression circuitry. This noise is in the range from ± 5 counts to ± 20 counts.

The application should “ignore” this offset as well the small noise floor and focus on the reflected pulses by subtracting them from the proximity readings.

The customer defines the detection algorithm used with the VCNL4000. As an example, an averaging routine will be used to demonstrate these calculations. The flowchart for determining the average offset level is shown in fig. 12.
The VCNL4000 Demo Kit has an "Offset Compensation" function. If a plastic material which blocks 10 % of the infrared light is used to cover the sensor, the kit will display the proximity reading, fig. 13. This material can be used to represent a dirty, scratched surface and is more representative of the consumer applications in which the VCNL4000 will be used.

The upper graph shows the full 16-bit response range while the lower graph shows the peak to peak range of the offset plus noise level. The offset plus noise has a range of just 19 counts from a minimum of 10 200 to a maximum of 10 219 counts. The offset count is high because of the extra layer of less infrared-transparent material. However, this has no effect on the proximity measurement. Using the kit’s "Offset Compensation" function, the offset value of 10 219 counts will be subtracted from the reflected signal count to yield the proximity count.

In the second example, the ambient lighting conditions have changed slightly, resulting in a slightly higher offset level. Again, using the software that is included with the evaluation kit, the output of the sensor with an object present is shown in fig. 14. The upper graph shows the full 16-bit response range while the lower graph shows the peak to peak range. The maximum of the offset plus noise is 10 248 counts. This is the value that must be subtracted from the reflected signal count for proper response.

With an object at a distance of 10 cm, proximity measurement 510 in fig. 14, the difference between the maximum offset plus noise value (blue line) and the reflected signal is only 12 counts. Given a threshold of T = 20 counts, this is not enough to result in a proximity detection. The chosen threshold has been set due to the existing noise floor to achieve a reliable proximity signal.

If the average value of the offset plus noise, 10 239 counts (green line), is used, the proximity count is 21 counts and would result in detection. At 5 cm distance, the difference between the maximum offset plus noise level and the reflected signal is 37 counts. The object would be detected at 5 cm.

The effective range of VCNL4000 is from 1 mm to 20 cm. With the second layer of less transparent material, the operating range is reduced. Because the evaluation kit’s software will always calculate the offset plus noise level and subtract it from the actual counts, the proximity sensor will work well in all lighting conditions, and with any transparent cover. This is true for the customer's application as well.

The flowchart for the proximity sensing using an average value algorithm including initialization and offset plus noise routine is shown in fig. 15. The VCNL4000 provides the proximity counts, the customer’s application processes the counts to determine if a proximity event has occurred.
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Fig. 15 - Flowchart for Proximity Sensing
Using a Kodak grey card which has 18 % reflectivity at varying distances yields the digital output counts in the graph shown below for infrared emitter currents of 20 mA, 100 mA, and 200 mA without a cover.

![Proximity Values vs. Distance](image)

**Proximity Current Consumption**

The standby current of the VCNL4000 is 1.5 μA. In this mode, only the I²C interface is active. In most consumer electronic applications the sensor will spend the majority of time in standby mode. For proximity sensing, the current consumption of the VCNL4000 is primarily a function of the infrared emitter current and, secondarily, signal processing done by the ASIC. Sample current consumption calculations are shown below for a range of IRED current and measurement rates. The current between burst pulse frames is equivalent to the standby mode. The duty cycle of the emitter is 50 %.

<table>
<thead>
<tr>
<th>Measurement Rate</th>
<th>Emitter Current</th>
<th>ASIC Current</th>
<th>Total Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 measurement per second, emitter current = 100 mA</td>
<td>ASIC: 2.5 mA x 170 μs/1 s x 10 = 4.25 μA</td>
<td>IRED: 100 mA x 140 μs/1 s x 0.5 x 10 = 70.00 μA</td>
<td>74.25 μA</td>
</tr>
<tr>
<td>250 measurement per second, emitter current = 200 mA</td>
<td>ASIC: 2.5 mA x 170 μs/1 s x 250 = 106.25 μA</td>
<td>IRED: 200 mA x 140 μs/1 s x 0.5 x 250 = 3.50 mA</td>
<td>3.61 mA</td>
</tr>
</tbody>
</table>

**Initialization and I²C Timings**

The VCNL4000 contains twelve 8-bit registers for operation control, parameter setup and result buffering. All registers are accessible via I²C communication. Fig. 24 shows the basic I²C communication with VCNL4000.

The built in I²C interface is compatible with all I²C modes: standard, fast and high speed. I²C H-Level voltage range is from 1.7 V to 5.0 V.

Please see also chapter “Register Functions” on page 10.

The following provides the timing related to taking a single proximity reading using an I²C bus operating at a standard speed of 100 kHz. At this speed, an 8-bit write or read command which includes the slave address, register, data, start, stop and acknowledge bits takes 100 μs.

When the device is turned on, the VCNL4000 is powered on and initialized. Each write to a register requires 3 bytes or 300 μs.

**Power Up of VCNL4000**

- release of reset, start oscillator and signal processor: 2.5 ms
- Initialize VCNL4000

- Write to 3 registers: 900 μs
- IR LED current
- Proximity measurement signal frequency
- Proximity modulator timing adjustment

Once the device is powered on and the device initialized, a proximity measurement can be taken. Before the first read out of the proximity count, a wait time is required. Subsequent reads do not require this wait time.

- Start measurement: 300 μs
- Measurement being made: 170 μs
- Wait time prior to first read: 400 μs
- Read out of the proximity data: 600 μs

Total: 1470 μs

Using the averaging example in the flow chart above, taking 10 readings to establish the noise plus offset and 10 proximity readings, would result in a total time of 14.7 ms.

**Ambient Light Sensing**

Ambient light sensors are used to detect light or brightness in a manner similar to the human eye. They allow settings to be adjusted automatically in response to changing ambient light conditions. By turning on, turning off, or adjusting features, ambient light sensors can conserve battery power or provide extra safety while eliminating the need for manual adjustments.

Illuminance is the measure of the intensity of light incident on a surface and can be correlated to the brightness perceived by the human eye. In the visible range, it is measured in units called “lux.” Light sources with the same lux measurement appear to be equally bright. In fig. 17, the incandescent light and sunlight have been scaled to have the same lux measurement. In the infrared region, the intensity of the incandescent light is significantly higher. A standard silicon photodiode is much more sensitive to infrared light than visible light. Using it to measure ambient light will result in serious deviations between the lux measurements of different light sources and human-eye
Designing VCNL4000 into an Application

perception. Using Vishay’s ambient light sensors will solve this problem because they are most sensitive to the visible part of the spectrum.

The human eye can see light with wavelengths from 380 nm to 780 nm. The Ambient Light Sensor closely matches this range of sensitivity and provides a digital output based on a 16 bit signal.

**AMBIENT LIGHT MEASUREMENT RESOLUTION AND OFFSET**

The 16-bit digital resolution is equivalent to 65 536 counts. The ambient light sensors measurement resolution is 0.25 lux/count. This results to a measurement range from 0.25 lux to 16 383 lux with cover transparency of 100 %.

There is a general digital offset deviation of - 3 counts which has to be considered when setting up the application thresholds. This deviation comes from tolerances within the digital compensation process. Especially for low counts below less transparent cover these 3 counts should be added to the actual ambient light value and then the typically dividing factor of (averaged) 4 lead to the actual corresponding lux value.

**AMBIENT LIGHT SENSOR CURRENT CONSUMPTION**

The ambient light sensor can operate in single or continuous mode. In single mode operation, an ambient light measurement consists of up to 128 individual measurement cycles which are averaged. The timing diagram for a single measurement is shown in fig. 20.

In single-mode operation, an ambient light measurement takes 100 ms. The single measurement cycles are evenly spread inside this 100 ms frame. fig. 21 shows an example where 8 single measurement cycles are averaged. The maximum number of single measurement cycles that can be used to calculate an average is 128. The maximum number of times this average can be calculated in one second is 10.
A high number of averaging measurement cycles helps to reduce the influence of the frequency modulation of artificial lights.

During one measurement cycle, the ASIC consumes approximately 2.7 mA. Between the single measurements, the current consumption is 9 μA. Sample current consumption calculations are shown below.

**Current Calculations for Ambient Light Measurements:**

1. **1 measurement per second, AVG = 32**
   
   \[ \text{Current Calculation} = 2.7 \text{ mA} \times \frac{450 \mu\text{s}}{1 \text{ s}} \times 32 = 39 \mu\text{A} \]

2. **10 measurement per second, AVG = 128**
   
   \[ \text{Current Calculation} = 2.7 \text{ mA} \times \frac{450 \mu\text{s}}{1 \text{ s}} \times 128 \times 10 = 1.55 \text{ mA} \]

The current consumption for the ambient light sensor is strongly dependent on the number of measurements taken. In single-mode operation, the highest average current is 1.55 mA. Increasing the number of average measurements can further improve the reading at the expense of a higher current consumption, see “Current Calculations for Ambient Light Measurements” above.

**Fig. 21 - Ambient Light Noise vs. Averaging**

In continuous conversion mode, the ambient light sensor measurement time can be reduced. A timing example of continuous mode where 8 measurements are averaged is shown in the following fig. 23.

**Fig. 22 - Ambient Light Measurement with Averaging = 8 Using Continuous Conversion Mode**

The single measurements are done sequentially. One measurement cycle, including offset compensation, takes approximately 450 μs. The gap time is 180 μs. In the shown example the result is already accessible after about 6 ms. However, fluorescent light suppression is less effective in this mode.
Send byte
Write command to VCNL4000

S Slave address  Wr A Register address  A Data byte A P

Receive byte
Read data from VCNL4000

S Slave address  Wr A Register address A P

S Slave address  Rd A Data byte A P

S = start condition
P = stop condition
A = acknowledge

Please refer to the I²C specification from NXP for details.

Register #0 Command Register
Register address = 80h
The register #0 is for starting ambient light or proximity measurements. This register contains 2 flag bits for data ready indication.

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Config lock</td>
<td>als data rdy</td>
<td>Prox. data rdy</td>
<td>als od</td>
<td>Prox. od</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Description
- **Config lock**: Read only bit. Value = 1
- **als data rdy**: Read only bit. Value = 1 when ambient light measurement data is available in the result registers. This bit will be reset when one of the corresponding result registers (reg #5, reg #6) is read.
- **Prox. data rdy**: Read only bit. Value = 1 when proximity measurement data is available in the result registers. This bit will be reset when one of the corresponding result registers (reg #7, reg #8) is read.
- **als od**: R/W bit. Starts a single on-demand measurement for ambient light. If averaging is enabled, starts a sequence of readings and stores the averaged result. Result is available at the end of conversion for reading in the registers #5 (HB) and #6 (LB).
- **Prox. od**: R/W bit. Starts a single on-demand measurement for proximity. Result is available at the end of conversion for reading in the registers #7 (HB) and #8 (LB).

With setting bit 3 and bit 4 at the same write command, a simultaneously measurement of ambient light and proximity is done.

Register #1 Product ID Revision Register
Register address = 81h. This register contains information about product ID and product revision.
Register data value of current revision = 11h.

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product ID</td>
<td>Revision ID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Description
- **Product ID**: Read only bits. Value = 1
- **Revision ID**: Read only bits. Value = 1

Register #2 without Function in Current Version
Register address = 82h.
Register #3 LED Current Setting for Proximity Mode
Register address = 83h. This register is to set the LED current value for proximity measurement. The value is adjustable in steps of 10 mA from 0 mA to 200 mA. This register also contains information about the used device fuse program ID.

<table>
<thead>
<tr>
<th>TABLE 3 - IR LED CURRENT REGISTER #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Fuse prog ID</td>
</tr>
</tbody>
</table>

**Description**
- Fuse prog ID: Read only bits. Information about fuse program revision used for initial setup/calibration of the device.
- IR LED current value: R/W bits. IR LED current = Value (dec.) x 10 mA. Valid Range = 0 to 20d. e.g.: 0 = 0 mA, 1 = 10 mA, ..., 20 = 200 mA (2 = 20 mA = DEFAULT). LED current is limited to 200 mA for values higher as 20d.

Register #4 Ambient Light Parameter Register
Register address = 84h.

<table>
<thead>
<tr>
<th>TABLE 4 - AMBIENT LIGHT PARAMETER REGISTER #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Cont. conv. mode</td>
</tr>
</tbody>
</table>

**Description**
- Bit 7: Cont. conversion mode. R/W bit. Continuous conversion mode. Enable = 1; Disable = 0 = DEFAULT. This function can be used for performing faster ambient light measurements.
- Bit 3: Auto offset compensation. R/W bit. Automatic offset compensation. Enable = 1 = DEFAULT; Disable = 0. In order to compensate a technology, package or temperature related drift of the ambient light values there is a built in automatic offset compensation function. With active auto offset compensation the offset value is measured before each ambient light measurement and subtracted automatically from actual reading.
- Bit 0 to bit 2: Averaging function. R/W bits. Averaging function. Bit values sets the number of single conversions done during one measurement cycle. Result is the average value of all conversions. Number of conversions = 2^decimal_value e.g. 0 = 1 conv., 1 = 2 conv, 2 = 4 conv., ..., 7 = 128 conv. DEFAULT = 32 conv.

Register #5 and #6 Ambient Light Result Register
Register address = 85h and 86h. These registers are the result registers for ambient light measurement readings. The result is a 16 bit value. The high byte is stored in register #5 and the low byte in register #6.

<table>
<thead>
<tr>
<th>TABLE 5 - AMBIENT LIGHT RESULT REGISTER #5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Description</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 6 - AMBIENT LIGHT RESULT REGISTER #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Description</td>
</tr>
</tbody>
</table>

For technical questions, contact: sensorstechsupport@vishay.com

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Register #7 and #8 Proximity Measurement Result Register
Register address = 87h and 88h. These registers are the result registers for proximity measurement readings. The result is a 16 bit value. The high byte is stored in register #7 and the low byte in register #8.

<table>
<thead>
<tr>
<th>TABLE 7 - PROXIMITY MEASUREMENT RESULT REGISTER #7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Read only bits. High byte (15:8) of proximity measurement result</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 8 - PROXIMITY MEASUREMENT RESULT REGISTER #8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Read only bits. Low byte (7:0) of proximity measurement result</td>
</tr>
</tbody>
</table>

Register #9 Proximity Measurement Signal Frequency
Register address = 89h.

<table>
<thead>
<tr>
<th>TABLE 9 - PROXIMITY MEASUREMENT SIGNAL FREQUENCY REGISTER #9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>R/W bits. Setting the proximity IR test signal frequency. The proximity measurement is using a square IR signal as measurement signal. Four different values are possible:</td>
</tr>
<tr>
<td>00 = 3.125 MHz</td>
</tr>
<tr>
<td>01 = 1.5625 MHz</td>
</tr>
<tr>
<td>02 = 781.25 kHz (DEFAULT)</td>
</tr>
<tr>
<td>03 = 390.625 kHz</td>
</tr>
</tbody>
</table>

Register #10 Proximity Modulator Timing Adjustment
Register address = 8Ah.

<table>
<thead>
<tr>
<th>TABLE 10 - PROXIMITY MODULATOR TIMING ADJUSTMENT REGISTER #10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit 7</td>
</tr>
<tr>
<td>Modulation delay time</td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Modulation delay time</td>
</tr>
<tr>
<td>R/W bits. Setting a delay time between IR LED signal and IR input signal evaluation. This function is for compensation of delays from IR LED and IR photo diode. Also in respect to the possibility for setting different proximity signal frequency. Correct adjustment is optimizing measurement signal level.</td>
</tr>
<tr>
<td>Modulation dead time</td>
</tr>
<tr>
<td>R/W bits. Setting a dead time in evaluation of IR signal at the slopes of the IR signal. This function is for reducing of possible disturbance effects. This function is reducing signal level and should be used carefully.</td>
</tr>
</tbody>
</table>

Note
• The settings for best performance will be provided by Vishay. With first samples this is evaluated to: delay time = 4 and dead time = 1, with that register #10 should be programmed with: 129 (dez.)

Register #11 Ambient IR Light Level Register
Register address = 8Bh. This register is not intended to be used by customer.