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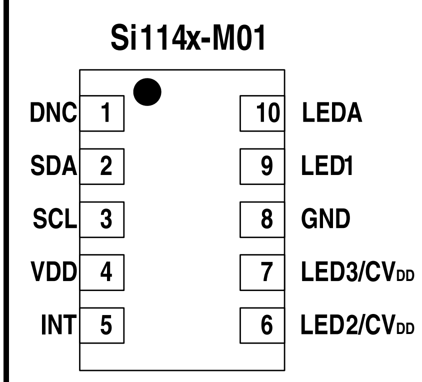
Si1145/46/47-M01

PROXIMITY/UV/AMBIENT LIGHT SENSOR MODULE WITH I²C INTERFACE

Features

- Integrated infrared proximity detector
  - Proximity detection adjustable from under 1 cm to over 50 cm
  - Three independent LED drivers
  - 15 current settings from 5.6 mA to 360 mA for each LED driver
  - 25.6 µs LED driver pulse width
  - 50 cm proximity range with single pulse (<3 klx)
  - 15 cm proximity range with single pulse (>3 klx)
  - Operates at up to 128 klx (direct sunlight)
  - High reflectance sensitivity < 1 µW/cm^2
  - High EMI immunity without shielded packaging
- Integrated UV index sensor
- Integrated ambient light sensor
  - 100 mlx resolution possible, allowing operation under dark glass
  - 1 to 128 klx dynamic range possible across two ADC range settings
  - Accurate lux measurements with IR correction algorithm
- Industry's lowest power consumption
  - 1.71 to 3.6 V supply voltage
  - 9 µA average current (LED pulsed 25.6 µs every 800 ms at 180 mA plus 3 µA Si1145/46/47-M01 supply)
  - < 500 nA standby current
  - Internal and external wake support
  - Built-in voltage supply monitor and power-on reset controller
  - 25.6 µs LED "on" time keeps total power consumption duty cycle low without compromising performance or noise immunity
- IR LED integrated inside the module
- I^{2}C Serial communications
  - Up to 3.4 Mbps data rate
  - Slave mode hardware address decoding (0x60)
- Small-outline 10-lead 4.9x2.85x1.2 mm QFN
- Temperature Range
  - –40 to +85 °C

Pin Assignments



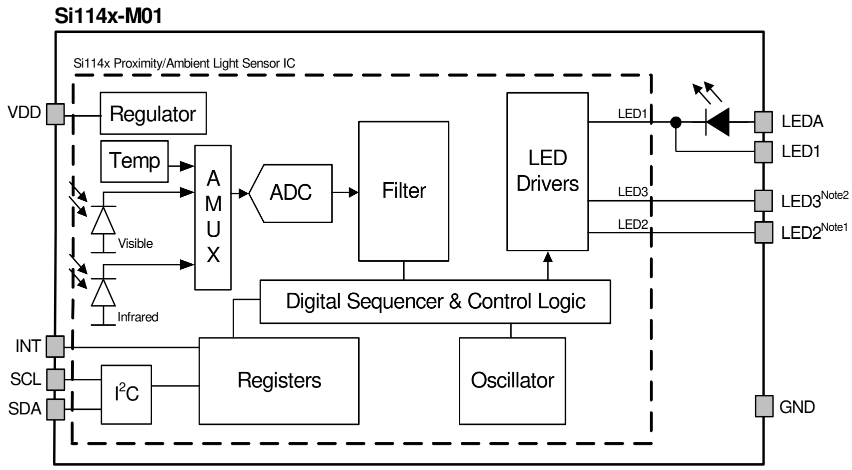
Applications

- Handsets
- Heart rate monitoring
- Pulse oximetry
- Wearables
- E-book readers
- Notebooks/Netbooks
- Portable consumer electronics
- Touchless switches
- Touchless sliders
- Consumer electronics
- Display backlighting control

Description

The Si1145/46/47-M01 is a low-power, reflectance-based, proximity, UV Index and ambient light module with integrated single IR LED, two additional LED driver outputs, I^{2}C digital interface, and programmable-event interrupt output. This touchless sensor module includes an analog-to-digital converter, integrated high-sensitivity visible and infrared photodiodes, digital signal processor, and three integrated infrared LED drivers with fifteen selectable drive levels. The Si1145/46/47-M01 offers excellent performance under a wide dynamic range and a variety of light sources including direct sunlight. The Si1145/46/47-M01 can also work under dark glass covers. The photodiode response and associated digital conversion circuitry provide excellent immunity to artificial light flicker noise and natural light flutter noise. With two or more LEDs, the Si1145/46/47-M01 is capable of supporting multiple-axis proximity motion detection. The Si1145/46/47-M01 devices are provided in a 10-lead 4.9x2.85x1.2 mm QFN package and are capable of operation from 1.71 to 3.6 V over the –40 to +85 °C temperature range.

Functional Block Diagram



Notes:

1. Si1146-M01 and Si1147-M01 only. Must be tied to V_{DD} with Si1145-M01.
2. Si1147-M01 only. Must be tied to V_{DD} with Si1145-M01 and Si1146-M01.

Figure 1. Si114x-M01 Sensor Module

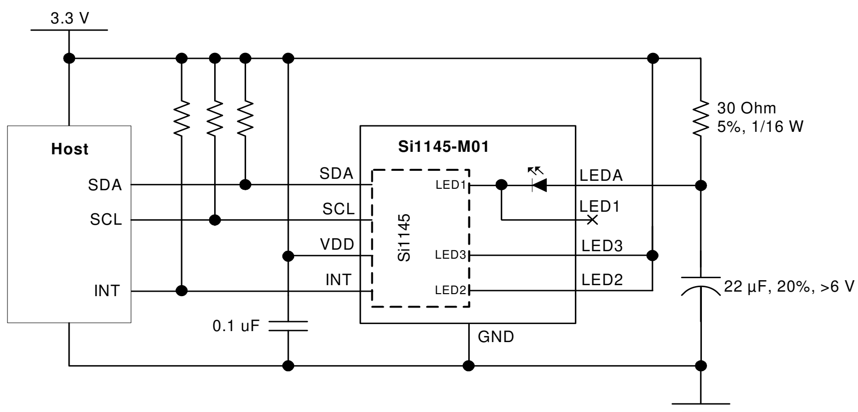


Figure 2. Si1145-M01 Module Basic Application Schematic for 1 LED

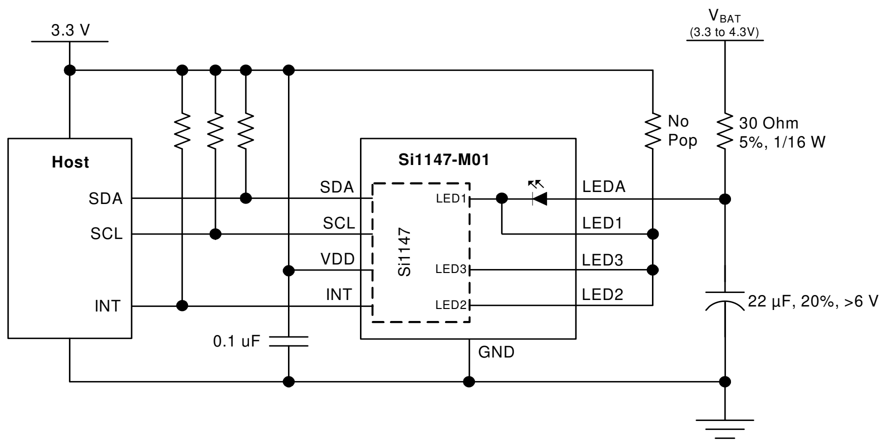


Figure 3. Si1147-M01 Module Application Schematic for Long-Range Proximity Detection

Note: For more application examples, refer to “AN498: Si114x Designer’s Guide”.

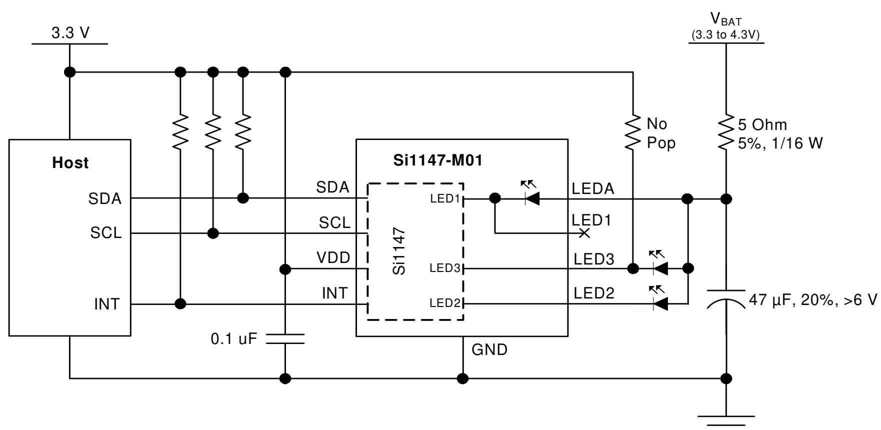


Figure 4. Si1147-M01 Module Application Schematic with Three LEDs and Separate LED Power Supply

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1. Electrical Specifications

1.1. Performance Tables

Table 1. Recommended Operating Conditions

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
V_{DD} Supply Voltage	V_{DD}		1.71	—	3.6	V
V_{DD} OFF Supply Voltage	V_{DD_OFF}	OFF mode	–0.3		1.0	V
V_{DD} Supply Ripple Voltage		V_{DD} = 3.3 V 1 kHz–10 MHz	—	—	50	mVpp
Operating Temperature	T		–40	25	85	°C
SCL, SDA, Input High Logic Voltage	I^2C_{VIH}		V_{DD}x0.7	—	V_{DD}	V
SCL, SDA Input Low Logic Voltage	I^2C_{VIL}		0	—	V_{DD}x0.3	V
PS Operation under Direct Sunlight	Edc		—	—	128	klx
IrLED Emission Wavelength	l		750	850	950	nm
IrLED Supply Voltage	VLED	IrLED V_F = 1.0 V nominal	V_{DD}	—	4.3	V
IrLED Supply Ripple Voltage		Applies if IrLEDs use separate supply rail 0–30 kHz 30 kHz–100 MHz	 — —	 — —	 250 100	 mVpp mVpp
Start-Up Time		V_{DD} above 1.71 V	25	—	—	ms
LED3 Voltage		Start-up	V_{DD}x0.77	—	—	V

Table 2. Performance Characteristics[1]

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
I_{DD} OFF Mode	I_{off}	$V_{DD} < V_{DD\_OFF}$ (leakage from SCL, SDA, and INT not included)	—	240	1000	nA
I_{DD} Standby Mode	I_{sb}	No ALS / PS Conversions No I^2C Activity V_{DD} = 1.8 V	—	150	500	nA
I_{DD} Standby Mode	I_{sb}	No ALS / PS Conversions No I^2C Activity V_{DD} = 3.3 V	—	1.4	—	µA
I_{DD} Actively Measuring	I_{active}	Without LED influence, V_{DD} = 3.3 V	—	4.3	5.5	mA
Peak IDD while LED1, LED2, or LED3 is Actively Driven		V_{DD} = 3.3 V	—	8	—	mA
LED Driver Saturation Voltage[2,3]		Vdd = 1.71 to 3.6 V PS_LEDn = 0001 PS_LEDn = 0010 PS_LEDn = 0011 PS_LEDn = 0100 PS_LEDn = 0101 PS_LEDn = 0110 PS_LEDn = 0111 PS_LEDn = 1000 PS_LEDn = 1010 PS_LEDn = 1010 PS_LEDn = 1011 PS_LEDn = 1100 PS_LEDn = 1101 PS_LEDn = 1110 PS_LEDn = 1111	 — — — — — — — — — — — — — — —	 50 60 70 80 115 150 185 220 255 290 315 340 360 385 410	 70 105 105 105 450 450 450 450 450 450 600 600 600 600 600	mV
LED1, LED2, LED3 Pulse Width	t_{PS}		—	25.6	30	µs
LED1, LED2, LED3, INT, SCL, SDA Leakage Current		V_{DD} = 3.3 V	–1	—	1	µA

Notes:
1. Unless specifically stated in "Conditions", electrical data assumes ambient light levels < 1 klx.
2. Proximity-detection performance may be degraded, especially when there is high optical crosstalk, if the LED supply and voltage drop allow the driver to saturate and current regulation is lost.
3. Guaranteed by design and characterization.
4. Represents the time during which the device is drawing a current equal to I_{active} for power estimation purposes. Assumes default settings.

Table 2. Performance Characteristics[1] (Continued)

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
LED1, LED2, LED3 Active Current	I_{LEDx}	V_{DD} = 3.3 V, single drive				mA
		V_{LEDn} = 1 V, PS_LEDn = 0001	3.5	5.6	7	
		V_{LEDn} = 1 V, PS_LEDn = 0010	—	11.2	—	
		V_{LEDn} = 1 V, PS_LEDn = 0011	13	22.4	29	
		V_{LEDn} = 1 V, PS_LEDn = 0100	—	45	—	
		V_{LEDn} = 1 V, PS_LEDn = 0101	—	67	—	
		V_{LEDn} = 1 V, PS_LEDn = 0110	—	90	—	
		V_{LEDn} = 1 V, PS_LEDn = 0111	—	112	—	
		V_{LEDn} = 1 V, PS_LEDn = 1000	—	135	—	
		V_{LEDn} = 1 V, PS_LEDn = 1001	—	157	—	
		V_{LEDn} = 1 V, PS_LEDn = 1010	—	180	—	
		V_{LEDn} = 1 V, PS_LEDn = 1011	—	202	—	
		V_{LEDn} = 1 V, PS_LEDn = 1100	—	224	—	
		V_{LEDn} = 1 V, PS_LEDn = 1101	—	269	—	
		V_{LEDn} = 1 V, PS_LEDn = 1110	—	314	—	
		V_{LEDn} = 1 V, PS_LEDn = 1111	—	359	—	
Actively Measuring Time[4]		Single PS	—	155	—	µs
		ALS VIS + ALS IR	—	285	—	µs
		Two ALS plus three PS	—	660	—	µs
Visible Photodiode Response		Sunlight ALS_VIS_ADC_GAIN = 0 VIS_RANGE = 0	—	0.282	—	ADC counts/ lux
		2500K incandescent bulb ALS_VIS_ADC_GAIN = 0 VIS_RANGE = 0	—	0.319	—	ADC counts/ lux
		"Cool white" fluorescent ALS_VIS_ADC_GAIN = 0 VIS_RANGE = 0	—	0.146	—	ADC counts/ lux
		Infrared LED (875 nm) ALS_VIS_ADC_GAIN = 0 VIS_RANGE = 0	—	8.277	—	ADC counts. m^2/W

Notes:

1. Unless specifically stated in "Conditions", electrical data assumes ambient light levels < 1 klx.
2. Proximity-detection performance may be degraded, especially when there is high optical crosstalk, if the LED supply and voltage drop allow the driver to saturate and current regulation is lost.
3. Guaranteed by design and characterization.
4. Represents the time during which the device is drawing a current equal to I_{active} for power estimation purposes. Assumes default settings.

Table 2. Performance Characteristics[1] (Continued)

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
Small Infrared Photodiode Response		Sunlight ALS_IR_ADC_GAIN = 0 IR_RANGE = 0	—	2.44	—	ADC counts/ lux
		2500K incandescent bulb ALS_IR_ADC_GAIN = 0 IR_RANGE = 0	—	8.46	—	ADC counts/ lux
		“Cool white” fluorescent ALS_IR_ADC_GAIN = 0 IR_RANGE = 0	—	0.71	—	ADC counts/ lux
		Infrared LED (875 nm) ALS_IR_ADC_GAIN = 0 IR_RANGE = 0	—	452.38	—	ADC counts. m^2/W
Large Infrared Photodiode Response		Sunlight PS_ADC_GAIN = 0 PS_RANGE = 0 PS_ADC_MODE = 0	—	14.07	—	ADC counts/ lux
		2500K incandescent bulb PS_ADC_GAIN = 0 PS_RANGE = 0 PS_ADC_MODE = 0	—	50.47	—	ADC counts/ lux
		“Cool white” fluorescent PS_ADC_GAIN = 0 PS_RANGE = 0 PS_ADC_MODE = 0	—	3.97	—	ADC counts/ lux
		Infrared LED (875 nm) PS_ADC_GAIN = 0 PS_RANGE = 0 PS_ADC_MODE = 0	—	2734	—	ADC counts. m^2/W
Visible Photodiode Noise		All gain settings	—	7	—	ADC counts RMS
Small Infrared Photodiode Noise		All gain settings	—	1	—	ADC counts RMS

Notes:

1. Unless specifically stated in "Conditions", electrical data assumes ambient light levels < 1 klx.
2. Proximity-detection performance may be degraded, especially when there is high optical crosstalk, if the LED supply and voltage drop allow the driver to saturate and current regulation is lost.
3. Guaranteed by design and characterization.
4. Represents the time during which the device is drawing a current equal to I_{active} for power estimation purposes. Assumes default settings.

Table 2. Performance Characteristics[1] (Continued)

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
Large Infrared Photodiode Noise		All gain settings	—	10	—	ADC counts RMS
Visible Photodiode Offset Drift		VIS_RANGE = 0 ALS_VIS_ADC_GAIN = 0 ALS_VIS_ADC_GAIN = 1 ALS_VIS_ADC_GAIN = 2 ALS_VIS_ADC_GAIN = 3 ALS_VIS_ADC_GAIN = 4 ALS_VIS_ADC_GAIN = 5 ALS_VIS_ADC_GAIN = 6 ALS_VIS_ADC_GAIN = 7	—	 –0.3 –0.11 –0.06 –0.03 –0.01 –0.008 –0.007 –0.008	—	ADC counts/ °C
Small Infrared Photodiode Offset Drift		IR_RANGE = 0 IR_GAIN = 0 IR_GAIN = 1 IR_GAIN = 2 IR_GAIN = 3	—	 –0.3 –0.06 –0.03 –0.01	—	ADC counts/ °C
SCL, SDA, INT Output Low Voltage	V_{OL}	I = 4 mA, V_{DD} > 2.0 V I = 4 mA, V_{DD} < 2.0 V	— —	— —	V_{DD}x0.2 0.4	V V
Temperature Sensor Offset		25 °C	—	11136	—	ADC counts
Temperature Sensor Gain			—	35	—	ADC counts/ °C

Notes:
1. Unless specifically stated in "Conditions", electrical data assumes ambient light levels < 1 klx.
2. Proximity-detection performance may be degraded, especially when there is high optical crosstalk, if the LED supply and voltage drop allow the driver to saturate and current regulation is lost.
3. Guaranteed by design and characterization.
4. Represents the time during which the device is drawing a current equal to I_{active} for power estimation purposes. Assumes default settings.

Table 3. I^2C Timing Specifications

Parameter	Symbol	Min	Typ	Max	Unit
Clock Frequency	f_{SCL}	0.09	—	3.4	MHz
Clock Pulse Width Low	t_{LOW}	160	—	—	ns
Clock Pulse Width High	t_{HIGH}	60	—	—	ns
Start Condition Hold Time	$t_{HD.STA}$	160	—	—	ns
Start Condition Setup Time	$t_{SU.STA}$	160	—	—	ns
Input Data Setup Time	$t_{SU.DAT}$	10	—	—	ns
Input Data Hold Time	$t_{HD.DAT}$	0	—	—	ns
Stop Condition Setup Time	$t_{SU.STO}$	160	—	—	ns

Table 4. LED Electro-Optical Characteristics*

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
Forward voltage	V_{f1}	I_f = 10 µA	0.8	—	—	V
	V_{f2}	I_f = 50 mA	—	1.6	1.9	V
Reverse current	I_r	V_r = 10 V	—	—	5.0	µA
Peak wavelength	λ_p	I_f = 50 mA	840	855	870	nm
Spectral half-width	$\Delta\lambda$	I_f = 50 mA	—	30	—	nm
Radiant flux	Po	I_f = 50 mA	12	—	—	mW
Radiant Intensity	I_e	I_f = 50 mA	17	23	30	mW/sr
Half Angle	φ		—	25	—	Degrees
***Note:** All specifications measured at 25 °C.						

Table 5. Absolute Maximum Ratings*

Parameter	Test Condition	Min	Max	Unit
V_{DD} Supply Voltage		–0.3	4	V
Operating Temperature		–40	85	°C
Storage Temperature		–65	85	°C
LED1, LED2, LED3 Voltage	at VDD = 0 V, T_A < 85 °C	–0.5	3.6	V
LEDA Voltage		–0.5	4.3	V
INT, SCL, SDA Voltage	at VDD = 0 V, T_A < 85 °C	–0.5	3.6	V
Maximum Total Current Through LED1, LED2, LED3 and LEDA		—	500	mA
Maximum Total Current Through GND		—	600	mA
Forward DC Current Through LEDA	T_A = 25 °C	—	70	mA
ESD Rating	Human Body Model	—	2	kV
	Machine Model	—	225	V
	Charged-Device Model	—	2	kV

***Note:** Permanent device damage may occur if the absolute maximum ratings are exceeded.

1.2. Typical Performance Graphs

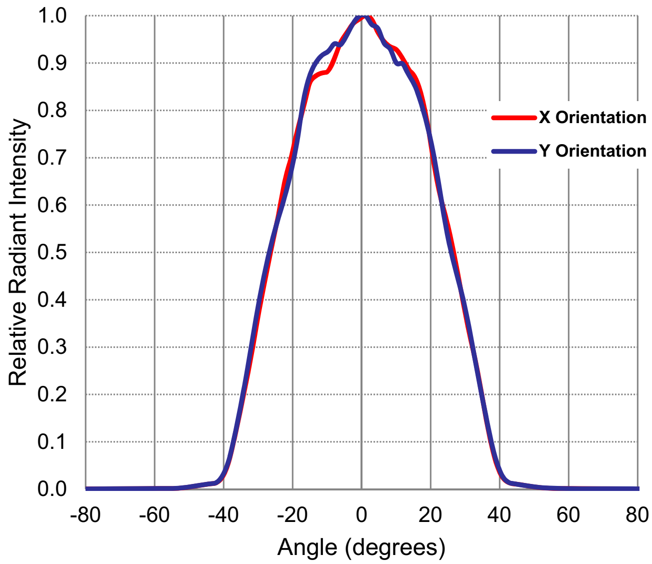

Figure 5. LED Radiant Intensity vs. Angle

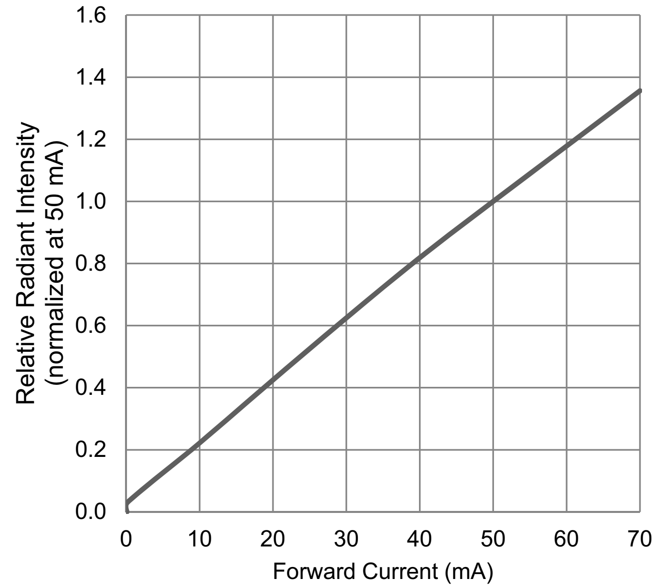

Figure 6. LED Radiant Intensity vs. Forward Current

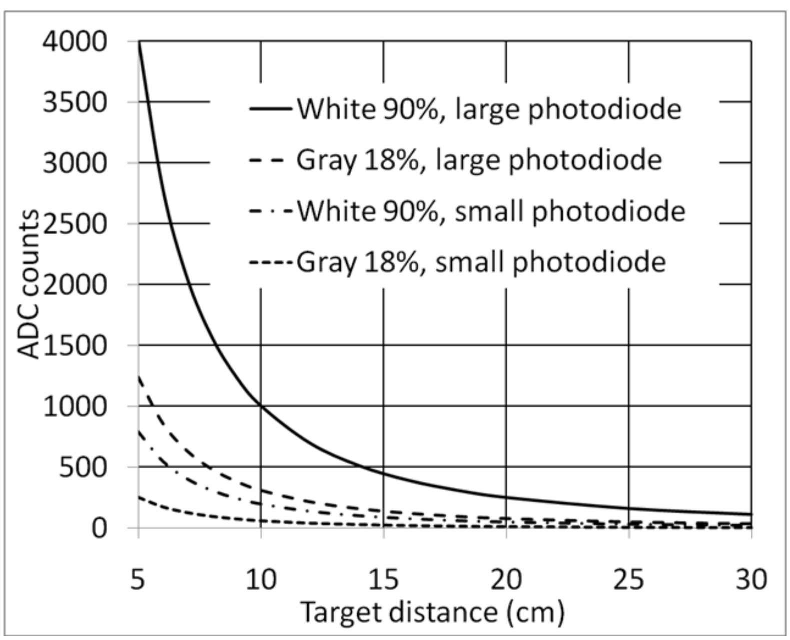

Figure 7. Proximity Response Using Kodak Gray Cards, PS_RANGE = 0, PS_ADC_GAIN = 0 (Single 25.6 µs LED Pulse), 22.5 mW/sr, No Overlay (Preliminary)

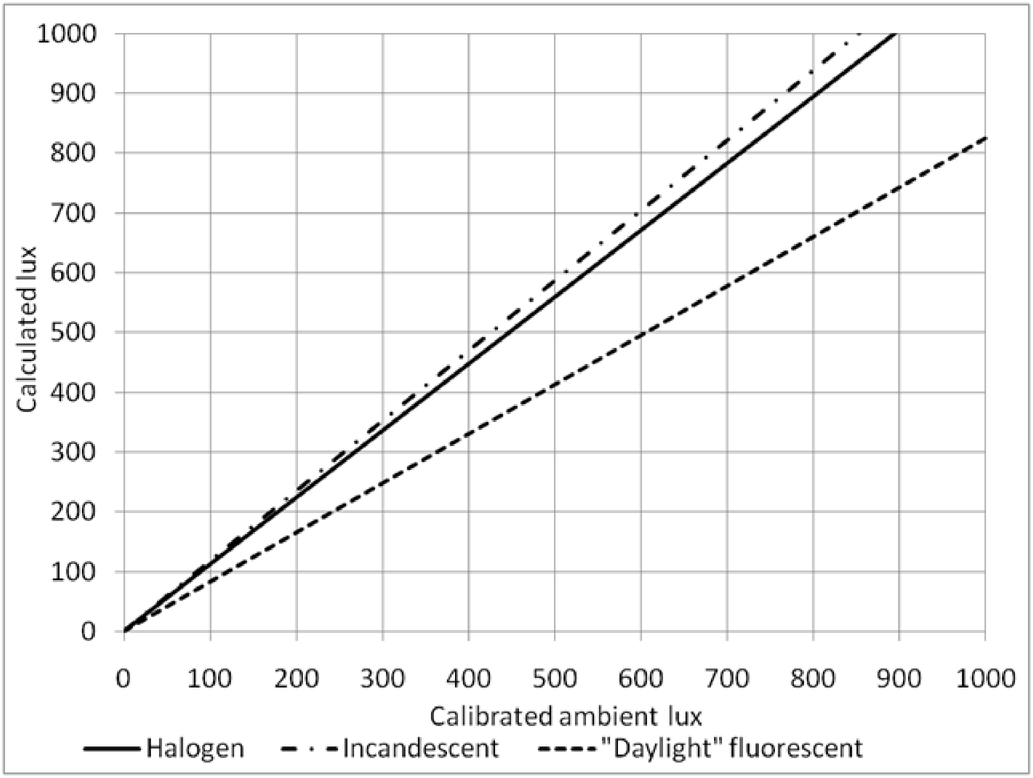

Figure 8. ALS Variability with Different Light Sources

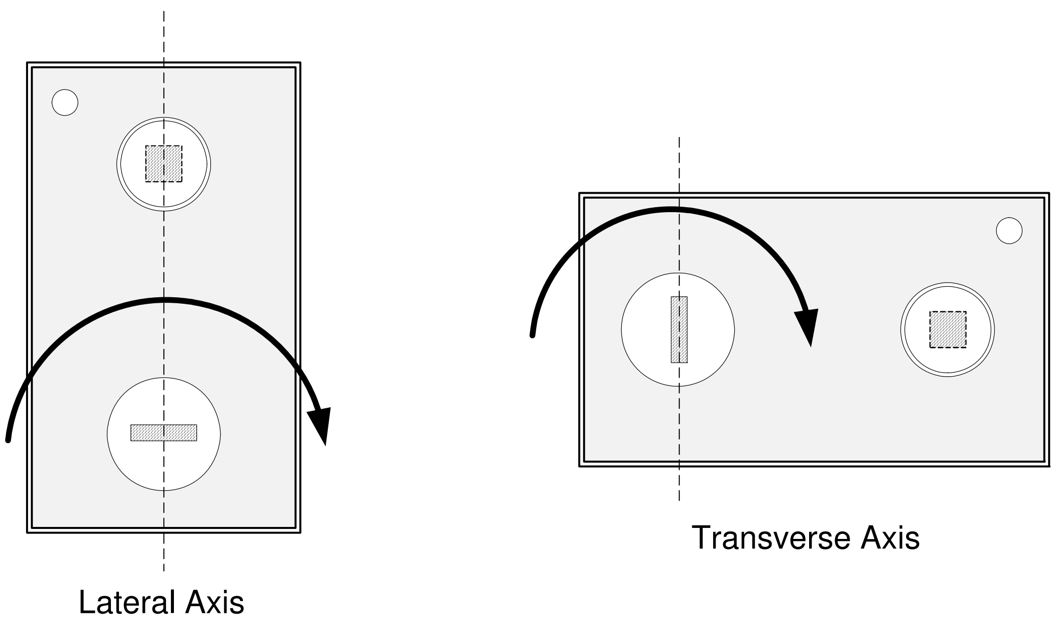

Figure 9. Module Axis Orientation

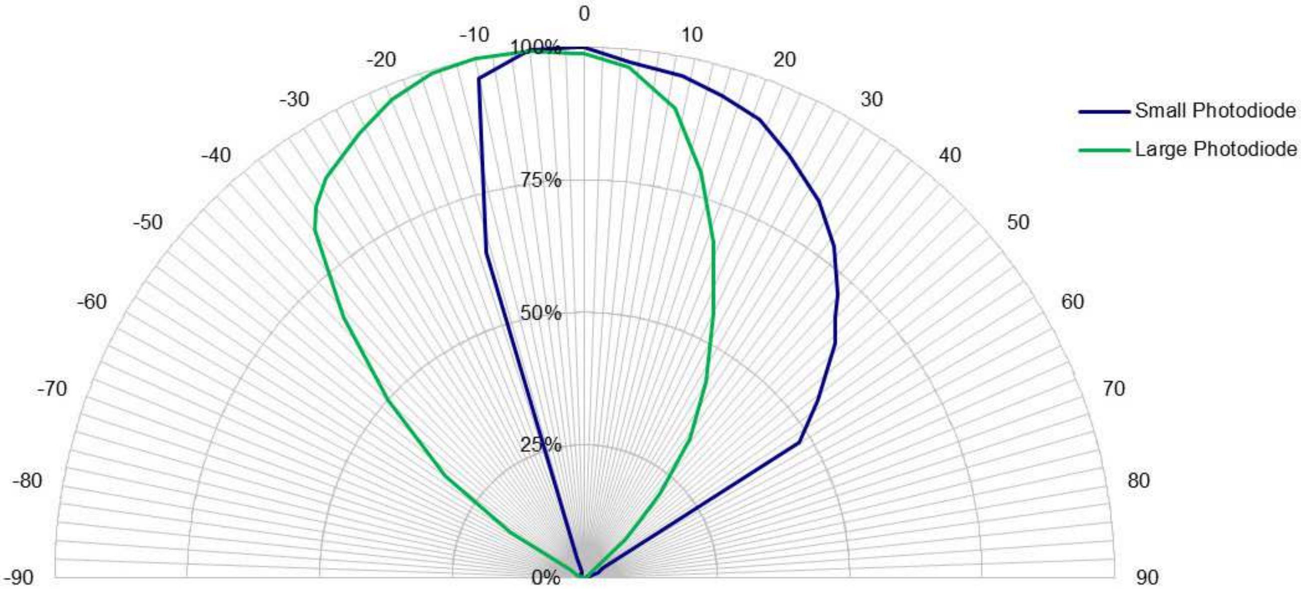

Figure 10. Lateral Photodiode View Angle

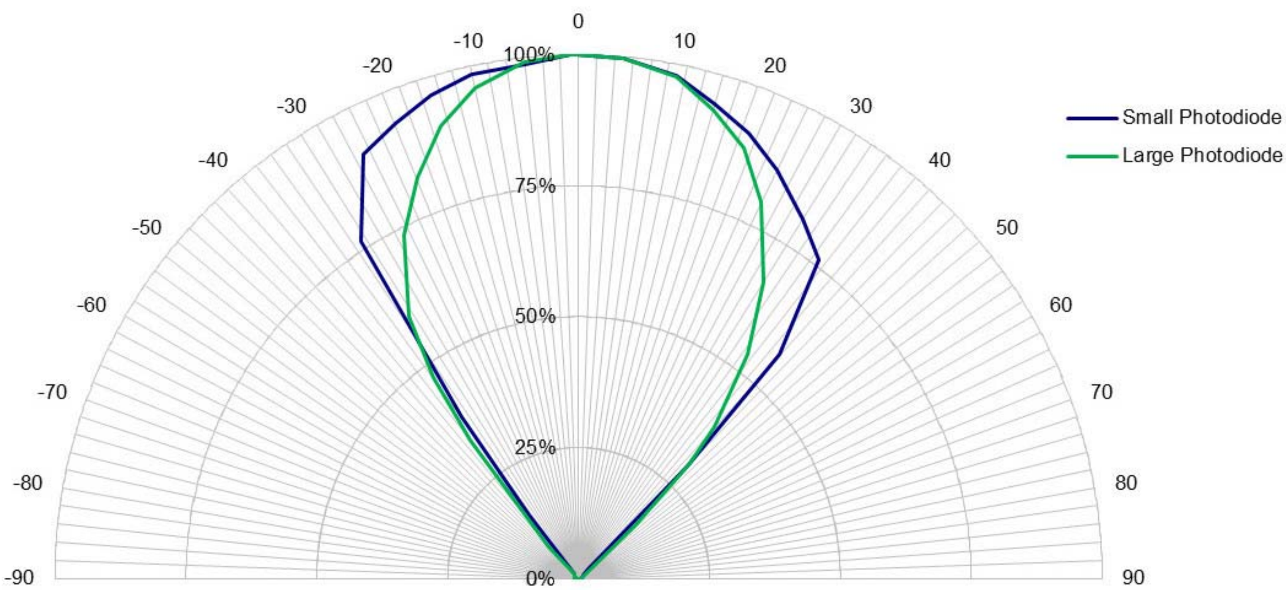

Figure 11. Transverse Photodiode View Angle

2. Functional Description

2.1. Introduction

The Si1145/46/47-M01 is an active optical reflectance proximity detector, UV Index, and ambient light sensor with an integrated infrared LED in a single module. By combining the proximity detector and LED into a single module, the Si1145/46/47-M01 delivers optimized optical performance in a single compact package. Unlike discrete implementations, module-based proximity sensor designs include the necessary optical blocking between the sensor and LED. This reduces “blind spots” that can occur in discrete implementations that lack proper optical blocking.

The Si1145/46/47-M01’s operational state is controlled through registers accessible through the I^2C interface. The host can command the Si1145/46/47-M01 to initiate on-demand proximity detection, UV Index, or ambient light sensing. The host can also place the Si1145/46/47-M01 in an autonomous operational state where it performs measurements at set intervals and interrupts the host either after each measurement is completed. This results in an overall system power saving allowing the host controller to operate longer in its sleep state instead of polling the Si1145/46/47-M01. For more details, refer to “AN498: Si114x Designer's Guide”.

2.2. Proximity Sensing (PS)

The Si1145/46/47-M01 has been optimized for use as either a dual-port or single-port active reflection proximity detector. Over distances of less than 50 cm, the dual-port active reflection proximity detector has significant advantages over single-port, motion-based infrared systems, which are only good for triggered events. Motion-based infrared detectors identify objects within proximity, but only if they are moving. Single-port motion-based infrared systems are ambiguous about stationary objects even if they are within the proximity field. The Si1145/46/47-M01 can reliably detect an object entering or exiting a specified proximity field, even if the object is not moving or is moving very slowly. However, beyond about 30–50 cm, even with good optical isolation, single-port signal processing may be required due to static reflections from nearby objects, such as table tops, walls, etc. If motion detection is acceptable, the Si1145/46/47-M01 can achieve ranges of up to 50 cm, through a single product window.

For small objects, the drop in reflectance is as much as the fourth power of the distance. This means that there is less range ambiguity than with passive motion-based devices. For example, a sixteenfold change in an object's reflectance means only a fifty-percent drop in detection range.

The Si1145/46/47-M01 contains three LED drivers. For long-range proximity detection, the three LED drivers can be connected in parallel to deliver high drive current for the internal LED. The LED drivers can also be used to drive up to two external LEDs, in addition to the LED integrated within the Si1145/46/47-M01. When the three infrared LEDs are placed in an L-shaped configuration, it is possible to triangulate an object within the three-dimensional proximity field. Thus, a touchless user interface can be implemented with the aid of host software.

The Si1145/46/47-M01 can initiate proximity sense measurements when explicitly commanded by the host or periodically through an autonomous process. Refer to Section "3. Operational Modes" on page 22 for additional details of the Si1145/46/47-M01's Operational Modes.

Whenever it is time to make a PS measurement, the Si1145/46/47-M01 makes up to three measurements, depending on what is enabled in the CHLIST parameter. Other ADC parameters for these measurements can also be modified to allow proper operation under different ambient light conditions.

The LED choice is programmable for each of these three measurements. By default, each measurement turns on a single LED driver. However, the order of measurements can be easily reversed or even have all LEDs turned on at the same time.

The Si1145/46/47-M01 can also generate an interrupt after a complete set of proximity measurements.

To support different power usage cases dynamically, the LED current of each output is independently programmable. The current can be programmed anywhere from a few to several hundred milliamps. Therefore, the host can optimize for proximity detection performance or for power saving dynamically. This feature can be useful since it allows the host to reduce the LED current once an object has entered a proximity sphere, and the object can still be tracked at a lower current setting. Finally, the flexible current settings make it possible to control the infrared LED currents with a controlled current sink, resulting in higher precision.

The ADC properties are programmable. For indoor operation, the ADC should be configured for low signal range for best reflectance sensitivity. When under high ambient conditions, the ADC should be configured for high signal level range operation.

When operating in the lower signal range, it is possible to saturate the ADC when the ambient light level is high. Any overflow condition is reported in the RESPONSE register, and the corresponding data registers report a value of 0xFFFF. The host can then adjust the ADC sensitivity. Note, however, that the overflow condition is not sticky. If the light levels return to a range within the capabilities of the ADC, the corresponding data registers begin to operate normally. However, the RESPONSE register will continue to hold the overflow condition until a NOP command is received. Even if the RESPONSE register has an overflow condition, commands are still accepted and processed.

Proximity detection ranges beyond 50 cm and up to several meters can be achieved without lensing by selecting a longer integration time. The detection range may be increased further, even with high ambient light, by averaging multiple measurements. Refer to “AN498: Si114x Designer's Guide” for more details.

2.3. Ambient Light

The Si1145/46/47-M01 has photodiodes capable of measuring both visible and infrared light. However, the visible photodiode is also influenced by infrared light. The measurement of illuminance requires the same spectral response as the human eye. If an accurate lux measurement is desired, the extra IR response of the visible-light photodiode must be compensated. Therefore, to allow the host to make corrections to the infrared light’s influence, the Si1145/46/47-M01 reports the infrared light measurement on a separate channel. The separate visible and IR photodiodes lend themselves to a variety of algorithmic solutions. The host can then take these two measurements and run an algorithm to derive an equivalent lux level as perceived by a human eye. Having the IR correction algorithm running in the host allows for the most flexibility in adjusting for system-dependent variables. For example, if the glass used in the system blocks visible light more than infrared light, the IR correction needs to be adjusted.

If the host is not making any infrared corrections, the infrared measurement can be turned off in the CHLIST parameter.

By default, the measurement parameters are optimized for indoor ambient light levels where it is possible to detect light levels as low as 6 lx. For operation under direct sunlight, the ADC can be programmed to operate in a high signal operation so that it is possible to measure direct sunlight without overflowing the 16-bit result.

For low-light applications, it is possible to increase the ADC integration time. Normally, the integration time is 25.6 µs. By increasing this integration time to 410 µs, the ADC can detect light levels as low as 1 lx. The ADC can be programmed with an integration time as high as 3.28 ms, allowing measurement to 100 mlx light levels. The ADC integration time for the Visible Light Ambient measurement can be programmed independently of the ADC integration time of the Infrared Light Ambient measurement. The independent ADC parameters allow operation under glass covers having a higher transmittance to Infrared Light than Visible Light.

When operating in the lower signal range, or when the integration time is increased, it is possible to saturate the ADC when the ambient light suddenly increases. Any overflow condition is reported in the RESPONSE register, and the corresponding data registers report a value of 0xFFFF. Based on either of these two overflow indicators, the host can adjust the ADC sensitivity. However, the overflow condition is not sticky. If the light levels return to a range within the capabilities of the ADC, the corresponding data registers begin to operate normally. The RESPONSE register will continue to hold the overflow condition until a NOP command is received. Even if the RESPONSE register has an overflow condition, commands are still accepted and processed.

The Si1145/46/47-M01 can initiate ALS measurements either when explicitly commanded by the host or periodically through an autonomous process. Refer to "3. Operational Modes" on page 22 for additional details of the Si1145/46/47-M01's Operational Modes. The conversion frequency setting is programmable and independent of the Proximity Sensor. This allows the Proximity Sensor and Ambient Light sensor to operate at different conversion rates, increasing host control over the Si1145/46/47-M01.

When operating autonomously, the ALS has a slightly different interrupt structure compared to the Proximity Sensor. An interrupt can be generated to the host on every sample, or when the ambient light has changed.

The “Ambient Light Changed” interrupt is accomplished through two thresholds working together to implement a window. As long as the ambient light stays within the window defined by the two thresholds, the host is not interrupted. When the ambient light changes and either threshold is crossed, an interrupt is sent to the host, thereby allowing the host notification that the ambient light has changed. This can be used by the host to trigger a recalculation of the lux values.

The window can be applied to either the Visible Ambient Measurement, or the Infrared Ambient Measurement, but not both. However, monitoring the ambient change in either channel should allow notification that the ambient light level has changed.

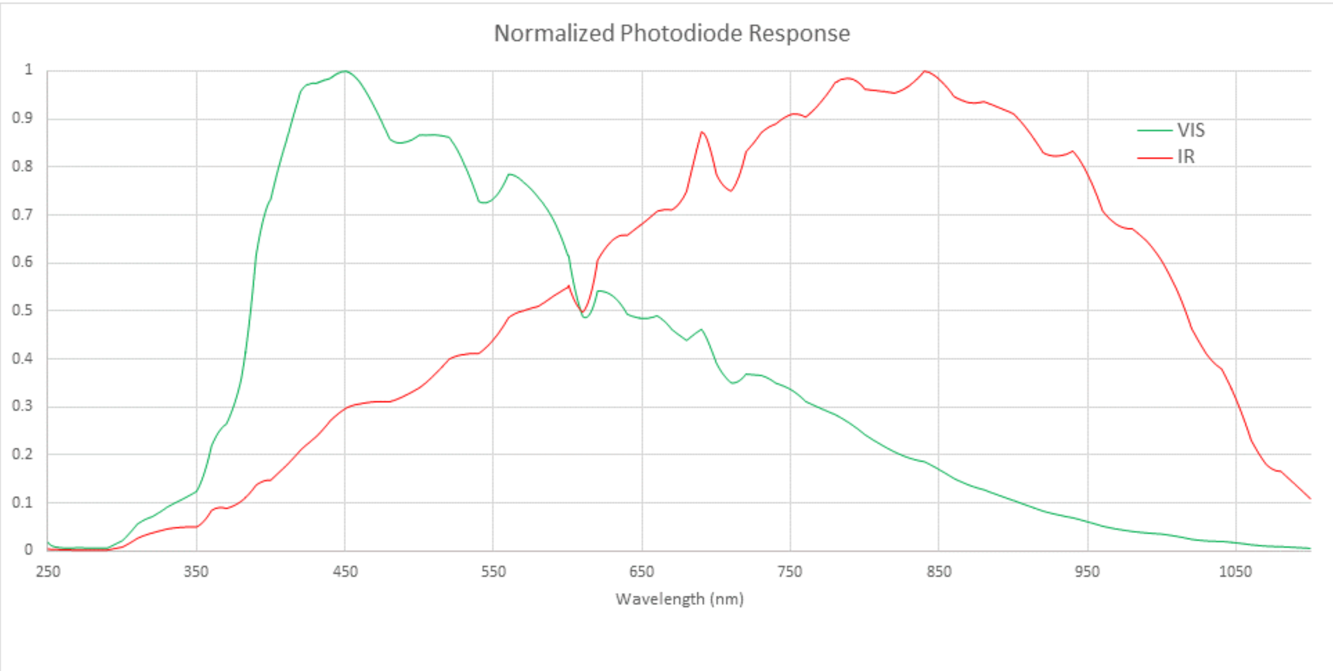

Figure 12. Photodiode Spectral Response to Visible and Infrared Light (Indicative)

2.4. Ultraviolet (UV) Index

The UV Index is a number linearly related to the intensity of sunlight reaching the earth and is weighted according to the CIE Erythemal Action Spectrum as shown in Figure 13. This weighting is a standardized measure of human skin's response to different wavelengths of sunlight from UVB to UVA. The UV Index has been standardized by the World Health Organization and includes a simplified consumer UV exposure level as shown in Figure 14 and Figure 15.

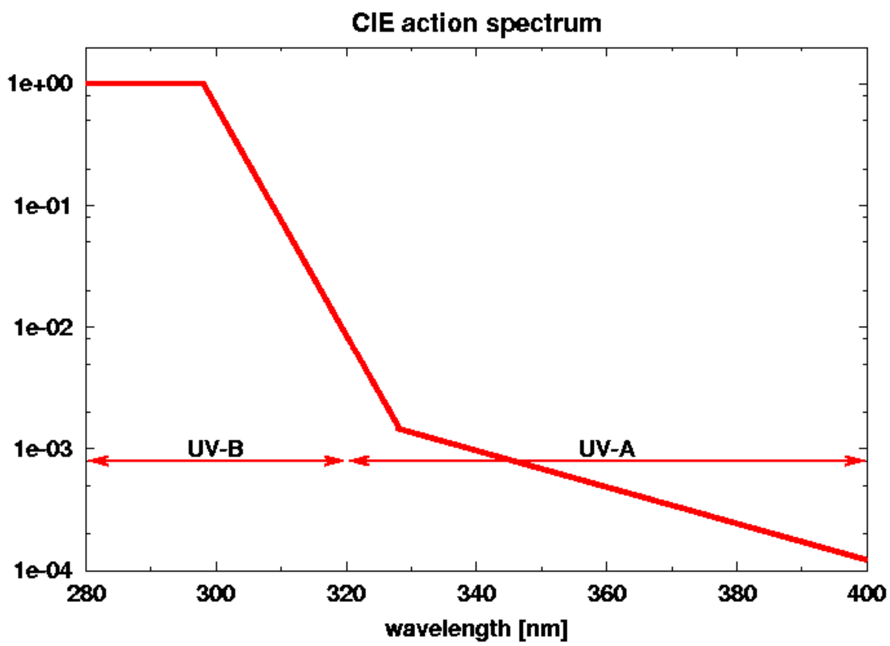

Figure 13. CIE Erythemal Action Spectrum

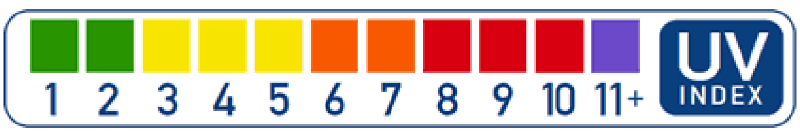

Figure 14. UV Index Scale

Figure 15. UV Levels

To enable UV reading, set the EN_UV bit in CHLIST, and configure UCOEF [0:3] to the default values of 0xDB, 0x8F, 0x01, and 0x00. Also set the VIS_RANGE and IR_RANGE bits. If the sensor will be under an overlay that is not 100% transmissive to sunlight, contact Silicon Labs for more information on adjusting these coefficients.

Typically, after 285 µs, AUX_DATA will contain a 16-bit value representing 100 times the sunlight UV Index. Host software must divide the results from AUX_DATA by 100.

The accuracy of UV readings can be improved by using calibration parameters that are programmed into the Si1145/46/47-M01 at Silicon Labs' production facilities to adjust for normal part-to-part variation. The calibration parameters are recovered from the Si1145/46/47-M01 by writing Command Register @ address 0x18 with the value 0x12.

When the calibration parameters are recovered they show up at I^2C registers 0x22 to 0x2D. These are the same registers used to report the VIS, IR, PS1, PS2, PS3, and AUX measurements.

The use of calibration parameters is documented in the file, Si114x_functions.h, which is part of the Si114x Programmer's Toolkit example source code and is downloadable from Silabs.com. The host code is expected to allocate memory for the SI114X_CAL_S structure. The si114x_calibration routine will then fill it up with the appropriate values.

Once the calibration parameters have been recovered the routine Si114x_set_ucoef is used to modify the default values that go into the UCOEF0 to UCOEF3 UV configuration registers to remove normal part-to-part variation.

The typical calibrated UV sensor response vs. calculated ideal UV Index is shown in Figure 16 for a large database of sunlight spectra from cloudy to sunny days and at various angles of the sun/time of day.

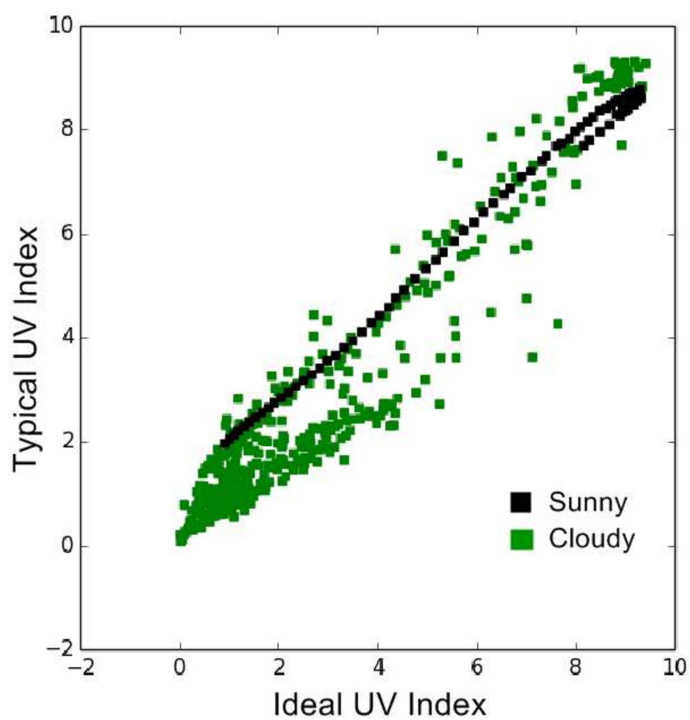

Figure 16. Calibrated UV Sensor Response vs. Calculated Ideal UV Index (AUX_DATA Measurement / 100)

2.5. Host Interface

The host interface to the Si1145/46/47-M01 consists of three pins:

- SCL
- SDA
- INT

SCL and SDA are standard open-drain pins as required for I^2C operation.

The Si1145/46/47-M01 asserts the INT pin to interrupt the host processor. The INT pin is an open-drain output. A pull-up resistor is needed for proper operation. As an open-drain output, it can be shared with other open-drain interrupt sources in the system.

For proper operation, the Si1145/46/47-M01 is expected to fully complete its Initialization Mode prior to any activity on the I^2C.

The INT, SCL, and SDA pins are designed so that it is possible for the Si1145/46/47-M01 to enter the Off Mode by software command without interfering with normal operation of other I^2C devices on the bus.

The Si1145/46/47-M01 I^2C slave address is 0x60. The Si1145/46/47-M01 also responds to the global address (0x00) and the global reset command (0x06). Only 7-bit I^2C addressing is supported; 10-bit I^2C addressing is not supported.

Conceptually, the I^2C interface allows access to the Si1145/46/47-M01 internal registers. Table 15 on page 33 is a summary of these registers.

An I^2C write access always begins with a start (or restart) condition. The first byte after the start condition is the I^2C address and a read-write bit. The second byte specifies the starting address of the Si1145/46/47-M01 internal register. Subsequent bytes are written to the Si1145/46/47-M01 internal register sequentially until a stop condition is encountered. An I^2C write access with only two bytes is typically used to set up the Si1145/46/47-M01 internal address in preparation for an I^2C read.

The I^2C read access, like the I^2C write access, begins with a start or restart condition. In an I^2C read, the I^2C master then continues to clock SCK to allow the Si1145/46/47-M01 to drive the I^2C with the internal register contents.

The Si1145/46/47-M01 also supports burst reads and burst writes. The burst read is useful in collecting contiguous, sequential registers. The Si1145/46/47-M01 register map was designed to optimize for burst reads for interrupt handlers, and the burst writes are designed to facilitate rapid programming of commonly used fields, such as thresholds registers.

The internal register address is a six-bit (bit 5 to bit 0) plus an Autoincrement Disable (on bit 6). The Autoincrement Disable is turned off by default. Disabling the autoincrementing feature allows the host to poll any single internal register repeatedly without having to keep updating the Si1145/46/47-M01 internal address every time the register is read.

It is recommended that the host should read PS or ALS measurements (in the I^2C Register Map) when the Si1145/46/47-M01 asserts INT. Although the host can read any of the Si1145/46/47-M01's I^2C registers at any time, care must be taken when reading 2-byte measurements outside the context of an interrupt handler. The host could be reading part of the 2-byte measurement when the internal sequencer is updating that same measurement coincidentally. When this happens, the host could be reading a hybrid 2-byte quantity whose high byte and low byte are parts of different samples. If the host must read these 2-byte registers outside the context of an interrupt handler, the host should “double-check” a measurement if the measurement deviates significantly from a previous reading.

I^2C Broadcast Reset: The I^2C Broadcast Reset should be sent prior to any I^2C register access to the Si1145/46/47-M01. If any I^2C register or parameter has already been written to the Si1145/46/47-M01 when the I^2C Broadcast Reset is issued, the host must send a reset command and reinitialize the Si1145/46/47-M01 completely.

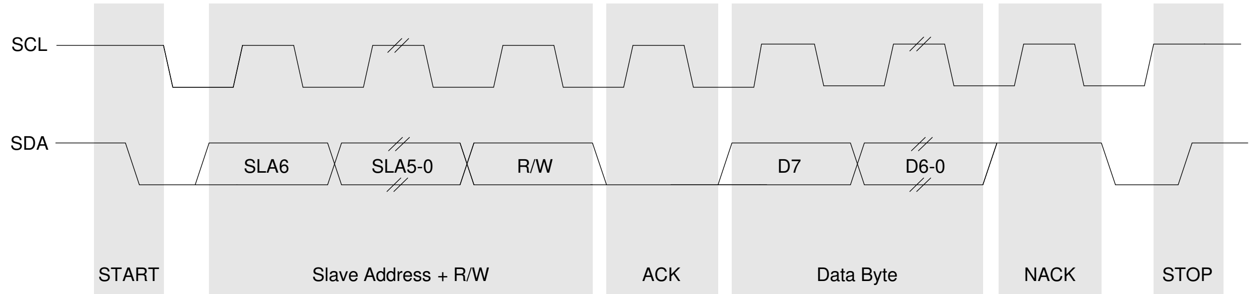

Figure 17. I^{2}C Bit Timing Diagram

S	SLAVE ID	0	A	REG ADDRESS	A	DATA	A	P

Figure 18. Host Interface Single Write

S	SLAVE ID	1	A	DATA	N	STOP

Figure 19. Host Interface Single Read

S	SLAVE ID	0	A	REG ADDRESS	A	DATA	A	DATA	A	DATA	A	P

Figure 20. Host Interface Burst Write

S	SLAVE ID	0	A	REG ADDRESS	A	Sr	SLAVE ID	1	DATA	A	DATA	A	DATA	N	STOP

Figure 21. Host Interface Burst Read

7	6	5:0
0	AI	6 bit address 0x00 to 0x3F

Figure 22. Si1145/46/47-M01 REG ADDRESS Format

Notes:

- Gray boxes are driven by the host to the Si1145/46/47-M01
- White boxes are driven by the Si1145/46/47-M01 to the host
- A = ACK or “acknowledge”
- N = NACK or “no acknowledge”
- S = START condition
- Sr = repeat START condition
- P = STOP condition
- AI = Disable Auto Increment when set

3. Operational Modes

The Si1145/46/47-M01 can be in one of many operational modes at any one time. It is important to consider the operational mode since the mode has an impact on the overall power consumption of the Si1145/46/47-M01. The various modes are:

- Off Mode
- Initialization Mode
- Standby Mode
- Forced Conversion Mode
- Autonomous Mode

3.1. Off Mode

The Si1145/46/47-M01 is in the Off Mode when V_{DD} is either not connected to a power supply or if the V_{DD} voltage is below the stated VDD_OFF voltage described in the electrical specifications. As long as the parameters stated in Table 4, “LED Electro-Optical Characteristics*,” on page 10 are not violated, no current will flow through the Si1145/46/47-M01. In the Off Mode, the Si1145/46/47-M01 SCL and SDA pins do not interfere with other I^2C devices on the bus. The LED pins will not draw current through the infrared diodes. Keeping V_{DD} less than VDD_OFF is not intended as a method of achieving lowest system current draw. The reason is that the ESD protection devices on the SCL, SDA and INT pins also from a current path through V_{DD}. If V_{DD} is grounded for example, then, current flow from system power to system ground through the SCL, SDA and INT pull-up resistors and the ESD protection devices.

Allowing V_{DD} to be less than VDD_OFF is intended to serve as a hardware method of resetting the Si1145/46/47-M01 without a dedicated reset pin.

The Si1145/46/47-M01 can also reenter the Off Mode upon receipt of either a general I^2C reset or if a software reset sequence is initiated. When one of these software methods is used to enter the Off Mode, the Si1145/46/47-M01 typically proceeds directly from the Off Mode to the Initialization Mode.

3.2. Initialization Mode

When power is applied to V_{DD} and is greater than the minimum V_{DD} Supply Voltage stated in Table 1, “Recommended Operating Conditions,” on page 5, the Si1145/46/47-M01 enters its Initialization Mode. In the Initialization Mode, the Si1145/46/47-M01 performs its initial startup sequence. Since the I^2C may not yet be active, it is recommended that no I^2C activity occur during this brief Initialization Mode period. The “Start-up time” specification in Table 1 is the minimum recommended time the host needs to wait before sending any I^2C accesses following a power-up sequence. After Initialization Mode has completed, the Si1145/46/47-M01 enters Standby Mode. The host must write 0x17 to the HW_KEY register for proper operation.

3.3. Standby Mode

The Si1145/46/47-M01 spends most of its time in Standby Mode. After the Si1145/46/47-M01 completes the Initialization Mode sequence, it enters Standby mode. While in Standby Mode, the Si1145/46/47-M01 does not perform any Ambient Light measurements or Proximity Detection functions. However, the I^2C interface is active and ready to accept reads and writes to the Si1145/46/47-M01 registers. The internal Digital Sequence Controller is in its sleep state and does not draw much power. In addition, the INT output retains its state until it is cleared by the host.

I^2C accesses do not necessarily cause the Si1145/46/47-M01 to exit the Standby Mode. For example, reading Si1145/46/47-M01 registers is accomplished without needing the Digital Sequence Controller to wake from its sleep state.

3.4. Forced Conversion Mode

The Si1145/46/47-M01 can operate in Forced Conversion Mode under the specific command of the host processor. The Forced Conversion Mode is entered if either the ALS_FORCE or the PS_FORCE command is sent. Upon completion of the conversion, the Si1145/46/47-M01 can generate an interrupt to the host if the corresponding interrupt is enabled. It is possible to initiate both an ALS and multiple PS measurements with one command register write access by using the PSALS_FORCE command.

3.5. Autonomous Operation Mode

The Si1145/46/47-M01 can be placed in the Autonomous Operation Mode where measurements are performed automatically without requiring an explicit host command for every measurement. The PS_AUTO, ALS_AUTO and PSALS_AUTO commands are used to place the Si1145/46/47-M01 in the Autonomous Operation Mode.

The Si1145/46/47-M01 updates the I^2C registers for PS and ALS automatically. Each measurement is allocated a 16-bit register in the I^2C map. It is possible to operate the Si1145/46/47-M01 without interrupts. When doing so, the host poll rate must be at least twice the frequency of the conversion rates for the host to always receive a new measurement. The host can also choose to be notified when these new measurements are available by enabling interrupts.

The conversion frequencies for the PS and ALS measurements are set up by the host prior to the PS_AUTO, ALS_AUTO, or PSALS_AUTO commands.

4. Programming Guide

4.1. Command and Response Structure

All Si1145/46/47-M01 I^2C registers (except writes to the COMMAND register) are read or written without waking up the internal sequencer. A complete list of the I^2C registers can be found in "4.5. I2C Registers" on page 33. In addition to the I^2C Registers, RAM parameters are memory locations maintained by the internal sequencer. These RAM Parameters are accessible through a Command Protocol (see "4.6. Parameter RAM" on page 48). A complete list of the RAM Parameters can be found in "4.6. Parameter RAM" on page 48.

The Si1145/46/47-M01 can operate either in Forced Measurement or Autonomous Mode. When in Forced Measurement mode, the Si1145/46/47-M01 does not make any measurements unless the host specifically requests the Si1145/46/47-M01 to do so via specific commands (refer to the Section 3.2). The CHLIST parameter needs to be written so that the Si1145/46/47-M01 would know which measurements to make. The parameter MEAS_RATE, when zero, places the internal sequencer in Forced Measurement mode. When in Forced Measurement mode, the internal sequencer wakes up only when the host writes to the COMMAND register. The power consumption is lowest in Forced Measurement mode (MEAS_RATE = 0).

The Si1145/46/47-M01 operates in Autonomous Operation mode when MEAS_RATE is non-zero. The MEAS_RATE represents the time interval at which the Si1145/46/47-M01 wakes up periodically. Once the internal sequencer has awoken, up to three proximity measurements are made (PS1, PS2, and PS3) depending on which measurements are enabled via the lower bits of the CHLIST parameter. All three PS measurements are performed in sequence beginning with the PS1 measurement channel. Up to three measurements are made (ALS_VIS, ALS_IR, and AUX) depending on which measurements are enabled via the upper bits of the CHLIST parameter. All three measurements are made in the following sequence: ALS_VIS, ALS_IR, and AUX.

The operation of the Si1145/46/47-M01 can be described as two measurement groups bound by some common factors. The PS Measurement group consists of the three PS measurements while the ALS Measurement group consists of the Visible Light Ambient Measurement (ALS_VIS), the Infrared Light Ambient Measurement (ALS_IR) and the Auxiliary measurement (AUX). Each measurement group has three measurements each. The Channel List (CHLIST) parameter enables the specific measurements for that measurement grouping.

Each measurement (PS1, PS2, PS3, ALS_VIS, ALS_IR, AUX) are controlled through a combination of I2C Register or Parameter RAM. Tables 7 to 9 below summarize the properties and resources used for each measurement.

4.2. Command Protocol

The I^2C map implements a bidirectional message box between the host and the Si1145/46/47-M01 Sequencer. Host-writable I^2C registers facilitate host-to-Si1145/46/47-M01 communication, while read-only I^2C registers are used for Si1145/46/47-M01-to-host communication.

Unlike the other host-writable I^2C registers, the COMMAND register causes the internal sequencer to wake up from Standby mode to process the host request.

When a command is executed, the RESPONSE register is updated. Typically, when there is no error, the upper four bits are zeroes. To allow command tracking, the lower four bits implement a 4-bit circular counter. In general, if the upper nibble of the RESPONSE register is non-zero, this indicates an error or the need for special processing.

The PARAM_WR and PARAM_RD registers are additional mailbox registers.

In addition to the registers in the I^2C map, there are environmental parameters accessible through the Command/ Response interface. These parameters are stored in the internal ram space. These parameters generally take more I^2C accesses to read and write. The Parameter RAM is described in "4.6. Parameter RAM" on page 48.

For every write to the Command register, the following sequence is required:

1. Write 0x00 to Command register to clear the Response register.
2. Read Response register and verify contents are 0x00.
3. Write Command value from Table 5 into Command register.
4. *Read the Response register and verify contents are now non-zero*. If contents are still 0x00, repeat these steps.

The Response register will be incremented upon the successful completion of a Command. If the Response register remains 0x00 for over 25 ms after the Command write, the entire Command process should be repeated from Step 1.

Step 4 above is not applicable to the Reset Command because the device will reset itself and does not increment the Response register after reset. No Commands should be issued to the device for at least 1 ms after a Reset is issued.