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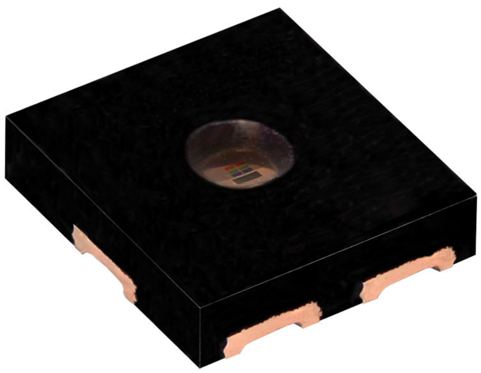
Application Note

Designing the VEML6046X00 Into an Application

By Stephen Widenmeyer and Rene Schulreich



ABSTRACT

This application note provides an introduction to the functionality of the VEML6046X00 sensor, application circuits, and mechanical design considerations.

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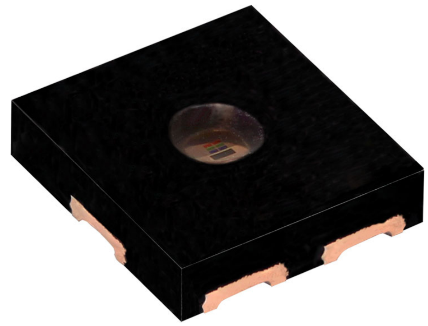
1. INTRODUCTION

The VEML6046X00 is a high accuracy digital ambient light sensor with 16-bit resolution in a miniature opaque 2.67 mm x 2.45 mm package. It includes a high sensitivity photodiode, low noise amplifier, and 16-bit A/D converter, and supports an easy to use I^2C bus communication interface and additional interrupt feature.

The ambient light read-out is available as a digital value, and the built-in photodiode response is near that of the human eye. The 16-bit dynamic range offers ambient light detection up to about 176 klx, with a resolution down to 0.0053 lx/counts.

Besides 100 Hz and 120 Hz flicker noise rejection and a low temperature coefficient, the device consumes just 0.5 µA in shutdown mode. The sensor is AEC-Q100 qualified and has an operating range from -40 °C to +110 °C.



The device's high senstivity of 0.0053 lx/counts allows the sensor to be placed behind very dark cover glasses that will dramatically reduce the total light reaching it. The sensor will also work behind clear cover glass, because even high illumination - such as daylight and all indoor lights - will not saturate the device and read-outs up to 176 klx are possible.

2. PIN DESCRIPTION AND BLOCK DIAGRAM

2.1 Pin Description

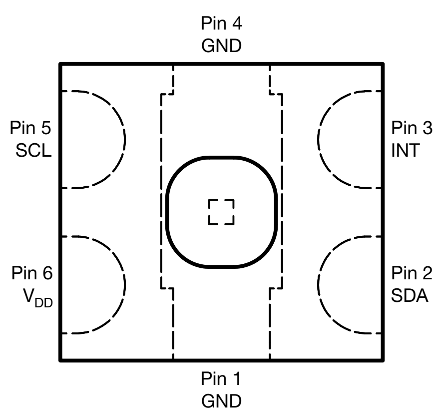


Fig. 1 - Pin Assignment (top view) of the VEML6046X00

TABLE 1 - PIN DESCRIPTION

PIN NUMBER	PIN NAME	TYPE	DESCRIPTION
1	GND	I	Ground
2	SDA	I / O (open drain)	I^2C serial data
3	INT	O (open drain)	Interrrupt
4	GND	I	Ground
5	SCL	I / O (open drain)	I^2C serial clock
6	V_{DD}	I	Supply voltage

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2.2 Block Diagram

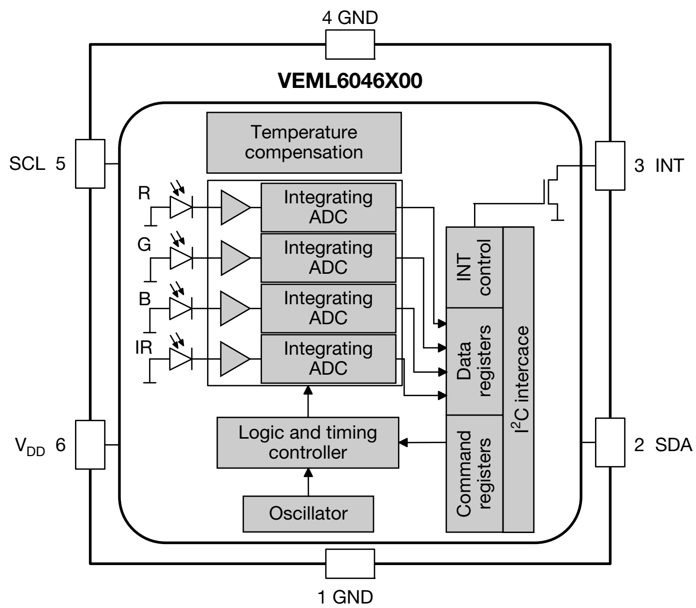

Fig. 2 - Block Diagram

TABLE 2 - BLOCK DIAGRAM DESCRIPTION	
COMPONENT	DESCRIPTION
Command registers	Memory storage for writing and reading I^2C commands
I^2C interface	I^2C interface with active low open drain circuitry
Interrupt control	Interrupt control with active low open drain output
R, G, B, IR	The photodiode of the R, G, B, and IR channels that is converting the received light into a photocurrent, which is then fed into the 16-bit ADC
Integrating ADC	16-bit analog to digital converter converts the analog signal to the digital signal (1); then, the input signal is amplified with an amplifier
Logic & timing controller	Control timer for the proximity measurement
Temperature compensation	Internal temperature compensation structure
Oscillator	Generate internal clock signal

Note

(1) The actual bit resolution is 16 bit for integration times up to 6.25 ms. For 3.125 ms, the 16 bit can no longer be achieved. Please see the resolution table for more detailed information

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3. APPLICATION CIRCUIT

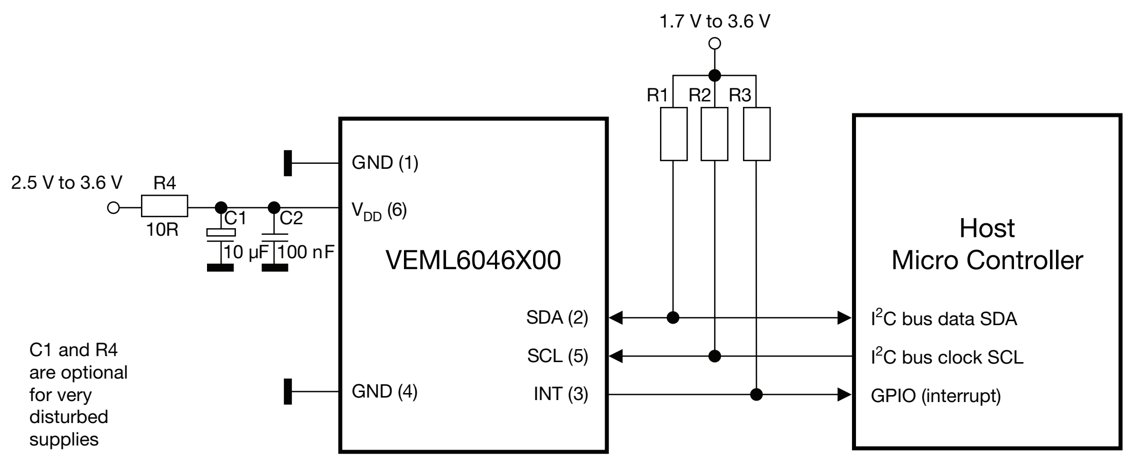

Fig. 3 - Application Circuity to Communicate With the VEML6046X00 via I²C

TABLE 3 - APPLICATION CIRCUIT PARAMETERS		
CIRCUIT PARAMETER	**VALUE**	**DESCRIPTION**
V_{DD}	2.5 V to 3.6 V	A stable power supply, such as a low dropout regulator or a switching regulator, is required; the power supply isolation can be further improved with a decoupling capacitor C_1
C_1 - C_2	100 nF to 1 µF	Decoupling capacitors are recommended to reduce the noise in the supply voltage
R_1 - R_2	2.2 kΩ to 4.7 kΩ	Pull-up resistors within the range of 2.2 kΩ to 4.7 kΩ are recommended; any increase in bus capacitance or resistance will increase the logic-high transition time
R_3	4.7 kΩ to 22 kΩ	A pull-up resistor within the range of 4.7 kΩ to 22 kΩ is recommended
R_4	10 Ω	Decoupling resistor for noise rejection

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4. REGISTER DESCRIPTION

4.1 DEVICE ADDRESS

The predefined 7-bit I^{2}C bus slave address of the VEML6046X00 is set to 0101001 = 0x29.

The 7-bit address can be converted into the 8-bit slave address by adding another bit to the 8-bit command. The least significant bit (LSB) then defines the read or write mode, which results in the 8-bit address of 0101 0010 = 0x52 for write and 0101 0011 = 0x53 for read.

TABLE 4 - REGISTER NAME: DEVICE ADDRESS

ORDERING CODE	7-BIT SLAVE ADDRESS	8-BIT SLAVE ADDRESS	
VEML6046X00	0x29	0x52 (write)	0x53 (read)

4.2 REGISTER OVERVIEW

The sensor has eighteen user-accessible registers from 0x00 to 0x1B (0x02 and 0x03, 0x08 to 0x0F, and 0x16 are not defined / reserved) with different functionalities. Note that due to the location of the two shutdown bits (SD_ON_0 in register 0x00 and SD_ON_1 in register 0x01), it is necessary to always write to both registers at once when configuring the device.

TABLE 5 - REGISTER OVERVIEW

COMMAND CODE	DATA BYTE LOW / HIGH	REGISTER NAME	DEFAULT VALUE	FUNCTION	ACCESS
0x00	-	RGB_CONF_0	0x01	Set the integration time Measurement mode of the sensor Enable interupt function of the green channel Switch the sensor on / off	Write and read
0x01	-	RGB_CONF_1	0x80	Switch the sensor on / off GAIN and photodiode size setting Interrupt persistance counter	Write and read
0x04	Low	G_THDH_L	0x00	Green channel high threshold window setting (low byte)	Write and read
0x05	High	G_THDH_H	0x00	Green channel high threshold window setting (high byte)	Write and read
0x06	Low	G_THDL_L	0x00	Green channel low threshold window setting (low byte)	Write and read
0x07	High	G_THDL_H	0x00	Green channel low threshold window setting (high byte)	Write and read
0x10	Low	R_DATA_L	0x00	Low byte of 16-bit red channel result data	Read only
0x11	High	R_DATA_H	0x00	High byte of 16-bit red channel result data	Read only
0x12	Low	G_DATA_L	0x00	Low byte of 16-bit green channel result data	Read only
0x13	High	G_DATA_H	0x00	High byte of 16-bit green channel result data	Read only
0x14	Low	B_DATA_L	0x00	Low byte of 16-bit blue channel result data	Read only
0x15	High	B_DATA_H	0x00	High byte of 16-bit blue channel result data	Read only
0x16	Low	IR_DATA_L	0x00	Low byte of 16-bit IR channel result data	Read only
0x17	High	IR_DATA_H	0x00	High byte of 16-bit IR channel result data	Read only
0x18	Low	VEML6046X00_ID_L	0x01	ID code	Read only
0x19	High	VEML6046X00_ID_H	0x00	ID code	Read only
0x1A	Low	INT_FLAG	0x00	Reserved	Read only
0x1B	High	INT_FLAG	0x00	Interrupt and active force mode event flag	Read only

Notes

- Command code 0x00 default value is 0x01 = device is shutdown
- Command 0x00 and command 0x01 must be executed together, they cannot be executed independently

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4.3 SENSETIVITY SETTINGS OF THE SENSOR

The resolution of the R, G, B, and IR channels can be determined by the setting of the integration time, the gain factor, and the PD size. The IT, GAIN factor, and PD size cannot be determined individually for each channel and are therefore applied to all four channels simultaneously.

To achieve the highest resolution of 0.0053 lx/counts for the green channel, the max. integration time (400 ms), max. GAIN (gain x 2), and the complete photodiode size (RGB_PDDIV, 2/2 PD used) need to be applied. Accordingly, with the lowest resolution of 2.6624 lx/counts for the green channel, at the min. integration time (6.25 ms), min. GAIN (gain x 0.5), and one half of the photodiode size (RGB_PDDIV, 1/2 PD used), the max. illumination level of 174 klx is achievable.

Integration Time Setting

The integration time of the sensor determines its sensitivity, as well as its measurement rate. Hence an increase in the sampling rate can be achieved by decreasing the integration time of the sensor, but this will accordingly result in a reduction of the sensor's sensitivity. The bit RGB_IT in the command code RGB_CONF_0 (0x00) can be used to set the integration time.

TABLE 6 - INTEGRATION TIME

COMMAND CODE (RGB_CONF_0)			0x00	
BIT NAME	**FUNCTION**	**BIT**	**VALUE**	**DESCRIPTION**
RGB_IT	Set the integration time	6 : 4	0x0 (0b000)	3.125 ms (default)
			0x1 (0b001)	6.25 ms
			0x2 (0b010)	12.5 ms
			0x3 (0b011)	25 ms
			0x4 (0b100)	50 ms
			0x5 (0b101)	100 ms
			0x6 (0b110)	200 ms
			0x7 (0b111)	400 ms

Remark: For the integration time of 3.125 ms, the max. available resolution of the output channel is around 15 bit, which accordingly no longer leads to a doubling of the achievable illumination level.

GAIN and PD Size Setting

In command code RGB_CONF_1 (0x01), the bits RGB_PDDIV and RGB_GAIN can be used to adjust the GAIN settings of the VEML6046X00. The settings are irrespective of the channel and will be applied to all of them simultaneously. The RGB_PDDIV changes the effective size of the photodiode. This change will lead to a halving of the sensitivity when applied. The RGB_GAIN sets the internal gain factor and additionally can be used to further tune the sensitivity of the sensors. Please refer to Table 13 and Table 14 from the datasheet to get the best settings for the expected illumination level.

TABLE 7 - GAIN

COMMAND CODE (RGB_CONF_1)			0x01	
BIT NAME	**FUNCTION**	**BIT**	**VALUE**	**DESCRIPTION**
RGB_PDDIV	Set the effective photodiode size for the R,G,B, and IR channel	6	0x0 (0b0)	2/2 PD used
			0x1 (0b1)	1/2 PD used
RGB_GAIN	Set the gain of the RGB	4 : 3	0x0 (0b00)	Gain x1
			0x1 (0b01)	Gain x2
			0x2 (0b10)	Gain x0.66
			0x3 (0b11)	Gain x0.5

Remark: Possible saturation effects during the measurement start can be avoided if the application starts with the lowest gain setting: GAIN x 0.5, PD_DIV = 1 (1/2 PD used). The setting GAIN x2 and PD_DIV = 0 (2/2 PD used) should only be used if a high resolution is necessary. For example, if the sensor is placed under a dark cover glass where the illumination level is reduced to a low level.

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4.4 BASIC INITZIALIZATION

Active Force and Selftimed Mode

The sensor can be configured in selftimed or active force mode. When the sensor is configured in selftimed mode the measurements are performed continuously until the measurement is stopped. Within the active force mode every measurement must be individually triggered via a software command. Unless not specifically needed due to the application requirements, the selftimed mode is the recommended operating mode. Per default, the sensor is operated in the selftimed mode.

The below figures show the basic initialization flow chart of both modes.

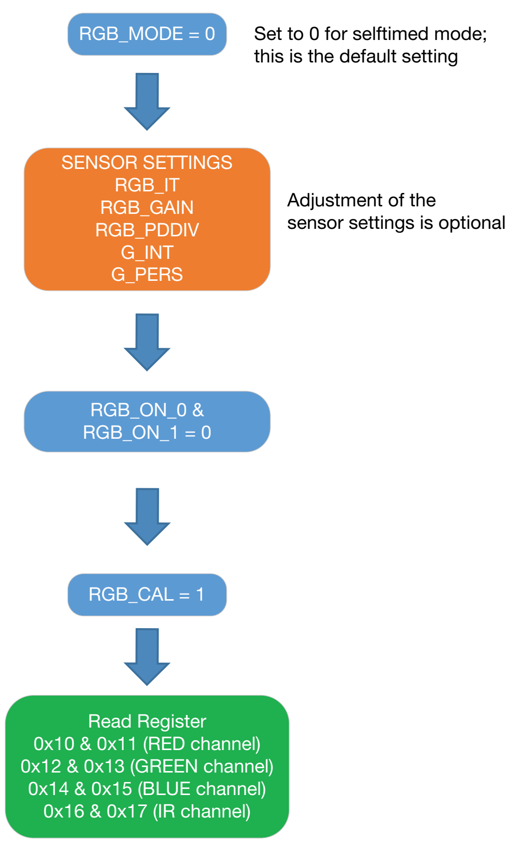

Fig. 4 - Basic Initialization for Selftimed Mode

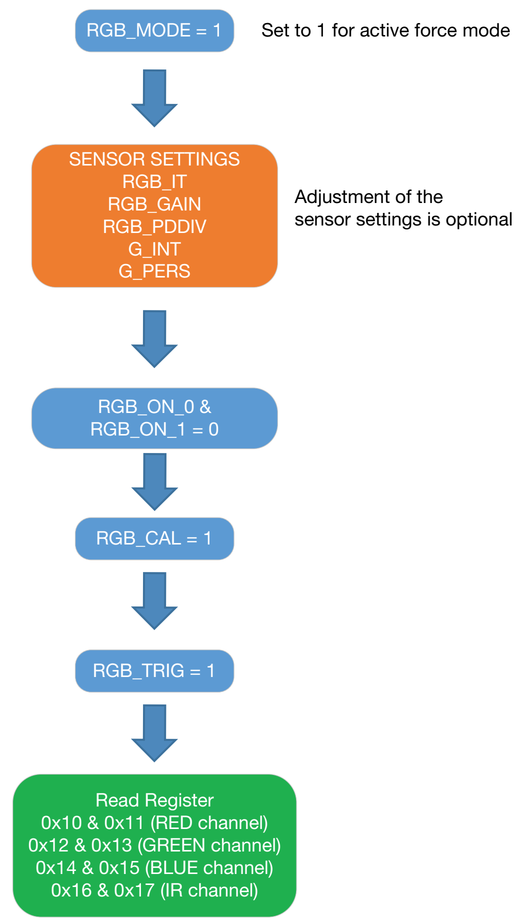

Fig. 5 - Basic Initialization for Active Force Mode

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Automatic Gain Control

When the sensor is exposed to a wide range of illumination levels that cannot be covered with one set of sensitivity, the sensitivity of the sensor needs to be adjusted dynamically according to the received illumination level. This can be achieved by adjusting the GAIN and integration time settings of the sensor dynamically by implementing an automatic gain adjustment (AGC) into the software.

The below flow chart shows a general AGC approach based on the green channel results. Nevertheless, this concept can also be applied to all the other channels within the VEML6046X00.

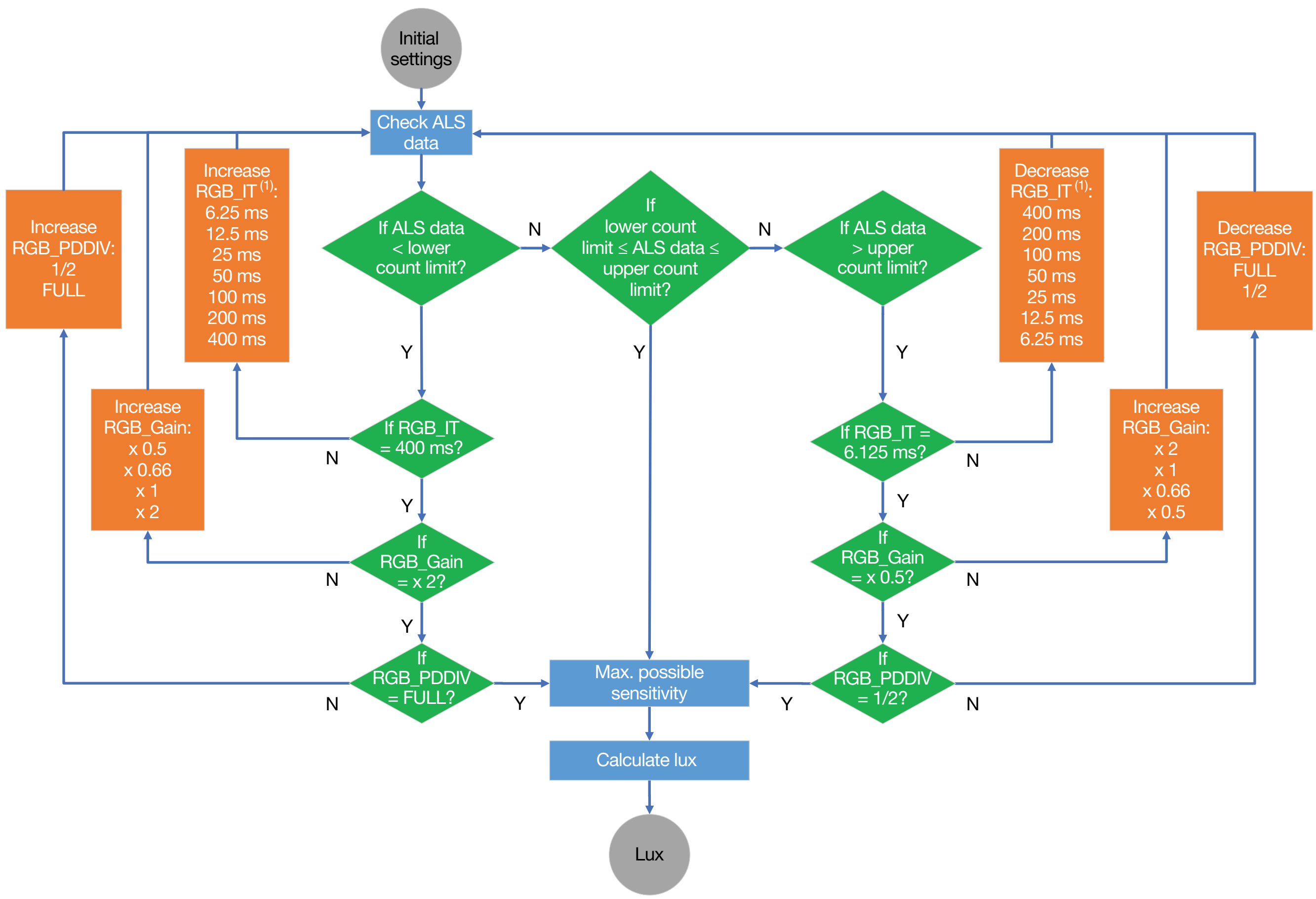

Fig. 6 - VEML6046X00 AGC

Note

- The integration time of 3.125 ms should not be used in the AGC algorithm because the data is no longer 16 bit

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4.5 INTERRUPT HANDLING

As discussed in more detail in Chapter 6 (Ambient Light Measurement), the green channel has a close match to the human eye response (V_λ) and can therefore be used for ambient light measurements. The interrupt feature of the VEML6046X00 focuses on the green channel results of the sensor only, and is not available for the other channels. The interrupt can be used to reduce the interactions between the sensor and the microcontroller. The interrupt mode can be enabled with the G_INT bit in register RGB_CONF_0 (0x00).

TABLE 8 - INTERRUPT				
COMMAND CODE (RGB_CONF_1)			0x01	
BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
G_INT	Enable / disable the interrupt function of the green channel	1	0x0 (0b0)	Disable (default)
			0x1 (0b1)	Enable

Persistence Settings

The persistence function G_PERS determines the number of consecutive measurements that have to remain above or below the chosen threshold level to activate the interrupt pin.

TABLE 9 - PERSISTANCE				
COMMAND CODE (RGB_CONF_1)			0x01	
BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
G_PERS	Set the amount of consecutive threshold crossing events necessary to trigger the interrupt	2 : 1	0x0 (0b00)	1 time (default)
			0x1 (0b01)	2 times
			0x2 (0b10)	4 times
			0x3 (0b11)	8 times

Interrupt Thresholds

The high and low threshold levels for the interrupt can be set individually. In register G_THDH - 0x04, the 0x05 high threshold window can be determined.

TABLE 10 - INTERRUPT HIGH THRESHOLD							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
G_THDH_L							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
G_THDH_H							
COMMAND	BIT NAME	FUNCTION		BIT	VALUE	DESCRIPTION	
0x04	G_THDH_L	Set the high threshold interrupt value		7 : 0	0 to 65 535	Low byte	
0x05	G_THDH_H			7 : 0		High byte	

In register G_THDL - 0x06, the 0x07 low threshold window can be determined.

TABLE 11 - INTERRUPT LOW THRESHOLD							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
G_THDL_L							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
G_THDL_H							
COMMAND	BIT NAME	FUNCTION		BIT	VALUE	DESCRIPTION	
0x06	G_THDL_L	Set the low threshold interrupt value		7 : 0	0 to 65 535	Low byte	
0x07	G_THDL_H			7 : 0		High byte	

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Interrupt Results

With the bits G_IF_L and G_IF_H in register 0x1B, the interrupt flags for the high and low thresholds can be monitored. The interrupt flag is triggered as soon as the required number of consecutive measurements, determined by the persistence counter, is exceeded. The reading of the interrupt flag automatically clears the interrupt function. The next activation of the interrupt happens as soon as the applied threshold is exceeded again. When the interrupt is cleared and still remains within the limits of the determined threshold, no consecutive activation is triggered. At first the measurement must cross the threshold again to be able to trigger the interrupt flag again. In addition to the interrupt flag, the interrupt pin (pin 3) of the sensor is pulled low immediately when the interrupt flag is triggered.

TABLE 12 - INTERRUPT FLAG

COMMAND CODE	BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
0x1B	G_IF_L	Low threshold interupt flag	2	0x0 (0b0)	No low threshold crossing
				0x1 (0b1)	Low threshold crossing interrupt event flag for the green channel
	G_IF_H	High threshold interupt flag	1	0x0 (0b0)	No high threshold crossing
				0x1 (0b1)	High threshold crossing interrupt event flag for the green channel

4.6 READ-OUT MEASUREMENT RESULTS

The output values of the RGB-IR channels are stored in the dedicated output registers. The raw value always consists of two bytes. The values can be read out as soon as the measurement cycle is completed. The VEML6046X00 stores the last results of all the channels before the device is shut down, keeping the data accessible. When the VEML6046X00 is in shutdown mode, the host can freely read this data via the read command directly. The sensor will lose the data as soon as it is disconnected from the V_{DD}.

Red Channel Measurement Results

The command codes 0x10 and 0x11 (R_DATA) contain the measurement results of the red channel. The low byte is stored in the command code 0x10 (R_DATA_L) while the command code 0x11 (R_DATA_H) accesses the red channel results from the high byte.

TABLE 13 - REGISTER NAME: R_DATA

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
R_DATA_L							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
R_DATA_H							

COMMAND	BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
0x10	R_DATA_L	Read the red channel output data	7 : 0	0 to 65 535	Low byte
0x11	R_DATA_H		7 : 0		High byte

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Green Channel Measurement Results

The command codes 0x12 and 0x13 (G_DATA) contain the green channel / ambient light measurement results. The low byte is stored in the command code 0x12 (G_DATA_L), while the command code 0x13 (G_DATA_L) accesses the high byte of the green channel results.

TABLE 14 - REGISTER NAME: G_DATA							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
G_DATA_L							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
G_DATA_H							

COMMAND	BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
0x12	G_DATA_L	Read the green channel output data	7 : 0	0 to 65 535	Low byte
0x13	G_DATA_H		7 : 0		High byte

Blue Channel Measurement Results

The command codes 0x14 and 0x15 (B_DATA) contain the blue channel measurement results. The low byte is stored in the command code 0x14 (B_DATA_L), while the command code 0x15 (B_DATA_H) accesses the high byte of the blue channel results.

TABLE 15 - REGISTER NAME: B_DATA							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
B_DATA_L							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
B_DATA_H							

COMMAND	BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
0x14	B_DATA_L	Read the blue channel output data	7 : 0	0 to 65 535	Low byte
0x15	B_DATA_H		7 : 0		High byte

IR Channel Measurement Results

The command codes 0x16 and 0x17 (IR_DATA) contain the IR channel measurement results. The low byte is stored in the command code 0x16 (IR_DATA_L), while the command code 0x17 (IR_DATA_H) accesses the high byte of the IR measurement results.

TABLE 16 - REGISTER NAME: IR_DATA							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
IR_DATA_L							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
IR_DATA_H							

COMMAND	BIT NAME	FUNCTION	BIT	VALUE	DESCRIPTION
0x16	IR_DATA_L	Read the IR channel output data	7 : 0	0 to 65 535	Low byte
0x17	IR_DATA_H		7 : 0		High byte

5. I²C AND TIMING

5.1 I²C WRITE AND READ PROTOCOL

The communication with the VEML6046X00 can be performed via I²C. The I²C write and read protocol when communicating with the proximity sensor is shown in Fig. 7.

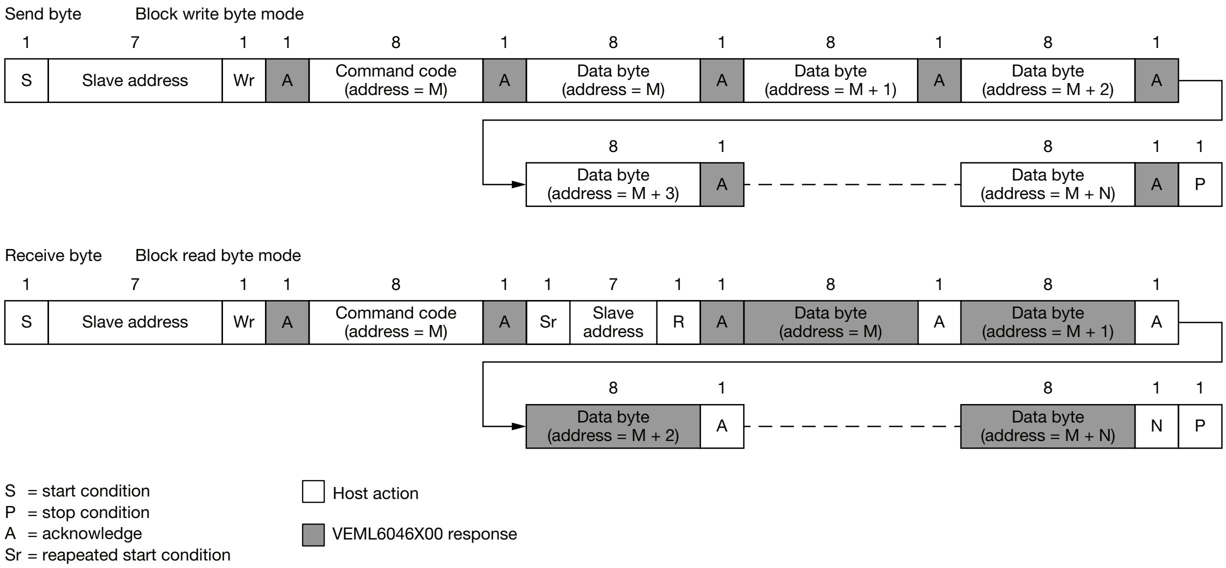

Fig. 7 - Send Byte / Receive Byte Protocol

It is imperative that only the restart condition for the I²C read is implemented instead of the stop and restart condition. For example, Fig. 8 shows an oscilloscope screenshot of the SCL and SDA line when reading the register VEML6046X00_ID for the VEML6046X00 with a slave address of 0x29. Here, the restart condition, indicated by the blue box, has been implemented and the data of 0x01 for the low byte and 0x00 matches the default values of the VEML6046X00_ID register stated in the datasheet.

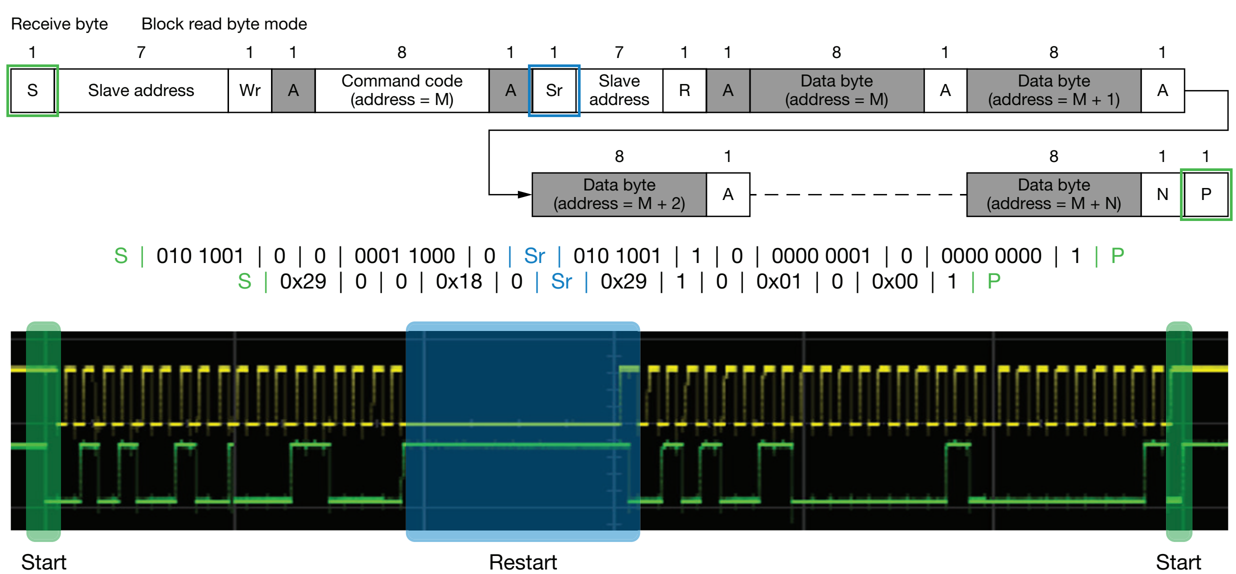

Fig. 8 - I²C Read With Necessary Repeated Start Condition

On the other hand, Fig. 9 shows the logic analyzer screenshot, but with an incorrect read I²C protocol when reading the register VEML6046X00_ID. Here, the stop and restart conditions have been applied, causing an error in the data field. As a result, the sensor writes a constant 0x00 in the VEML6046X00_ID register.

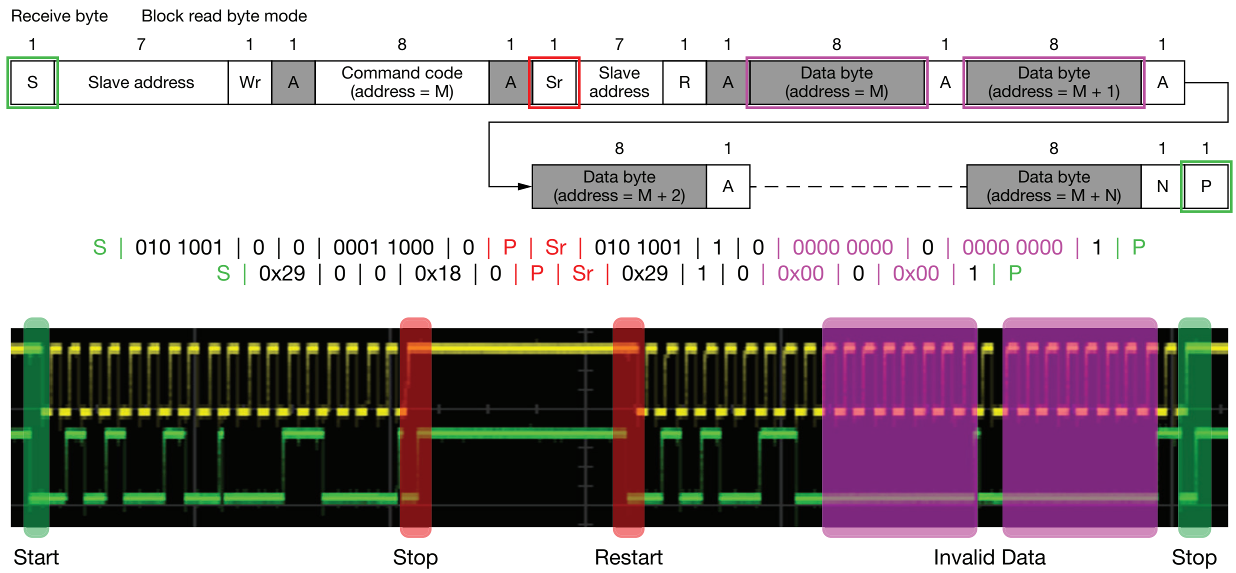

Fig. 9 - I²C Read With Invalid Stop and Read Condition

Therefore, the designer should use the correct I²C library, especially the I²C read, from the microcontroller manufacturer that implements only the restart condition, without the stop condition before the restart condition. This is a typical mistake when communicating with the VEML6046X00_ID, as shown in Fig. 9.

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6. AMBIENT LIGHT MEASUREMENT

The spectral characteristics of the green channel match well to the so-called "Human Eye" v(λ) curve (Fig. 10). Accordingly, reading the 16-bit green channel and multiplying the data with the given resolution, based on the selected sensitivity, will lead to an accurate ALS result in lux.

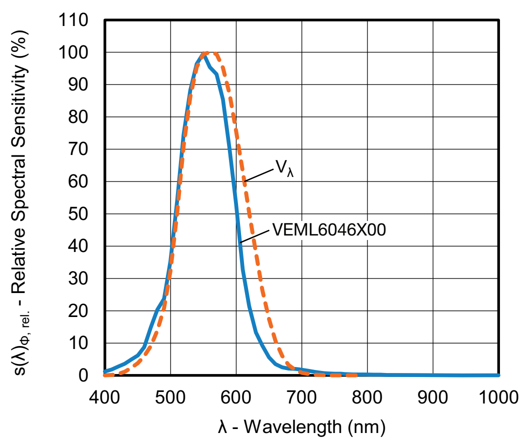

Fig. 10 - Spectral Response vs. Wavelength

6.1 CALCULATING THE LUX LEVEL

The command codes 0x12 and 0x13 contain the results of the green channel measurement. As the green channel matches the human-eye response, this 16-bit code can be converted into an illuminance (lux) level. Therefore, the measured count level needs to be multiplied with the given resolution at the applied settings. The resolution changes linearly over the corresponding settings. For example, every time the integration time is halved, the resolution is doubled. The adjustment of the resolutions due to the setting change leads to a wide dynamic range of the sensor from the sub lux range up to 176 klx. Table 17 contains all the available resolutions and maximum possible illumination levels with regard to the applied setting combinations.

TABLE 17 - RESOLUTION AND MAXIMUM DETECTION RANGE AT RGB_PDDIV (2/2 PD USED)

	TYPICAL RESOLUTION (lx/cnt)					MAXIMUM POSSIBLE ILLUMINATION (lx)			
	RGB_GAIN					RGB_GAIN			
IT (ms)	x2	x1	x0.66	x0.5		x2	x1	x0.66	x0.5
400	0.0053	0.0105	0.0159	0.0210		344	688	1043	1376
200	0.0105	0.0210	0.0318	0.0420		688	1376	2085	2752
100	0.0210	0.0420	0.0636	0.0840		1376	2752	4170	5505
50	0.0420	0.0840	0.1273	0.1680		2752	5505	8341	11 010
25	0.0840	0.1680	0.2545	0.3360		5505	11 010	16 682	22 020
12.5	0.1680	0.3360	0.5091	0.6720		11 010	22 020	33 363	44 040
6.25	0.3360	0.6720	1.0182	1.3440		22 020	44 040	66 727	88 079
3.125	0.6720	1.3440	2.0364	2.6880		(-) (1)	(-) (1)	(-) (1)	(-) (1)

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TABLE 18 - RESOLUTION AND MAXIMUM DETECTION RANGE AT RGB_PDDIV (1/2 PD USED)

	TYPICAL RESOLUTION (lx/cnt)					MAXIMUM POSSIBLE ILLUMINATION (lx)			
	RGB_GAIN					RGB_GAIN			
IT (ms)	x2	x1	x0.66	x0.5		x2	x1	x0.66	x0.5
400	0.0105	0.0210	0.0318	0.0420		688	1376	2085	2752
200	0.0210	0.0420	0.0636	0.0840		1376	2752	4170	5505
100	0.0420	0.0840	0.1273	0.1680		2752	5505	8341	11 010
50	0.0840	0.1680	0.2545	0.3360		5505	11 010	16 682	22 020
25	0.1680	0.3360	0.5091	0.6720		11 010	22 020	33 363	44 040
12.5	0.3360	0.6720	1.0182	1.3440		22 020	44 040	66 727	88 079
6.25	0.6720	1.3440	2.0364	2.6880		44 040	88 079	133 453	176 158
3.125	1.3440	2.6880	4.0727	5.3760		(-) [1]	(-) [1]	(-) [1]	(-) [1]

Note

[1] For an integration time of 3.125 ms, the maximum count level is no longer 16 bit, so, half the integration time no longer leads to double the max. lux level.

Example

The example shows the conversion of the 16-bit raw values measured by the sensor into an illuminance value. At the programmed setting are RGB_IT = 100ms, RGB_GAIN = x1, and RGB_PDDIV (2/2 used), and an assumed measurement result of 1480(dec) counts from the sensor.

$$\text{Illuminance} = \text{resolution} \times \text{raw value green channel} \quad (1)$$

$$\text{Illuminance} = 0.0420\ \text{lx/cts} \times 1480\ \text{cts}$$

With Formula (1), this leads to an illuminance of 62.16 lx at the given settings.

IT, GAIN, and PD Size Settings

The output value of the sensor is linear across the integration (RGB_IT), gain (RGB_GAIN), and photodiode size (RGB_PDDIV) settings, respectively.

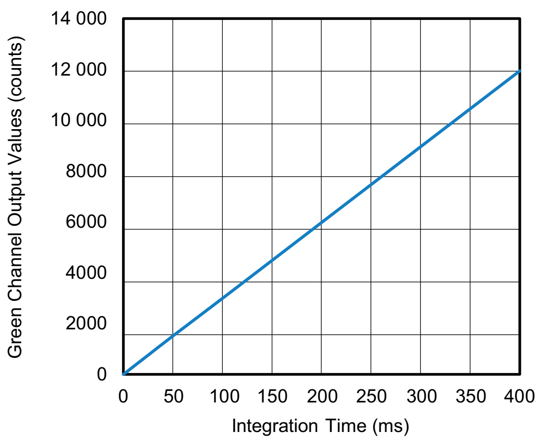


Fig. 11 - Linearity of the Integration Time

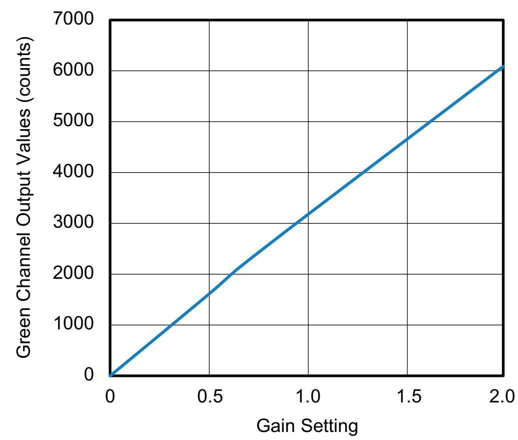


Fig. 12 - Linearity of the Gain

The integration time has a linear relationship to the output value in counts. A doubling in the integration time leads to a doubling in counts.

Designing the VEML6046X00 Into an Application

6.2 AMBIENT LIGHT MEASUREMENT OVER DIFFERENT LIGHT SOURCES

The VEML6046X00 shows very good matching for all kinds of light sources. The results are based on the green channel results of the VEML6046X00.

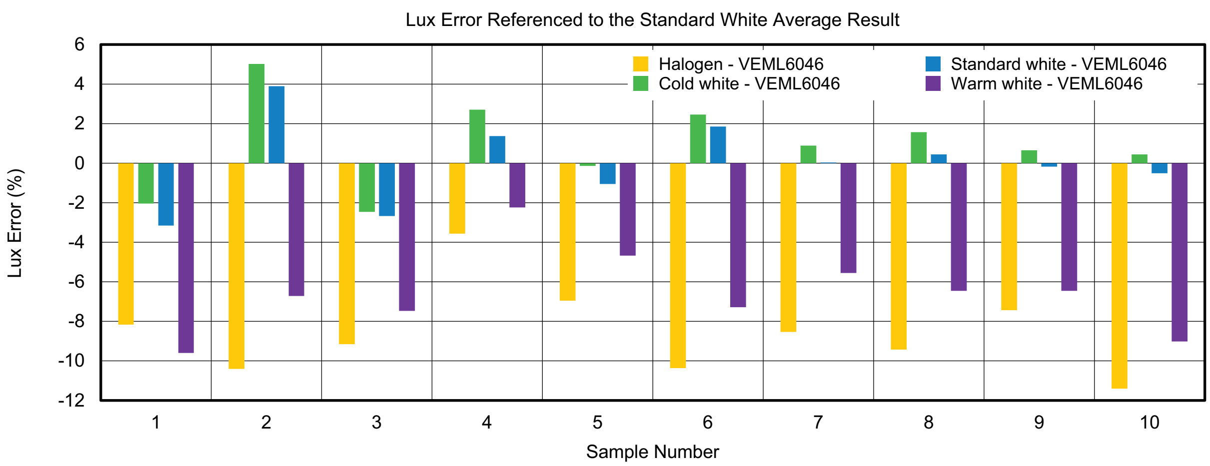


Fig. 13 - Tolerances for Different Light Sources

6.3 GATHERING ADDITIONAL INFORMATION WITH THE IR CHANNEL

In addition to the RGB channels, the sensor also has an IR channel available, which offers a much higher responsivity for light with wavelengths > 800 nm.

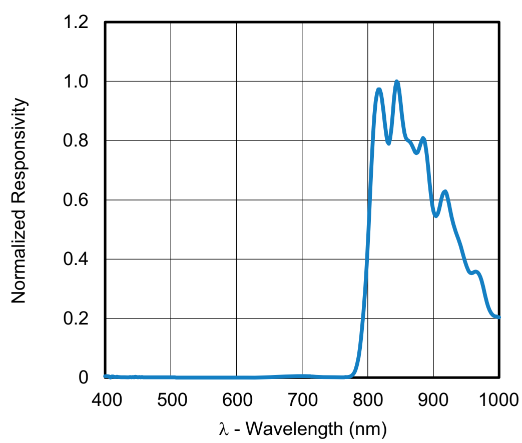


Fig. 14 - IR Channel Response

Due to the fact that the sensor can be exposed to light sources with different spectral responses, it can be helpful for an application to be able to differentiate between those light sources and react accordingly. The additional IR channel offers the possibility of doing a light source differentiation based on the IR content measured with the IR channel. A ratio between the IR and ALS channel can be calculated to determine the amount of IR light within the light source's spectrum. This easily allows, for example, for the differentiation between a halogen bulb and an LED light.

Designing the VEML6046X00 Into an Application

7. CCT CALCULATION AND COLOR DETECTION

The main use case for color sensors, compared to ambient light sensors, is to obtain more information about the measured light due to the information provided by the RGB channels. With the those values, a calculation of the color temperature or the determination of color codes is possible. This can be used to implement white point balancing for displays or for optical encoding. This chapter provides information on how the raw counts, which are provided by the sensor, can be transferred into actual color information like x, y coordinates in the chromaticity diagram, or even calculate correlated color temperature (CCT) values.

7.1 CORRELATED COLOR TEMPERATURE (CCT)

Another major application of an RGB sensor is to sense the CCT. This information can then be used in a feedback system to control a light source, such as a television backlight or an LED array. This can help to maintain the light source's output with reference to drifts associated with aging and temperature changes. Ambient light conditions in a room may also be monitored, so that backlights can be adjusted to make the screen appear more appealing to the human eye. The procedure for calculating the CCT from the sensors' raw RGB channels is explained below.

XYZ Tristimukus Values and the Color Gamut

In order to help define a light source to specific common parameters, the International Commission on Illumination (CIE) has defined a color space called the XYZ color space. These XYZ values are called the "tristimulus" values. The color space calls upon a set of specified spectral sensitivity functions, called the color matching functions, from which the tristimulus values are derived. The tristimulus values are arrived at by integrating over the visible spectrum. The color matching functions and the corresponding tristimulus values are shown below:

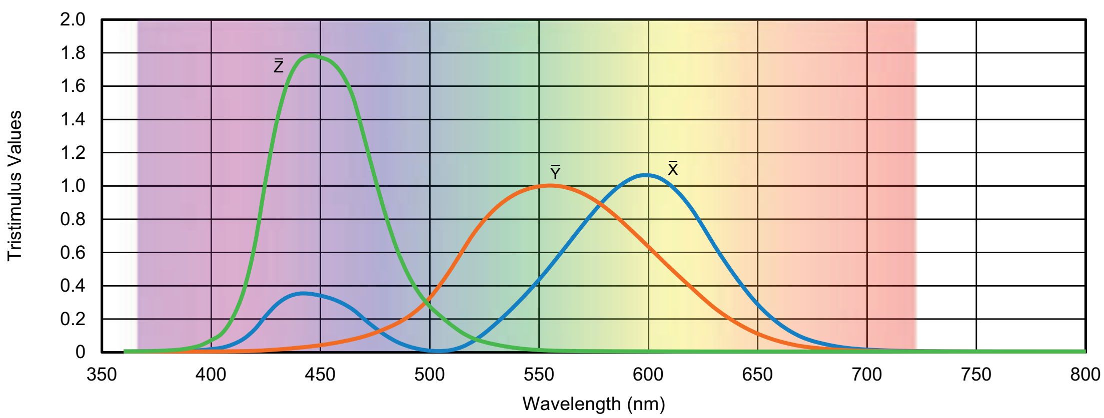


Fig. 15 - Color Matching Functions

$$X = \int_{360}^{780} \bar{X}(\lambda)d\lambda, \quad Y = \int_{360}^{780} \bar{Y}(\lambda)d\lambda, \quad Z = \int_{360}^{780} \bar{Z}(\lambda)d\lambda$$

The chromaticity coordinate (x, y) values can then be derived from the normalized XYZ values. This allows the color gamut (CIE 1931 chromaticity diagram) to be used to arrive at the color of the light and calculate the color temperature, for example, by using the McCamy formula. The process of calculating the CCT from the RGB sensor values is described in the next section. The color gamut and the corresponding equations to arrive at the (x, y) coordinates are shown below.

Designing the VEML6046X00 Into an Application

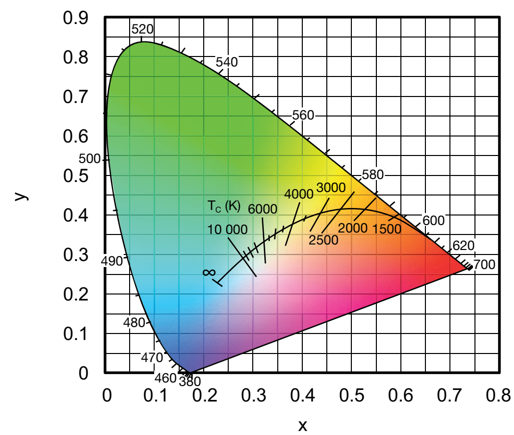


Fig. 16 - The CIE1931 (x, y) Chromaticity Space, also Showing the Chromaticities of Black-Body Light Sources of Various Temperatures (Planckian Locus), and Lines of Constant Correlated Color Temperature

$$y = \frac{Y}{X + Y + Z}$$

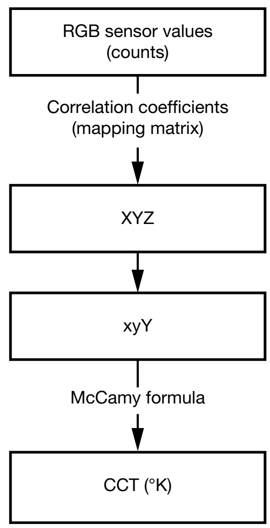
$$x = \frac{X}{X + Y + Z}$$

When converting between the XYZ color space and the xyY color space, the Y value (illuminance) is simply kept the same:

$$Y = Y$$

7.2 USING THE VEML6046X00 TO CALCULATE THE CCT (McCAMY FORMULA)

In order to calculate CCT values from the RGB values (counts) that are read by the VEML6046X00, the following steps can be taken:



As indicated by the first step, a so-called mapping matrix is required to convert the RGB values to XYZ values. The coefficients in this matrix map the RGB sensor values to the defined color matching functions, to then accurately arrive at the XYZ tristimulus values. Once the correlation coefficients of the mapping matrix are found, the following equation can be used to arrive at the XYZ values:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} M_1 & M_2 & M_3 \\ M_4 & M_5 & M_6 \\ M_7 & M_8 & M_9 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} \text{Correction coefficient} \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Where $\begin{bmatrix} M_1 & M_2 & M_3 \\ M_4 & M_5 & M_6 \\ M_7 & M_8 & M_9 \end{bmatrix}$ is the mapping matrix and $\begin{bmatrix} R \\ G \\ B \end{bmatrix}$ are the values read from the sensor.

Designing the VEML6046X00 Into an Application

7.3 CALCULATING THE MAPPING MATRIX

In order to get accurate results for the calculated XYZ values, accurate correlation coefficients need to be derived to fill the mapping matrix. This is done through a calibration procedure where values read from the sensor are mapped to XYZ values measured by a reference chroma meter or lux meter (e.g. Minolta CL-200). This is done over a range of different light sources in order to allow for a broad transformation. The light sources chosen for the calibration should be close enough to the desirable limits that are to be measured, as well as a light source that is very close to the conditions the application will be exposed to. Accurate results can be found by using at least three light sources. Typical choices here are:

- "A" light or incandescent - this light source has high IR content
- 6500 K LED D65 standard iluminant for cool color temperature
- 3200 K LED light source for warm color temperature

The measurements taken during the calibration process are then used to populate the matrices of the following equation, to then arrive at the correlation coefficients matrix:

$$\text{Corr\_Coeff.} = \underbrace{\begin{bmatrix} X_{\text{incandesent}} & X_{6500\text{ D65}} & X_{3200\text{ LED}} \\ Y_{\text{incandesent}} & Y_{6500\text{ D65}} & Y_{3200\text{ LED}} \\ Z_{\text{incandesent}} & Z_{6500\text{ D65}} & Z_{3200\text{ LED}} \end{bmatrix}}_{\text{Values from chroma meter}} \times \underbrace{\begin{bmatrix} R_{\text{incandesent}} & R_{6500\text{ D65}} & R_{3200\text{ LED}} \\ G_{\text{incandesent}} & G_{6500\text{ D65}} & G_{3200\text{ LED}} \\ B_{\text{incandesent}} & B_{6500\text{ D65}} & B_{3200\text{ LED}} \end{bmatrix}^{-1}}_{\text{Counts from VEML6046X0}}$$

The calibration procedure is conducted as follows:

- Place the sensor and reference chroma meter side by side, so that they are exposed to the same light conditions throughout the calibration
- Warm up the illuminant "A" light source to a stable brightness and color temperature condition. Use the chroma meter to measure the X, Y, and Z values of the illuminant "A" light source and use the VEML6046X00 to make a measurement, reading out the red, green, and blue channels
- Use these values to populate the first column in both matrices
- Warm up the 6500 K light source to a stable brightness and color temperature condition. Again take note of the X, Y, and Z values from the chroma meter and the red, green, and blue results from the VEML6046X00
- Use these values to populate the second column in both matrices
- Warm up the 3200 K light source to a stable brightness and color temperature. Again take note of the X, Y, and Z values from the chroma meter and the red, green, and blue results from the VEML6046X00
- Use these values to populate the third column in both matrices

The below matrix can be used as an example for calculations under mixed light conditions. To achieve the most accurate results, the best approach is to determine the correlating coefficient individually based on the application-specific light sources.

$$\text{Corr\_Coeff.} = \begin{bmatrix} 0.000001056 & 0.00010221 & -0.000061504 \\ -0.00001550 & 0.00010266 & -0.000047278 \\ -0.00007810 & 0.00009523 & 0.00000994 \end{bmatrix}$$

Designing the VEML6046X00 Into an Application

7.4 CALCULATING THE X, Y VALUES USING THE McCAMY FORMULA TO CALCULATE CCT

Once the XYZ have been found, these can be used to derive the (x, y) coordinates, which then denote a specific color, as depicted on the axes CIE color gamut on page 7. For this the following equations can be used:

$$x = X/(X+Y+Z)$$

$$y = Y/(X+Y+Z)$$

To give a sample calculation, the following RGB values will be used, which were measured with the VEML6046X00 sensor under the standard room lighting in our lab:

$$\begin{bmatrix} R = 1304\ \text{counts} \\ G = 2743\ \text{counts} \\ B = 2193\ \text{counts} \end{bmatrix}$$

Using the correlation matrix (created with a "A" light, 6500K LED D65 standard illuminant, and 3200K LED light source) stated above and solving for X, Y, and Z gives the following:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.000001056 & 0.00010221 & -0.000061504 \\ -0.00001550 & 0.00010266 & -0.000047278 \\ -0.00007810 & 0.00009523 & 0.00000994 \end{bmatrix} \times \begin{bmatrix} 1304 \\ 2743 \\ 2193 \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.14687 \\ 0.15765 \\ 0.17896 \end{bmatrix}$$

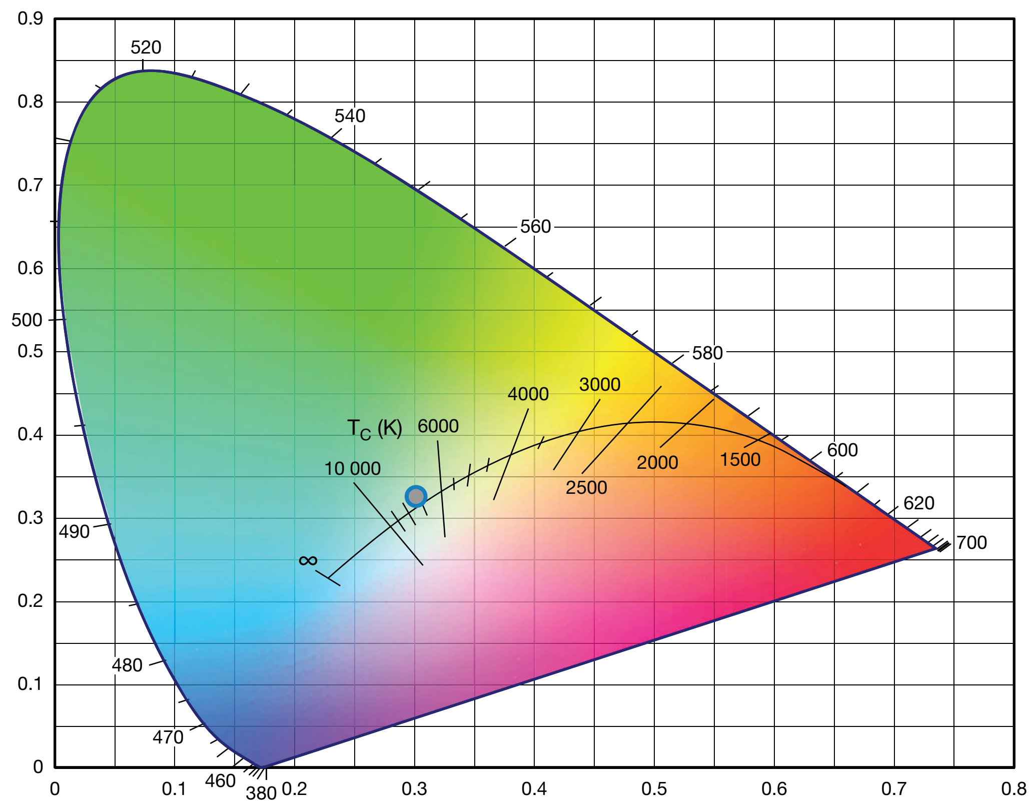
Having found the XYZ values, the (x, y) coordinates can be calculated using the equations above:

$$x = 0.14687/(0.14687 + 0.15765 + 0.17896) = 0.30378$$

$$y = 0.15765/(0.14687 + 0.15765 + 0.17896) = 0.32607$$

Designing the VEML6046X00 Into an Application

Plotting these coordinates on the CIE gamut chart shows that it is a white light source that is close to 7000 Kelvin, which is what we would have expected for our lab light lighting.



The (x, y) coordinates can now be used to calculate the CCT. This can be done via the McCamy formula, which is stated as follows:

$$CCT = 449.0 \times n^3 + 3525.0 \times n^2 + 6823.3 \times n + 5520.33$$

Where:

$$n = (x - Xe)/(Ye - y)$$

Xe and Ye are constants:

$$Xe = 0.3320$$

$$Ye = 0.1858$$

For our test, this gives the following result for n:

$$n = (0.30378 - 0.3320)/(0.1858 - 0.32607) = 0.2012$$

This can now be inserted into the McCamy formula to calculate the CCT value:

$$CCT = 449.0 \times (0.2012)^3 + 3525.0 \times (0.2012)^2 + 6823.3 \times (0.2012) + 5520.33 = 7039\ K$$

The comparison with the optometer, which measures a CCT value of 6962 K, shows that the calculated value is quite similar to the measured one.

Designing the VEML6046X00 Into an Application

8. MECHANICAL AND OPTICAL DESIGN CONSIDERATIONS

Within most applications, a housing is an essential part of the product design. To ensure a properly functioning RGB sensor within this environment, the window design for the sensor is a key parameter during the design-in phase. For a cover, generally every type of material can be used as a window material, as long as it is transmissive to the light that should be detected by the sensor. The window should be transmissive at a sensitivity range from around 400 nm to 700 nm (for RGB) and from 400 nm to 1100 nm (for RGB + IR). Accordingly, the amount of transmissivity determines the attenuation of the light, meaning, for example, an 80 % transmissive material within this region leads to attenuation of 20 % of the signal compared to an open-air measurement, which accordingly diminishes the dynamic range of the sensor. This trade-off must be considered when choosing the cover material for the application.

Besides the transmissivity, the dimensions of the cover window need to be calculated correctly to ensure the optimal performance of the sensor. While in most designs the window should be kept as small as possible, the window size should still be large enough to ensure that enough light reaches the sensor and the active area of the sensor is illuminated properly. When calculating the window size, the main dimension that has to be considered is the distance from the top of the surface to the outside surface of the window, and the required viewing angle of the sensor.

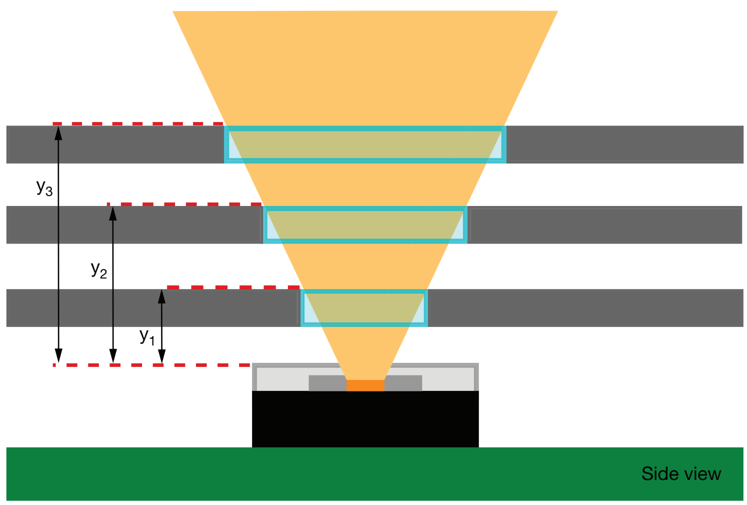


Fig. 17 - Asymmetric Window Design Where the Diameter Increases With Increasing Distance From the Sensor

In the beginning, the center of the sensor and center of the window should be aligned. Then the calculation can be done based on Formula (2). For the viewing angle of the sensor, a good approach is to use the angle of half sensitivity, which is ± 50° for the VEML6046X00, as show in Fig. 18.

The minimum window cover diameter D can be calculated as follows:

$$D = x + 2 \times (y \times \tan\theta) \quad (2)$$

Designing the VEML6046X00 Into an Application

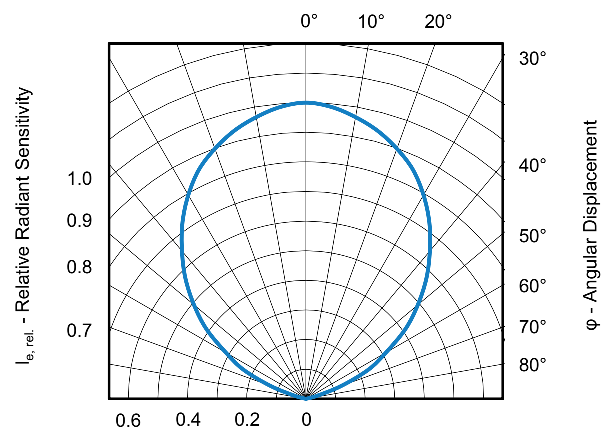
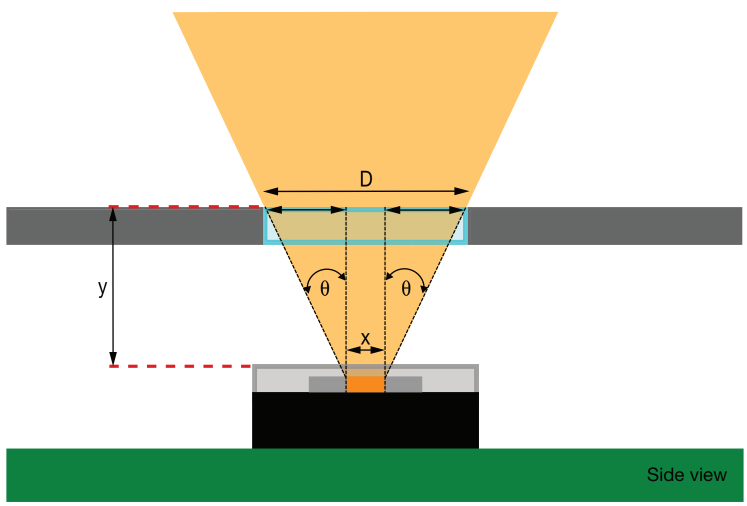


Fig. 18 - Relative Sensitivity vs. Angular Displacement

Remark:

This wide angle and the placement of the sensor as close as possible to the cover is needed to show comparable results to an optometer, which also detects light reflections from the complete surroundings.



$$D = x + 2 \times (y \times \tan\theta)$$

Fig. 19 - Window Design Calculation

Table 19 provides an overview of possible window diameters at different distances between the cover and sensor.

Designing the VEML6046X00 Into an Application

TABLE 19 - MINIMUM WINDOW COVER DIAMETER

y (mm)	x (mm)	θ1 (°)	D (mm)
0.5	0.2	50	1.99
1.0	0.2	50	2.58
1.5	0.2	50	3.78
2.0	0.2	50	4.97
2.5	0.2	50	6.16
3.0	0.2	50	7.35
3.5	0.2	50	8.54
4.0	0.2	50	9.73