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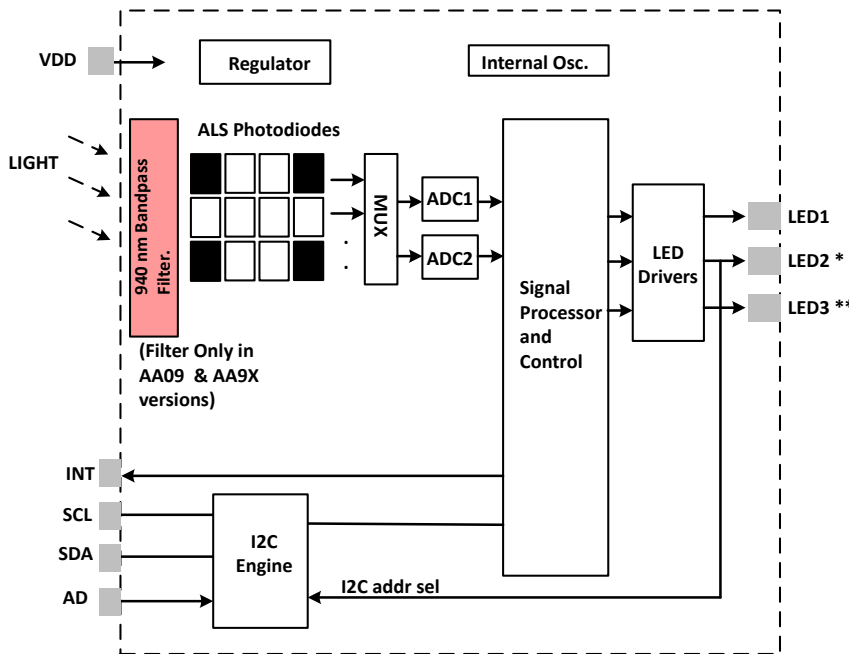


Si1153 Data Sheet

Proximity/Ambient Light Sensor IC with I²C Interface

The Si1153-AA00/AA09/AA9x is an ambient light sensor, proximity, and gesture detector with I2C digital interface and programmable-event interrupt output.

This touchless sensor IC includes dual 23-bit analog-to-digital converters, an integrated high-sensitivity array of visible and infrared photodiodes, a digital signal processor, and three integrated LED drivers with programmable drive levels. The Si1153 offers excellent performance under a wide dynamic range and a variety of light sources, including direct sunlight. The Si1153 can also work under dark glass covers. The photodiode response and associated digital conversion circuitry provide excellent immunity to artificial light flicker noise and natural light flutter noise. With two or more LEDs, the Si1153 is capable of supporting multiple-axis proximity motion detection. The Si1153 is provided in a 10-lead 2x2 mm DFN package or in a 10-lead 2.9x4.9 mm LGA module with integrated LED, and is capable of operation from 1.62 to 3.6 V over the -40 to +85 °C temperature range.



* Pull up to VDD with 47 kOhm resistor to select primary I2C address (0x53), or down to GND for alt I2C address 0x52.

** Pull up to VDD with 47 kOhm resistor

KEY FEATURES

- Proximity detector
 - From under 1 cm, to 50 cm without additional lensing.
 - From under 1 cm, to 200 cm with additional lensing (e.g., 5 mm hemispherical lens as in our EVB).
 - Up to three independent LED drivers.
 - 30 current settings from 5.6 mA to 360 mA for each LED driver.
 - Operates in direct sunlight with optional on-die 940 nm passband filter.
 - On die 940 bandpass filter that rejects unwanted visible light and IR from daylight and other sources (Si1153-AA09/AA9X).
- Ambient light sensor
 - <100 mlx resolution possible, allowing operation under dark glass.
 - Up to 128 klx dynamic range possible across two ADC range settings.
- Industry's lowest power consumption
 - 1.62 to 3.6 V supply voltage.
 - 9 µA average current (LED pulsed 25.6 µs every 800 ms at 180 mA plus 3 µA Si1153 supply).
 - <500 nA standby current.
 - 25.6 µs LED "on" time keeps total power consumption duty cycle low without compromising performance or noise community.
 - Internal and external wake support.
 - Built-in voltage supply monitor and power-on reset controller.

APPLICATIONS

- Wearables
- Handsets
- Display backlighting control
- Consumer electronics

1. Feature List

- Proximity detector
 - From under 1 cm to 50 cm without additional lensing.
 - From under 1 cm to 200 cm with additional lensing (e.g., 5 mm hemispherical lens).
 - Up to three independent LED drivers.
 - 30 current settings from 5.6 mA to 360 mA for each LED driver.
 - Operates in direct sunlight with optional on-die 940 nm passband filter.
 - On die 940 bandpass filter that rejects unwanted visible light and IR from daylight and other sources (Si1153- AA09/ AA9X).
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 - 9 μ A average current (LED pulsed 25.6 μ s every 800 ms at 180 mA plus 3 μ A Si1153 supply).
 - <500 nA standby current.
 - 25.6 μ s LED "on" time keeps total power consumption duty cycle low without compromising performance or noise community.
 - Internal and external wake support.
 - Built-in voltage supply monitor and power-on reset controller.
- Trim-able internal oscillator with typical 1% accuracy.
- I²C Serial communications
 - Up to 3.4 Mbps data rate.
 - Slave mode hardware address decoding.
- Two package options:
 - 10-lead 2 x 2 x 0.65 mm DFN
 - 10-lead 2.9 x 4.9 x 1.2 mm LGA module with integrated 940 nm LED
- Temperature Range: -40 to +85 °C

2. Ordering Guide

Table 2.1. Ordering Guide

| Family | DFN OPNs | Package | ALS | 940 nm Filter | Proximity (# of LED Drivers) | # of LEDs Included |
|--------|-----------------|-----------------------------|-----|------------------|---------------------------------|--------------------|
| Si1153 | Si1153-AA00-GMR | 2 x 2 mm DFN | Y | | 3 | 0 |
| Si1153 | Si1153-AA09-GMR | 2 x 2 mm DFN | | Y | 3 | 0 |
| Si1153 | Si1153-AA9x-GMR | 2.85 x 4.9 mm LGA Module | | Y | 3 | 1 |

3. Functional Description

The Si1153 is an active optical reflectance proximity detector, with ambient light sensors whose operational state is controlled through registers accessible through the I2C interface. The host can command the Si1153 to initiate on-demand Ambient Light or proximity measurements. The host can also place the Si1153 in an autonomous operational state where it performs measurements at set intervals and interrupts the host either after each measurement is completed or whenever a set threshold has been crossed. This results in overall system power saving, allowing the host controller to operate longer in its sleep state instead of polling the Si1153.

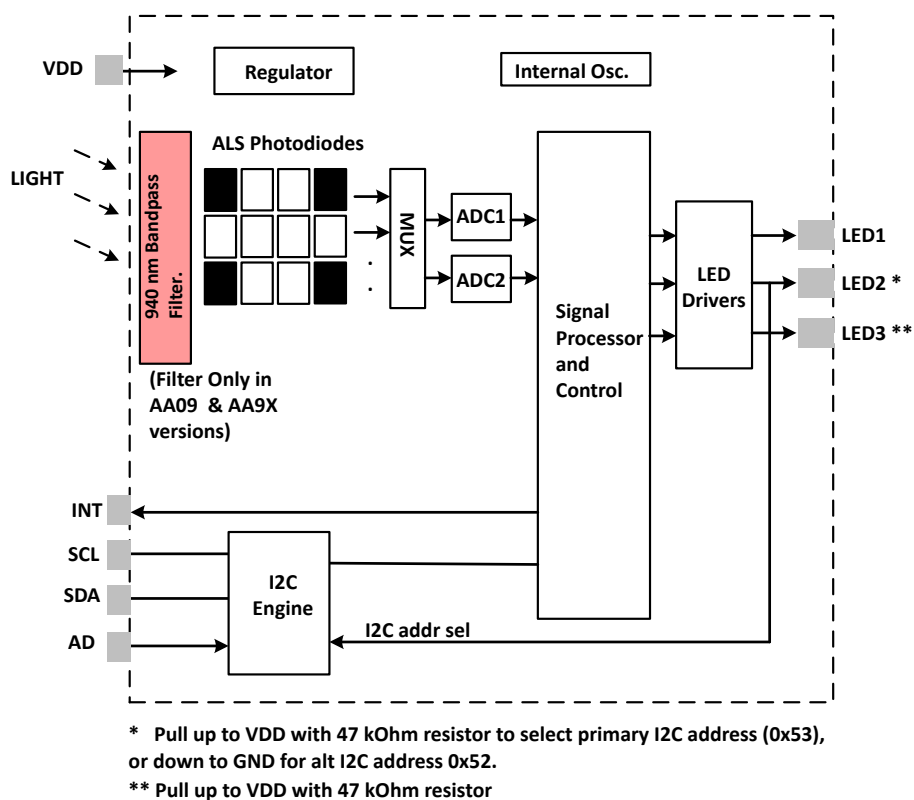


Figure 3.1. Functional Block Diagram

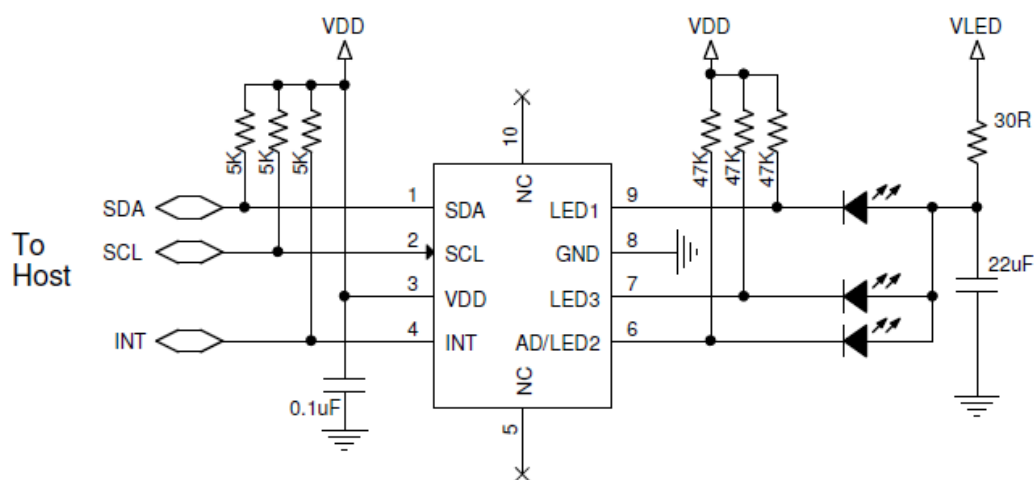


Figure 3.2. Si1153 DFN Package Basic Application

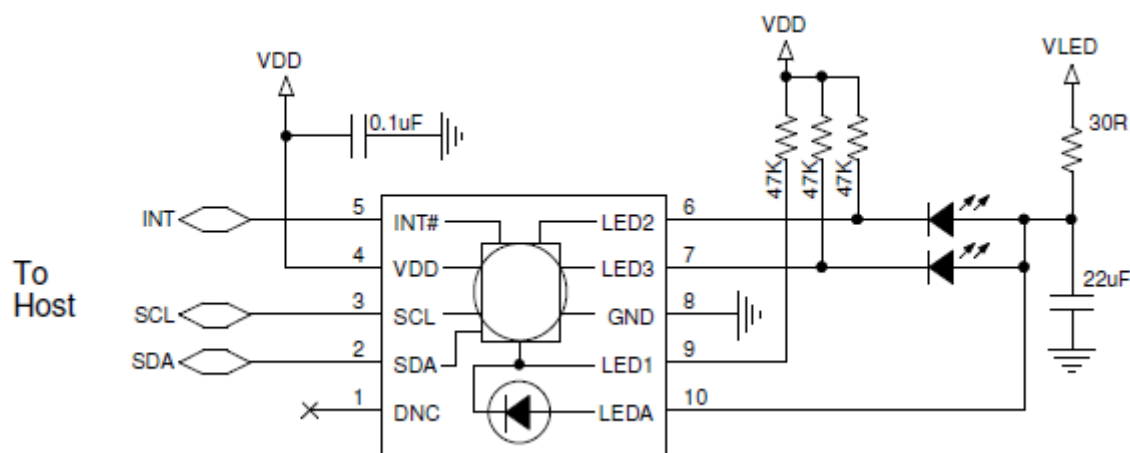


Figure 3.3. Si1153 LGA Module Basic Application

3.1 Ambient Light Sensing

The Si1153 has photodiodes capable of measuring visible and infrared light. However, the visible photodiode is also influenced by infrared light. The measurement of illuminance requires the same spectral response as the human eye. If an accurate lux measurement is desired, the extra IR response of the visible-light photodiode must be compensated. Therefore, to allow the host to make corrections to the infrared light's influence, the Si1153 reports the infrared light measurement on a separate channel. The separate visible and IR photodiodes lend themselves to a variety of algorithmic solutions. The host can then take these two measurements and run an algorithm to derive an equivalent lux level as perceived by a human eye. Having the IR correction algorithm running in the host allows for the most flexibility in adjusting for system-dependent variables. For example, if the glass used in the system blocks visible light more than infrared light, the IR correction needs to be adjusted. Si1153 parts with the bandpass 940 nm filter cannot be used for ambient light sensing.

If the host is not making any infrared corrections, the infrared measurement can be turned off in the `CHAN_LIST` parameter.

By default, the measurement parameters are optimized for indoor ambient light levels, where it is possible to detect low light levels. For operation under direct sunlight, the ADC can be programmed to operate in a high signal operation so that it is possible to measure direct sunlight without overflowing.

For low-light applications, it is possible to increase the ADC integration time. Normally, the integration time is 24.4 μ s. By increasing this integration time, the ADC can detect light levels as low as 100 mlx. The ADC integration time for the Visible Light Ambient measurement can be programmed independently of the ADC integration time of the Infrared Light Ambient measurement. The independent ADC parameters allow operation under glass covers having a higher transmittance to Infrared Light than Visible Light.

When operating in the lower signal range, or when the integration time is increased, it is possible to saturate the ADC when the ambient light suddenly increases. Any overflow condition will have the corresponding data registers report a value of 0xFFddFF for 16-bit mode and 0x7FFFFFFF for 24-bit mode. The host can adjust the ADC sensitivity to avoid an overflow condition. If the light levels return to a range within the capabilities of the ADC, the corresponding data registers begin to operate normally.

The Si1153 can initiate ALS measurements either when explicitly commanded by the host or periodically through an autonomous process. Refer to Section 4. [Operational Modes](#) for additional details.

Two ADCs can be used for simultaneous readings of the visible or proximity photodiode and black dark current reference photodiode. When subtracted, these differential measurements remove dark current, reducing noise that enables lower light sensitivity.

3.2 Proximity Sensing

The Si1153 has been optimized for use as either a dual-port or single-port active reflection proximity detector. Over distances of less than 50 cm, the dual-port active reflection proximity detector has significant advantages over single-port, motion-based infrared systems, which are only good for triggered events. Motion-based infrared detectors identify objects within proximity, but only if they are moving. Single-port motion-based infrared systems are ambiguous about stationary objects even if they are within the proximity field. The Si1153 can reliably detect an object entering or exiting a specified proximity field, even if the object is not moving or is moving very slowly. However, beyond about 30–50 cm, even with good optical isolation, single-port signal processing may be required due to static reflections from nearby objects, such as tables, walls, etc. If motion detection is acceptable, the Si1153 can achieve ranges of up to 50 cm, through a single product window.

For small objects, the drop in reflectance is as much as the fourth power of the distance. This means that there is less range ambiguity than with passive motion-based devices. For example, a sixteen fold change in an object's reflectance means only a fifty-percent drop in detection range.

The Si1153 can drive up to three separate infrared LEDs. When the three infrared LEDs are placed in an L-shaped configuration, it is possible to triangulate an object within the three-dimensional proximity field. Thus, a touchless user interface can be implemented with the aid of host software.

The Si1153 can initiate proximity sense measurements when explicitly commanded by the host or periodically through an autonomous process.

Whenever it is time to make a PS measurement, the Si1153 makes up to six measurements, depending on what is enabled in the CHLIST parameter. Other ADC parameters for these measurements can also be modified to allow proper operation under different ambient light conditions.

The LED choice is programmable for each of these six measurements. Each measurement can select which combination of 3 LEDs are turned on and which of two LED current setting banks are used to set the LED currents. Optionally, each proximity measurement can be compared against a host-programmable threshold. With threshold settings for each PS channel, it is also possible for the Si1153 to notify the host whenever the threshold has been crossed. This reduces the number of interrupts to the host, aiding in efficient software algorithms.

The Si1153 can also generate an interrupt after a complete set of proximity measurements, ignoring any threshold settings.

To support different power usage cases dynamically, the LED current of each output is independently programmable. The current can be programmed anywhere from 5.5 to 354 mA. (See [Table 8.8 Typical LED Current vs. LED Code on page 44.](#)) Therefore, the host can optimize for proximity detection performance or for power saving dynamically. This feature can be useful since it allows the host to reduce the LED current once an object has entered a proximity sphere, and the object can still be tracked at a lower current setting. Finally, the flexible current settings make it possible to control the infrared LED currents with a controlled current sink, resulting in higher precision. The ADC properties are programmable. For indoor operation, the ADC should be configured for low signal range for best reflectance sensitivity. When under high ambient conditions, the ADC should be configured for high signal level range operation.

When operating in the lower signal range, it is possible to saturate the ADC when the ambient light level is high. Any overflow condition is reported with a value of 0xFFFF for 16-bit mode and 0x7FFFFF for 24-bit mode. The host can then adjust the ADC sensitivity to avoid an overflow condition. If the light levels return to a range within the capabilities of the ADC, the corresponding data registers begin to operate normally.

The Si1153 can be configured with three different sizes of proximity photodiode to enable the highest sensitivity without saturation.

Proximity detection ranges beyond 50 cm can be achieved with lensing and by selecting a longer integration time. The detection range may be increased further, even with high ambient light, by averaging multiple measurements.

The Si1153-AA09 version of the Si1153 is designed with an on die 940 nm bandpass filter. It is designed to reject sunlight and to pass as much of the LED excitation energy as possible. 940 nm is selected as the operating wavelength since it corresponds to a dip in the energy of the solar spectrum.

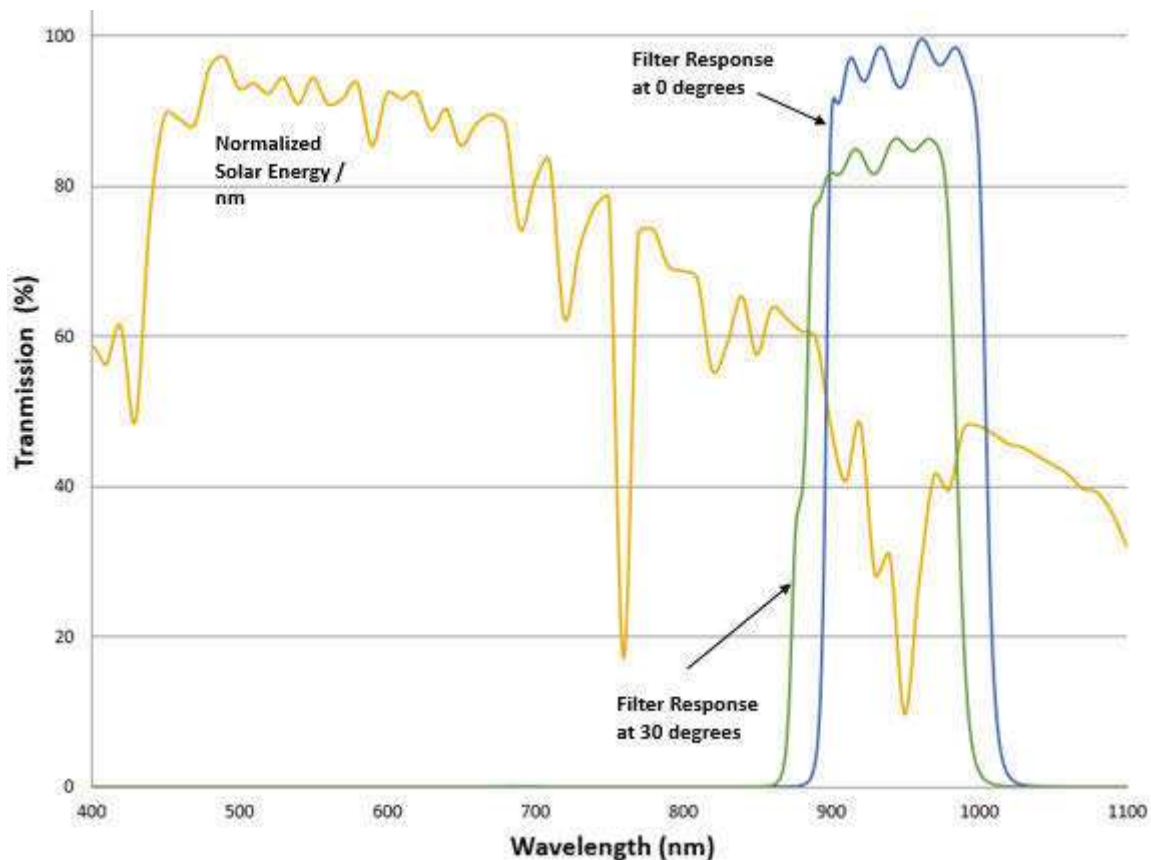


Figure 3.4. Typical Si1153-AA09 Filter Response Compared to the Sunlight Energy Spectrum

3.3 Power Consumption

The Si1153 alternates between three power consumption states: Active, Suspend, and Sleep. (See the diagram below for an illustration of each of these states.) The total power consumed by the part depends heavily on the measurement rate, measurement mode, and measurement gain for the various channels enabled. The power levels for the three modes, as well as the Active Power time per reading, are provided in this document. The Suspend time (where the A/D and PD are operating) has two parts. One is determined by the user setup and can be determined by the DECIM_RATE and HW_GAIN setup information in Section 7.2 Channel Specific Setup Areas of the Parameter Table, while the other (A/D Startup time) is determined by $t_{adstart}$, shown in Table 8.2 Electrical Performance Characteristics on page 38.

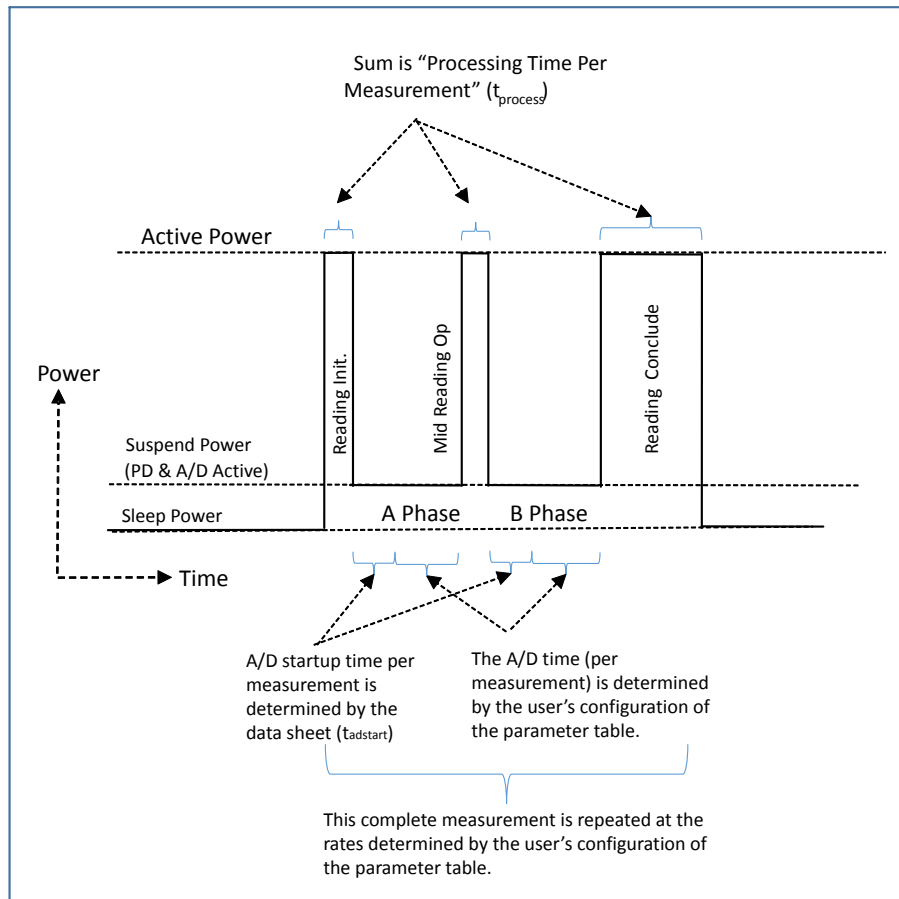


Figure 3.5. Power Consumption States During a Reading

Every A/D conversion has three periods:

- 155 μ s at 4.5 mA (setup time by internal controller)
- 48.8 μ s at 525 μ A (setup time by A/D)
- 48.8 μ s * ($2^{HW_GAIN[3:0]}$) at 525 μ A (Actual A/D time that will vary with integration time)

3.4 Host Interface

The host interface to the Si1153 consists of three pins:

- SCL
- SDA
- INT

SCL and SDA are standard open-drain pins as required for I²C operation. The Si1153 asserts the INT pin to interrupt the host processor. The INT pin is an open-drain output. A pull-up resistor is needed for proper operation. As an open-drain output, it can be shared with other open-drain interrupt sources in the system.

For proper operation, the Si1153 is expected to fully complete its Initialization Mode prior to any activity on the I²C.

The default I²C address of the Si1153 can be changed by pulling the LED pin to ground. This changes the I²C address to 0x52 (the default value is 0x53).

The INT, SCL, and SDA pins are designed so that it is possible for the Si1153 to enter the Off Mode by software command without interfering with normal operation of other I²C devices on the bus.

Conceptually, the I²C interface allows access to the Si1153 internal registers.

An I²C write access always begins with a start (or restart) condition. The first byte after the start condition is the I²C address and a read-write bit. The second byte specifies the starting address of the Si1153 internal register. Subsequent bytes are written to the Si1153 internal register sequentially until a stop condition is encountered. An I²C write access with only two bytes is typically used to set up the Si1153 internal address in preparation for an I²C read.

The I²C read access, like the I²C write access, begins with a start or restart condition. In an I²C read, the I²C master then continues to clock SCK to allow the Si1153 to drive the I²C with the internal register contents. The Si1153 also supports burst reads and burst writes. The burst read is useful in collecting contiguous, sequential registers. The Si1153 register map was designed to optimize for burst reads for interrupt handlers, and the burst writes are designed to facilitate rapid programming of commonly used fields, such as thresholds registers.

The internal register address is a six-bit (bit 5 to bit 0) plus an Auto increment Disable (on bit 6). The Auto increment Disable is turned off by default. Disabling the auto incrementing feature allows the host to poll any single internal register repeatedly without having to keep updating the Si1153 internal address every time the register is read.

It is recommended that the host should read performance measurements (in the I²C Register Map) when the Si1153 asserts INT. Although the host can read any of the Si1153's I²C registers at any time, care must be taken when reading 2-byte measurements outside the context of an interrupt handler. The host could be reading part of the 2-byte measurement when the internal sequencer is updating that same measurement coincidentally. When this happens, the host could be reading a hybrid 2-byte quantity whose high byte and low byte are parts of different samples. If the host must read these 2-byte registers outside the context of an interrupt handler, the host should "double-check" a measurement if the measurement deviates significantly from a previous reading.

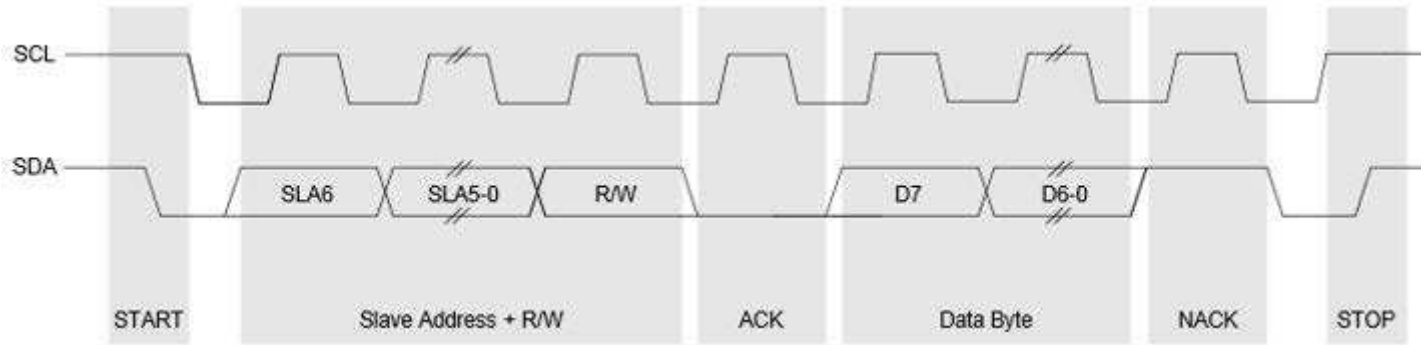


Figure 3.6. I²C Bit Timing Diagram



Figure 3.7. Host Interface Single Write

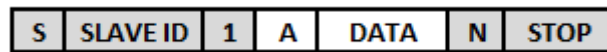


Figure 3.8. Host Interface Single Read

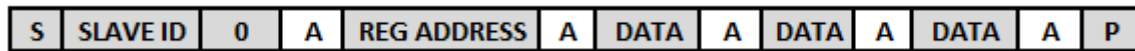


Figure 3.9. Host Interface Burst Write

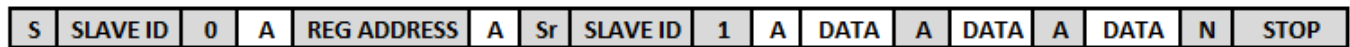


Figure 3.10. Host Interface Burst Read

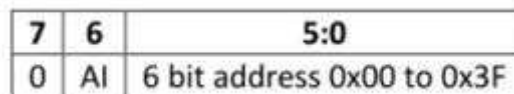


Figure 3.11. Si1153 REG ADDRESS Format

The following notes apply for the figures above:

1. Gray boxes are driven by the host to the Si1153.
2. White boxes are driven by the Si1153.
3. A = ACK or "acknowledge".
4. N = NACK or "no acknowledge".
5. S = START condition.
6. Sr = repeat START condition.
7. P = STOP condition.
8. AI = Disable Auto Increment when set.

4. Operational Modes

The Si1153 can be in one of many operational modes at any time. It is important to consider the operation mode, since the mode has an impact on the overall power consumption of the Si1153. The various modes are:

- Off Mode
- Initialization Mode
- Standby Mode
- Forced Conversion Mode
- Autonomous Mode

4.1 Off Mode

The Si1153 is in the Off Mode when V_{DD} is either not connected to a power supply or if the V_{DD} voltage is below the stated V_{DD_OFF} voltage described in the electrical specifications. As long as the parameters stated in [Table 8.7 Absolute Maximum Ratings on page 43](#) are not violated, no current will flow through the Si1153. In the Off Mode, the Si1153 SCL and SDA pins do not interfere with other I²C devices on the bus. Ensure that none of the pins have a voltage larger than the voltage on the VDD pin. If V_{DD} is grounded, for example, then current flows from system power to system ground through the SCL, SDA, and INT pull-up resistors and the ESD protection devices. Allowing V_{DD} to be less than V_{DD_OFF} is intended to serve as a hardware method of resetting the Si1153 without a dedicated reset pin.

The Si1153 can also re-enter the Off Mode upon receipt of a software reset sequence. Upon entering Off Mode, the Si1153 proceeds directly from the Off Mode to the Initialization Mode.

4.2 Initialization Mode

When power is applied to V_{DD} and is greater than the minimum V_{DD} Supply Voltage stated in the electrical specification table, the Si1153 enters its Initialization Mode. In the Initialization Mode, the Si1153 performs its initial startup sequence. Since the I²C may not yet be active, it is recommended that no I²C activity occur during this brief Initialization Mode period. The “Start-up time” specification in the electrical specification table is the minimum recommended time the host needs to wait before sending any I²C accesses following a power-up sequence. After Initialization Mode has completed, the Si1153 enters Standby Mode. During the Initialization mode, the I²C address selection is made according to whether LED2 is pulled up or down.

4.3 Standby Mode

The Si1153 spends most of its time in Standby Mode. After the Si1153 completes the Initialization Mode sequence, it enters Standby Mode. While in Standby Mode, the Si1153 does not perform any Ambient Light measurements or Proximity Detection functions. However, the I²C interface is active and ready to accept reads and writes to the Si1153 registers. The internal Digital Sequence Controller is in its sleep state and does not draw much power. In addition, the INT output retains its state until it is cleared by the host.

I²C accesses do not necessarily cause the Si1153 to exit the Standby Mode. For example, reading Si1153 registers is accomplished without needing the Digital Sequence Controller to wake from its sleep state.

4.4 Forced Conversion Mode

The Si1153 can operate in Forced Conversion Mode under the specific command of the host processor. The Forced Conversion Mode is entered when the FORCE command is sent. Upon completion of the conversion, the Si1153 can generate an interrupt to the host if the corresponding interrupt is enabled. It is possible to initiate both a proximity and ALS measurement.

4.5 Automated Operation Mode

The Si1153 can be placed in the Autonomous Operation Mode where measurements are performed automatically without requiring an explicit host command for every measurement. The START command is used to place the Si1153 in the Autonomous Operation Mode.

The Si1153 updates the I²C registers for proximity and ALS automatically. The host can also choose to be notified when these new measurements are available by enabling interrupts. The conversion frequency for autonomous operation is set up by the host prior to the START command.

The Si1153 can also interrupt the host when the proximity or ALS measurement reach a pre-set threshold. To assist in the handling of interrupts the registers are arranged so that the interrupt handler can perform an I²C burst read operation to read the necessary registers, beginning with the interrupt status register, and cycle through the various output registers.

5. User to Sensor Communication

5.1 Basic I²C Operation

I²C operation is dependent on serial I²C reads and writes to an addressable bank of memory referred to as I²C space. The diagram below outlines the registers used, some functionality and the direction of data flow. The I²C address is initially fixed but can be programmed to a new value. This new value is volatile and reverts to the old value on hardware or software reset. Only 7-bit I²C addressing is supported; 10-bit I²C addressing is not supported. The Si1153 responds to the I²C address of 0x53 or to an alternate address of 0x52.

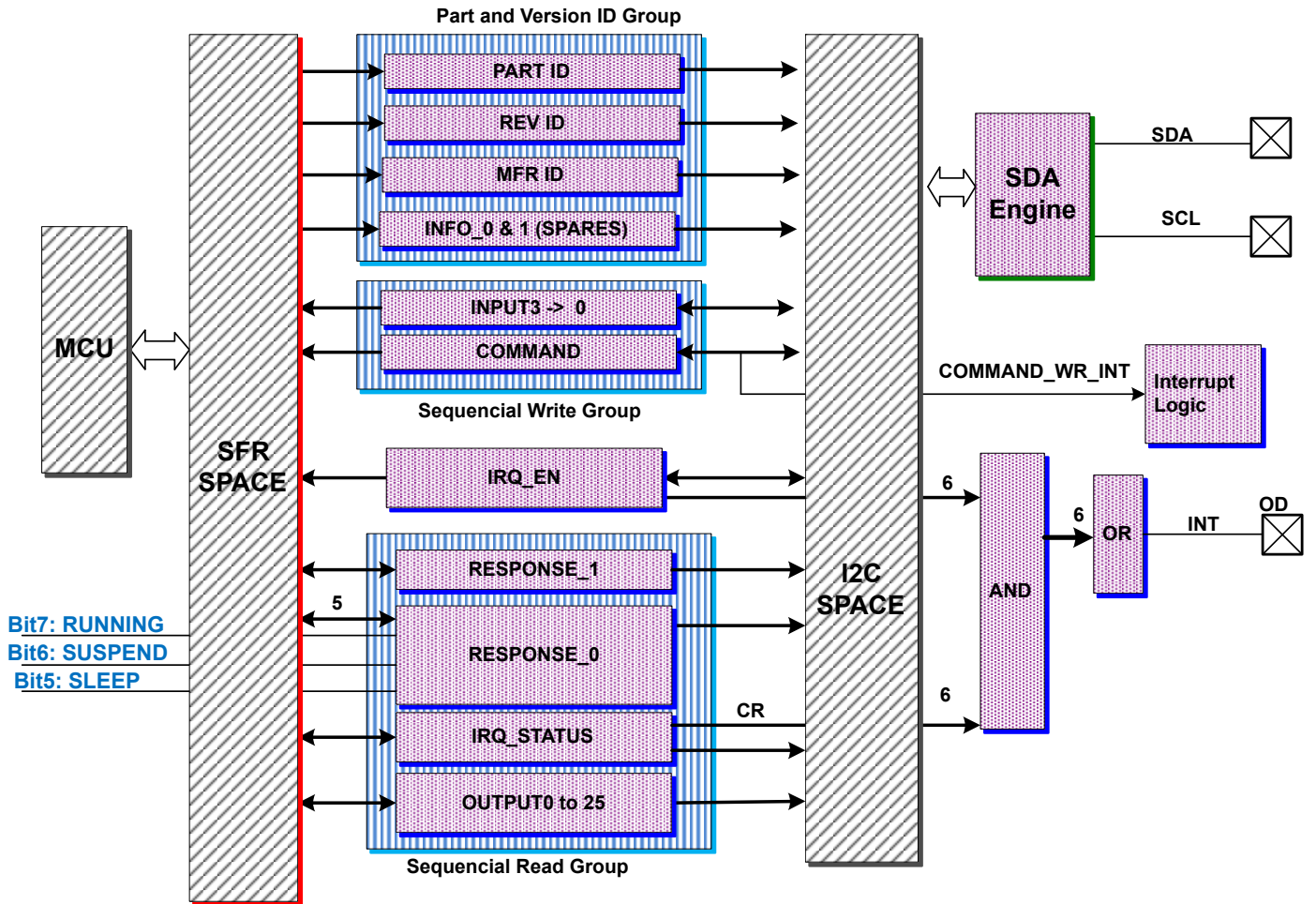


Figure 5.1. I²C Interface Block Diagram

5.2 Relationship Between I²C Registers and Parameter Table

Note that most of the Si1153 configuration is accomplished through 'Parameters'. The Si1153 has an internal MCU with SRAM. The Parameters are stored in the Si1153 Internal MCU SRAM. The I²C Registers can be viewed as mailbox registers that form an interface between the host and the internal MCU. The figure below shows the relationship between some of the key interface registers to the internal Parameters managed by the internal MCU.

- The I²C registers are directly accessible by the host.
- The parameter table is:
 - Accessible indirectly via the command register (and others).
 - Used during setup to fix the operating modes of the Si1153.
 - 0x2C bytes long and is read and written indirectly, one byte at a time, via the command register.

The data stored in the parameter table is volatile and is lost when the part is powered down or software reset command is sent to the part via the I²C part.

I2C Registers Directly Accessible by Host

| Register Name | I2C Address | Direction WRT Host |
|---------------|-------------|--------------------|
| PART_ID | 0 | IN |
| REV_ID | 1 | IN |
| MFR_ID | 2 | IN |
| INFO0 | 3 | IN |
| INFO1 | 4 | IN |
| HOSTIN3 | 7 | IN/OUT |
| HOSTIN2 | 8 | IN/OUT |
| HOSTIN1 | 9 | IN/OUT |
| HOSTIN0 | 0A | IN/OUT |
| COMMAND | 0B | IN/OUT |
| IRQ_ENABLE | 0F | IN/OUT |
| RESPONSE1 | 10 | IN |
| RESPONSE0 | 11 | IN |
| IRQ_STATUS | 12 | IN |
| HOSTOUT0 | 13 | IN |
| HOSTOUT1 | 14 | IN |
| HOSTOUT2 | 15 | IN |
| HOSTOUT3 | 16 | IN |
| HOSTOUT4 | 17 | IN |
| HOSTOUT5 | 18 | IN |
| HOSTOUT6 | 19 | IN |
| HOSTOUT7 | 1A | IN |
| HOSTOUT8 | 1B | IN |
| HOSTOUT9 | 1C | IN |
| HOSTOUT10 | 1D | IN |
| HOSTOUT11 | 1E | IN |
| HOSTOUT12 | 1F | IN |
| HOSTOUT13 | 20 | IN |
| HOSTOUT14 | 21 | IN |
| HOSTOUT15 | 22 | IN |
| HOSTOUT16 | 23 | IN |
| HOSTOUT17 | 24 | IN |
| HOSTOUT18 | 25 | IN |
| HOSTOUT19 | 26 | IN |
| HOSTOUT20 | 27 | IN |
| HOSTOUT21 | 28 | IN |
| HOSTOUT22 | 29 | IN |
| HOSTOUT23 | 2A | IN |
| HOSTOUT24 | 2B | IN |
| HOSTOUT25 | 2C | IN |

Fields used to write to Parameter Table



Sensor Parameter Table. Indirectly Accessible by Host

| Parameter Address | NAME |
|-------------------|--------------|
| 0x00 | I2C_ADDR |
| 0x01 | CHAN_LIST |
| 0x02 | ADCCONFIG0 |
| 0x03 | ADCSENS0 |
| 0x04 | ADCPPOST0 |
| 0x05 | MEASCONFIG0 |
| 0x06 | ADCCONFIG1 |
| 0x07 | ADCSENS1 |
| 0x08 | ADCPPOST1 |
| 0x09 | MEASCONFIG1 |
| 0x0A | ADCCONFIG2 |
| 0x0B | ADCSENS2 |
| 0x0C | ADCPPOST2 |
| 0x0D | MEASCONFIG2 |
| 0x0E | ADCCONFIG3 |
| 0x0F | ADCSENS3 |
| 0x10 | ADCPPOST3 |
| 0x11 | MEASCONFIG3 |
| 0x12 | ADCCONFIG4 |
| 0x13 | ADCSENS4 |
| 0x14 | ADCPPOST4 |
| 0x15 | MEASCONFIG4 |
| 0x16 | ADCCONFIG5 |
| 0x17 | ADCSENS5 |
| 0x18 | ADCPPOST5 |
| 0x19 | MEASCONFIG5 |
| 0x1A | MEASRATE_H |
| 0x1B | MEASRATE_L |
| 0x1C | MEASCOUNT0 |
| 0x1D | MEASCOUNT1 |
| 0x1E | MEASCOUNT2 |
| 0x1F | LED1_A |
| 0x20 | LED1_B |
| 0x21 | LED2_A |
| 0x22 | LED2_B |
| 0x23 | LED3_A |
| 0x24 | LED3_B |
| 0x25 | THRESHOLD0_H |
| 0x26 | THRESHOLD0_L |
| 0x27 | THRESHOLD1_H |
| 0x28 | THRESHOLD1_L |
| 0x29 | THRESHOLD2_H |
| 0x2A | THRESHOLD2_L |
| 0x2B | BURST |

Figure 5.2. Accessing Parameters through I²C Registers

5.3 I²C Command Register Operation

Writing the codes shown below in the command summary table signals the sensor to undertake one of several complex operations.

These operations take time and all commands should be followed by a read of the RESPONSE0 register to confirm the operation is complete by examining the counter and to check for an error in the error bit. The error bit is set in the RESPONSE0 register's command counter if there is an error in the previous command (e.g., attempt to write to an illegal address beyond the parameter table, or a channel and /or burst configuration that exceeds the size of the output field (26 bytes)). If there is no such error, then the counter portion of the command counter will be incremented.

The RESPONSE_0 register should be read after every command to determine completion and to check for an error. If an error is found, which should not happen except for a host SW bug, the host should clear the error with a RESET command or a RESET_CMD_CTR command.

One operating option is to do a RESET_CMD_CTR command before every command.

Two of the commands imply another I²C register contains an argument.

- STORE_NEW_I2C_ADDR command implies a new address has been loaded in the parameter table location I2CID PARAMETER.
- PARAM_SET command implies a byte has been stuffed into INPUT0 register.
- The three CHAN_LIST commands imply the CHAN_LIST location in the parameter table has been configured. A valid CHAN_LIST implies other configuration areas in the parameter table are correctly setup as well.

Two of the commands result in another I²C register containing return arguments (aside from incrementing RESPONSE0).

- PARAM_SET results in the write data being copied in to I2C RESPONSE1 register.
- PARAM_QUERY results in read data in the I2C RESPONSE1 register.

Table 5.1. Command Summary

| Command Register Commands | Code | Input to Sensor | Output of Sensor |
|---|------------|-----------------|--------------------|
| RESET_CMD_CTR Resets RESPONSE0 CMMND_CTR field to 0. | 0x00 | ----- | ----- |
| RESET_SW Forces a Reset, Resets RESPONSE0 CMMND_CTR field to 0xXXX01111. | 0x01 | ----- | ----- |
| FORCE Initiates a set of measurements specified in CHAN_LIST parameter. A FORCE command will only execute the measurements which do not have a meas counter index configured in MEASCONFIGx. | 0x11 | ----- | ----- |
| PAUSE Pauses autonomous measurements specified in CHAN_LIST. | 0x12 | ----- | ----- |
| START Starts autonomous measurements specified in CHAN_LIST. A START autonomous command will only start the measurements which has a counter index selected in MEASCONFIGx. | 0x13 | ----- | ----- |
| PARAM_QUERY Reads Parameter xxxxxx and store results in RESPONSE1.xxxxxx is a 6 bit Address Field (64 bytes). | 0b01xxxxxx | | RESPONSE1 = result |
| PARAM_SET Writes INPUT0 to the Parameter xxxxxx.xxxxxx is a 6 bit Address Field (64 bytes). | 0b10xxxxxx | INPUT0 | RESPONSE1 = INPUT0 |
| Notes: <ol style="list-style-type: none"> 1. The successful completion of all commands except RESET_CMD_CTR and RESET_SW causes an increment of the CMD_CTR field of the RESPONSE0 register (bits [3:0]). 2. Resets RESPONSE0 CMMND_CTR field to 0. 3. Forces a Reset, Resets RESPONSE0 CMMND_CTR field to 0xXXX01111. 4. Uses CHAN_LIST in Parameter Space. 5. "xxxxxx" is a 6-bit Address Field (64 bytes). | | | |

5.3.1 Accessing the Parameter Table (PARAM_QUERY & PARAM_SET Commands)

The parameter table is written to by writing the INPUT_0 I2C register and the PARAM_SET command byte to the Command I²C register. The format of the PARAM_SET word is such that the 6 LSBits contain the location of the target byte in the parameter table.

Example: To transfer 0xA5 to parameter table location 0b010101.

Read RESPONSE0 (address 0x11) and store the CMMND_CTR field.

Write 0xA5 to INPUT0 (address 0x0A).

Write 0b10010101 to COMMAND (address 0x0B).

Read RESPONSE0 (address 0x11) and check if the CMMND_CTR field incremented.

If there is no increment or error, repeat the “read the RESPONSE0” step until the CMMND_CTR has incremented. If there is an error send a RESET or a RESET_CMD_CTR command.

The two write commands (to INPUT0 and COMMAND) can be in the same I²C transaction.

Example: To read data from the parameter table location 0b010101.

Read the RESPONSE0 (address 0x11) and store the CMMND_CTR field.

Write 0b01010101 to the COMMAND (address 0x0B).

Read RESPONSE0 (address 0x11) and check if the CMMND_CTR field incremented.

If there is no increment or error, repeat the “read RESPONSE0” step until the CMMND_CTR has incremented.

Read RESPONSE1 (address 0x10) this gives the read result. If there is an error send RESET or a RESET_CMD_CTR command.

The last two read commands (from RESPONSE0 and RESPONSE1) should not be in the same I²C transaction.

5.3.2 Sensor Operation Initiation Commands

The FORCE, PAUSE, and START commands make use of the information in CHAN_LIST. Configure CHAN_LIST prior to using any of these commands.

5.3.3 RESET_CMD_CTR Command

Resets RESPONSE0 CMMND_CTR field and does nothing else.

5.3.4 RESET Command

Resets the sensor and puts it into the same state as when powering up. The parameter table and all I²C registers are reset to their default values.

5.4 I²C Register Summary

The content of the three MSBits of Response0 after reset will depend on the running state (see the Response0 write up).

Table 5.2. I2C Registers

| Register Name | I2C Address | Direction WRT Host | Function | Value after Reset (Hard or Soft) | Direction WRT Sensor |
|-----------------------------|--------------------|--------------------|--|----------------------------------|----------------------|
| PART_ID | 0x00 | IN | Returns DEVID (0x53 for the Si1153). | PART_ID | OUT |
| HW_ID | 0x01 | IN | Returns Hardware ID. | HW_ID | OUT |
| REV_ID | 0x02 | IN | Hardware Rev (0xMN). | REV_ID | OUT |
| HOSTIN0 | 0x0A | IN/OUT | Data for parameter table on PARAM_SET write to COMMAND register. | 0x00 | IN |
| COMMAND | 0x0B | IN/OUT | Initiated action in Sensor when specific codes written here. | 0x00 | IN |
| IRQENABLE | 0x0F | IN/OUT | The six least significant bits enable Interrupt Operation. | 0x00 | IN |
| RESPONSE1 | 0x10 | IN | Contains the read-back value from a param query or a param set command. | 0x00 | IN/OUT |
| RESPONSE0 | 0x11 | IN | The 5 th MSB of the counter is an error indicator, with the 4 LSBits indicating the error code when the MSB is set. | 0XXXXX1111 | IN/OUT |
| IRQ_STATUS | 0x12 | IN | The six least significant bits show the interrupt status. | 0x00 | IN/OUT |
| HOSTOUT0 to HOSTOUT25 | 0x13 to 0x2C | IN | Captured Sensor Data. | 0x00 | IN/OUT |

5.4.1 PART_ID

I2C Address = 0x00;

Contains Part ID, e.g., 0x53 for Si1153.

5.4.2 HW_ID

I2C Address = 0x01;

Contains the Hardware information.

BITS4:0 = Filter, LED & Module code

BITS7:5 = Silicon HW rev (Steps with silicon mask change)

| Part Number | Features | BITS4:0 code |
|-------------|---------------------------------|--------------|
| Si1153-AA00 | — | 0x00 |
| Si1153-AA09 | 940 nm filter | 0x01 |
| Si1153-AAX9 | Module with 940 nm filter & LED | 0x02 |

5.4.3 REV_ID

I2C Address = 0x02;

Contains the product revision, in a 0xMN format where “M” is the major rev and “N” the minor rev.

5.4.4 INFO0

I2C Address = 3;

Contains 0 after a hard reset or a RESET Command.

5.4.5 INFO1

I2C Address = 4;

Contains 0 after a hard reset or a RESET Command.

5.4.6 HOSTIN0

| Name | I2C Address |
|---------|-------------|
| HOSTIN0 | 0x0A |

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---------|---|---|---|---|---|---|---|
| Name | HOSTIN0 | | | | | | | |
| Type | R/W | | | | | | | |
| Reset | 0 | | | | | | | |

| Bit | Name | Function |
|-----|---------|--|
| 7:0 | HOSTIN0 | This Register is the Input to the Sensor and Output of the Host. |

Contain 0 after a hard reset or a RESET Command.

5.4.7 COMMAND

I2C Address = 0x0B;

Contains 0 after a hard reset or a RESET Command.

5.4.8 IRQENABLE

I2C Address = 0x0F;

Contains 0 after a hard reset or a RESET Command.

5.4.9 RESPONSE1**I2C Address = 0x10;**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----------------|---|---|---|---|---|---|---|
| Name | RESPONSE1[7:0] | | | | | | | |
| Type | R | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | Name | Function |
|-----|----------------|---|
| 7:0 | RESPONSE1[7:0] | The sensor mirrors the data byte written to the parameter table here for the user to verify the write was successful. A parameter read command results in the byte read being available here for the host. |

5.4.10 RESPONSE0**I2C Address = 0x11;**

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---------|---------|-------|---------|--------------|---|---|---|
| Name | RUNNING | SUSPEND | SLEEP | CMD_ERR | CMD_CTR[4:0] | | | |
| Type | R | R | R | R | R | R | R | R |
| Reset | N/A | N/A | N/A | 0 | 1 | 1 | 1 | 1 |

| Bit | Name | Function | | |
|------|---|--|--|--|
| 7 | RUNNING | Indicator of MCU state. | | |
| 6 | SUSPEND | Indicator of MCU state. | | |
| 5 | SLEEP | Indicator of MCU state. | | |
| 4 | CMD_ERR | It is cleared by a hardware reset (power up) or a RESET command or a RESET_CMD_CTR. It is set by a bad command. E.g., an attempt to write beyond the parameter table. If it is set, the CMMND_CTR field is the error code. | | |
| 3:0 | CMMND_CTR | IF CMD_ERR = 0 | A counter that increments on every GOOD command (successful I ² C Command Register write and sensor execution of the command). It is reset to 0 by the RESET_CMD_CTR command. It is set to 0b1111 on Power Up or a RESET command. This is how a user can detect a fresh SW reset or a power up event. | |
| | | IF CMD_ERR = 1 | Code | Meaning |
| | | | 0x10 | Invalid command. |
| | | | 0x11 | Parameter access to an invalid location. |
| | | | 0x12 | Saturation of the ADC or overflow of accumulation. |
| 0x13 | Output buffer overflow—this can happen when Burst mode is enabled and configured for greater than 26 bytes of output. | | | |

The RESPONSE0 register will show “RUNNING” immediately after reset and then “SLEEP” after initialization is complete.

5.4.11 IRQ_STATUS

I2C Address = 0x12;

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|---|------|------|------|------|------|------|
| Name | — | | IRQ5 | IRQ4 | IRQ3 | IRQ2 | IRQ1 | IRQ0 |
| Type | RSVD | | CR | CR | CR | CR | CR | CR |
| Reset | | | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | Name | Function |
|-----|--------|--|
| 7:6 | UNUSED | Unused. Read = 00b; Write = Don't Care. |
| 5 | IRQ5 | Enables an IRQ for channel 5 result being ready. |
| 4 | IRQ4 | Enables an IRQ for channel 4 result being ready. |
| 3 | IRQ3 | Enables an IRQ for channel 3 result being ready. |
| 2 | IRQ2 | Enables an IRQ for channel 2 result being ready. |
| 1 | IRQ1 | Enables an IRQ for channel 1 result being ready. |
| 0 | IRQ0 | Enables an IRQ for channel 0 result being ready. |

5.4.12 HOSTOUTx

This section covers the twenty-six I2C Host Output Registers. These registers are the output of the sensor and input to the host.

| Name | I2C Address |
|-----------|-------------|
| HOSTOUT0 | 0x13 |
| to | to |
| HOSTOUT25 | 0x2C |

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----------|---|---|---|---|---|---|---|
| Name | HOSTOUTx | | | | | | | |
| Type | R | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | Name | Function |
|-----|----------|---|
| 7:0 | HOSTOUTx | <p>These registers are the output of the MCU and input to the host. The results of the CHAN_LIST enabled “active channel” readings are located sequentially in this table. Each channel may use 2 or 3 bytes depending on the setup.</p> <p>The validity of the various channel outputs located in this table is determined by other factors. Data is valid when an IRQ status says that it is and remains valid until another reading happens. This is why it is imperative to service the interrupt before the next measurement cycle begins (Autonomous Mode), unless forced mode is used.</p> |

6. Measurement: Principle of Operation

Operation is based on the concept of channels. Channels are essentially tasks that have been setup by the user.

To setup these channels, the channel specific areas of the parameter table need to be loaded with the correct information as well as the global area of this table.

The channels' specific areas are described below, including:

- ADC gain
- The photodiode selected
- The counter selected to time
- How often to make a measurement
- The format of the output (16 vs. 24 bits)
- And other areas

The global area includes global information that affect all tasks, such as:

- The list of channels that are enabled.
- The setup of the two counters that can be used by the channels.
- The three light thresholds that can be selected from by the channels.

The list of channels, `CHAN_LIST`, in the global area determines what operations are run and how the results are packed in the output fields.

The packing of the result data in the output fields is totally determined by the enabled channels as they are packed sequentially from the lowest enabled channel to the highest in the output field (I2C space- `HOSTOUT0` to `HOSTOUT25`). The amount of space used by each channel is determined by the 16 vs. 24 bit selection made in the channel setup.

Although space in the output buffer is reserved by the `CHAN_LIST`, the data validity is determined by the `IRQ_STATUS` register in Autonomous Mode and by elapsed time in Forced Mode. In Burst Mode, a subset of Autonomous Mode, all the expected data is valid.

6.1 Output Field Utilization

In all modes, the `CHAN_LIST` configuration determines how the data is stacked in the 26 byte output field. It is done on a first-come first-served basis, with the enabled lower channels taking up the lower addresses. When burst is enabled, the channel arrangement is just repeated to higher and higher addresses. See the example below.

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

| I2C Register | I2C Address | Content |
|--------------|-------------|---|
| H0STOUT0 | 13 | Channel 1 Result: Most Significant Byte |
| H0STOUT1 | 14 | Channel 1 Result: Middle Significant Byte |
| H0STOUT2 | 15 | Channel 1 Result: Least Significant Byte |
| H0STOUT3 | 16 | Channel 3 Result: Most Significant Byte |
| H0STOUT4 | 17 | Channel 3 Result: Least Significant Byte |
| H0STOUT5 | 13 | Channel 4 Result: Most Significant Byte |
| H0STOUT6 | 14 | Channel 4 Result: Middle Significant Byte |
| H0STOUT7 | 1A | Channel 4 Result: Least Significant Byte |
| H0STOUT8 | 1B | Channel 5 Result: Most Significant Byte |
| H0STOUT9 | 1C | Channel 5 Result: Least Significant Byte |
| H0STOUT10 | 1D | Unused |
| H0STOUT11 | 1E | Unused |
| H0STOUT12 | 1F | Unused |
| H0STOUT13 | 20 | Unused |
| H0STOUT14 | 21 | Unused |
| H0STOUT15 | 22 | Unused |
| H0STOUT16 | 23 | Unused |
| H0STOUT17 | 24 | Unused |
| H0STOUT18 | 25 | Unused |
| H0STOUT19 | 26 | Unused |
| H0STOUT20 | 27 | Unused |
| H0STOUT21 | 28 | Unused |
| H0STOUT22 | 29 | Unused |
| H0STOUT23 | 2A | Unused |
| H0STOUT24 | 2B | Unused |
| H0STOUT25 | 2C | Unused |

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

Figure 6.1. Output Table Data Packing

6.2 Autonomous and Forced Modes

In Autonomous Mode, the user uses the timer fields in both the global and channels specific areas in order to set up the timing for repeated measurements. The user then sends the command to start these autonomous measurements repeatedly. When each channel's timer is tripped, the measurement for that channel is started. When the channel measurement completes, it is signaled by the IRQ_STATUS bits and by an interrupt (if the interrupt is enabled). After that signal, the sensor restarts the channel timer and waits for it to trip and signal the next measurement. The host must read the data before the next reading is generated, or risk losing the reading or getting garbage data to sample smearing (reading data in the midst of it changing).

In Forced Mode, all measurements enabled in the CHAN_LIST start as a result of a FORCE command and are only done once. If there are multiple channels enabled, then the measurements are done back-to-back starting with the lower number channel. The completion signaling is the same as for autonomous, the IRQ_STATUS and interrupt if it is enabled. The logical difference is that all the enabled channels are always shown as simultaneously ready in the IRQ_STATUS, whereas in Autonomous Mode this is not true. FORCE command only works on measurements which do not have a measurement counter selected in MEASCONFIGx.

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

| I2C SPACE | | |
|------------|-------|---------|
| IRQ_STATUS | | |
| Value | Bit | Meaning |
| 0 | Bit 0 | Chan 0 |
| 0 | Bit 1 | Chan 1 |
| 0 | Bit 2 | Chan 2 |
| 1 | Bit 3 | Chan 3 |
| 0 | Bit 4 | Chan 4 |
| 1 | Bit 5 | Chan 5 |
| X | Bit 6 | X |
| X | Bit 7 | X |

| I2C Register | I2C Address | Content |
|--------------|-------------|---|
| H0STOUT0 | 13 | Channel 1 Result: Most Significant Byte |
| H0STOUT1 | 14 | Channel 1 Result: Middle Significant Byte |
| H0STOUT2 | 15 | Channel 1 Result: Least Significant Byte |
| H0STOUT3 | 16 | Channel 3 Result: Most Significant Byte |
| H0STOUT4 | 17 | Channel 3 Result: Least Significant Byte |
| H0STOUT5 | 13 | Channel 4 Result: Most Significant Byte |
| H0STOUT6 | 14 | Channel 4 Result: Middle Significant Byte |
| H0STOUT7 | 1A | Channel 4 Result: Least Significant Byte |
| H0STOUT8 | 1B | Channel 5 Result: Most Significant Byte |
| H0STOUT9 | 1C | Channel 5 Result: Least Significant Byte |
| H0STOUT10 | 1D | Unused |
| H0STOUT11 | 1E | Unused |
| H0STOUT12 | 1F | Unused |
| H0STOUT13 | 20 | Unused |
| H0STOUT14 | 21 | Unused |
| H0STOUT15 | 22 | Unused |
| H0STOUT16 | 23 | Unused |
| H0STOUT17 | 24 | Unused |
| H0STOUT18 | 25 | Unused |
| H0STOUT19 | 26 | Unused |
| H0STOUT20 | 27 | Unused |
| H0STOUT21 | 28 | Unused |
| H0STOUT22 | 29 | Unused |
| H0STOUT23 | 2A | Unused |
| H0STOUT24 | 2B | Unused |
| H0STOUT25 | 2C | Unused |

The IRQ_STATUS bits signal which of the possible fields are updated with new information. All other fields should be considered invalid and possibly containing wrong transitory information.

This is despite the reserved space in the output table for the readings that have not yet happened.

Figure 6.2. IRQ_STATUS Shows Which Output Fields Have Valid Data