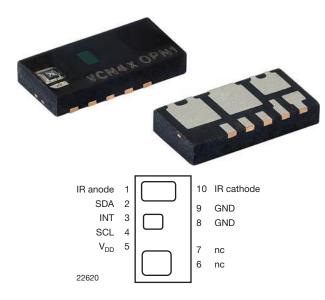
Fully Integrated Proximity and Ambient Light Sensor With Infrared Emitter, I²C Interface, and Interrupt Function



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DESCRIPTION

The VCNL4020X01 is a fully integrated proximity and ambient light sensor. Fully integrated means that the infrared emitter is included in the package. It has 16 bit resolution. It includes a signal processing IC and features standard I^2C communication interface. It features an interrupt function.

APPLICATIONS

- Proximity sensor for:
 - **Mobile devices** (e.g. smart phones, touch phones, PDAs, GPS) for touch screen locking, power saving etc.
 - Automotive for presence detection
- Integrated ambient light function for display / keypad contrast control and dimming of mobile devices
- Rear view mirror dimming in automotive
- Proximity / optical switch for consumer, computing, automotive and industrial devices, and displays (like notebooks, tablet PCs, and automotive touch panels)
- Dimming control for consumer, computing, industrial, and automotive displays

FEATURES

- Package type: surface-mount
- Dimensions (L x W x H in mm): 4.90 x 2.40 x 0.83
- AEC-Q101 qualified
- Integrated modules: infrared emitter (IRED), ambient light sensor (ALS-PD), proximity sensor (PD), and signal conditioning IC
- e4 RoHS

COMPLIANT HALOGEN FREE GREEN

(5-2008)

- Interrupt function
- Supply voltage range V_{DD}: 2.5 V to 3.6 V
- Supply voltage range IR anode: 2.5 V to 5 V
- Communication via I²C interface
- I²C bus H-level range: 1.7 V to 5 V
- Floor life: 168 h, MSL 3, according to J-STD-020
- Low stand by current consumption: 1.5 μA
- Material categorization: for definitions of compliance please see <u>www.vishay.com/doc?99912</u>

PROXIMITY FUNCTION

- Built-in infrared emitter and photo-pin-diode for proximity function
- 16 bit effective resolution for proximity detection range ensures excellent cross talk immunity
- Programmable LED drive current from 10 mA to 200 mA in 10 mA steps
- Excellent ambient light suppression by signal modulation
- Proximity distance up to 200 mm

AMBIENT LIGHT FUNCTION

- Built-in ambient light photo-pin-diode with close-tohuman-eye sensitivity
- 16 bit dynamic range from 0.25 lx to 16 klx
- 100 Hz and 120 Hz flicker noise rejection

PRODUCT S	PRODUCT SUMMARY											
PART NUMBER	OPERATING RANGE (mm)	OPERATING VOLTAGE RANGE (V)	I ² C BUS VOLTAGE RANGE (V)	LED PULSE CURRENT ⁽¹⁾ (mA)	AMBIENT LIGHT RANGE (lx)	AMBIENT LIGHT RESOLUTION (Ix)	OUTPUT CODE	ADC RESOLUTION PROXIMITY / AMBIENT LIGHT				
VCNL4020X01	1 to 200	2.5 to 3.6	1.7 to 5	10 to 200	0.25 to 16 383	0.25	16 bit, l ² C	16 bit / 16 bit				

Note

⁽¹⁾ Adjustable through I²C interface

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ORDERING CODE	PACKAGING	VOLUME ⁽¹⁾	REMARKS
VCNL4020X01-GS08	Tapa and real	MOQ: 3300 pcs	4.90 mm x 2.40 mm x 0.83 mm
VCNL4020X01-GS18	Tape and reel	MOQ: 13 000 pcs	4.50 11111 X 2.40 11111 X 0.83 11111

Note

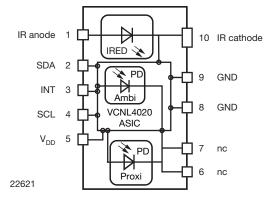
⁽¹⁾ MOQ: minimum order quantity

ABSOLUTE MAXIMUM RATINGS (T _{amb} = 25 °C, unless otherwise specified)										
PARAMETER	TEST CONDITION	SYMBOL	MIN.	MAX.	UNIT					
Supply voltage		V _{DD}	-0.3	5.5	V					
Operation temperature range		T _{amb}	-40	+105	°C					
Storage temperature range		T _{stg}	-40	+105	°C					
Total power dissipation	T _{amb} ≤ 25 °C	P _{tot}		50	mW					
Junction temperature		Tj		105	°C					

PARAMETER	TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Supply voltage V _{DD}			2.5		3.6	V
Supply voltage IR anode			2.5		5	V
I ² C Bus H-level range			1.7		5	V
INT H-level range			1.7		5	V
INT low voltage	3 mA sink current				0.4	V
Current consumption	Standby current, no IRED-operation			1.5	2	μA
Current consumption proximity mode incl. IRED (averaged)	2 measurements per second, IRED current 20 mA			5		μA
	250 measurements per second, IRED current 20 mA			520		μA
	2 measurements per second, IRED current 200 mA			35		μA
	250 measurements per second, IRED current 200 mA			4		mA
	2 measurements per second averaging = 1			2.5		μA
Current consumption ambient	8 measurements per second averaging = 1			10		μA
light mode	2 measurements per second averaging = 64			160		μA
	8 measurements per second averaging = 64			640		μA
Ambient light resolution	Digital resolution (LSB count)			0.25		lx
Ambient light output	E _V = 100 lx averaging = 64			400		counts
I ² C clock rate range		f _{SCL}			3400	kHz

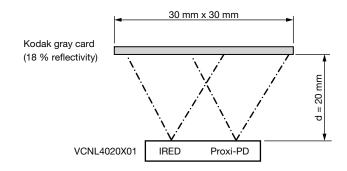


CIRCUIT BLOCK DIAGRAM



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TEST CIRCUIT



Note

nc must not be electrically connected Pads 6 and 7 are only considered as solder pads

BASIC CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

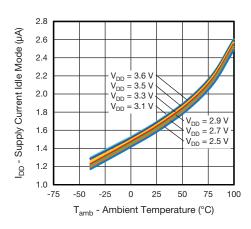


Fig. 1 - Idle Current vs. Ambient Temperature

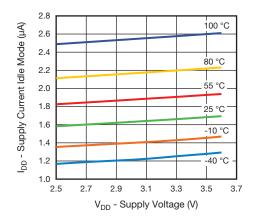


Fig. 2 - Idle Current vs. V_{DD}

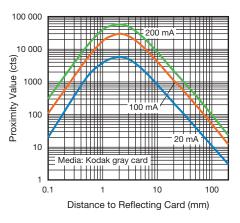


Fig. 3 - Proximity Value vs. Distance

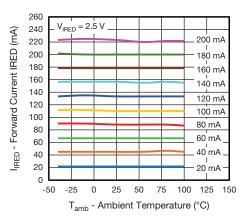


Fig. 4 - Forward Current vs. Temperature

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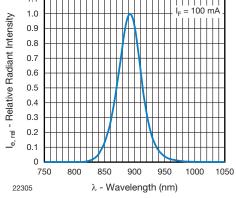


Fig. 5 - Relative Radiant Intensity vs. Wavelength

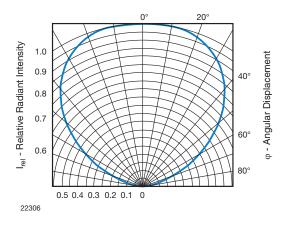


Fig. 6 - Relative Radiant Intensity vs. Angular Displacement

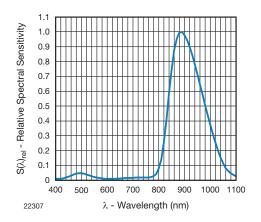


Fig. 7 - Relative Spectral Sensitivity vs. Wavelength (Proximity Sensor)

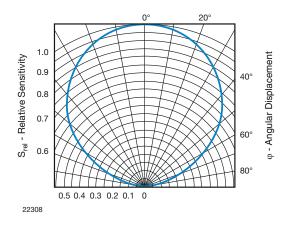


Fig. 8 - Relative Radiant Sensitivity vs. Angular Displacement (Proximity Sensor)

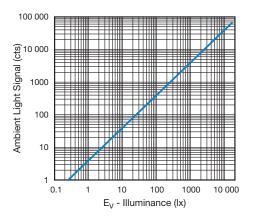


Fig. 9 - Ambient Light Value vs. Illuminance

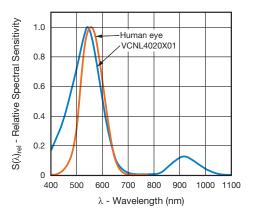


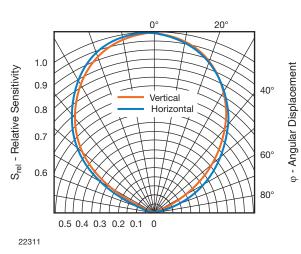
Fig. 10 - Relative Spectral Sensitivity vs. Wavelength (Ambient Light Sensor)

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Document Number: 84177

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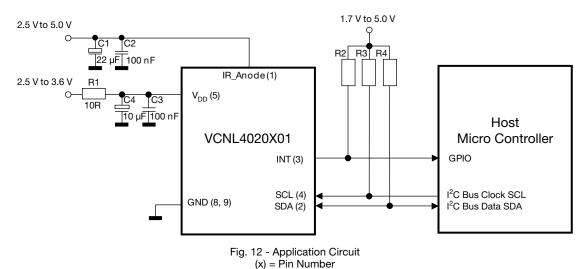
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Fig. 11 - Relative Radiant Sensitivity vs. Angular Displacement (Ambient Light Sensor)

APPLICATION INFORMATION

VCNL4020X01 is a cost effective solution of proximity and ambient light sensor with I²C bus interface. The standard serial digital interface is easy to access "Proximity Signal" and "Light Intensity" without complex calculation and programming by external controller. Beside the digital output also a flexible programmable interrupt pin is available.

1. Application Circuit



Notes

The interrupt pin is an open drain output. The needed pull-up resistor may be connected to the same supply voltage as the application controller and the pull-up resistors at SDA/SCL. Proposed value R2 should be >1 kΩ, e.g. 10 kΩ to 100 kΩ. Proposed value for R3 and R4, e.g. 2.2 kΩ to 4.7 kΩ, depend also on the I²C bus speed.

For detailed description about set-up and use of the interrupt as well as more application related information see AN: "Designing VCNL4020 into an Application".

• IR_Cathode needs no external connection. The needed connection to the driver is done internally.



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2. I²C Interface

The VCNL4020X01 contains seventeen 8 bit registers for operation control, parameter setup and result buffering. All registers are accessible via I²C communication. Figure 13 shows the basic I²C communication with VCNL4020X01.

The built in I²C interface is compatible with all I²C modes (standard, fast and high speed).

 I^2C H-level range = 1.7 V to 5 V.

Please refer to the I²C specification from NXP for details.

Sen	Send byte Write command to VCNL4020X01							
s	Slave address	Wr	А	Register address	А			

Receive byte Read data from VCNL4020X01



VCNL4020X01 response

Fig. 13 - Send Byte/Receive Byte Protocol

Device Address

The VCNL4020X01 has a fix slave address for the host programming and accessing selection. The predefined 7 bit l^2 C bus address is set to 0010 011 = 13h. The least significant bit (LSB) defines read or write mode. Accordingly the bus address is set to 0010 011x = 26h for write, 27h for read.

A = acknowledge

Register Addresses

Data byte

VCNL4020X01 has seventeen user accessible 8 bit registers. The register addresses are 80h (register #0) to 90h (register #16).

Р

REGISTER FUNCTIONS

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.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
config_lock	als_data_rdy	prox_data_rdy	als_od	prox_od	als_en	prox_en	selftimed_en
			Descr	iption			•
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_c	lata_rdy	a_rdy Read only bit. Value = 1 when proximity measurement data is available in the result registers. This bit w be reset when one of the corresponding result registers (reg #7, reg #8) is read.					
als	s_od	sequence of rea	a single on-demar dings and stores gisters #5(HB) an	nd measurement for the averaged resu d #6(LB).	or ambient light. If It. Result is availa	averaging is enable at the end of	bled, starts a conversion for
pro	x_od		0	nd measurement for nead		s #7(HB) and #8(LB).
als	s_en	R/W bit. Enables	s periodic als mea	asurement			
pro	x_en	R/W bit. Enables	s periodic proximi	ty measurement			
selftimed_en R/W bit. Enables state machine and LP oscillator for self timed measurements; no measurement performed until the corresponding bit is set						asurement is	

Note

With setting bit 3 and bit 4 at the same write command, a simultaneously measurement of ambient light and proximity is done. Beside als_en and/or prox_en first selftimed_en needs to be set. On-demand measurement modes are disabled if selftimed_en bit is set. For the selftimed_en mode changes in reading rates (reg #4 and reg #2) can be made only when b0 (selftimed_en bit) = 0. For the als_od mode changes to the reg #4 can be made only when b4 (als_od bit) = 0; this is to avoid synchronization problems and undefined states between the clock domains. In effect this means that it is only reasonable to change rates while no selftimed conversion is ongoing.



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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 = 21h.

TABLE 2 -	TABLE 2 - PRODUCT ID REVISION REGISTER #1										
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0				
	Prod	uct ID		Revision ID							
			Descr	iption							
Prod	uct ID	Read only bits.	Value = 2								
Revis	ion ID	Read only bits. Value = 1									

Register #2 Rate of Proximity Measurement

Register address = 82h.

TABLE 3 - PROXIMITY RATE REGISTER #2											
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0				
		n/a			Rate of Proximity Measurement (no. of measurements per second)						
			Descr	ription							
Proxir	nity rate	R/W bits. 000 - 1.95 meas 001 - 3.90625 m 010 - 7.8125 meas 101 - 16.625 meas 100 - 31.25 meas 101 - 62.5 meas 110 - 125 meas 111 - 250 meas	easurements/s easurements/s asurements/s surements/s urements/s	AULT)							

Note

• If self_timed measurement is running, any new value written in this register will not be taken over until the mode is actualy cycled.

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 4 -	TABLE 4 - IR LED CURRENT REGISTER #3										
Bit 7	Bit 6	Bit 5 Bit 4 Bit 3 Bit 2 Bit 1 Bit 0									
Fuse prog ID IR LED current value											
Description											
Fuse p	Fuse prog ID Read only bits. Information about fuse program revision used for initial setup/calibration of the device.										
IR LED cu	IR LED current valueR/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.

Bit 7	AMBIENT LI Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Cont. conv. mode	Bit 0	als_rate	Dit 4	Auto offset compensation		Averaging functio	n
			Desc	ription	-		
R/W bit. Continuous conversion mode. Enable = 1; Disable = 0 = DEFAULT This function can be used for performing faster ambient light measurements. This mode shou used with ambient light on-demand measurements. Do not use with self-timed mode. Please r application information chapter 3.3 for details about this function. R/W bits. Ambient light measurement rate							
Ambient light m	easurement rate	000 - 1 sample	s/s s/s = DEFAULT s/s s/s s/s s/s s/s s/s	ment rate			
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 there is a built in automatic offset compensation function. With active auto offset compensation the offset value is measured before each ambient lig measurement and subtracted automatically from actual reading.						Ū	
Averaging function R/W bits. Averaging function. Bit values sets the number of single conversions done during one measurement cycle. Result is 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. (bit 2 to bit 0: 101)							

Note

• If self_timed measurement is running, any new value written in this register will not be taken over until the mode is actually cycled.

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 6 - AMBIENT LIGHT RESULT REGISTER #5									
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0		
Description									
Read only bits. High byte (15:8) of ambient light measurement result									

TABLE 7 - AMBIENT LIGHT RESULT REGISTER #6										
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0			
	Description									
Read only bits. Low byte (7:0) of ambient light measurement result										



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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 8 - PROXIMITY RESULT REGISTER #7											
Bit 7	Bit 7 Bit 6 Bit 5 Bit 4 Bit 3 Bit 2 Bit 1 Bit 0										
	Description										
	Read only bits. High byte (15:8) of proximity measurement result										

TABLE 9 - PROXIMITY RESULT REGISTER #8											
Bit 7	Bit 7 Bit 6 Bit 5 Bit 4 Bit 3 Bit 2 Bit 1 Bit 0										
	Description										
	Read only bits. Low byte (7:0) of proximity measurement result										

Register #9 Interrupt Control Register

Register address = 89h.

ABLE 10	- INTERRUP	CONTROL	REGISTER #	9			
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Int count exceed		n/a	INT_PROX_ ready_EN	INT_ALS_ ready_EN	INT_THRES_EN	INT_THRES SEL	
			Desci	ription			
R/W bits. These bits contain the threshold 000 - 1 count = DEFAULT 001 - 2 count 010 - 4 count 011 - 8 count 100 -16 count 101 - 32 count 110 - 64 count 111 - 128 count				number of consec	utive measuremen	nts needed above/	below the
INT_PROX	_ready_EN	R/W bit. Enable	s interrupt genera	tion at proximity c	lata ready		
INT_ALS_	ready_EN	R/W bit. Enable	s interrupt genera	tion at ambient da	ata ready		
INT_TH	RES_EN	R/W bit. Enable	s interrupt genera	tion when high or	low threshold is e	exceeded	
INT_THF	RES_SEL		resholds are applie are applied to als	ed to proximity me measurements	easurements		



Register #10 and #11 Low Threshold

Register address = 8Ah and 8Bh. These registers contain the low threshold value. The value is a 16 bit word. The high byte is stored in register #10 and the low byte in register #11.

TABLE 11	TABLE 11 - LOW THRESHOLD REGISTER #10											
Bit 7	Bit 7 Bit 6 Bit 5 Bit 4 Bit 3 Bit 2 Bit 1 Bit 0											
	Description											
	R/W bits. High byte (15:8) of low threshold value											

TABLE 12 - LOW THRESHOLD REGISTER #11											
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0				
	Description										
	R/W bits. Low byte (7:0) of low threshold value										

Register #12 and #13 High Threshold

Register address = 8Ch and 8Dh. These registers contain the high threshold value. The value is a 16 bit word. The high byte is stored in register #12 and the low byte in register #13.

TABLE 13	TABLE 13 - HIGH THRESHOLD REGISTER #12										
Bit 7	Bit 7 Bit 6 Bit 5 Bit 4 Bit 3 Bit 2 Bit 1 Bit 0										
	Description										
	R/W bits. High byte (15:8) of high threshold value										

TABLE 14 - HIGH THRESHOLD REGISTER #13											
Bit 7	Bit 7 Bit 6 Bit 5 Bit 4 Bit 3 Bit 2 Bit 1 Bit 0										
	Description										
	R/W bits. Low byte (7:0) of high threshold value										

Register #14 Interrupt Status Register

Register address = 8Eh. This register contains information about the interrupt status for either proximity or ALS function and indicates if high or low going threshold exceeded.

TABLE 15	TABLE 15 - INTERRUPT STATUS REGISTER #14											
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0					
	n,	/a		int_prox_ready	int_als_ready	int_th_low	int_th_hi					
	Description											
int_pro:	x_ready	R/W bit. Indicat	es a generated in	terrupt for proximi	ty							
int_als	_ready	R/W bit. Indicat	es a generated in	terrupt for als								
int_th_low R/W bit. Indicates a low threshold				d exceed								
int_t	th_hi	R/W bit. Indicates a high threshold exceed										

Note

• Once an interrupt is generated the corresponding status bit goes to 1 and stays there unless it is cleared by writing a 1 in the corresponding bit. The int pad will be pulled down while at least one of the status bit is 1.



Register #15 Proximity Modulator Timing Adjustment

Register address = 8Fh.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Modulation delay time			Proximity	frequency	М	odulation dead tir	ne
			Desc	ription			
Modulation delay time 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 measurem signal level. (DEFAULT = 0)							
Proximit	y frequency		neasurement is us Hz (DEFAULT) z Hz	R test signal freque ing a square IR sig		ent signal. Four di	iferent values a
Modulation dead time R/W bits. Setting a dead time in evaluation of IR signal at the slopes of the IR signal. (DEFAUL Modulation dead time This function is for reducing of possible disturbance effects. This function is reducing signal level and should be used carefully.						DEFAULT = 1)	

Note

• The settings for best performance will be provided by Vishay. With first samples this is evaluated to:

Delay Time = 0; Dead Time = 1 and Prox Frequency = 0. With that register#15 should be programmed with 1 (= default value).

Register #16 Ambient IR Light Level Register

Register address = 90h.

This register is not intended to be used by customer.

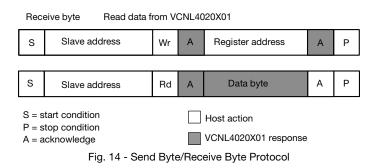
3. IMPORTANT APPLICATION HINTS AND EXAMPLES

3.1 Receiver standby mode

In standby mode the receiver has the lowest current consumption of about 1.5 μ A. In this mode only the I²C interface is active. This is always valid, when there are no measurement demands for proximity and ambient light executed. Also the current sink for the IR-LED is inactive, so there is no need for changing register #3 (IR LED current).

3.2 Data Read

In order to get a certain register value, the register has to be addressed without data like shown in the following scheme. After this register addressing, the data from the addressed register is written after a subsequent read command.



The stop condition between these write and read sequences is not mandatory. It works also with a repeated start condition.

Note

For reading out 2 (or more) subsequent registers like the result registers, it is not necessary to address each of the registers separately. After
one read command the internal register counter is increased automatically and any subsequent read command is accessing the next
register.

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Example: read register "Ambient Light Result Register" #5 and #6:

- Addressing: command: 26h, 85h (VCNL4020X01_I²C_Bus_Write_Adr., Ambient Light Result Register #5 [85])
- Read register #5: command: 27h, data (VCNL4020X01_I²C_Bus_Read_Adr., {High Byte Data of Ambient Light Result register #5 [85])}
- Read register #6: command: 27h, data (VCNL4020X01_I²C_Bus_Read_Adr., {Low Byte Data of Ambient Light Result register #6 [86])}

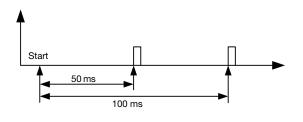
3.3 Continuous Conversion Mode in Ambient Light Measurement

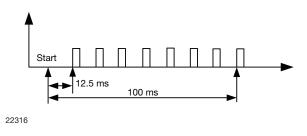
In the following is a detail description of the function "continuous conversion" (bit 7 of register #4)

Standard mode (bit 7 of reg #4 = 0):

In standard mode the ambient light measurement is done during a fixed time frame of 100 ms. The single measurement itself takes actually only appr. 300 µs.

The following figures show examples of this measurement timing in standard mode using averaging function 2 and 8 as examples for illustration (possible values up to 128).





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Fig. 15 - Ambient Light Measurement with Averaging = 2; Final Measurement Result = Average of these 2 Measurements Fig. 16 - Ambient Light Measurement with Averaging = 8; Final Measurement Result = Average of these 8 Measurements

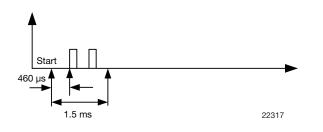
Note

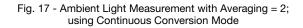
• \geq Independent of setting of averaging the result is available only after 100 ms.

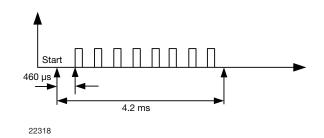
Continuous conversion mode (bit 7 of register #4 = 1):

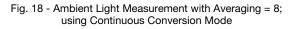
In continuous conversion mode the single measurements are done directly subsequent after each other.

See following examples in figure 17 and 18











0.685

0.65

0.78

0.15

0.69

2

Drawing-No.: 6.550-5319

PACKAGE DIMENSIONS in millimeters

0.73

2.03

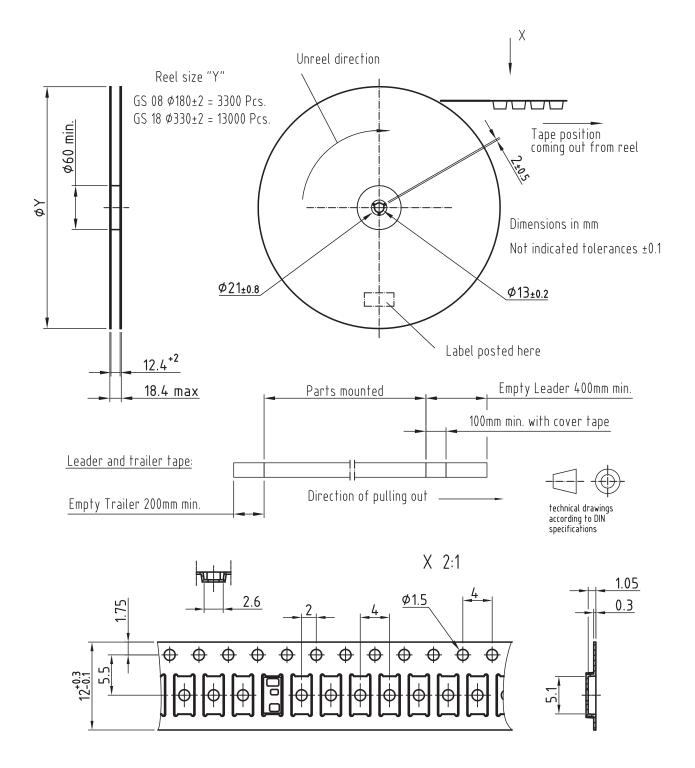
1.49

Pinning Bottom view 4x0.685=2.74 Emitter Anode SDA 0 SCL F 55 0.3 C Cathode PD Cathode Emitter VSS 0.24 0.95 0.98 Pinning Top view .62 1 Cathode PD Cathode Emitter technical drawings /SS according to DIN specifications Γ٦ ٢٦ 0.83 VDD Anode Emitter SDA Ł SCL 4.15 Proposed PCB Footprint (4.9)1.75 0.4 1.1 0.83 0.25 0.4 0.37 0.28 ω Ö 4 S N <u>_</u> C (2.4) Ö 4.9 2 C ω 0.45 0.4 o. 4x 0.685=2.74 Not indicated tolerances ± 0.1

13



TAPE AND REEL DIMENSIONS in millimeters

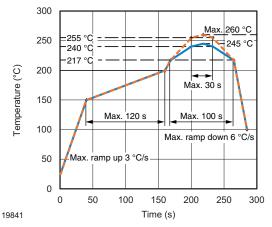


Drawing-No.: 9.700-5387.01-4

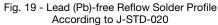
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SOLDER PROFILE



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DRYPACK

Devices are packed in moisture barrier bags (MBB) to prevent the products from moisture absorption during transportation and storage. Each bag contains a desiccant.

FLOOR LIFE

Floor life (time between soldering and removing from MBB) must not exceed the time indicated on MBB label:

Floor life: 168 h

Conditions: $T_{amb} < 30\ ^\circ C,\ RH < 60\ \%$

Moisture sensitivity level 3, according to J-STD-020.

DRYING

In case of moisture absorption devices should be baked before soldering. Conditions see J-STD-020 or label. Devices taped on reel dry using recommended conditions 192 h at 40 °C (+ 5 °C), RH < 5 %.



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