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15-bit Ambient Light Sensor with I^2C Interface

n Description

The LS-3139 is a digital-output light sensor with a two-wire, I^2C serial interface that is compatible with SMBus when working at 100 KHz serial clock frequency. It combines a photodiode and an analog-to-digital converter (ADC) on a single CMOS integrated circuit to provide light measurements over an effective 15-bit dynamic range with a response similar to that of the human eye. Two operation modes are provided with one for constantly refreshing ADC and the other for one time integration. When working in "one time integration" mode, no external resister is required. This device is intended primarily for use in applications in which measurement of ambient light is used to control display backlighting such as laptop computers, PDAs, camcorders, and GPS systems. Other applications include contrast control in LED signs and displays, camera exposure control, lighting controls, etc. The integrating conversion technique used by the LS-3139 effectively eliminates the effect of flicker from AC-powered lamps, increasing the stability of the measurement.

n Features

- Human eye type spectral response
- 15-bit effective resolution
- Provides an output count proportional to ambient light over the full operating range
- High dynamic sensing range from 0 to more than 68,000Lux
- Linear response over the full operating range
- Rejects 50Hz/60Hz lighting ripple
- Low power consumption, less than 2mW while operating
- Shut-down mode, current consumption less than 0.1uA
- I^2C serial port communication: (1) Standard 100kHz, (2).Fast 400kHz
- Guaranteed operating temperature range from -40 to 85°C
- Wide operating voltage range: 2.7 ~ 5.5V

n Applications

- Backlight control for TFT LCD display
- Residential and commercial lighting management
- Contrast enhancement for electronic signboard
- Ambient light monitoring device for daylight and artificial light

Functional Block Diagram

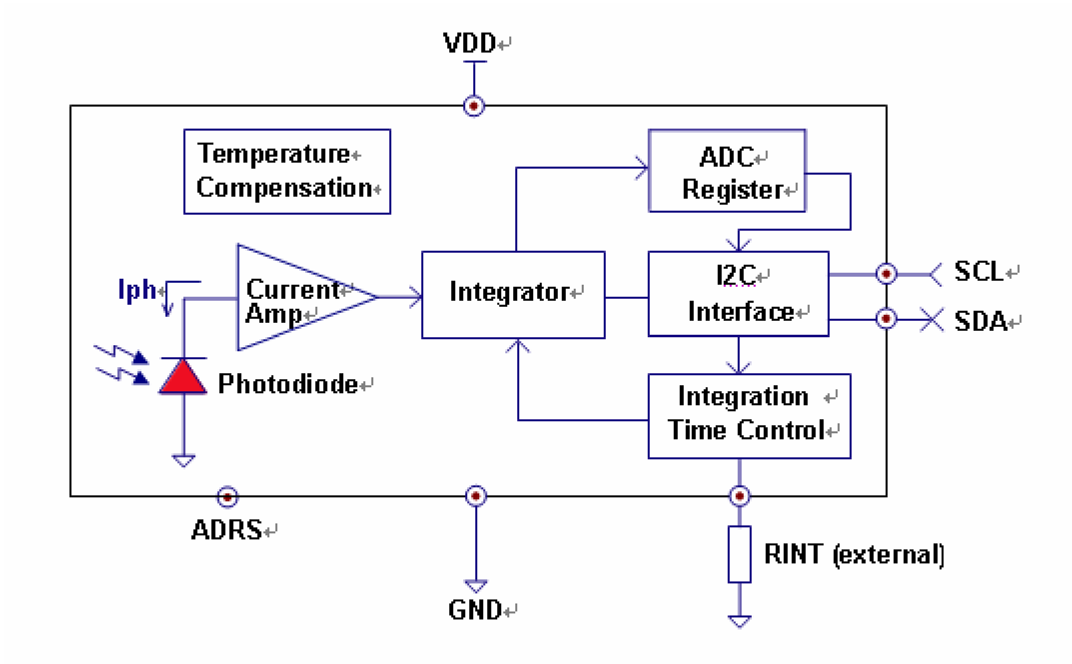


Figure 1. LS-3139 ***Functional Block Diagram***

Pad Descriptions

Pad Name	I/O	Function
VDD	Power	Supply voltage
GND	Power	Power and signal return
RINT	Input	Connecting a resistor to GND for adjusting integration time
SDA	I/O	I^2C serial data input/output terminal
SCL	Input	I^2C serial clock input terminal
ADRS	I/P	I^2C address option pad

Absolute Maximum Ratings

For implementations where case to ambient thermal resistance is <= 50°C/W

Parameter	Symbol	Min.	Max.	Units
Storage temperature	T_{STG}	-40	100	°C
Operating temperature	T_{OPR}	-40	85	°C
Supply voltage	V_{DD}	-0.3	6.0	V
Digital output voltage	Vo	-0.3	6.0	V
Digital output current	Io	-10	+10	mA
ESD tolerance, human body model	-	2	-	KV

Electrical & Optical Specifications (Ta = 25°C, V_{DD}=3.3V)

Parameter	SYB	Test Conditions	Min.	Typ.	Max.	Units
Supply current	I_{DD}	Active mode	-	0.4	0.5	mA
	I_{DDQ}	Power-down mode	-	0.01	0.1	uA
I^2C output low voltage	V_{OL}	Io = 4mA	-	-	0.4	V
Detection limit		Full scale	-	-	32,767	count
		Tint = 100mS	-	-	68,000	lux
Peak sensitivity wavelength	λp	-	-	580	-	nm
Response in dark environment	R_{dak}	Ev = 0 lux, Tint = 100 mS	-	-	1	count
incandescent /fluorescent response Ratio	RIF	Ev = 100 lux Tint = 100 mS		1		
Response to white LED lamp	R_{led}	Ev = 100 lux Tint = 100 mS	41	48	56	count

DC Characteristics of I²C Signals in Standard and Fast Mode

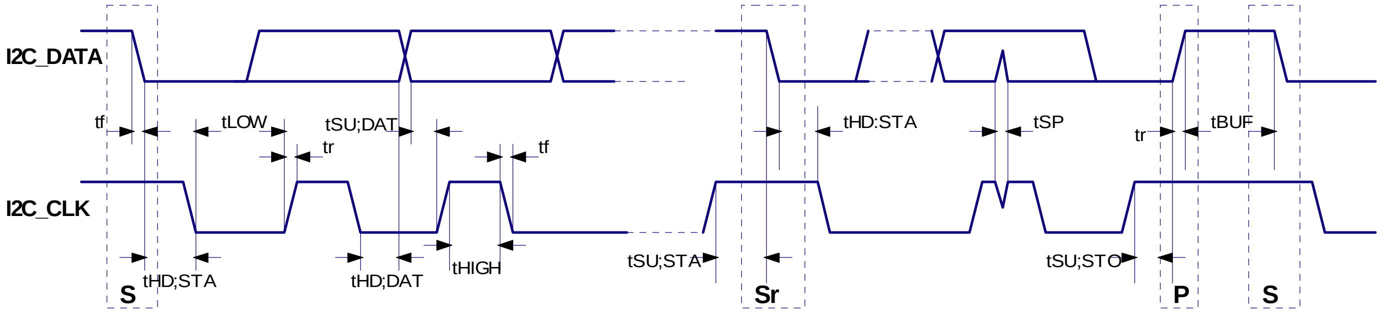
Parameter	Symbol	Standard Mode		Fast Mode		Unit
		Min.	Max.	Min.	max.	
Power supply voltage (recommend)	V_{DD}	2.7	5.5	2.7	5.5	V
Low level input voltage	V_{IL}	-0.5	1.0	-0.5	1.0	V
High level input voltage	V_{IH}	2.0		2.0		V
Hysteresis of Schmit trigger inputs (V_{DD} > 2V)	V_{hys}	$0.05V_{DD}$	-	$0.05V_{DD}$	-	V
Low level output voltage (open drain) at 3mA sink current (V_{DD} > 2V)	V_{OL1}	0	0.4	0	0.4	V
Output fall time from V_{IHMIN} to V_{ILMAX} with a bus capacitance from 10pF to 400pF	t_{of}	-	250[2]	20+0.1Cb [1]	250 [2]	nS
Input current of each IO pins with an input voltage between $0.1V_{DD}$ and $0.9V_{DD}$	I_i	-10	10	-10	10	uA
Capacitance for each IO pin	C_i	-	10	-	10	pF

Notes:
1. Cb = capacitance of one bus line in pF
2. The maximum tf for the I²C data and clock bus lines quoted in the AC table is longer than the specified maximum t_{of} for the output stages (250nS). This allows series protection resistors (Rs) to be connected between I²C data / clock pins and the I²C data / clock bus lines without exceeding the maximum specified t_f.

AC Characteristics of I²C Signals in Standard and Fast Mode

Parameter	Symbol	Standard Mode		Fast Mode		Unit
		Min.	Max.	Min.	max.	
I²C clock frequency	f_{SCL}	0	100	0	400	KHz
Hold time (repeated) START condition. After this period, the first clock pulse is generated.	$t_{HD;STA}$	4.0		0.6	-	uS
Low period of I²C clock	t_{LOW}	4.7		1.3		uS
High period of I²C clock	t_{HIGH}	4.0		0.6		uS
Set-up time for a repeated START condition	$t_{SU;STA}$	4.7		0.6		uS
Data hold time for I²C-bus devices	$t_{HD;DAT}$	0	3.45	0	0.9	uS
Data set-up time	$t_{SU;DAT}$	250	-	100	-	nS
Rise time of both I²C data and clock	t_r	-	1000	5	300	nS

signalss						
Fall time of both I^{2}C data and clock signals	tf	-	300	0.1	300	nS
Set-up time for STOP condition	$t_{SU;STO}$	4.0	-	0.6	-	uS
Bus free time between STOP and START condition	t_{BUF}	4.7	-	1.3	-	uS
Capacitive load for each bus line	Cb	-	400	-	400	pF
Noise margin at the low level for each connected device (including hysteresis)	V_{nL}	$0.1V_{DD}$	-	$0.1V_{DD}$	-	V
Noise margin at the high level for each connected device (including hysteresis)	V_{nH}	$0.2V_{DD}$	-	$0.2V_{DD}$	-	V



S: Start **Sr**: Repeated Start **P**: Stop

Figure 2.* I^{2}C *Timing Diagram

n Communication Protocol

The LS-3139 contains an 8-bit command register that can be written and read via the I^{2}C bus. The command register controls the overall operation of the device. There is a two-byte word read-only register that contains the latest converted value of A/D converter. The I^{2}C slave address is hardwired internally as 0111001 (0x39, MSB to LSB, A6 to A0). All the *Send Byte protocol*, the *Receive Byte protocol* and *Receive Word protocol* are implemented in the LS-3139.

The *Send Byte protocol* allows single bytes of data to be written to the device (see *Figure* 3-a). The written byte is called the COMMAND byte. The *Receive Byte protocol* allows one-byte data to be read from the device (see *Figure* 3-b). Two-byte data can be read by following the *Receive Word Protocol* shown in *Figure* 3-c. In *Figure* 3, the clear area represents data sent by the host (master) and the shaded area represents data returned by the ambient light sensor (slave device).

1	7	1	1	8	1	1
S	Slave Address	WR	A	Command Byte	A	P
		0	0		0	

(a) send byte protocol

1	7	1	1	8	1	1
S	Slave Address	RD	A	Data	NA	P
		1	0		1	

(b) Receive byte protocol

1	7	1	1	8	1	8	1	1
S	Slave Address	RD	A	LS byte of ADC	A	MS byte of ADC	NA	P
		1	0		0		1	

(c) Receive word (two bytes) protocol

S = start condition P = stop condition Shaded = slave transmission

A = acknowledge NA = not acknowledge WR = write RD= read

Figure 3. Communication Protocol

n Communication Format

This LS-3139 is capable of working as an I²C slave. Address of this device on I²C bus is always 0x39 (hexadecimal number 39). Registers of the slave device can be programmed by sending commands over I²C bus.

Figure 4 shows an I²C write operation. To write to an internal register of the slave device a command must be sent by an I²C master. As illustrated in *Figure 4*, the I²C write command begins with a start condition. After the start condition, seven bits of address are sent with MSB going first. RD / WRn (=Low) command bit follows the address bits. Upon receiving a valid address the slave device responds by driving SDA low for an ACK. After receiving an ACK, I²C master sends eight bits of data with MSB first. Upon receiving eight bits of data the slave device generates an ACK. I²C master terminates this write command with a stop condition.

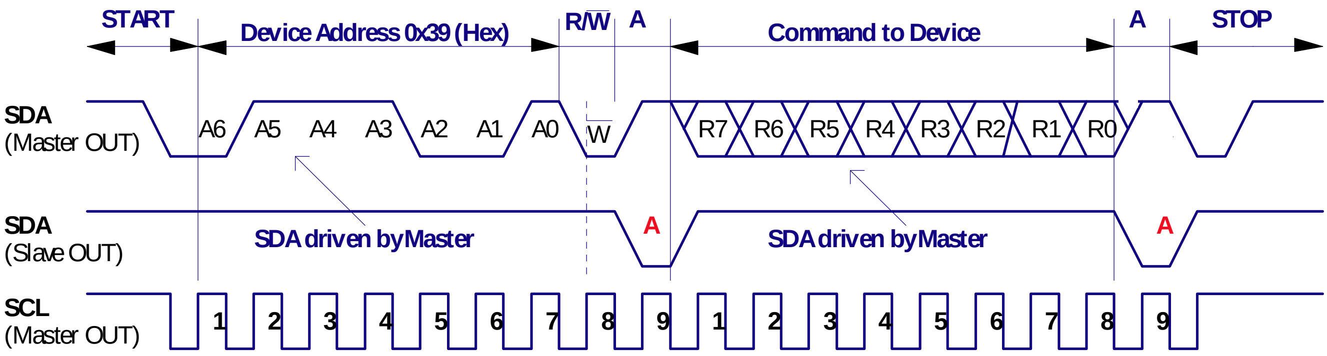


Figure 4.* I²C Timing Diagram for *Send Byte Format

Figure 5 shows an I²C read command sent by the master to the slave device. I²C read command begins with a start condition. After the start condition seven bits of address are sent by the master with MSB going first. After the address bits, RD / WRn command bit is sent. For a read command the RD / WRn bits is high. Upon receiving the address bits and RD / WRn command bits the slave device responds with an ACK. After sending an ACK, the slave device sends eight bits of data with MSB going first. After receiving the one byte data, the I²C master terminates this transaction by issuing a NACK command to indicate that the master only wanted to read one byte from the device. The master generates a stop condition to end this transaction.

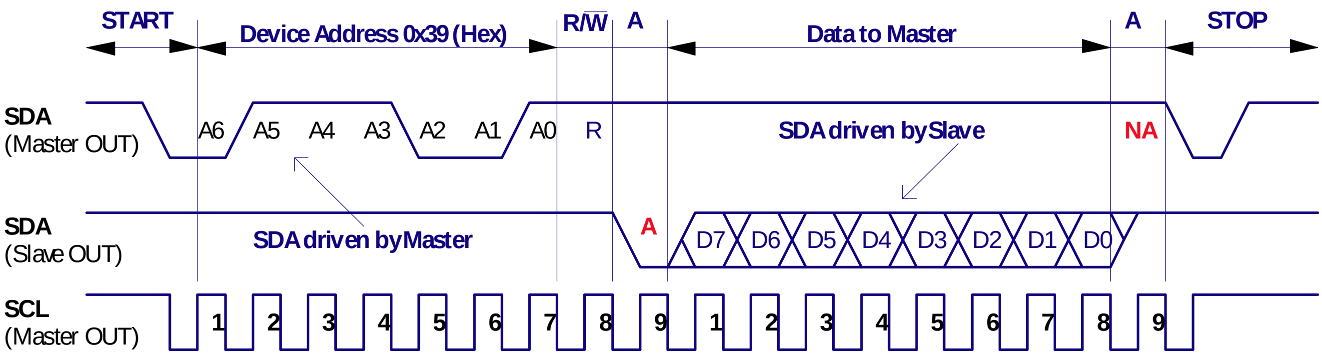
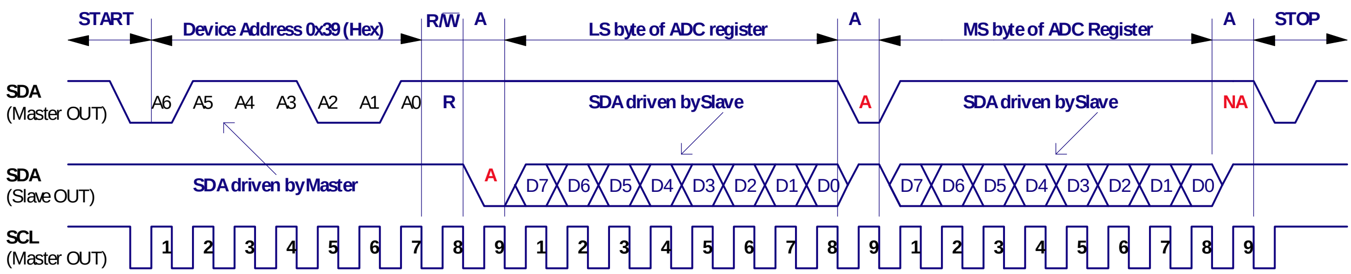


Figure 5 **I²C Timing Diagram for *Receive Byte Format***

Ambient light intensity count value can be obtained by reading registers of this device. Ambient light intensity count is a 15-bit wide number plus a valid bit and hence word (two bytes) read operation is needed, as shown in *Figure 6*. After receiving the two byte data, the I²C master terminates this transaction by issuing a NACK command to indicate that the master only wanted to read two bytes from the device. The master generates a stop condition to end this transaction.

Figure 6. **I²C Timing Diagram for *Receive Word Format***



n Theory of Operation

The photocurrent, generated by the built-in photodiode while being illuminated, is proportionally converted to frequency; the digital frequency signal is then integrated by a 15-bit counter for a predetermined period of time (t_{int}). This period of time is called integration time which can be adjusted by changing the nominal value of the resistor between the RINT and GND terminals. The converted data are read out through a two-wire, I²C Interface bus. Since the photodiode has been specially processed to suppress the spectral response in infrared region, the readout is very close to the photopic transfer function, v(**λ**), which is the mathematic expression of human-eye's response to ambient light.

n Option for I^{2}C Address

The I^{2}C address for LS-3139 is optional. users can assign any one of the three addresses (0x39, 0x29, 0x44) for their specific application. Without any prior request for a specific I^{2}C address, the default address is 0x39.

Table 1. Bonding options of I^{2}C address

Address Pin Configuration	I2C Address
Floating	0x39 (default)
Tied to GND	0x29
Tied to VCC	0x44

n ADC Register

The ADC register contains 16 bits with a 15-bit wide data from D0 to D14 and a valid bit D15. The register is divided into two groups; D[15..8] is the most significant (MS) byte and D[7..0] is the least significant (LS) byte. See Table 2 for details.

Table 2. ADC Register Structure

Valid Bit	Data Bits			
D15	D14	D13 ~ D8	D7~D1	D0
	MSB			LSB
Most Significant (MS) byte			Least Significant (LS) byte	

Device Command

There are eight command codes are provided for I²C master to control the ambient light sensor. The specific function corresponding to each command code is elaborate in Table 3.

Table 3. Command Code List

Command Code	Function
1xxx_xxxx (binary code)	Shut-down mode, this is the default state after applying V_{DD} power to the device. During shut-down mode, users can do the communication test. Except the MSB must be logic 1, the value written to the command register will not change any function and can be read back via the I²C bus by issuing *Receive Byte Protocol*.
0x0C	Activate the ambient light sensor and put the device in [continuous operation mode], The ADC register will be refreshed every t_{int} integration time which is set by an external resistor R_{INT}. See Table 4 for details.
0x04	Activate the ambient light sensor and put the device in [one time integration mode]. The integration time is controlled by I²C commands, start and stop integration.
0x08	Start integration: This command will reset the ADC register to 0x0000 and begin a new integration in [one time integration mode]. This is an invalid command in [continuous operation mode].
0x30	Stop integration: This command will stop the integration in [one time integration mode] and set the valid bit (D[15]) high. This is an invalid command in [continuous operation mode].
0x34	Reserved for future expansion.

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n Programming Sequence

Case 1: Using internal integration timing

(1). After being powered on, the device will initially be in the shut-down mode (default setting).

(2). To operate the device, issue an *Send Byte protocol* (see *Figure 3-a*) with the device address 0x39 followed by a command byte of 0x0C to activate the ambient light sensor and put the device into "*continuous operation mode"*.

(3). To read the ADC conversion result, issue an *Receive Word protocol* (see *Figure 3-c*) with the device address 0x39 followed by two-byte reading procedures.

(4). If a conversion has not been completed since being activated, the valid bit (D[15]) will be 0 to indicate that the data is not valid. If there is a valid conversion result available, the valid bit (D[15]) will be set logic high, and the remaining 15 bits will represent valid data from the ADC register.

(5). Data may be read repeatedly from the ADC register, and although it will remain valid, the ADC register will not be updated until a new conversion completes.

Case 2: Using external integration timing

(1). After being powered on, the device will initially be in the shut-down mode (default setting).

(2). To operate the device, issue an *Send Byte protocol* (see *Figure 3-a*) with the device address 0x39 followed by a command byte of 0x04 to activate the ambient light sensor and put the device into "*one time integration mode"*.

(3). I^2C master sends a "start integration command" to the salve device by issuing Send Byte protocol with the device address 0x39 followed by a command byte of 0x08.

(4). After a period of user defined integration time, I^2C master sends a "stop integration command" to the salve device by issuing Send Byte protocol with the device address 0x39 followed by a command byte of 0x30.

(5). To read the ADC conversion result, issue an *Receive Word protocol* (see *Figure 3-c*) with the device address 0x39 followed by two-byte reading procedures.

(6). If the stop integration command is not received by the device, the valid bit (D[15]) will be 0 to indicate that the data is not valid. If there is a valid conversion result available, the valid bit (D[15]) will be set logic high, and the remaining 15 bits will represent valid data from the ADC register.

(7). Data may be read repeatedly from the ADC register, and although it will remain valid, the ADC register will not be updated until a new complete integration cycle has been carried out.

In both cases, the power consumption of the device can be reduced by issue an *Send Byte protocol* with the device address 0x39 followed by a data byte of 0x8C.

n Noise Rejection and Integration Time

In general, integrating type ADC's have an excellent noise rejection characteristics for periodic noise sources whose frequency is an integer multiple of the integration time. For instance, a 60Hz AC unwanted signal's sum from 0ms to n*16.66ms (n = 1,2...ni) is zero. Similarly, setting the LS-3139's integration time to an integer multiple of periodic noise signal greatly improves the light sensor output signal in the presence of noise. The integration time, **t**int**,** of the LS-3139 is set by an external resistor RINT. The maximum detection range is inversely proportional to the integration time; that means the longer integration time the lower detection range.

Table 4. RINT Resistor Selection Guide (light source: white LED)

RINT (KΩ)	Integration time (mS)	Detection range (lux)	Resolution (lux / count)
50	50	136,000	4.16
100	100	68,000	2.08
200	200	34,000	1.04
300	300	22,000	0.69
400	400	17,000	0.52

In order to achieve both 60Hz and 50Hz AC rejection, the integration time needs to be adjusted to coincide with an integer multiple of the AC noise cycle times. To determine a suitable integration time, **t**int, that will ignore the presence of both 60Hz and 50Hz noise, users can use the formula:

tint = n(1/60Hz) = m(1/50Hz), where n and m are integers.

n/m = 60Hz/50Hz = 6/5.

The first instance of integer values at which **t**int rejects both 60Hz and 50Hz is when m = 5, and n = 6, thus,

tint = 6(1/60Hz) = 5(1/50Hz) = 100ms,

RINT = **t**int * (100kΩ/100ms) = 100kΩ, (see *Table 4*)

By populating RINT = 100kΩ, the LS-3139 defaults to 100ms integration time in continuous operation mode, and will reject the presence of both 60Hz and 50Hz power line signals. When working in one-time integration mode, the master must control the integration time to be an integer multiple of 100mS.

n Power Supply Decoupling and Layout

The power supply lines must be decoupled with capacitors, 4.7uF and 0.1uF, placed as close to the device package as possible. The bypass capacitor should have low effective series resistance (ESR) and effective series inductance (ESI), such as the common ceramic types, which provide a low impedance path to ground at high frequencies to handle transient currents caused by internal logic switching. The LS-3139 is relatively insensitive to layout. Like other I^2C devices, it is intended to provide excellent performance even in significantly noisy environments. There are only a few considerations that will ensure best performance. Route the supply and I^2C traces as far as possible from all sources of noise. Use two power-supply decoupling capacitors, 4.7μF and 0.1μF, placed close to the device.

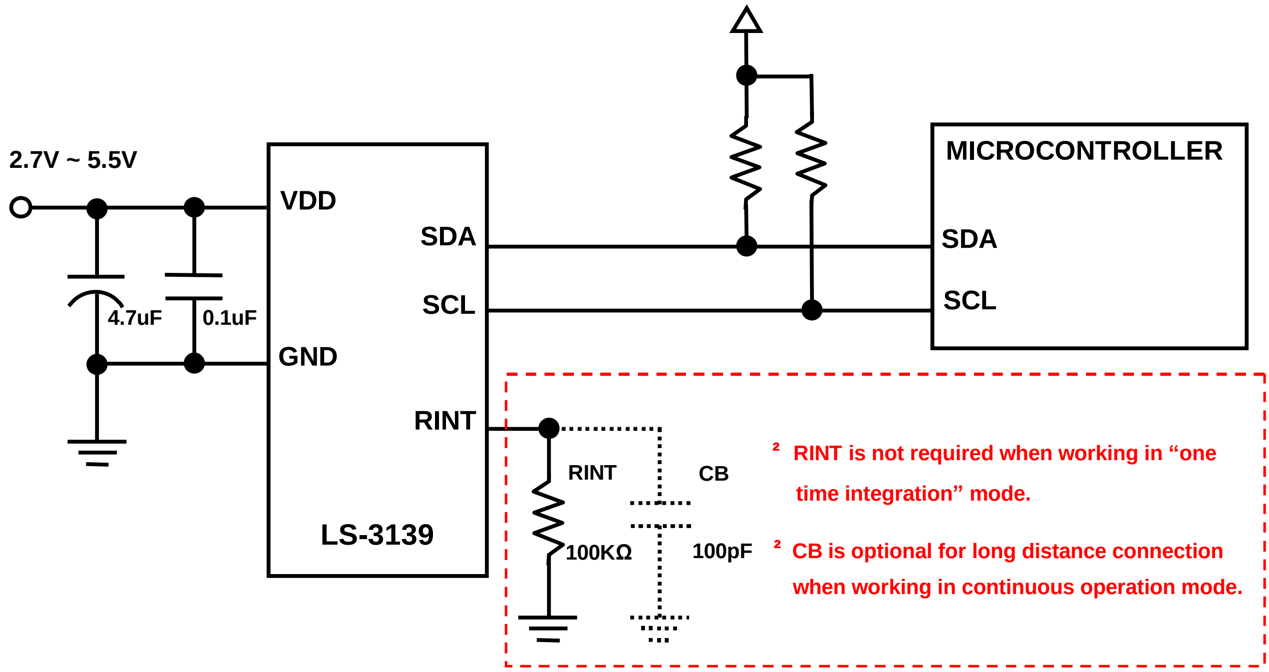
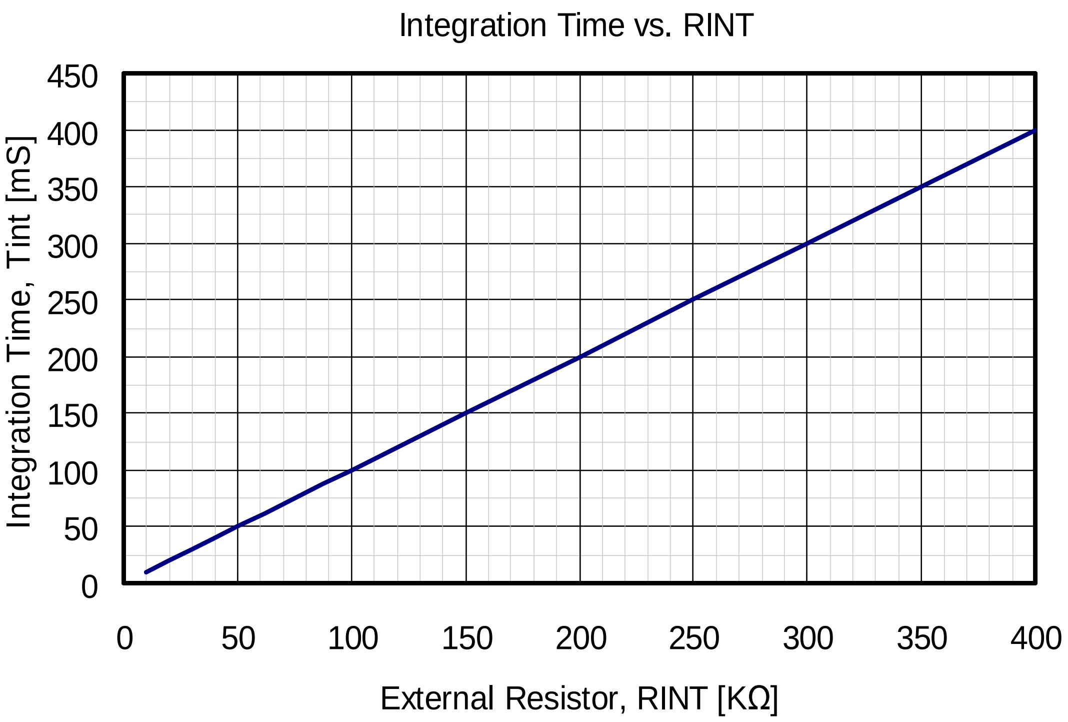
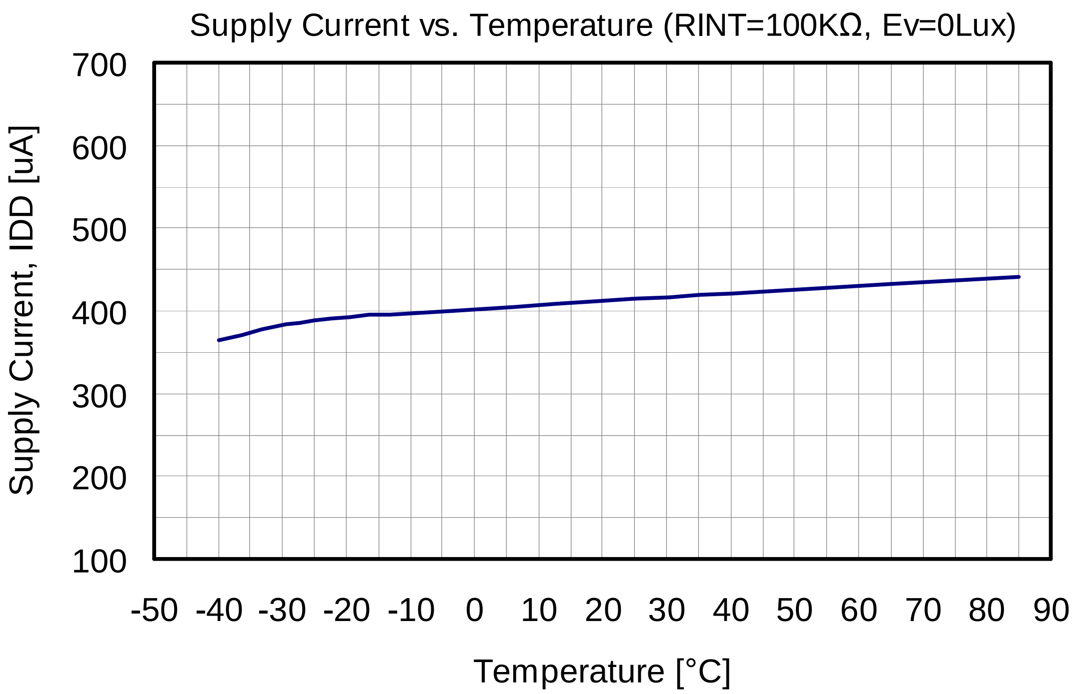


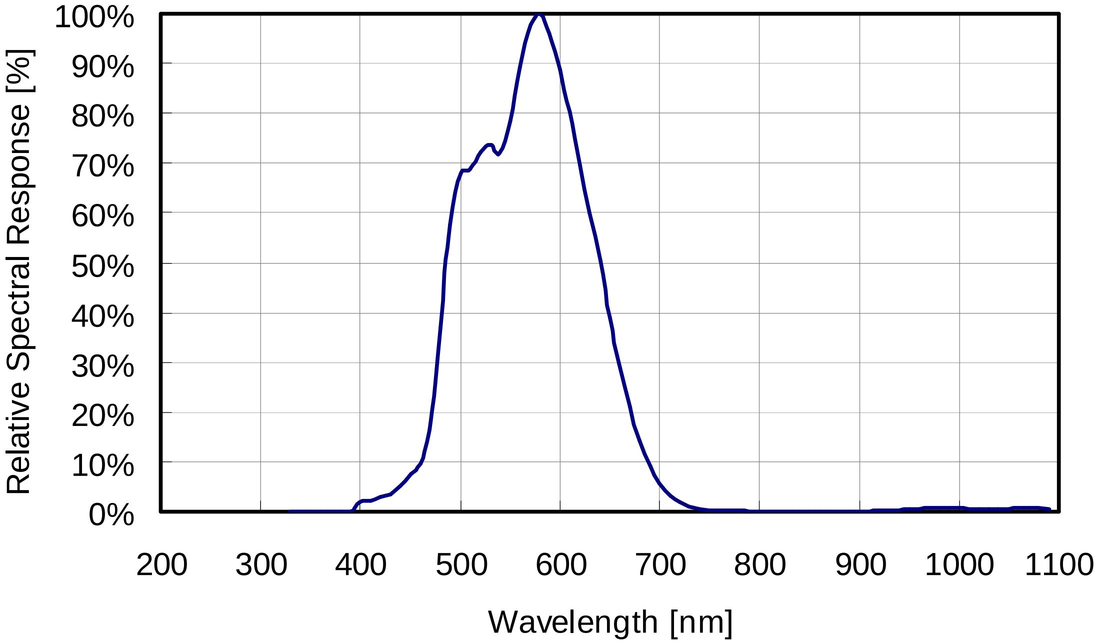
Figure 7. Typical hardware connection

■ Typical Characteristic Curves



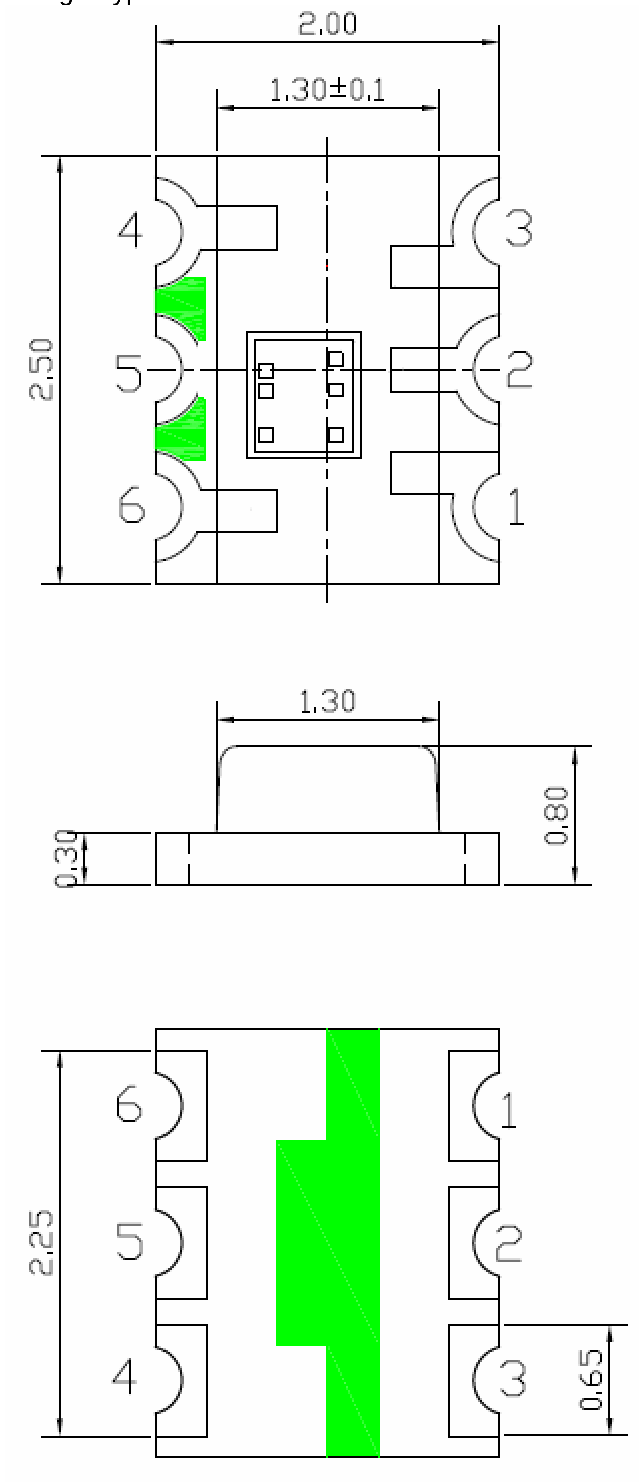


Relative Spectral Response



■ Package Information

Package Type: SMD 0810



Pad Number	Pad Name
1	SCL
2	VDD
3	RINT
4	ADRS
5	GND
6	SDA

Notes:

1. All dimensions are in millimeters.
2. All tolerances are ±0.1mm (0.004 inch) unless otherwise noted.