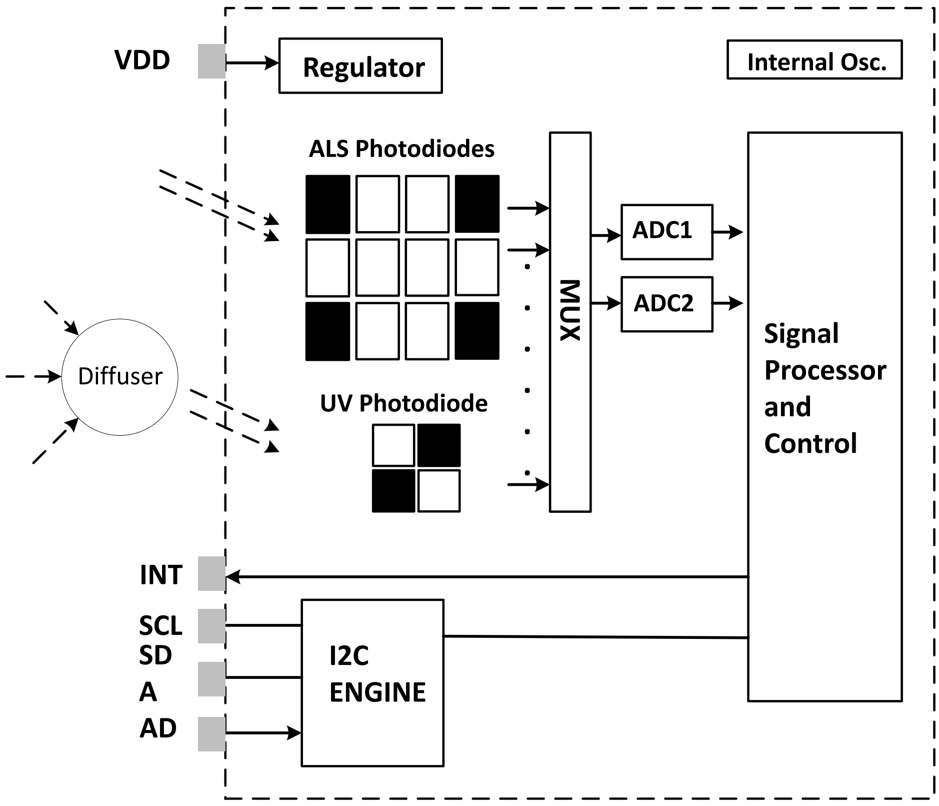
AN968: Si1133 UV Index Sensor Electrical and Optical Design Guide

The Si1133 is a UV Index Sensor and Ambient Light Sensor with I^2C digital interface and programmable-event interrupt output. This sensor IC includes dual 23-bit analog-to-digital converters, integrated high-sensitivity array of UV, visible, and infrared photodiodes, and digital signal processor. The Si1133 is provided in a 10-lead 2×2 mm DFN package and capable of operation from 1.62 to 3.6 V over the –40 to +85 °C temperature range.



KEY FEATURES

- High accuracy UV index sensor (0 to > 20 UV index)
  - Matches erythemal curve
- Ambient light sensor
  - <100 mlx resolution possible, allowing operation under dark glass
  - Up to 128 klx dynamic range possible across two ADC range settings
- Industry's lowest power consumption
  - 1.62 to 3.6 V supply voltage
  - <500 nA standby current
  - Internal and external wake support
  - Built-in voltage supply monitor and power-on reset controller

APPLICATIONS

- Wearables
- Handsets
- Display backlighting control
- Consumer electronics

1. Formal Requirements for UV Index Measurements

The formal requirement for measuring UV is that the sensor have a relative filter response that follows the CIE action spectrum curve (the erythemal curve), as shown below.

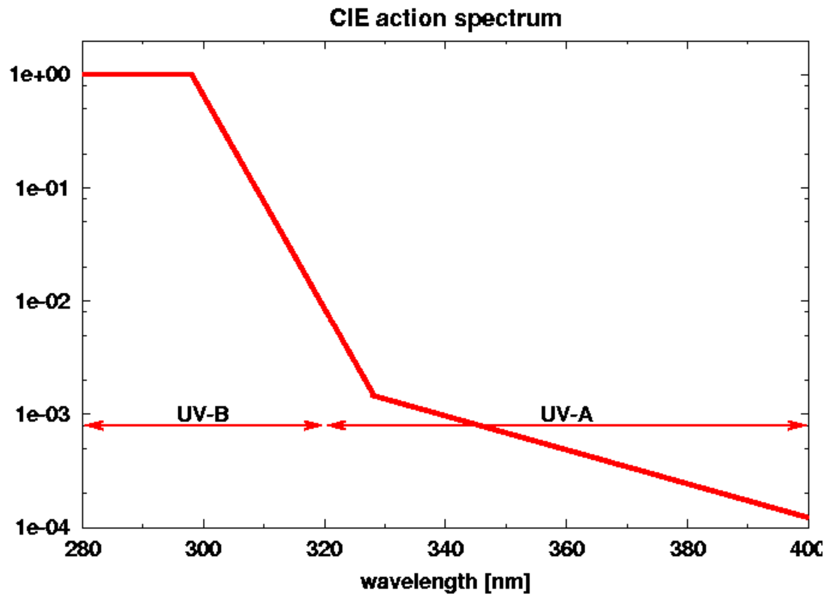


Figure 1.1. CIE Action Spectrum/Erythemal Skin Reddening Curve

The UV Index is an estimate of the UV levels that affect human skin, where 1 unit equals 25 mW/m2 after the solar energy is weighted by the erythemal curve. The erythemal curve tells you how to weigh the UV energy spectrum.

An analogy of this is: Lux light measurement level is extracted from visible light using the photopic curve and a scaling factor. In the UV-Index case, UV-Index is extracted from UV light using the erythemal curve and a multiplicative scaling factor of 1/(25 mW/m×m). The analogy is that the retina is sensing visible light, while the skin is sensing UV by turning red.

The math for measuring UV is simple. One integrates all the energy in the spectrum multiplied by the erythemal action curve and divides the result by 25 mW/m×m.

For example, the spectrum can be plotted as [mW/(m×m×nm) vs. nm], then integrated while using the erythemal curve as a weighing factor and get X mW/m×m as a result. Then one divides X by 25 mW/m×m to get the UV Index.

Since the erythemal curve is 1.0 at 280 nm, it means that 25 mW/m×m at 280 nm is 1 UV index.

The sensor’s most sensitive direction must be maximum while pointing at the Zenith or “straight up”, and the sensor's response must reduce gradually following the cosine law.

A good reference is https://en.wikipedia.org/wiki/Ultraviolet_index.

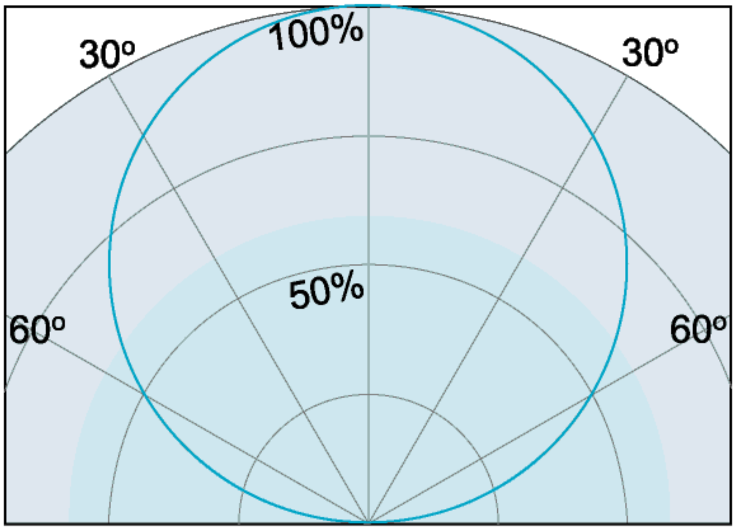


Figure 1.2. Desired Cosine Response of the UV Index Sensor

2. Electrical Considerations

The Si1133 is a UV and Ambient Light sensor whose operational state is controlled through registers accessible through the I2C interface.

The host can command the Si1133 to initiate on-demand UV or Ambient Light measurement. The host can also place the Si1133 in an autonomous operational state where it performs measurements at set intervals and interrupts the host either after each measurement is completed or whenever a set threshold has been crossed. This results in overall system power saving, allowing the host controller to operate longer in its sleep state instead of polling the Si1133.

The I2C electrical interface to the host is shown in the typical diagram below. It consists of two wires for the I2C control, plus one wire for the Interrupt signal. All three signals are driven by open drain drivers and need a resistive pull-up to VDD of approximately 5 kΩ.

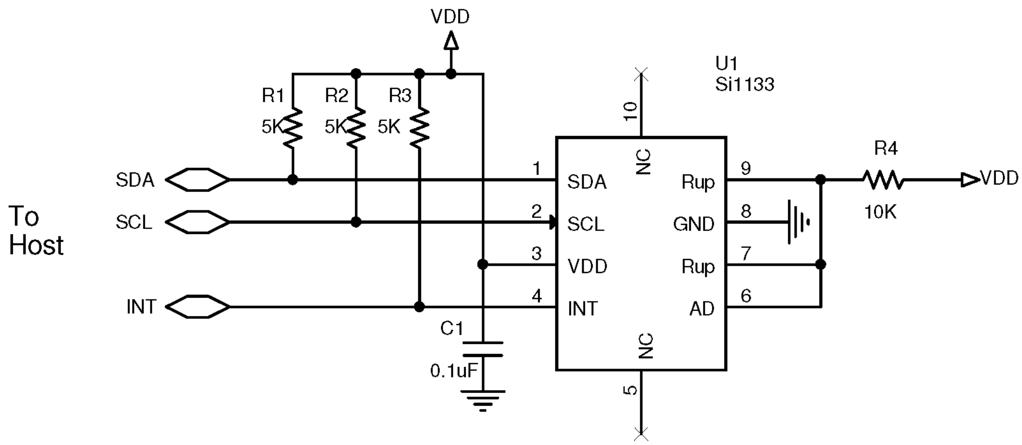


Figure 2.1. Basic Application Circuit

There is a mandatory pull-up resistor, R4, shown on the circuits in this section. It is critical that it be used. If the alternate I2C address is to be used, tie pin 6 to ground, as shown in the schematic below.

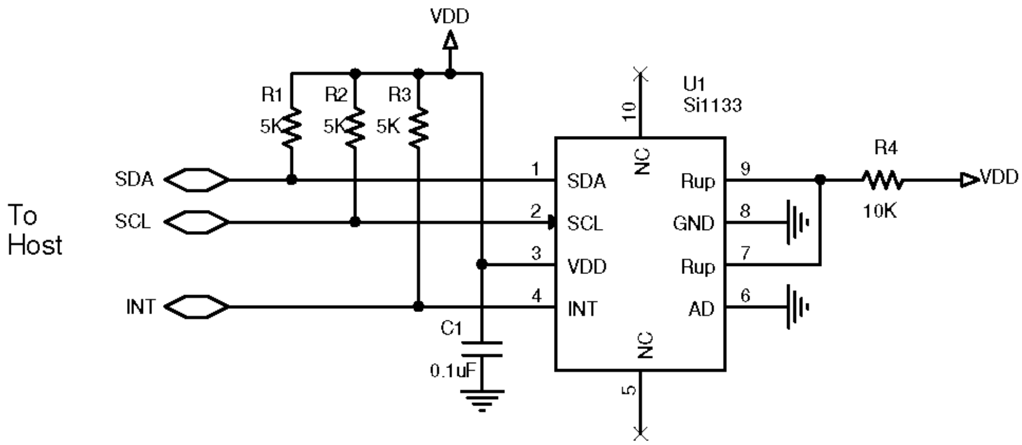


Figure 2.2. Basic Application Circuit Using the Alternate I2C Address

The VDD supply should be at the same voltage as the I2C Host Device to ensure signal threshold level compatibility. VDD may be as low as 1.8 V ±10%, or as high as 3.3 V ±10%.

3. Sensor Location in the 2×2 mm QFN package

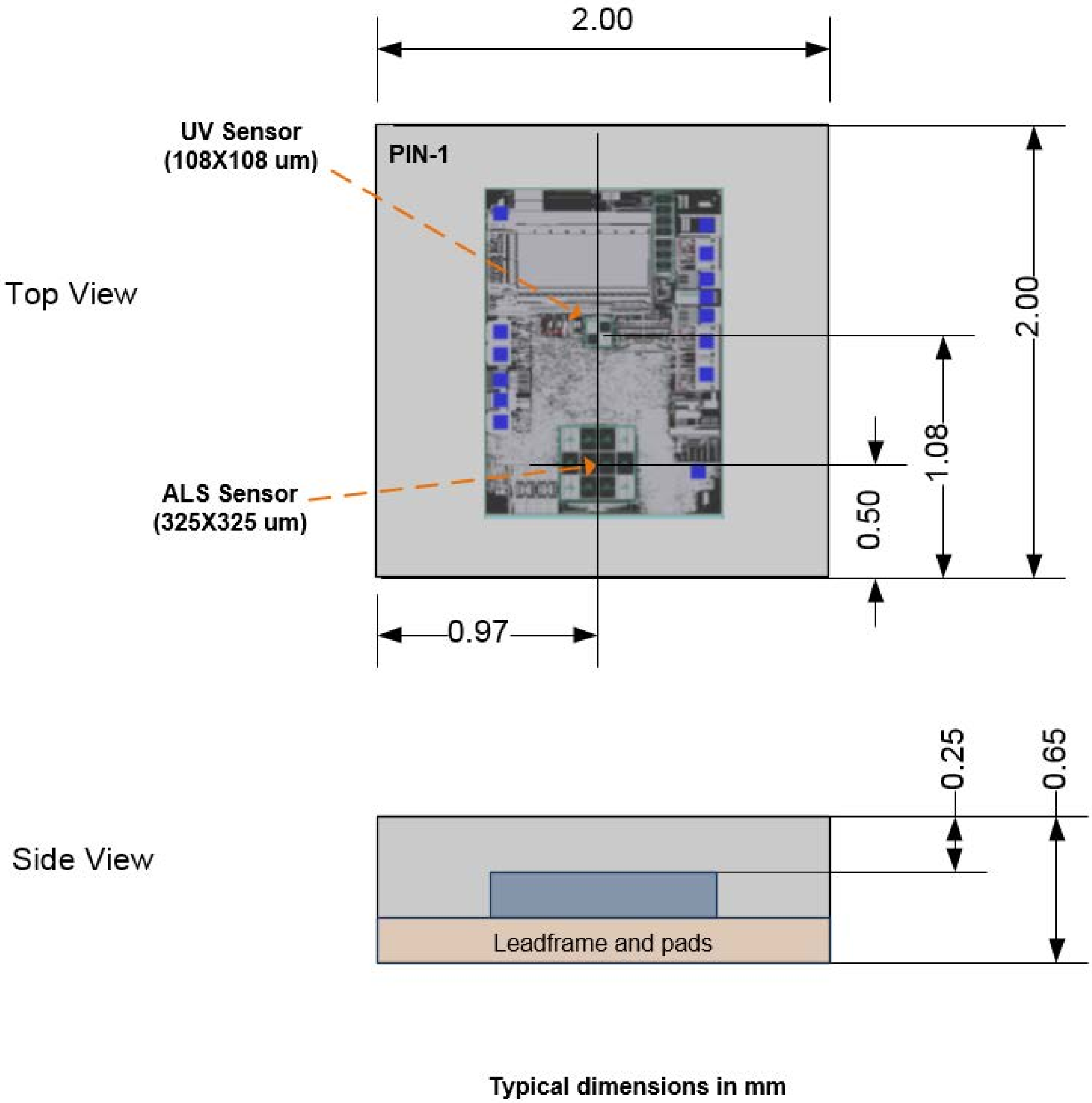


Figure 3.1. Location of the Sensor Elements

4. Overlay Material

The spectral transmission of the overlay material should include the 305 to 400 nm region with less than 50% attenuation. The transmission in the visible and/or IR region can be high or low. It is of no consequence.

The following materials are acceptable:

- Fused Silica (10 mm thick or less)
- Asahi Glass Corporation (AGC) Dragontrail™ (0.7 mm thick or less)
- Corning Gorilla Glass© (0.7 mm thick or less)
- BAYER Makrolon© OD2015 (0.7 mm thick or less) (without UV stabilizer)
- Plexiglass© G-UVT (5.0 mm thick or less)
- Polymethylpentene e.g. Goodfellows TPX RT18 (0.7 mm thick or less)

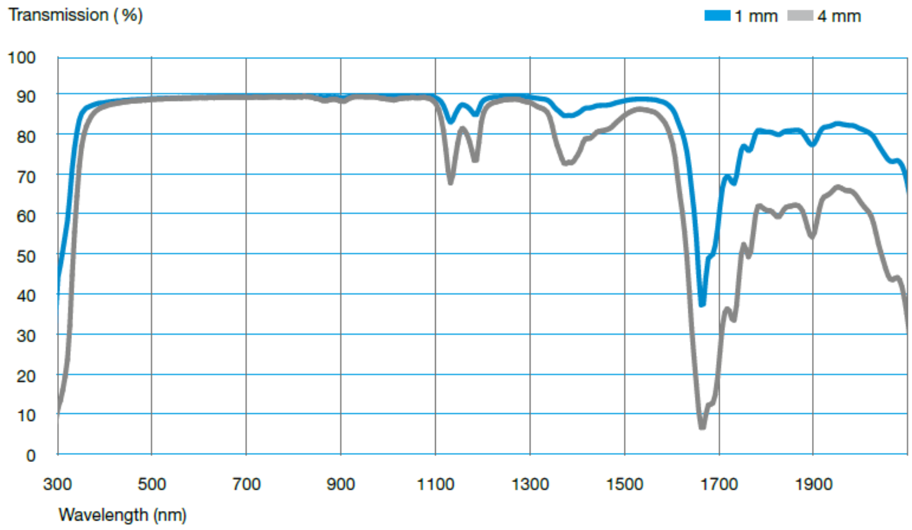


Figure 4.1. BAYER Makrolon

Note: For Bayer Makrolon, a UV Stabilizer cannot be used. It degrades UV performance.

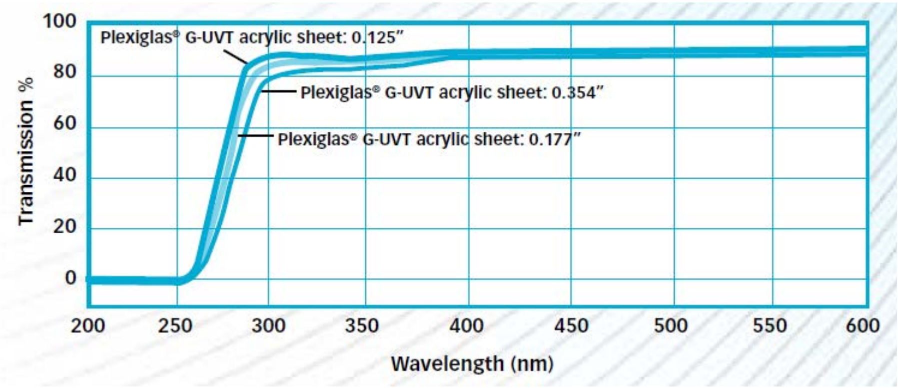


Figure 4.2. Plexiglass G-UVT

5. Simplest, Basic Performance Mounting Technique

If the sensor is directly exposed to wide-angle light, then the accuracy is reduced (approximately ±2 UV Index accuracy). Without the diffuser, not only is the accuracy reduced, but the power consumption will be much higher than it would be using the diffuser, because it requires more averaging.

The measurements (both dark reference and UV) should be made with the Si1133 configured for a measurement time of 48.8 μs and 128 samples averaged. Giving a total time of 2×48.8×128 = 12.5 ms.

It is important to note that the Si1133 must be shielded from direct sunlight approaching from the side. Notice the ±70° angle of incidence in the diagram below.

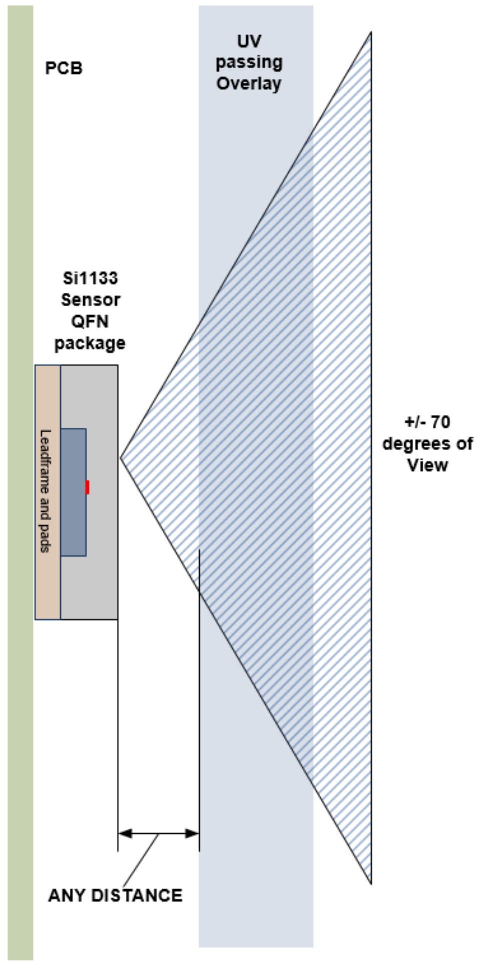


Figure 5.1. Basic Sensor Mounting Technique

This technique can be improved with a proper diffuser. See below.

6. High Performance Compact Assembly

For the best accuracy (approximate values of ±0.75 UV Index), the UV sensor is designed to be aimed at a UV light diffuser. The angle of view of the diffuser should be approximately ±30° for correct performance.

PTFE tape with a thickness of 0.1 mm is an excellent diffuser. For prefabricated glue-on dots, contact the sales manager listed in 9. Diffusers.

The best mounting approach has the sensor close to the overlay with a diffuser. See the diagram below. The negative consequence of this approach is that the position of the sensor under the hole needs to be very controlled. The measurements (both dark reference and UV) should be made with the Si1133 configured for a measurement time of 12.5 ms and only one reading is taken. This results in a total time of 2×12.5 ms = 25 ms..

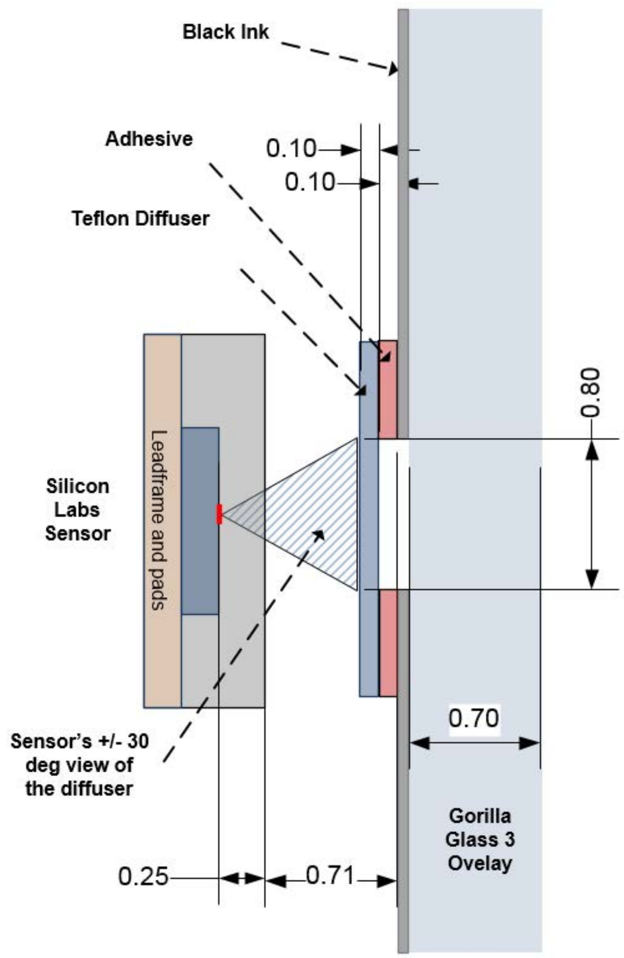


Figure 6.1. Compact Sensor Assembly

7. Good Performance, Less Compact Assembly

The techniques cited previously can be expanded with a larger diffuser area. This will still ensure good accuracy and reduce the need for positioning accuracy. As before, both IR and visible light from outside this ±30° cone must be blocked.

The measurements (both dark reference and UV) should be made with the Si1133 configured for a measurement time of 97.6 µs and 128 samples averaged. This results in a total time of 2×97.6×128 = 25 ms.

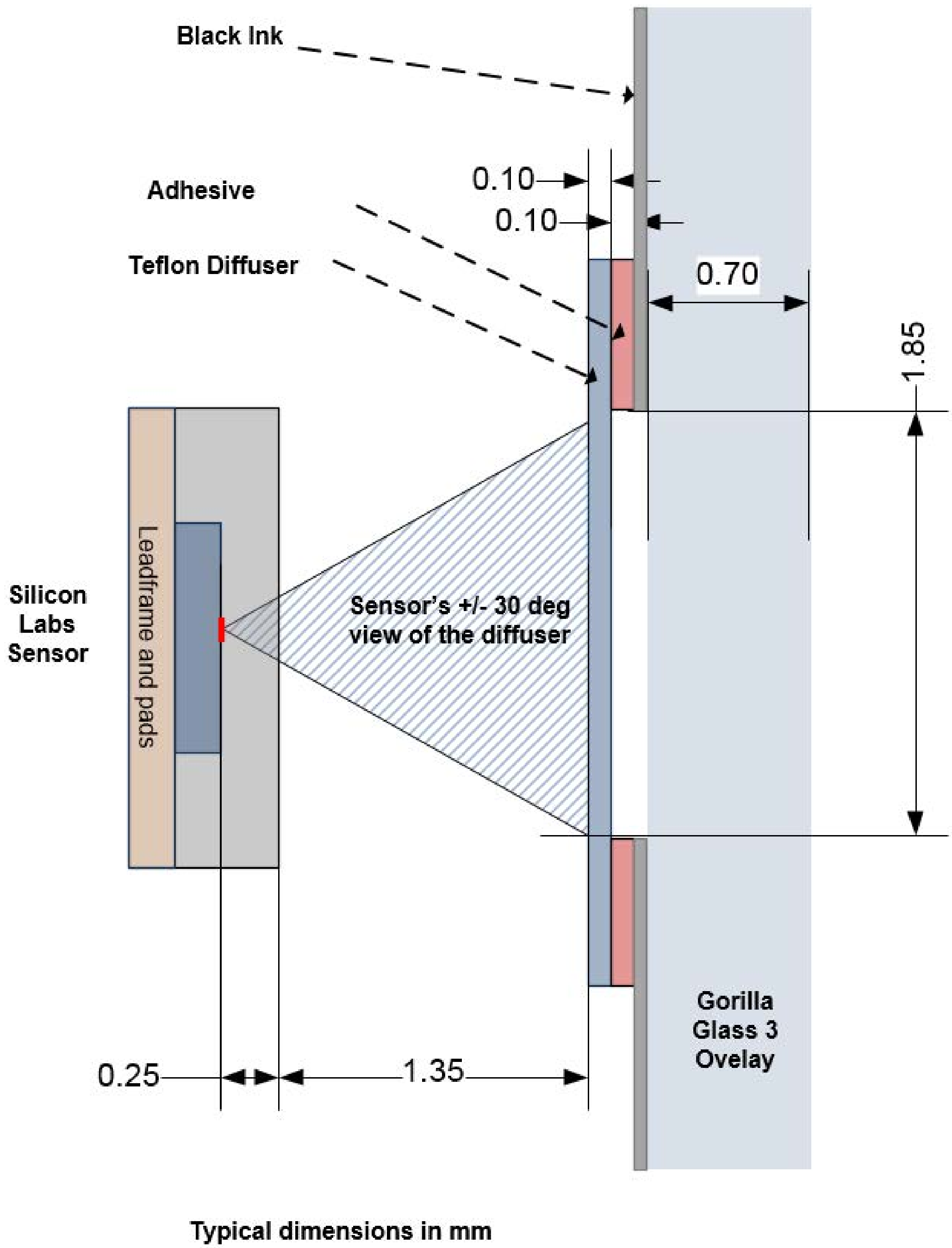


Figure 7.1. Sensor Placement and Angular Light Control

8. UV-Index Calculation

The raw reading of the UV photodiode needs to be converted to the UV-Index value using the following formula:

$$UV\ index = k(m \times Input^2 + Input)$$

Where *m* is 0.00391 and *k* is dependent on the ADC gain used and the optical design implemented. The gain used depends strongly on the optical configuration.

Using the excellent setup shown in 6. High Performance Compact Assembly, an ADC gain mode of 9, (in reality 2**9) and only one A/D sample per reading, *k* is equal to 0.0187. This high gain can and should be used when the the sensor is configured with good blocking and a small 0.8 mm diffuser, resulting in a ±30° sensor view of the diffuser.

The setup is listed below:

- Overlay: Corning Gorilla© Glass (0.7 mm thick)
- Diffuser: 0.8 mm diameter diffuser, 0.25 mm above QFN package, under glass
- ADC Gain: 9
- Decimation Filter Setting: 3
- Number of readings added together

Using the simpler but less accurate setup shown in 5. Simplest, Basic Performance Mounting Technique, an ADC gain mode of 1 (actually 2**1), 128 A/D samples should be taken and summed per reading, and *k* is equal to 0.0104.

If you take into account the number of samples summed and the ADC gain of one compared to the prior setup, you would expect a *k* factor of 0.038 as there are twice as many samples being summed. In this case, two times the value in the diffuser case above, but this is not true because of the light increase caused by the absence of a diffuser.

The setup is listed below:

- Overlay: Corning Gorilla© Glass (0.7 mm thick)
- Diffuser: None, Light Angle limited to ±70°
- ADC Gain: 1
- Decimation Filter Setting: 3
- Number of readings added together: 128

The following calculation examples are meant for guidance only. The exact value of *k* will be sensitive to the characteristics of the diffuser and the variations in the angle of view of the sensor.

9. Diffusers

A diffuser scatters the light so that a direct light beam is scattered beyond the diffuser into a cone of light. A lossy diffuser that transmits only 50% of the light forward, such as a 0.1 mm thick porous PTFE film, is the best diffuser to use and has a very low material cost (< $20/kg).

Sandblasting or polishing both sides of the clear overlay material (Glass, polycarbonate, etc.) with 120 grit abrasive can create a diffuser. This double "ground glass" approach comes close to the performance of a thin PTFE diffuser, but is not better.

Suggested Types of PTFE Film are:

- Porex™ PM6M material
- US standard MIL-T-27730A Grade Material
- US standard A-A-58092 Grade

The Porex™ material is generally used in industrial and medical applications that need to pass gas, but block dust and water.

The last two materials are sold by many vendors, mainly for thread seal tape (also known as PTFE tape).

To use PTFE tape with the sensor in a production environment, it needs to be cut to a specific shape, have adhesive applied at specific areas, and be put onto reels or sheets of wax paper ready for production assembly.

This last process is handled by specialty companies known as “Converters”. The name and contact information for one such supplier is shown below.

Craig Carroll, Sales Manager

Address:	Marian Fort Worth
	1501 Northpark Dr.
	Fort Worth, TX 76102
Direct Phone:	817.332.6151 x167
Website:	http:www.marianinc.com

10. UV-Index Calibration

For best performance, calibration is needed because of sensor-to-sensor and unit-to-unit variation in sensor placement with respect to the diffuser (or window opening), as well as the variation in the material of the overlay and diffuser.

For an easier alternative with lower performance, the customer can skip the calibration of each unit. However, they must maintain tight tolerances on the field of view of the sensor, the performance of the diffuser, and perform periodic calibration checking using production sampling techniques to ascertain they are hitting the desired accuracy.

One option is to use the sun as a test source. On a cloudless day with the sun elevated above 60°, point both a commercial UV Index meter and the device under test (with the Si1133) straight up (i.e not at the sun unless it is at 90° elevation) Read both items, note the difference, and use the information to calibrate the DUT.

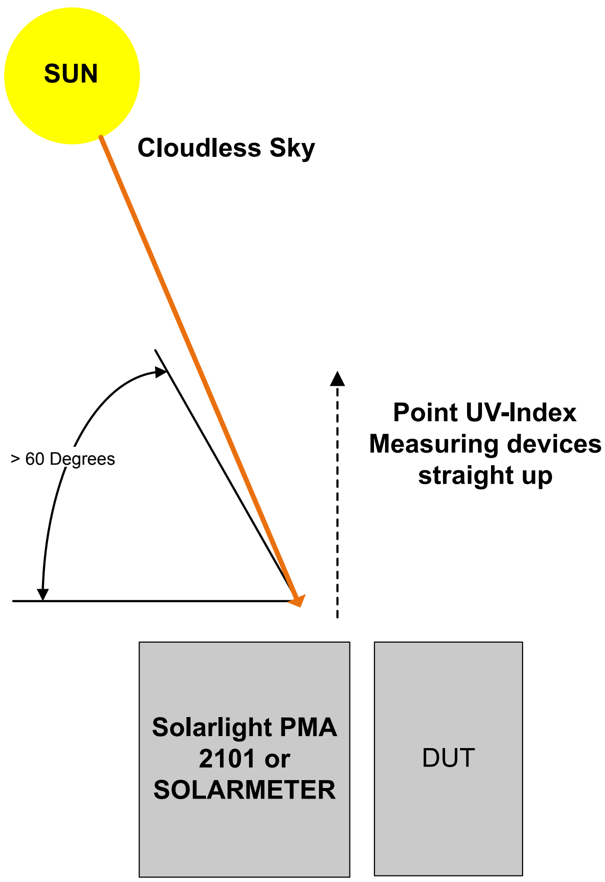


Figure 10.1. Using the Sun to Calibrate the Sensor

Another option is to use a solar simulator. A full spectrum solar simulator with accurate UV content is not currently made, so one starts with a Xenon UV source designed for SPF and biological testing and adds a Schott WG-320 shaping filter and an attenuator that makes the source approximate the UV content of sunlight. Since the Si1133 is essentially blind to sunlight, the lack of visible light in the output is of little consequence.

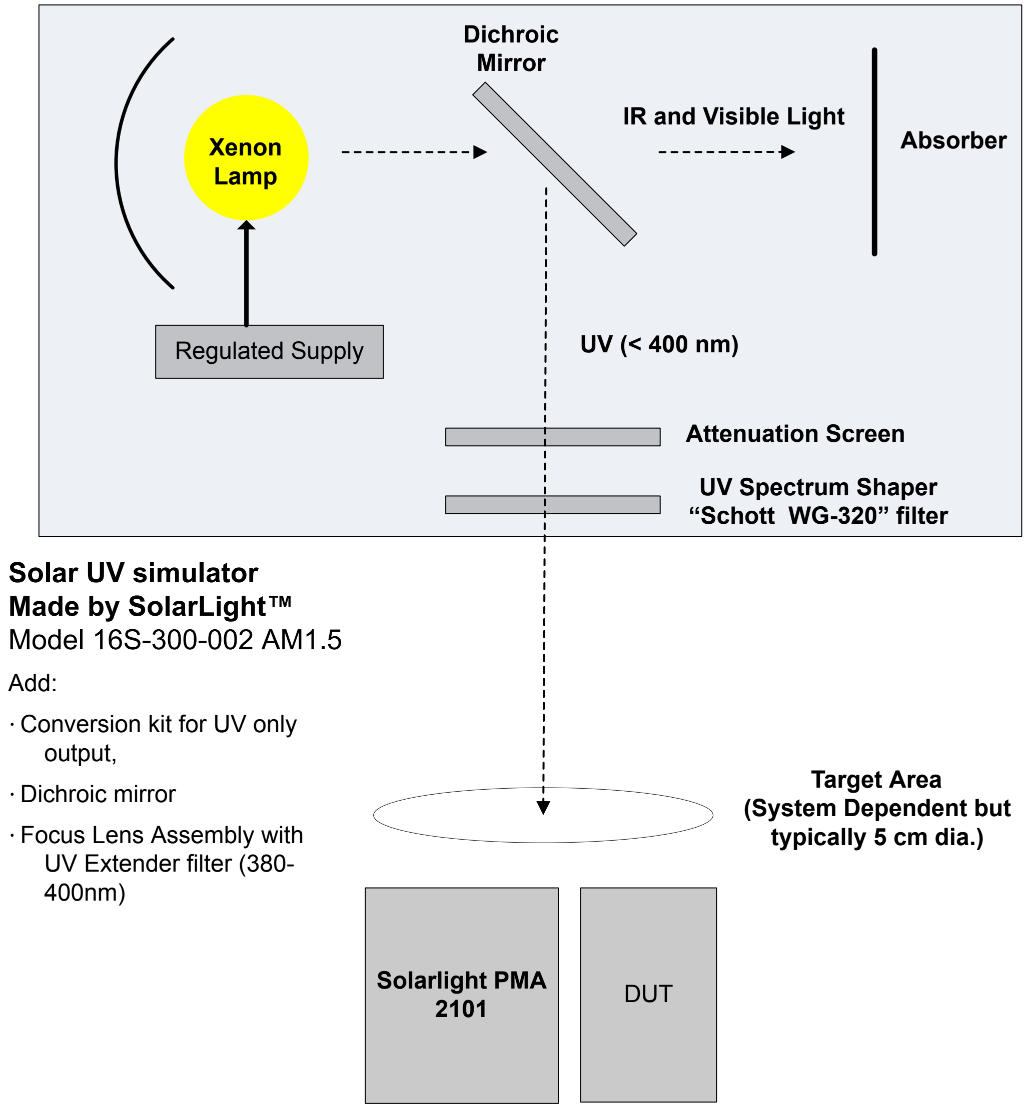


Figure 10.2. Using a Solar Simulator to Calibrate the Sensor

Read both items, note the difference, and use the information to calibrate the DUT.

The output of the Si1133 is a reading value corrected with the following prototype formula:

$$UV\,index = k\left(m \times Input^2 + Input\right)$$

The factor *k* varies with the optical design, but the list of conditions described below yield the formula shown:

- Overlay: Corning Gorilla© Glass (0.7 mm thick)
- Diffuser: 0.8 mm diameter diffuser, 0.25 mm above QFN package, under glass
- ADC Gain: 9
- Decimation Filter Setting: 3
- Samples averaged/reading: 1
- Formula: UV index = $0.0187(0.0039 \times Input^2 + Input)$

Note: In the non-diffuser case discussed in another section, the factor *k* is different.

The shape factor *m* can be taken from this app note and the gain factor *k* can be calculated during the calibration process. The *m* factor in the above formula can change if elements are added to the optical design that filter out part of the UV spectrum.

Note: ***Protect your eyes and skin from UV rays whenever a UV source is used.***

See the calibration flowchart below. It shows that two calibration factors are used. The first *m* is the "curve shape" correction while the second, *k*, is an amplitude correction that the customer obtains by comparing the finished unit to a commercial UV-Index meter.

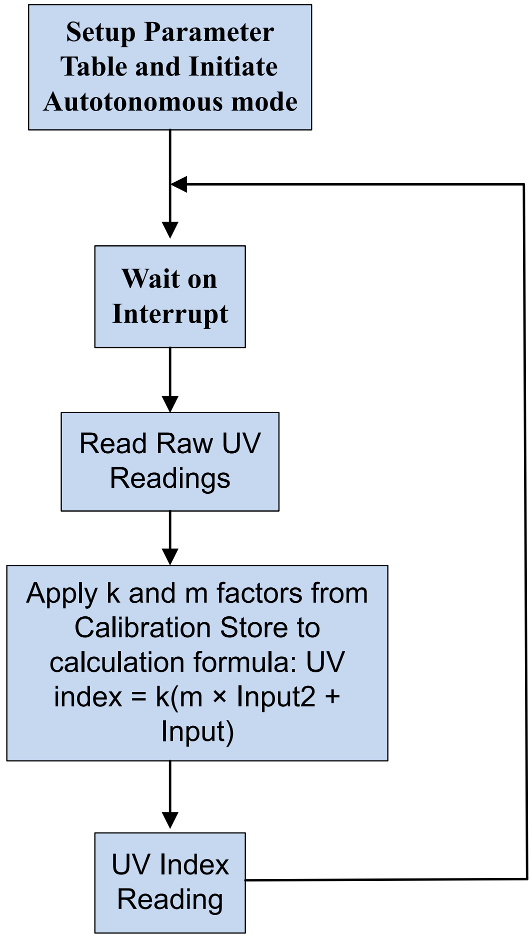
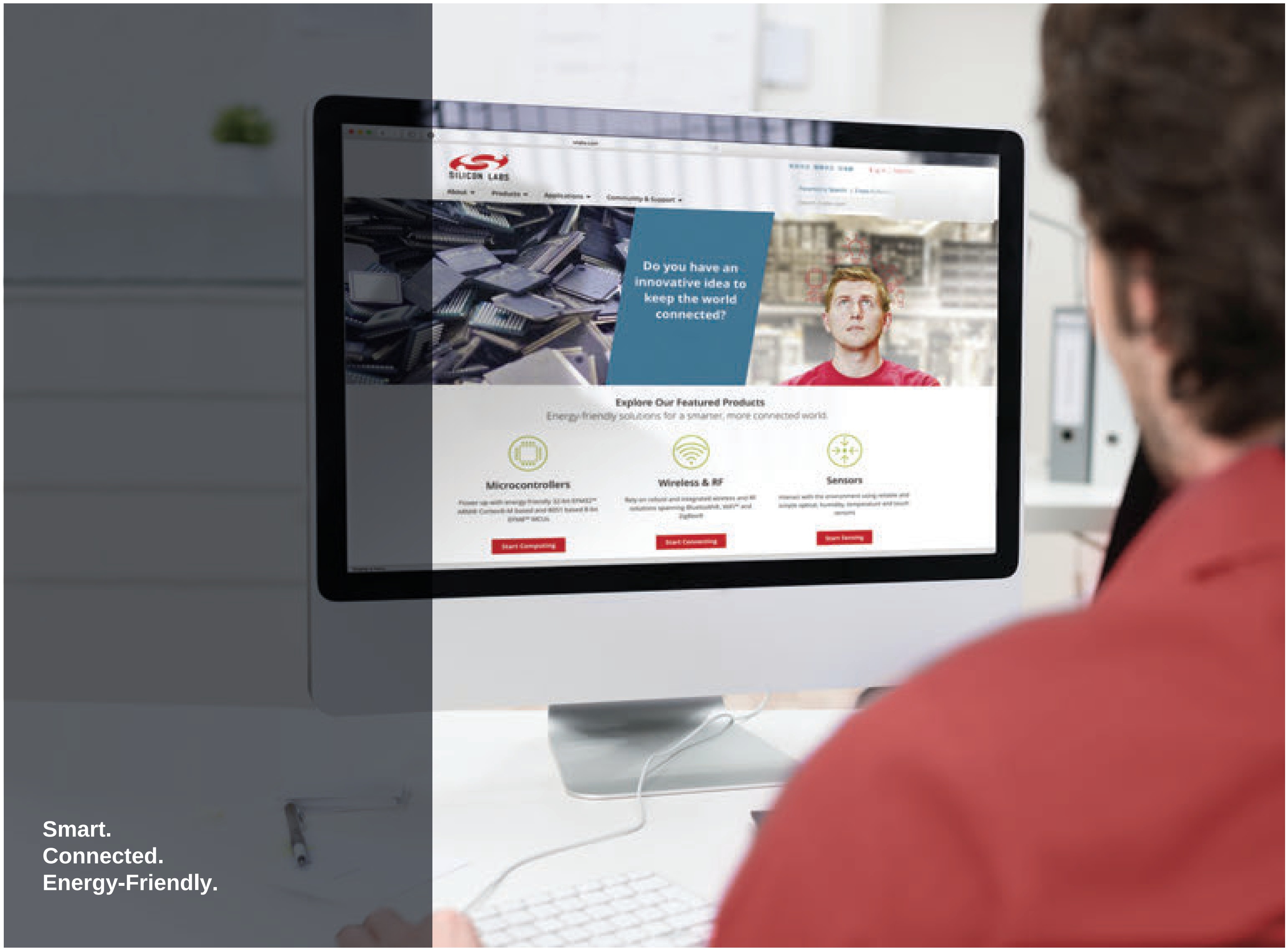


Figure 10.3. Calibration Flowchart

If the customer wishes to also calibrate the *m* parameter because of an unusual overlay situation that absorbs more UV than our guidelines for the overlay section, they should collect collect solar field data from both Si1133 and the UV meter across a wide range of UV index (1~10) values. The customer can then perform curve fitting to determine *k* and *m*.



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