Optical Sensors | Application Note

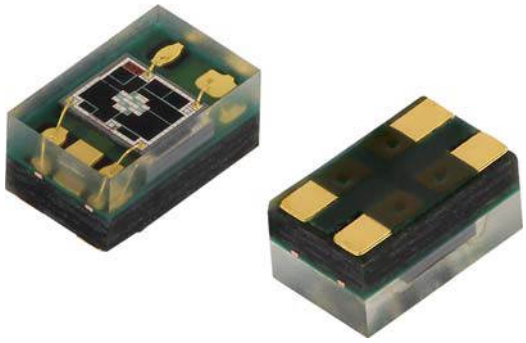
Designing the VEML6075 into an Application

By Reinhard Schaar

UV-A / UV-B LIGHT SENSOR WITH I²C INTERFACE

VEML6075 is an advanced ultraviolet (UV-A / UV-B) light sensor with I²C protocol interface and designed in CMOS process.

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



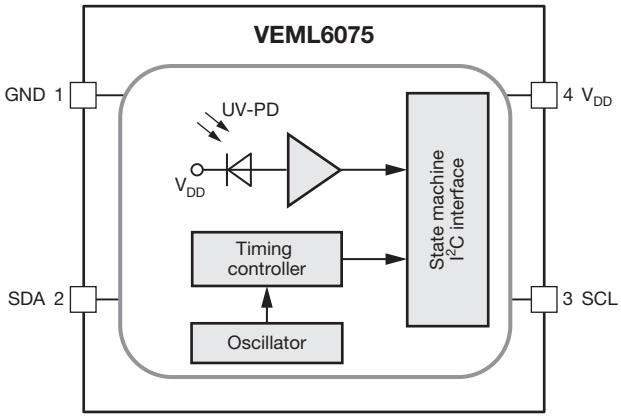


Fig. 1 - Block Diagram of the VEML6075

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

VEML6075 shows linear sensitivity to solar UV-B as well as UV-A light and its sensitivity can easily be adjusted with selecting 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.

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

VEML6075 operates within a supply voltage range from 1.8 V to 3.6 V. The necessary pull-up resistors at I²C line can be connected to same supply as the micro controller is connected to, between 1.8 V and 3.6 V.

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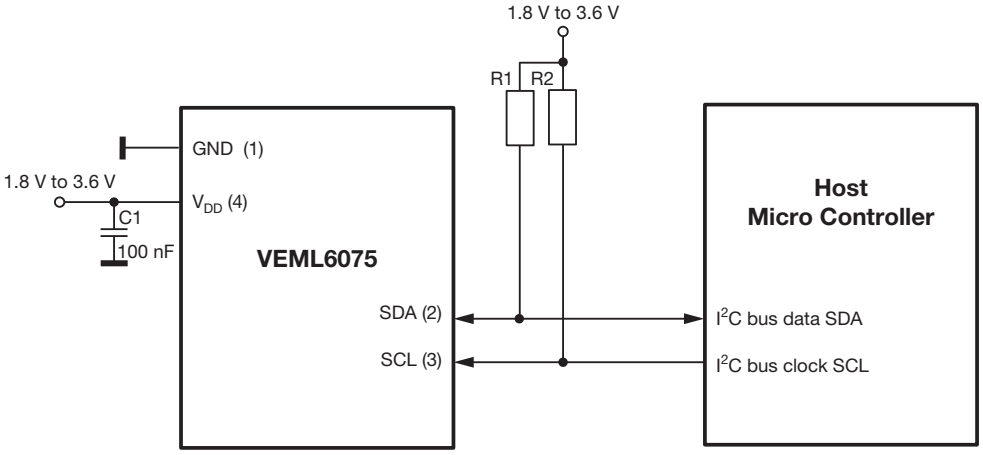


Fig. 2 - Application Circuit

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

The supply current of this device is in activated measuring mode typical 500 µA, where in shut-down mode (SD = 1) it is typical just 800 nA. 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}	1.8	-	3.6	V
Supply current			I_{DD}	-	500	-	µA
I^2C signal input	Logic high	V_{DD} = 3.3 V (1)	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} = 3.6 V, T_{amb} = 25 °C	I_{DD} (SD)	-	800	-	nA
UVA sensitivity		I_T = 50 ms (2)		-	0.93	-	µW/cm²/step
UVB sensitivity		I_T = 50 ms (3)		-	2.1	-	µW/cm²/step

Notes

(1) Test condition: V_{DD} = 3.3 V

(2) Nichia NCSU033X (365 nm)

(3) UVTOP310TO39HS (315 nm)

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VEML6075 shows a peak sensitivity at 320 nm for UVB channel.

Bandwidth ($\lambda_{0.5}$) of this UVB peak is in a range of about 310 nm to 330 nm.

Bandwidth ($\lambda_{0.5}$) of second UV-A / UV-B channel is within a range of about 310 nm to 360 nm. Its irradiance responsivity is about half compared with the UVB channel.

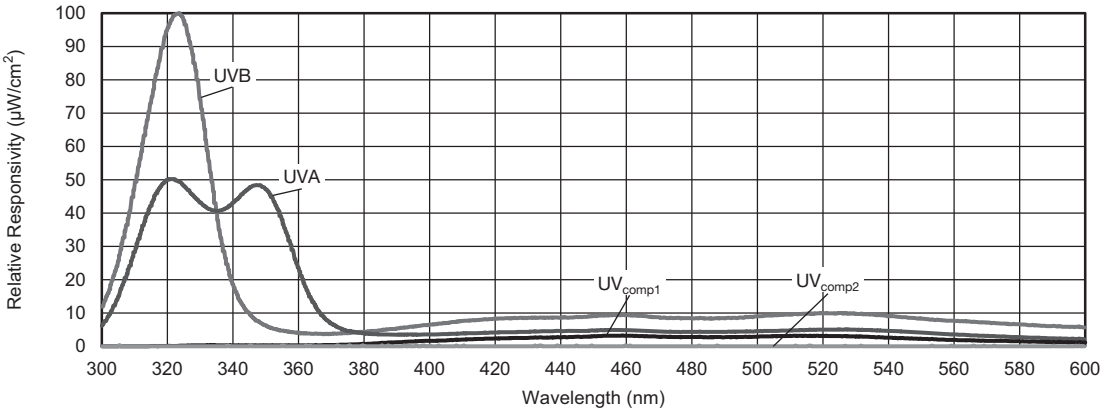


Fig. 3 - Relative Responsivity vs. Wavelength incl. Response at Higher Wavelength

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

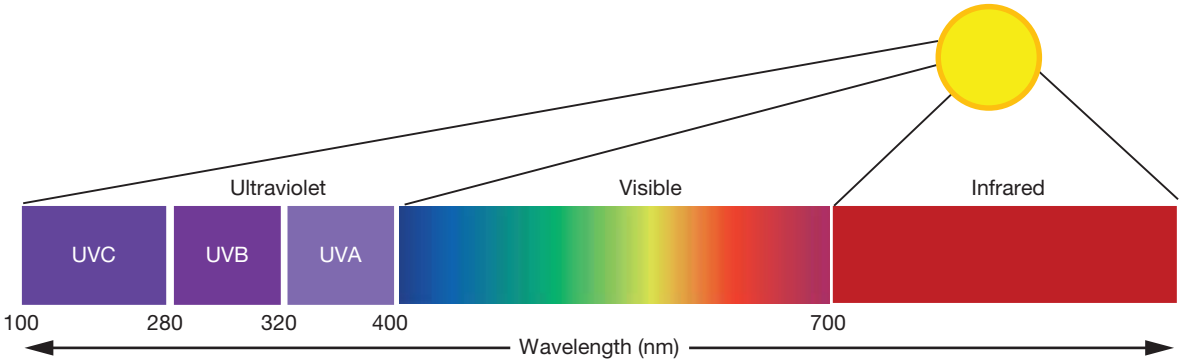


Fig. 4 - Light Spectrum

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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 reaches earth, UVC is blocked by our atmosphere, so it does not harm.

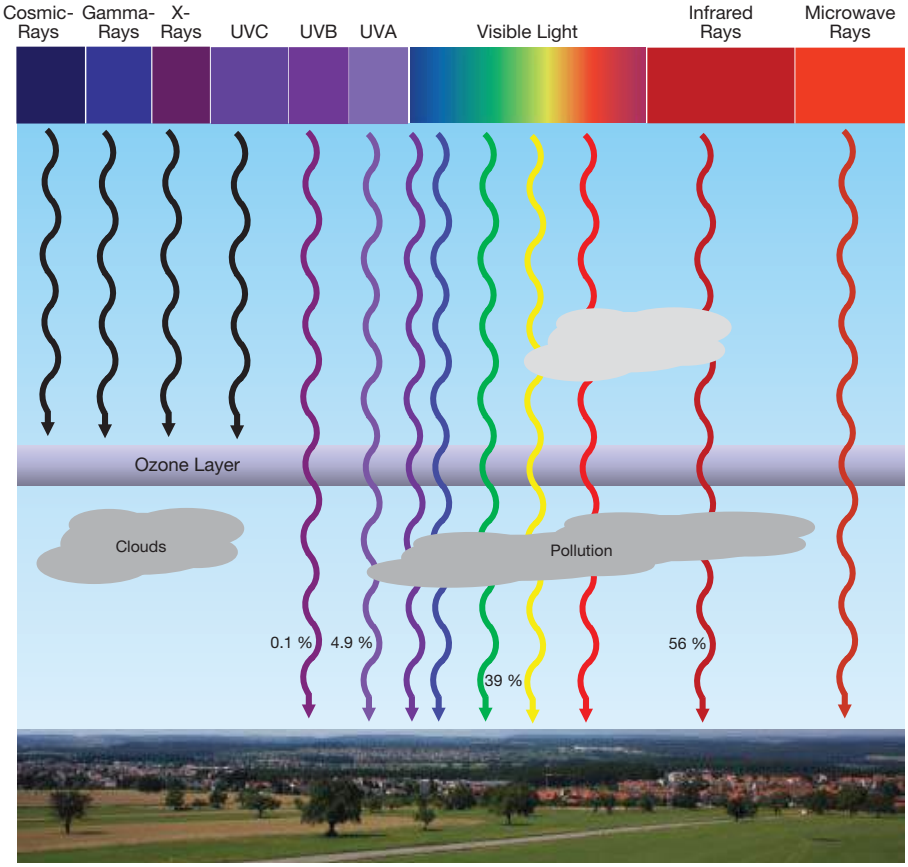


Fig. 5 - Radiation that Reaches Earth Surface

The UVB rays - wavelength 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 the 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 - wavelength 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 the photo aging and favoring 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 now what energy is behind this UV radiation and what risk level is seen with, a so-called UV Index is established.

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

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

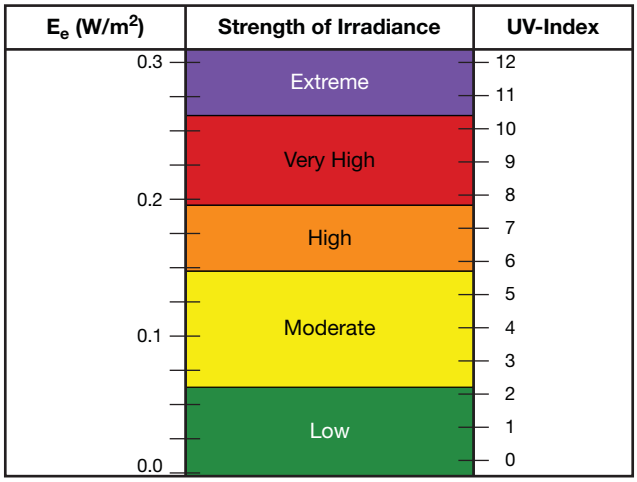


Fig. 6 - Strength of Irradiance and the UV-Index

In order to define now what energy is behind this UV radiation and what risk level is seen, VEML6075 enables now this simply by reading out the irradiance values and calculate according exact measured UVB and UV-A / UV-B values. Also the visible and infrared noise is 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 VEML6075 is easily handled by just 1 I^2C-bus command register: command code “0”. All required functions what need to be set, 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 16 bit wide read register for the UV as well as so-called compensation data and 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 time cycle VEML6075 output one cycle data every time host writes in ‘1’ to sensor. The state 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 UV-A / UV-B 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

Command codes 10 (0A) and 11 (0B) contain in addition so-called compensation values. These deliver information about the whole received light within visible wavelength area (0A) and strength of the infrared content within the received light (0B).

Command code 8 informs about the dark current value.

The last command code12 (0C) 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 generate undesirable noise current. In order to correct such error sources, VEML6075 incorporates UV_{comp1} and UV_{comp2} noise compensation channels. In addition, there is a UVD dummy channel for dark current cancellation.

- **UV_{comp1}** channel allows only visible noise passing through this channel
- **UV_{comp2}** channel allows only infrared noise passing through this channel
- **UVD** channel is a dummy channel which 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 5 channels (UVB, UVAB, UV_{comp1}, UV_{comp2}, and UVD), simple $UVA_{compand}$ UVB_{comp} formulas are used to calculate the UVI signal.

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

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

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

Note

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

In both Eq. (1) and Eq. (2) formulas, there are 4 coefficients we need to solve for. For open air system with and without a teflon diffuser over the VEML6075 sensor, the following default VIS and IR coefficients are used:

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

In 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) equations to zero.

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

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

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

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

With all above calculations to eliminate 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.

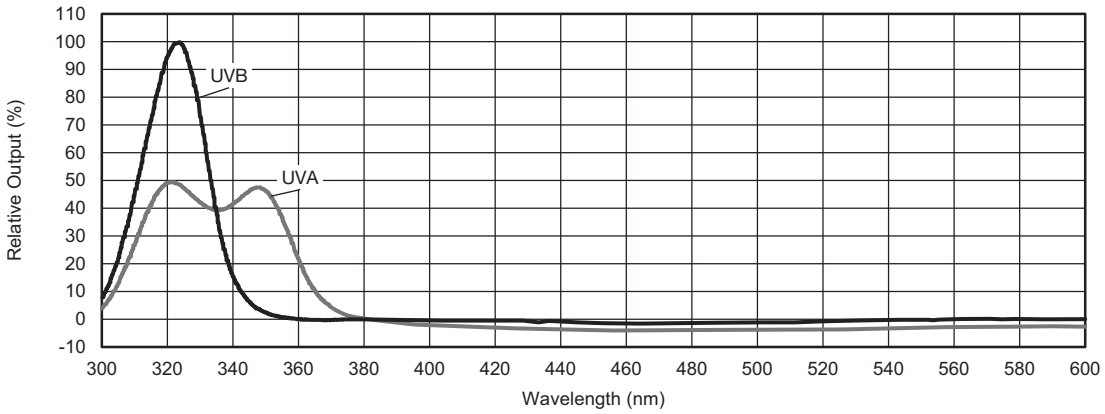


Fig. 7 - Relative Responsivity vs. Wavelength (adjusted with compensation channels)

This may help to understand sensors behavior when testing just with lab conditions and defined calibrated light sources.

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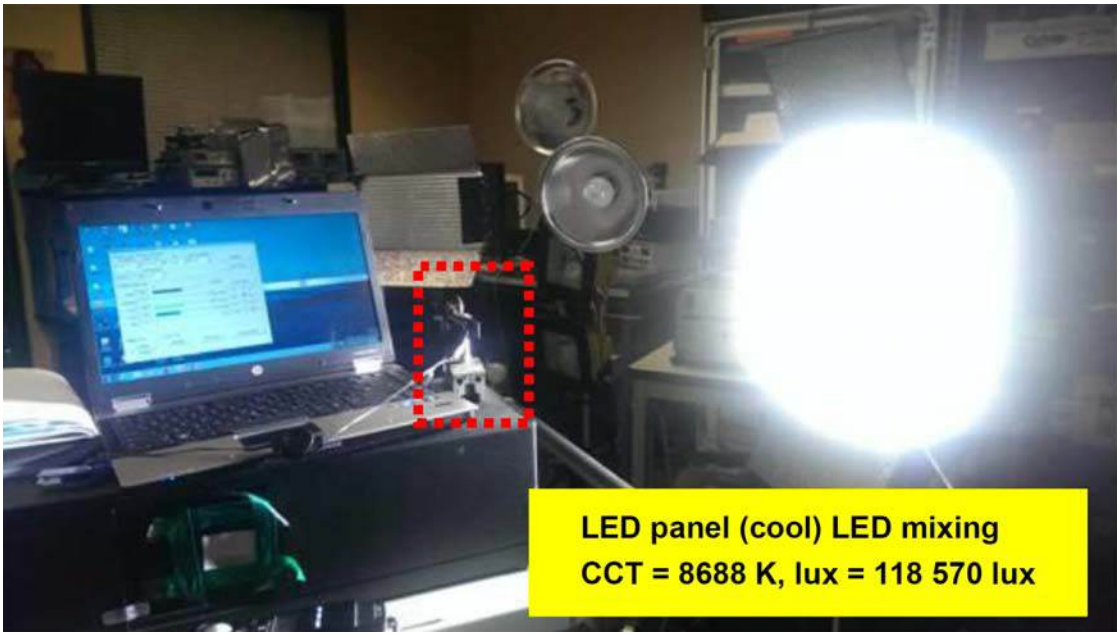


Fig. 8 - VEML6075 Test Set-Up using a White LED as Light Source

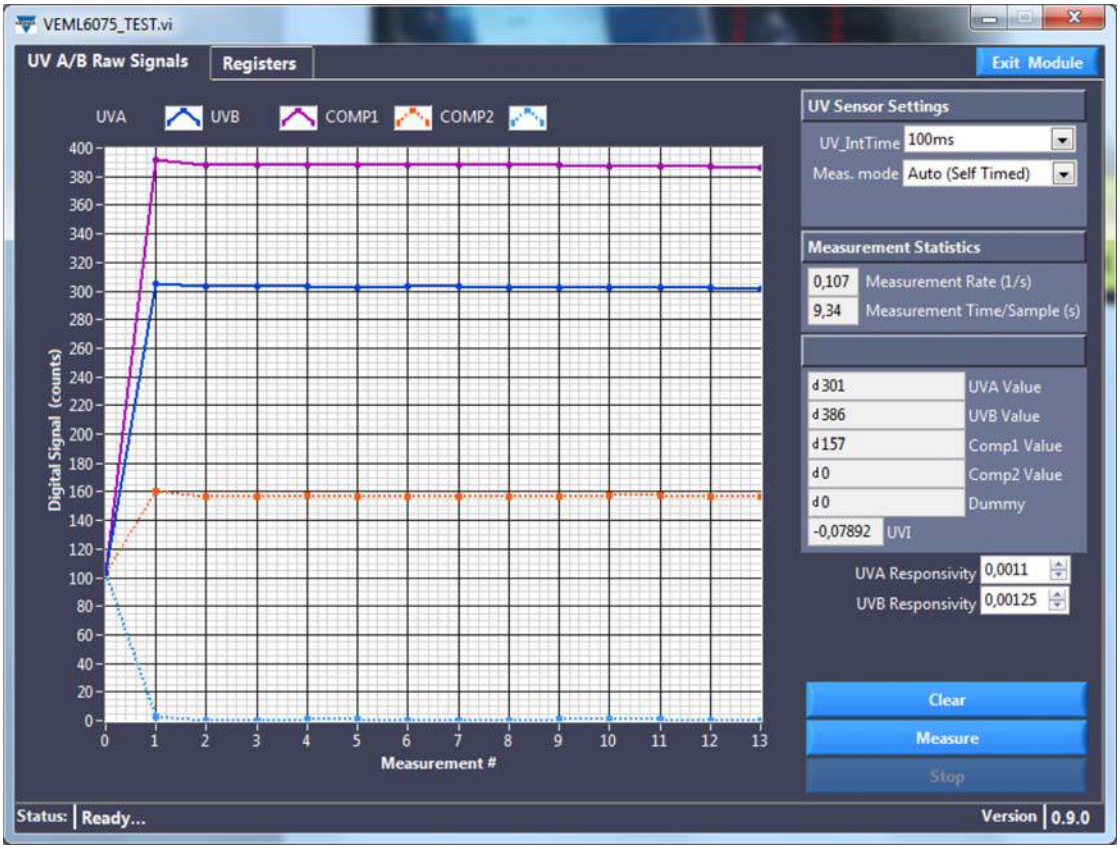


Fig. 9 - VEML6075 Demo Software View when used Light Source is a White LED

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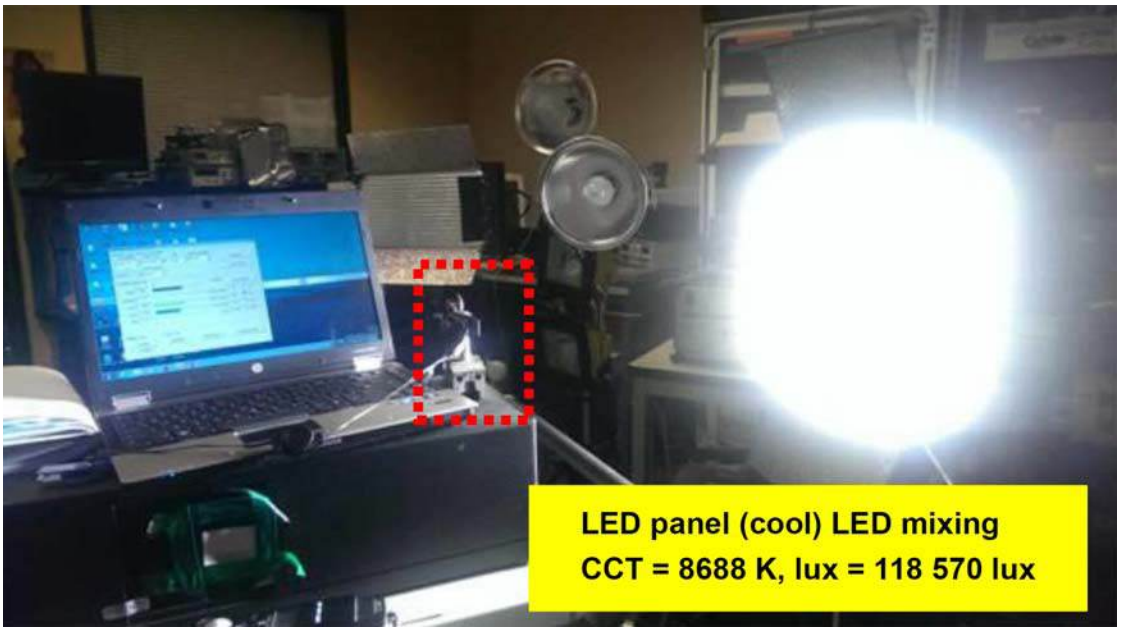


Fig. 10 - VEML6075 Test Set-Up using an Incadescent Lamp as Light Source

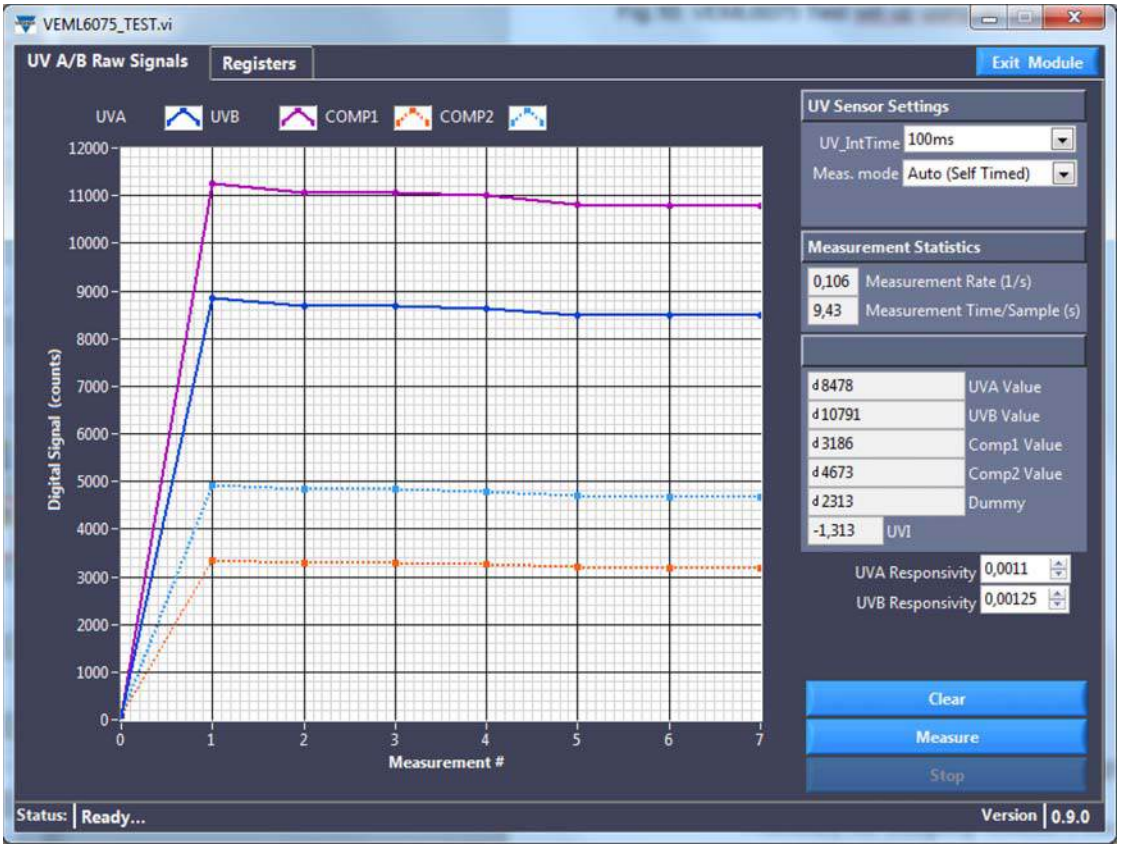


Fig. 11 - VEML6075 Demo Software View when used Light Source is an Incandescent Lamp

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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 x (UV_{comp2}) = 0

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

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

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

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

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

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

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

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

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.

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

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

Using a = 1.92 and $b = \frac{UVA - (a \times UV_{comp1})}{UV_{comp2}}$ 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 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 that every wavelength between 286.5 nm and 400 nm needs to be measured - in steps of 0.5 nm - but also a weighting function needs to be applied.

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

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)

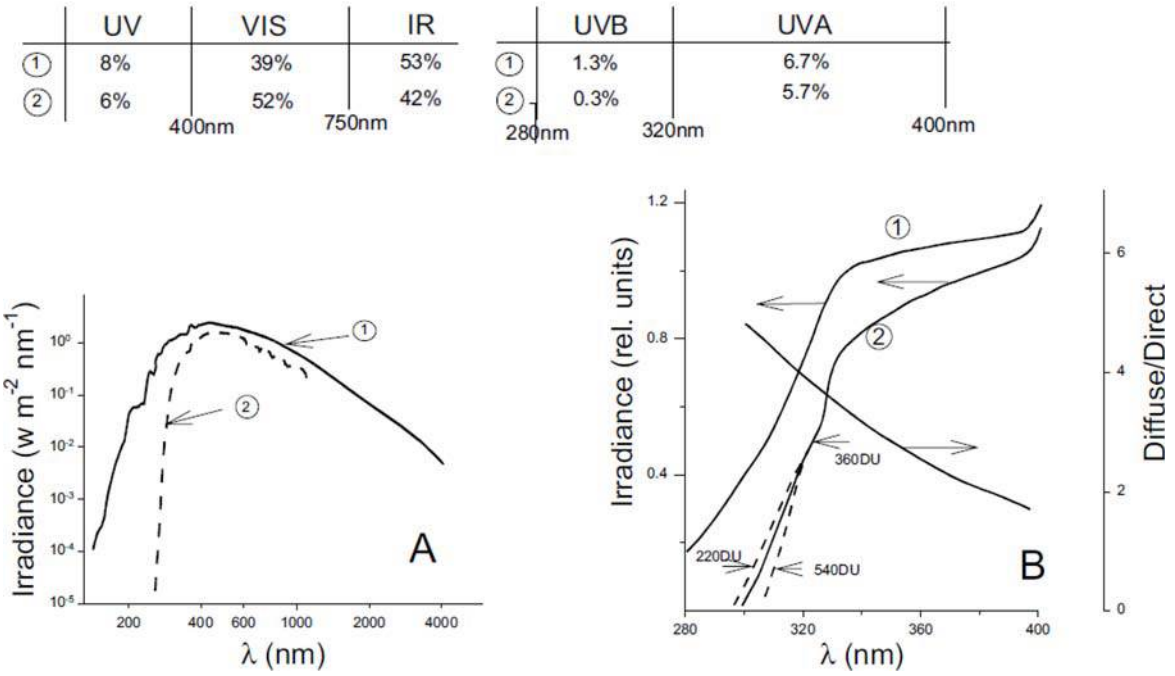


Fig. 12 - Spectrum of Solar Radiation, 1: Outside the Atmosphere and 2: at Sea Level

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WHAT VALUES MAY BE SEEN WITH VEML6075

The defined UV light source shown also within the datasheet (NichiaNCSU033X-365nm) to check UVA sensitivity and UVTOP310TO39HS - 315 nm to verify UVB sensitivity will not be available within most labs, and also the set-up with before mentioned white LED and incandescent lamp needs accurate set-up and alignment to deliver comparable results.

Even “normal” daylight to study and compare VEML6075’s response may lead to misinterpretation as the ultraviolet power is strong dependent on day-time as well as on season, and, also the place on earth where this measurement will be done.

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

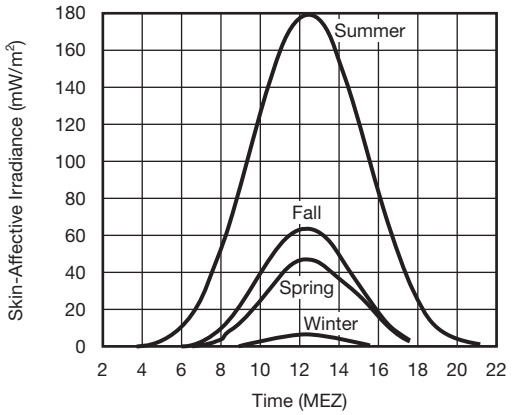


Fig. 13 - Skin Affecting Irradiance Level vs. Time Seen at the Beginning of the Four Seasons

The correct UV index needs a well calibrated measurement tool as e.g. Davis weather station what is used to calibrate VEML6075 also.

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WHAT VALUES ARE MEASURED WITH VEML6075

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



Fig. 14 - Measurement Set-Up

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UVI tracking with Davis UVI sensor full day tracking, T148 has no diffuser. Maximum UVI is 9.7.

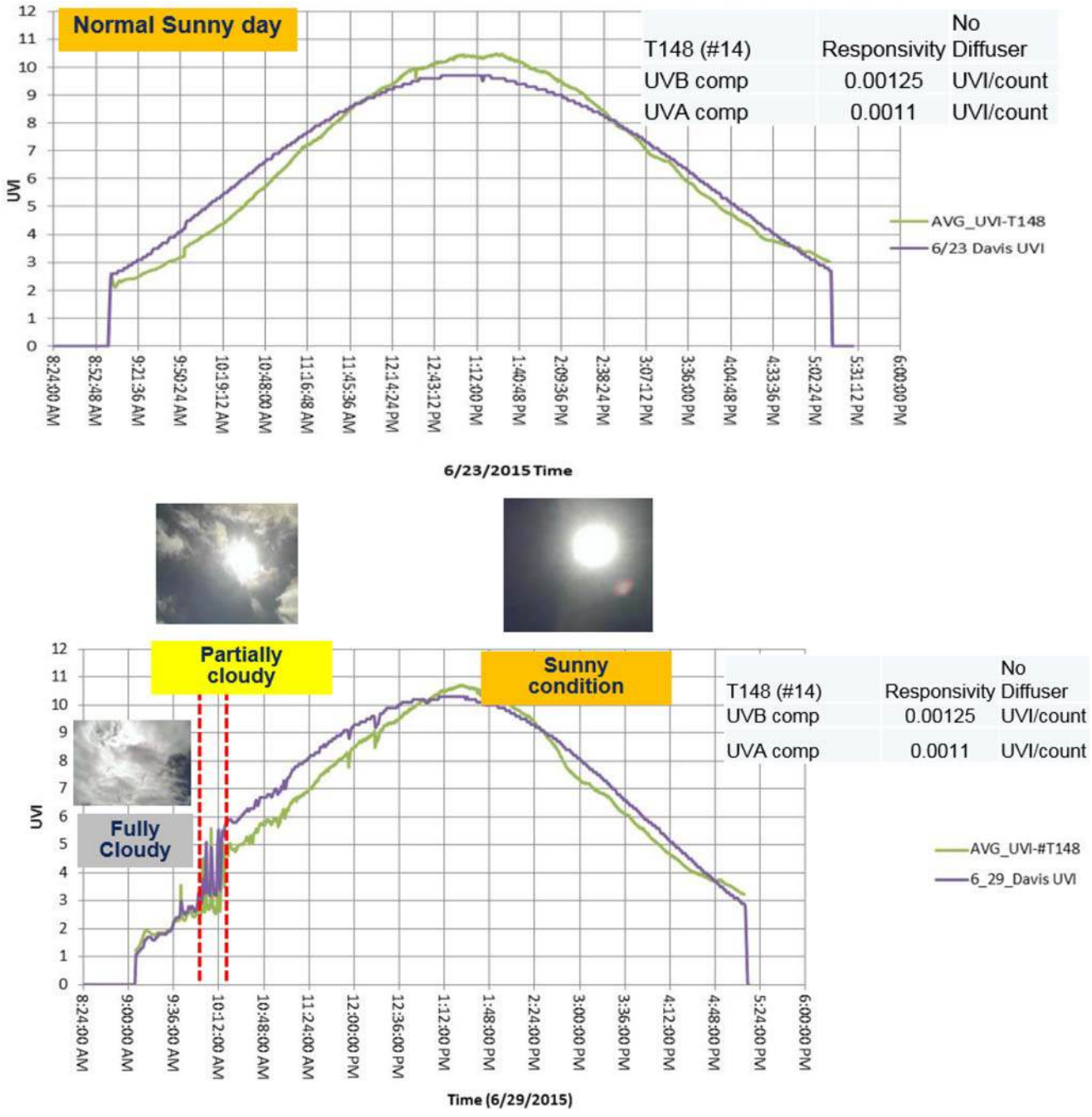


Fig. 15 - Test Data showing calculated UVI and Comparison to Reference

With empirical finding 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	2.5			
UVA coefficient b	2.5			
UVA coefficient c	2.75			
UVA coefficient d	2.75			
TYPICAL RESPONSIVITY WITHOUT DIFFUSER				
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 DIFFUSER 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 diffuser 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 UV-A / UV-B sensor will need a well selected cover what takes care also that this window material should be not only completely transmissive to visible light (400 nm to 700 nm), but also for UVA and UVB wavelength, so, for 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 diffuser (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 diffuser 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 diffuser is less than 10 %.

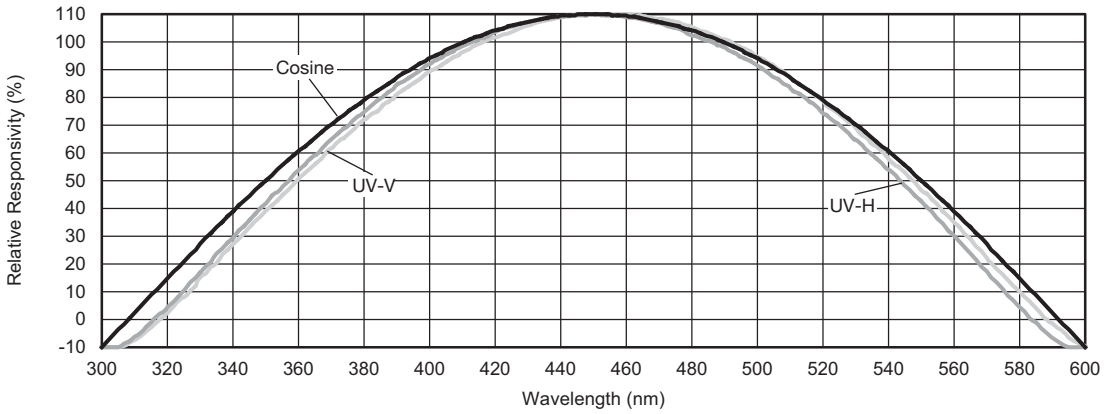


Fig. 16 - Relative Radiant Sensitivity vs. Angular Displacement

For more information please see also, e.g. here:

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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Designing the VEML6075 into an Application

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.

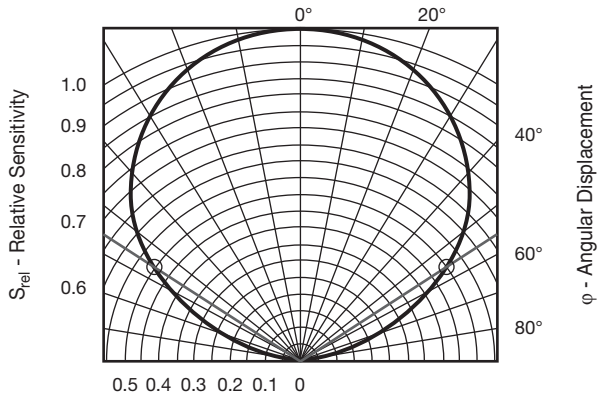


Fig. 17 - Relative Radiant Sensitivity vs. Angular Displacement

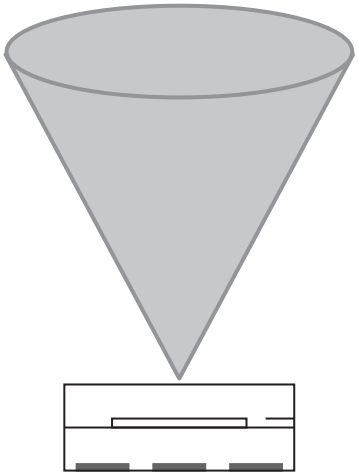


Fig. 18 - Angle of Half Sensitivity: Cone

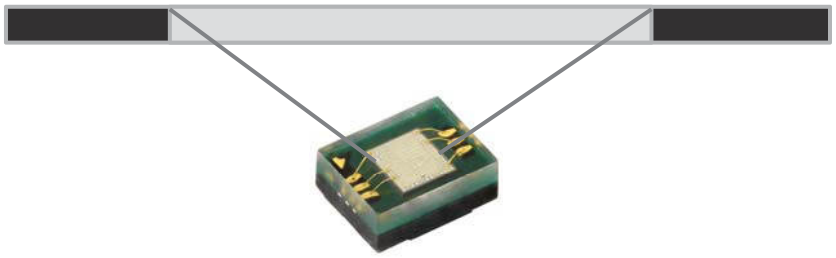


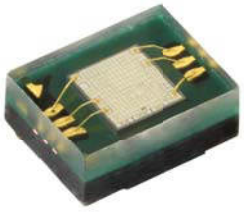
Fig. 19 - Window Above Sensitive Area

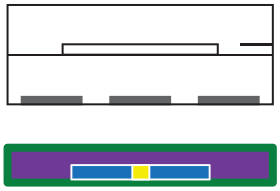
Remark:
This wide angle and the placement of the sensor as close as possible to the cover is needed to show good responsivity.

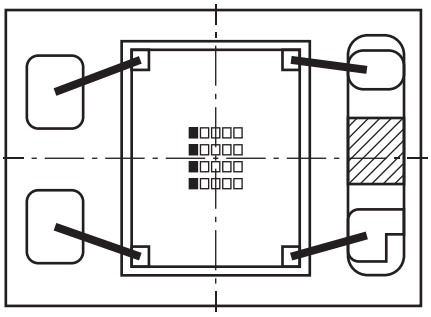
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Designing the VEML6075 into an Application

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

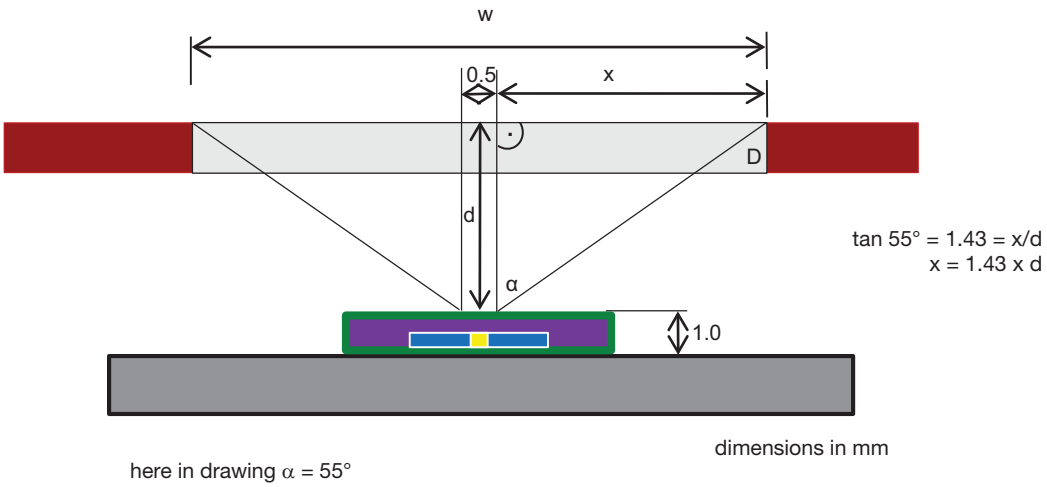


Fig. 20 - Window Area for an Opening Angle of ± 55°

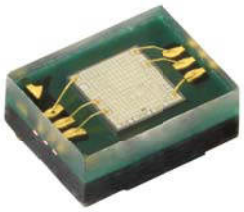
Calculation is then: tan α = x/d $\rightarrow$ with α = 55° and tan 55° 1.43 = x/d $\rightarrow$ x = 1.43 x d
Then the total width is w = 0.5 mm + 2 x x.

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

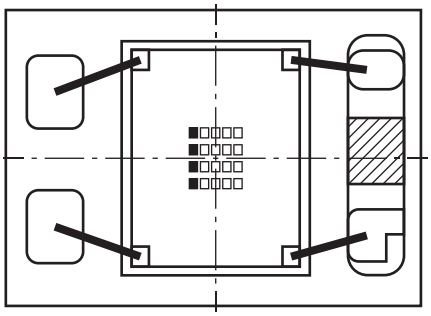
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Designing the VEML6075 into an Application

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

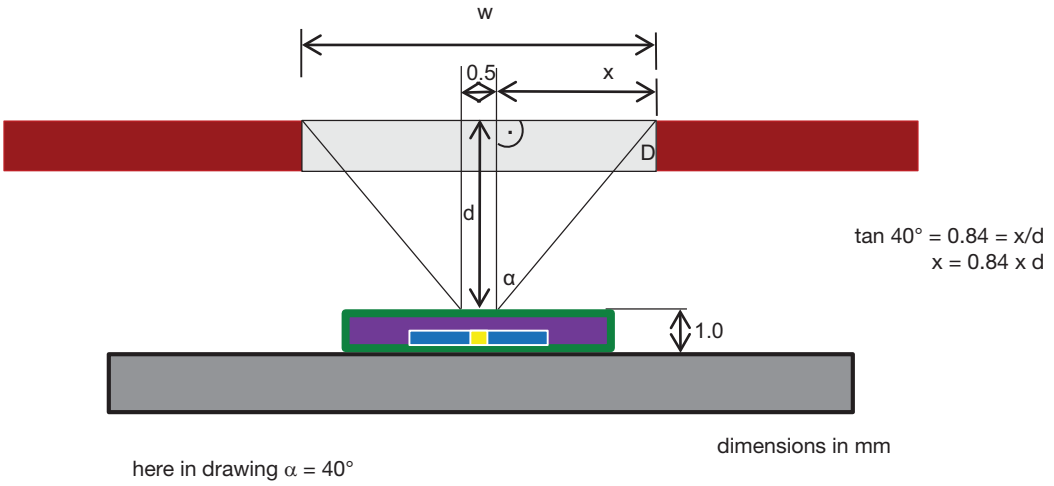


Fig. 21 - Window Area for an Opening Angle of ± 40°

Calculation is then: tan α = x/d $\rightarrow$ with α = 40° and tan 40° 0.84 = x/d $\rightarrow$ x = 0.84 x d
Then the total width is w = 0.5 mm + 2 x x.

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

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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/



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Designing the VEML6075 into an Application

With help of the VEML6075 sensor board and the demo software one can easily test this UV-A / UV-B sensor. Beside the raw data of all five channels also the UV index is given with before shown calculations. The five integration times are also selectable. Belonging result counts are strict linear, means, a factor 2 in integration time results also in a factor 2 of output data counts.

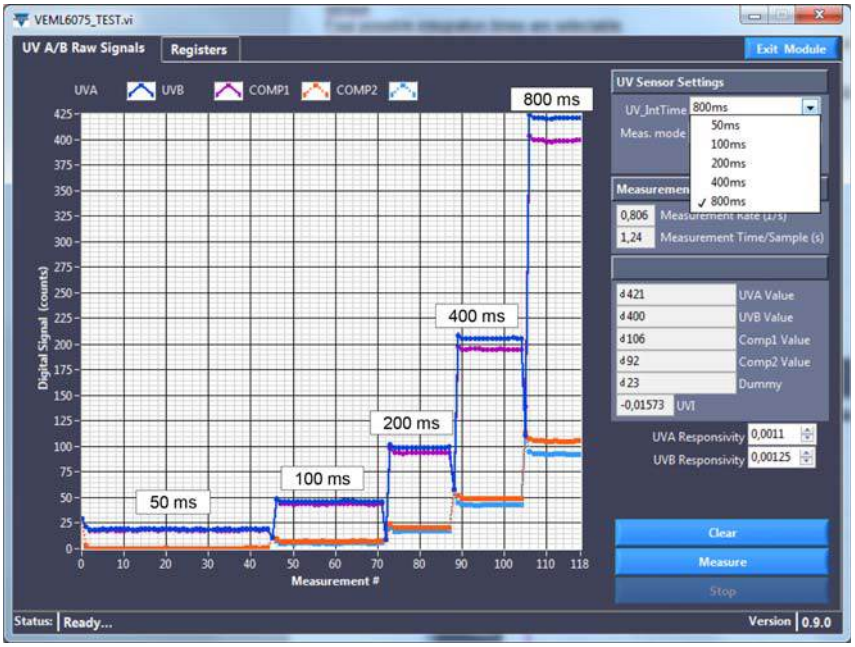


Fig. 22 - Linearity of Integration Times for Small and High Data Values

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

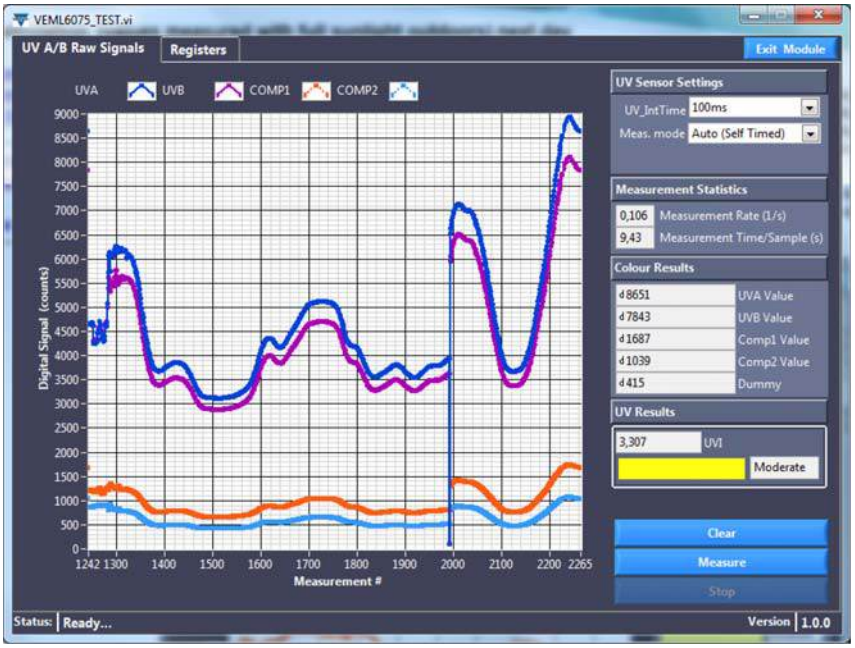


Fig. 23 - View of the VEML6075 Demo Software Showing Raw Data, UVI, and Risk Level

APPLICATION NOTE

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