# Si114x Designer's Guide

## 1. Introduction

This application note provides an outline for using the Si114x proximity detector and ambient-light sensor. General considerations of electrical and optical component selection, programming, and power consumption are explained so as to cover the majority of situations. Specific topics are discussed elsewhere:

- AN521: IRLED Selection Guide for Si114x Proximity Applications
- AN522: Using the Si1141 for Touchless Lavatory Appliances
- AN523: Overlay Considerations for the Si114x Sensor
- AN540: Hair Immune Cheek Detection in SmartPhones Using the Si1141 Infrared Sensor
- AN541: Smoke Detection using the C8051F990 and Si1141
- AN580: Infrared Gesture Sensing

## 2. Optical Considerations toward Mechanical Design

This section focuses on mechanical and industrial design considerations.

### 2.1. Topology

Figure 1 highlights and defines the various system topologies.

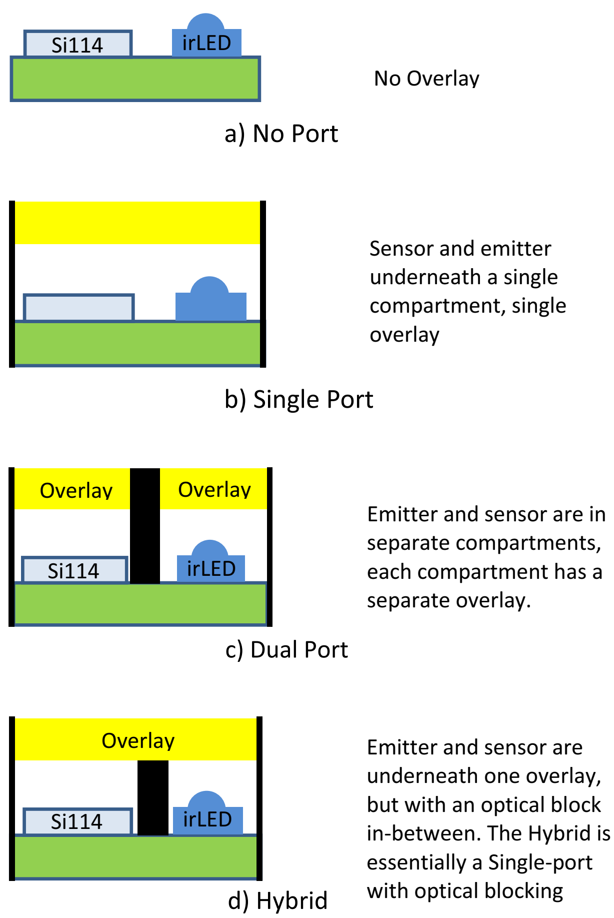



**Figure 1. System Topologies**

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.

## 2.2. Optical Leakage

Also refer to "4. Proximity Measurements" on page 26 for information on how the Si114x makes Proximity Sense (PS) measurements.

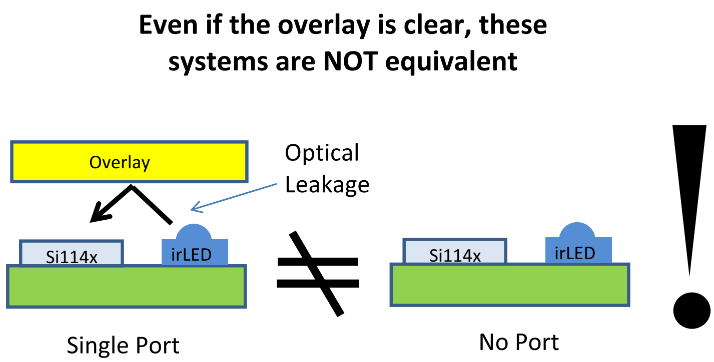


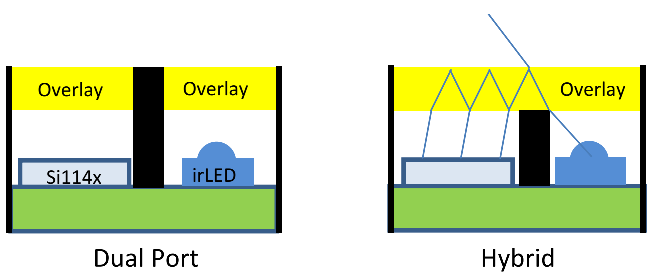

**Figure 2. Common Misconception**

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 PS_ADC_GAIN setting. To be able to use the settings with high PS_ADC_GAIN settings, the optical leakage must be carefully controlled.




- Single overlay in hybrid is a medium for secondary sources of light leakage from irLED compartment to sensor compartment.
- Dual Port is recommended for long range targets where PS_ADC_GAIN needs to be increased.

**Figure 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. Figure 4 illustrates two light rays, each hitting the Si114x photodiode. In Figure 4, 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 Si114x photodiode, it increases the ADC reading proportional to the level of reflectance emitted by the target.

Figure 4 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.

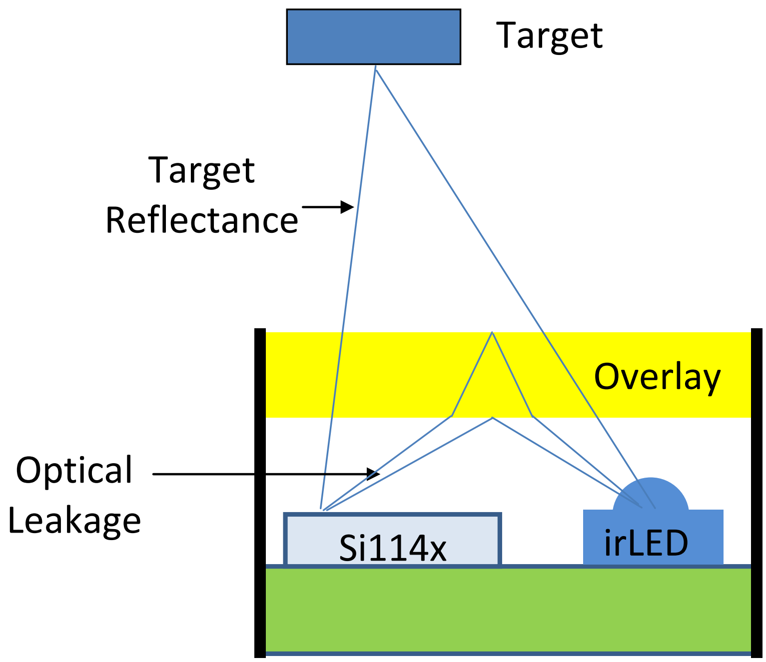



**Figure 4. Optical Leakage**

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.

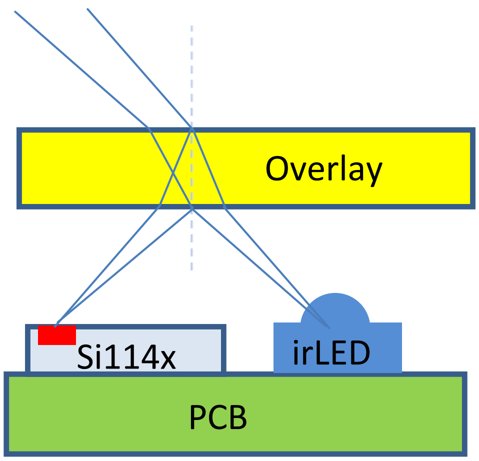
Reducing the leakage from these two primary paths can also be achieved by placing the irLED close to the overlay. This way, only light rays with very steep angles relative to the axial direction are allowed to originate from the irLED. The radiant intensity is typically a function of the radiation angle, 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 Si114x 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 5. Optical Leakage Summary**

## 2.3. Optical/Mechanical Components

### 2.3.1. Optical Blocking Material

An Si114x 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:

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:

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:

search.digikey.com/scripts/DkSearch/dksus.dll?vendor=0&keywords=bumpon+roll

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.

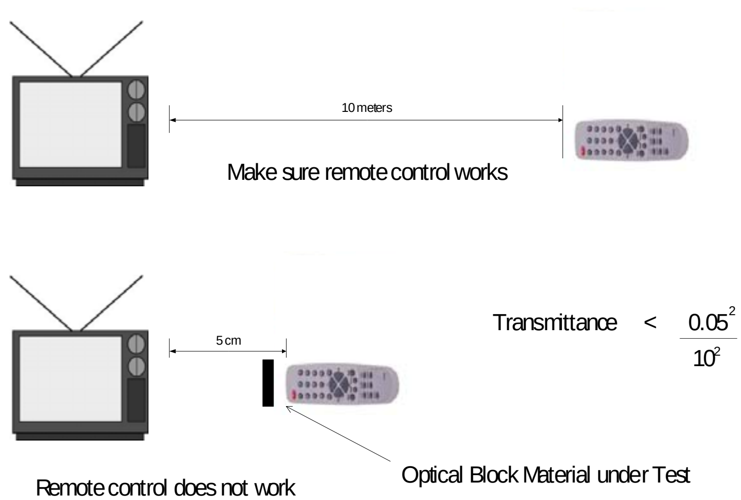



**Figure 6. Infrared Opacity Test**

### 2.3.2. 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 Si114x is an effective method of reducing the amount of optical leakage through the PCB material.

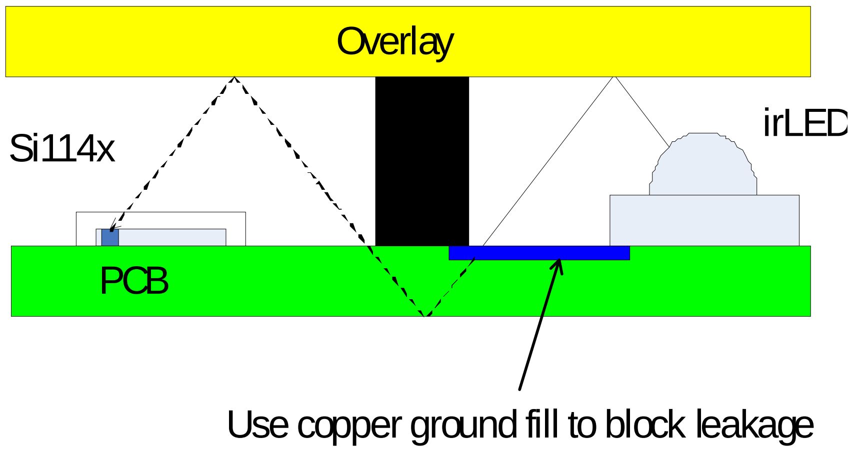



**Figure 7. PCB has High IR Transmittance**

### 2.3.3. Choosing an Overlay

The Si114x does not require any optical filter for proper operation.

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.

As a reference, purple light is at 400 nm; green light is 550 nm; red light is 700 nm, and the infrared light typically chosen for proximity is 850 nm.

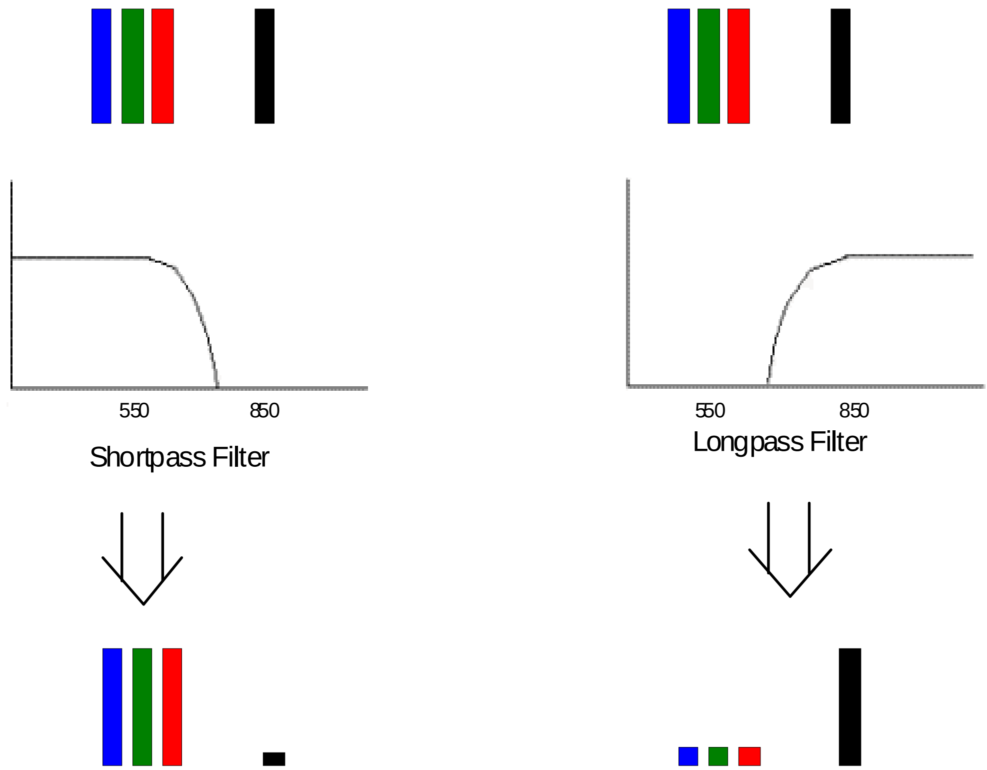



**Figure 8. Shortpass Filter vs. Longpass Filter**

A “Long Pass Filter” with a corner wavelength of 700 nm blocks visible light while allowing the infrared spectrum to pass through. The opposite of a long pass filter is the short pass filter. So, a short pass filter with a 700 nm corner wavelength allows visible light while blocking the infrared spectrum.

In general, there is a desire for most products to hide internal electronics from visible view. Common materials and inks generally have a higher transmittance to infrared light compared to visible light. For the most part, this means that there is a tendency to having the overlay act more as a “long pass filter” than a “short pass filter”, since a design goal of many products is to obstruct visible light from the view of human users.

Let us stop for a moment and consider “what is the signal” being measured in a proximity sensing application and an ambient light sensor.

In the case of a proximity sensing application, the “signal” is 850 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” are the wavelengths 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”. A “bandpass filter” that is shaped in the form of a human eye response is called a “photopic” filter.

Hiding the internal electronics from view somewhat conflicts with the concept of “maximizing the signal” for ALS usage.

**2.3.3.1. Overlay Considerations**

In proximity-only applications, the “signal” is the light of the wavelength emitted from the irLED (e.g. 850 nm). Obviously, 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.

Since there is often a “target object distance” consideration, a significant optical overlay loss can translate to a loss in sensitivity with target object distance unless the overlay loss is compensated for with a different irLED or higher irLED current.

For a proximity-only application, aside from aesthetic reasons or industrial design constraints, maximizing the 850 nm transmittance should be the design goal. For applications requiring the highest performance under direct sunlight, a bandpass overlay allowing a narrow band of wavelengths around 850 nm provides the best performance.

The following common overlay approaches are possible with the Si114x. They are listed in order of preference by performance.

- Clear plastic or glass overlay
- Clear overlay with ink applied through a silkscreen process
- 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. Refer to "3.7. Selecting RLED" on page 25.

Note that even if an overlay has a relatively low IR transmittance, this does not necessarily mean that the Si114x 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 simple procedure using a common TV remote control can be used to determine the transmittance of the overlay material. Although the transmittance of the TV remote control measures the transmittance at 940 nm, the estimate is often sufficiently close to the transmittance at 850 nm.

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 at which the TV remote control operates but begins to fail to control the TV (the boundary of operation).
4. Locate the IR sensor on the TV.
5. Verify that this is the IR sensor by placing the TV remote control directly on top of the IR sensor.
6. Cover the TV remote control with the overlay material.
7. Attempt to control the TV, noting the boundary of operation.
8. The ratio of the distance squared is the IR transmittance.

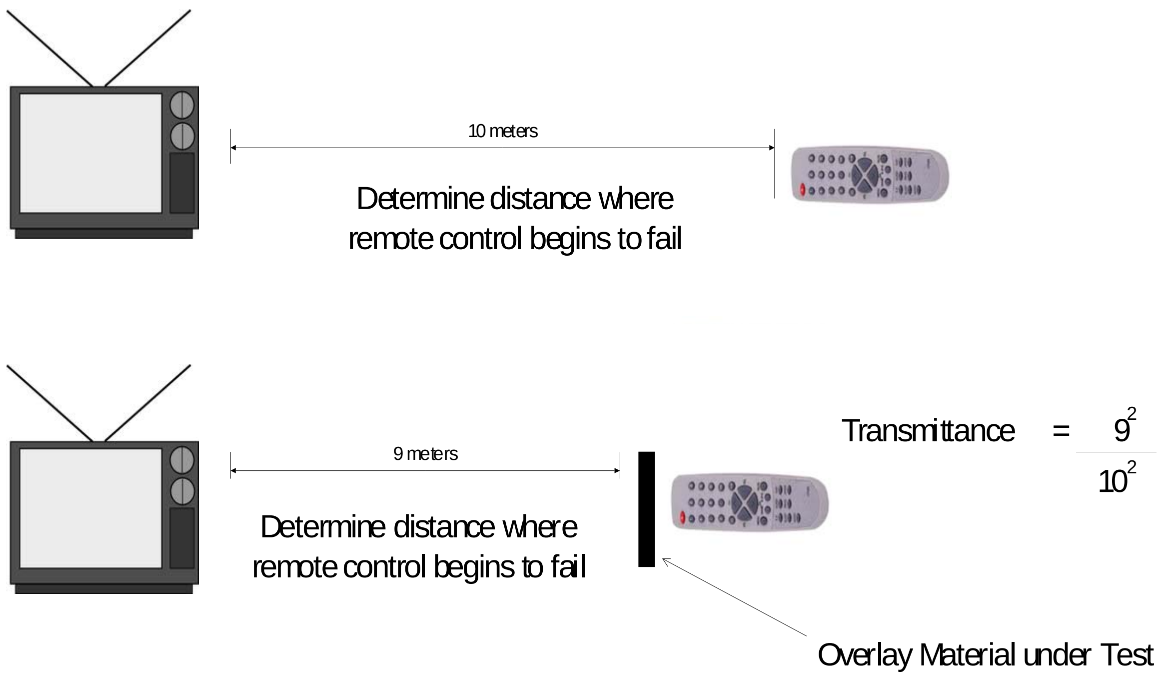



**Figure 9. Estimating Overlay Transmittance**

Once the IR transmittance is estimated, the estimate can be considered when choosing an irLED and its current. It is generally possible, with the correct choice of irLED and irLED current, for the target object to be detected despite the overlay transmittance. Refer to “AN521: irLED Selection Guide for Si114x Proximity Applications”.

In an application that also includes ALS, wavelengths in the visible light spectrum (400 nm to 700 nm) are now part of the “signal”. Better performance is achieved in any system by maximizing the signal.

Due to the typical system goal of obscuring electronics from view, there is a tendency to use an overlay that has a low transmittance of visible light. Since visible light is also part of the signal to be measured, it is no longer possible to simply use a visible-light-opaque material.

A balance must be maintained between the goals of obscuring electronics from visible sight versus allowing in sufficient light to measure the visible ambient light. In general, an overlay that allows 5% to 10% of visible light is recommended. A 5% to 10% transmittance should allow the electronics to be virtually invisible under most conditions, while still allowing sufficient light for proper ALS operation.

“AN523: Overlay Considerations for the Si114x Sensor” provides additional information in choosing an overlay. AN523 also provides the lux calculation coefficients needed for some overlays.

#### 2.3.3.2. Clear Acrylic and Polycarbonate Sheets

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:

www.eplastics.com/Plastic/
Samples;jsessionid=hv2TMsxLG1JTL9x1TGf2wJhk1TqJ6mRJgsLDXFkXyxD34yxG56nwThb5lT4LxbT9fvQbyW28gLGGBvQTFgznztlprMWT51fWTQyhDVQtJZKhJ8wybm8phTntW7TJSwlw!328655193

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 Sabic (Lexan™) and Bayer (Makrolon®).

Information on Lexan™ polycarbonate can be found here:

www.sabic-ip.com/sfs/SFS/en/Product/ProductLevel1/lexansolidsheet.html

Distributors of Lexan™ polycarbonate sheets can be found at the following web site:

www.sabic-ip.com/sfs/SFS/en/ContactUs/ContactUs/contact_us_specialtyfilmsheet.html

The following web site is a good starting point for obtaining Makrolon®:

http://plastics.bayer.com/plastics/emea/en/product/makrolon/Product_description.html

#### 2.3.3.3. Silk Screen Inks

The following inks can be used for infrared applications.

Teikoku

MRX-HF IR Transmittable Black:

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 Si114x.

Seiko Advance Ltd.

IR Black Series:

www.seikoadvance.co.jp/en/products/category/category05.php

Nazdar

Nazdar 6002050584 Special 84 IR

www.nazdar.com/pdf/6002050584-Special-IR-84-Transmitting-Black_Rev-1-00.pdf

#### 2.3.3.4. Colored Overlays

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.

In general, 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.

Although it is convenient to lump together "transmittance" in a single number, actual transmittance vs. spectral curve is far from linear. 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. In Figure 9, 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. Table 1 illustrates how the numbers are affected by an exponential relationship.

**Table 1. Transmittance vs Thickness Illustration**

| Unit Thickness Transmittance | 2 x Unit Thickness Transmittance |
|---|---|
| 10% | 1% (10% x 10%) |
| 99% | 98% (99% x 99%) |

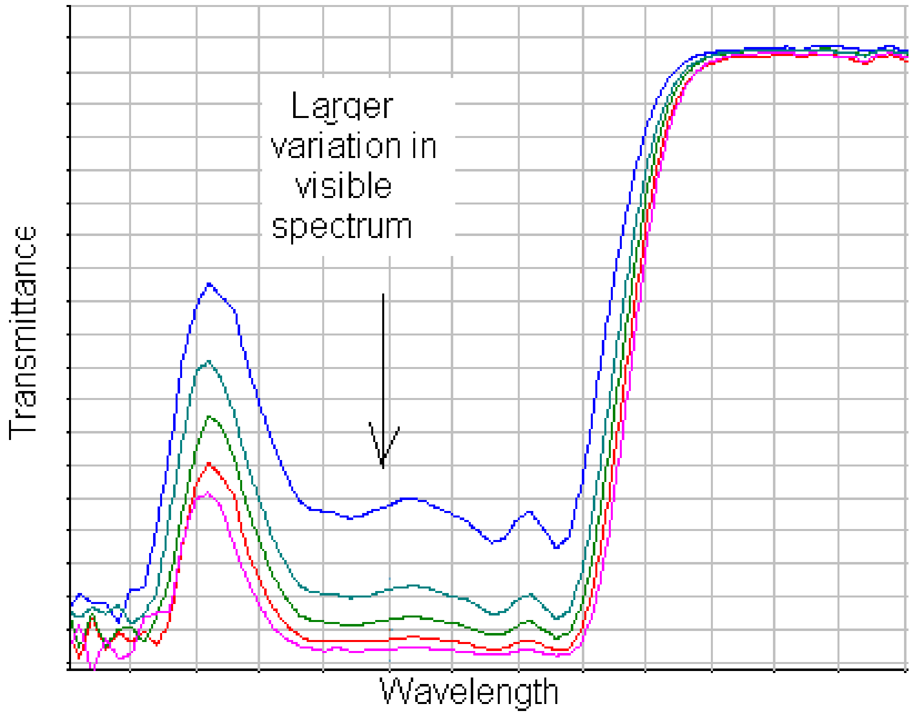



**Figure 10. Transmittance vs. Thickness Spectral Graph**

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.

Acrylic colored overlay samples:

www.eplastics.com/Plastic/Samples;jsessionid=hv2TMsxLG1JTL9x1TGf2wJhk1TqJ6mRJgsLDXFkXyxD34yxG56nwThb5lT4LxbT9fvQbyW28gLGGBvQTFgznztlprMWT51fWTQyhDVQtJZKhJ8wybm8phTntW7TJSwlw!328655193

Makrolon color chip samples (requires registration)

https://www.competenceincolor.com/ChipRequest?channel_id=27

Lexan color chip samples (requires registration)

https://www.sabic-ip.com/cxp/ColorXPress

## 2.4. Photodiode Locations, Apertures, and View Angles

The photodiodes locations are shown in Figure 11. It is generally accepted that these photodiodes are treated as a single strip for layout and mechanical design considerations.

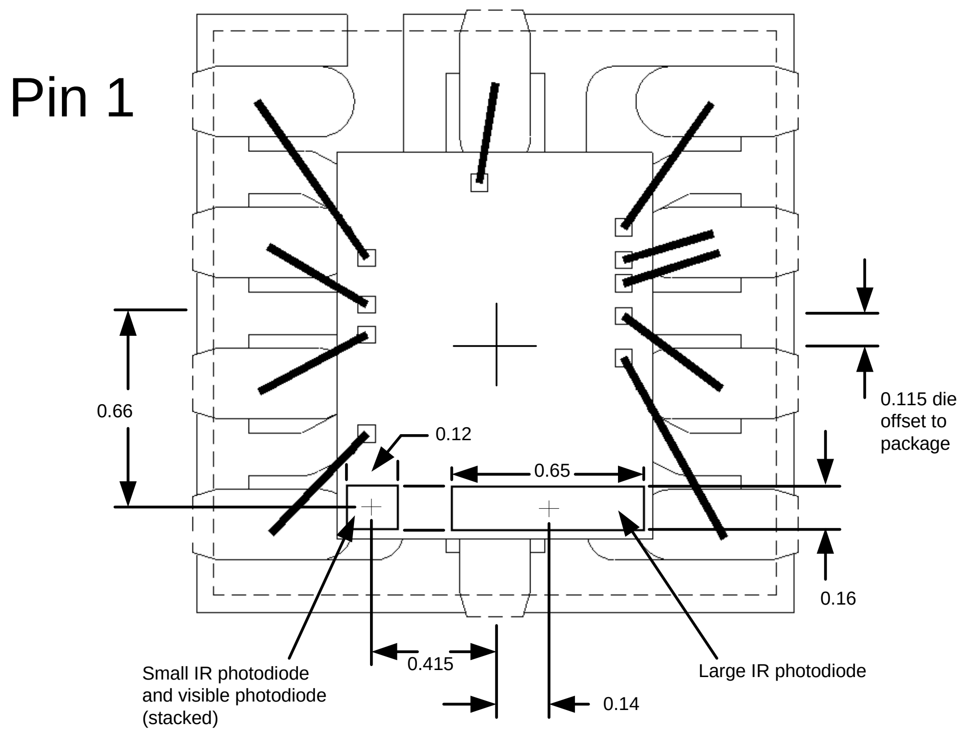



**Figure 11. Si114x Photodiode Centers**

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 Si114x 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”.

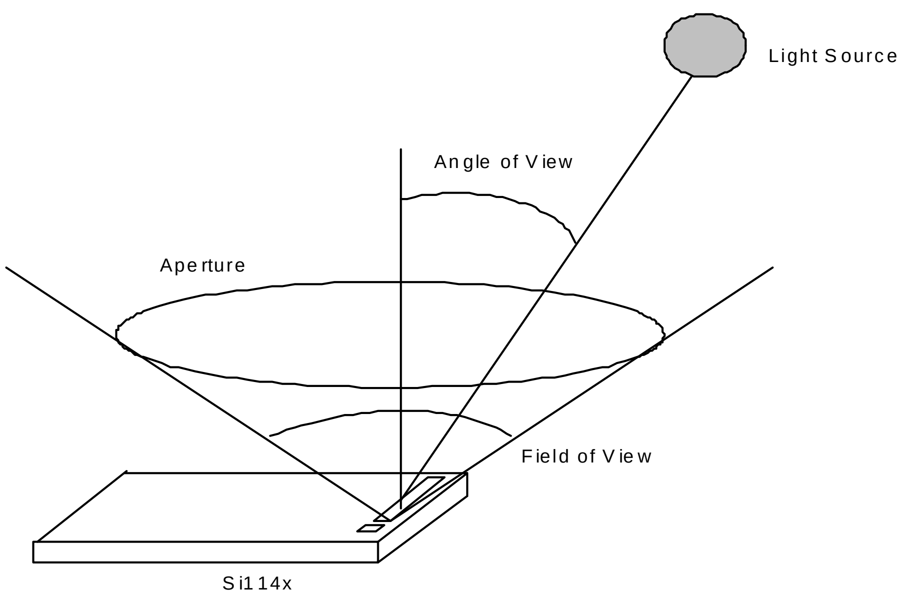



**Figure 12. Aperture, Field of View and View Angle**

The radiant power that falls on the photodiode is a function of the angle of view. The number of ADC codes reported by the Si114x 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.

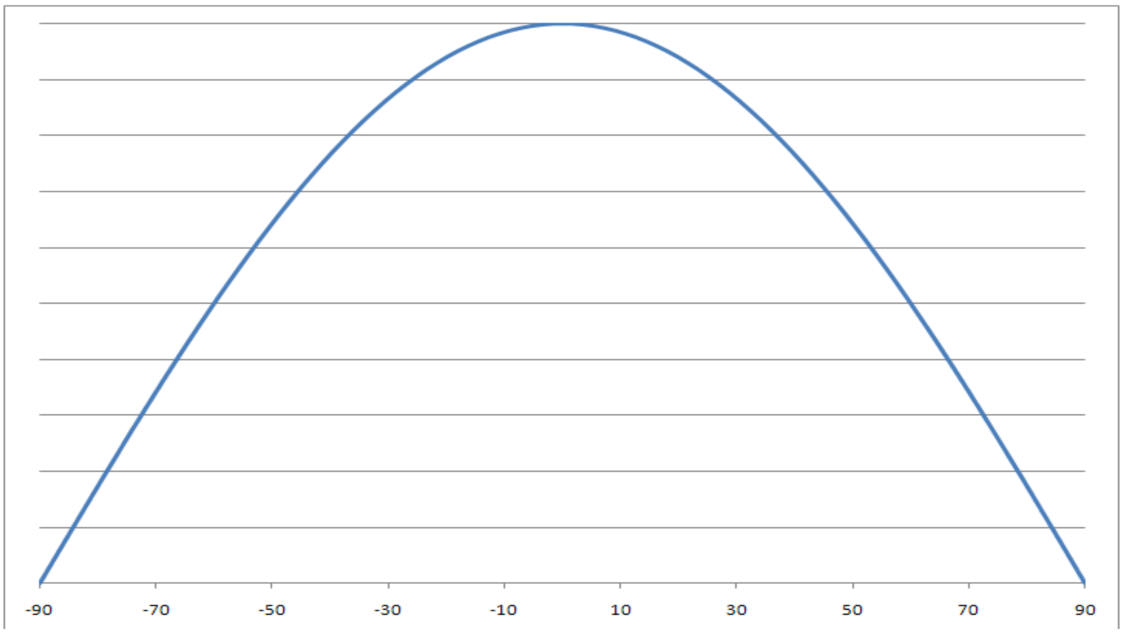



**Figure 13. ADC Reading of Equidistant Point Light Source vs. Angle of View**

When the light source is an infinite distributed surface, the relationship of the field of view versus the total available reading is shown on Table 2.

**Table 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 Si114x 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 Si114x 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 Si114x. By increasing the aperture, the greatest amount of light can enter the Si114x, and less light needs to be thrown at the target object, leading to a more efficient design.

## 2.5. Close Range Application with Single-Port Topology

This section applies 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.

### 2.5.1. IrLED Choice

The irLED chosen for this must have a half-angle of 22° or less. As described in "2.3. Optical/Mechanical Components" on page 5, 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 Si114x 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°.

### 2.5.2. Si1141 Orientation

It is best to orient the Si1141 so that the distance between the irLED and the photodiodes is maximized. Pin 1, Pin 10, and Pin 9 should face the irLED. The worst orientation is facing Pins 4, 5, and 6 towards the irLED. Using this orientation allows the furthest distance between the irLED and the Si1141 photodiodes leading to the least optical leakage.

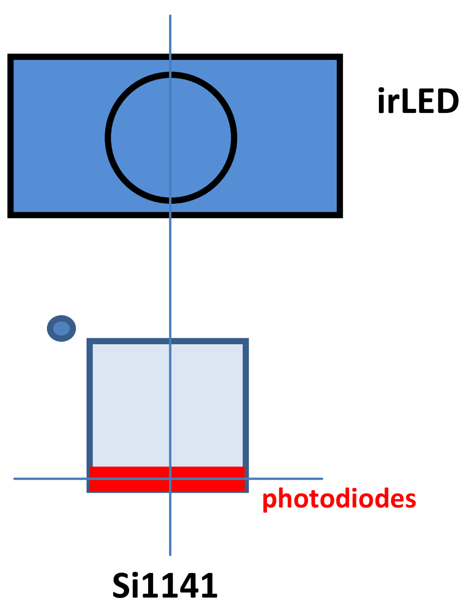



**Figure 14. Si1141 Orientation**

### 2.5.3. 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.

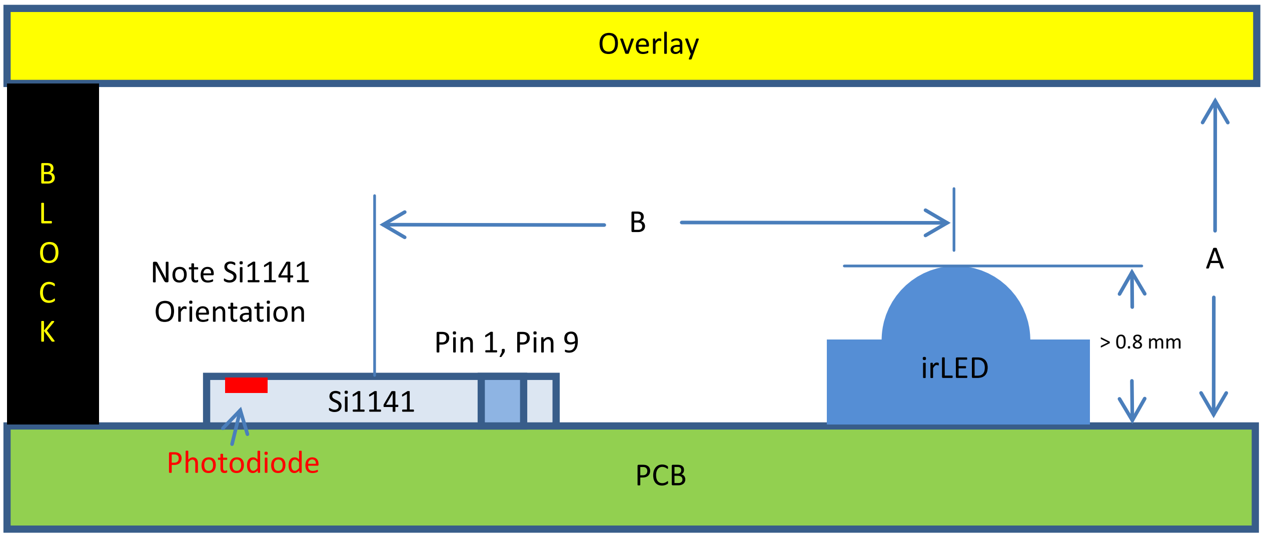



**Figure 15. Si1141 Single Port Reference Drawing**

**Table 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 Si1141 should be oriented so that pins 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 Si1141 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.

### 2.5.4. Partial Optical Block

If the dimensions in Table 3 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 Si1141 be traced, and these rays should be blocked.

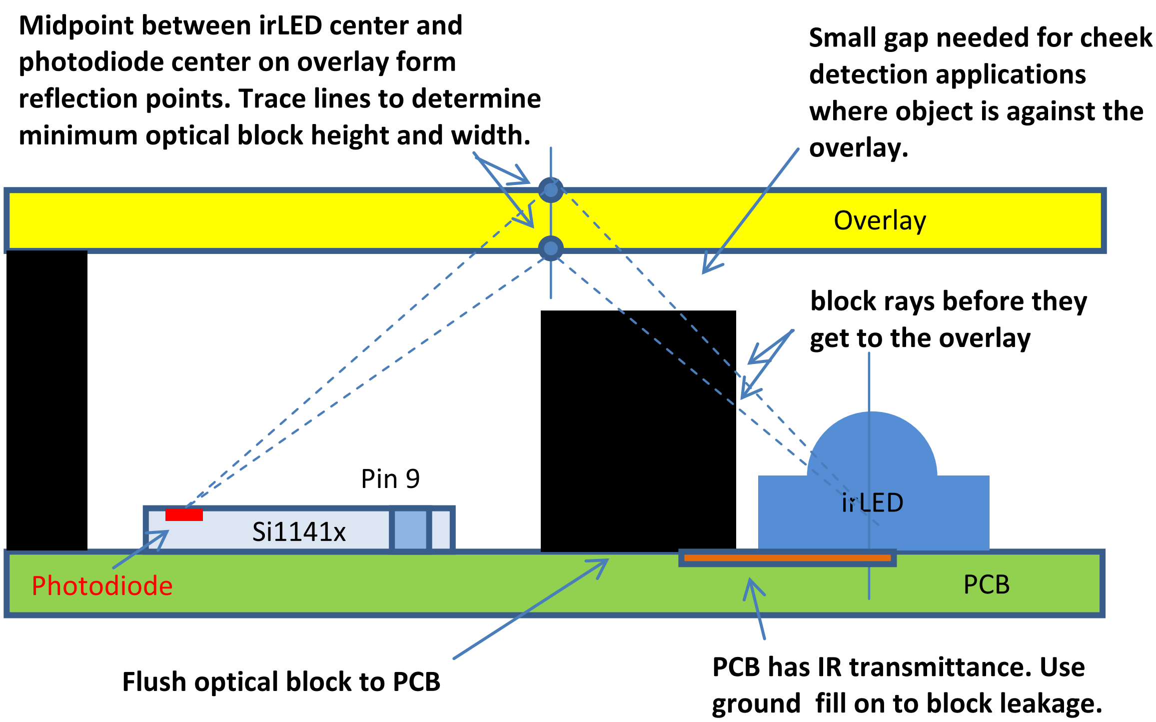



**Figure 16. Partial Optical Blocking**

### 2.6. Long Range Applications

If the target is small or far away, the Si1141 may need to operate at a higher ADC sensitivity setting. This is accomplished through increasing the PS_ADC_GAIN setting. When increasing the PS_ADC_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 PS_ADC_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 "2.4. Photodiode Locations, Apertures, and View Angles" on page 12)
2. Limiting field of view by using Lenses
3. Using special overlays, such as a Visible Light Blocking Overlay (Longpass 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.

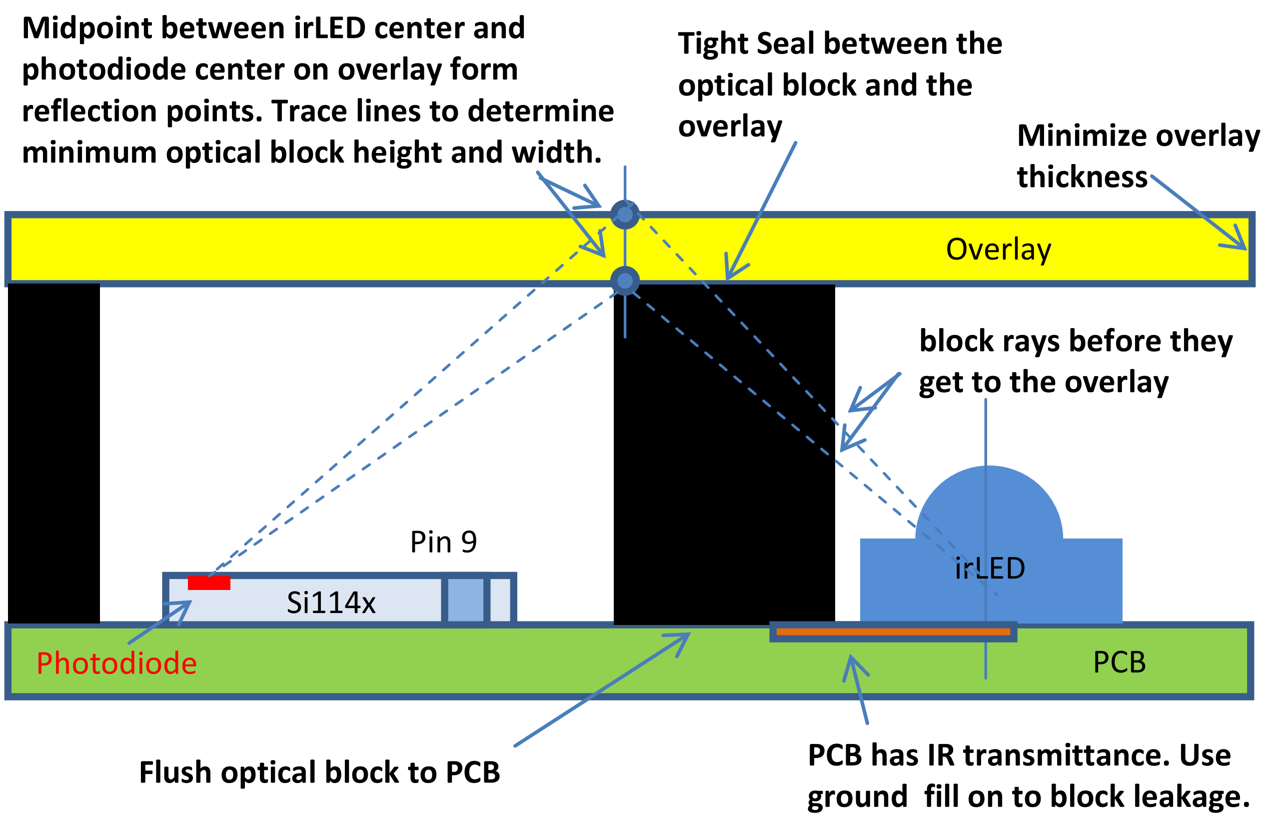



**Figure 17. Long Range Application using Hybrid Topology (Optical Blocking)**

## 2.7. 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 ("2.4. Photodiode Locations, Apertures, and View Angles" on page 12).
- Optical Blocking is needed (Figure 20 on page 21).
- Overlay IR transmittance should be maximized for best performance.
- irLED recommendations are in “AN521: IR LED Selection Guide for Si114x Proximity Applications”.

Whether this is for an Si1142 or Si1143, avoid placing an irLED on the side nearest the photodiodes. Figure 18 illustrates where the components should be placed.

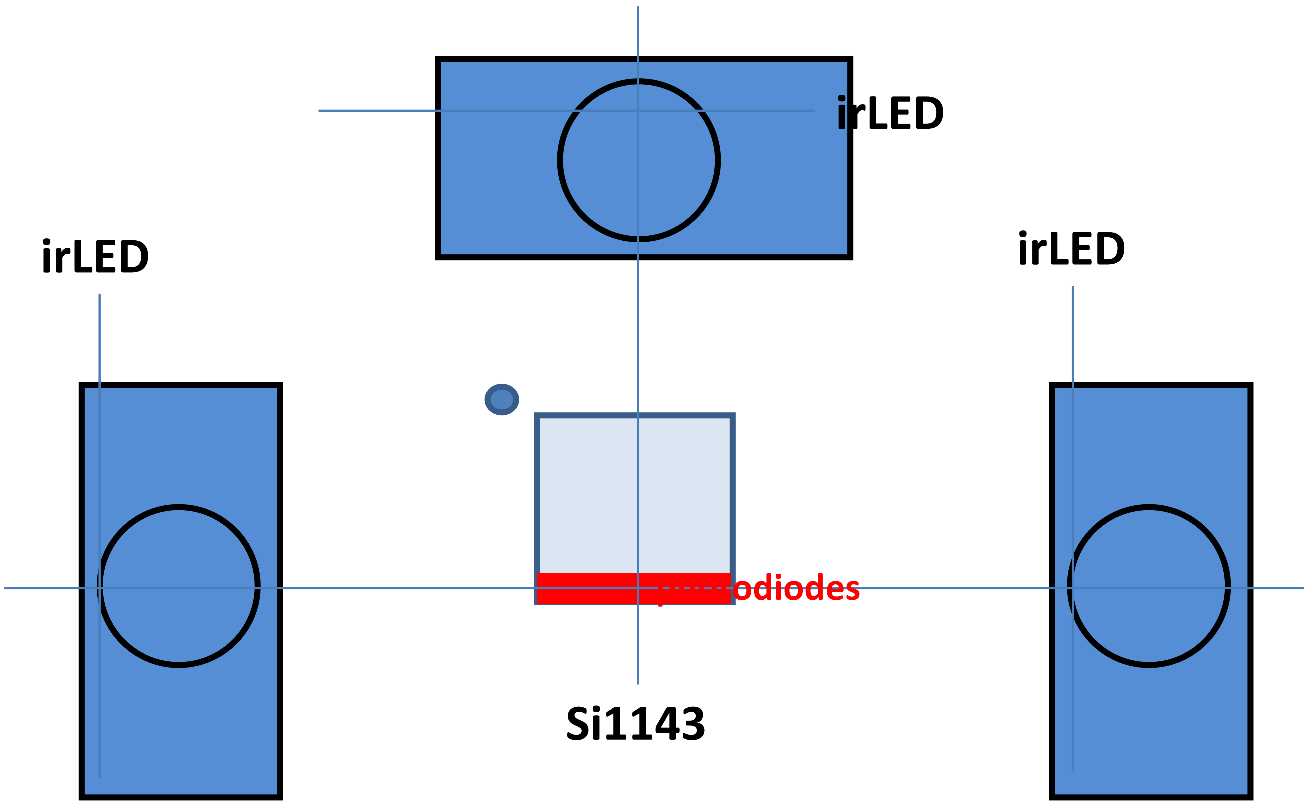



**Figure 18. Si1143 Placement**

# 3. Electrical Component Selection

## 3.1. Typical Application Schematic Diagrams

Schematic Diagrams for the Si1141, Si1142, and Si1143 are shown in Figures 19 through 21.

Figure 1a shows a schematic of the Si1143, with both VDD and the $V_{LED}$ rail at 3.3 V. Figure 1b shows a split-rail design where the VDD is at 3.3 V, while the $V_{LED}$ rail is at 4.3 V.

Figure 2a shows a schematic of the Si1142, with both VDD and the $V_{LED}$ rail at 3.3 V. Figure 2b shows a split-rail design where the VDD is at 3.3 V, while the $V_{LED}$ rail is at 4.3 V.

Figure 3a shows a schematic of the Si1141, with both VDD and the $V_{LED}$ rail at 3.3 V. Figure 3b shows a split-rail design where the VDD is at 3.3 V, while the $V_{LED}$ rail is at 4.3 V.

In Figures 19 through 21, the component choices for the capacitor and resistor shown in these schematics assume the following:

- PS_ADC_GAIN = 0 (25.6 µs irLED pulse width)
- PS_LEDn = 1111 irLED current setting for each channel (359 mA typical)
- 100 Hz maximum sample rate (one proximity measurement for each channel every 10 ms)
- irLED $V_F$ = 2.2 V at 360 mA (Osram SFH 4056 for example)
- Minimizing instantaneous current draw is a system design goal.

For most applications, one of the schematic diagrams in Figures 19, 20, or 21 should be used.

Refer to "3.4. LED Drive Circuit" on page 24 for customizing the irLED drive circuit components.

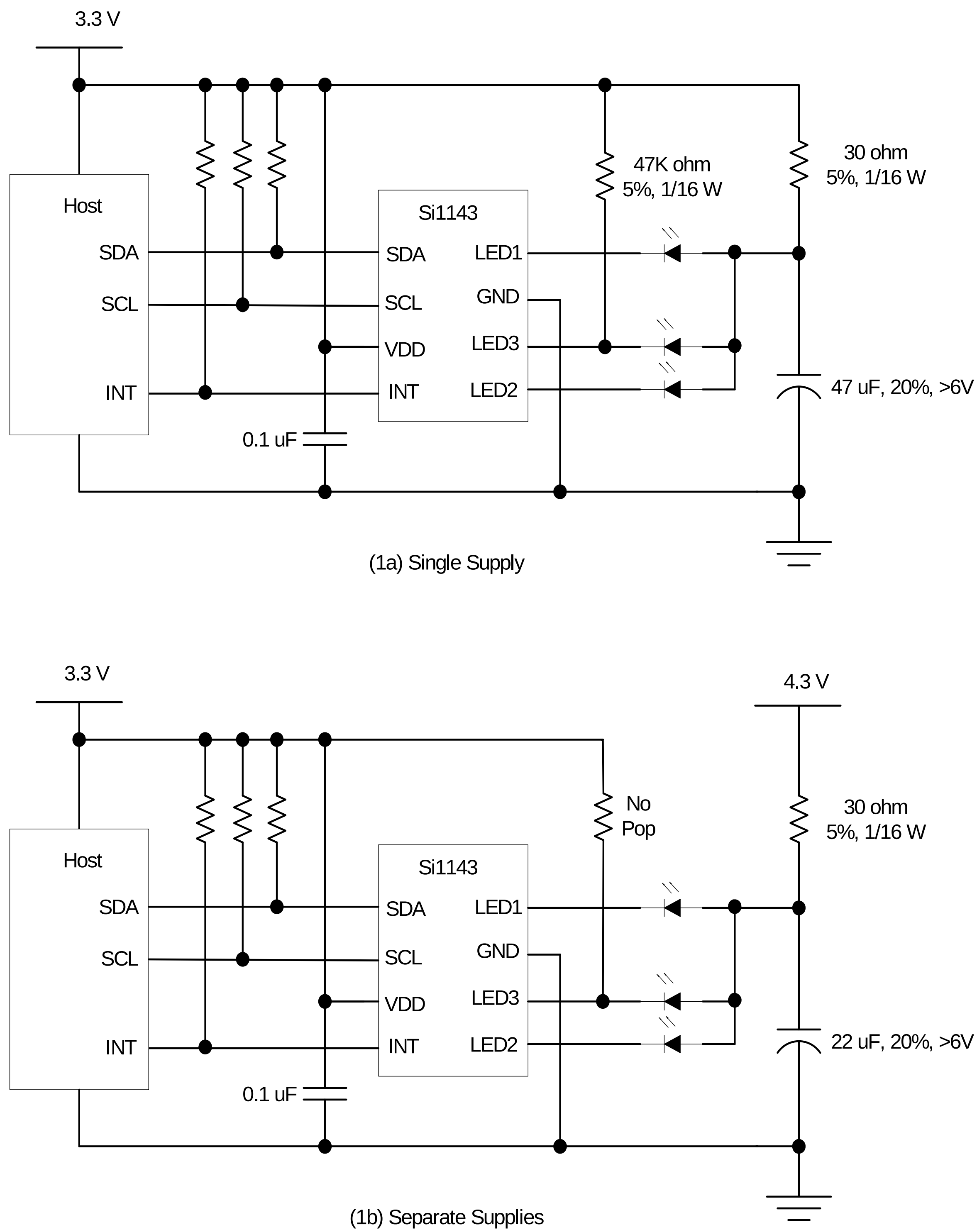



**Figure 19. Si1143 Schematic Diagrams**

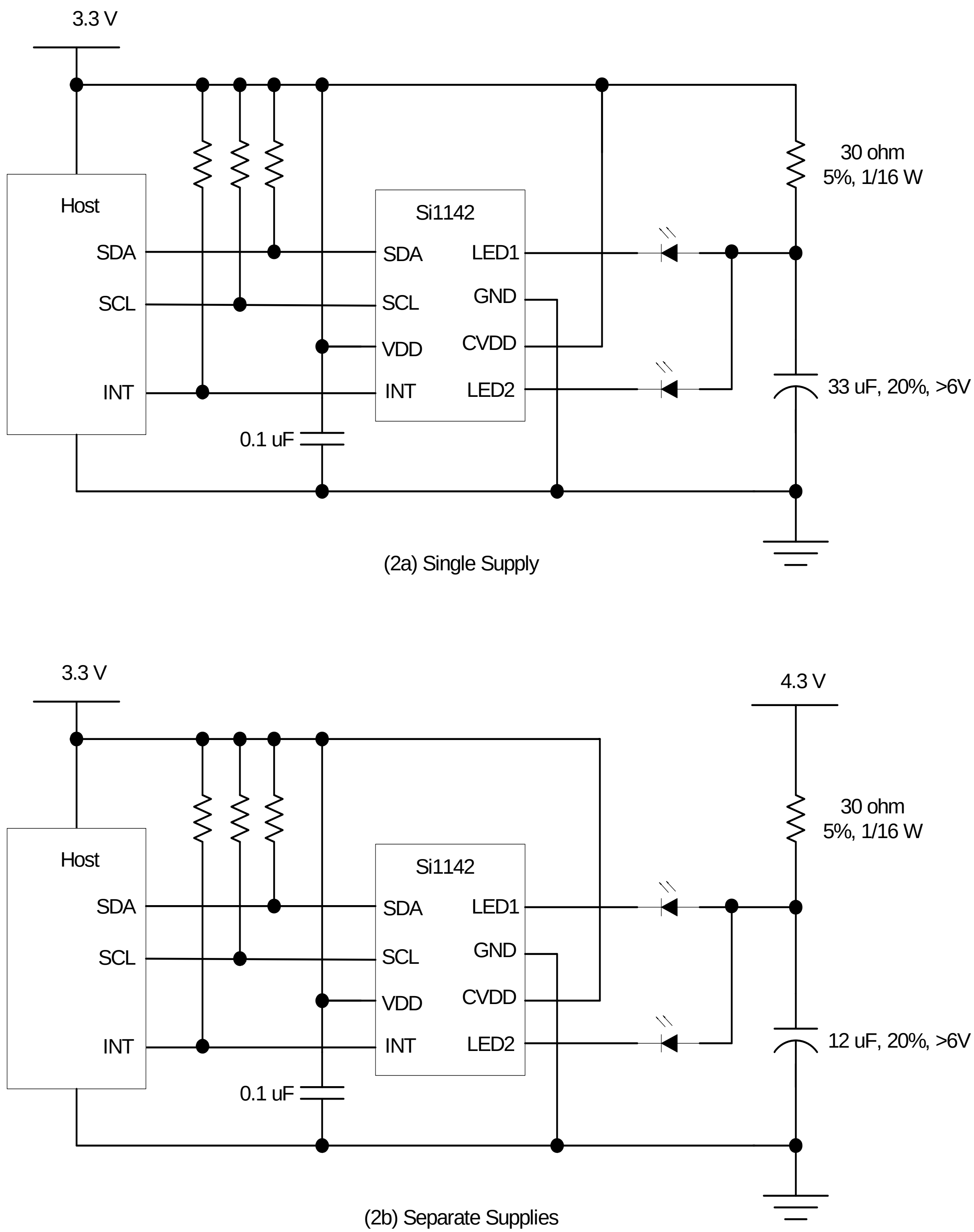
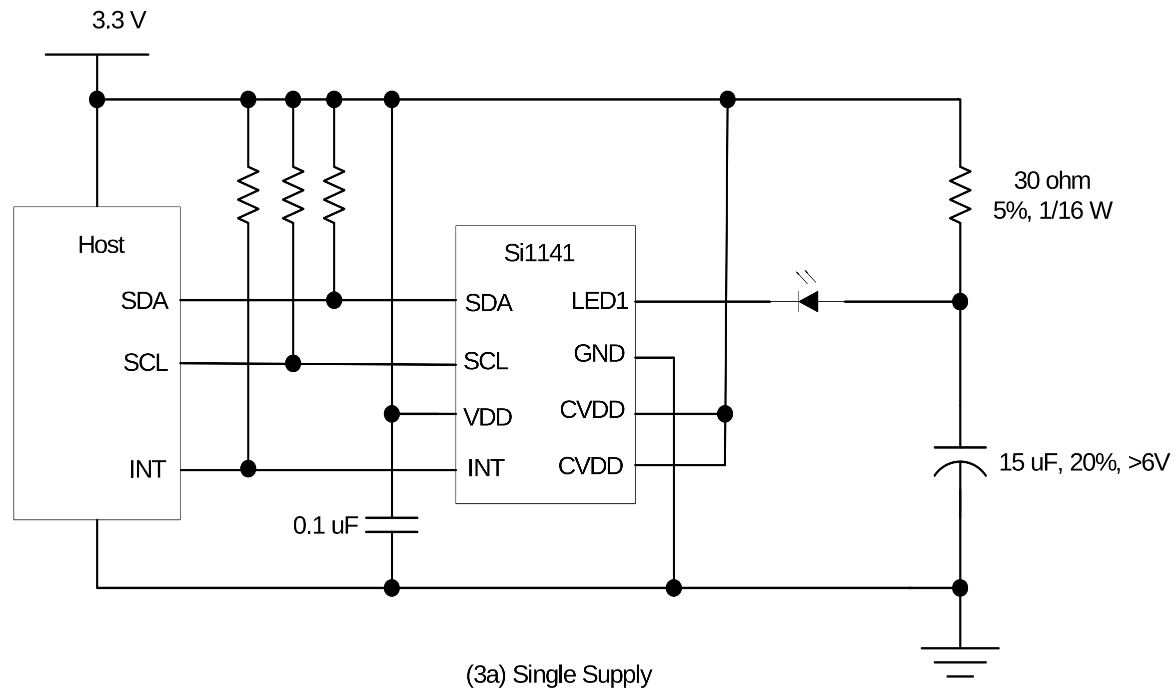
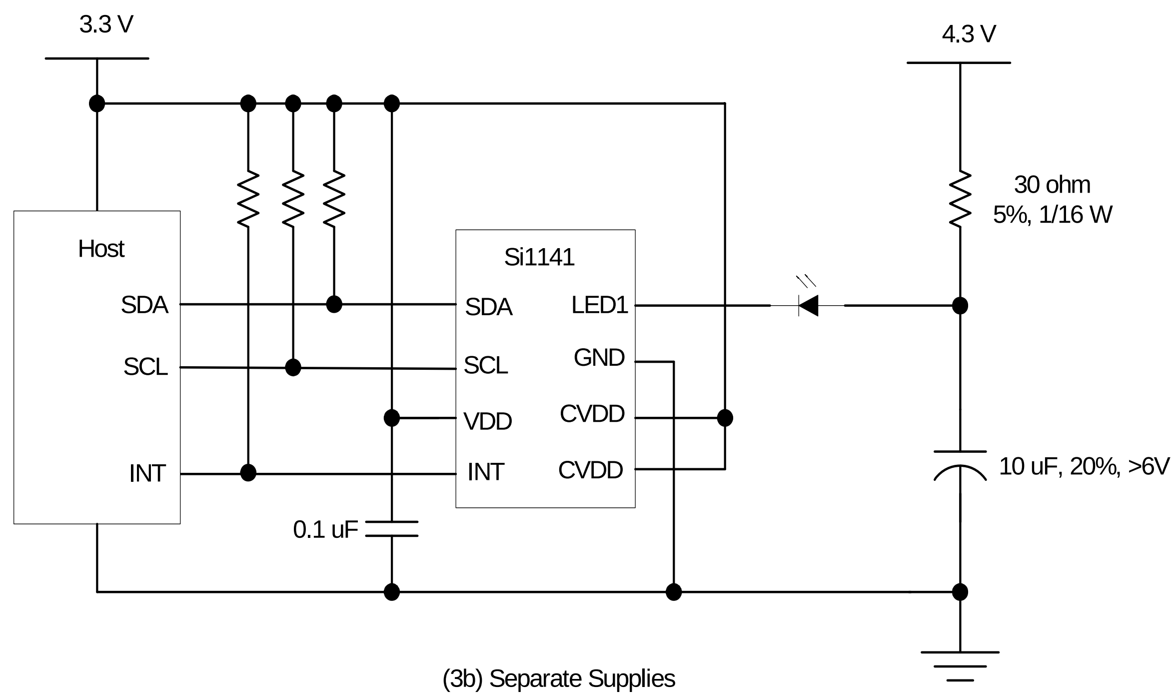



**Figure 20. Si1142 Schematic Diagrams**




(3a) Single Supply




(3b) Separate Supplies

**Figure 21. Si1141 Schematic Diagrams**

### 3.2. Mandatory LED3 Pull-Up Resistor

This section applies to the 47 kΩ pull-up resistor from the LED3 pin to VDD. Refer to Figure 19.

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 Si1143 does not come out of reset.

Functionally, the Si1142 and Si1141 are similar to the Si1143 concerning this pin. However, on the Si1141 and Si1142, the LED3 pin has been renamed “CVDD”. For the Si1142 and Si1143, the CVDD pin must already be externally connected to VDD.

In Figure 1b, note that the LED3 Pull-up resistor is designated as a “no population” option. The reason for this is that most irLED will have a forward voltage of 0.5 V when not actively driven. If the $V_{LED}$ rail is at 4.3 V as shown in the schematic, the VDD is effectively pulled up to the VDD rail, ensuring proper operation.

To determine if the resistor is needed, it is necessary to calculate the difference between the $V_{LED}$ 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 Si1143 LED3 pin ceases to have the test pin function once the HW_KEY register is written.

The following symptoms can occur when the LED3 pin or the CVDD 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.

### 3.3. Mandatory INT Pull-up Resistor

The INT pin must have a pull-up resistor. A typical pull-up resistor value of 4.7 kΩ is recommended. Even if the INT function is not used, the INT Pull-up resistor *must* be present.

The INT pin is used during boot-up to determine if the device is allowed to go to sleep or not. If the INT pin is low during reset, the Si114x does not go to sleep, thereby drawing more current from the VDD rail.

The device may or may not work as expected if the INT pin has no pull-up. If the system has a robust power system, the device may work.

The following symptoms can occur if the INT Pull-up Resistor is not present:

- The device will operate normally but may suddenly reset if the system is unable to handle the unexpected current draw. This is especially true for systems with a common VDD and $V_{LED}$ rail.
- If the system is not expecting the higher current draw, non-deterministic behavior can occur.

## 3.4. 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.

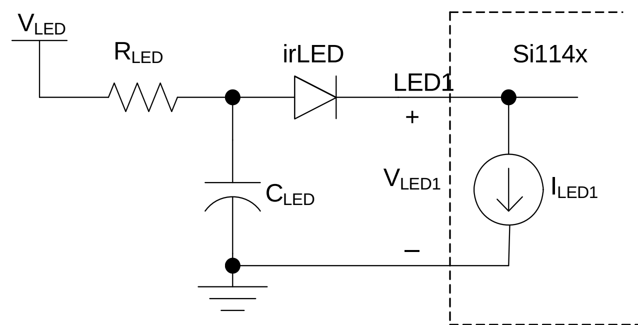



**Figure 22. irLED Reference Circuit**

## 3.5. Selecting $V_{LED}$ Voltage Rail

The irLED circuit can be powered from either the same VDD used to power the Si114x, 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 400 mA for 25.6 µs instantaneously without bringing the system voltage rail down.

Using an unregulated supply introduces the least amount of supply ripple through the entire system. When drawing current from an unregulated supply, 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.

## 3.6. Selecting $C_{LED}$

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

$$C_{LED} = \frac{\text{Number of LEDs} \times \text{Max ir LED Current} \times 25.6\ \mu s \times 2^{(PS\_ADC\_GAIN)}}{V_{LED} - V_F - 0.5}$$

The Si1143 contains three proximity channels and makes three measurements before going back to sleep. Since these three 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 PS_ADC_GAIN is zero. $2^0$ is 1.

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

$$C_{LED} = \frac{3 \times 360\ \text{mA} \times 25.6\ \mu s \times 2^0}{4.3 - 2.2 - 0.5} = 17.28\ \mu F \text{ -> round to } 22\ \mu F$$

This means that, if $C_{LED}$ is 17.28 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 25.6 µs period when the irLEDs are being driven.

## 3.7. 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.

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

Assuming $C_{LED}$ is greater than or equal to the calculation in Section 1.3.1.2

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:

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

Assuming $C_{LED}$ is greater than or equal to the calculation in Section 1.3.1.2

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.

## 3.8. irLED Electrical Considerations

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

The Si114x 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 Si114x pulses the irLED for 25.6 µs. However, this pulse width is host-programmable through PS_ADC_GAIN and can be much higher.

# 4. Proximity Measurements

## 4.1. Ambient IR, Optical Leakage, Target Reflectance

This section intends to provide an illustration of "what" is being measured in a proximity channel. In a proximity measurement, the Si114x actually makes two separate measurements back-to-back.

The first measurement is done without the irLED being turned on. When this happens, the Si114x 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 Si114x. This direct coupling is called "Optical Leakage" or "Crosstalk".

The two measurements made are done within 25.6 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 Si114x performs the subtraction between these two measurements and reports this difference measurement onto the output registers. Refer to Figure 23 for an illustration. As indicated in Figure 23, the reported measurement contains both the "target reflectance" and "optical leakage".

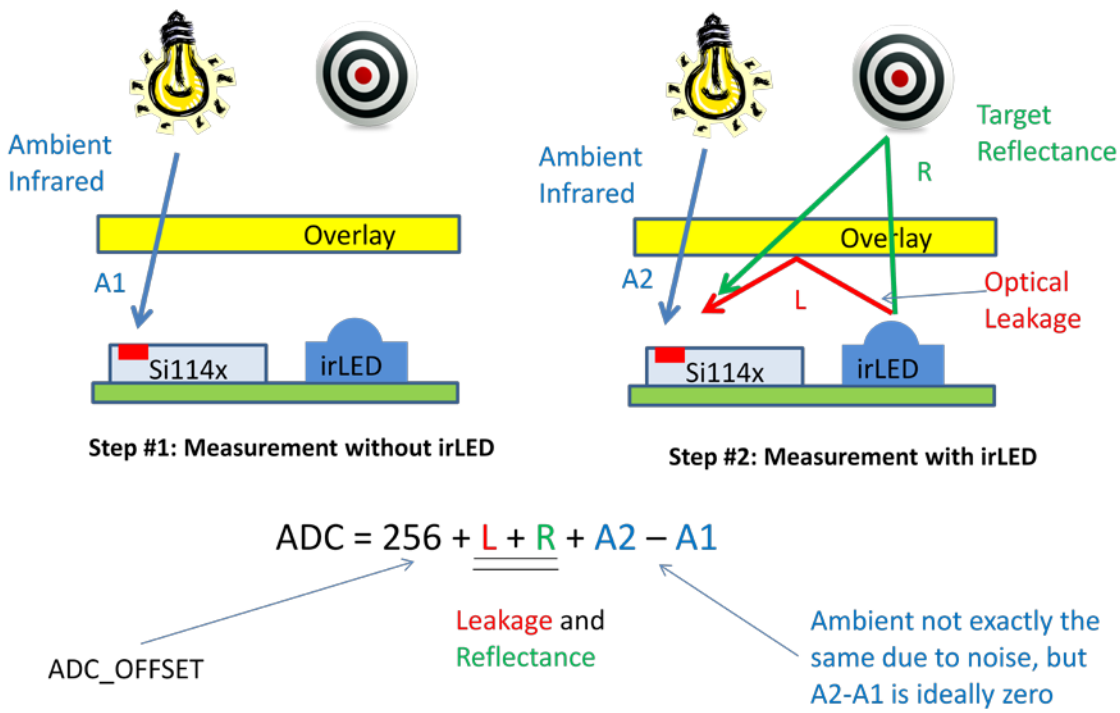



**Figure 23. Proximity Measurement Concept**

## 4.2. Proximity Baselining

As stated in the previous section, the proximity measurement represents the Optical Leakage plus in addition to 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.

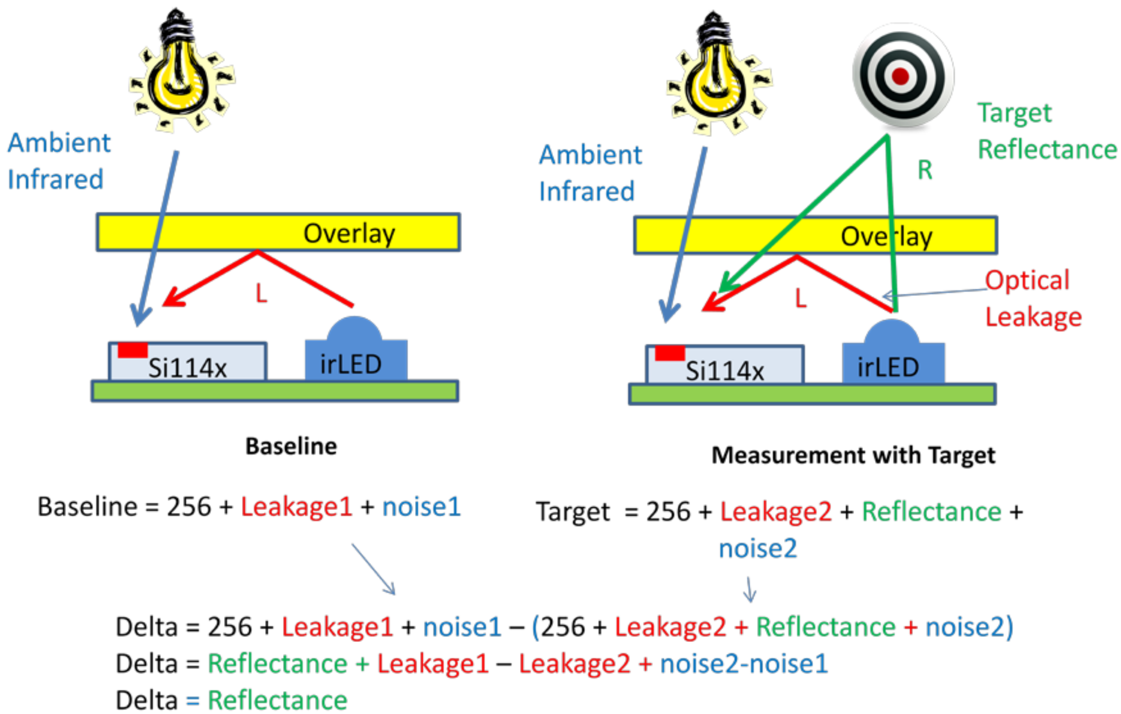



**Figure 24. Proximity Baselining Concept**

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 operates 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.

## 4.3. Notes on Associating LED Drives with Proximity Measurements

By default, the PS1 Channel is associated with a proximity measurement while the irLED connected to LED1 pin is driven. The same is true for the PS2 Channel (drives LED2) and the PS3 Channel (drives LED3).

Conceptually, the “PS1 Channel” and the LED1 Drive are separate concepts even though they are typically associated with one another.

To illustrate, it is possible for the PS1 Channel to drive the LED2 Drive or even the LED3. In fact, it is even possible for the PS1 Channel to drive all three LED3 drives as long as the total current does not exceed the limits listed in Table 1 of the Si114x Data Sheet.

Driving multiple LED drives is one method of increasing the amount of light thrown out for reflectance. The effect is additive.

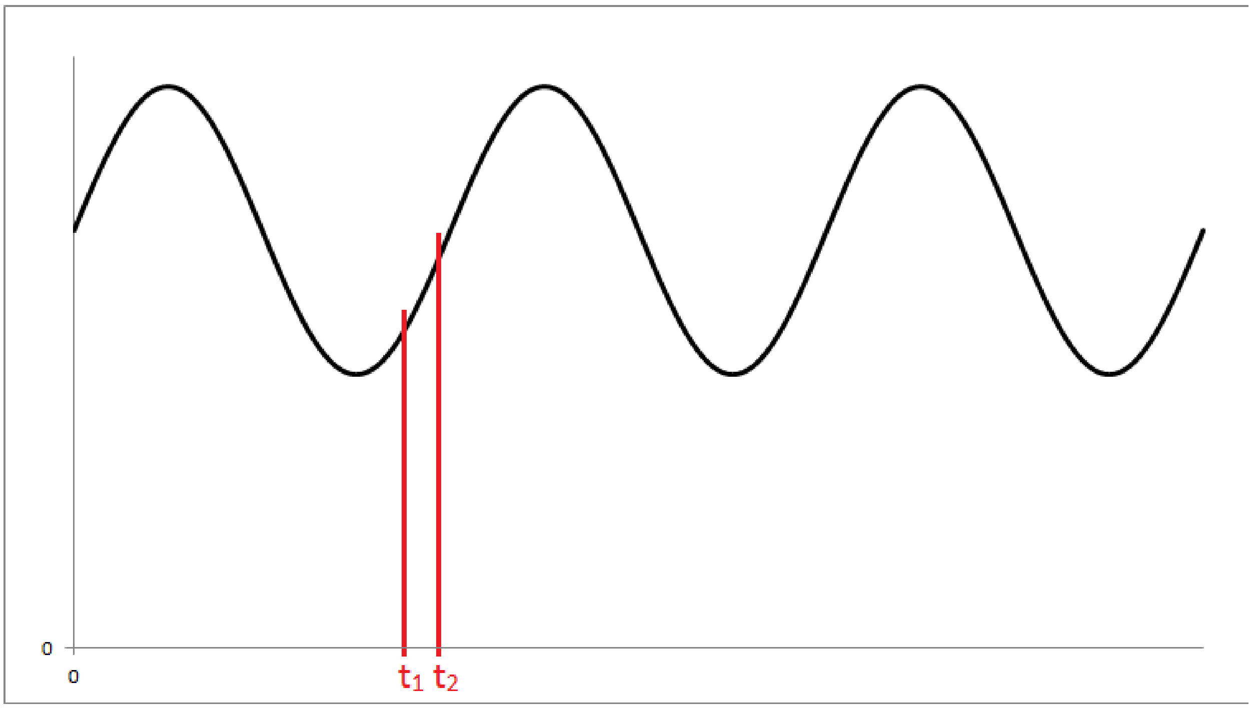
In the same way, the PS2 and PS3 channels have access to all LED drives. The sequence of measurement is fixed. The PS1 channel is always done first, and the PS3 channel is always be done last.

### 4.4. Minimizing the Effect of Ambient-Light Ripple

During proximity detection, the Si114x 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 120Hz, 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.




If the off and on measurements are made at $t_1$ and $t_2$ 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 $t_1$ and $t_2$, 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 PS_ADC_GAIN), which makes the measurement time proportional to the gain. Best results are obtained with a gain of 1 or 2 (PS_ADC_GAIN = 0 or 1). Additional sensitivity may be obtained by setting PS_RANGE to 0 and selecting the large photodiode for proximity. Refer to Table 10 for combinations of PS_ADC_GAIN, PS_RANGE, and photodiode selection versus ambient-light operating range. While Table 9 helps prioritize gain settings for minimizing ADC noise, ambient-ripple noise is best minimized by selecting lower gain settings, as when minimizing power consumption. Therefore, Table 10 is more relevant than Table 9 if ambient-light ripple noise is the dominant noise factor.

Proximity error caused by ambient-light ripple also depends on the recovery time between measurements, set by IR_ADC_REC. Minimizing the recovery time below the recommended default value (see Table 5, “Recommended Proximity Recovery Times,” on page 41) can reduce the ripple noise, but can also increase ADC noise. That may or may not be advantageous, depending on whether ripple noise or ADC noise is dominant in a particular system.

The online IR Range Estimator tool can help model which kind of noise is dominant, depending on settings. For more details, refer to Section "8. Putting It All Together with the Range Estimator Web Tool" on page 45.

If all three Si114x proximity channels are available and only one proximity measurement is needed, the other two channels may be used for precise error correction in combination with the above steps. The graph below illustrates the correction algorithm:


Channel assignments are made thus:

| Channel | LED Current Setting | Time | LED | Function |
|---|---|---|---|---|
| PS1 | 0 mA | $t_1$ | Off | Ambient light |
| | | $t_2$ | Off | Ambient-light change before proximity |
| PS2 | As required | $t_3$ | Off | Ambient-light first-order correction |
| | | $t_4$ | **On** | Proximity |
| PS3 | 0 mA | $t_5$ | Off | Ambient light |
| | | $t_6$ | Off | Ambient-light change after proximity |

The three results collected in the PS1, PS2, and PS3 data registers are combined thus:

Proximity = PS2 – 0.5 × ( PS1 + PS3 ).

Alternatively, if two LEDs are used to perform the same detection function, the channel arrangement can be as follows:

| Channel | LED Current Setting | Time | LED1 | LED2 | Function |
|---|---|---|---|---|---|
| PS1 | As required (LED1) | $t_1$ | Off | Off | Ambient-light first-order correction |
| | | $t_2$ | **On** | Off | Proximity for LED1 |
| PS2 | 0 mA for both LEDs | $t_3$ | Off | Off | Ambient light |
| | | $t_4$ | Off | Off | Ambient-light change between LED1 and LED2 measurements |
| PS3 | 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 × ( PS1 + PS3 ) – PS2.

If only two channels are available, a small amount of slope correction is still possible with the following arrangement:

| Channel | LED Current Setting | Time | LED | Function |
|---|---|---|---|---|
| PS1 | 0 mA | $t_1$ | Off | Ambient light |
| | | $t_2$ | Off | Ambient-light change before proximity |
| PS2 | As required | $t_3$ | Off | Ambient-light first-order correction |
| | | $t_4$ | **On** | Proximity |

In this case, the corrected proximity is PS2 – PS1. This method works for gains of 1 or 2 only (PS_ADC_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 Si114x 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.

# 5. Programming Guide

For a full description of the registers and bit fields, refer to the Si114x Data Sheet. The registers are described in the Si114x Data Sheet and are not repeated here. This guide provides additional information to the Si114x Data Sheet. The CD that comes with the evaluation kits also contains source code that can be used as a starting point.

## 5.1. 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 Si114x_defs.h. It is recommended that the symbols within the files be used so that the code is more readable.

Some functions are assumed to exist:

```
U8   ReadFromRegister(U8 reg)           returns byte from I2C Register 'reg'
void WriteToRegister(U8 reg, U8 value)  writes 'value' into I2C Register reg'
void ParamSet(U8 address, U8 value)     writes 'value' into Parameter 'address'
PsAlsForce()                            equivalent to WriteToRegister(REG_COMMAND,0x07)
                                           This forces PS and ALS measurements
```

```
// Send Hardware Key
// I2C Register 0x07 = 0x17
WriteToRegister(REG_HW_KEY, HW_KEY_VAL0);

// Initialize LED Current
// I2C Register 0x0F = 0xFF
// I2C Register 0x10 = 0x0F
WriteToRegister(REG_PS_LED21,(MAX_LED_CURRENT<<4) + MAX_LED_CURRENT);
WriteToRegister(REG_PS_LED3, MAX_LED_CURRENT);

// Parameter 0x01 = 0x37
ParamSet(PARAM_CH_LIST, ALS_IR_TASK + ALS_VIS_TASK + PS1_TASK + PS2_TASK + PS3_TASK);

// I2C Register 0x18 = 0x0x07
PsAlsForce();  // can also be written as WriteToRegister(REG_COMMAND,0x07);

// Once the measurements are completed, here is how to reconstruct them
// Note very carefully that 16-bit registers are in the 'Little Endian' byte order
// It may be more efficient to perform block I2C Reads, but this example shows
// individual reads of registers

ALS_VIS = ReadFromRegister(REG_ALS_VIS_DATA0) +
          256 * ReadFromRegister(REG_ALS_VIS_DATA1);
ALS_IR =  ReadFromRegister(REG_ALS_IR_DATA0) +
          256 * ReadFromRegister(REG_ALS_IR_DATA1);
PS1 =     ReadFromRegister(REG_PS1_DATA0) +
          256 * ReadFromRegister(REG_PS1_DATA1);
PS2 =     ReadFromRegister(REG_PS2_DATA0) +
          256 * ReadFromRegister(REG_PS2_DATA1);
PS3 =     ReadFromRegister(REG_PS3_DATA0) +
          256 * ReadFromRegister(REG_PS3_DATA1);
```

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

## 5.2. Tracking Executed Commands

As long as the Si114x has not started autonomous operation, it is possible to initiate commands without having to always poll the RESPONSE register.

This is accomplished by making use of the NOP command to clear the response counter before sending commands to the Si114x. 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 (PS_AUTO, ALS_AUTO, PSALS_AUTO), 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 SET_PARAM and other commands associated with manipulating parameters.

This allows proper Command/Response tracking to ensure that intended settings take effect. This will help avoid unusual operation if, for any reason, the setting was not received by the Si114x. 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:

```
void pauseMeasurement(void)
{
   if (measurementPaused)
      return;

   WriteToRegister(REG_IRQ_CFG, 0);            // tri-states INT pin
                                               // to stop any Si114x interrupts
   // Need to make sure the machine is paused
   // the error condition in response register is asynchronous
   while (1)
   {
      // Keep sending nops until the response is zero
      while (1)
      {
         if ( GetResponse() == 0)
            break;
         else
            Nop();
      }

      // Pause the device
      PsAlsPause();

      // Wait for response
      while(1)
      {
        if (GetResponse() != 0)
           break;
      }

      // When the PsAlsPause() 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 below.

```
void resumeMeasurement(void)
{
   if (!measurementPaused)
      return;

   ClearIrqStatus(IE_ALL);
   WriteToRegister(REG_IRQ_CFG, ICG_INTOE);    // re-enables INT pin
   PsAlsAuto();
   measurementPaused = 0;
}
```

### 5.3. Resetting the Si114x

The Si114x has an internal microcontroller. When the Si114x receives a reset command from the host (The $I^2C$ Command Register is written with 0x01), the Si114x controller initiates an internal hardware reset.

This reset command is intended to place the Si114x in its hardware reset state. It is not a software reset. If the reset command is initiated, prior initialization steps need to be repeated.

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 Si114x 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 Si114x is unaware of this event. Therefore, if the Si114x is already performing autonomous measurements, the Si114x 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 Si114x is already performing autonomous measurements from a prior context. Therefore, the example code in the Si114x Evaluation Systems generally shows a reset sequence performed at the very beginning of an Si114x initialization sequence. If both the Si114x 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 an Si114x 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 Si114x reset command would be nullified.

### 5.4. Compression Concept

Many of the registers and parameters accept or return a “compressed value”. The interface to the Si114x for these registers or parameters is an 8-bit value that becomes a 16-bit value when uncompressed by the Si114x.

The source code for the compress and uncompress functions is available in the Silicon Labs Evaluation System Kits. It is recommended that the function be reused. This section attempts to explain what this compression concept is by going through some examples. Although the uncompress() source code is available, this is for documentation purposes and shows how the Si114x performs the uncompression.

There is information loss that occurs through the compression process. However, the error is less than 3% of the intended 16-bit value.

Figure 25 shows how a compressed 0xAC becomes an uncompressed 0x0700

Figure 26 shows how a compressed 0x08 becomes an uncompressed 0x0001

Figure 27 shows how a value of 0x0700 compresses into 0xAC

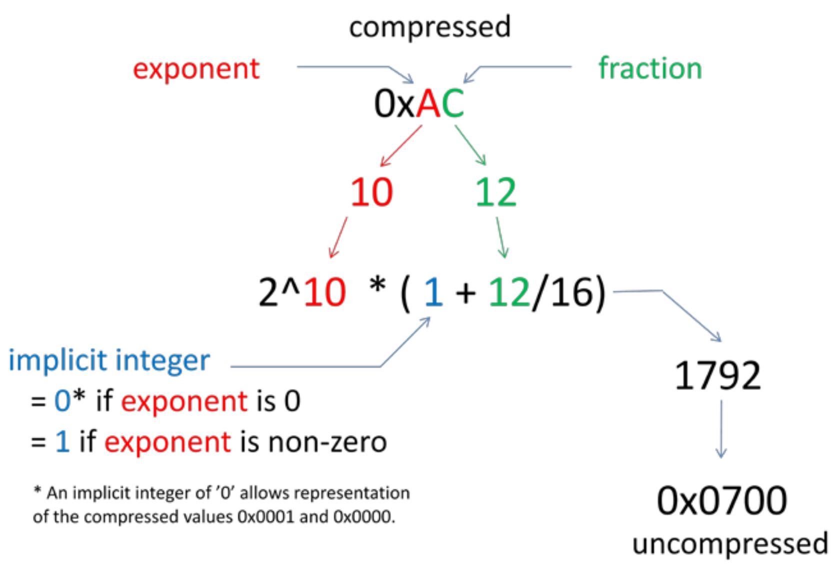



**Figure 25. Example 8→16-Bit Compression**

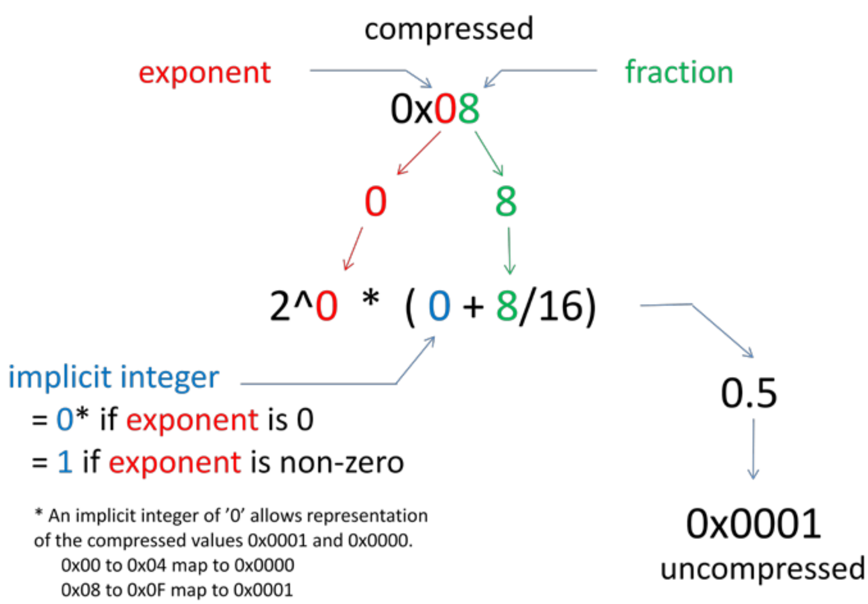



**Figure 26. Example 8→16-Bit Compression of "0x0001"**

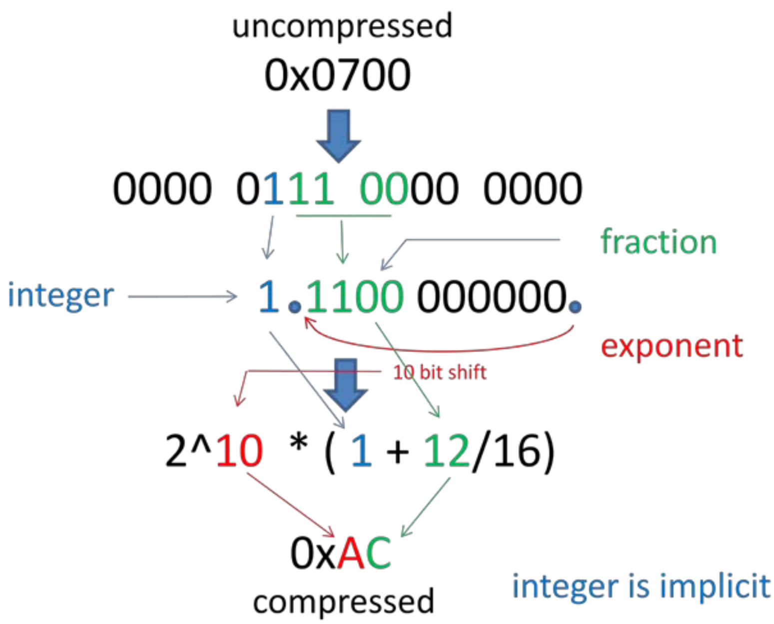



**Figure 27. Example 16→8-Bit Uncompression Example**

## 5.5. MEAS_RATE, PS_RATE and ALS_RATE

The MEAS_RATE register is an 8-bit compressed byte. The uncompressed 16-bit value represents the number of 32 kHz clock ticks before the device wakes up.

Once the Si114x wakes up, it determines whether or not it is time to perform a group of proximity measurements, if it is time to perform a group of ambient measurements, or if it is time to perform both.

The PS_RATE is an 8-bit compressed byte. The uncompressed 16-bit value it represents is the number of times the device wakes up before making a measurement. If PS_RATE is zero, no proximity measurements are made. If the uncompressed value of PS_RATE represents the value, 0x0001, then proximity measurements are made every time the Si114x wakes up from sleep.

In the same way, the uncompressed 16-bit value that ALS_RATE represents is the number of times the device should wake up before making a measurement. For example, if the uncompressed ALS_RATE value is 0x0004, this means that the ambient light measurements are performed only once every four times the device wakes up.

In general, proximity measurements are made every time the device wakes up. If not, then there is some power usage. However, the maximum wake-up time period possible with the MEAS_RATE is around 1.9 seconds. If the desire is to have a proximity measurement performed every 10 seconds, it can be supported by a PS_RATE value greater than one.

Example: Assume that proximity measurements are to be performed at a frequency of 100 Hz and that ambient measurements are to be performed once every second (1 Hz).

```
MeasRateHz = 100;     // 100 Hz
PSRateHz = 100;       // 100 Hz
ALSRateHz = 1;        // 1 Hz

WriteToRegister(MEAS_RATE, compress( 32000/MeasRateHz)  );
WriteToRegister(PS_RATE, compress(MeasRateHz/PSRateHz)  );
WriteToRegister(MEAS_RATE, compress( MeasRateHz/ALSRateHz)  );
```

## 5.6. Evaluating ADC Measurements

This section focuses on information reported by the Si114x through the various registers. In this section, these registers are “output registers” as the Si114x communicates information through these mailbox registers.

**Table 4. ADC Output Registers**

| Output Register | Address | Purpose |
|---|---|---|
| ALS_VIS_DATA0<br>ALS_VIS_DATA1 | 0x22<br>0x23 | Visible Photodiode Measurement<br>(dedicated) |
| ALS_IR_DATA0<br>ALS_IR_DATA1 | 0x24<br>0x25 | Infrared Photodiode Measurement<br>(uses small IR photodiode by default) |
| PS1_DATA0<br>PS1_DATA1 | 0x26<br>0x27 | Proximity Channel 1 Measurement<br>(drives LED1 by default)<br>(uses Large IR photodiode by default) |
| PS2_DATA0<br>PS2_DATA1 | 0x28<br>0x29 | Proximity Channel 2 Measurement<br>(drives LED2 by default)<br>(uses Large IR photodiode by default) |
| PS3_DATA0<br>PS3_DATA1 | 0x2A<br>0x2B | Proximity Channel 3 Measurement<br>(drives LED3 by default)<br>(uses Large IR photodiode by default) |
| AUX_DATA0<br>AUX_DATA1 | 0x2C<br>0x2D | Electrical Measurements |

### 5.6.1. Byte Alignment

All of the output registers contain two bytes. They form 16-bit quantities. For example, ALS_VIS_DATA1 and ALS_VIS_DATA0 combine to form a 16-bit quantity in the following way:

$$\text{ALS\_VIS\_DATA} = 256 \times \text{ALS\_VIS\_DATA1} + \text{ALS\_VIS\_DATA0}$$

Note the “ordering” of the registers from the perspective of where it is in the $I^2C$ Register Map.

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

Register ordering is “little-endian” by nature. Therefore, if the host processor is “big endian”, simply pointing to ALS_VIS_DATA0, for example, and casting it as a 16-bit variable will result in a byte swap. To avoid byte-swapping, it is recommended that the 16-bit quantity be explicitly calculated similar to the example shown above.

### 5.6.2. Host Interrupt Latency

When the Si114x 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 does not read these output registers within the time frame relative to the interrupt, then, depending on the timing, one of the measurements would have the upper byte from a previous measurement coupled with the lower byte of the current measurement.

When performing autonomous measurements, the output registers must be read after the INT pin asserts and before the next group of measurements is started. Therefore, the host must be aware of this timing for proper operation.

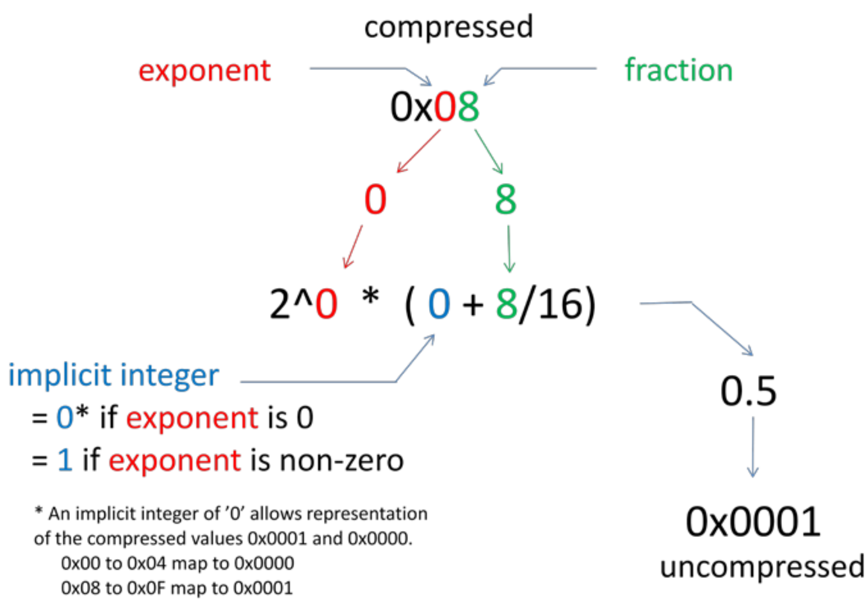



**Figure 28. Safe-to-Read Window Example**

Figure 28 shows an example of when to safely read the output registers once autonomous measurements have 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 "6. Latency" on page 39 for more details on the latency of various measurement channel combinations.

### 5.6.3. ADC Number System

By default, all measurements reported contain an offset of 256 codes. 256 codes means that no reflectance is measured (PS) or the ambient condition is dark (ALS). Codes 255 to 0 are “negative numbers”. The offset is configurable using the ADC_OFFSET (Parameter 0x1A).

Due to effect of ambient noise, it is possible that the values provided by the Si114x can be slightly negative.

The Si114x uses the ADC value, 0xFFFF, whenever the ADC saturates.

Since the value, –1, in 2s complement is 0xFFFF also, it is not recommended to lower the ADC_OFFSET less than 256 so that negative numbers will not be misinterpreted as an ADC saturation condition.

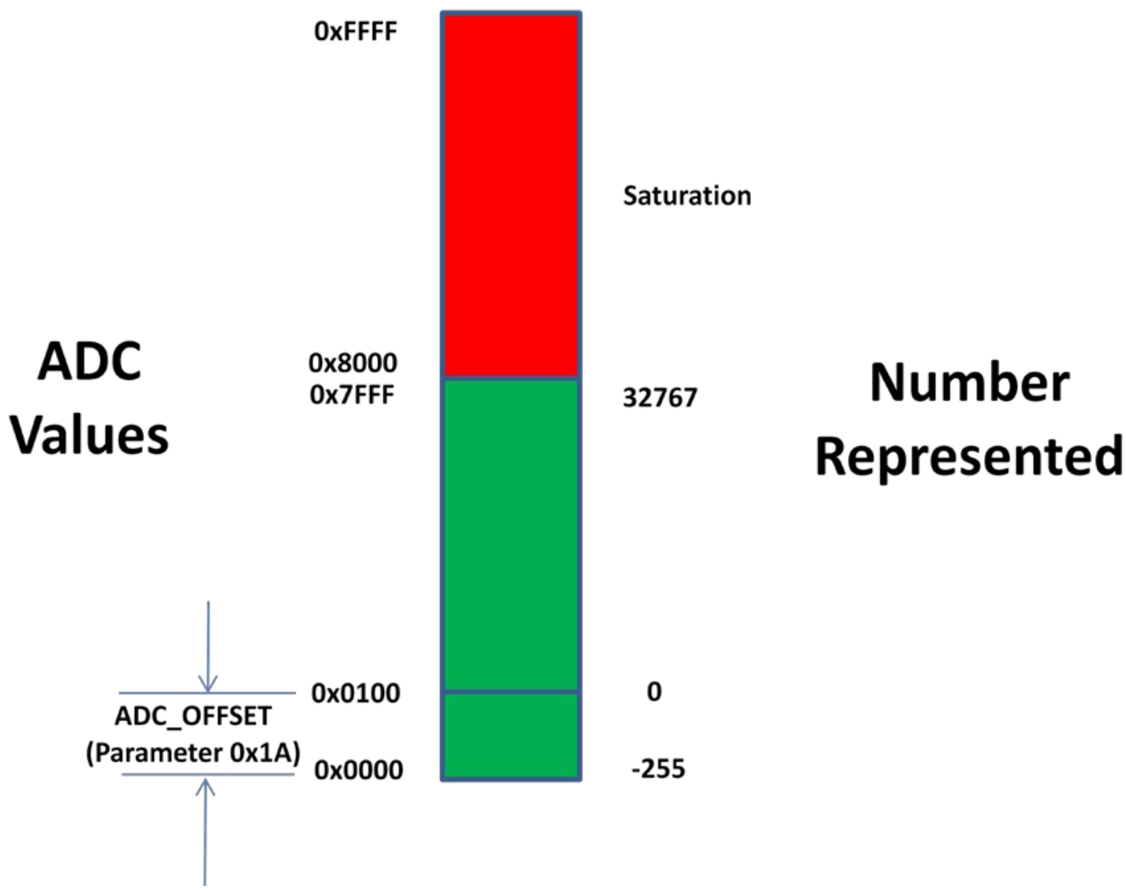



**Figure 29. ADC Number System**

## 6. Latency

In autonomous measurement mode, measurements are performed periodically based on MEAS_RATE, PS_RATE, and ALS_RATE 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 only PS_FORCE or ALS_FORCE (but not PSALS_FORCE) is used, no other measurement is being made, and the latencies are given by the following formulas.

1. For the first proximity measurement, the latency is:

$$t_{DPS1} = 4\ \mu s + 2 \times (25.6\ \mu s + t_{PSREC}) \times 2^{PS\_ADC\_GAIN}$$

2. If a second proximity measurement is enabled, the latency for that measurement is:

$$t_{DPS2} = 2 \times t_{DPS1}$$

3. If a third proximity measurement is enabled, the latency for that measurement is:

$$t_{DPS3} = 3 \times t_{DPS1}$$

4. If the visible ALS measurement is enabled, the latency for that measurement is:

$$t_{DVIS} = 4\ \mu s + 2 \times (25.6\ \mu s + t_{VISREC}) \times 2^{ALS\_VIS\_ADC\_GAIN}$$

If the visible ALS measurement is not enabled, then tDVIS is zero.

5. If the infrared ALS measurement is enabled, the latency for that measurement is:

$$t_{DIR} = t_{DVIS} + 4\ \mu s + 2 \times (25.6\ \mu s + t_{IRREC}) \times 2^{ALS\_IR\_ADC\_GAIN}$$

If the infrared ALS measurement is not enabled, then tDIR is zero.

6. If the auxiliary measurement is enabled, the latency for that measurement is:

$$t_{DAUX} = t_{DVIS} + t_{DIR} + 61.5\ \mu s$$

Refer to “7. Power Consumption” for the definitions of $t_{PSREC}$, $t_{VISREC}$, and $t_{IRREC}$. All times are typical. The maximum is 6.67% higher (the internal 20 MHz system clock is trimmed to within ±6.25%).

If PSALS_FORCE is used, proximity measurements are performed first, followed by the ALS and auxiliary measurements, and all the latencies above 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). The situation is even more complex when both proximity and ambient-light measurements run autonomously at different rates if one rate is not a multiple of the other.

# 7. Power Consumption

Power consumption calculation proceeds in discrete steps. Since the Si114x 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 proximity detection, if enabled.
2. Calculate the duty cycle associated with the ambient light channels, if enabled.
3. Calculate the duty cycle associated with the auxiliary channel, if enabled.
4. Calculate the duty cycle associated with wake-up timer overhead, if any.
5. Calculate the duty cycle associated with the Si114x being in standby, i.e. the rest of the time.
6. Calculate the LED duty cycle, and multiply by the LED current and driver current.

The complete current-consumption formula is given below:

$$I_{DD} = (DC_{Prox} + DC_{ALS} + DC_{Aux} + DC_{WUT}) \times I_{active} + DC_{SB} \times I_{SB} + DC_{LED} \times (I_{LEDx} + I_{DRV})$$

Where $DC_{Prox}$, $DC_{ALS}$, $DC_{Aux}$, $DC_{WUT}$, $DC_{LED}$ and $DC_{SB}$ are the duty cycles of the proximity, ALS and auxiliary channels, the wake-up timer overhead, the LED "on" time, and the Si114x standby time respectively.

$I_{active}$, $I_{LEDx}$, $I_{DRV}$ and $I_{SB}$ are the device active current, LED current, LED (internal) drive current and standby current respectively. Typical and maximum standby currents and active currents can be found in the Si114x data sheet. LED and LED driver currents are defined in Section 5.6.1.2 below.

If multiple proximity 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 defined as the uncompressed time interval set by MEAS_RATE, or $t_{MEASRATE}$, multiplied as required by the uncompressed factor set by PS_RATE ($PSRATE_{UNC}$) or by ALS_ RATE ($ALSRATE_{UNC}$) for the corresponding channel.

## 7.1. Proximity Channel Duty Cycle

The duty cycle of the proximity channels is affected by the number of channels, the recovery time indicated by PS_ADC_REC ($t_{PSREC}$), the proximity gain, and the proximity measurement rate according to the following formula (provided that PS_RATE is non-zero):

$$DC_{Prox} = \frac{2 \times (\text{number of proximity channels}) \times (2\ \mu s + (25.6\ \mu s + t_{PSREC}) \times 2^{PS\_ADC\_GAIN})}{t_{MEASRATE} \times PSRATE_{UNC}}$$

If PS_RATE is zero, then $DC_{Prox}$ is zero.

Power consumption can be minimized by reducing $t_{PSREC}$ to the recommended minimum:

- If PS_RANGE is low, make PS_ADC_REC the complement of PS_ADC_GAIN:
- If PS_RANGE is high or PS_ADC_GAIN is 7 (gain of 128), make PS_ADC_REC 000 (one ADC clock).

**Table 5. Recommended Proximity Recovery Times**

| PS_RANGE | PS_ADC_GAIN | Gain | PS_ADC_REC | Recovery Formula | Recovery Time |
|---|---|---|---|---|---|
| 0 | 000 | 1 | 111 | 511 ADC clocks | 25.55 µs |
| 0 | 001 | 2 | 110 | 255 ADC clocks | 25.5 µs |
| 0 | 010 | 4 | 101 | 127ADC clocks | 25.4 µs |
| 0 | 011 | 8 | 100 | 63 ADC clocks | 25.2 µs |
| 0 | 100 | 16 | 011 | 31 ADC clocks | 24.8 µs |
| 0 | 101 | 32 | 010 | 15 ADC clocks | 24 µs |
| 0 | 110 | 64 | 001 | 7 ADC clocks | 22.4 µs |
| 0 | 111 | 128 | 000 | One ADC clock | 6.4 µs |
| 1 | Any | Any | 000 | One ADC clock | 6.4 µs |

## 7.2. ALS Channel Duty Cycle

The duty cycle of the ALS channels is affected by the number of channels, the gain, the recovery time indicated by VIS_ADC_REC ($t_{VISREC}$) or IR_ADC_REC ($t_{IRREC}$), and the ALS measurement rate according to the formulas below:

$$DC_{ALS} = DC_{VIS\_ALS} + DC_{IR\_ALS}$$

If the visible ALS channel is disabled or ALS_RATE is zero, $DC_{VIS\_ALS} = 0$. If it is enabled:

$$DC_{VIS\_ALS} = \frac{4\ \mu s + 2 \times (25.6\ \mu s + t_{VISREC}) \times 2^{ALS\_VIS\_ADC\_GAIN}}{t_{MEASRATE} \times ALSRATE_{UNC}}$$

If the infrared ALS channel is disabled or ALS_RATE is zero, $DC_{IR\_ALS} = 0$. If it is enabled:

$$DC_{IR\_ALS} = \frac{4\ \mu s + 2 \times (25.6\ \mu s + t_{IRREC}) \times 2^{ALS\_IR\_ADC\_GAIN}}{t_{MEASRATE} \times ALSRATE_{UNC}}$$

Power consumption can be minimized by reducing $t_{VISREC}$ and $t_{IRREC}$ to the recommended minima:

- If VIS_RANGE is low, make VIS_ADC_REC the complement of ALS_VIS_ADC_GAIN.
- If VIS_RANGE is high or ALS_VIS_ADC_GAIN is 7 (gain of 128), make VIS_ADC_REC 000 (one ADC clock).

**Table 6. Recommended Visible ALS Recovery Times**

| VIS_RANGE | ALS_VIS_ADC_GAIN | Gain | VIS_ADC_REC | Recovery Formula | Recovery Time |
|---|---|---|---|---|---|
| 0 | 000 | 1 | 111 | 511 ADC clocks | 25.55 µs |
| 0 | 001 | 2 | 110 | 255 ADC clocks | 25.5 µs |
| 0 | 010 | 4 | 101 | 127ADC clocks | 25.4 µs |
| 0 | 011 | 8 | 100 | 63 ADC clocks | 25.2 µs |
| 0 | 100 | 16 | 011 | 31 ADC clocks | 24.8 µs |
| 0 | 101 | 32 | 010 | 15 ADC clocks | 24 µs |
| 0 | 110 | 64 | 001 | 7 ADC clocks | 22.4 µs |
| 0 | 111 | 128 | 000 | One ADC clock | 6.4 µs |
| 1 | Any | Any | 000 | One ADC clock | 6.4 µs |

- If IR_RANGE is low, make IR_ADC_REC the complement of ALS_IR_ADC_GAIN.
- If IR_RANGE is high or ALS_IR_ADC_GAIN is 7 (gain of 128), make IR_ADC_REC 000 (one ADC clock).

**Table 7. Recommended IR ALS Recovery Times**

| IR_RANGE | ALS_IR_ADC_GAIN | Gain | IR_ADC_REC | Recovery Formula | Recovery Time |
|---|---|---|---|---|---|
| 0 | 000 | 1 | 111 | 511 ADC clocks | 25.55 µs |
| 0 | 001 | 2 | 110 | 255 ADC clocks | 25.5 µs |
| 0 | 010 | 4 | 101 | 127ADC clocks | 25.4 µs |
| 0 | 011 | 8 | 100 | 63 ADC clocks | 25.2 µs |
| 0 | 100 | 16 | 011 | 31 ADC clocks | 24.8 µs |
| 0 | 101 | 32 | 010 | 15 ADC clocks | 24 µs |
| 0 | 110 | 64 | 001 | 7 ADC clocks | 22.4 µs |
| 0 | 111 | 128 | 000 | One ADC clock | 6.4 µs |
| 1 | Any | Any | 000 | One ADC clock | 6.4 µs |

## 7.3. Auxiliary Channel Duty Cycle

If the auxiliary channel is disabled or ALS_RATE is zero, $DC_{Aux} = 0$. If it is enabled, the duty cycle of the auxiliary channel is affected by the ALS measurement rate according to this formula:

$$DC_{Aux} = \frac{61.5\ \mu s}{t_{MEASRATE} \times ALSRATE_{UNC}}$$

## 7.4. Wake-Up Timer Duty Cycle

The wake-up timer has a periodicity of $t_{MEASRATE}$. The proximity and ambient-light measurement periods are the following respective multiples:

- $t_{MEASRATE} \times PSRATE_{UNC}$
- $t_{MEASRATE} \times ALSRATE_{UNC}$

If MEAS_RATE is very low and PS_RATE and/or ALS_RATE very high, the wake-up timer will activate the Si114x frequently, most of the time only to advance the PS_RATE and ALS_RATE counters rather than to make actual measurements. In some cases, that overhead may be greater than the actual measurement time. If very long measurement cycles are desired, this overhead can be minimized by making MEAS_RATE as large as possible and PS_RATE and ALS_RATE smaller accordingly. The overhead duty cycle is computed in the following way:

$$DC_{WUT} = \frac{12.8\ \mu s}{t_{MEASRATE}} + DC_{PS\_WUT} + DC_{ALS\_WUT}$$

Where $DC_{PS\_WUT}$ is the overhead duty cycle for proximity and $DC_{ALS\_WUT}$ is the overhead for the ALS and auxiliary channels.

If PS_RATE is zero, $DC_{PS\_WUT}$ is zero. If PS_RATE is nonzero, autonomous proximity measurements are enabled and:

$$DC_{PS\_WUT} = \frac{51.2\ \mu s}{t_{MEASRATE} \times PSRATE_{UNC}}$$

If ALS_RATE is zero, $D_{CALS\_WUT}$ is zero. If ALS_RATE is nonzero, autonomous ambient-light and auxiliary measurements are enabled and:

$$DC_{ALS\_WUT} = \frac{51.2\ \mu s}{t_{MEASRATE} \times ALSRATE_{UNC}}$$

## 7.5. Standby Duty Cycle

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

$$DC_{SB} = 1 - DC_{Prox} - DC_{ALS} - DC_{Aux} - DC_{WUT}$$

## 7.6. LED Power

On each proximity measurement, the LED current is on for 25.6 µs times the gain. Thus, for each proximity channel, if PS_RATE is nonzero, the LED duty cycle is:

$$DC_{LED} = \frac{25.6\ \mu s \times 2^{PS\_ADC\_GAIN}}{t_{MEASRATE} \times PSRATE_{UNC}}$$

If PS_RATE is zero, then $DC_{LED}$ is zero.

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 as shown in the table below. The LED-related extra current draw is not proportional to the set LED drive current.

**Table 8. LED Currents and LED Internal Driver Currents**

| Current setting | Typical $I_{LEDx}$ | Maximum $I_{LEDx}$ | Typical $I_{DRV}$ | Maximum $I_{DRV}$ | Unit |
|---|---|---|---|---|---|
| PS_LEDn = 0001<br>PS_LEDn = 0010<br>PS_LEDn = 0011<br>PS_LEDn = 0100 | 5.6<br>11.2<br>22.4<br>45 | 7<br>14<br>29<br>56 | 0.7 | 0.8 | mA |
| PS_LEDn = 0101 | 67 | 83 | 1.0 | 1.2 | mA |
| PS_LEDn = 1000 | 135 | 168 | 1.3 | 1.5 | mA |
| PS_LEDn = 0110<br>PS_LEDn = 1001<br>PS_LEDn = 1010 | 90<br>157<br>180 | 112<br>195<br>224 | 1.6 | 1.9 | mA |
| PS_LEDn = 0111<br>PS_LEDn = 1100 | 112<br>224 | 139<br>279 | 1.9 | 2.3 | mA |
| PS_LEDn = 1011<br>PS_LEDn = 1101 | 202<br>269 | 251<br>335 | 2.2 | 2.7 | mA |
| PS_LEDn = 1110 | 314 | 391 | 2.6 | 3.0 | mA |
| PS_LEDn = 1111 | 359 | 447 | 2.9 | 3.4 | mA |

If multiple LEDs are on for any given proximity cycle (Si1142 or Si1143 only), all respective LED currents and LED drive currents must be summed.

# 8. Putting It All Together with the Range Estimator Web Tool

Designing an optimized proximity/ALS system can appear daunting because of the multiple dependencies between the various design options:

- The operating ambient light, overlay, optical leakage, LED type, LED placement, LED current, photodiode selection, and proximity gain together determine the maximum usable photodiode sensitivity.
- The above settings also affect power consumption, which may or may not need to be prioritized over performance, depending on the application.
- System noise is dominated sometimes by internal (ADC) noise and sometimes by ambient-light ripple, depending on the type of ambient light, the ADC settings and the photodiode selection.
- There is a trade-off between the need to maximize IR transparency of the overlay versus its transparency to visible light. More IR transparency benefits proximity sensitivity at the expense of ALS performance.
- The amount of optical leakage greatly depends on mechanical factors.

In order to help make design choices systematically, the following methodology is proposed. This sequence of engineering decisions is aided by the range estimator web tool.

1. Identify the system requirements:
   a. Proximity-detection range
   b. Operating ambient light
   c. Better performance or lower power consumption
2. Choose a construction method:
   a. Single port, dual port or hybrid
   b. Overlay type
   c. LED type and placement
3. Select the proximity photodiode, proximity gain and proximity range.
4. Set the LED current.
5. Obtain the system's raw signal-to-noise ratio and determine the oversampling factor if required.
6. Calculate the ALS coefficients.
7. Calculate the values of $C_{LED}$ and $R_{LED}$.
8. Calculate the system's power consumption according to the formulas in "7. Power Consumption" on page 40.

The range estimator web tool may be accessed at this URL:

http://www.silabs.com/ir-range-estimator/

The IR Range Estimator initially appears in the browser thus:

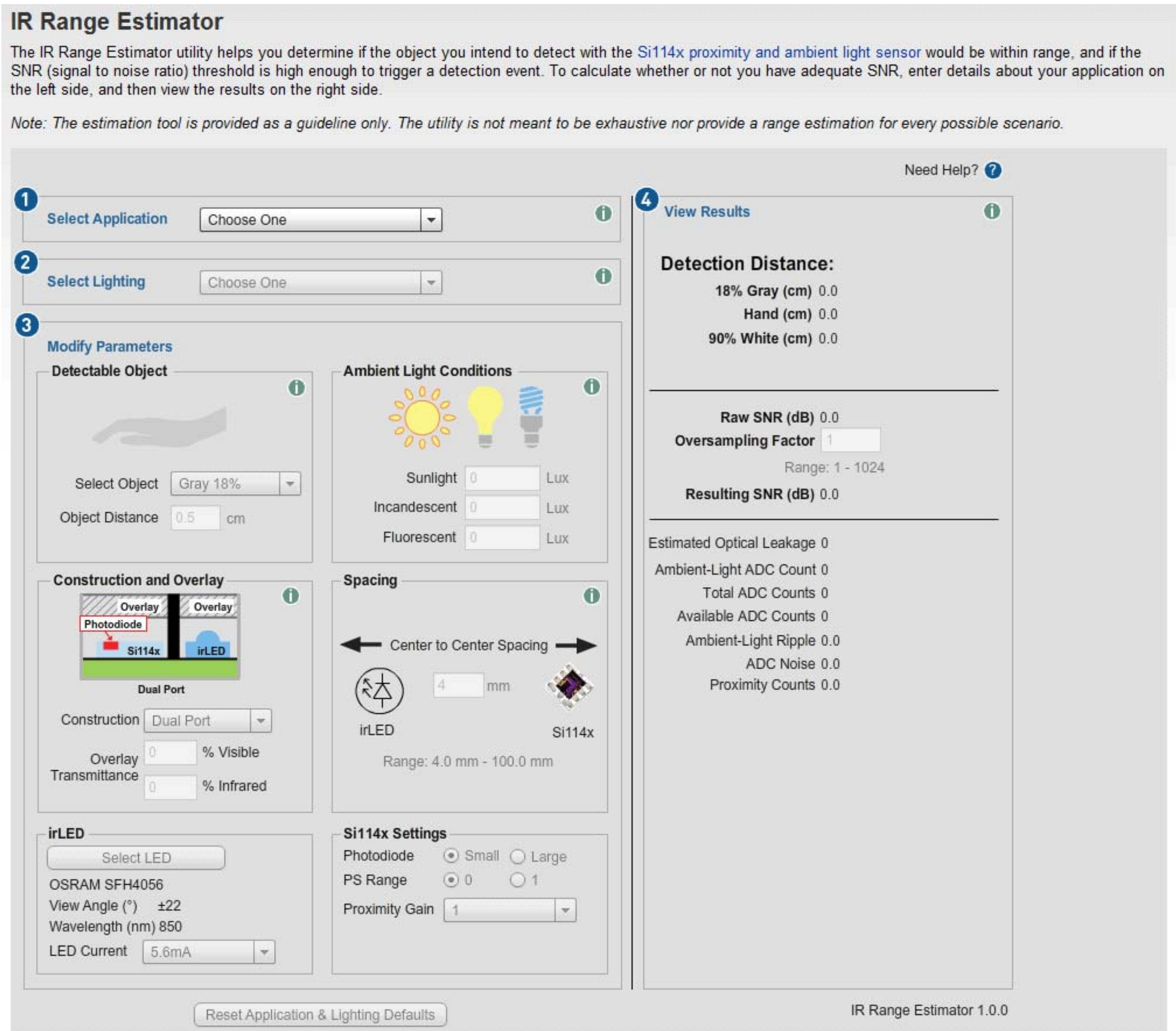



**Figure 30. IR Range Estimator Start-Up Screen**

## 8.1. Identifying the System Requirements

In general, the proximity detection range is defined from the outset by the application, e.g. cheek detection for a handset usually operates at a distance of 3 cm. The operating ambient light is more complex because of the variety of possible light sources and intensity levels. Indoor lighting can be as low as 50 lux, while full sunlight can be as high as 120 klux.

When wide variations of ambient light are expected, it may be desirable to design both the proximity detector and the ALS to operate over multiple gain ranges rather than always using the least sensitive settings. Automatic range selection can improve system noise, resolution, and/or power consumption. If the system is intended to function across multiple settings, steps 3 through 8 above must be repeated for each setting.

The Range Estimator simplifies the system design with presets for commonly-found applications and lighting conditions. The preset applications are:

- Handset (ear/cheek detection)
- IR button (detection of a finger very close to the system)
- Long range (detection of persons or objects up to two meters away)
- Towel dispenser (hand-operated devices used indoors)

The preset lighting conditions are:

- Full sunlight
- Shaded outdoors (indirect sunlight)
- Office or industrial (fluorescent only)
- Mixed indoors (incandescent and fluorescent)
- Home (incandescent only)
- Worst-case indoors (high levels of fluorescent and incandescent)

First, the desired application must be selected:

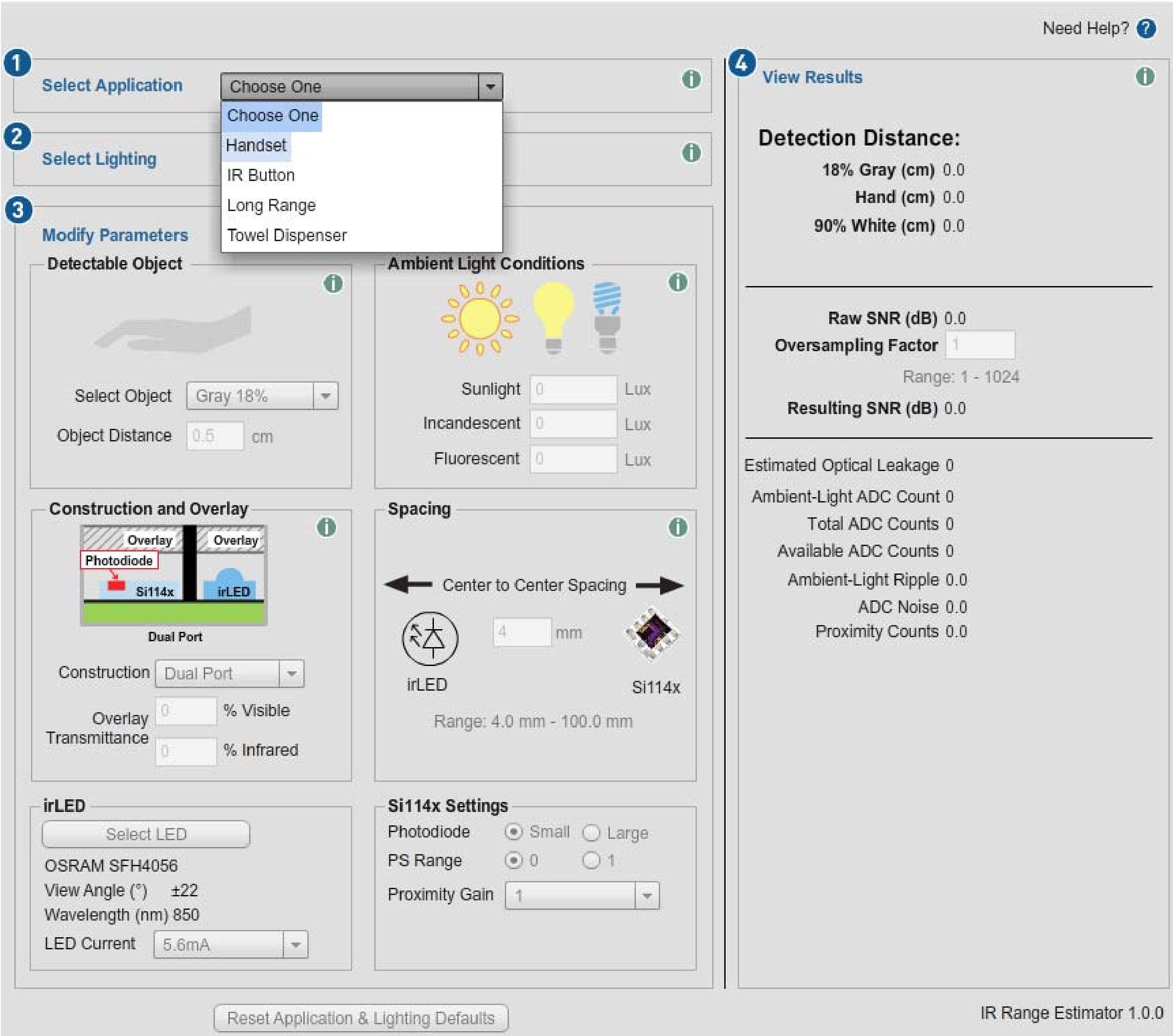



**Figure 31. IR Range Estimator Application Selection**

Next, the lighting conditions must be specified:

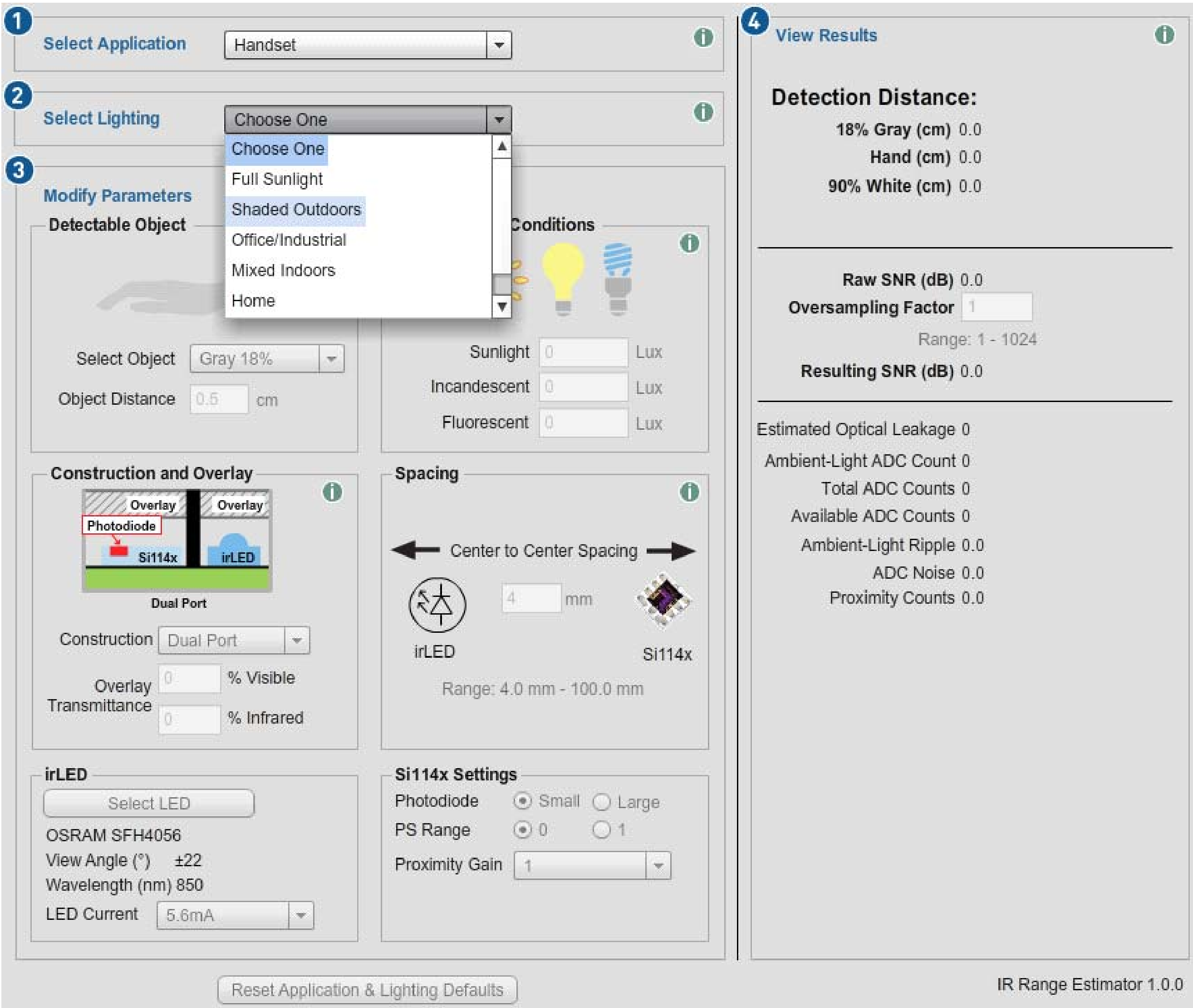



**Figure 32. IR Range Estimator Lighting Selection**

The Range Estimator then sets the parameters that satisfy the system requirements and computes the resulting detection distance for a range of objects and the ADC counts that result for the typical object selected for the application:

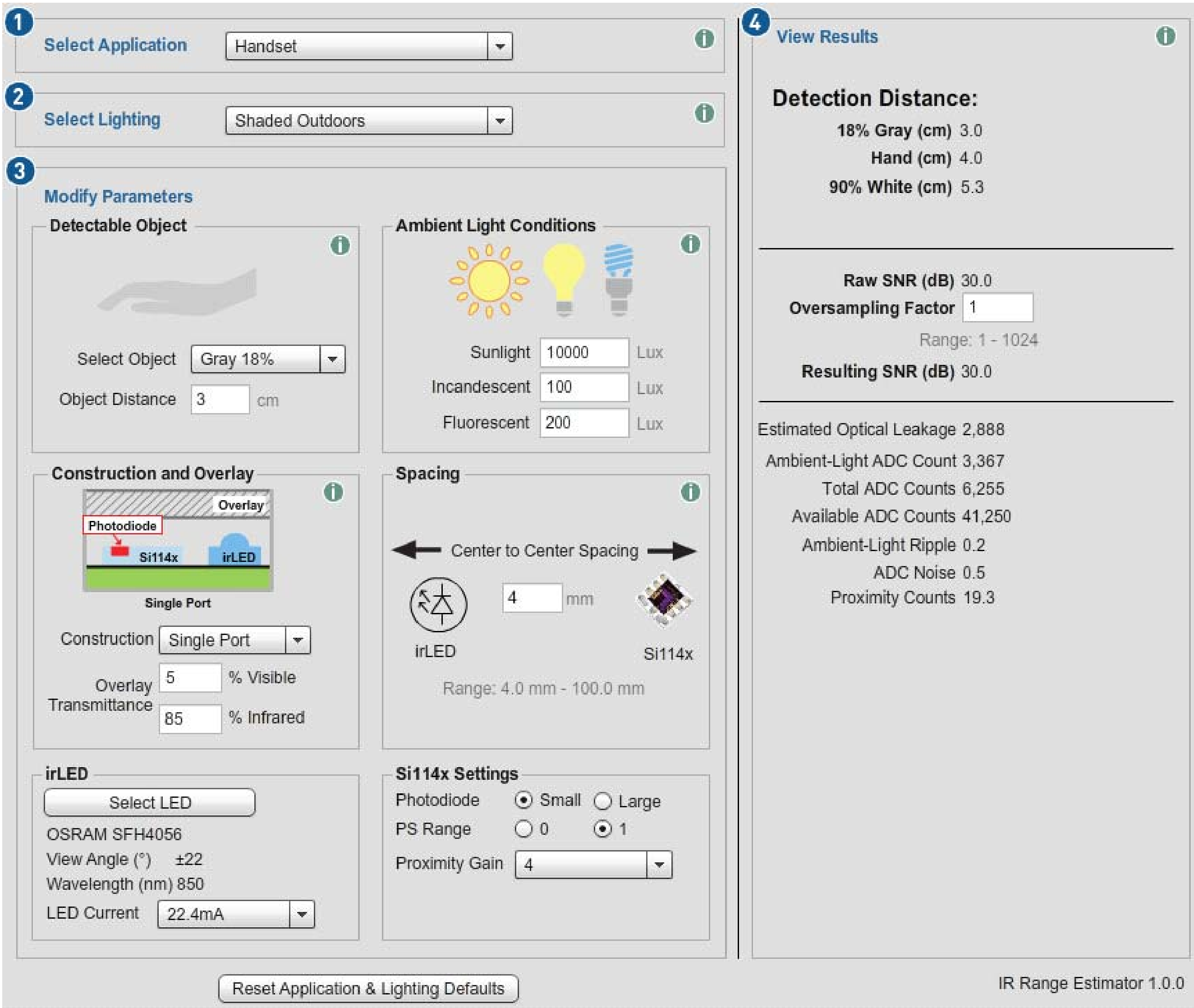



**Figure 33. IR Range Estimator with Default Parameters and System Performance**

The user is free to modify all the parameters to see their effect on the system performance, and fine-tune the application. The next section discusses those parameters in detail.

## 8.2. Construction

### 8.2.1. Single Port, Dual Port or Hybrid

When the proximity detection distance is very short, e.g. 0.5 cm for an optical button, single-port construction is adequate. For very long detection ranges, the light reflected from a detected object is very low compared to the optical leakage, in which case every effort must be made to minimize leakage. Therefore, dual-port construction is optimal for long-range detection. If a dual-port system is not practical, a hybrid construction can also be made to perform adequately, depending on other aspects of the design.

### 8.2.2. Overlay Selection

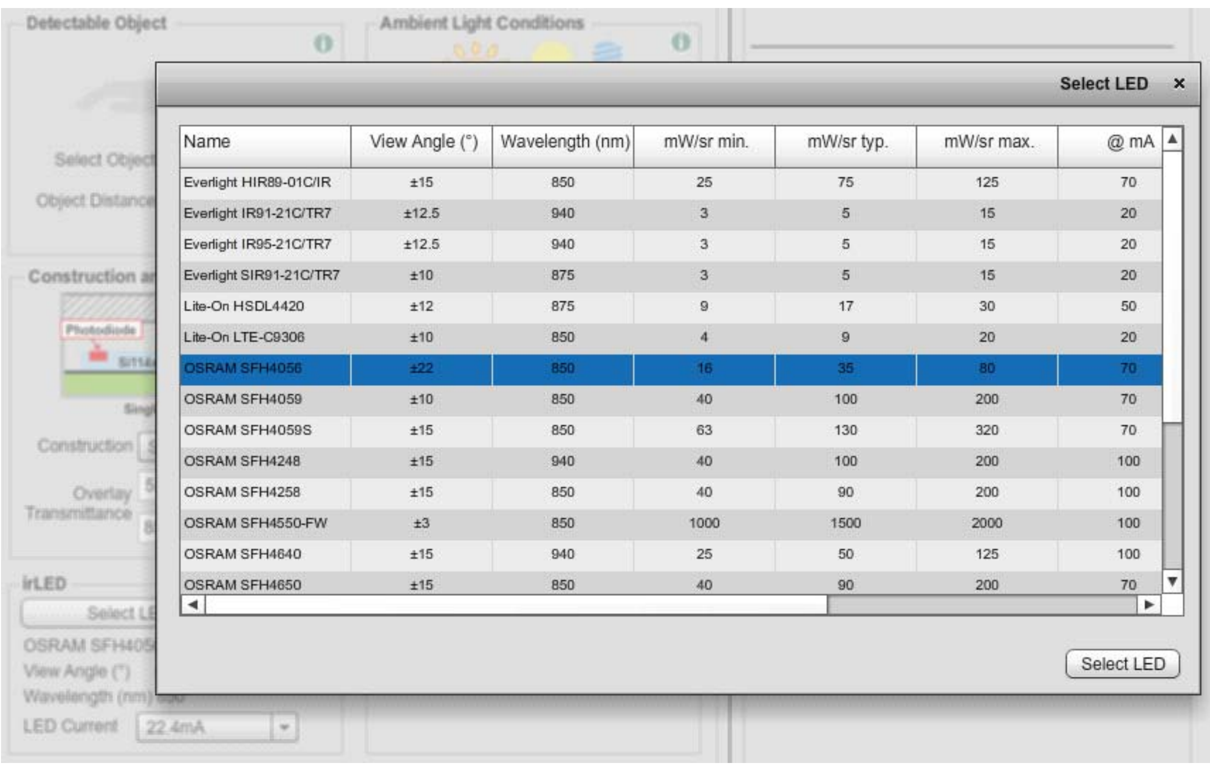
The choice of overlay must reflect a compromise between the desire for high IR transparency for efficient proximity detection and a low IR/visible ratio for efficient ALS, i.e. rejection of infrared light and correct evaluation of visible light alone.

The recommended IR transparency is 50% or more, unless the proximity application is not very demanding. The recommended IR-to-visible transparency ratio is 25:1 or less, e.g. 80% IR transparency or less and 3% visible transparency or more. If ALS is not required, it is sufficient to maximize the transparency of the overlay at the LED's wavelength and minimize transparency at other wavelengths to the extent possible.

### 8.2.3. LED Selection

The choice of LED is primarily dictated by the detection distance; the larger the distance, the narrower the LED beam angle should be. LED efficiency is also an important consideration. The Si114x can operate with a variety of LED wavelengths. Common LEDs are modeled in the range estimator web tool, taking data-sheet minimum output efficiency and wavelength derating into account.

When “Select LED” is clicked on the Range Estimator, the following choices appear:




| Name | View Angle (°) | Wavelength (nm) | mW/sr min. | mW/sr typ. | mW/sr max. | @ mA |
|---|---|---|---|---|---|---|
| Everlight HIR89-01C/IR | ±15 | 850 | 25 | 75 | 125 | 70 |
| Everlight IR91-21C/TR7 | ±12.5 | 940 | 3 | 5 | 15 | 20 |
| Everlight IR95-21C/TR7 | ±12.5 | 940 | 3 | 5 | 15 | 20 |
| Everlight SIR91-21C/TR7 | ±10 | 875 | 3 | 5 | 15 | 20 |
| Lite-On HSDL4420 | ±12 | 875 | 9 | 17 | 30 | 50 |
| Lite-On LTE-C9306 | ±10 | 850 | 4 | 9 | 20 | 20 |
| OSRAM SFH4056 | ±22 | 850 | 16 | 35 | 80 | 70 |
| OSRAM SFH4059 | ±10 | 850 | 40 | 100 | 200 | 70 |
| OSRAM SFH4059S | ±15 | 850 | 63 | 130 | 320 | 70 |
| OSRAM SFH4248 | ±15 | 940 | 40 | 100 | 200 | 100 |
| OSRAM SFH4258 | ±15 | 850 | 40 | 90 | 200 | 100 |
| OSRAM SFH4550-FW | ±3 | 850 | 1000 | 1500 | 2000 | 100 |
| OSRAM SFH4640 | ±15 | 940 | 25 | 50 | 125 | 100 |
| OSRAM SFH4650 | ±15 | 850 | 40 | 90 | 200 | 70 |

**Figure 34. IR Range Estimator LED Selection**

The LEDs are specified by view angle, wavelength, output power per mA, height, and overall efficiency as seen by the Si114x. Higher overall efficiency translates into longer detection distances, lower power consumption and/or higher signal-to-noise ratio, depending on other system parameters. For more details on LED selection, refer to “AN521: irLED Selection Guide for Si114X Proximity Applications”.

### 8.2.4. LED Placement and Orientation

The LED placement is especially important with respect to optical leakage. The amount of optical leakage increases with the inverse of the square of the distance between the LED and the Si114x. For this reason, a center-to-center distance of 4 mm or more is recommended between sensor and LED. The photodiodes, which lie on one side of the Si114x, should be oriented away from the LED.

## 8.3. Range and Photodiode Selection

The range estimator web tool can model the overlay as a function of visible and infrared transparencies. This is only an approximation, and small adjustments may be required during prototyping. The combination of gain settings, sensitivity range, and photodiode affects the overall sensitivity of the proximity detector. Some combinations are inherently noisier than others. On the other hand, high proximity gain settings require the LED to be turned on for a longer time in proportion to the gain. Therefore, two gain-selection tables are presented, which prioritize ADC noise performance or power consumption. The ADC noise is not always dominant; sometimes, the ripple caused by artificial light is greater, and the power-optimized gain setting may have noise performance similar to that of the noise-optimized setting. This is modeled in the range estimator web tool.

**Table 9. Gain and Photodiode Selections for Optimized ADC Noise**

| Photodiode / PS_RANGE | Gain Setting | ADC Noise (LSBs) | LED "ON" Time | $nW/cm^2$ per LSB at 875 nm | Lux per LSB, Sunlight | Available ADC Counts | Maximum Sunlight, Lux | Maximum Incandescent Light, Lux | Maximum Fluorescent Light, Lux |
|---|---|---|---|---|---|---|---|---|---|
| Small / 1 | 1 | 0.5 | 25.6 µs | 3180 | 5.8959 | 47674 | 281083 | 81069 | 965977 |
| Small / 1 | 2 | 0.5 | 51.2 µs | 1590 | 2.9480 | 47655 | 140486 | 40518 | 482796 |
| Small / 1 | 4 | 0.5 | 102 µs | 795.0 | 1.4740 | 47505 | 70022 | 20195 | 240638 |
| Small / 1 | 8 | 0.5 | 205 µs | 397.5 | 0.7370 | 47505 | 35011 | 10098 | 120319 |
| Small / 1 | 16 | 0.5 | 410 µs | 198.8 | 0.3685 | 47205 | 17395 | 5017 | 59780 |
| Small / 1 | 32 | 0.5 | 819 µs | 99.38 | 0.1842 | 46079 | 8490 | 2449 | 29177 |
| Small / 1 | 64 | 0.5 | 1.64 ms | 49.69 | 0.0921 | 43879 | 4042 | 1166 | 13892 |
| Small / 1 | 128 | 0.5 | 3.28 ms | 24.84 | 0.0461 | 39471 | 1818 | 524 | 6248 |
| Small / 0 | 16 | 2 | 410 µs | 13.82 | 0.0256 | 47205 | 1209 | 349 | 4155 |
| Small / 0 | 32 | 2 | 819 µs | 6.908 | 0.0128 | 46079 | 590 | 170 | 2028 |
| Small / 0 | 64 | 2 | 1.64 ms | 3.454 | 0.0064 | 43879 | 281 | 81 | 966 |
| Small / 0 | 128 | 2 | 3.28 ms | 1.727 | 0.0032 | 39471 | 126 | 36 | 434 |
| Large / 0 | 32 | 11 | 819 µs | 1.143 | 0.0022 | 46079 | 102 | 29 | 363 |
| Large / 0 | 64 | 14 | 1.64 ms | 0.572 | 0.0011 | 43879 | 49 | 14 | 173 |
| Large / 0 | 128 | 20 | 3.28 ms | 0.286 | 0.0006 | 39471 | 22 | 6.1 | 78 |

**Table 10. Gain and Photodiode Selections for Optimized Power Consumption**

| Photodiode / PS_RANGE | Gain Setting | ADC Noise (LSBs) | LED "ON" Time | nW/cm$^2$ per LSB at 875 nm | Lux per LSB, Sunlight | Available ADC Counts | Maximum Sunlight, Lux | Maximum Incandescent Light, Lux | Maximum Fluorescent Light, Lux |
|---|---|---|---|---|---|---|---|---|---|
| Small / 1 | 1 | 0.5 | 25.6 µs | 3180 | 5.8959 | 47674 | 281083 | 81069 | 965977 |
| Small / 1 | 2 | 0.5 | 51.2 µs | 1590 | 2.9480 | 47655 | 140486 | 40518 | 482796 |
| Small / 1 | 4 | 0.5 | 102 µs | 795.0 | 1.4740 | 47505 | 70022 | 20195 | 240638 |
| Large / 1 | 1 | 1 | 25.6 µs | 526.2 | 1.0225 | 47674 | 48745 | 13589 | 172757 |
| Large / 1 | 2 | 1 | 51.2 µs | 263.1 | 0.5112 | 47655 | 24363 | 6792 | 86344 |
| Small / 0 | 1 | 2 | 25.6 µs | 221.1 | 0.4098 | 47674 | 19539 | 5635 | 67146 |
| Small / 0 | 2 | 2 | 51.2 µs | 110.5 | 0.2049 | 47655 | 9765 | 2816 | 33560 |
| Small / 0 | 4 | 2 | 102 µs | 55.26 | 0.1025 | 47505 | 4867 | 1404 | 16727 |
| Large / 0 | 1 | 11 | 25.6 µs | 36.58 | 0.0711 | 47674 | 3388 | 945 | 12009 |
| Large / 0 | 2 | 11 | 51.2 µs | 18.29 | 0.0355 | 47655 | 1693 | 472 | 6002 |
| Large / 0 | 4 | 11 | 102 µs | 9.144 | 0.0178 | 47505 | 844 | 235 | 2991 |
| Large / 0 | 8 | 11 | 205 µs | 4.572 | 0.0089 | 47505 | 422 | 118 | 1496 |
| Large / 0 | 16 | 11 | 410 µs | 2.286 | 0.0044 | 47205 | 210 | 58 | 743 |
| Large / 0 | 32 | 11 | 819 µs | 1.143 | 0.0022 | 46079 | 102 | 29 | 363 |
| Large / 0 | 64 | 14 | 1.64 ms | 0.572 | 0.0011 | 43879 | 49 | 14 | 173 |
| Large / 0 | 128 | 20 | 3.28 ms | 0.286 | 0.0006 | 39471 | 22 | 6.1 | 78 |

### 8.4. LED Current

If best performance is desired, set the LED current to the highest level that does not saturate the ADC. If the lowest power is desired, set the LED current to the lowest level that gives the desired SNR.

### 8.5. Signal-to-Noise Ratio

Proximity detection noise originates from by two main sources: ADC noise and ambient-light ripple. Both noise sources are modeled in the range estimator web tool. After all settings have been entered into the range estimator web tool, the system's SNR is calculated. This is defined as the ratio of the number of proximity counts over the RMS system noise. A suggested target SNR is 20 dB. This amounts to a one-sigma variation of about ±10% of the detection signal. Since the signal usually is inversely proportional to the square of the distance, an SNR of 20 dB usually amounts to a one-sigma variation of about ±5% of the distance.

If the range estimator web tool returns an SNR figure lower than desired, the SNR can be improved by oversampling. The noise reduction factor is the square root of the oversampling factor, e.g. every factor of 4 in oversampling will improve the SNR by about 6 dB. Oversampling increases the response time and/or power consumption and can often be avoided by choosing the settings judiciously.

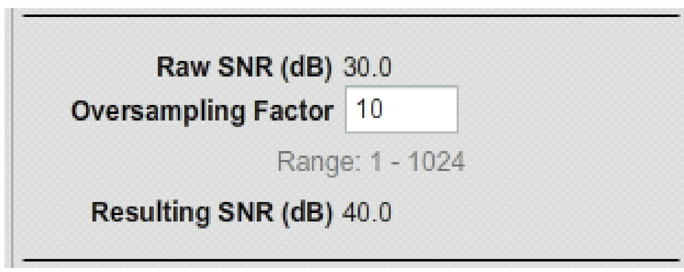



**Figure 35. Improving the Signal-to-Noise Ratio through Oversampling**

Also refer to Section “4.4. Minimizing the Effect of Ambient-Light Ripple” .

### 8.6. ALS Coefficients

Refer to “AN523: Overlay Considerations for the Si114x Sensor” to obtain ALS coefficients for a variety of standard overlays. If the overlay being considered is not described in the application note, it is possible to determine ALS coefficients by prototyping the product and recording each ALS photodiode's response to two different light sources. Coefficients can then be adjusted so as to give the same lux value for both types of lamp.

At Silicon Labs, best results were obtained using a rough-service, low-wattage incandescent light bulb with a color temperature of 2500 K (Westinghouse 03952 or equivalent) and a broad-spectrum metal-halide lamp with a color temperature of 6500 K and CRI (color-rendering index) of 96 (Iwasaki M150P36SD or equivalent). The lamps must be calibrated using an illuminance photometer. Incandescent bulbs must be allowed to stabilize for at least one minute after turning on. Metal-halide lamps typically require 15 mn of warm-up time. Narrow-spectrum lamps, such as tri-band fluorescents (including compact fluorescent bulbs), are not recommended for the computation of ALS coefficients.

Coefficients can be scaled to account for different gain settings. In general, it is best to set the infrared and visible ALS gains to the highest ranges that will not be saturated under the expected light conditions. However, if power consumption is critical, a lower gain setting may be desirable because the measuring time is proportional to the gain. On the other hand, in an application that also requires proximity detection, power consumption is usually dominated by the LED current.

### 8.7. $C_{LED}$ and $R_{LED}$ Selection

Select $C_{LED}$ and $R_{LED}$, in that order. Please refer to “3.6. Selecting CLED” and "3.7. Selecting RLED" on page 25 for details. If the system is intended to function across multiple settings, which require different values of $C_{LED}$ and/or $R_{LED}$, the highest value of $C_{LED}$ and the lowest value of $R_{LED}$ should be used.

## 8.8. Power Consumption

Refer to "7. Power Consumption" on page 40 for a detailed explanation of power consumption. Typical and maximum values for $I_{active}$, $I_{LEDx}$, $I_{DRV}$, and $I_{SB}$ can be found in the Si114x data sheet. Values for $I_{LEDx}$ and $I_{DRV}$ can be found in "7.6. LED Power" on page 44. A simplified power-consumption estimator tool is available online at:

http://www.silabs.com/support/Pages/sensor-current-estimator.aspx

# DOCUMENT CHANGE LIST

## Revision 0.2 to Revision 0.3

- Added "1. Introduction" on page 1.
- Swapped sections 2 and 3.
- Promoted section 4.7 to 5.
- Swapped sections 4 and 5.
- Reordered subsections.
- Renamed “Electrical Considerations” to "3. Electrical Component Selection" on page 19.
- Numerous text edits throughout.
- Removed “3.7. ADC Table”.
- Added "6. Latency" on page 39.
- Added "7. Power Consumption" on page 40.
- Added "8. Putting It All Together with the Range Estimator Web Tool" on page 45.

## Revision 0.3 to Revision 0.4

- Added screenshots and explanations for IR Range Estimator.
- Minor update of noise tables.
- Minor corrections.

## Revision 0.4 to Revision 0.5

- Added ADC ranges for incandescent and fluorescent lux levels.

## Revision 0.5 to Revision 0.6

- Updated Figure 11, “Si114x Photodiode Centers,” on page 12.

## Revision 0.6 to Revision 0.7

- Added "4.4. Minimizing the Effect of Ambient-Light Ripple" on page 28.
- Added crossreference to “4.4. Minimizing the Effect of Ambient-Light Ripple” to end of "8.5. Signal-to-Noise Ratio" on page 54.

## NOTES:

## CONTACT INFORMATION

Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
Tel: 1+(512) 416-8500
Fax: 1+(512) 416-9669
Toll Free: 1+(877) 444-3032

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