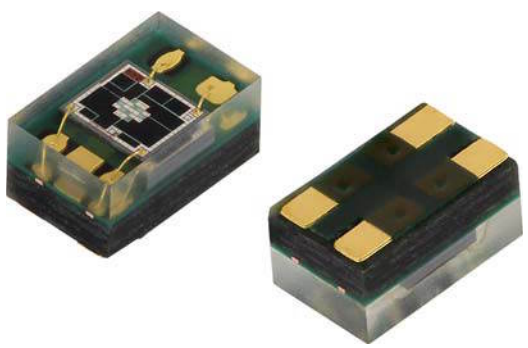
Designing the VEML6075 into an Application

By Reinhard Schaar

UVA / UVB LIGHT SENSOR WITH I²C INTERFACE

The VEML6075 is an advanced ultraviolet (UVA / UVB) light sensor with an I²C protocol interface and designed in the CMOS process.

An accurate VEML6075 UVI sensing system requires visible and infrared noise compensation and a teflon diffusor for cosine angular response correction. The UVI formulas and related UVI formula coefficients are discussed here in detail. The coefficient extraction method and a calculated example are also presented in this application note.



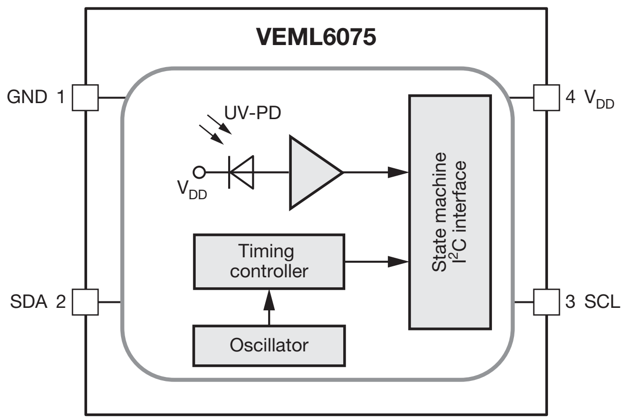


Fig. 1 - Block Diagram of the VEML6075

The VEML6075 is easily operated via a simple I²C command. It incorporates a photodiode, amplifiers, and analog / digital circuits into a single chip. The VEML6075's adoption of Filtron™ UV technology provides the best spectral sensitivity to cover UVB and UVA / UVB spectrum sensing. It has excellent temperature compensation and a robust refresh rate setting without the need for an external RC low-pass filter.

The VEML6075 shows linear sensitivity to solar UVB as well as UVA light and its sensitivity can easily be adjusted with selecting the proper integration times.

The device can be used as a solar UV indicator for cosmetic / outdoor sport handheld products or any kind of consumer products.

The VEML6075 comes within a very small surface-mount package with dimensions of just 2.0 mm x 1.25 mm x 1.0 mm (L x W x H).

The VEML6075 operates within a supply voltage range from 1.7 V to 3.6 V. The necessary pull-up resistors at the I²C line can be connected to the same supply as the micro controller is connected to, between 1.7 V and 3.6 V.

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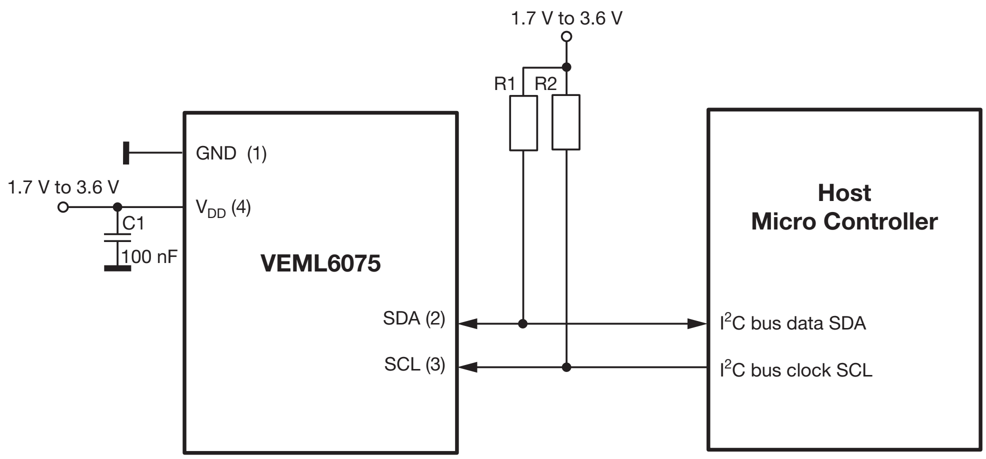

Fig. 2 - Application Circuit

The value for the pull-up resistors should be 2.2 kΩ.

The supply current of this device in activated measuring mode is 500 μA typical, whereas in shut-down mode (SD = 1) it is typically just 800 nA. The operating temperature range is specified for -40 °C to +85 °C.

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

PARAMETER		TEST CONDITION	SYMBOL	MIN.	TYP.	MAX.	UNIT
Supply operation voltage			V_{DD}	1.7	-	3.6	V
Supply current			I_{DD}	-	480	-	μA
I^2C signal input	Logic high	V_{DD} = 3.3 V	V_{IH}	1.5	-	-	V
	Logic low		V_{IL}	-	-	0.8	
I^2C signal input	Logic high	V_{DD} = 2.6 V	V_{IH}	1.4	-	-	V
	Logic low		V_{IL}	-	-	0.6	
Operating temperature			T_{amb}	-40	-	+85	°C
Shutdown current		Light condition = dark; V_{DD} = 1.8 V, T_{amb} = 25 °C	I_{DD} (SD)	-	800	-	nA
UVA sensitivity		I_T = 50 ms (1)		-	0.93	-	counts/μW/cm²
UVB sensitivity		I_T = 50 ms (2)		-	2.1	-	counts/μW/cm²

Notes

(1) Nichia NCSU033X (365 nm)

(2) UVTOP310TO39HS (315 nm)

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The VEML6075 shows a peak sensitivity at 365 nm for the UVA channel and 330 nm for the UVB channel.

The bandwidth ($\lambda_{0.5}$) of this UVB peak is in a range of about 320 nm to 340 nm.

The bandwidth ($\lambda_{0.5}$) of the UVA channel is within a range of about 350 nm to 375 nm. Its irradiance responsivity is about half when compared with the UVB channel.

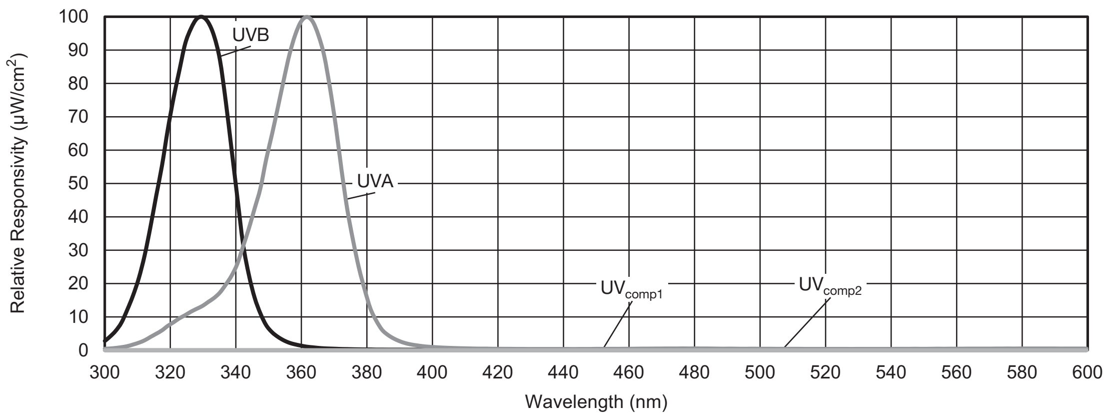

Fig. 3 - Relative Responsivity vs. Wavelength Including Response at Higher Wavelength

What does this wavelength mean? To understand this, the diagram below shows that 310 nm is within the so-called UVB region, and 310 nm to 360 nm covers almost half from each region: UVA and UVB.

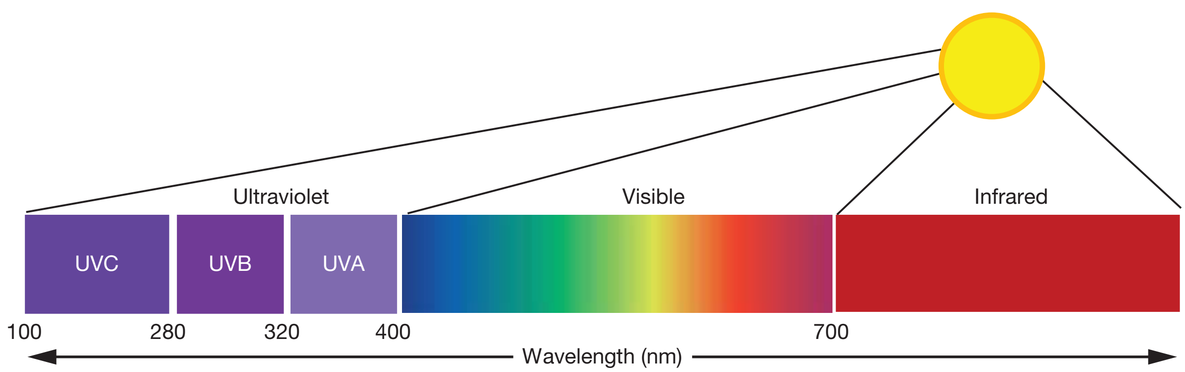

Fig. 4 - Light Spectrum

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Visible light has wavelengths between 400 nm and 750 nm.
UV light has shorter wavelengths, from 200 nm to 400 nm.
UV type A has light with wavelengths between 320 nm and 400 nm.
UV type B has wavelengths between 280 and 320 nm.
UV type C is between 200 nm and 280 nm.

While UVA and UVB reach earth, UVC is blocked by our atmosphere, so it does no harm.

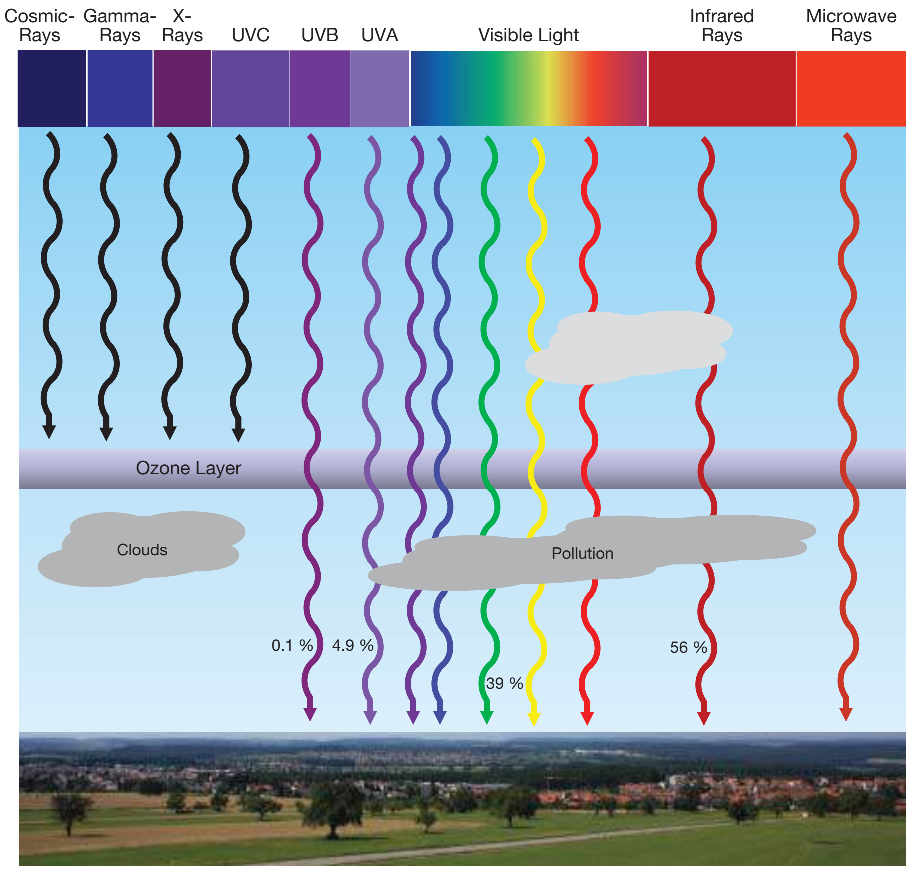

Fig. 5 - Radiation that Reaches Earth Surface

The UVB rays - wavelengths ranging from 280 nm to 320 nm - are extremely energetic and harmful for the skin to the extent that they are responsible for 65 % of skin tumors. Thankfully, only 0.1 % of the solar energy that arrives on the earth's surface is in the shape of UVB radiation.

The UVA rays - wavelengths ranging from 320 nm to 400 nm - are less powerful than the previous ones, but highly penetrating. They are capable of reaching the skin, becoming responsible for photoaging and promoting the onset of different forms of skin cancer. 4.9 % of the solar energy is made up of UVA rays.

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In order to estimate the energy behind this UV radiation and the risk level seen with it, a so-called UV index has been established.

It is a quite complex calculation, weighted according a curve and integrated over the whole spectrum. So, it cannot simply be related to the irradiance (measured in W/m^2). Also see fig. 12.

The calculated index value appears on a scale of 0 to 11+. This index scale is linear and the relation to strength of the irradiance is shown below.

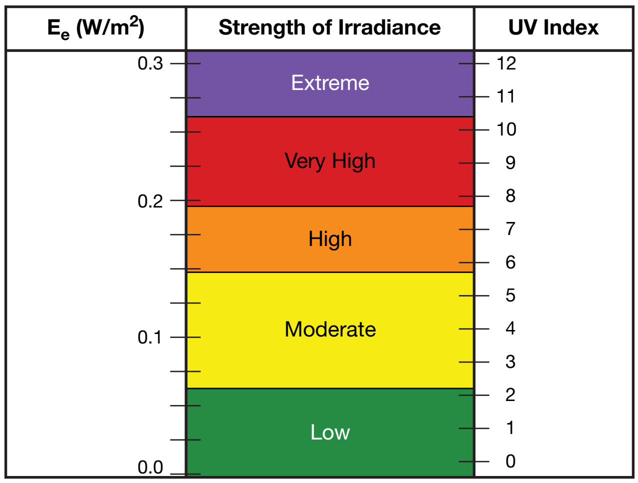

Fig. 6 - Strength of Irradiance and the UV Index

In order to define the energy behind this UV radiation and the risk level seen, the VEML6075 enables the simple reading out of the irradiance values and calculation of the exact measured UVB and UVA / UVB values. The visible and infrared noise is also measured and two compensation channels help to remove the solar visible and IR noise outside the UV region. Further on, a so-called "dummy" channel provides the dark current for accurate compensation.

Setting up and programming the VEML6075 is easily handled by just one I^{2}C-bus command register: command code "0". All required functions that need to be set of are located there: power on (SD), integration time (IT), and measurement mode, either continuous or on-demand (UV_AF and UV_TRIG). The bit "HD" allows for increasing the dynamic. The five following 16-bit-wide command codes are the read register for the UV, as well as the so-called compensation data, and the last one shows information about the device ID.

REGISTER UV_CONF DESCRIPTION									
REGISTER NAME		**COMMAND CODE: 0x00_L (0x00 DATA BYTE LOW) OR 0x00_H (0x00 DATA BYTE HIGH)**							
COMMAND	BIT	7	6	5	4	3	2	1	0
REGISTER: UV_CONF		**COMMAND CODE: 0x00_L (0x00 DATA BYTE LOW)**							
COMMAND	BIT	Description							
Reserved	7	0							
UV_IT	6 : 4	(0 : 0 : 0) = 50 ms, (0 : 0 : 1) = 100 ms, (0 : 1 : 0) = 200 ms, (0 : 1 : 1) = 400 ms, (1 : 0 : 0) = 800 ms, (1 : 0 : 1) = reserved, (1 : 1 : 0) = reserved, (1 : 1 : 1) = reserved.							
HD	3	0 = normal dynamic setting, 1 = high dynamic setting							
UV_TRIG	1	0 = no active force mode trigger, 1 = trigger one measurement With UV_AF = 1 the VEML60754 conducts one measurement every time the host writes UV_Trig = 1. This bit returns to "0" automatically.							
UV_AF	0	0 = active force mode disable (normal mode), 1 = active force mode enable							
SD	0	0 = power on, 1 = shut down							

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UVA data is available within command code 7 and UVA / UVB within command code 9.

07h	L	UVA_Data	R	0x00	UVA LSB output data
	H	UVA_Data	R	0x00	UVA MSB output data
08h	L	Dummy	R	0x00	UVD
	H	Dummy	R	0x00	UVD
09h	L	UVB_Data	R	0x00	UVB LSB output data
	H	UVB_Data	R	0x00	UVB MSB output data
0Ah	L	UVCOMP1_Data	R	0x00	UV_{comp1} LSB output data
	H	UVCOMP1_Data	R	0x00	UV_{comp1} MSB output data
0Bh	L	UVCOMP2_Data	R	0x00	UV_{comp2} LSB output data
	H	UVCOMP2_Data	R	0x00	UV_{comp2} MSB output data

In addition, command codes 10 (0x0A) and 11 (0x0B) contain so-called compensation values. These deliver information about the whole received light within the visible wavelength area (0x0A) and the strength of the infrared content within the received light (0x0B).

Command code 8 provides information about the dark current value.

The last command code 12 (0x0C) contains information about the device ID:

ID	0x0C_L (0x0C data byte low)	07:00	Default = 0x26, device ID LSB byte
	0x0C_H (0x0C data byte high)	07:06 05:04 03:00	Company code = 00, (0 : 0) Slave address = 0x20 Version code (0 : 0 : 0 : 0) = VEML6075 CS Device ID MSB byte

Silicon photodiode detectors are known to have good optical response for visible and infrared light. Therefore, the injection of visible and infrared lights into silicon photodiodes generates undesirable noise current. In order to correct such error sources, the VEML6075 incorporates UV_{comp1} and UV_{comp2} noise compensation channels. In addition, there is a UVD dummy channel for dark current cancellation.

- The $\mathbf{UV_{comp1}}$ channel allows only visible noise to pass through
- The $\mathbf{UV_{comp2}}$ channel allows only infrared noise to pass through
- The **UVD** channel is a dummy channel that allows the other UV channels to cancel out the dark current or any stray light injection to the silicon substrate.

After reading the raw data through the I^2C bus for all five channels (UVB, UVA, UV_{comp1}, UV_{comp2}, and UVD), simple UVA_{comp} and UVB_{comp} formulas are used to calculate the UVI signal.

$$UVA_{comp} = (UVA - UVD) - a \times (UV_{comp1} - UVD) - b \times (UV_{comp2} - UVD) \qquad \text{Eq. (1)}$$

$$UVB_{comp} = (UVB - UVD) - c \times (UV_{comp1} - UVD) - d \times (UV_{comp2} - UVD) \qquad \text{Eq. (2)}$$

$$UVI = \frac{(UVB_{comp} \times UVB_{resposivity}) + (UVA_{comp} \times UVA_{responsivity})}{2} \qquad \text{Eq. (3)}$$

Note

- Based on the actual UVI measurement data under various sunlight conditions, the average UVI from UVB and UVA signals provides a better UVI tracking with the reference Davis 6490 UVI sensor.

In both Eq. (1) and Eq. (2) formulas, there are four coefficients we need to solve for. For open-air systems with and without a teflon diffusor over the VEML6075 sensor, the following default VIS and IR coefficients are used:

a = uva_a_coef= 3.33, which is the default value for the UVA VIS coefficient
b = uva_b_coef= 2.5, which is the default value for the UVA IR coefficient
c = uvb_c_coef= 3.66, which is the default value for the UVB VIS coefficient
d = uvb_d_coef= 2.75, which is the default value for the UVB IR coefficient

In the mass production process, each VEML6075 die will be trimmed under reference light sources to ensure a tight sensitivity distribution for UVI calculation.

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To extract the visible and IR coefficients (a, b, c, and d), we need two light sources (WLED and incandescent) and set Eq. (1) and Eq. (2) to zero.

$$UVA_{calc} = (UVA - UVD) - a \times (UV_{comp1} - UVD) - b \times (UV_{comp2} - UVD) = 0 \quad \text{Eq. (4)}$$

$$UVB_{calc} = (UVB - UVD) - c \times (UV_{comp1} - UVD) - d \times (UV_{comp2} - UVD) = 0 \quad \text{Eq. (5)}$$

Eq. (4) is solved for coefficients a and b using two light sources (WLED and incandescent).

Eq. (5) is solved for coefficients c and d using two light sources (WLED and incandescent).

With all calculations above eliminating the influence within the UVA and UVB response from visible and infrared content, as well as dark current, the “clean” response of the UVA and UVB channel will look as shown in fig. 7 below.

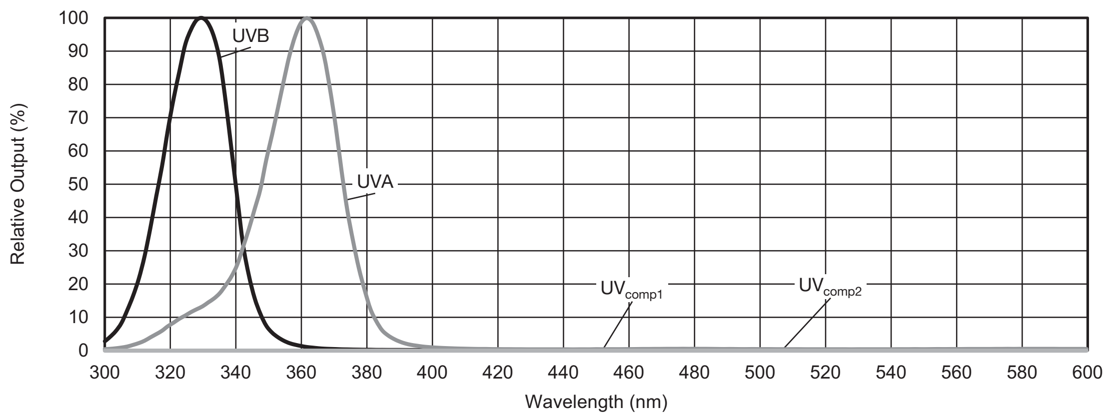

Fig. 7 - Relative Responsivity vs. Wavelength
(Adjusted with Compensation Channels)

This may help to understand the sensor’s behavior when testing just with lab conditions and defined, calibrated light sources.

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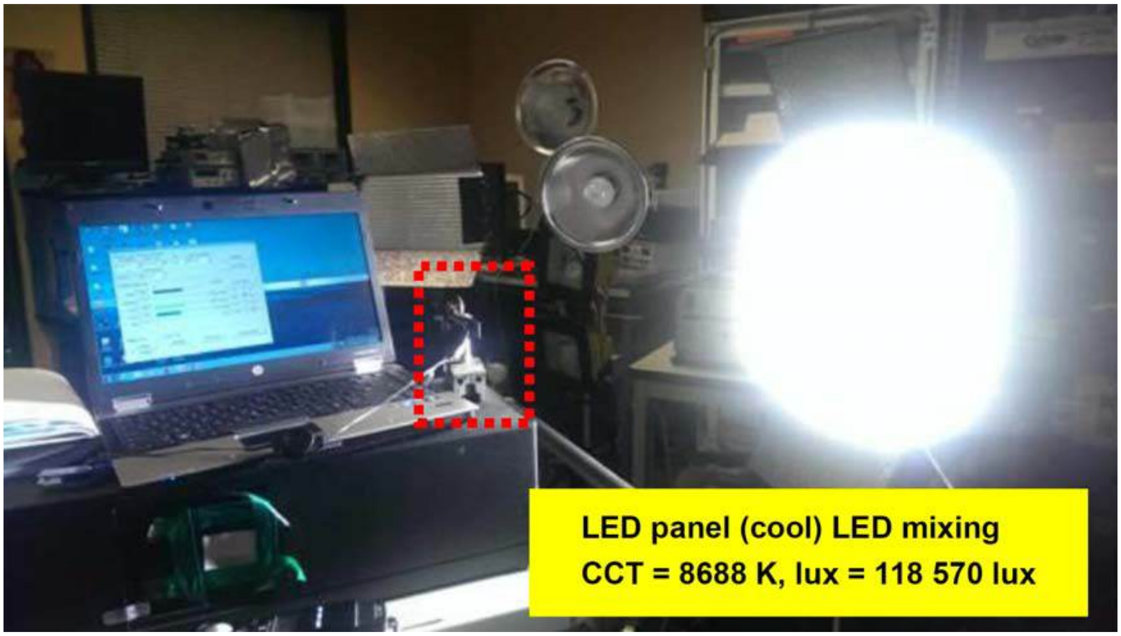

Fig. 8 - VEML6075 Test Set-Up Using a White LED as Light Source

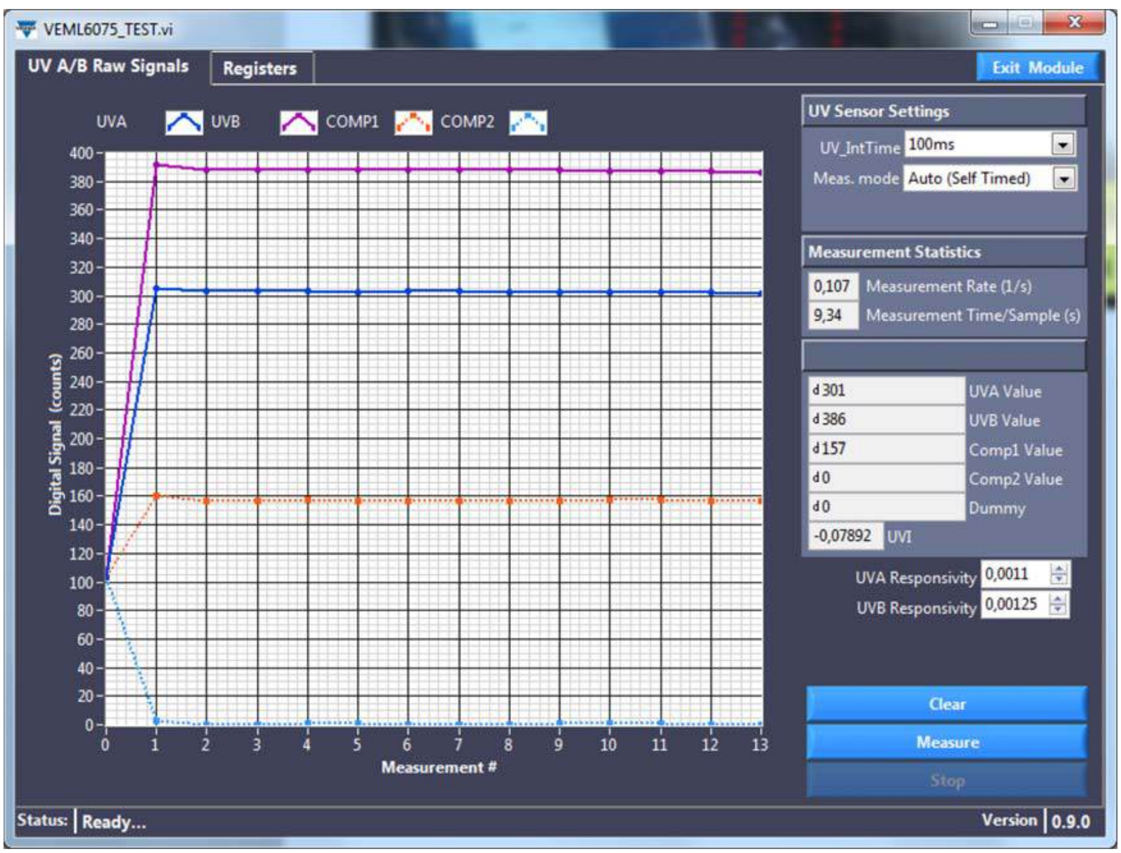

Fig. 9 - VEML6075 Demo Software View When Light Source Used a White LED

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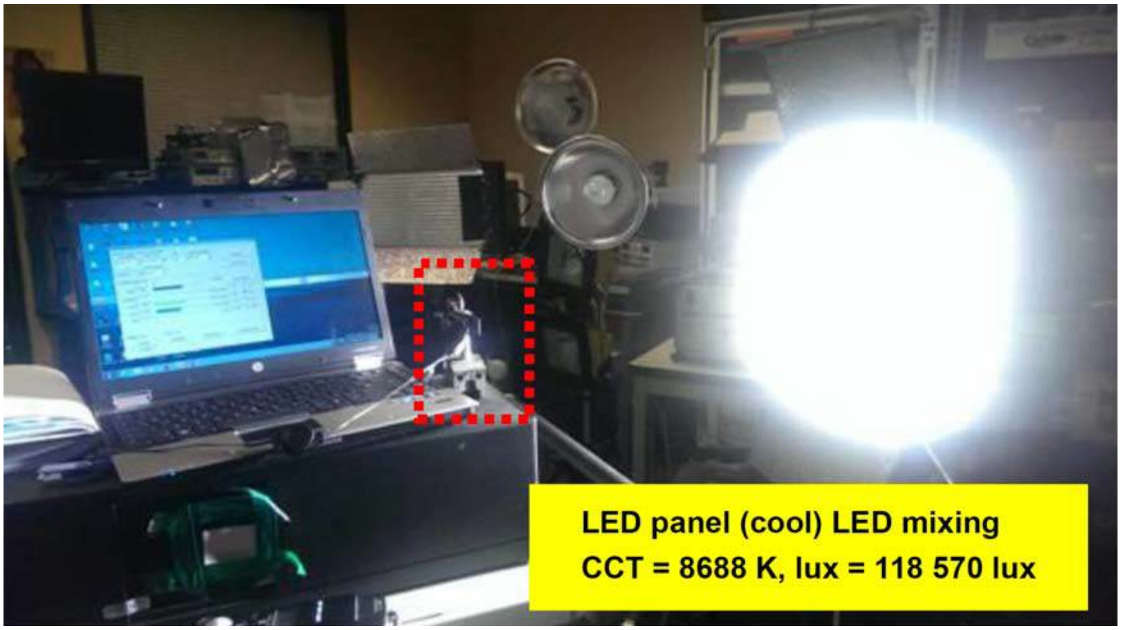

Fig. 10 - VEML6075 Test Set-Up Using an Incandescent Lamp as Light Source

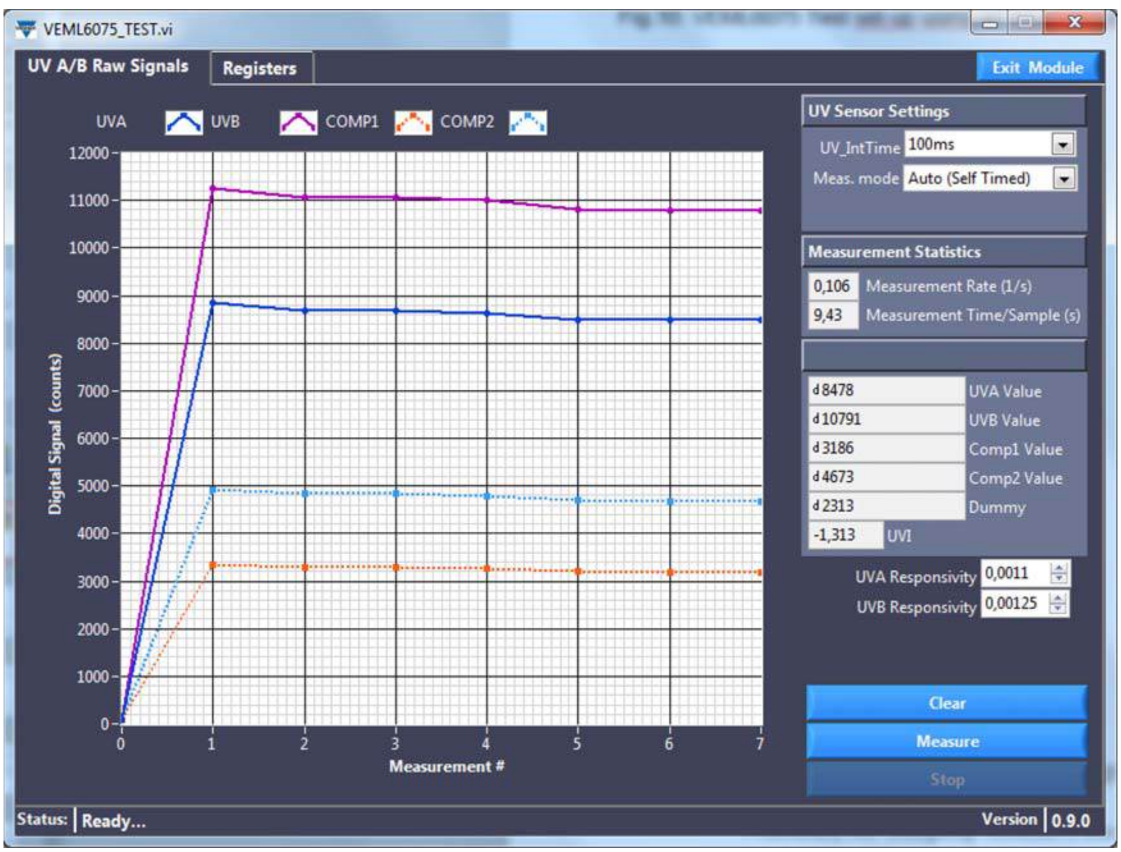

Fig. 11 - VEML6075 Demo Software View When Light Source Used an Incandescent Lamp

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To calculate visible light coefficients a and c, use a WLED since $UV_{comp2} = 0$, because a white LED delivers no infrared signal, so $d \times (UV_{comp2}) = 0$.

$$UVB_{calc} = UVB - (c \times UV_{comp1}) - (d \times UV_{comp2}) = 0 \qquad \text{Eq. (5)}$$

$$UVB = c \times UV_{comp1}$$

$$c = \frac{UVB}{UV_{comp1}}$$

UVB data is measured to: **386**, UV_{comp1} data is measured to: **157**.

UVB visible coefficient **c = 386/157 = 2.46**.

$$UVA_{calc} = UVA - (a \times UV_{comp1}) - (b \times UV_{comp2}) = 0 \qquad \text{Eq. (4)}$$

$$UVA = a \times UV_{comp1}$$

$$a = \frac{UVA}{UV_{comp1}}$$

UVA data is measured to: **301**, UV_{comp1} data is measured to: **157**.

UVA visible coefficient **a = 301/157 = 1.92**.

To calculate IR coefficients b and d, use a 2700 K, 60 W incandescent light to record the raw data.

$$\text{Using } c = 2.46 \text{ and } d = \frac{UVB - (c \times UV_{comp1})}{UV_{comp2}} \qquad \text{Eq. (5)}$$

UVB infrared coefficient, **d = (10 791 - (2.46 x 3186))/4673 = 0.63**

$$\text{Using } a = 1.92 \text{ and } b = \frac{UVA - (a \times UV_{comp1})}{UV_{comp2}} \qquad \text{Eq. (4)}$$

UVA infrared coefficient, **b = (8478 - (1.92 x 3186))/4673 = 0.55**

Notes

- The typical empirical coefficients b and d for achieving best IR cancellation under a sunlight condition are b = 2.5 and d = 2.75. The open-air VEML6075 UVI sensitivity is calibrated with the Davis weather station.
- Typical UVB responsivity = 0.00125 UVI/UVB_{calc} counts.
- Typical UVA responsivity = 0.0011 UVI/UVA_{calc} counts.
- The VEML6075 UVI sensing resolution is 0.01 UVI.

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CALCULATING THE UV INDEX

Calculation of the UVI is quite complex. Not only does every wavelength between 286.5 nm and 400 nm need to be measured - in steps of 0.5 nm - but a weighting function also needs to be applied.

The UV index is defined as: $\text{UVI} = \frac{1}{25\ \frac{\text{mW}}{\text{m}^2}} \int_{286.5\ \text{nm}}^{400\ \text{nm}} I(\lambda) \times w(\lambda) \times d(\lambda)$,

where the weighting function for erythema is given as:

$$w(\lambda) = \begin{cases} 1 & 250 < \lambda \leq 298 \\ 10^{0.094 \times (298 - \lambda)} & 298 < \lambda \leq 328 \\ 10^{0.015 \times (139 - \lambda)} & 328 < \lambda \leq 400 \\ 0 & 400 < \lambda \end{cases}$$

after A. F. McKinlay and B. L. Diffey (1987)

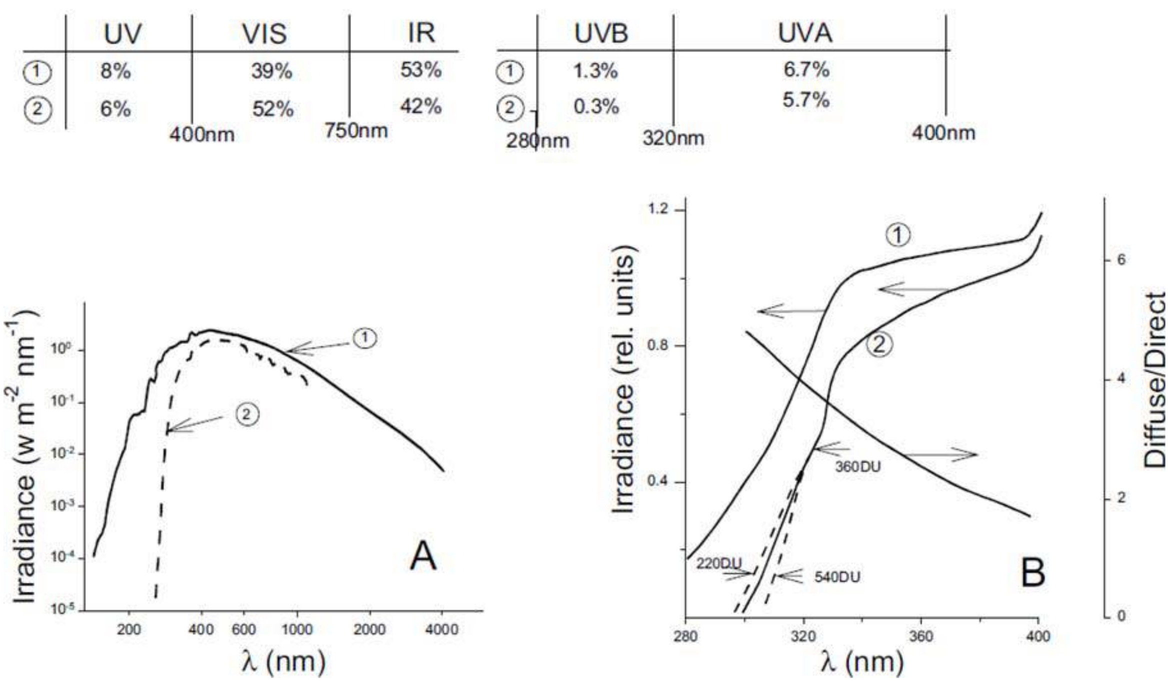

Fig. 12 - Spectrum of Solar Radiation: Outside the Atmosphere (1) and at Sea Level (2)

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WHAT VALUES MAY BE SEEN WITH THE VEML6075

The defined UV light source also shown within the datasheet (Nichia NCSU033X-365 nm) to check UVA sensitivity and the 315 nm UVTOP310TO39HS to verify UVB sensitivity will not be available within most labs. In addition, the set-up with the before-mentioned white LED and incandescent lamp needs accuracy and an alignment to deliver comparable results.

Even “normal” daylight to study and compare the VEML6075’s response may lead to misinterpretation, as the UV power is strongly dependent on the time of day, season, and location where the measurement will be made.

During winter times, the total skin-affecting irradiance may be so low that even within full sunshine no remarkable values will be seen.

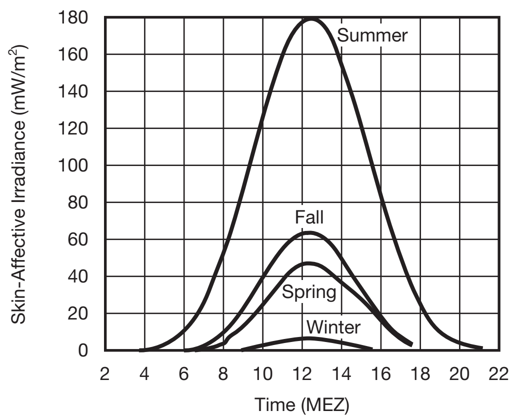

Fig. 13 - Skin-Affecting Irradiance Level vs. Time Seen at the Beginning of the Four Seasons

The correct UV index needs a well-calibrated measurement tool, such as the Davis weather station used to calibrate the VEML6075.

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WHAT VALUES ARE MEASURED WITH THE VEML6075

Placing the sensor AND the reference measurement tool (e.g. Davis 6490 UVI sensor) in an open area over the whole day shows the exact performance of the VEML6075.

Fig. 14 - Measurement Set-Up

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Below, full-day UVI tracking with the Davis UVI sensor and T148 with no diffusor is shown. The maximum UVI is 9.7.

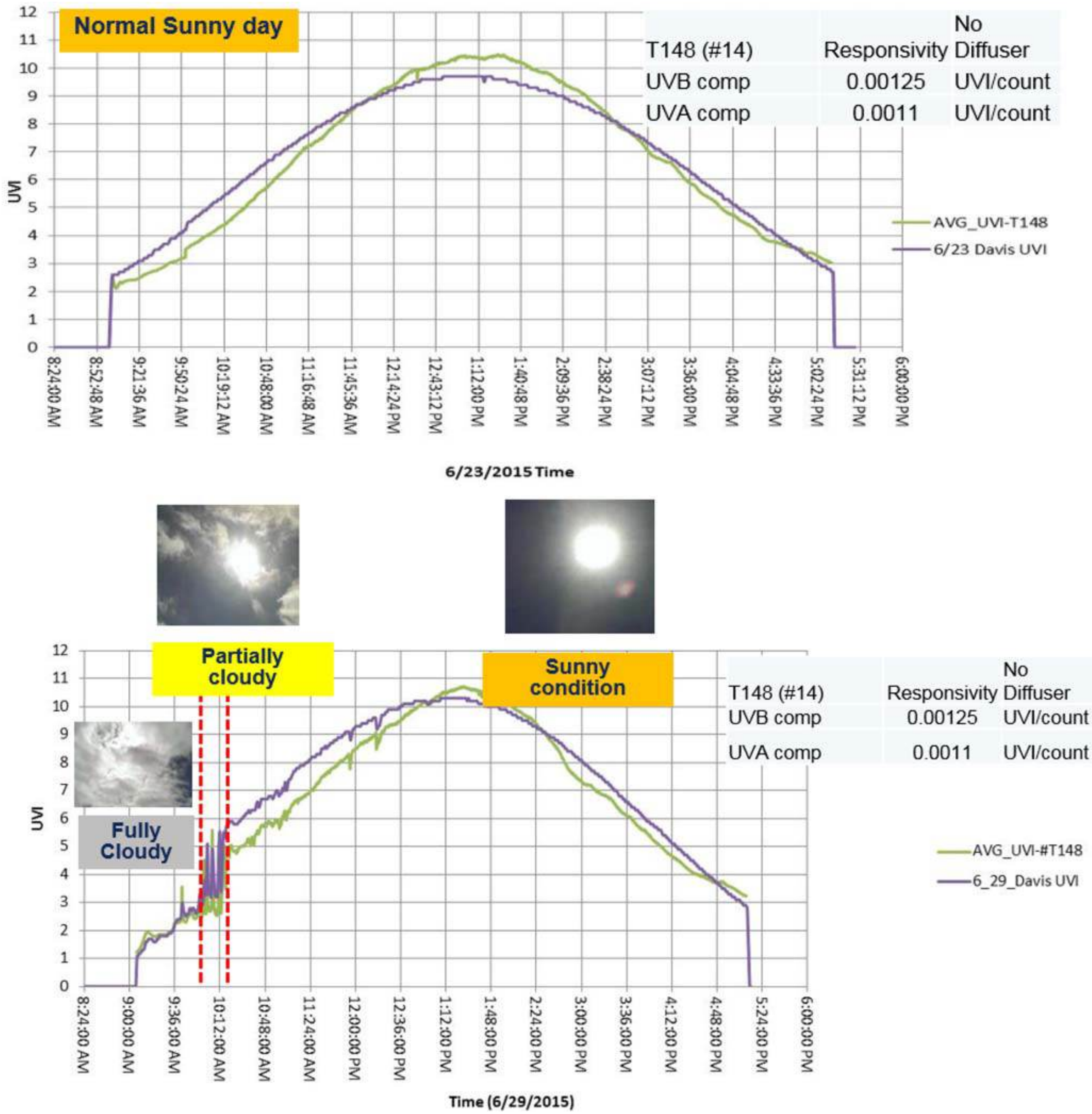

Fig. 15 - Test Data Showing Calculated UVI and Comparison to Reference

With the empirical findings of the coefficients and comparable measured UV responsivity, the exact UVI is seen.

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UV COEFFICIENTS AND RESPONSIVITY				
UV COEFFICIENTS - EMPIRICAL VALUES				
UVA coefficient a	3.33			
UVA coefficient b	2.5			
UVA coefficient c	3.66			
UVA coefficient d	2.75			
TYPICAL RESPONSIVITY WITHOUT DIFFUSOR				
UVA responsivity	0.0011	UVI/count	909	counts for 1 UVI
UVB responsivity	0.00125	UVI/count	800	counts for 1 UVI
TYPICAL RESPONSIVITY WITH 0.125 mm DIFFUSOR AND 2 mm WALL				
UVA responsivity	0.002805	UVI/count	356.5	counts for 1 UVI
UVB responsivity	0.002347	UVI/count	426.1	counts for 1 UVI

For responsivity without a diffusor and I_T = 100 ms:

UVA sensing resolution of 0.01 UVI = 9 counts

UVB sensing resolution of 0.01 UVI = 8 counts

MECHANICAL CONSIDERATIONS AND WINDOW CALCULATIONS FOR THE VEML6075

As already mentioned, this UVA / UVB sensor will need a well-selected cover that is not only completely transmissive to visible light (400 nm to 700 nm), but also to UVA and UVB wavelengths (280 nm to 400 nm).

Teflon or polytetrafluoroethylene (PTFE) is a known optical material that allows transmission of UV up to near infrared signals. A teflon diffusor (PTFE sheet) radiates like Lambert's cosine law. Thus PTFE enables a cosine angular response for a detector measuring the optical radiation power at a surface.

Using a 0.4 mm teflon diffusor placed on top of the VEML6075 sensor generates a very close to cosine view angle response. Compared with the ideal cosine response, the measured view angle response error of a 0.4 mm teflon diffusor is less than 10 %.

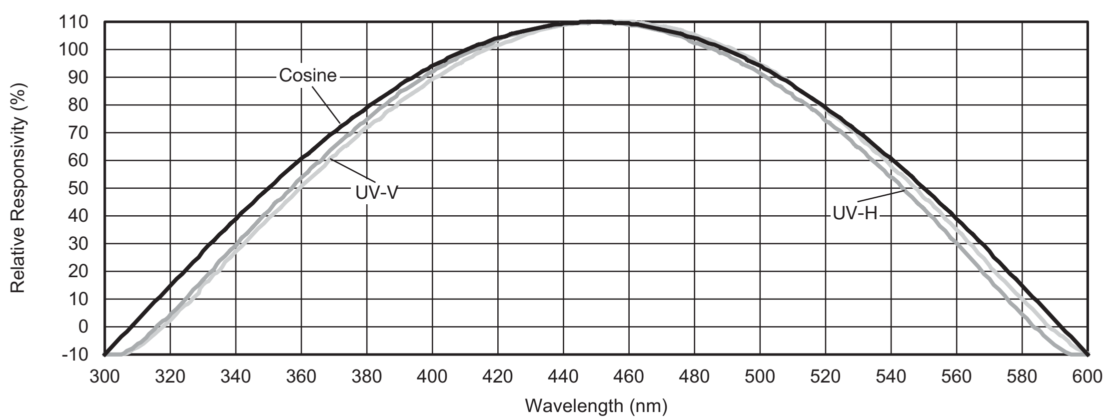

Fig. 16 - Relative Radiant Sensitivity vs. Angular Displacement

For more information please also see:

www.berghof.com/en/products/ptfe-products/optical-ptfe/

www.aetnaplastics.com/site_media/media/documents/Acrylite_OP-4_Material_Data_Sheet.pdf

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For optimal performance, the window size should be large enough to maximize the light irradiating the sensor. In calculating the window size, the only dimensions that the design engineer needs to consider are the distance from the top surface of the sensor to the outside surface of the window and the size of the window. These dimensions will determine the size of the detection zone.

First, the center of the sensor and center of the window should be aligned. The VEML6075 has an angle of half sensitivity of about ± 55°, as shown in the figure below.

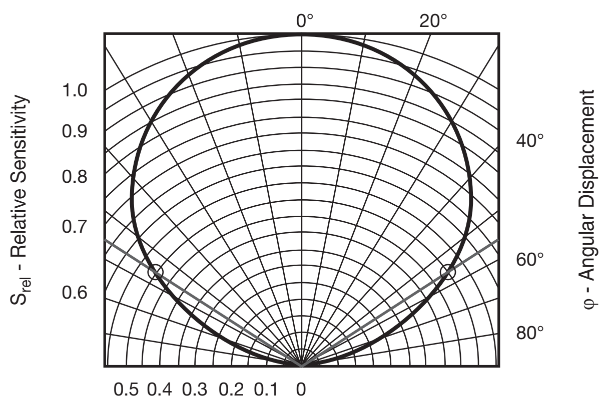

Fig. 17 - Relative Radiant Sensitivity vs. Angular Displacement

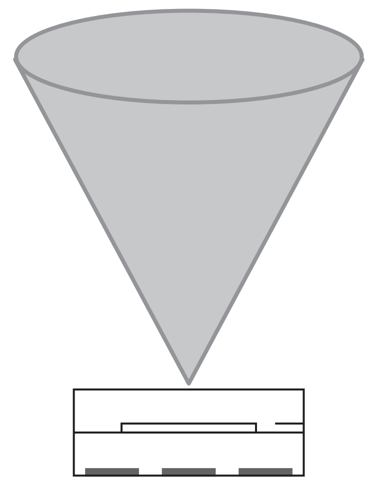

Fig. 18 - Angle of Half Sensitivity: Cone

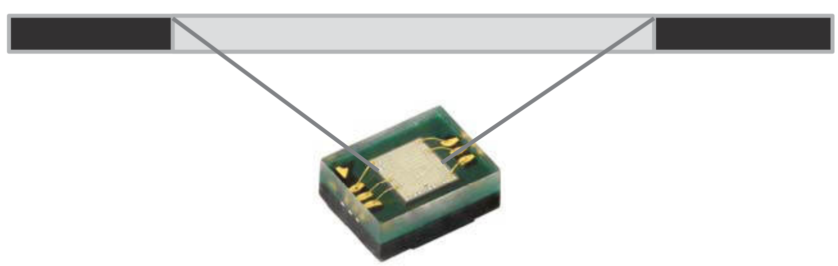

Fig. 19 - Window Above Sensitive Area

Remark:
This wide angle and the placement of the sensor as close as possible to the cover is needed to show good responsivity.

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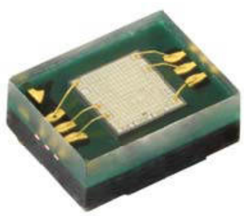
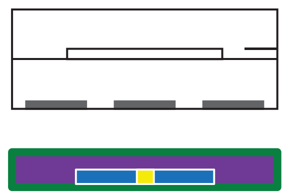
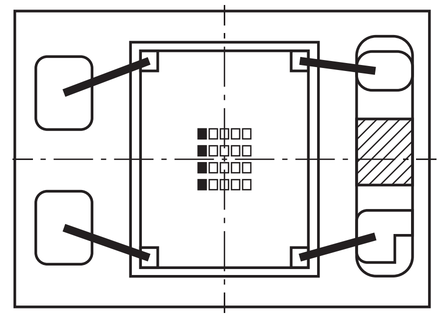
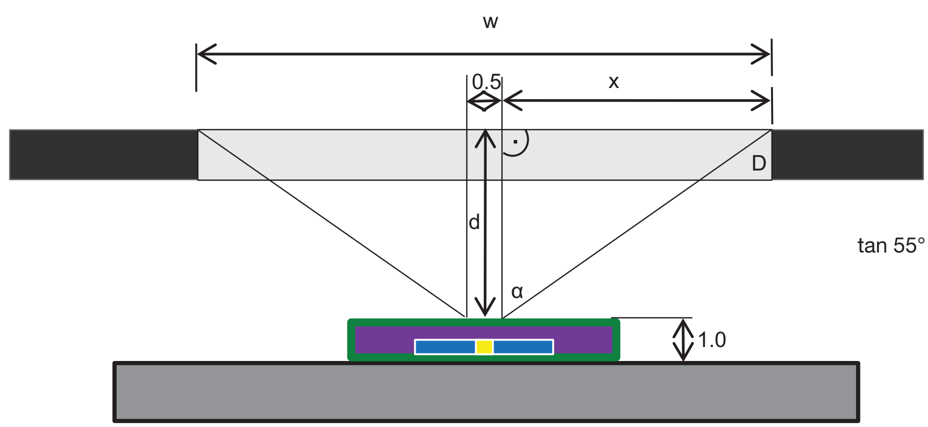
The size of the window is simply calculated according to triangular rules. The dimensions of the device, as well as the sensitive area, are shown within the datasheet. For best results, the distance below the window's upper surface and the specified angle below the given window diameter (w) are known.







Dimensions (L x W x H in mm): 2.0 x 1.25 x 1.0



tan 55° = 1.43 = x/d
x = 1.43 x d

here in drawing α = 55°

dimensions in mm

Fig. 20 - Window Area for an Opening Angle of ± 55°

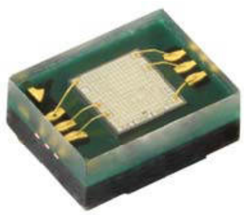
The calculation is then: tan α = x/d → with α = 55° and tan 55° 1.43 = x/d → x = 1.43 x d.

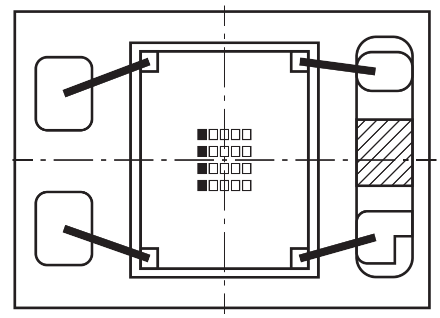
Then the total width is w = 0.5 mm + 2 x x.

d = 0.5 mm → x = 0.72 mm → w = 0.5 mm + 1.44 mm = 1.94 mm
d = 1.0 mm → x = 1.43 mm → w = 0.5 mm + 2.86 mm = 3.36 mm
d = 1.5 mm → x = 2.15 mm → w = 0.5 mm + 4.30 mm = 4.80 mm
d = 2.0 mm → x = 2.86 mm → w = 0.5 mm + 5.72 mm = 6.22 mm
d = 2.5 mm → x = 3.58 mm → w = 0.5 mm + 7.16 mm = 7.66 mm
d = 3.0 mm → x = 4.29 mm → w = 0.5 mm + 8.58 mm = 9.08 mm

Designing the VEML6075 into an Application

A smaller window will also be sufficient, although it will reduce the total sensitivity of the sensor.





Dimensions (L x W x H in mm): 2.0 x 1.25 x 1.0

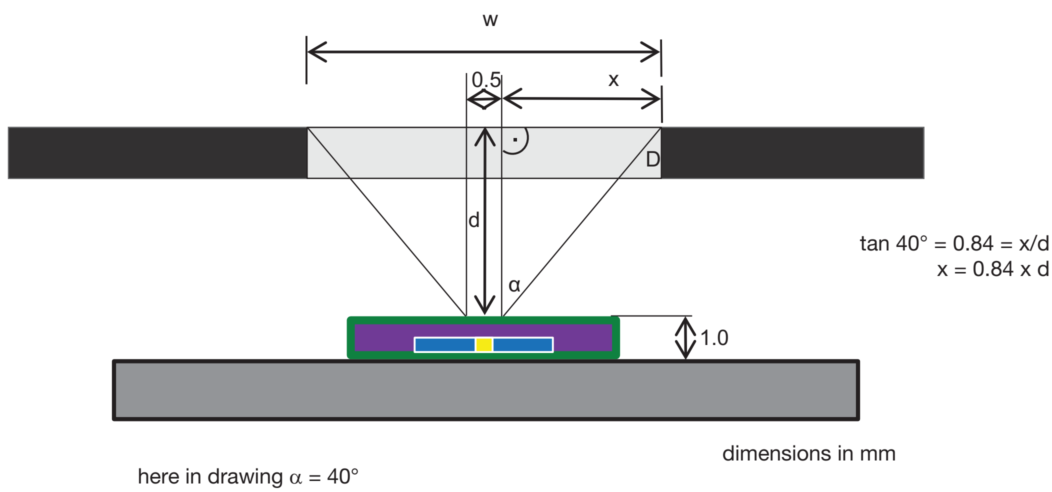


Fig. 21 - Window Area for an Opening Angle of ± 40°

The calculation is then: tan α = x/d → with α = 40° and tan 40° 0.84 = x/d → x = 0.84 x d.

Then the total width is w = 0.5 mm + 2 x x.

d = 0.5 mm	→	x = 0.42 mm	→	w = 0.5 mm + 0.84 mm	=	1.34 mm
d = 1.0 mm	→	x = 0.84 mm	→	w = 0.5 mm + 1.68 mm	=	2.18 mm
d = 1.5 mm	→	x = 1.28 mm	→	w = 0.5 mm + 2.56 mm	=	3.06 mm
d = 2.0 mm	→	x = 1.68 mm	→	w = 0.5 mm + 3.36 mm	=	3.86 mm
d = 2.5 mm	→	x = 2.10 mm	→	w = 0.5 mm + 4.20 mm	=	4.70 mm
d = 3.0 mm	→	x = 2.52 mm	→	w = 0.5 mm + 5.04 mm	=	5.54 mm

Designing the VEML6075 into an Application

VEML6075 SENSOR BOARD AND DEMO SOFTWARE

The small blue VEML6075 sensor board fits to the so-called sensor starter kit.
Please also see: www.vishay.com/moreinfo/vcnldemokit/.

Designing the VEML6075 into an Application

With help of the VEML6075 sensor board and the demo software, one can easily test this UVA / UVB sensor. Beside the raw data of all five channels, the UV index is also given with the calculations shown before. The five integration times are also selectable. The resulting counts are strictly linear, meaning a factor of 2 in integration time also results in a factor of 2 in output data counts.

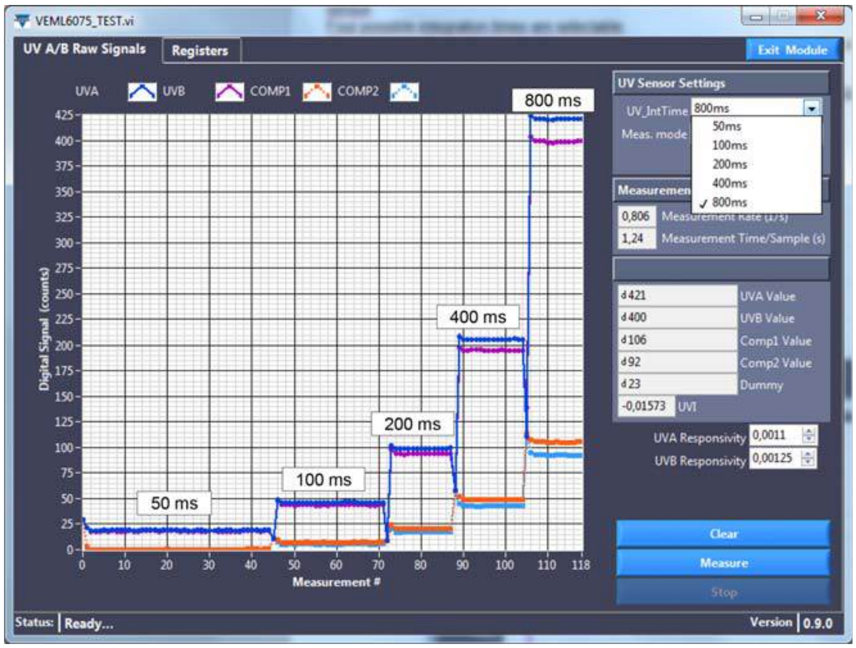


Fig. 22 - Linearity of Integration Times for Small and High Data Values

Beside the raw data read out of command codes 0x07 and 0x09, the corresponding UV index is also shown, as well as the risk level indicated with changing the color according to fig. 6.

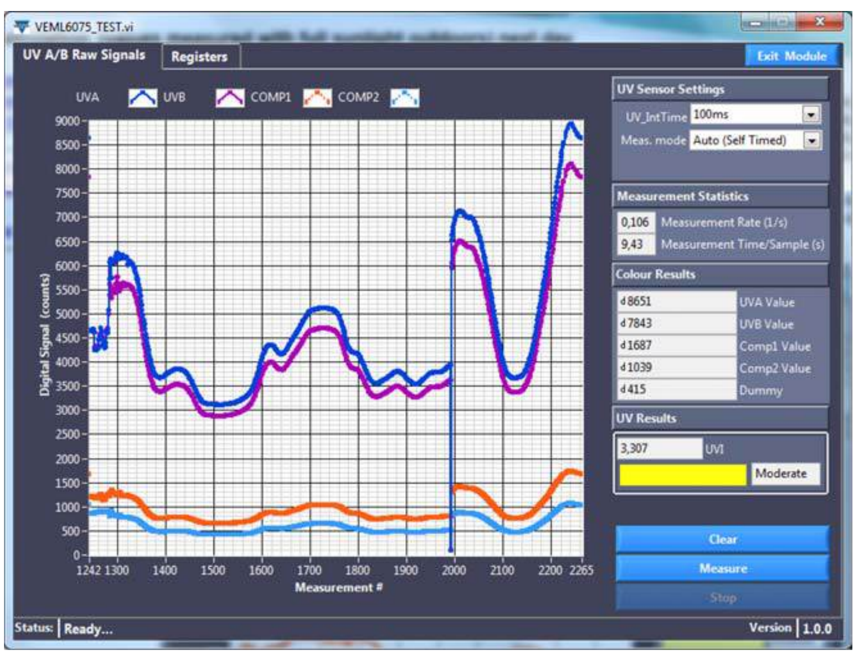


Fig. 23 - View of the VEML6075 Demo Software Showing Raw Data, UVI, and Risk Level