ROHM Sensing Solutions

# Ultraviolet Sensor IC with Voltage Output

## ML8511 (UV Photodiode + Amp)

No.0000000016

### ●Introduction

This application note will show how to use the ML8511's linear output voltage to approximate the real-time UV Index (UVI), the international standard measurement of the strength of ultraviolet radiation from the sun.

### ●Description

A UV Index is calculated from a skin-damaging UV radiation metric called the Erythemal action spectrum. Implemented by the International Commission on Illumination (CIE), the Erythemal curve represents the average skin response over the solar UV spectrum. Weighing factors are provided for the UV wavelength spectrum (280-400nm) –the more damaging the wavelength, the larger the factor. The World Health Organization's recommendation for calculating UVI multiplies the intensity at each wavelength with the Erythemal action function and the resulting sum is the total Erythemal-weighted UV intensity in milliwatts/meter$^2$. This sum can be multiplied by 0.04 to obtain the standardized UVI. True UVI calculation requires an expensive and large spectrophotometer to scan and measure the intensities of each UV wavelength. ROHM's broad spectrum UV sensor, capable of measuring 280-400nm wavelengths while having a similar Erythemal response, can be used to approximate the UV Index within ±1 UVI error.

### ●Applications

Smart Phone, Watch, Weather station, Bicycle Navigation, Gaming, Health, Fitness, Accessories

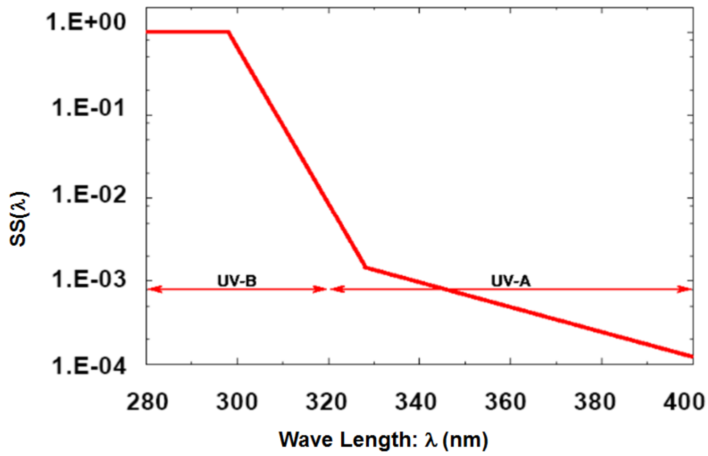
### ●Electrical Characteristics ($T_a$=25°C, $V_{EN}$=$V_{DD}$)

| Parameter | Symbol | Limit | | | Unit |
|---|---|---|---|---|---|
| | | MIN | TYP | MAX | |
| **Operating Voltage** | | | | | |
| | $V_{DD}$ | 2.7 | 3.3 | 3.6 | V |
| **Supply Current (active mode)** | | | | | |
| | $I_{DDA}$ | - | 300 | 500 | µA |
| **Output Voltage ($UV_{AB}$=0)** | | | | | |
| | $V_{REF}$ | 0.95 | 1.0 | 1.05 | V |
| **Output Voltage (10mW/cm$^2$ at $\lambda_P$)** | | | | | |
| | $V_o$ | 2.08 | 2.2 | 2.32 | V |

### ●McKinlay-Diffey Erythemal Action Spectrum

Below is the CIE adopted action spectrum which desribes the effect of solar energy at different wavelengths in producing erythema –the reddening of the skin due to sunburn.

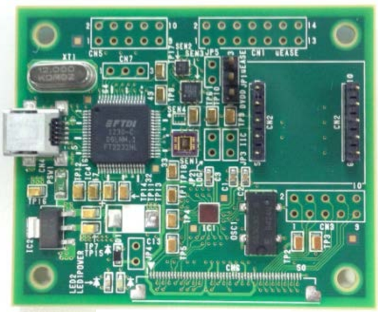
$$UV-I=(\int SS(\lambda)*Ery(\lambda))*0.04$$



## ●Test Equipment and Measurement Procedure

An ML8511 evaluation board, powered at 3.3$V_{DD}$, was used with a multimeter to measure and record analog voltages during various ultraviolet intensities throughout the day. In addition, a National Institute of Standards and Technology (NIST) traceable and calibrated Solarmeter Model 6.5 UVI Meter was used alongside ML8511's sensor opening to record actual UVI. During testing, both the ML8511 sensor and UVI meter were facing straight up toward a global normal (perpendicular to level ground) inclination. Solar irradiance measured this way includes direct (solar zenith angle) and diffuse (atmospheric diffusion) rays.

During the measurement process, the ML8511 sensor was used without a protective lens. ROHM recommends the usage of an optical lens/filter in end product design. Due to the lack of a diffusive transmission lens, solar irradiance is not uniform across the active area of the ML8511. The maximum voltages were typically seen when the sensor was facing the sun while still parallel to the ground and minimum voltages resulted with a 90° rotation. For accurate solar measurements independent of sensor orientation, the maximum and minimum voltages were taken and averaged before the UVI approximation calculation.


ML8511 Evaluation Board

Solarmeter Model 6.5

## ●Calculation of the actual UV Index from Vout of ML8511

Application: ML8511 + Ideal Lens filter (100% transmission of UVA + UVB)*. This section will first describe how to derive ROHM's UVI approximation equation from the UVI function. UVA and UVB are given a fixed ratio and their respective Erythemal factors are averaged. The resulting equation will approximate the UVI from Vout of ML8511 with an ideal filter with 100% UV transmission characteristics.

Key points to remember:

1. ML8511 measures the total UV strength of UVA and UVB (un-weighted UV strength)
2. Voltage output from ML8511 is directly proportional to the total strength of UVA + UVB
3. Under most solar conditions, the ratio of UVA/UVB is a fixed value. UVI can be approximated by multiplying the output of ML8511 by a factor.

*UV Index Function:*

$$UVI = (\int SS\,(\lambda) * Ery(\lambda)) * 0.04$$

*Variables:*

*SS(λ) = Solar Irradiance Spectrum*
*Ery (λ) = McKinlay-Diffey Erythemal Action Spectrum*

*Assumed fixed ratio* $\begin{cases} UVA = UVTotal * 94.1\% \\ UVB = UVTotal * 5.9\% \end{cases}$

*$K_1$ = Averaged Erythemal factor for UVA (320-400nm) = 0.00071*
*$K_2$ = Averaged Erythemal factor for UVB (280-320nm) = 0.05220*

$\Delta V_{out} = V_{out} - V_{out\_i}$ →
$V_{out\_i} = 1.0V$ @ shading ($UV_{Total} = 0$)
$V_{out} = 2.2V$ @ $10mW/cm^2$ → since 10,000mW/m2 = 0.1mW/cm2 → ΔVout = 1.2 @ mW/cm2
$\Delta V_{out} = 0.12V$ @ $10{,}000mW/m^2$
$UV_{Total} = \Delta V_{out} * 10{,}000/0.12$

*UVI Approximation Equation:*

$$UVI = (UV_A * k_1 + UV_B * k_2) * 0.04$$
$$UVI = (UV_{Total} * 0.941 * k_1 + UV_{Total} * 0.059 * k_2) * 0.04$$
$$UVI = UV_{Total}\,(0.941 * k_1 + 0.059 * k_2) * 0.04$$
$$UVI = \Delta V_{out}\,(0.941 * k_1 + 0.059 * k_2) * 0.04 * 10000 \div 0.12$$
$$UVI = \Delta V_{out} * 12.49$$

$$\mathbf{UVI = 12.49V_{out} - 12.49}$$

Below shows how to calculate the UVI approximation equation offset. This offset is the result of various geographic and climatic conditions that vary depending on location and time of year.

*UVI Approximation Equation with offset:*

1. *At a specific $V_{out}$ value, measure the actual UVI and compare against the calculated UVI value using the UVI approximation equation.*

2. *Here is an example: $V_{out}$ = 1.5, calculated UVI (using UVI approximation equation) = 6.245, Real UVI (using meter) = 4*

   *Real UVI - Calculated UVI = Error offset*
   *4 - 6.245 = -2.245*

3. *UVI Equation with offset*

   *UVI = 12.49Vout – 12.49 – (2.245)*

   *UVI = 12.49$V_{out}$ – 14.735*

Using collected UV data from field testing in Santa Clara (CA), the typical offset is -1.8735. With this offset, the UVI approximation has only a +/-1UVI error.

*UVI Approximation Equation with offset (Santa Clara):*

$$\boldsymbol{UVI = 12.49V_{out} - 14.3635\ (for\ Vout \geq 1.23V\ and\ UVI \geq 1)}$$

## ●Using the UVI approximation equation with a non-ideal filter

Application: ML8511 + Non-ideal Lens Filter (Only UVA transmission, UVB = 0)*. This section will show how to adjust the UVI approximation equation when using a non-ideal filter of known transmissivity.

In this example a lens filter material (such as acrylic) is used that only passes UVA. UVB strength is not measured and cannot be measured. Using the same assumption of a fixed ratio between UVB/UVA (94.1% UVA), the output of ML8511 will drop by 5.9% due to UVB blockage. With that relationship, the scaling factor can be calculated.

Scaling factor: 12.5 / 94.1% = 13.28

$$\boldsymbol{UVI = 13.28V_{out} - 13.28}$$

*UVI Equation with calibration can be calculated as in previous Application 1*

*This application note does not include testing results using a lens cover. A lens cover for the ML8511 is recommended due to protection of the sensor and improved uniformity of solar radiation across the sensor element due to the diffusion of the filter. ROHM can provide recommendations on lens cover material, orientation, and dimensions.

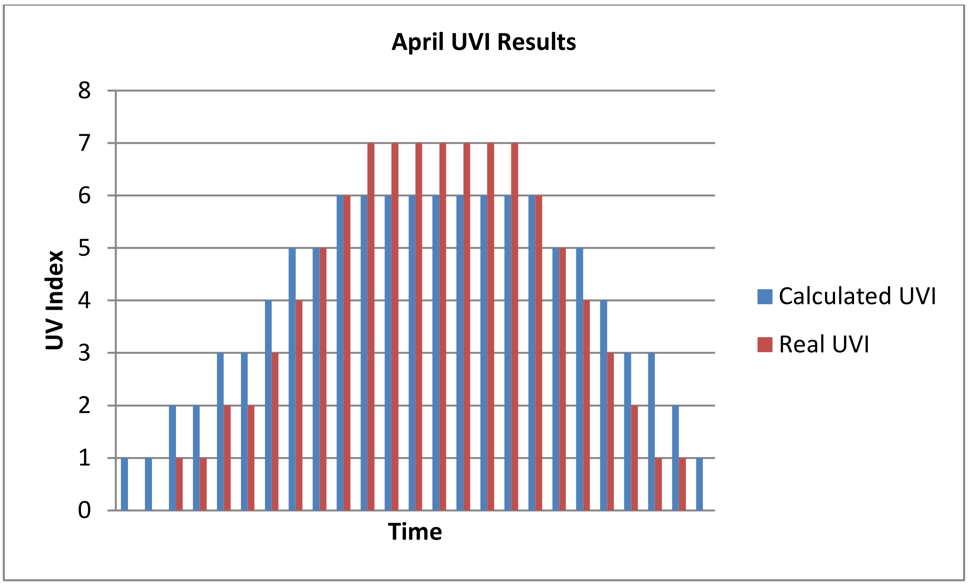
## ●Sample Raw Measurement Data from Application 1 Testing

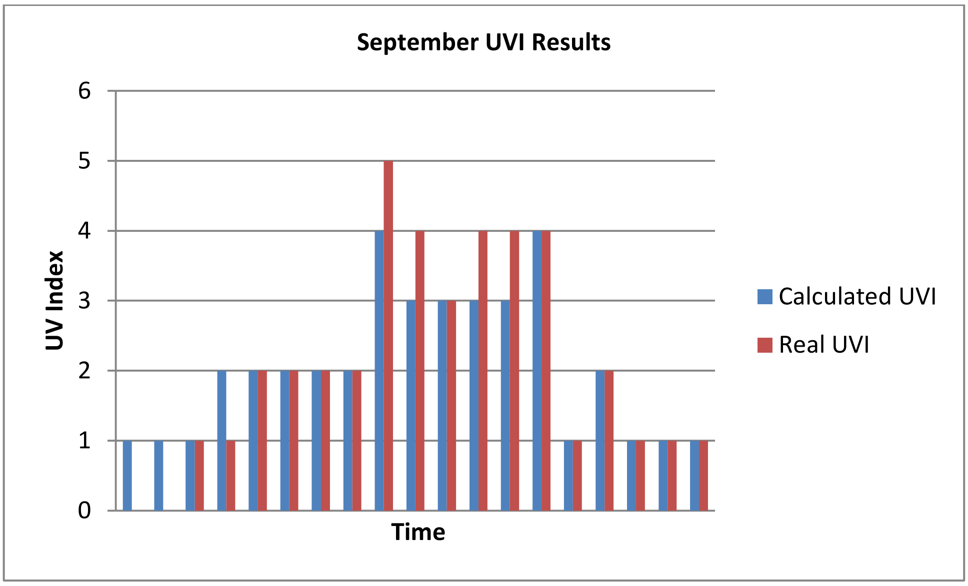
Using the measurement procedures and UVI approximation equation with offset as described above, the calculated UVI accurately matches the real UVI results within ±1UVI error.

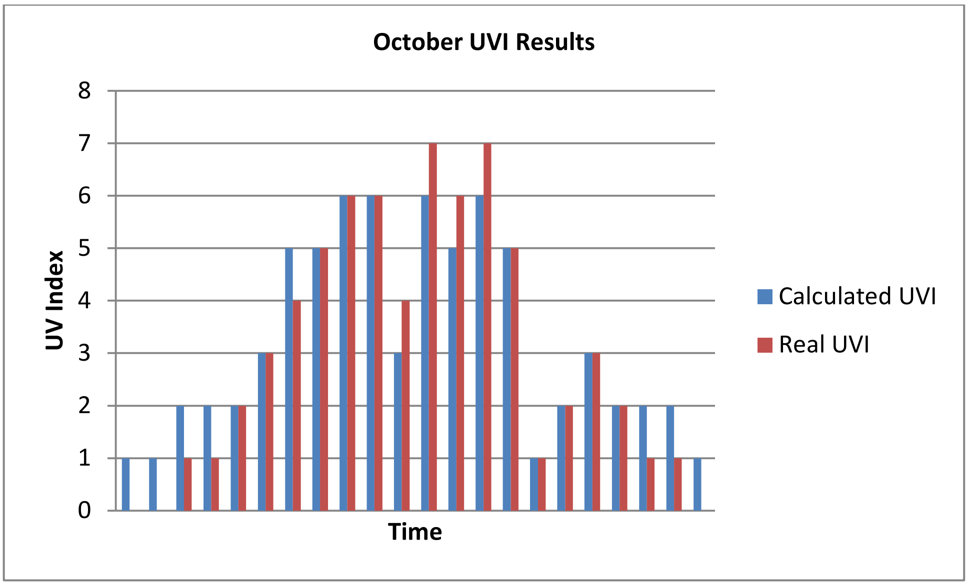
| ML8511 Vout_average | Real UVI | Calculated UVI | Error | Error (Integer) |
|---|---|---|---|---|
| Vout_max (sensor facing sun) - Vout_min (sensor orthogonal to sun) | SOLARMETER | [Vout*12.49]-14.36 | Real UVI - Calc UVI | Real UVI - Calc UVI |
| 1.243 | 1.1 | 1.16157 | -0.06 | 0 |
| 1.279 | 1.4 | 1.61121 | -0.21 | 0 |
| 1.291 | 1.7 | 1.76109 | -0.06 | 0 |
| 1.305 | 1.9 | 1.93595 | -0.04 | 0 |
| 1.301 | 2 | 1.88599 | 0.11 | 0 |
| 1.358 | 2.3 | 2.59792 | -0.30 | 0 |
| 1.395 | 2.6 | 3.06005 | -0.46 | 0 |
| 1.42 | 2.7 | 3.3723 | -0.67 | 1 |
| 1.43 | 2.8 | 3.4972 | -0.70 | 1 |
| 1.435 | 2.9 | 3.55965 | -0.66 | 1 |
| 1.44 | 3 | 3.6221 | -0.62 | 1 |
| 1.457 | 3.1 | 3.83443 | -0.73 | 1 |
| 1.459 | 3.1 | 3.85941 | -0.76 | 1 |
| 1.462 | 3 | 3.89688 | -0.90 | 1 |
| 1.475 | 3.2 | 4.05925 | -0.86 | 1 |
| 1.476 | 3.5 | 4.07174 | -0.57 | 1 |
| 1.477 | 3.6 | 4.08423 | -0.48 | 0 |
| 1.48 | 3.7 | 4.1217 | -0.42 | 0 |
| 1.482 | 3.6 | 4.14668 | -0.55 | 1 |
| 1.484 | 3.6 | 4.17166 | -0.57 | 1 |
| 1.488 | 3.9 | 4.22162 | -0.32 | 0 |
| 1.49 | 3.9 | 4.2466 | -0.35 | 0 |
| 1.494 | 4.1 | 4.29656 | -0.20 | 0 |
| 1.496 | 4.1 | 4.32154 | -0.22 | 0 |
| 1.498 | 4 | 4.34652 | -0.35 | 0 |
| 1.502 | 4.2 | 4.39648 | -0.20 | 0 |
| 1.504 | 4.2 | 4.42146 | -0.22 | 0 |
| 1.506 | 4.3 | 4.44644 | -0.15 | 0 |
| 1.509 | 4.5 | 4.48391 | 0.02 | 0 |
| 1.51 | 4.7 | 4.4964 | 0.20 | 0 |
| 1.512 | 4.8 | 4.52138 | 0.28 | 0 |
| 1.514 | 4.8 | 4.54636 | 0.25 | 0 |
| 1.518 | 4.9 | 4.59632 | 0.30 | 0 |

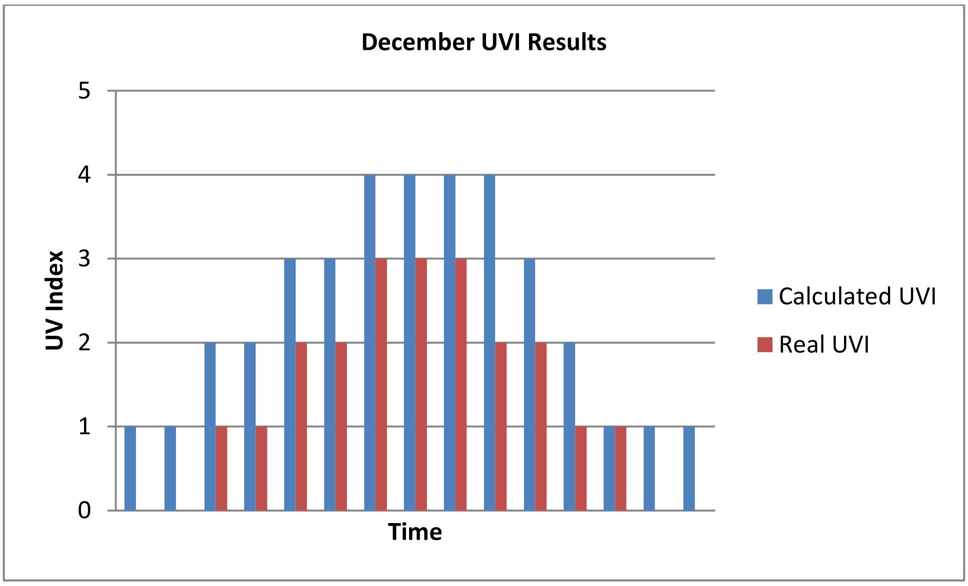
**●Graphical Sample Measurement Data from Application 1 Testing**

The results below are from separate testing in Hong Kong at different times of the year. The same UVI approximation calculation was used and a similar ±1UVI error was established.




October UVI Results
UV Index
0
1
2
3
4
5
6
7
8
Time
Calculated UVI
Real UVI


December UVI Results
UV Index
0
1
2
3
4
5
Time
Calculated UVI
Real UVI

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