OPT4001 High Speed, High Precision, Digital Ambient Light Sensor

1 Features

- High precision, high speed light-to-digital conversion over high speed I^{2}C interface in two package variants
- Precision optical filtering to closely match human eye with excellent near infrared (IR) rejection
- Semi-logarithmic output with 9 binary logarithmic full-scale light range and highly linear response within each range
- Built-in automatic full-scale light range selection logic, which switches measurement range based on input light condition with excellent gain matching between ranges
- 28 bits of effective dynamic range from
  - 312.5 µlux to 83 klux for PicoStar™ package variant
  - 437.5 µlux to 117 klux for SOT-5x3 package variant
- 12 configurable conversion times from 600 µs to 800 ms is an excellent choice for a wide variety of high speed and high precision applications
- External pin interrupt for hardware synchronized trigger and interrupts (only on SOT-5X3 package variant)
- Internal FIFO for output registers with I^{2}C burst readout
- Low operating current: 30 µA with ultra-low power standby: 2 µA
- Operating temperature range: –40°C to +85°C
- Wide power-supply range: 1.6 V to 3.6 V
- 5.5 V Tolerant I/O pins
- Selectable I^{2}C address
- Small-form factor
  - PicoStar™ package: 0.84 mm x 1.05 mm x 0.226 mm
  - SOT-5X3: 2.1mm x 1.9mm x 0.6mm

2 Applications

- Display backlight controls for
  - Smartwatches, wearable electronics, and health fitness bands
  - Tablets and notebooks
  - Multi-function printers
  - Home automation interfaces
  - Thermostats and home automation appliances
- Lighting control systems to detect light level (day or night)
- Point-of-sale terminals
- Outdoor traffic and street lighting
- IP Network Cameras
- Flicker rate detection of light sources

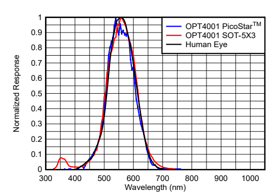
3 Description

The OPT4001 is a light-to-digital sensor (single chip lux meter) that measures the intensity of visible light. The spectral response of the sensor tightly matches the photopic response of the human eye. A specially engineered filter on the device rejects near-infrared component from the common light sources to measure accurate light intensity. Output of OPT4001 is semi-logarithmic with 9 binary logarithmic full-scale light ranges along with highly linear response within each range, bringing capability to measure from 312.5 µlux to 83 klux for PicoStar™ variant and 437.5 µlux to 117 klux for the SOT-5X3 variant. This capability allows light sensor to have 28-bit effective dynamic range. With built-in automatic full-scale range selection, logic users do not have to select appropriate gain settings based on light levels.

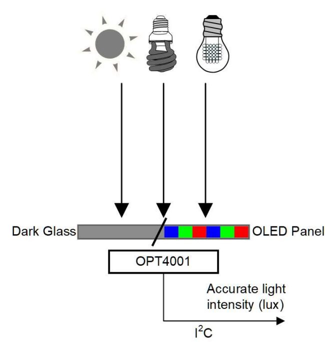
Device Information

PART NUMBER	PACKAGE(1)	BODY SIZE (NOM)
OPT4001	PicoStar™ (4)	0.84mm x 1.05 mm x 0.226mm
	SOT-5X3 (8)	1.9mm X 2.1mm X 0.6mm

(1) For all available packages, see the package option addendum at the end of the data sheet.



Spectral Response: The OPT4001 and Human Eye



Typical Application Diagram of OPT4001

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4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (August 2019) to Revision A (January 2022) **Page**

- Added a new package variant for the device SOT-5X3.......... 1
- Added Section 8.4.2 for package variants.......... 15
- Changed values for Table 8-3 17
- Added and changed register names for both package variants.......... 26

5 Description (continued)

The engineered optical filter on OPT4001 provides strong infrared rejection, which aids in maintaining high accuracy, despite placing the sensor under dark glass, which is common requirement from industrial design of end products due to aesthetics.

The OPT4001 is designed for systems that require light level detection to enhance user experience and typically replaces low accuracy photo diodes, photo-resistors and other ambient light sensors with underwhelming human eye matching and near infra-red rejection.

The OPT4001 device can be configured to operate with light conversion times all the way from 600 µs to 800 ms in 12 steps, providing system flexibility based on application need. Conversion time includes the light integration time and ADC conversion time. Resolution of the measurement is determined by a combination of light intensity and the integration time, effectively bringing in capability to measure down to 312.5 µlux of light intensity changes for the PicoStar™ variant and 437.5 µlux for the SOT-5X3 variant.

The digital operation is flexible for system integration. Measurements can be either continuous or triggered in one shots with register writes or hardware pin (only on SOT-5X3 variant). The device features a threshold detection logic, which allows the processor to sleep while the sensor watches for appropriate wake-up event to report via the interrupt pin (only on SOT-5X3 variant).

Digital output, representing the light level is reported over an I^2C and SMBus compatible, two-wire serial interface. An internal FIFO on output registers is available to read out the measurements from the sensor at a slower pace while still preserving all the data captured by the device. OPT4001 also supports I^2C burst mode helping host read data from FIFO with minimal I^2C overhead.

The low power consumption and low power-supply voltage capability of the OPT4001 helps enhance the battery life of battery-powered systems.

6 Pin Configuration and Functions

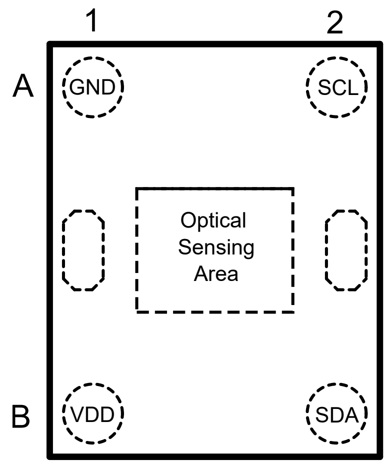


Figure 6-1. YMN (PicoStar™) Package, 4-Pin, Top View

Table 6-1. Pin Functions

PIN		TYPE	DESCRIPTION
NO.	NAME		
A1	GND	Power	Ground
B1	VDD	Power	Device power. Connect to a 1.6-V to 3.6-V supply.
A2	SCL	Digital input	I^{2}C clock. Connect with a 10-kΩ resistor to a 1.6-V to 5.5-V supply.
B2	SDA	Digital input/ output	I^{2}C data. Connect with a 10-kΩ resistor to a 1.6-V to 5.5-V supply.

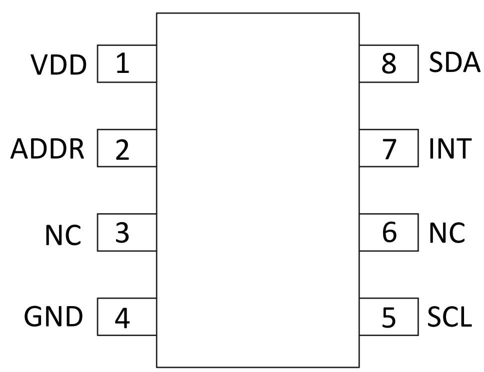


Figure 6-2. DTS Package, 6-Pin USON, Top View

Table 6-2. Pin Functions

PIN		TYPE	DESCRIPTION
NO.	NAME		
1	VDD	Power	Device power. Connect to a 1.6-V to 3.6-V supply.
2	ADDR	Digital input	Address pin. This pin sets the LSBs of the I^{2}C address.
3	NC	No Connection	No Connection
4	GND	Power	Ground
5	SCL	Digital input	I^{2}C clock. Connect with a 10-kΩ resistor to a 1.6-V to 5.5-V supply.
6	NC	No Connection	No Connection
7	INT	Digital I/O	Interrupt input/output open-drain. Connect with a 10-kΩ resistor to a 1.6-V to 5.5-V supply.
8	SDA	Digital I/O	I^{2}C data. Connect with a 10-kΩ resistor to a 1.6-V to 5.5-V supply.

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[(1)]

		MIN	MAX	UNIT
Voltage	VDD to GND	–0.5	6	V
	SDA and SCL to GND	–0.5	6	V
Current in to any pin			10	mA
T_J	Junction temperature		150	°C
T_{stg}	Storage temperature	–65	150[(2)]	°C

(1) Operation outside the Absolute Maximum Ratings may cause permanent device damage. Absolute Maximum Ratings do not imply functional operation of the device at these or any other conditions beyond those listed under Recommended Operating Conditions. If used outside the Recommended Operating Conditions but within the Absolute Maximum Ratings, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
(2) Long exposure to temperatures higher than 105°C can cause package discoloration, spectral distortion, and measurement inaccuracy.

7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins[(1)]	±2000	V
		Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002, all pins[(2)]	±500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.precautions.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
VDD	Supply voltage	1.6		3.6	V
T_J	Junction temperature	–40		85	°C

7.4 Thermal Information

THERMAL METRIC[(1)]		OPT4001		UNIT
		PicoStar^{TM} (YMN)	SOT-5X3 (DTS)	
		4 Pins	8 Pins	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	122.8	112.2	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	1.4	28.4	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	34.9	22.1	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	0.8	1.2	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	35.3	22	°C/W

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.

7.5 Electrical Characteristics

All specifications at TA = 25°C, VDD = 3.3 V, 800-ms conversion-time (CONVERSION_TIME=0xB), automatic full-scale range, white LED and normal-angle incidence of light, unless otherwise specified.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OPTICAL						
PicoStar™ Variant						
E_{vLSB}	Resolution	Lowest auto gain range, 800 ms converion-time		312.5		µlux
E_{vLSB}	Resolution	Lowest auto gain range, 100 ms converion-time		2.5		mlux
E_{vFS}	Full-scale illuminance			83886		lux
	Angular response (FWHM)			96		°
	Drift across temperature	Visible Light, Input illuminance = 2000 lux		0.01		%/°C
	Linearity	Input illuminance > 328 lux 100 ms conversion-time CONVERSION_TIME=0x8		2		%
	Linearity	Input illuminance < 328 lux 100 ms conversion-time CONVERSION_TIME=0x8		5		%
SOT-5X3 Variant						
E_{vLSB}	Resolution	Lowest auto gain range, 800 ms converion-time		437.5		µlux
E_{vLSB}	Resolution	Lowest auto gain range, 100 ms converion-time		3.5		mlux
E_{vFS}	Full-scale illuminance			117441		lux
	Angular response (FWHM)			120		°
	Drift across temperature	Visible Light, Input illuminance = 2000 lux		0.015		%/°C
	Linearity	Input illuminance > 459 lux 100 ms conversion-time CONVERSION_TIME=0x8		2		%
	Linearity	Input illuminance < 459 lux 100 ms conversion-time CONVERSION_TIME=0x8		5		%
Common Specifications						
	Peak irradiance spectral responsivity			550		nm
	Effective MANTISSA bits (Register R_MSB & R_LSB)	Dependent on Converstion Time selected (Register CONVERSION_TIME)	9		20	bits
	Exponent bits (Register E)	Denotes the full-scale range		4		bits
E_v	Measurement output result	2000 lux input(1)	1800	2000	2200	lux
Tconv	Light Conversion-time(4)	Minimum Selectable (CONVERSION_TIME=0x0), fixed lux range, 2000 lux input		600		µs
Tconv	Light Conversion-time(4)	Maximum Selectable (CONVERSION_TIME=0xB), fixed lux range, 2000 lux input		800		ms
	Light source variation (incandescent, halogen, fluorescent)	Bare device, no cover glass		4		%
E_{vIR}	Infrared response	850nm Near Infrared		0.2		%
	Relative accuracy between gain ranges (2)			0.4		%
	Dark Measurement			0	10	mlux
PSRR	Power-supply rejection ratio(3)	VDD at 3.6 V and 1.6 V		0.1		%/V
POWER SUPPLY						

7.5 Electrical Characteristics (continued)

All specifications at TA = 25°C, VDD = 3.3 V, 800-ms conversion-time (CONVERSION_TIME=0xB), automatic full-scale range, white LED and normal-angle incidence of light, unless otherwise specified.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{DD}	Power supply		1.6		3.6	V
V_{I2C}	Power supply for I^2C pull up resistor	I^2C pullup resistor, $V_{DD} \leq {}_{VI2C}$	1.6		5.5	V
$I_{QACTIVE}$	Active Current	Dark		22		µA
		Full-scale lux		30		µA
I_Q	Quiescent current	Dark		1.6		µA
		Full-scale lux		2		uA
POR	Power-on-reset threshold			0.8		V
DIGITAL						
C_{IO}	I/O Pin Capacitance			3		pF
T_{ss}	Trigger to Sample Start	Low-power shutdown mode		0.5		ms
V_{IL}	Low-level input voltage (SDA, SCL, and ADDR)		0		0.3 X V_{DD}	V
V_{IH}	High-level input voltage (SDA, SCL, and ADDR)		0.7 X V_{DD}		5.5	V
I_{IL}	Low-level input current (SDA, SCL, and ADDR)			0.01	0.25(5)	µA
V_{OL}	Low-level output voltage (SDA and INT)	I_{OL}=3mA			0.32	V
I_{ZH}	Output logic high, high-Z leakage current (SDA, INT)	Measured with V_{DD} at pin		0.01	0.25(5)	µA
TEMPERATURE						
	Specified temperature range		–40		85	°C

(1) Tested with the white LED calibrated to 2000 lux
(2) Characterized by measuring fixed near-full-scale light levels on the higher adjacent full-scale range setting.
(3) PSRR is the percent change of the measured lux output from the current value, divided by the change in power supply voltage, as characterized by results from 3.6-V and 1.6-V power supplies
(4) The conversion-time, from start of conversion until the data are ready to be read, is the integration-time plus analog-to-digital conversion-time.
(5) The specified leakage current is dominated by the production test equipment limitations. Typical values are much smaller

7.6 Typical Characteristics

At T_A = 25°C, V_{DD} = 3.3 V, 800-ms conversion time (CONVERSION_TIME = 0xB), automatic full-scale range (RANGE = 0xC), white LED, and normal-angle incidence of light, unless otherwise specified.

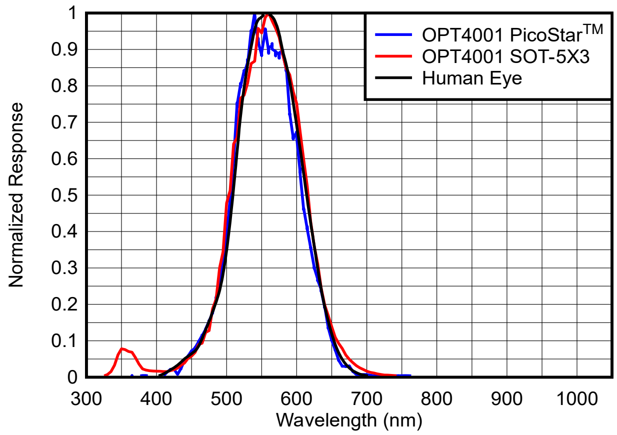
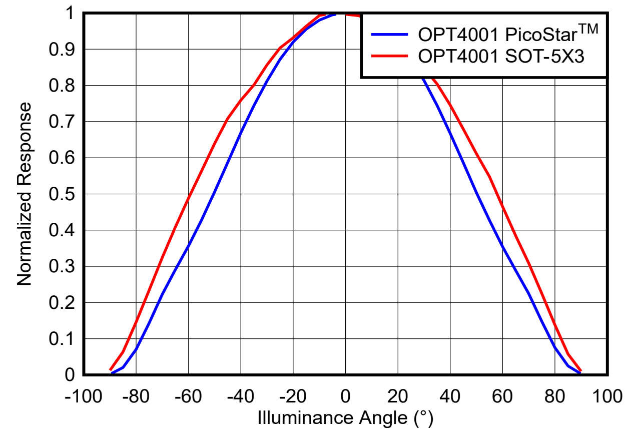
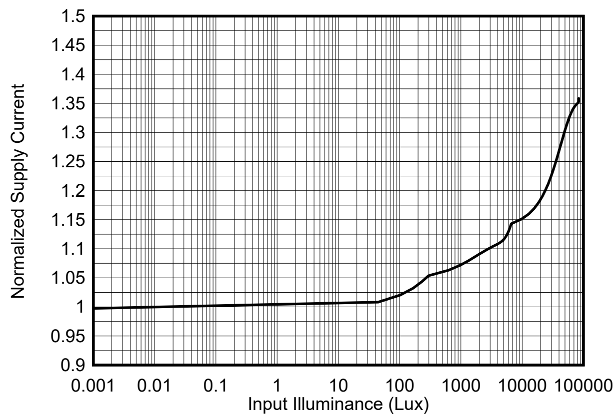


Figure 7-1. Spectral Response vs Wavelength



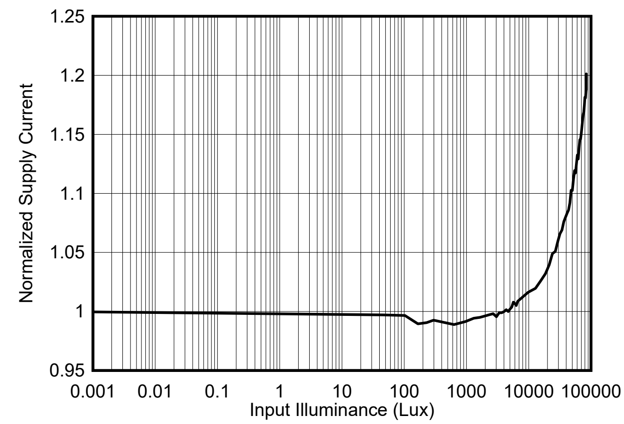
Normalized to 0°

Figure 7-2. Device Response vs Illuminance Angle



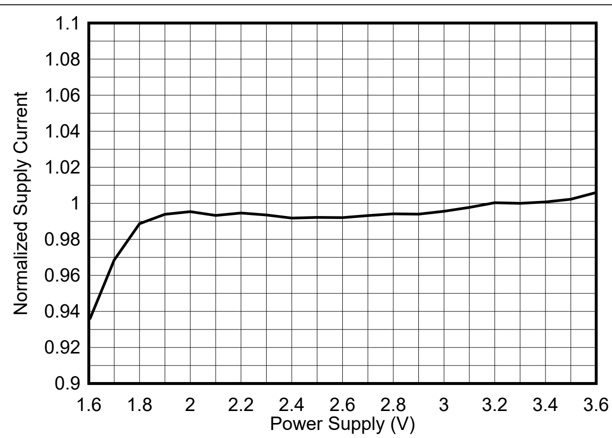
Normalized to dark condition

Figure 7-3. Active Current vs Input Light Level



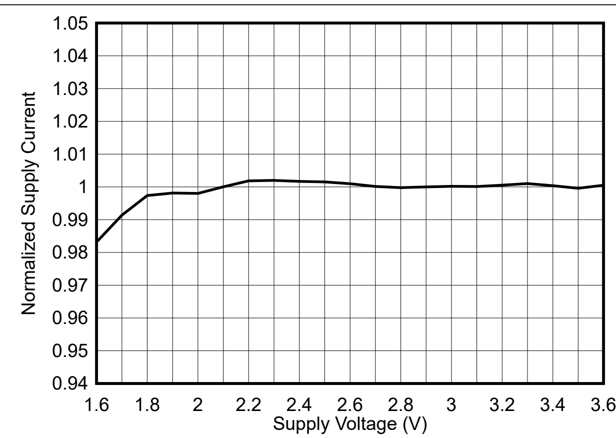
Normalized to dark condition

Figure 7-4. Standby Current vs Input Light Level



Normalized to 3.3 V

Figure 7-5. Active Current vs Power Supply

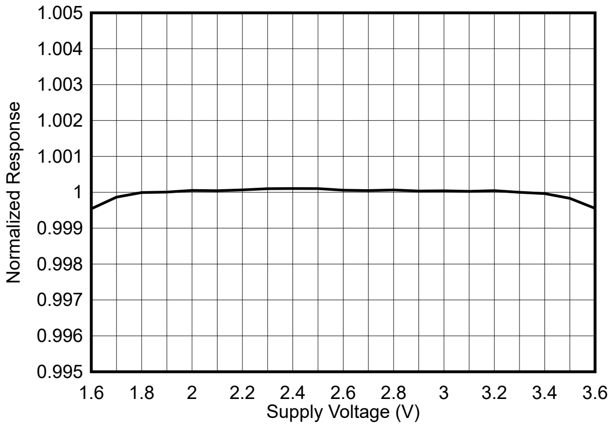


Normalized to 3.3 V

Figure 7-6. Standby Current vs Power Supply

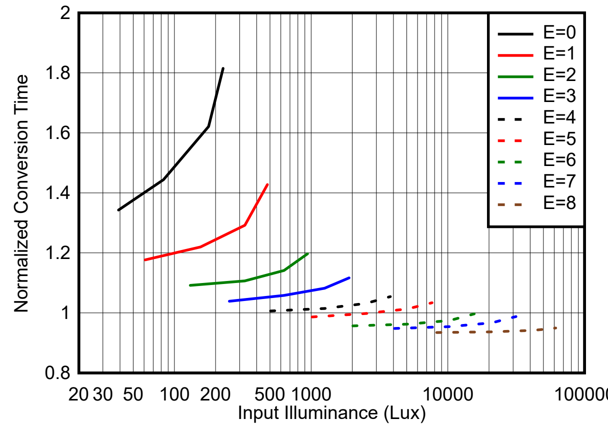
7.6 Typical Characteristics (continued)

At T_A = 25°C, V_{DD} = 3.3 V, 800-ms conversion time (CONVERSION_TIME = 0xB), automatic full-scale range (RANGE = 0xC), white LED, and normal-angle incidence of light, unless otherwise specified.



Normalized to 3.3 V

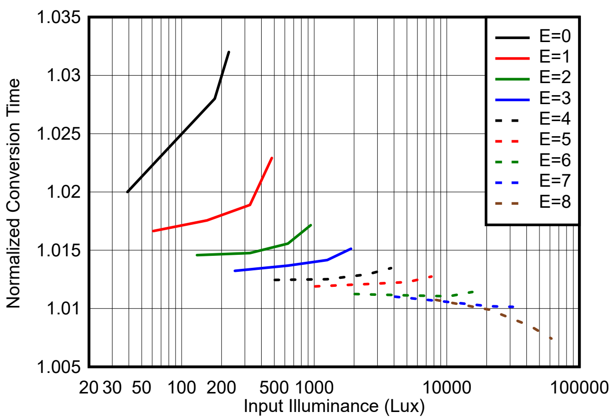
Figure 7-7. Device Response vs Power Supply



Register E (exponent) denotes the full-scale range

Normalized to 600 µs

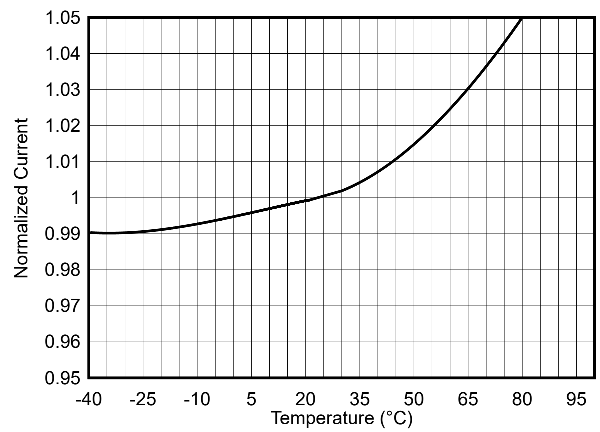
Figure 7-8. Conversion Time at 600 µs vs Input Light Level



Register E (exponent) denotes the full-scale range

Normalized to 25 ms

Figure 7-9. Conversion Time at 25 ms vs Input Light Level

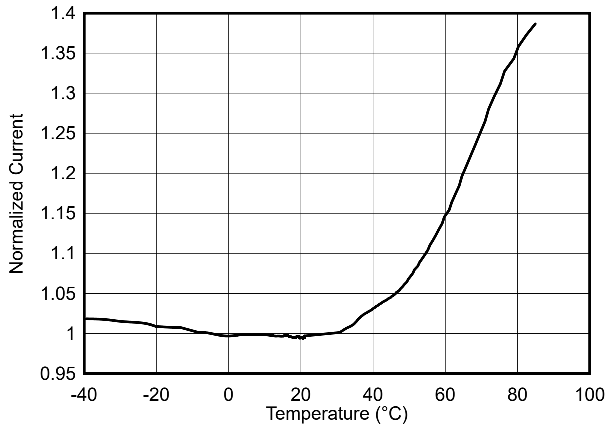


Normalized to 25°C

Figure 7-10. Active Current vs Temperature

7.6 Typical Characteristics (continued)

At T_A = 25°C, V_{DD} = 3.3 V, 800-ms conversion time (CONVERSION_TIME = 0xB), automatic full-scale range (RANGE = 0xC), white LED, and normal-angle incidence of light, unless otherwise specified.



Normalized to 25°C

Figure 7-11. Standby Current vs Temperature

8 Detailed Description

8.1 Overview

OPT4001 measures the ambient light that illuminates the device. This device measures light with a spectral response very closely matched to the human eye, and with excellent infrared rejection.

Matching the sensor spectral response to that of the human eye response is vital because ambient light sensors are used to measure and help create excellent human lighting experiences. Strong rejection of infrared light, which a human does not see, is a crucial component of this matching. This matching makes the OPT4001 especially good for operation underneath windows that are visibly dark, but infrared transmissive.

OPT4001 is fully self-contained to measure the ambient light and report the result in ADC codes directly proportional to lux digitally over the I^{2}C bus. The result can also be used to alert a system and interrupt a processor with the INT pin (with SOT-5X3 package variant). The result can also be summarized with a programmable threshold comparison and communicated with the INT pin(with SOT-5X3 package variant).

OPT4001 is by default configured to operate in automatic full-scale range detection mode that always selects the best full-scale range setting for the given lighting conditions. There are 9 full-scale range settings, one of which can be selected manually as well. Setting the device to operate in automatic full-scale range detection mode frees the user from having to program their software for potential iterative cycles of measurement and readjustment of the full-scale range until good for any given measurement. With device exhibiting excellent linearity over the entire 28 bit dynamic range of measurement no additional linearity calibration is required at system level.

OPT4001 can be configured to operate in continuous or one-shot measurement modes. The device offers 12 conversion times ranging from 600 µs to 800 ms. The device starts up in a low-power shutdown state, such that the OPT4001 only consumes active-operation power after being programmed into an active state.

OPT4001 optical filtering system is not excessively sensitive to small particles and micro-shadows on the optical surface. This reduced sensitivity is a result of the relatively minor device dependency on uniform density optical illumination of the sensor area for infrared rejection. Proper optical surface cleanliness is always recommended for best results on all optical devices.

8.2 Functional Block Diagram

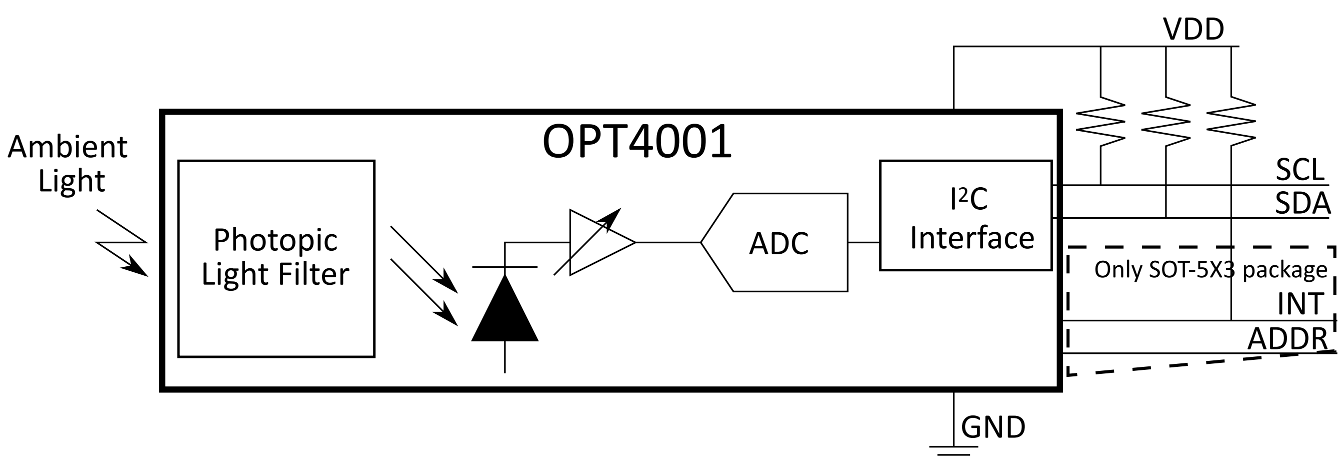


Figure 8-1. Functional Block Diagram of OPT4001