AN950: Si115x User's Guide

This application note provides an outline for using the Si115x ambient-light and proximity sensors. General considerations of electrical and optical component selection, programming, and power consumption are explained to cover the majority of situations.

Specific topics are discussed in other documents (see 7. Additional Resources) and may help understanding. The physics of the Si114x series and the Si115x series have some details in common, and their respective data sheets may be consulted for more information.

KEY POINTS

- Discusses optical considerations toward mechanical design
- Explains electrical component selection
- Shows proximity measurements
- Includes programming guide
- Provides information on latency
- Explains power consumption calculations

1. Optical Considerations toward Mechanical Design

This section focuses on mechanical and industrial design considerations.

1.1 Topology

The following figure highlights and defines the various system topologies.

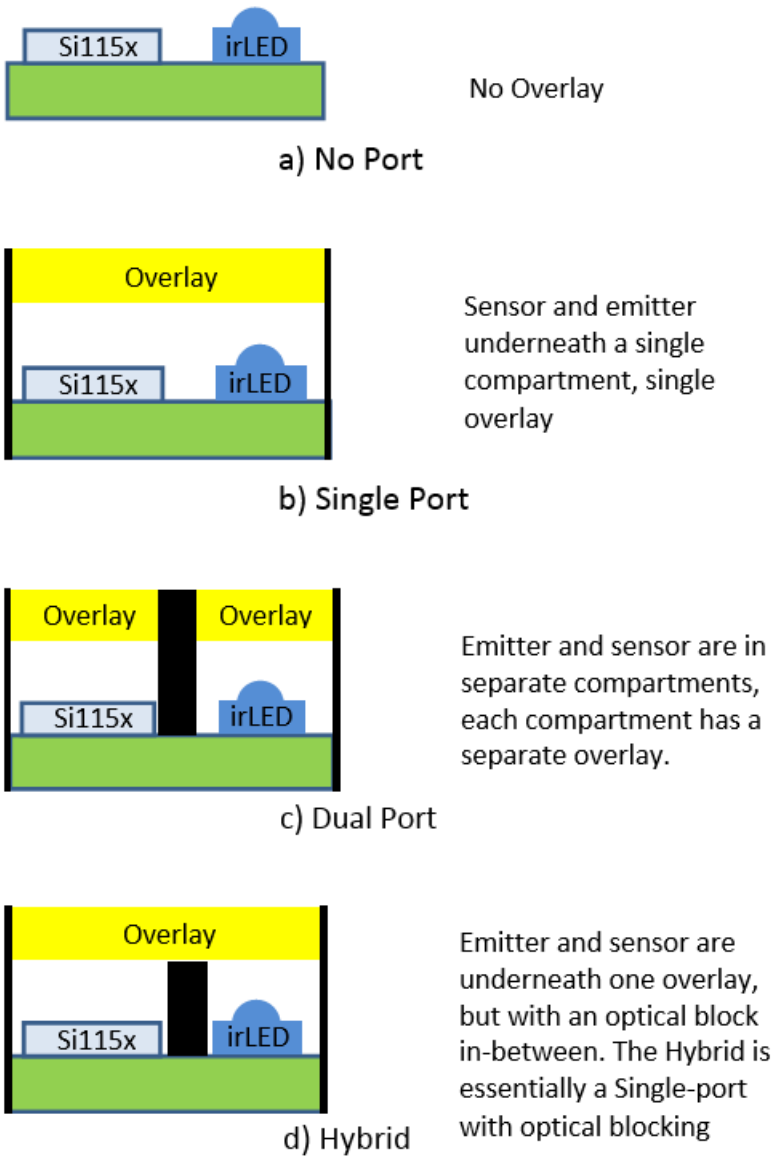


Figure 1.1. System Topologies

The purpose of the system topologies discussed is to provide a sense of the level of optical leakage or cross-talk expected in a proximity system. One common misconception is that a system without an overlay and one with a transparent overlay are “the same”. Although they might appear the same to the human eye, it is important to examine this from the perspective of the device.

1.2 Optical Leakage

Also refer to 3. Proximity Measurements for information on how the Si115x makes Proximity Sense (PS) measurements.

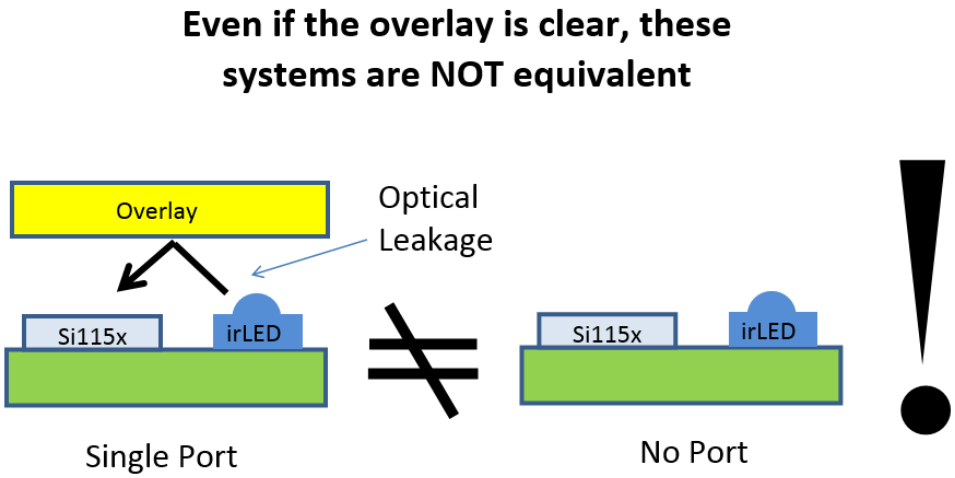


Figure 1.2. Common Misconception

In a Single-Port system, there exists a reflection from the overlay. The magnitude of the reflection is a function of the index of refraction and the incident angle relative to the overlay surface normal. There is a set of equations called 'Fresnel's Equations' that provides a prediction as to the amount of light reflected back to the sensor.

In a No-Port system, the optical leakage from the overlay is not present. However, this does not mean that optical leakage does not exist. There may be optical paths causing the optical leakage other than the overlay.

The most common topology used in cell-phones and hand-held devices is actually a hybrid between the Single-Port and the Dual-Port. The Dual-Port distinguishes itself from the Hybrid in that irLED and the sensors are fully compartmentalized, even to the point that two separate overlays are used.

In the Hybrid topology, the overlay itself becomes a medium for optical leakage. Light transfers from one compartment to the other through internal overlay reflections. The Hybrid topology can approach the optical performance of the Dual-port system topology. For systems requiring the highest ADC sensitivity, the host may need to choose a higher HW_GAIN setting. To be able to use the settings with high HW_GAIN settings, the optical leakage must be carefully controlled.

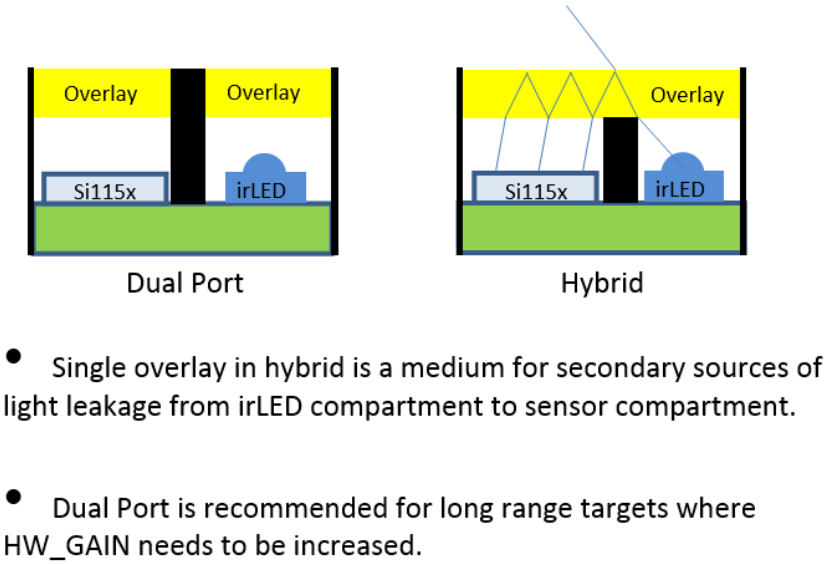


Figure 1.3. Dual Port vs. Hybrid Topology

Optical leakage is also sometimes called “crosstalk”. A proximity detector aims to measure the increase in light levels caused by turning on the irLED. Ideally, only light reflected from the target will reach the sensor. In the figure below, note that there are three light rays originating from the irLED. One of these light rays is shown to hit the Target. The target is assumed to be a diffuse surface and radiates

in all directions. When one of those rays falls onto the Si115x photodiode, it increases the ADC reading proportional to the level of reflectance emitted by the target.

The figure below also shows an additional two light rays originating from the irLED. These two rays do not hit the target, but instead hit the overlay. One light ray hits the top of the overlay surface (refraction is illustrated); the other hits the bottom of the overlay. A specular reflection is essentially a mirror-surface where the light ray is reflected at a very specific angle. In a specular reflection, the incident angle equals the reflected angle.

In Single-Port topologies, it is not unusual for the optical leakage to exceed the reflectance from the target. The optical leakage eats into the ADC Dynamic Range and may force the use of a less-sensitive ADC setting. A consequence of using a less-sensitive ADC setting is that it may require the use of a higher irLED current to detect the target object at the cost of higher power consumption.

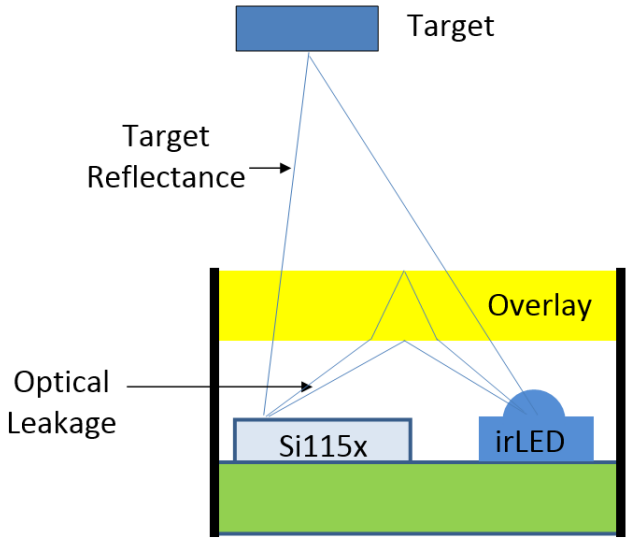


Figure 1.4. Optical Leakage

The greatest source of optical leakage is the specular reflection from the overlay. For this light ray, the radiant intensity of the irLED given the radiation angle, the reflection coefficient (function of the overlay's index of refraction and incident angle), and the travel distance (inverse square relationship) all combine to form the dominant leakage path. The overlay contains two surfaces, resulting in two rays hitting the photodiode. These two rays are roughly equal in magnitude; it is, therefore, important to block both of these rays.

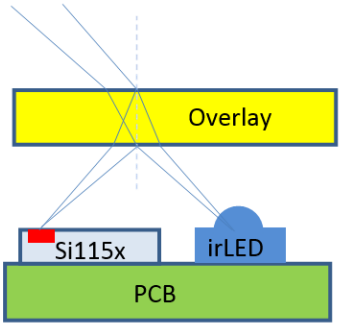
Reducing the leakage from these two primary paths can also be achieved by placing the irLED close to the overlay. This way, only light rays with very steep angles relative to the axial direction are allowed to originate from the irLED. The radiant intensity is typically a function of the radiation angle, and a higher radiation angle generally has a lower radiant intensity.

In addition to the primary leakage paths, there are other sources of optical leakage to consider. Unlike the primary leakage paths, where there is only a single reflection point prior to directing to the sensor, the rays of the secondary leakage paths generally take multiple bounces to get to the sensor.

For example, a light ray can bounce off the overlay and strike the PCB. The PCB can then reflect the ray as a diffuse surface, causing a small portion of that reflection to reach the Si115x photodiode through yet another specular reflection. Of course, the radiant power decreases with each bounce.

The PCB has a high transmittance to IR, but it is not obvious to the human eye since the PCB looks opaque. Use copper ground fill to make the PCB opaque to IR.

The irLED choice is also an important consideration. When an irLED has a wide radiation pattern, there is less light focused at the angles close to the axial direction. What this means is that there is more light radiated outwards at steep angles. The total light power becomes directed towards optical leakage. With more light energy in these steep angles, the more light there is to feed the secondary leakage paths. Choosing an irLED with a narrow half-angle leads generally leads to lower system optical leakage in addition to better overall proximity detection distance.



- Both inner and outer overlay surfaces reflect incident light

- The reflection coefficient is described by Fresnel's Equations. It is a function of the incident angle and the overlay's index of refraction.

- PCB has high IR transmittance. Copper (e.g. ground fill) is IR-opaque.

- Minimize the distance from top of irLED to bottom of overlay.

- irLED radiation pattern (radiant intensity vs angle) is an important consideration.

Figure 1.5. Optical Leakage Summary

1.3 Optical/Mechanical Components

1.3.1 Optical Blocking Material

A Si115x proximity system uses the “near infrared” wavelengths. As such, many objects that look black are candidates for optical blocking material.

Natural Rubber is a common material known to be opaque to visible light and the near-infrared band. Another property of Natural Rubber that makes it suitable for optical blocking is its elasticity. Commercially-available rubber sheets can be cut to size for optical blocking. For example:

http://www.rubbersheetroll.com/rubber-sheets.htm

Nitrile Rubber or “Buna-N” O-rings are used for optical blocking in Silicon Labs' evaluation platform and can be found at the following web site:

http://www.mcmaster.com/#4061t111/=9ujxqp

If an adhesive thin-sheet back device is desired, a polyurethane foam material from 3M (Bumpon™) can be used as an optical blocking material:

http://www.digikey.com/product-search/en?vendor=0&keywords=bumpon%20roll

There are more IR-opaque materials available than are discussed in this document. However, since many visible-opaque materials are not necessarily IR-opaque, it is best that materials be characterized by IR opacity. The easiest method of checking the infrared opacity of a material is with a television remote control:

1. Find a common TV remote control.
2. Verify that the TV remote control is able to control the television.
3. Note the maximum distance that the TV remote control operates.
4. Locate the location of the IR sensor on the TV.
5. Verify that this is the IR sensor correct by placing the TV remote control directly on top of the IR sensor.
6. Cover the material in front of the TV remote control.
7. Attempt to control the TV.
8. If the material is opaque to the near infrared band, then, you should not be able to operate the TV even if the remote control is positioned right up to the IR sensor window.

It is possible to determine infrared opacity by calculating the maximum transmittance of the material using this procedure. For example, if the TV remote control is able to operate at a distance of 10 meters, and the optical blocking material made it impossible for the TV remote control to operate even when it is only 5 cm away, then the transmittance of the material is, at most, .000025. This indicates that the material is opaque to the near-infrared spectrum.

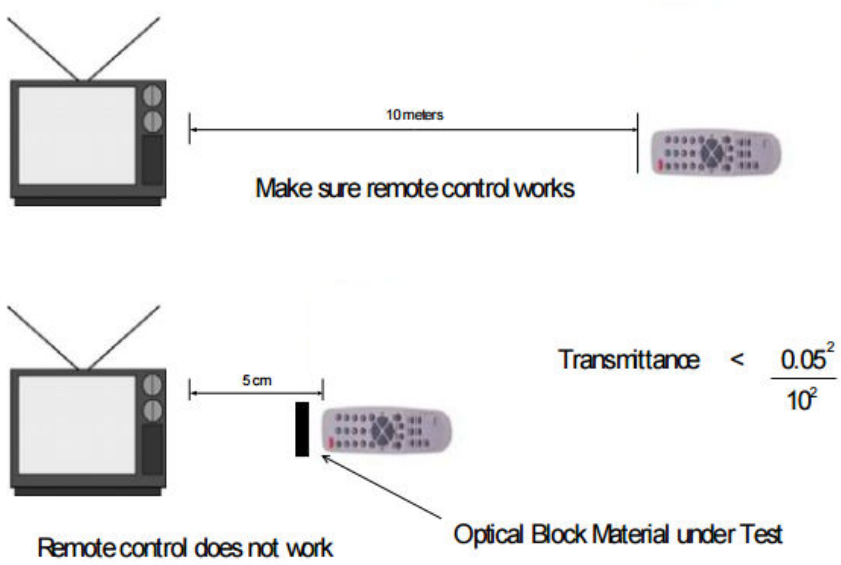


Figure 1.6. Infrared Opacity Test

1.3.2 Infrared Properties of Printed Circuit Boards

Many materials that appear visibly opaque to the human eye can have a high transmittance to infrared wavelengths. Printed Circuit Boards, for example, have high transmittance to near infrared light. Therefore, it is important to also consider Printed Circuit Boards as optical components.

The copper layers of printed circuit boards are opaque to infrared light. Maximizing the amount of copper underneath the irLED and the Si115x is an effective method of reducing the amount of optical leakage through the PCB material.

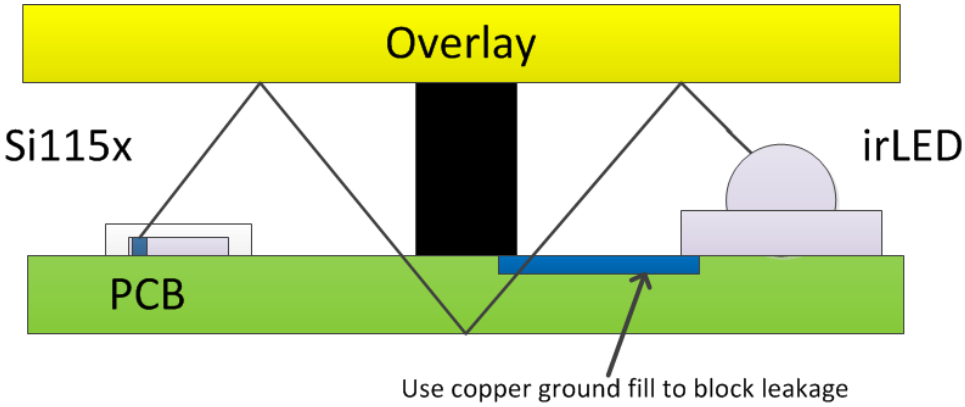


Figure 1.7. PCB has High IR Transmittance

1.3.3 Long Pass / Short Pass Filter Definitions

Electrical engineers are familiar with the terms “High Pass Filter” and “Low Pass Filter”. In optics, there are commonly-used analogous terms for describing overlays.

- “Long Pass Filter” refers to a material that allows long wavelengths to pass through while disallowing short wavelengths.
- “Short Pass Filter” refers to a material that allows short wavelengths to pass through while disallowing longer wavelengths.

See the figure below.

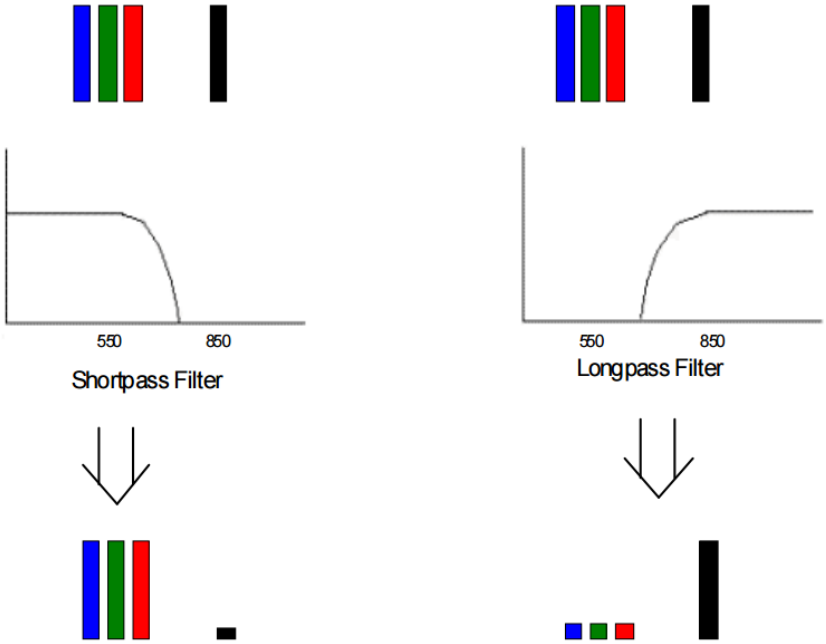


Figure 1.8. Short-Pass Filter vs. Long-Pass Filter

As a reference, the visible spectrum is between 400 and 700 nm; blue light is at 430 nm; green light is at 550 nm; red light is at 640 nm. Infrared light is between 700 nm and > 10,000 nm but silicon detectors (si115x) only operate as far as about 1,000 nm and the predominantly useful IR wavelengths used for proximity operations are 850 nm or 940 nm.

1.3.4 Optical Filter Characteristics of the Overlay

The Si115x does not require an optical filter for proper operation but one may be needed for additional performance or esthetic reasons. For the Si115x, there are two basic approaches when adding an optical filter:

1. IR Pass combined with moderate Visible attenuation (5% to 10% pass). This gives a dark look and allows both IR based proximity to work and ambient light sensing to work as well.
2. IR Pass combined with Visible blocking (< 2% pass). This gives a dark look and only allows IR based proximity to work. Ambient light sensing does not work.

A “Long Pass Filter” with a corner wavelength of 700 nm attenuates visible light while allowing the infrared spectrum to pass through. In general, there is a esthetic desire for most products to hide internal electronics from visible view. Fortunately common materials and inks naturally have a higher transmittance to infrared light compared to visible light. This means that a painted overlay usually acts as a “long pass filter”. This does not mean that one should rely on the inks just “happening” to have the correct characteristics. “Long pass” inks are available with well-defined transmission characteristics,

In the case of a *proximity sensing* application, the “signal” is 850 nm or 940 nm infrared light emitted from the irLED. In a *Proximity Sense (PS) only* application, if the overlay blocks everything except 850 nm ±30 nm, the system will operate.

In an *ambient light* application usage where there is a desire to measure the visible ambient light, the “signal” is light with a wavelength of between 400 nm to 700 nm. From the perspective of an *ambient light sensing* application, any spectral reading above 700 nm and any spectral reading below 400 nm are “noise”. Attenuating the visible light to hide the internal electronics from view conflicts with the concept of “maximizing the signal” for ALS usage BUT it allows the ambient light sensing to still function as long as a reasonable amount of light (~5% to 10%) is passed through the filter.

The optimal way to filter the visible light for *ambient light sensing* is to use a “bandpass filter” that is shaped in the form of a human eye. A filter with this response is called a “photopic” filter. When done correctly accuracies better than 10% can be achieved.

In the case of a combined *proximity sensing and ambient light sensing* application, Any attenuation of visible light must be moderate (5% pass or better) while the IR should not be attenuated (e.g. > 70% pass).

The exact allowable attenuation numbers are dependent on customer requirements such as detectable low light levels and distance that proximity must support.

In proximity applications, the “signal” is the light of the wavelength emitted from the irLED (e.g. 850 or 940 nm). If the transmittance at the irLED wavelength is low, then much of the light from the irLED is absorbed by the overlay, leading to lower performance when it comes to detecting more distant targets. Given the “target object distance” consideration, a significant optical overlay IR loss can translate to a loss in sensitivity with target object distance unless the overlay loss is compensated for with a more efficient irLED or higher irLED current. Note that the IR light used for proximity must pass through the overlay twice so that a poor 0.5 transmission yields a very poor coupling factor of 0.5×0.5 = 0.25. For a proximity application, aside from aesthetic reasons or industrial design constraints, maximizing the 850 nm or 940 nm transmittance should be the design goal. For applications requiring the highest performance under direct sunlight the Si115x parts with on die 940 nm filters provide the best performance.

The following links can be used for infrared applications:

Teikoku	MRX-HF IR Transmittable Black: http://www.teikokuink.com/en/product/techreport/146_tech.html Teikokuink’s GLS-HF 10415 SIL IR BLACK mix is especially recommended for tempered glass overlays for high-performance ALS and proximity applications using the Si115x.
Seiko Advance Ltd.	IR Black Series: http://www.seikoadvance.co.jp/en/products/category/category05.php
Nazdar	Nazdar 6002050584 Special 84 IR: https://sourceone.nazdar.com/portals/0/tds/NAZDAR_NSC61_IR_Transmitting_Black_Solvent-Based_Screen_Ink.pdf
EPOLIN	Visible Opaque IR-Transmitting Screen Inks: http://www.epolin.com/spectre%E2%84%A2-visibly-opaque-ir-transmitting-voirt-screen-inks

1.3.5 Overlay Characteristics and Choices

Clear acrylic material is generally available. A common trade name for acrylic sheet is “Plexiglass” and a Google search of that term typically yields the most hits. Many web-based plastics companies offer acrylic sheets cut to custom sizes. In the U.S., the following web site has low-cost samples of clear acrylic sheets. Some polycarbonate samples are available through this web site as well: http://www.eplastics.com/Plastic/samples

Acrylic sheets are generally thicker than Polycarbonate sheets. If sheet thickness is an important consideration, polycarbonate is a better choice. The two main sources of polycarbonate resins are:

1. Lexan™ polycarbonate sheets:

   http://www.sabic-ip.com/gep/Plastics/en/ProductsAndServices/ProductLine/lexan.html

   http://www.sabic-ip.com/gep/Plastics/en/UtilityPages/ContactUs/contact_us_resins.html
2. Bayer (Makrolon®) polycarbonate sheets:

   http://www.plastics.covestro.com/en/Products/Makrolon

The following common overlay approaches are possible with the Si115x. They are listed in order of preference by performance.

1. Clear plastic or glass overlay
2. Clear overlay with ink applied through a silkscreen process
3. Colored plastic or glass overlay

The choice of the overlay is often an industrial design decision. Many applications opt to start with a clear overlay material and screen-print the desired pattern using special inks.

Note that even if an overlay has a relatively low IR transmittance, this does not necessarily mean that the Si115x will not work with such an overlay. The overlay transmittance is merely one of many system factors that come into play. For example, if the system must operate under low IR transmittance overlays, then the following system-level tradeoffs include:

- Reducing target object distance
- Increase irLED current
- Higher efficiency irLED
- Narrower irLED half-angle

Typically, the irLED choice can compensate for overlay transmittance loss.

A common TV remote control can be used to determine the transmittance of the overlay material. Although the transmittance of the TV remote is at 940 nm, the ability of the overlay to pass 940 nm is close to its transmission at 850 nm.

Colored Overlay Considerations

Clear overlays with screen-printed ink are generally superior to colored overlay materials. Most companies focus effort in offering different colored materials based on appearance factors to the human eye. Many of the color materials have not been characterized for their IR transmittance. With sample “color chips”, it is generally possible to estimate the IR transmittance. There is, however, an important consideration. Most “color chip” samples come in specific thicknesses. The optical properties are a function of the thickness. The opacity and the thickness of materials have an exponential relationship. For example, if 1 mm of material has 70% transmittance, then 2 mm of material would have a transmittance of (70%)2= 49%. 3 mm will lead to (70%)3 = 34.3% transmittance.

In a colored overlay, the transmittance in the IR region is typically higher than that of the visible region. Given the exponential relationship of transmittance vs. thickness, the end spectral response looks quite different even on the same material. This is due to the exponential nature of transmittance vs. thickness. See Figure 1.9 Transmittance Curves Vary Strongly with Thickness on page 10 where the same material is shown to have a much higher variation with varying thickness while the transmittance in the IR region appears almost the same. The following table illustrates how the numbers are affected by an exponential relationship.

Table 1.1. Transmittance vs. Thickness

Unit Thickness Transmittance	2 × Unit Thickness Transmittance
10%	1% (10% × 10%)
99%	98% (99% × 99%)

Although it is convenient to lump together “transmittance” in a single number, actual transmittance vs. spectral curve is far from linear.

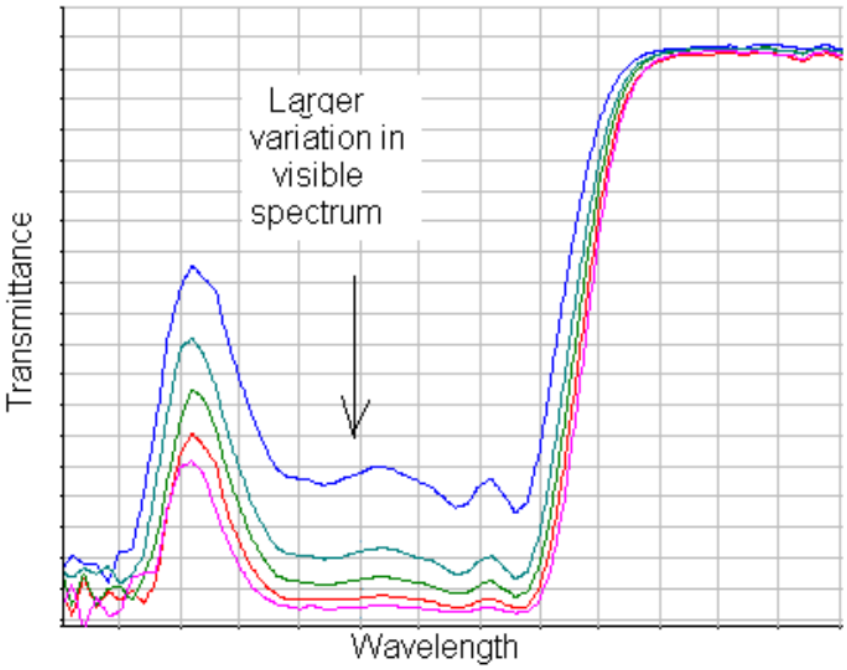


Figure 1.9. Transmittance Curves Vary Strongly with Thickness

Coefficients calculated for a given colored overlay thickness may not apply for the same material of a different thickness. It is strongly advised that lux calculation coefficients be characterized only when a colored overlay of the proper thickness is available.

The other consequence is that high relative transmittance between the visible and IR portions of the spectrum can result in high ALS variability. If ALS variation is an important system consideration, it may be advantageous to choose an overlay with a lower infrared transmittance so that the infrared transmittance more closely matches that of the visible light transmittance. Doing so will allow lower ALS variation across different light sources. Choosing an overlay with a significant spectral difference in visible and IR generally leads to higher ALS variance once the overlay thickness tolerance has been considered.

Information on Acrylic colored overlay samples can be found at the following web sites: http://www.eplastics.com/Plastic/samples

Information on Makrolon color chip samples can be found at the following URL (requires registration): http://www.plastics.covestro.com/Products/Color-Technologies.aspx

Information on Lexan color chip samples can be found at the following URL (requires registration): https://www.sabic-ip.com/cxp/ColorXPress

1.4 Photodiode Locations, Apertures, and View Angles

The photodiodes locations are shown in the following figure. It is generally accepted that these photodiodes are treated as a single strip for layout and mechanical design considerations.

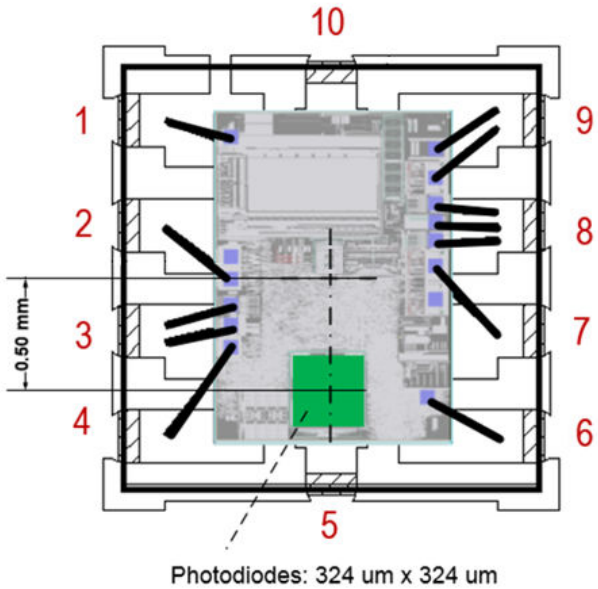


Figure 1.10. Si115x Photodiode Centers

An aperture is an opening through which light enters. The aperture is transparent or translucent and is surrounded by an opaque material. The distance from the aperture and the size of the aperture define the Si115x field of view. When a light source is within the field of view, the angle formed relative to the photodiode normal vector is called the “Angle of View”.

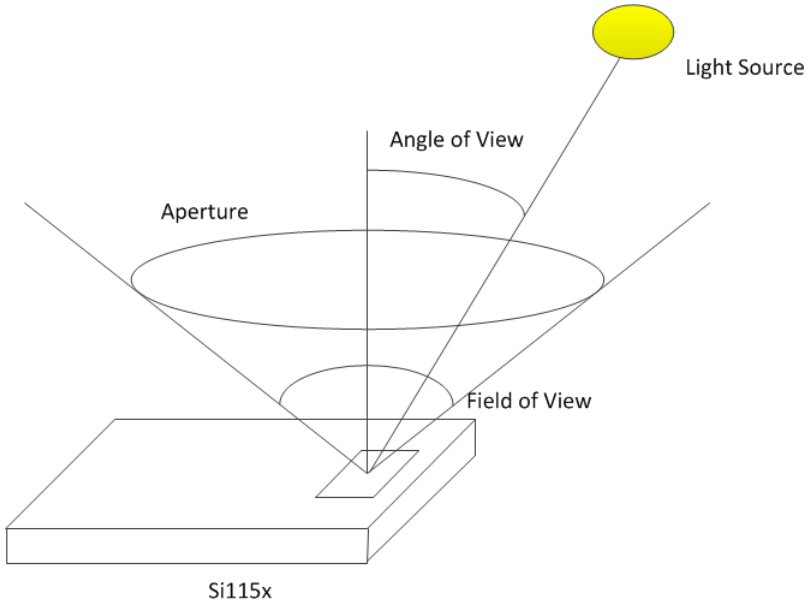


Figure 1.11. Aperture, Field of View and View Angle

The radiant power that falls on the photodiode is a function of the angle of view. The number of ADC codes reported by the Si115x is influenced by the angle of view through a cosine relationship. All things being equal, a light source at a larger view angle results in a lower ADC count.

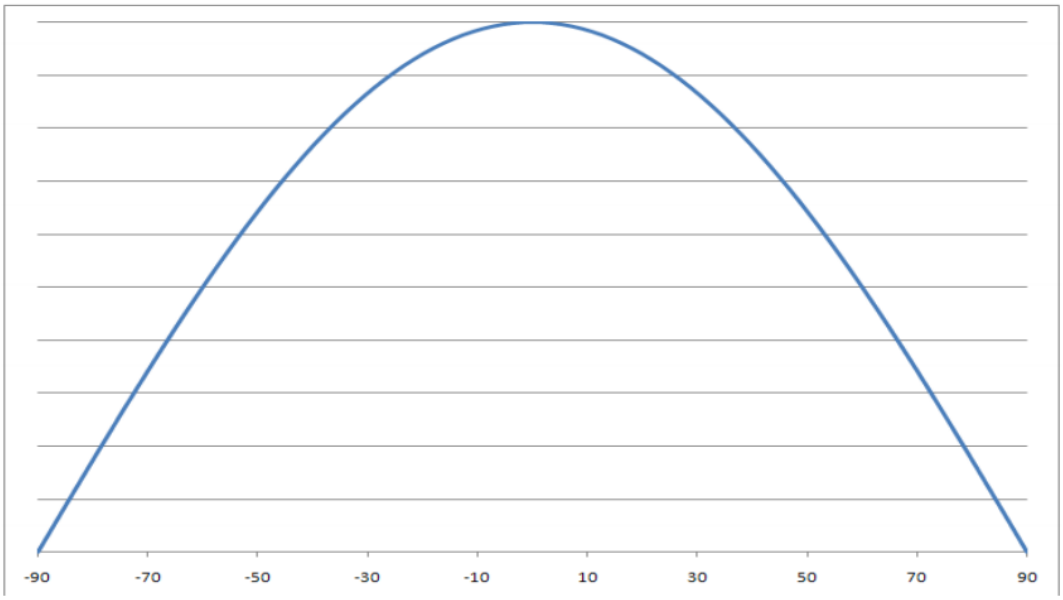


Figure 1.12. ADC Reading of Equidistant Point Light Source vs. Angle of View

When the light source is an infinite distributed surface, the relationship of the field of view versus the total available reading is shown in the following table.

Table 1.2. Relative ADC Reading vs. Field of View (Large Surface Light Source)

Field of View	ADC Codes
180	100%
170	100%
160	98%
150	97%
140	94%
130	91%
120	87%
110	82%
100	77%
90	71%
80	64%
70	57%
60	50%
50	42%
40	34%
30	26%
20	17%
10	9%

If the target object is small (smaller than the field of view), the ADC codes reported by the Si115x are influenced by the angle of view. The field of view only needs to be as big as the expected location of the target. An example of such an application is a 50 cm range where the angle subtended by the target object is small compared to the field of view.

If the target object is large (larger than the field of view), the amount of light received by the Si115x is influenced by the field of view. An example application is the cell-phone cheek detector; the cheek represents a large object due to its location relative to the sensor. For this case, maximizing the field of view is important. For these applications, a field of view of 120 ° is recommended. This means that, for best performance, the aperture either needs to be large or near the Si115x. By increasing the aperture, the greatest amount of light can enter the Si115x, and less light needs to be thrown at the target object, leading to a more efficient design.

1.5 Close Range Application with Single-Port Topology

Single-Port design is *not* recommended for general proximity applications. The performance will degrade due to the lack of optical blocking. Unless low cost is the primary objective of the system design, Dual-Port or Hybrid topology should always be the first choice.

This section and 1.6 Single-Port Design Dimensions apply only to Single-Port topology when the target is close. For systems that employ optical blocking or a Dual-Port topology, the optical leakage is controlled through the optical blocking material. In a Single-Port topology, geometry is the primary method of limiting the optical leakage.

1.5.1 IrLED Choice

The irLED chosen for this must have a half-angle of 22° or less. As described in 1.3 Optical/Mechanical Components, light power that does not exit the system generally ends up fueling optical leakage through secondary leakage paths. Choosing a low half-angle irLED causes much of the light power to be directed outside the system, resulting in lower optical leakage.

Another important consideration of the irLED is that it must be as tall as the product's construction will allow. By choosing a tall irLED, the irLED will be nearer the overlay. Having the irLED near the overlay causes most of the light to go outside the system rather than being reflected back in and causing higher levels of optical leakage.

The Si115x Evaluation Platforms use the Osram SFH 4056. Many of these recommendations can also apply to other irLEDs as long as the radiation pattern is narrower than 22°.

1.5.2 Si115x Orientation

It is best to orient the Si115x so that the distance between the irLED and the photodiodes is maximized. Pin 1, Pin 10, and Pin 9 should face the irLED. Using this orientation allows the furthest distance between the irLED and the Si115x photodiodes leading to the least optical leakage. The worst orientation is facing Pins 4, 5, and 6 towards the irLED.

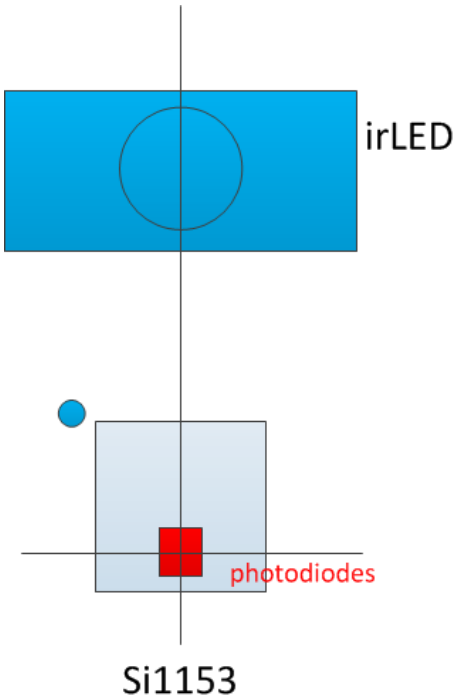


Figure 1.13. Si115x Orientation

1.6 Single-Port Design Dimensions

From the perspective of minimizing optical leakage, the overlay transmittance is not a factor. A high transmittance overlay is preferred for PS because this generally leads to lower system power as less light needs to be directed to the target to allow it to be detected. It is generally feasible to compensate for high transmittance by throwing more light out, but this becomes a power consumption consideration.

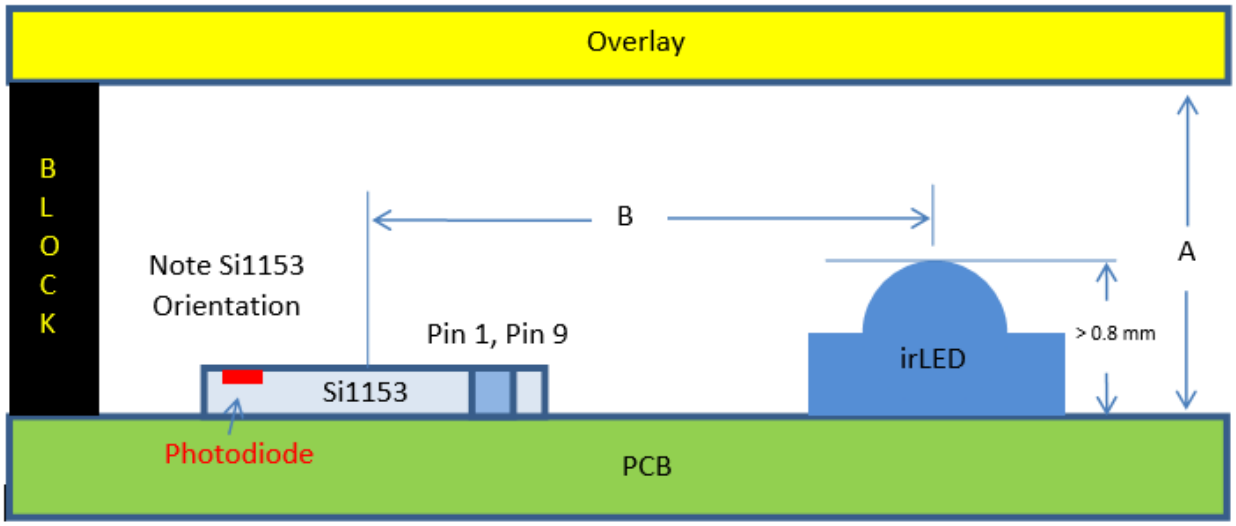


Figure 1.14. Si115x Single Port Reference Drawing

Table 1.3. Single-Port Dimensions (Cheek Detector Application)

PCB Surface to Overlay Bottom (A)	Center-to-Center Minimum (B)	Center-to-Center Maximum (B)
< 1 mm	5 mm	20 mm
1 mm to 2 mm	7 mm	20 mm
2 mm to 3 mm	10 mm	20 mm

Notes:

1. The Si115x should be oriented so that Pin 4 and Pin 6 are farthest away from the irLED.
2. The irLED height is assumed to be 0.8 mm. When possible, minimize the gap from the top of the irLED and the bottom of the overlay.
3. No optical isolation between the Si115x and irLED is assumed.
4. The target object is a cheek (5 cm) or black hair (2.5 cm).
5. The overlay thickness is 0.5 mm.
6. The irLED Power Rating is 1/16 W.

1.6.1 Partial Optical Blocking

If the dimensions in Table 1.3 Single-Port Dimensions (Cheek Detector Application) on page 14 cannot be met, some optical blocking is necessary. For applications where the target object can be pressed against the overlay (e.g., cheek detection) the optical blocking should be partial only. Otherwise, there would not be a reading when a cheek is pressed against the overlay.

The key concept in designing an optical block is that the primary reflection path from the irLED to the Si115x be traced, and these rays should be blocked.

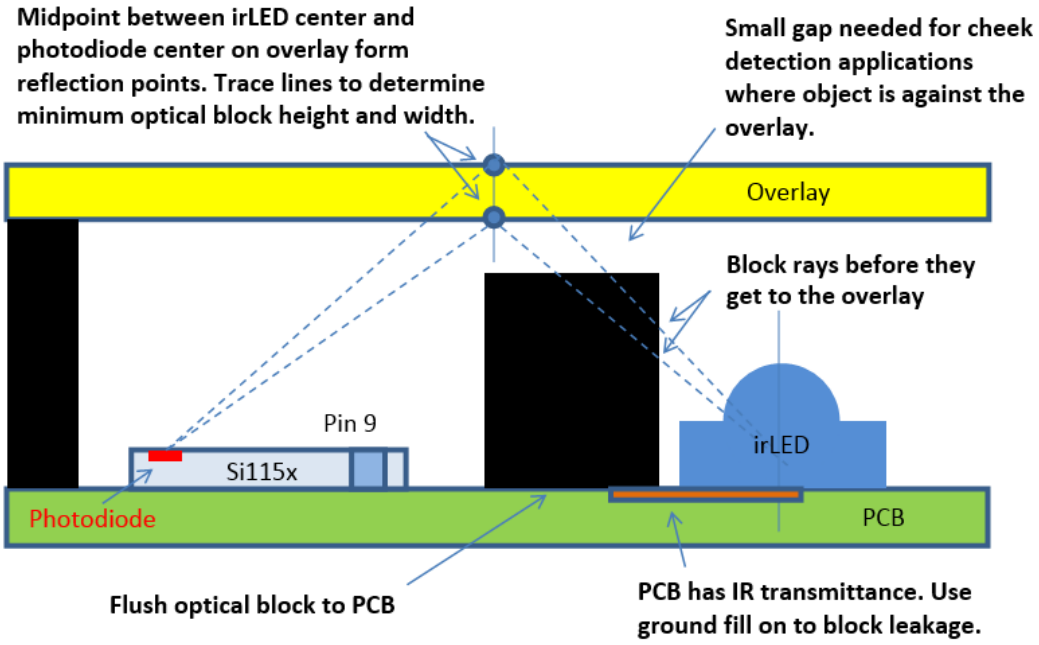


Figure 1.15. Partial Optical Blocking

1.7 Long Range Applications

If the target is small or far away, the Si115x may need to operate at a higher ADC sensitivity setting. This is accomplished through increasing the HW_GAIN setting. When increasing the HW_GAIN setting, both reflectance and optical leakage are magnified. To allow operation at the highest possible ADC sensitivity, the optical leakage should be kept low so as possible.

The limitation to how high the HW_GAIN setting can be set is a function of the following:

- Ambient IR
- Optical Leakage

The IR ambient can be controlled through the following methods:

1. Limiting field of view by using a smaller Aperture (see 1.4 Photodiode Locations, Apertures, and View Angles).
2. Limiting field of view by using lenses
3. Using special overlays, such as a Visible Light Blocking Overlay (Long pass Filters) when CFL/Fluorescent lighting is the predominant lighting condition.

In general, the Dual Port topology provides the lowest leakage. The Hybrid approach can be used as long as proper optical blocking is used.

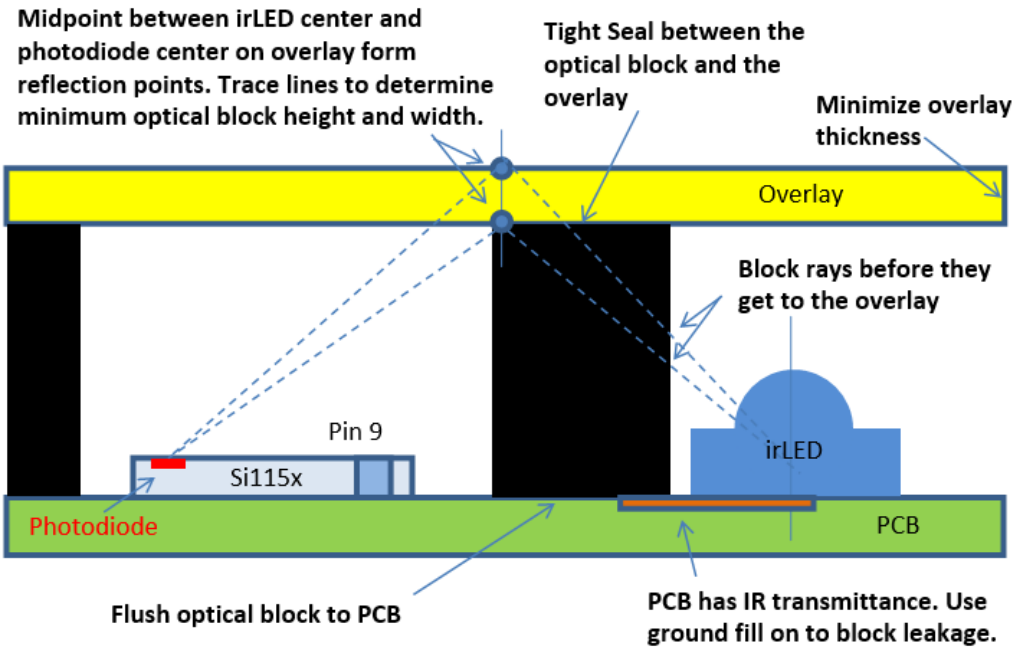


Figure 1.16. Long Range Application using Hybrid Topology (Optical Blocking)

A lensing arrangement where a lens is held over that photodiode in the DFN packaged version of the sensor (Si1151/52/53-AB09 or Si1151/52/53-AB00) is an excellent possibility to extend the range. The lens holder and lens designs are shown below. Note that the holder is an evaluation version not aimed at volume production. The lens as shown can be purchased in large volumes.

To get the most of the lensed approach which can deliver as much as 2 m detection distance under the right conditions, it is important to combine it with a narrow ±6° LED. These LEDs are widely available.

The lens and the LED can be mounted reasonably close, some 20 mm apart while a top layer ground plane is useful to not allow any stray IR light to penetrate the PCB.

The lensing design in the next two figures uses a relatively large 5 mm diameter lens held 2.65 mm above the PCB. As a result it has a narrow angle of operation of some ±5° and should be aligned carefully. A 2.5 mm diameter lens placed 1.52 mm above the PCB and over the photodiode in the Si115x die would have ±10° field of view and should be easier to implement.

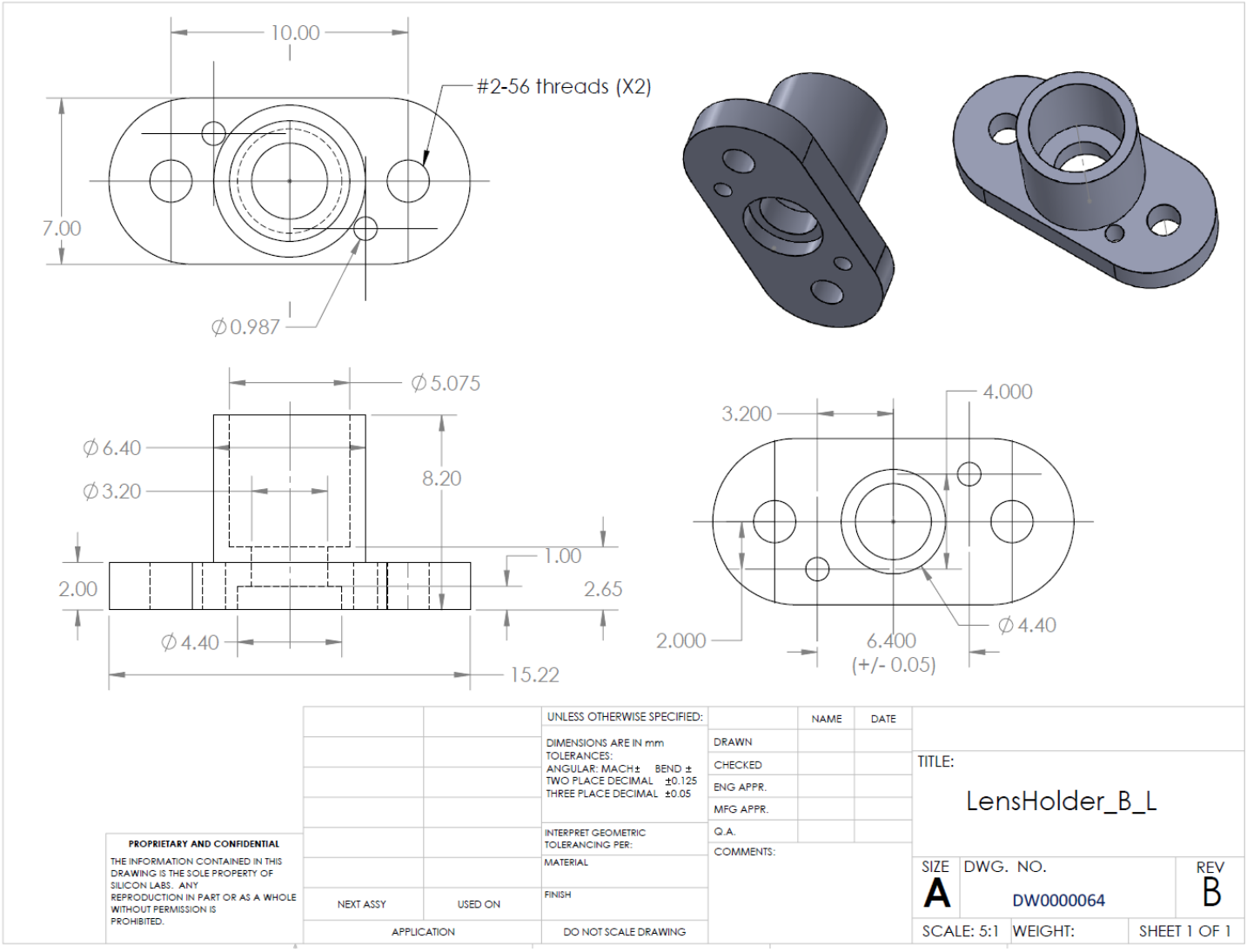


Figure 1.17. Evaluation Example of a Lens Holder for Distance Proximity

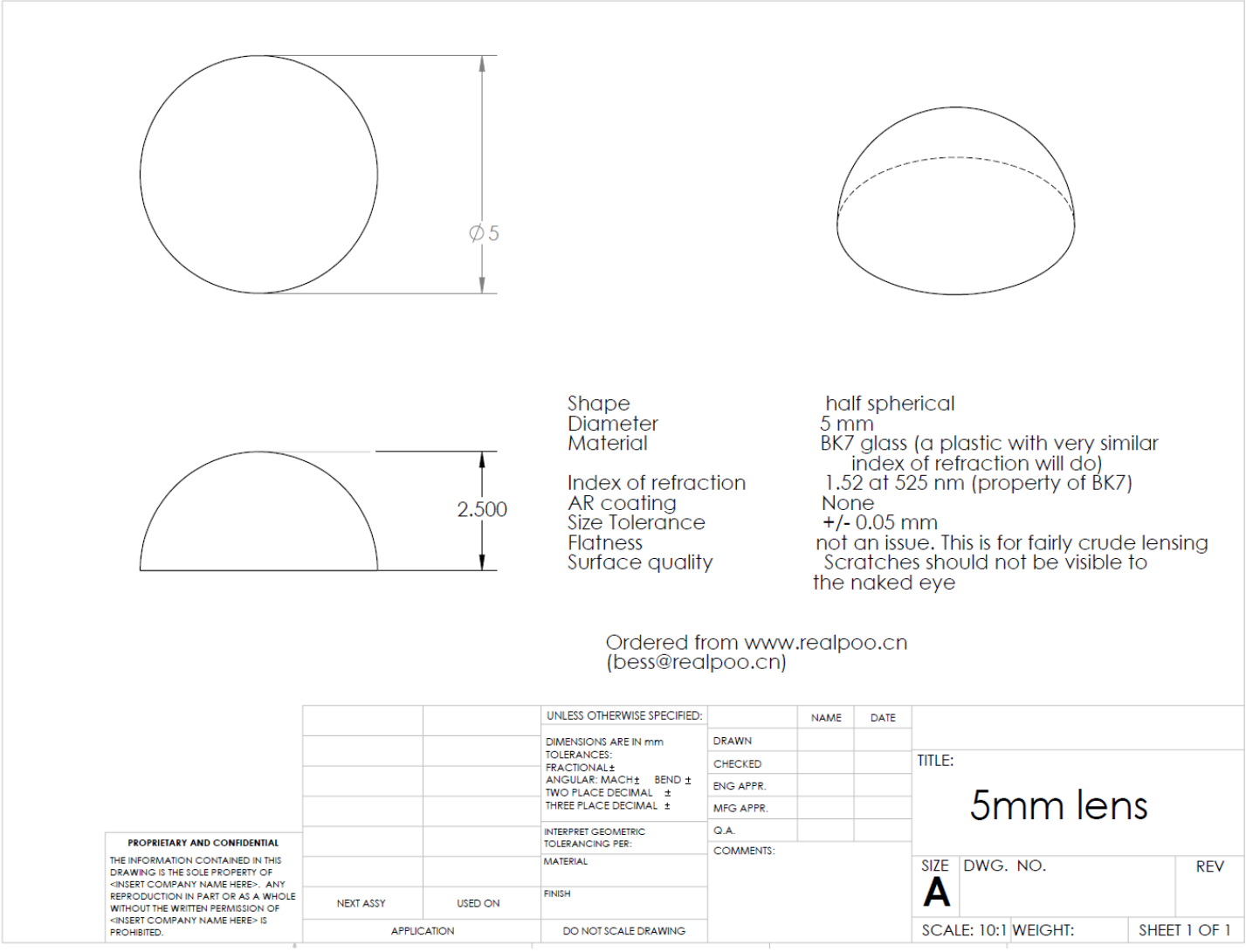


Figure 1.18. Drawing of a 5 mm Half Hemi Lens for Distance Proximity

1.8 Multiple irLED Applications

These are the recommendations for applications using multiple irLEDs, especially when motion detection or gestures are involved.

- Maximize field of view by maximizing the aperture (see 1.4 Photodiode Locations, Apertures, and View Angles).
- Optical Blocking (i.e., Dual Port) is needed (see Figure 2.2 irLED Reference Circuit on page 22).
- Overlay IR transmittance should be maximized for best performance.
- irLED recommendations can be found in “AN521: IR LED Selection Guide for Si114x Proximity Applications”.

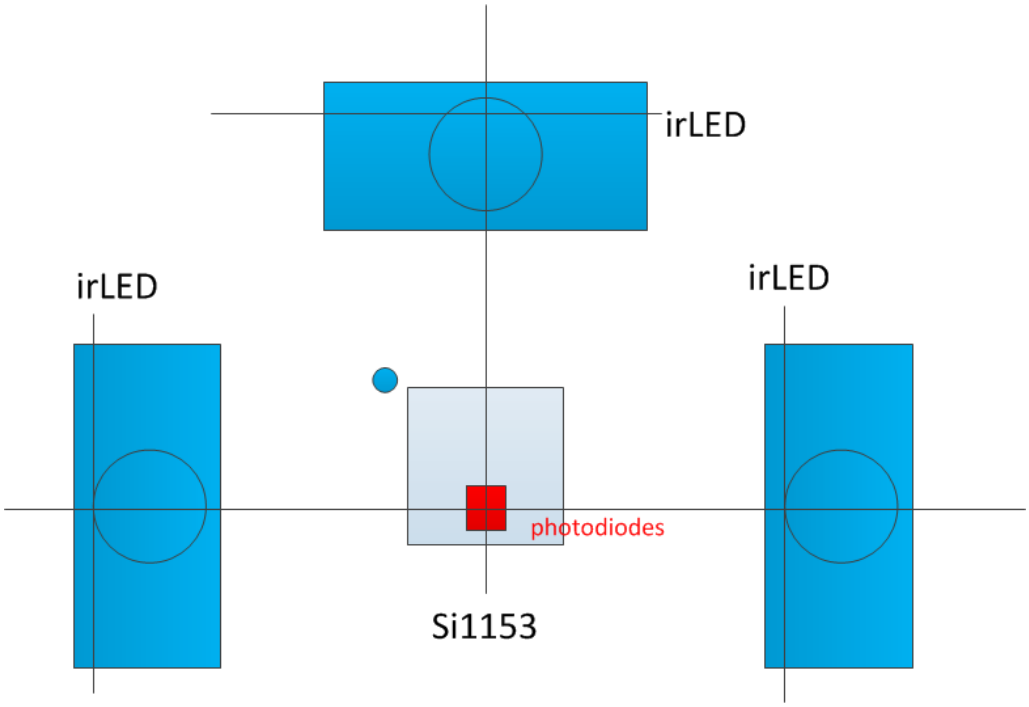


Figure 1.19. Si1153 Placement

1.9 Sunlight-Immune Applications

Sunlight immunity can be achieved for both short and long distance proximity applications by using the versions of the Si115x that has a 940 nm Filter deposited on the die. The filter is designed to reject sunlight and to pass as much of the LED excitation energy as possible. 940 nm is selected as the operating wavelength since it corresponds to a dip in the energy of the solar spectrum, as shown in the figure below.

These parts must be used in conjunction with 940 nm LEDs.

Note: The filter performance falls off beyond ±30° and the sensor should have light from off angles blocked.

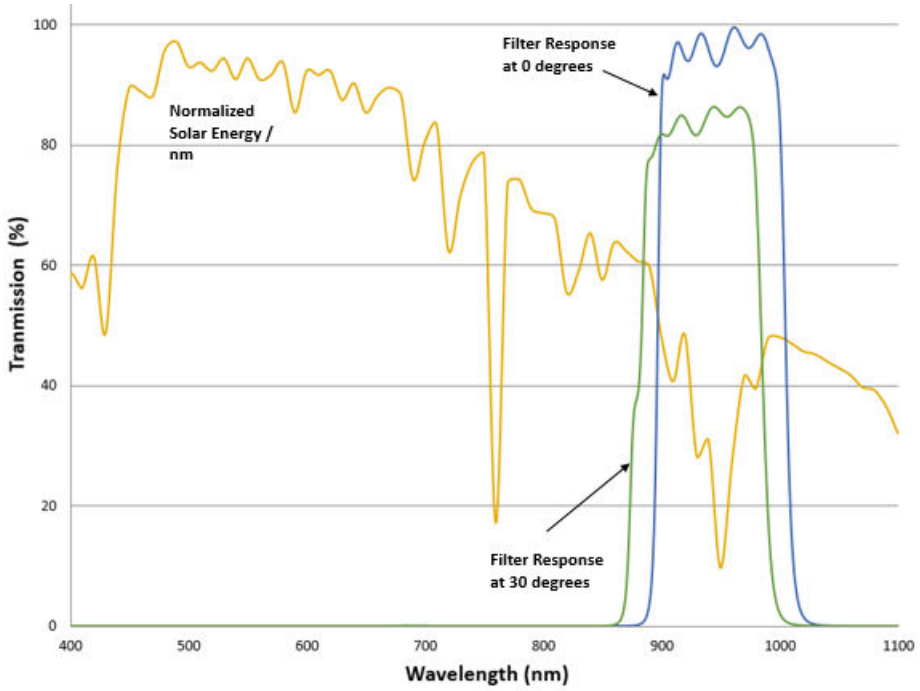


Figure 1.20. Typical Si1151/52/53-AB09 (or Si1153-AB9X) Response Compared to Sunlight Energy

2. Electrical Component Selection

2.1 Typical Application Schematic Diagrams

The following figure shows a schematic of the Si1153 for basic applications.

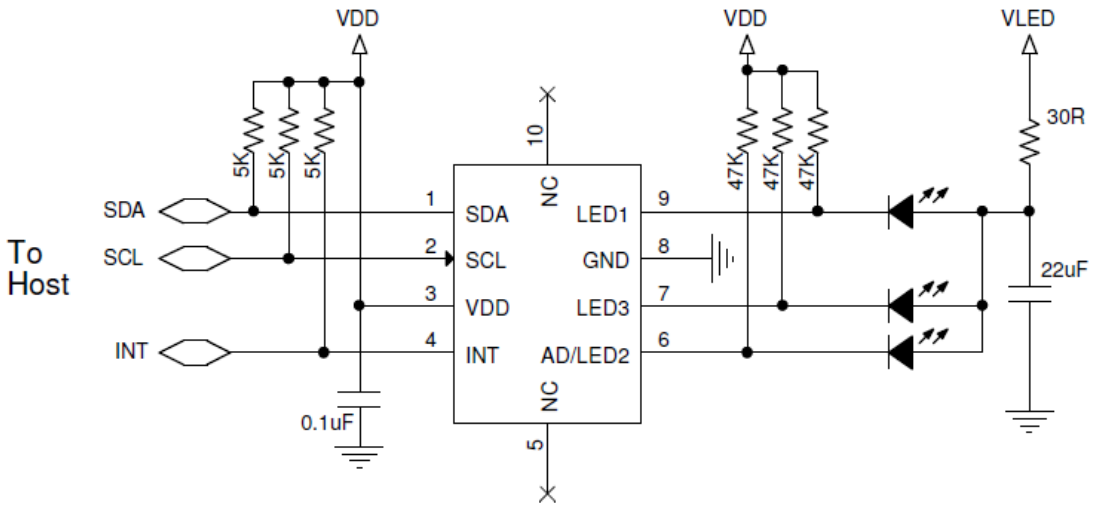


Figure 2.1. Si1153 Schematic Diagrams

2.2 Mandatory LED3 Pull-Up Resistor

This section applies to the 47 kΩ pull-up resistor from the LED3 pin to VDD. Refer to Figure 2.1 Si1153 Schematic Diagrams on page 21.

Upon reset, the LED3 pin operates as a factory test pin to the internal microcontroller. Under this boot-up condition, if the LED3 pin is not pulled-up to VDD, the Si1153 does not come out of reset.

To determine if the resistor is needed, it is necessary to calculate the difference between the VLED and VDD voltage rails and ensure that this difference is greater than the forward drop of the irLED under its leakage condition. The resistor can be removed if the VLED rail is high enough relative to the VDD rail.

If there is uncertainty whether the resistor is needed, it is recommended that a pad site be left on the PCB until this determination has been made.

The following symptoms can occur when the LED3 pins are not high during boot:

- The device does not communicate.
- Some parts can communicate; some parts do not communicate.
- Since there is a floating node, “non-booting” devices may begin to boot with temperature or ambient light changes.

2.3 LED Drive Circuit

This section discusses the operation of the LED drive circuit to allow for customization of the resistor and capacitor shown in the reference circuit.

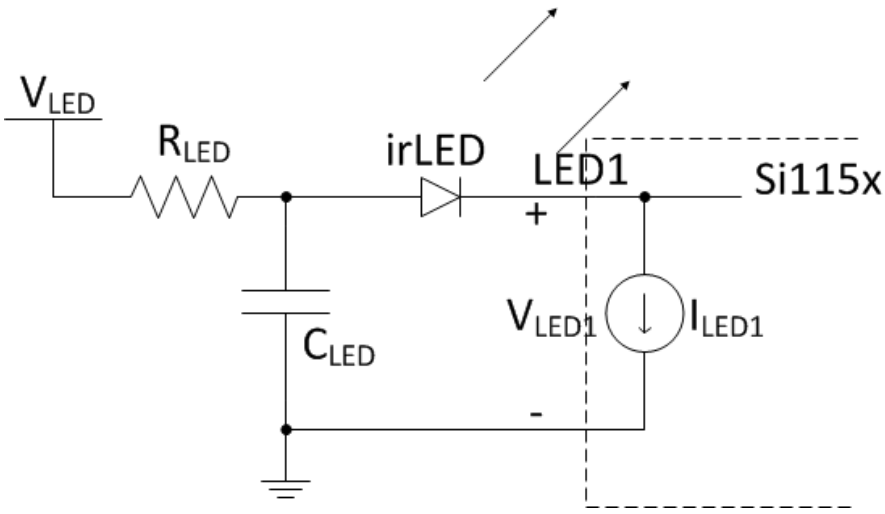


Figure 2.2. irLED Reference Circuit

2.4 Selecting V_{LED} Voltage Rail

The irLED circuit can be powered from either the same VDD used to power the Si115x, or it can be powered from a separate rail, V_{LED}.

The first consideration is how much current can be supplied by the chosen voltage rail. This is an important consideration if V_{LED} is from a regulated supply and if the regulated supply is not able to supply 360 mA for 24.4 µs instantaneously without bringing the system voltage rail down.

Using a separate RC circuit as shown in the figure above to supply the LED introduces the least amount of supply ripple through the entire system. When drawing current from such an RC filtered network, any supply ripple introduced into the system is further filtered by the system regulator. The circuit can still be used on the regulated voltage as-is since the large R_{LED} value is designed to limit the amount of current drawn instantaneously through the chosen V_{LED} rail.

2.5 Selecting C_{LED}

Ideally, the C_{LED} should possess sufficient capacitance to store enough charge for each of the measurements. This can be achieved by using the following equation:

$$C_{LED} = \frac{\text{Number of LEDs} \times \text{Max ir LED Current} \times 24.4\mu s \times 2^{(HW\_GAIN)}}{V_{LED} - V_f - 0.5}$$

The Si115x contains six measurement channels and makes up to six measurements before going back to sleep.

Since these six measurements are done in a very short time, the capacitor does not have much time to charge back up.

In the example below, the irLED current chosen for each of these channels is 360 mA.

V_F is the forward voltage dropped by the irLED at 360 mA. This is typically derived from looking at a data sheet of the irLED.

For example, an OSRAM SFH 4056 irLED drops around 2.2 V at 360 mA.

The default HW_GAIN is zero. 2^0 is 1.

In this example, assume that the V_{LED} chosen is 4.3 V.

$$R_{LED} < \frac{\text{Time between Proximity Measurements}}{C_{LED} \times 5}$$

This means that, if C_{LED} is 16 µF or more, there is sufficient charge stored within the capacitor to allow current to flow through the irLED. With this capacitor, there is not any significant current drawn from the system in the 24.4 µs period when the irLEDs are being driven.

2.6 Selecting R_{LED}

As long as the capacitor, C_{LED}, is able to provide enough charge to supply the current needed for the irLEDs, the R_{LED} resistor generally has two functions:

- Minimizes instantaneous current drawn from the voltage rail
- Charges up the C_{LED} capacitor.

When in this role, the design constraint is to make sure that the C_{LED} capacitor is fully charged by the time the next set of proximity measurements is made.

$$R_{LED} < \frac{\text{Time between Proximity Measurements}}{C_{LED} \times 5}$$

If the C_{LED} capacitor chosen is too small, it may be necessary to draw more current from the VDD supply to provide supplementary current so that the capacitor does not discharge before reaching an excessively low voltage.

For this case, the R_{LED} should be smaller to supply instantaneous current from the V_{LED} rail. For example, to be able to continuously supply 360 mA using an irLED with a 2.2 V forward drop:

$$R_{LED} < \frac{(V_{LED} - 2.2 - 0.5)}{0.360}$$

In this case, the system must be able to supply a peak instantaneous current of 360 mA. The charge stored in the capacitor reduces the amount of time the system draws from the V_{LED} rail, but, in the end, the current needs to be sourced through the resistor.

Due to the low duty cycle of the current pulses, the power rating of the resistor does not need to be very high since little heating is expected. A low-cost 1/16 W resistor can be used.

2.7 irLED Electrical Considerations

This section only refers to electrical considerations when choosing an irLED. Optical considerations are not discussed here.

The Si115x attempts to sink a constant current through the irLED. The irLED should be examined for the following parameters:

- Forward voltage V_F
- 360 mA capability

An irLED with a lower V_F is preferred. With a lower forward voltage, the voltage across C_{LED} can be charged to a higher value, allowing more charge to be stored. This may lead to a smaller C_{LED}, especially when the V_{LED} rail is relatively low.

If the irLED can operate at 360 mA, by default, the Si115x pulses the irLED for 24.4 µs. However, this pulse width is host-programmable through HW_GAIN and can be much higher.

3. Proximity Measurements

3.1 Ambient IR, Optical Leakage, and Target Reflectance

This section intends to provide an illustration of “what” is being measured in a proximity channel. In a proximity measurement, the Si115x actually makes two separate measurements back-to-back.

The first measurement is done without the irLED being turned on. When this happens, the Si115x is measuring the ambient light alone.

On the second measurement, the irLED is turned on. When the irLED turns on, the light from the irLED can either reach the intended target, or it can go directly to the Si115x. This direct coupling is called “Optical Leakage” or “Crosstalk”.

The two measurements made are done within 24.4 µs of each other. The main idea is that the ambient light condition taken during the second measurement has not significantly changed from the ambient condition taken during the first measurement. This greatly reduces errors caused by incandescent or fluorescent light ripple.

The Si115x performs the subtraction between these two measurements and reports this difference measurement onto the output registers. Refer to the figure below for an illustration. As indicated in the figure, the reported measurement contains both the “target reflectance” and “optical leakage”.

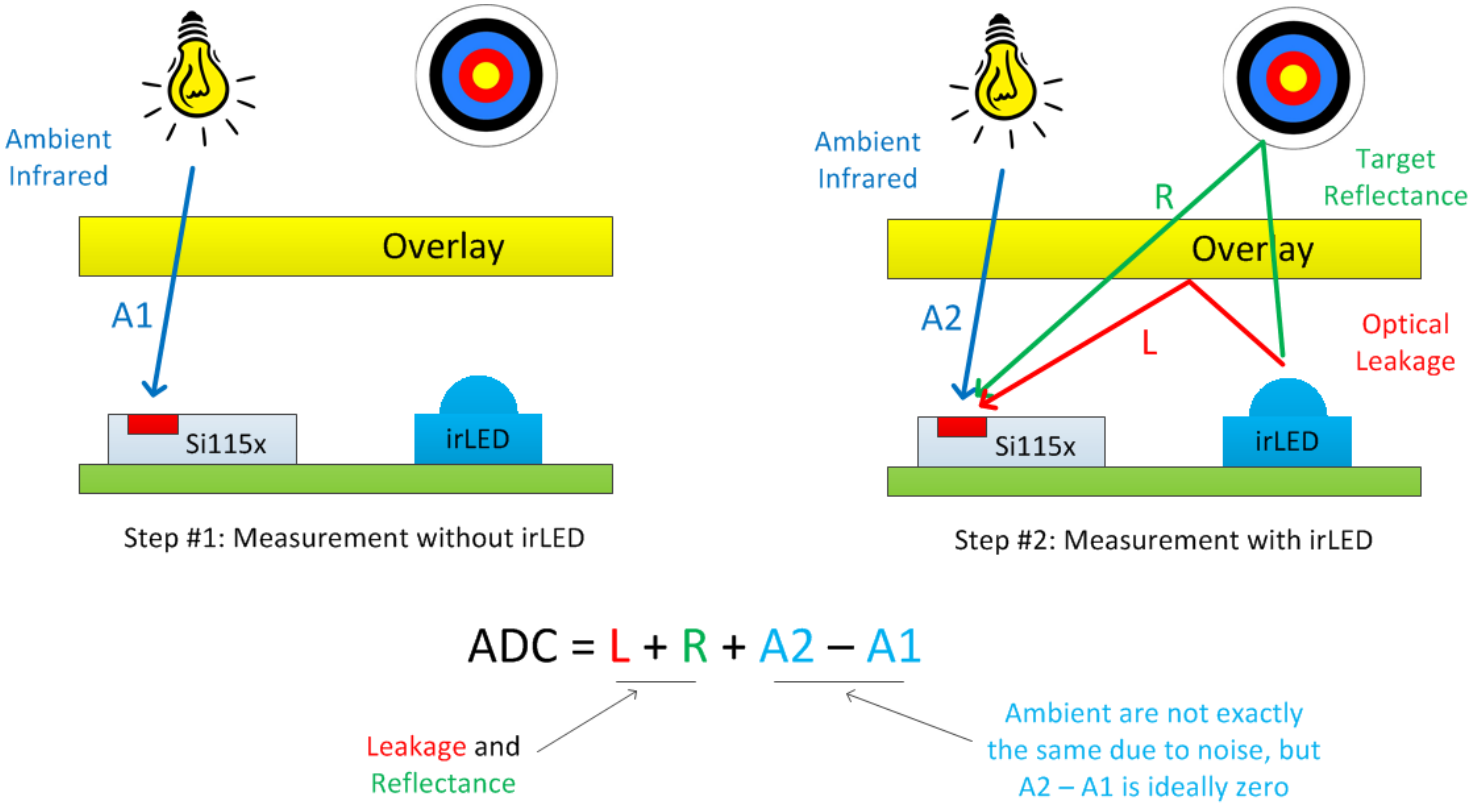


Figure 3.1. Proximity Measurement Concept

3.2 Proximity Baselining

As stated in the previous section, the proximity measurement represents the Optical Leakage plus the Target Reflectance.

The purpose of Proximity Baselining is to separate the Leakage from the Reflectance. This is accomplished by performing a series of measurements without the target.

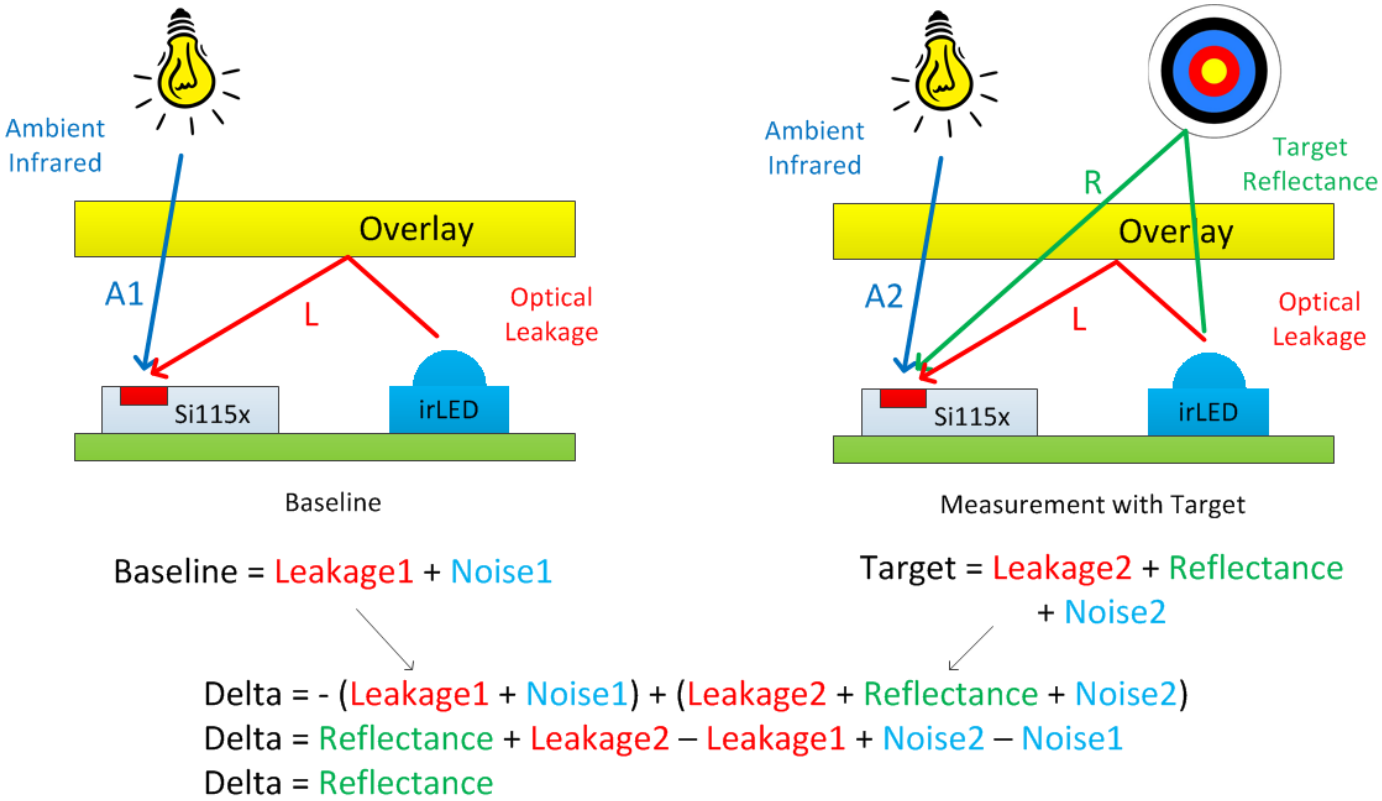


Figure 3.2. Proximity Baselining Concept

In a given system, the static baseline across different systems is going to be in the same ballpark. Therefore, there is typically a “characterization” performed so that it is possible to get close.

However, to account for system variation, it is recommended that a “dynamic baseline” be maintained. A dynamic baseline is typically suitable for systems that generally operate without a target. For example, a slow-moving baseline can be implemented through exponential filtering. Silicon Lab's sample source code contains examples of how this can be achieved.

3.3 Notes on Associating LED Drives with Proximity Measurements

Whenever it is time to make a PS measurement, the Si115x makes up to six measurements, depending on what is enabled in the CHLIST parameter.

The LED choice is programmable for each of these six measurements. Each measurement can select which combination of three LEDs are turned on and which of two LED current setting banks are used to set the LED currents. Optionally, each proximity measurement can be compared against a host-programmable threshold. With threshold settings for each PS channel, it is also possible for the Si115x to notify the host whenever the threshold has been crossed. This reduces the number of interrupts to the host, aiding in efficient software algorithms.

Driving multiple LED drives is one method of increasing the amount of light thrown out for reflectance. The effect is additive. In the same way, all the measurement channels have access to all LED drives. The sequence of measurement is fixed. Channel 1 is always performed first while Channel 6 is always done last.

3.4 Minimizing the Effect of Ambient-Light Ripple

During proximity detection, the Si115x cancels ambient light by subtracting the results of two measurements. The first measurement senses ambient light alone with the IRLED turned off. The second measurement is made with the IRLED turned on, thus sensing both the proximity signal and ambient light. This cancellation method works well if the ambient light does not change between measurements.

However, most light sources have a certain amount of ripple. For incandescent bulbs powered by the mains, the light level fluctuates at 100 or 120 Hz, depending on the mains frequency. Fluorescent bulbs fluctuate at lower amplitudes than incandescent bulbs, but at frequencies in the tens of kilohertz.

The graph below makes clear why proximity measurements are affected by ambient-light ripple. The horizontal axis represents time and the vertical axis represents ambient-light intensity.

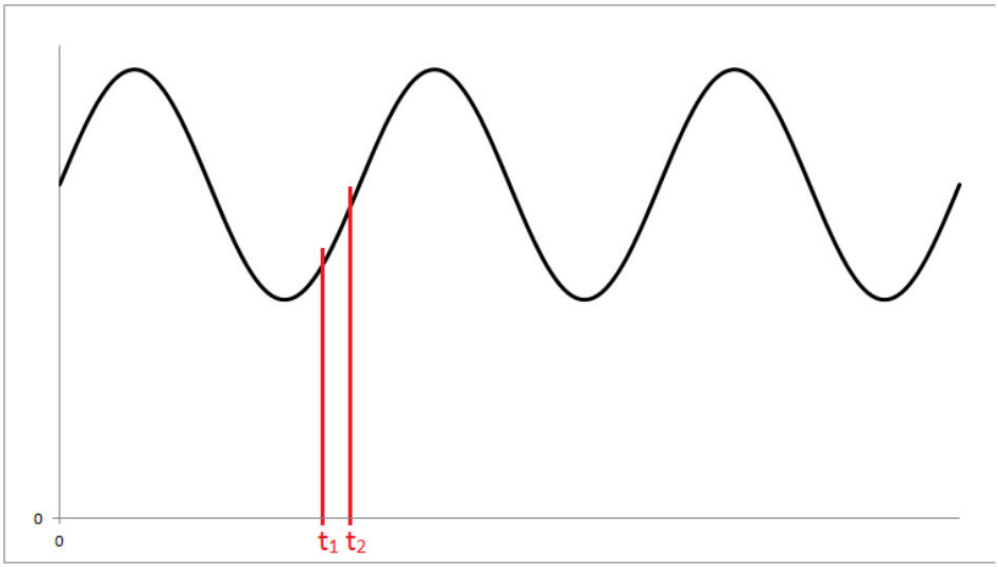


Figure 3.3. Ripple Interference with Proximity Measurements

If the off and on measurements are made at t1 and t2 respectively, the ambient-light correction value will be different from the ambient-light level at the time of the actual proximity measurement. Thus proximity detection, while inherently immune to constant ambient light, is affected by the ripple.

The greater the interval between t1 and t2, the greater the average error will be for a given amount of ripple (excluding synchronized measurements, which are hard to achieve, especially since fluorescent ripple frequency is not predictable). This interval is directly dependent on the proximity gain (set by HW_GAIN), which makes the measurement time proportional to the gain. Best results are obtained with a gain of 1 or 2 (HW_GAIN = 0 or 1). Additional sensitivity may be obtained by setting HSIG to 0 and selecting the large photodiode for proximity.

If all six Si115x measurement channels are available and only one proximity measurement is needed, the other channels may be used for precise error correction in combination with the above steps. The graph below illustrates the correction algorithm:

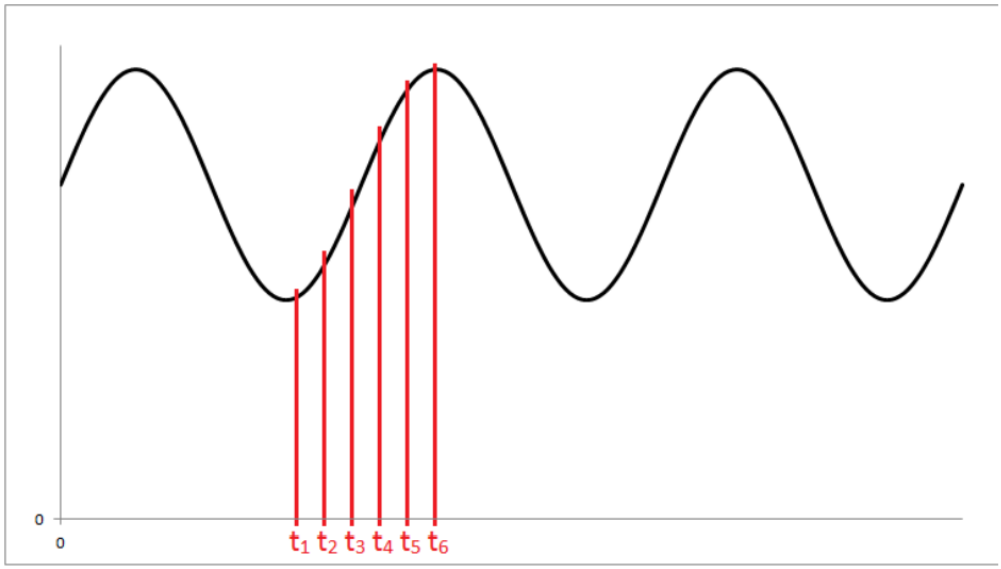


Figure 3.4. Error Correction for Ambient Light Ripple

Three Proximity Channels (CH1_PS, CH2_PS, and CH3_PS) are enabled, and channel assignments are made as shown in the following table.

Table 3.1. Setup for Light Ripple Correction Using Three LEDs and Three Channels

Channel	LED Current Setting	Time	LED	Function
CH1_PS	0 mA	t_1	Off	Ambient light
		t_2	Off	Ambient-light change before proximity
CH2_PS	As required	t_3	Off	Ambient-light first-order correction
		t_4	**On**	Proximity
CH3_PS	0 mA	t_5	Off	Ambient light
		t_6	Off	Ambient-light change after proximity

The three results collected in the CH1_PS, CH2_PS, and CH3_PS data registers are combined in the following way:

$$Proximity = CH2\_PS - 0.5 \times (CH1\_PS + CH3\_PS)$$

Alternatively, if two LEDs are used to perform the same detection function, the channel arrangement can be as shown in the following table:

Table 3.2. Setup for Light Ripple Correction Using Two LEDs and Two Channels

Channel	LED Current Setting	Time	LED1	LED2	Function
CH1_PS	As required (LED1)	t_1	Off	Off	Ambient-light first-order correction
		t_2	**On**	Off	Proximity for LED1
CH2_PS	0 mA for both LEDs	t_3	Off	Off	Ambient light
		t_4	Off	Off	Ambient-light change between LED1 and LED2 measurements
CH3_PS	As required (LED2)	t_5	Off	Off	Ambient-light first-order correction
		t_6	Off	**On**	Proximity for LED2

In this case, the corrected proximity is 0.5 × (CH1_PS + CH3_PS) – CH2_PS.

If only two channels (CH1_PS and CH2_PS) are enabled for proximity measurement, a small amount of slope correction is still possible with the arrangement shown in the following table:

Table 3.3. Setup for Light Ripple Correction using One LED and Two Channels

Channel	LED Current Setting	Time	LED	Function
Ch1_PS	0 mA	t_1	Off	Ambient light
		t_2	Off	Ambient-light change before proximity
CH2_PS	As required	t_3	Off	Ambient-light first-order correction
		t_4	**On**	Proximity

In this case, the corrected proximity is CH2_PS – CH1_PS. This method works for gains of 1 or 2 only (HW_GAIN = 0 or 1).

All the above correction methods work best for low-frequency ripple, such as that of incandescent bulbs. With fluorescent ripple, the error correction is much less effective because of the higher frequency; but fluorescent ripple is not as serious a problem because the typical ripple amplitude of fluorescent bulbs is lower, and mostly in the visible spectrum, to which the Si115x IR photodiodes are much less sensitive. For the same lux level, this results in noise an order of magnitude lower than with incandescent bulbs. Fluorescent ripple can be further minimized by using a visibly dark, IR-transparent overlay.

4. Programming Guide

This guide provides information that is suplemental to the data sheet. For a full description of the registers and bit fields, refer to the Si115x Data Sheet.

4.1 Minimum Initialization Code (Pseudo Code)

Upon reset, the minimum code necessary to obtain measurements out of each optical channel is shown. Note that many of the defines are in the file called Si115x_functions. It is recommended that the symbols within the files be used so that the code is more readable.

The following code uses hardware-independent functions for I^2C communication that the user must provide.

```
U8   Si115xReadFromRegister (U8 reg);            returns byte from I2C Register 'reg'
void Si115xWriteToRegister (U8 reg, U8 value);   writes 'value' into I2C Register reg'
void Si115xParamSet (U8 address, U8 value);      writes 'value' into Parameter 'address'
Si115xForce();                      equivalent to Si115xWriteToRegister (REG_COMMAND, 0x11)
                                                 This forces enabled channels' measurements

// Enable 3 channels for proximity measurement
Si115xParamSet( si115x_handle, PARAM_CH_LIST, 0x07);

// Initialize LED current
Si115xParamSet( si115x_handle, PARAM_LED1_A, 0x3f);
Si115xParamSet( si115x_handle, PARAM_LED2_A, 0x3f);
Si115xParamSet( si115x_handle, PARAM_LED3_A, 0x3f);

// Configure ADC and enable LED drive
Si115xParamSet( si115x_handle, PARAM_ADCCONFIG0, 0x62);
Si115xParamSet( si115x_handle, PARAM_MEASCONFIG0, 0x01);
Si115xParamSet( si115x_handle, PARAM_ADCCONFIG1, 0x62);
Si115xParamSet( si115x_handle, PARAM_MEASCONFIG1, 0x02);
Si115xParamSet( si115x_handle, PARAM_ADCCONFIG2, 0x62);
Si115xParamSet( si115x_handle, PARAM_MEASCONFIG2, 0x04);

// Enable Interrupt
Si115xWriteToRegister( si115x_handle, REG_IRQ_ENABLE, 0x07);

// Start Force measurement
Si115xForce();

// Once the measurements are completed, an interrupt will be generated to the host
// Here is how the host should reconstruct the sample in IRQ
// Note very carefully that 16-bit registers are in the 'Big Endian' byte order
// It will be more efficient to perform I2C Burst Reads, but this example shows
// individual reads of registers

CH0_PS =     Si115xReadFromRegister (REG_HOSTOUT1) +
          256 * Si115xReadFromRegister (REG_HOSTOUT0);
CH1_PS =     Si115xReadFromRegister (REG_HOSTOUT3) +
          256 * Si115xReadFromRegister (REG_HOSTOUT2);
CH2_PS =     Si115xReadFromRegister (REG_HOSTOUT5) +
          256 * Si115xReadFromRegister (REG_HOSTOUT4);
```

Be aware of the Big-endian ordering when constructing the 16-bit variable.

The sample code is also available in the Programmer's Toolkit which can be downloaded and installed from Silicon Labs website.

4.2 Tracking Executed Commands

As long as the Si115x has not started autonomous operation, it is possible to initiate commands without having to poll the RESPONSE register.

This is accomplished by making use of the RESET_CMD_CTR command to clear the response counter before sending commands to the Si115x. By clearing the response counter before executing a series of commands, it is possible to determine how many commands have executed.

However, once autonomous operation has started, the measurements could result in an ADC overflow and can cause an update of the RESPONSE register with an error code instead of the normal response code.

Therefore, it is recommended that autonomous operation be paused when it is necessary to modify parameters through the PARAM_SET and other commands associated with manipulating parameters.

This allows proper Command/Response tracking to ensure that intended settings take effect. This helps avoid unusual operation if, the setting was not received by the Si115x. Having the Response register recognize the command is the best way of ensuring that the intended parameter setting was executed. An example of a method of pausing the autonomous measurement is shown below:

```
static U8 measurementPaused = 0;
void pauseMeasurement(void)
{

   if (measurementPaused)
      return;

   WriteToRegister(REG_IRQ_ENABLE, 0); //to disable any Si115x interrupts

   // Need to make sure the machine is paused
   // the error condition in response register is asynchronous
   while (1)
   {
      // Keep sending RESET_CMD_CTR command until the response is zero
      while (1)
      {
         if ( GetResponse() == 0)
            break;
         else
            RESET_CMD_CTR();
      }

     // Pause the device
      Si115xPause ();

      // Wait for response
      while(1)
      {

       if (GetResponse() != 0)
           break;
      }

      // When the Si115xPause () response is good, we expect it to be a '1'.
      if (GetResponse() == 1)
         break; // otherwise, start over.
     }
     measurementPaused = 1;
   }
```

An example of a method of resuming an autonomous measurement is shown in the following code.

```
void resumeMeasurement(void)
{

   if (!measurementPaused)
      return;

ClearIrqStatus();
Si115xWriteToRegister( si115x_handle, REG_IRQ_ENABLE, 0x07);    // re-enables INT
Si115xStart ();
measurementPaused = 0;
}
```

4.3 Resetting the Si115x

The Si115x has an internal microcontroller. When the Si115x receives a RESET_SW command from the host (The I2C Command Register is written with 0x01), the Si115x controller initiates an internal hardware reset.

This reset command is intended to place the Si115x in its hardware reset state. If the reset command is initiated, prior initialization steps need to be repeated. Wait at least 10 ms before accessing the sensor upon reset.

The Reset Command is used with Silicon Labs Evaluation Systems for a specific reason. In Silicon Lab's Evaluation Systems, the host controller driving the Si115x contains flash memory. As it is a development environment, the flash memory can be reprogrammed through the Integrated Development Environment.

When the host controller goes through a flash memory reprogram cycle and resets, the Si115x is unaware of this event. Therefore, if the Si115x is already performing autonomous measurements, the Si115x does not know that it is supposed to stop.

On the other hand, after the host controller has been reprogrammed, it does not know whether the Si115x is already performing autonomous measurements from a prior context. Therefore, the example code in the Si115x Evaluation Systems generally shows a reset sequence performed at the very beginning of the Si115x initialization sequence. If both the Si115x and the host always operate from a power-on-reset sequence, the reset command does not need to be issued.

The reset command is useful in a system watchdog. If the software system has a watchdog looking for catastrophic errors, it is generally a good idea to include a Si115x reset sequence as part of the recovery.

The reset command, when used in the middle of other initialization settings, is not recommended. All settings prior to the Si115x reset command are lost.

4.4 Timing of Channel Measurements

The timing of Si115x measurements has two aspects:

- The length of time to take one measurement.
- How frequently the measurement is taken.

The amount of time to take one measurement is controlled by HW_GAIN (ADC integration time), SW_GAIN (sample averaging) and the DECIM_RATE (decimation rate) settings. Please note that, in one proximity measurement, two measurements are always taken, one without the LED light and one with the LED light. The Si115x data sheet provides detailed measuring time information and an example timing diagram.

The Si115x provides three counters (MEASCOUNTx) in the global parameter table to control the frequency of measurements. The main measurement rate counter uses an 800 µs time period base. To enable autonomous measurements, the host should configure the MEASRATE and MEASCOUNT registers first and then select the counter index in each channel's MEASCONFIG register separately. If a channel uses MEASCOUNTx (x = 1, 2 or 3) in the parameter table, the time between measurements for this channel is 800 µs x MEASRATE x MEASCOUNTx.

Example: Assume that channel 0 is configured to take proximity measurements at 50 Hz (20 ms per measurement):

```
// Select MEASCOUNT0 for channel 0 measurement
Si115xParamSet( si115x_handle, PARAM_MEASCONFIG0, 0x41)

// Set MEASCOUNT0 to 1
Si115xParamSet( si115x_handle, PARAM_MEASCOUNT0, 0x01);

// Set MEASRATE to 25 (25 * 800us = 20ms)
Si115xParamSet( si115x_handle, PARAM_MEASRATE_L, 0x19);

// Start Autonomous measurement
Si115xStart();
```

4.5 ADC Measurements Output

This section focuses on information reported by the Si115x through the various registers. In this section, these registers are “output registers” as the Si115x communicates information through these mailbox registers.

Global Section of Parameter Table			Channel Specific Section of Parameter Table
CHAN_LIST			Output mode
0	Bit 0	Chan 0	16
1	Bit 1	Chan 1	24
0	Bit 2	Chan 2	16
1	Bit 3	Chan 3	16
1	Bit 4	Chan 4	24
1	Bit 5	Chan 5	16
X	Bit 6	X	X
X	Bit 7	X	X

I2C Register	I2C Addresss	Content
HOSTOUT0	13	Channel 1 Result: Most Signoficant Byte
HOSTOUT1	14	Channel 1 Result: Middle Signoficant Byte
HOSTOUT2	15	Channel 1 Result: Least Signoficant Byte
HOSTOUT3	16	Channel 3 Result: Most Signoficant Byte
HOSTOUT4	17	Channel 3 Result: Least Signoficant Byte
HOSTOUT5	13	Channel 4 Result: Most Signoficant Byte
HOSTOUT6	14	Channel 4 Result: Middle Signoficant Byte
HOSTOUT7	1A	Channel 4 Result: Least Signoficant Byte
HOSTOUT8	1B	Channel 5 Result: Most Signoficant Byte
HOSTOUT9	1C	Channel 5 Result: Least Signoficant Byte
HOSTOUT10	1D	Unused
HOSTOUT11	1E	Unused
HOSTOUT12	1F	Unused
HOSTOUT13	20	Unused
HOSTOUT14	21	Unused
HOSTOUT15	22	Unused
HOSTOUT16	23	Unused
HOSTOUT17	24	Unused
HOSTOUT18	25	Unused
HOSTOUT19	26	Unused
HOSTOUT20	27	Unused
HOSTOUT21	28	Unused
HOSTOUT22	29	Unused
HOSTOUT23	2A	Unused
HOSTOUT24	2B	Unused
HOSTOUT25	2C	Unused

Packing of of these four channels in the output table is determined by the four enabled channels in the CHANNEL list above. This is independent of the IRQ_ENABLE and IRQ_STATUS

Figure 4.1. Output Data Packing

4.5.1 Byte Alignment

The Si115x has a total of 26 output registers. In all modes, the CHAN_LIST configuration determines how the data is stacked in the 26 byte output field. It is done on a first-come first-served basis, with the enabled lower channels taking up the lower addresses.

The format of the output is either a 16-bit unsigned number or a 24-bit signed number, determined by the selection made in the channel setup.

It is recommended that these output registers be read using an I^2C Burst Read operation.

Register ordering is “big-endian”.

4.5.2 Host Interrupt Latency

When the Si115x has started an autonomous measurement, the output registers are updated directly from the internal controller. The host interrupt handler is expected to read the I^2C registers before the next measurement cycle begins. The choice of the measurement rate should take the interrupt latency into consideration.

If the host reads the output registers while the Si115x is updating them with the next measurement, it is possible that the host may read an upper byte from the previous measurement and a lower byte from the current measurement. For this reason, it is imperative that the host reads the output before the next group of measurements is started.

In general, the host must read the registers any time after the interrupt pin has asserted up to the measurement time minus the maximum measurement time. The host interrupt latency should allow the output registers to be read by this time frame. Refer to 5. Latency for more details on the latency of various measurement channel combinations.

4.5.3 ADC Number System

Due to effect of ambient noise, it is possible that the values provided by the Si115x can be slightly negative. If the output format is configured as 16-bit unsigned mode, all negative values will be treated as 0. If the output format is configured as 24-bit signed mode, the negative value will be placed on the output registers as it is.

The Si115x uses the ADC value, 0xFFFF, whenever the ADC saturates.

5. Latency

In autonomous measurement mode, measurements are performed periodically based on MEASRATE and MEASCOUNT as applicable. When autonomous measurement mode is initiated, the wake-up timer and measurement rate counters begin to count down, and the first set of measurements is available at the end of that initial count and periodically afterwards. Upon each measurement, the result is placed in the corresponding data register, and the interrupt is triggered. By definition, the latency is zero.

In forced measurement mode, a measurement is processed as soon as possible. In the simplest case, where forced mode is used for CH0 proximity or ambient light measurement only, with DECIM_RATE set to 0 (48.8 µs measurement time) by default, the latency is given by the following formula:

$$t = t_{process} + 2 \times \left(t_{adcstart} + 48.8\mu s \times 2^{HW\_GAIN}\right)$$

The values for $t_{process}$ and $t_{adcstart}$ can be found in the electrical specifications of the data sheet.

In both autonomous and forced mode, measurements are performed in the order from CH0 to CH5 when enabled, and all the latencies apply cumulatively.

Conflicts may arise in some cases:

- A forced measurement is requested while an autonomous measurement is in progress.
- An autonomous measurement internal request from the wake-up timer occurs while a forced measurement is in progress.

In the above cases, measurement requests are executed in the order they have been received, and additional delays will be encountered. The worst-case latency can be calculated by adding all potential latencies based on expected measurements. Careful system design can prevent or minimize cumulative delays (e.g., by forcing measurements only after stopping the autonomous-measurement loop) or when no autonomous measurement is expected (e.g., immediately after an interrupt signals the last autonomous measurement).

6. Power Consumption

Power consumption calculation proceeds in discrete steps. Since the Si115x is in standby mode most of the time, the following duty cycle calculations are necessary to evaluate the overall power consumption:

1. Calculate the duty cycle associated with ADC measurement.
2. Calculate the duty cycle associated with controller processing.
3. Calculate the duty cycle associated with the Si115x being in standby, (i.e., the rest of the time).
4. Calculate the LED duty cycle, and multiply by the LED current and driver current.

The complete current-consumption formula is given below:

$$I_{DD} = DC_{ADC} \times I_{suspend} + DC_{Process} \times I_{active} + DC_{SB} \times I_{sleep} + DC_{LED} \times I_{LED}$$

Where DC_{ADC}, $DC_{Process}$, DC_{LED} and DC_{SB} are the duty cycles of the ADC measurements, the controller processing overhead, the LED “on” time, and the Si115x standby time, respectively.

I_{active}, $I_{suspend}$, I_{LED} and I_{sleep} are the device active current, ADC suspend current, LED current and standby current respectively. Typical and maximum standby currents and active currents can be found in the Si115x data sheet. Typical LED currents are listed in the Si115x data sheet.

If multiple channels are used, the duty cycle is increased in proportion, and an additional term must be added for each additional LED with its corresponding duty cycle, current, and driver current.

Measurement duty cycles are ratios of a given period of time, t, over the measurement cycle and thus take the form:

$$DC_{xx} = \frac{t_{Active}}{\text{Measurement Cycle}}$$

The measurement cycle is set by MEASRATE and MEASCOUNT globally, and COUNTER_INDEX for the corresponding channel.

6.1 ADC Measurement Duty Cycle

The duty cycle of the ADC measurement is affected by the number of channels, the ADC setup time, the ADC gain, and the measurement rate according to the following formula:

$$DC_{ADC} = \frac{2 \times \left(\text{number of channels}\right) \times \left(t_{setup} + 48.8\mu s \times 2^{HW\_GAIN}\right)}{t_{MEASRATE}}$$

Typically, t_{setup} is about 48.8 µs.

Power consumption can be minimized by reducing the HW_GAIN.

6.2 Controller Processing Duty Cycle

The controller processing duty cycle is determined by the number of channels and the total internal processing time including the setup time and post processing time:

$$DC_{Process} = \frac{\text{number of channels} \times t_{process}}{t_{MEASRATE}}$$

The sum of processing time per measurement $t_{process}$ is about 155 µs.

6.3 Standby Duty Cycle

The standby duty cycle is inferred from all the other duty cycles, thus:

$$DC_{SB} = 1 - DC_{ADC} - DC_{Process}$$

6.4 LED Power

On each proximity measurement, the LED current is on for 48.8 µs times the gain. Thus, for each proximity channel, the LED duty cycle is:

$$DC_{LED} = \frac{48.8\mu s \times 2^{HW\_GAIN}}{t_{MEASRATE}}$$

The LED driver requires internal mirroring, which requires current based on the LED current setting. Thus for each LED current setting, there is a corresponding internal power draw. The LED-related extra current draw is not proportional to the set LED drive current.

If multiple LEDs are on for any given proximity cycle (Si1153 only), all respective LED currents and LED drive currents must be summed.

7. Additional Resources

Si1153-AB00/AB09/AB9X Data Sheet

AN521: IRLED Selection Guide for Si114x Proximity Applications

AN522: Using the Si1141 for Touchless Lavatory Appliances

AN523: Overlay Considerations for the Si114x Sensor

AN580: Infrared Gesture Sensing

8. Revision History

Revision 0.6

September 2019

- Fixed a few errors.

Revision 0.5

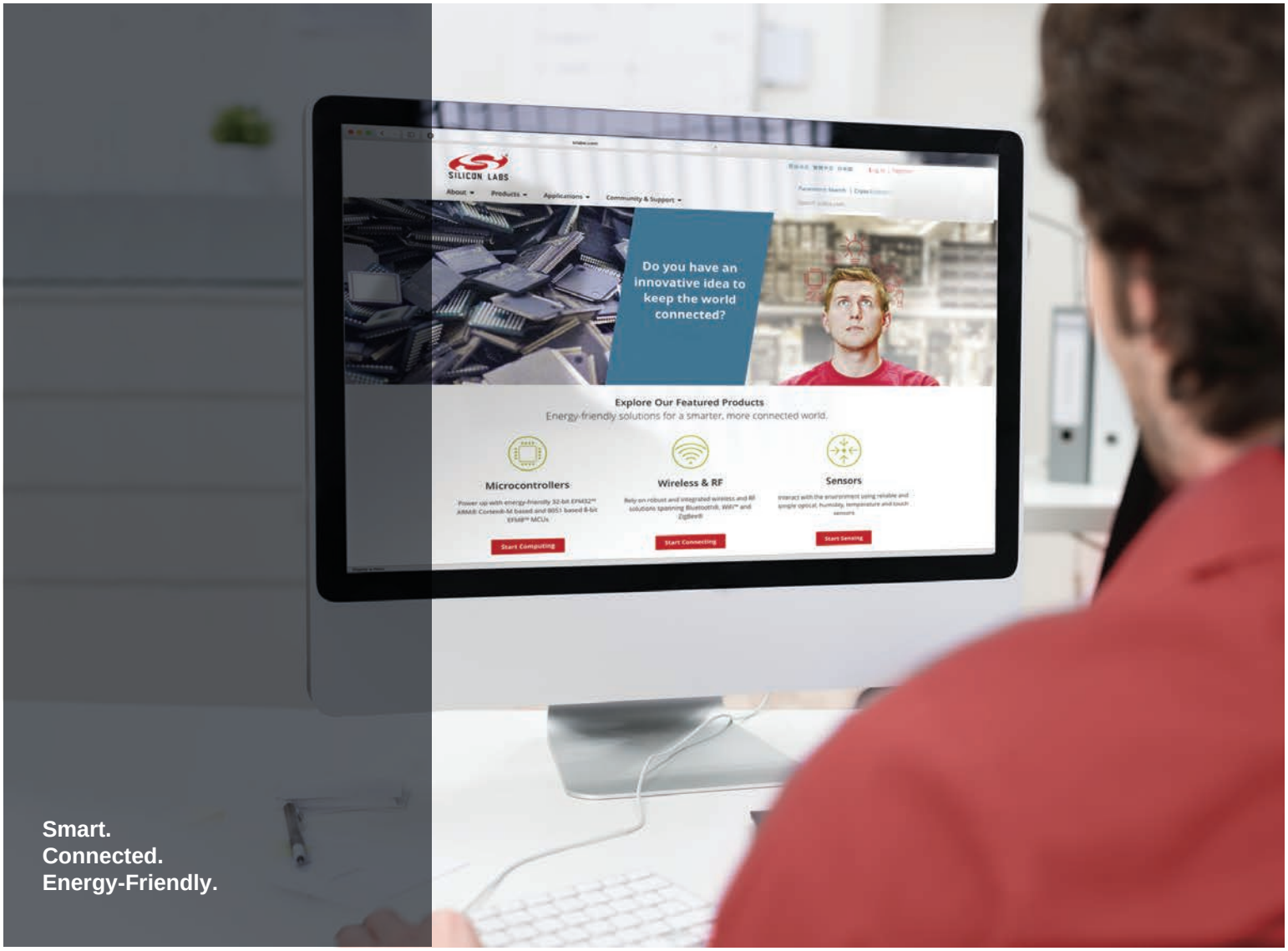
December 2018

- Added support for Si1151/52 parts.

Revision 0.4

December 2015

- Initial release.



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