

SB140M1 Datasheet

Preliminary

1. Features

Compact Photoplethysmography (PPG) module with a monolithic optical sensor embedding:

- Photosensitive pixel array
- Analog Front-End (AFE) for PPG applications
- Integrated analog-domain ambient light cancellation
- Analog-to-Digital Conversion (ADC) with variable resolution
- 3 fully independent driven green, red, NIR LEDs
- Up to 1MHz I²C interface

Ultra-low power performance

Over 90 dB DC light SNR

High quantum efficiency (QE) of >85%

Fully programmable through I²C interface

Multiplexed LED drivers for applications such as oximetry

Flexibility and configurability. The SB140M1 provides multiple user-defined options covering a wide range of performance levels, including:

- Multiple clocking options
- Flexible sampling rate with predefined frequencies and sample-on-trigger option
- Programmable sensitivity
- Programmable ADC resolution from 13 to 18 bits
- Programmable LED pulse width from 2 μ s to 128 μ s, drive current, and multiplexing scheme
- Programmable FIFO depth from 1 to 128 words
- Interrupt mode on programmable ambient/reflected light level threshold

2. Applications

The module can be combined with other devices, accelerometers for motion detection, and a processor for data analysis.

Applications made possible by the SB140M1 module include:

- Heart Rate Monitoring (HRM)
- Heart Rate Variability (HRV)
- Pulse Oximeter (SpO₂)
- Breathing Rate (BR)
- Blood Pressure Monitoring (BP)

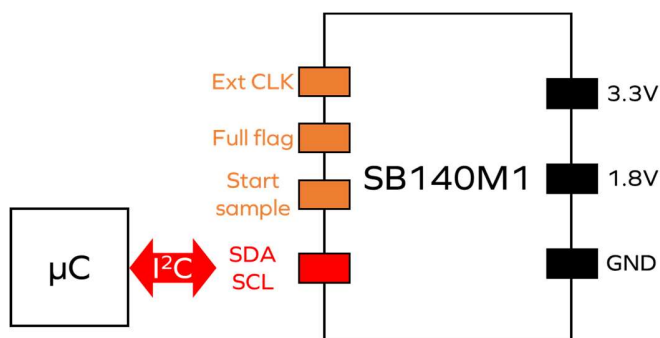
Product Use Cases:

- Earbuds
- Hearing aids
- Wrist fitness and activity monitors
- Smart rings

3. Description

The SB140M1 is a PPG module with a fully integrated array of high-performance pixels, an AFE, ADC, full digital control and programmability, local oscillators and 3 LEDs (red, green and infrared).

SB140M1 enables high fidelity PPG signal sensing with an ultra-low power consumption.



4. Document revision history

Document	Date	Revision	Description
2106181	June 18, 2021	V0.1	Preliminary Release Data Sheet
	Nov 10, 2021	V0.2	Add <i>Electrical specifications</i> and <i>Typical application circuit</i> , update <i>I²C communication</i> and <i>Power consumption</i>
	Jan 26, 2022	V0.3	Updated introduction Update device configuration Updated device operation Updated characterization
	Jan 27, 2022	V0.4	Industrial name update
	Feb 3, 2022	V0.5	Characterization data update
	Mar 11, 2022	V0.6	Characterization data update

5. Device family options

Table 1: SB140M1 device family options

Product	Size	Power Supply	Interface
SB140M1	2 mm × 2.66 mm × 0.75 mm	3.3 V / 1.8 V	I ² C

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6. Pin configuration and functions

6.1. Module bottom view

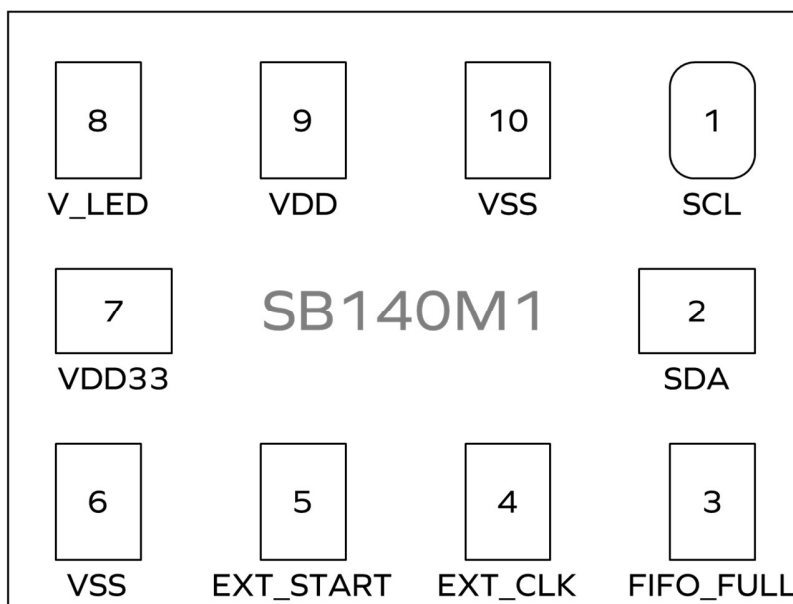


Figure 1: SB140M1 bottom view

6.2. Pin functions

Table 2: Pin functions

Pin		Function	Description
Name	No.		
SCL	1	I ² C	I ² C SCL
SDA	2	I ² C	I ² C SDA
FIFO_FULL	3	Digital	1: FIFO full (See I ² C register 0x5 - fifo_depth) 0: Once data in the FIFO is read. To be used as external MCU interrupt.
EXT_CLK	4	CLK	Optional external master CLK input of 500kHz (See I ² C register 0x5 - ext_ck_en)
EXT_START	5	CLK	Optional external trigger pin to be used when external trigger is enabled (See I ² C register 0x5 - ext_start_en)
VSS	6	Supply	Connect to common ground
VDD33	7	Supply	Connect to 3.3V voltage source
V_LED	8	Supply	LED voltage source. Can be connected to VDD33
VDD	9	Supply	Connect to 1.8V voltage source
VSS	10	Supply	Connect to common ground

7. Electrical specifications

Unless otherwise noted:

- $V_{DD33} = 3.3V$
- $V_{DD} = 1.8V$
- $I_{LED1/2/3} = 0\text{ mA}$
- $T_A = +25^\circ C$

Table 3: Electrical specifications

Parameters	Sym.	Min	Typ.	Max.	Units	Conditions
V_{DD33} Input Operating Voltage	V_{dd33}	3.2	3.3	3.4	V	
V_{DD} Input Operating Voltage	V_{dd}	1.7	1.8	1.9	V	
V_{DD33} Input Quiescent Current	I_{vdd33}		0.1		μA	Standby
V_{DD} Input Quiescent Current	I_{vdd}		2.4		μA	Standby
I ² C max speed	f_{scl}	0.1	1	1	MHz	
External clock frequency	$f_{ext\ ck}$	450	500	550	kHz	
External start pulse width	$t_{ext\ st}$	3	4	1000	μs	
Digital input threshold high	V_{ih}		$0.7 \cdot V_{dd33}$		V	
Digital input threshold low	V_{il}		$0.3 \cdot V_{dd33}$		V	
LED current n $n = 1, 2, 3$	I_{ledn}	$I_{ledn} \cdot 0.25$			mA	I_{ledn} set by I ² C registers 0x0 and 0x1
Sampling frequency deviation	σ_f	TBD	TBD	TBD	%	
Pulse width deviation	σ_{pulse}	TBD	TBD	TBD		
Time reset	t_{reset}			15	μs	Time to wait after I ² C ACK

8. Detailed description

8.1. Overview

The SB140M1 module includes all detection functions needed for PPG applications.

The required device environment must include:

- A power management unit or voltage regulator to provide 3.3V and 1.8V voltages.
- A microcontroller to program the module and acquire the data.
The microcontroller can program the module via the I²C (using 2 pins).
 - The output data can be acquired through the I²C interface via the 64/128 FIFO.
- The clocks and sampling trigger are embedded functions in the module. Alternatively, these elements can be also provided externally.

8.2. Functional block diagram

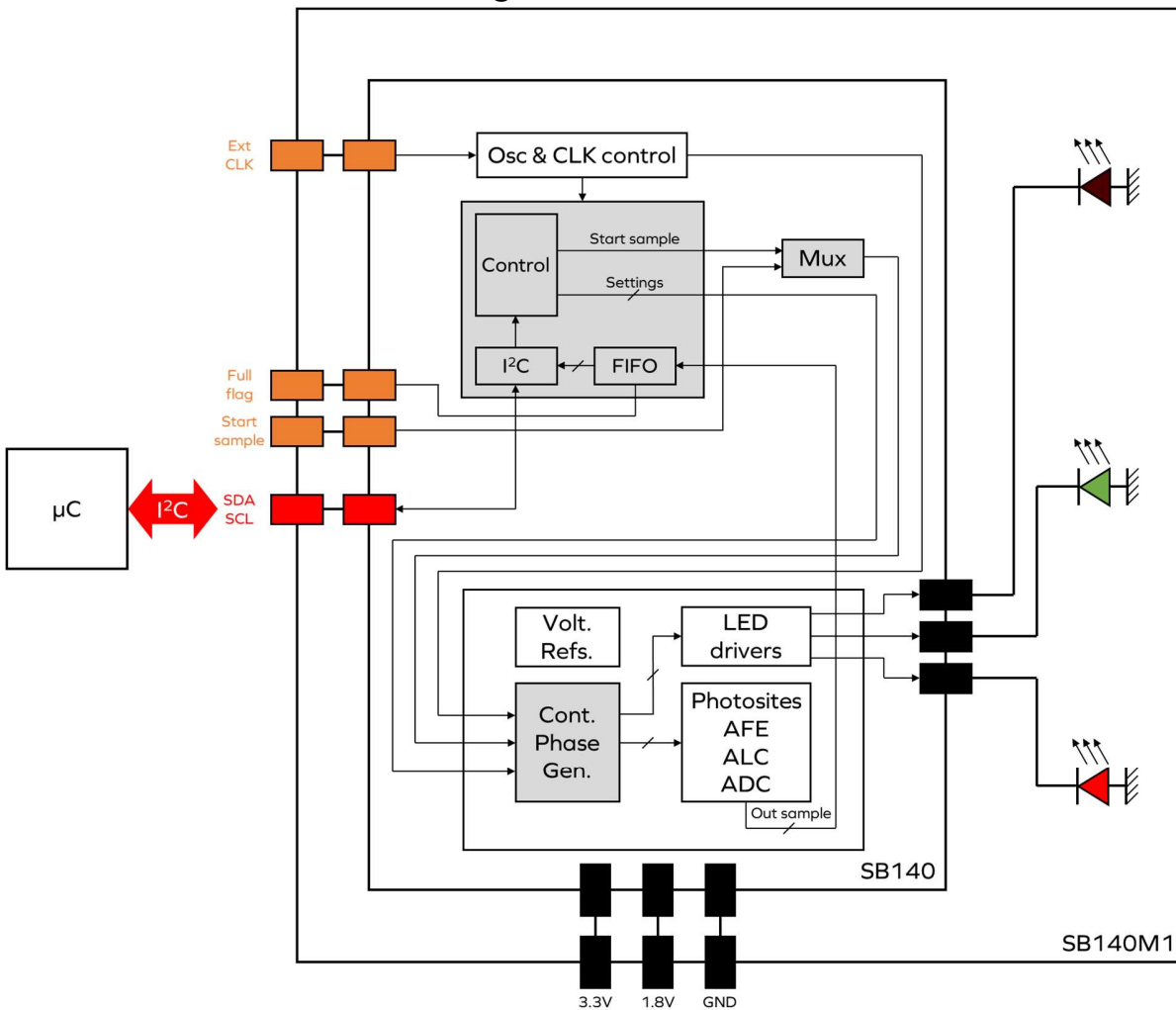


Figure 2: SB140M1 block diagram

8.3. Device operation & possible configurations

The device can operate in 3 modes: ambient light sensing mode (ALS), ambient light cancellation mode (ALC) or proximity mode.

For each mode, the device features flexibility on the sampling frequency and clocking. They can both be provided internally or externally as explained in the following subsections.

The device uses the I²C protocol for programming and readout. The output samples are stored in a FIFO.

8.3.1. Device possible configurations

SB140M1 offers configurability of the following functions/parameters:

Table 4: SB140M1 general possible configurations

Feature	Possible Configurations
Instructions	Through I ² C
CLK	Internal oscillator External clock
RST	Through I ² C instruction
Sampling trigger	Autonomous with selectable freq. Ext. Trigger with custom freq.
Operation modes	ALC (ambient light cancellation mode) ALS (ambient light sensing mode) Proximity/trigger mode with adjustable threshold
Autonomous Sampling frequencies [Hz]	8, 16, 25, 32, 50, 64, 100, 128
LED pulse width [μ s]	2, 4, 16, 32, 64, 100, 128
LED pulse current [mA]	8 bits DAC with an LSB of 0.25mA
ADC resolution [bit]	13 to 18
Pixels array sensitivity	High sensitivity (for low light conditions) Low sensitivity (for high dynamic conditions)
Output	I ² C readout from FIFO
FIFO depth [word]	1, 64, 96, 128
LED channels multiplexing	3 time division multiplexing channels with configurability for each channel

8.3.2. I²C communication

The SB140M1 can be fully configured with 8 registers described in the table below.

The registers can be written word-by-word or in a burst way. In the latter case, all the words exceeding the maximum address will loop in the registers starting from the address 0x0.

The following examples show how to write a configuration and to read the data.

ADD = 0x77

Write in/from a configuration register N

Word-by-word

ST	ADD	RW=0	ACK	CMD=0x0N	ACK	INSTR_REGN<15:8>	ACK	INSTR_REGN<7:0>	ACK	SP
----	-----	------	-----	----------	-----	------------------	-----	-----------------	-----	----

Burst X words

ST	ADD	RW=0	ACK	CMD=0x0N	ACK	INSTR_REGN<15:8>	ACK	INSTR_REGN<7:0>	ACK	...
...						INSTR_REG((N+X)%8)<15:8>	ACK	INSTR_REG((N+X)%8)<7:0>	ACK	SP

Read in/from a configuration register N

ST	ADD	RW=0	ACK	CMD=0x0N	ACK
----	-----	------	-----	----------	-----

Word-by-word

RS	ADD	RW=1	ACK	INSTR_REGN<15:8>	ACK	INSTR_REGN<7:0>	ACK	SP
----	-----	------	-----	------------------	-----	-----------------	-----	----

Burst X words

RS	ADD	RW=1	ACK	INSTR_REGN<15:8>	ACK	INSTR_REGN<7:0>	ACK	...
...				INSTR_REG((N+X)%8)<15:8>	ACK	INSTR_REG((N+X)%8)<7:0>	ACK	SP

Read FIFO

ST	ADD	RW=0	ACK	CMD=0x08	ACK			
RS	ADD	RW=1	ACK	FIFO<24:26>	ACK	FIFO<15:23>	ACK	..
...	FIFO<15:8>	ACK	FIFO<7:0>	ACK	SP			

Table 5: I²C registers map

Reg.	Bit	Function	Name
0x0	7:0	LED current 1	i_led1
	15:8	LED current 2	i_led2
0x1	7:0	LED current 3	i_led3
0x2	2:0	LED 1/2/3 activation	ts1_led_en
	5:3	ADC resolution	ts1_adc_resolution
	7:6	<i>Reserved</i>	-
	10:8	LED pulse width / Integr. Time	ts1_led_pulse_width
	11	ALS mode enable	ts1_als_en
	12	Sense node enable	ts1_sens_node_en
0x3	2:0	LED 1/2/3 activation	ts2_led_en
	5:3	ADC resolution	ts2_adc_resolution
	7:6	<i>Reserved</i>	-
	10:8	LED pulse width / Integr. Time	ts2_led_pulse_width
	11	ALS mode enable	ts2_als_en
	12	Sense node enable	ts2_sens_node_en
0x4	2:0	LED 1/2/3 activation	ts3_led_en
	5:3	ADC resolution	ts3_adc_resolution
	7:6	<i>Reserved</i>	-
	10:8	LED pulse width / Integr. Time	ts3_led_pulse_width
	11	ALS mode enable	ts3_als_en
	12	Sense node enable	ts3_sens_node_en
0x5	2:0	Sampling frequency	samp_freq
	4:3	FIFO depth	fifo_depth
	5	En/disable external start	ext_start_en
0x6	7:0	Proximity threshold	prox_threshold
	8	En/disable proximity	prox_en
0x7	0	En/disable external clock	ext_clk_en
	7	External reset	ext_rst
0x8	-	FIFO read only	fifo

Table 6: I²C registers configuration

0x0							
15 0x8000	14 0x4000	13 0x2000	12 0x1000	11 0x0800	10 0x0400	09 0x0200	08 0x0100
LED 2 Current value from 0 to 255 i_led2 * 0.3 mA for LED driving current							
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
LED 1 Current value from 0 to 255 i_led1 * 0.3 mA for LED driving current							
0x1							
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
LED 3 Current value from 0 to 255 i_led3 * 0.3 mA for LED driving current							
0x2							
15 0x8000	14 0x4000	13 0x2000	12 0x1000	11 0x0800	10 0x0400	09 0x0200	08 0x0100
			Sense node 0: disabled 1: enabled	ALS mode 0: disabled 1: enabled	LED pulse width / Integr. T. value from 0 to 7 2 - 4 - 8 - 16 - 32 - 64 - 100 - 128 µs		
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
Reserved must be set to 0b11		ADC resolution value from 0 to 5 from 13 to 18 bits			LED 3 0: disabled on timeslot 1 1: enabled on timeslot 1	LED 2	LED 1
0x3							
15 0x8000	14 0x4000	13 0x2000	12 0x1000	11 0x0800	10 0x0400	09 0x0200	08 0x0100
			Sense node 0: disabled 1: enabled	ALS mode 0: disabled 1: enabled	LED pulse width / Integr. T. value from 0 to 7 2 - 4 - 8 - 16 - 32 - 64 - 100 - 128 µs		
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
Reserved must be set to 0b11		ADC resolution value from 0 to 5 from 13 to 18 bits			LED 3 0: disabled on timeslot 2 1: enabled on timeslot 2	LED 2	LED 1
0x4							
15 0x8000	14 0x4000	13 0x2000	12 0x1000	11 0x0800	10 0x0400	09 0x0200	08 0x0100
			Sense node 0: disabled 1: enabled	ALS mode 0: disabled 1: enabled	LED pulse width / Integr. T. value from 0 to 7 2 - 4 - 8 - 16 - 32 - 64 - 100 - 128 µs		
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
Reserved must be set to 0b11		ADC resolution value from 0 to 5 from 13 to 18 bits			LED 3 0: disabled on timeslot 3 1: enabled on timeslot 3	LED 2	LED 1
0x5							
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
		Sampl. Trigger 0: internal 1: external	FIFO # of words value from 0 to 3 1 - 64 - 96 - 128		Sampling frequency value from 0 to 7 8 - 16 - 25 - 32 - 50 - 64 - 100 - 128 Hz		
0x6							
15 0x8000	14 0x4000	13 0x2000	12 0x1000	11 0x0800	10 0x0400	09 0x0200	08 0x0100
						Proximity 0: disabled 1: enabled	
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
Proximity threshold value from 0 to 255 Threshold _{ADC} = prox_threshold · ADC _{range} / 255 for any active timeslot							
0x7							
07 0x0080	06 0x0040	05 0x0020	04 0x0010	03 0x0008	02 0x0004	01 0x0002	00 0x0001
Ext. reset 0: disabled 1: enabled							Ext. clock 0: disabled 1: enabled
0x8 read only							
23 0x800000	22 0x400000	21 0x200000	...				00 0x000001
Timeslot tag value from 0 to 2 from timeslot_1 to timeslot_3		FIFO PPG value Depending on ADC resolution fro the given timeslot from 0 to 8'191 - 16'383 - 32'767 - 65'535 - 131'071 - 262'143					

8.3.3. Ambient light sensing (ALS)

In this mode, the device senses the input light by performing a single photonic integration. The integrated light corresponds to the ambient light in addition to the light generated by the LED pulses and back reflected to the sensor.

8.3.4. Ambient light cancellation mode (ALC)

In this mode, the device performs a double photonic integration. The first integration corresponds to the ambient light and the second corresponds to the sum of the ambient light and the light generated by the LED pulses and back reflected to the sensor. The device performs a subtraction of both samples, in analog domain, which leads to ambient light attenuation. The two integrated samples are consequent and performed with same integration time.

8.3.5. Proximity mode

In this mode, the device senses, in ALC or ALS mode, the input light and generate a interrupt/trigger when the light level reaches a threshold. This mode can be used for various applications such as proximity sensing using LED back reflected light in ALC mode.

8.3.6. Sampling trigger

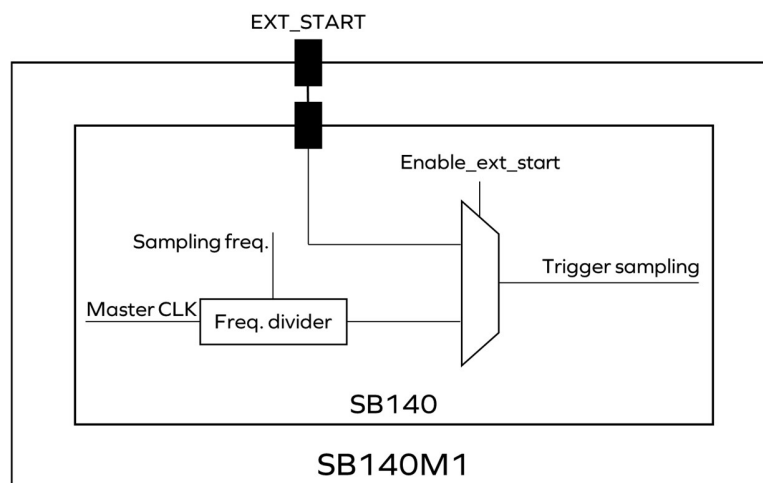


Figure 3: SB140M1 sampling trigger options

The device can be set to take samples on an external trigger or to use a programmable internal trigger with a set of frequencies.

8.3.7. Clock options

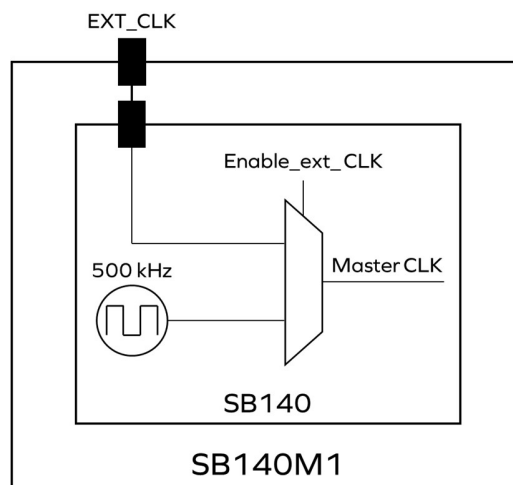


Figure 4: SB140M1 internal/external clock options

The device needs a clock that oscillate at 500kHz as a master clock. It can be generated either on-chip thanks to a local oscillator or with an external clock of 500 kHz for perfect synchronization with the microcontroller.

8.3.8. Time division multiplexed channels

The device can multiplex up to 3 channels (time slots), for each time slot, the LED to be activated, the ADC resolution, the pulse width, the array sensitivity and ALS/ALC mode can be set separately.

9. Typical application circuit

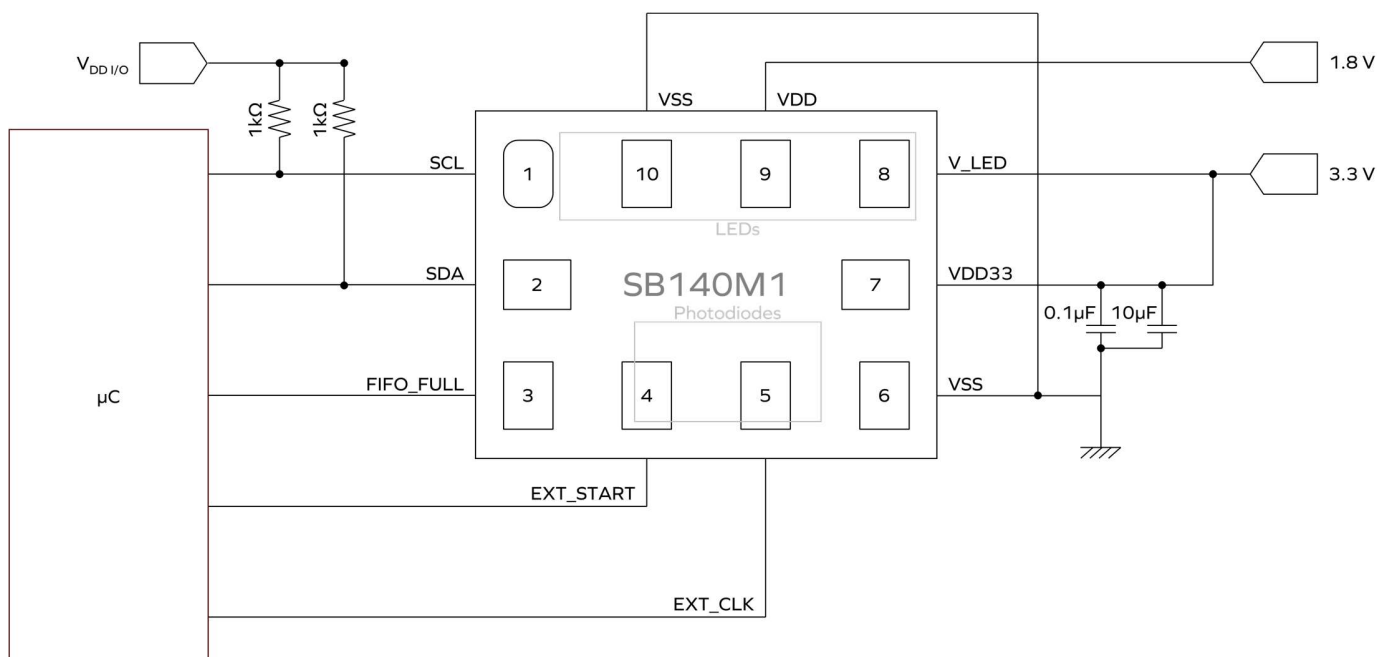


Figure 5: Typical application circuit

The value of I²C pull up resistors should be based on the system design.
V_{DD I/O} is the system I/O voltage supply.

10. Module drawing

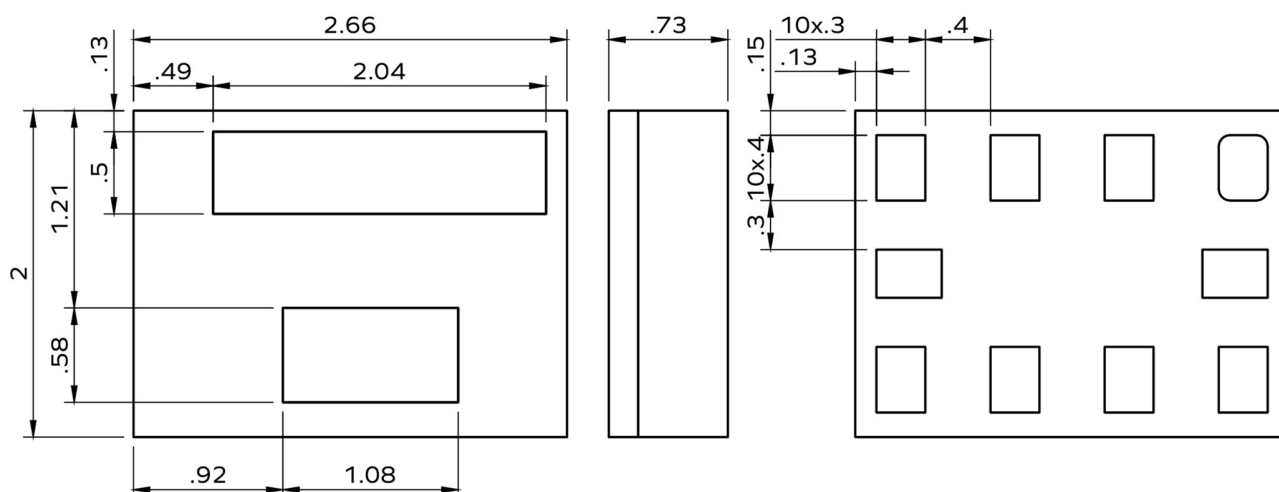


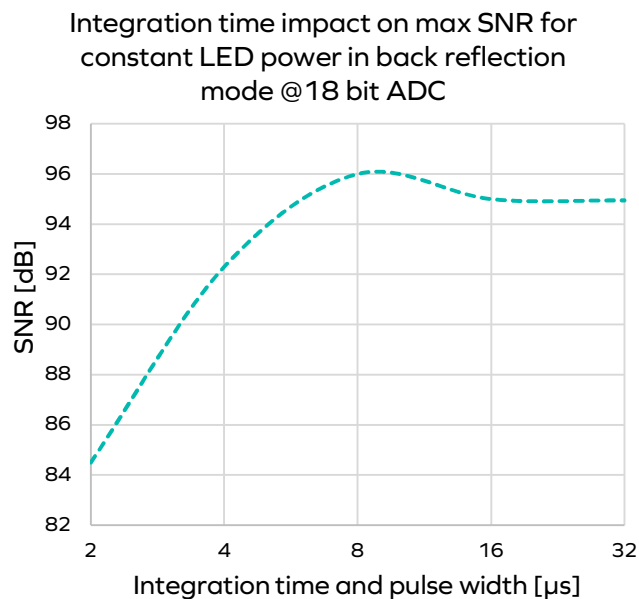
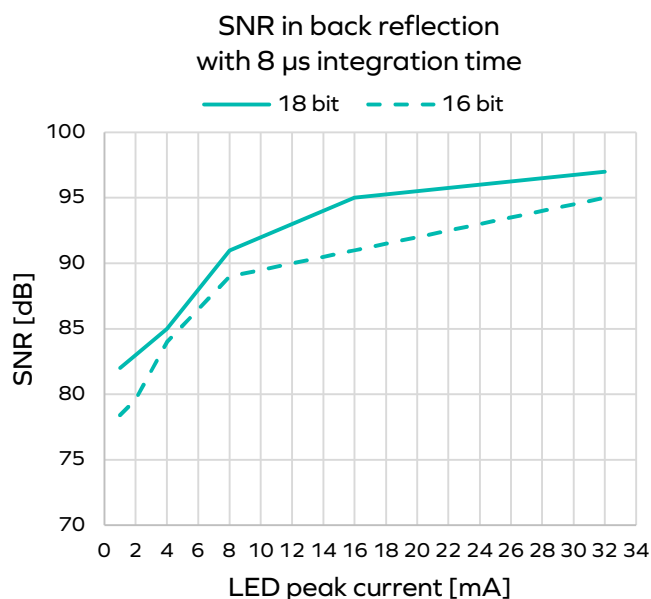
Figure 6: Top - side - bottom view of the module

The distances are in mm.

11. Characterization

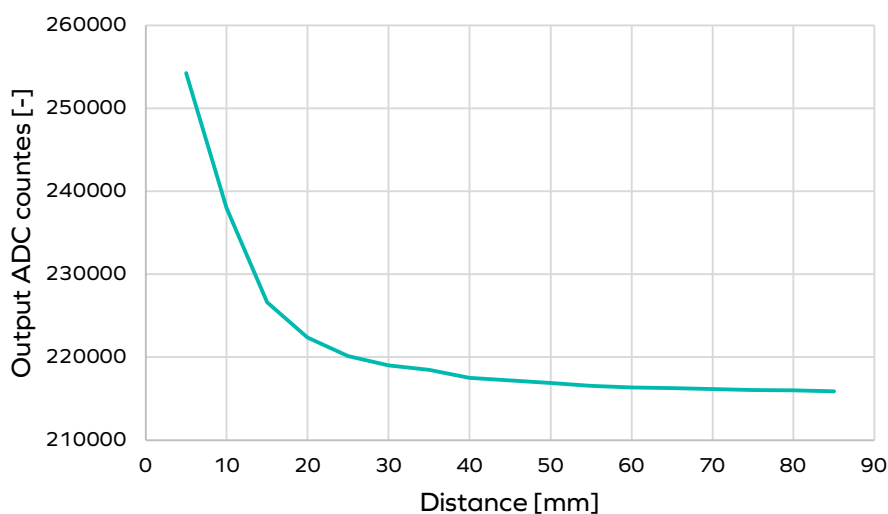
11.1. Signal to noise ratio in reflection-loop mode

The SNR is measured in back-loop mode, i.e., the sensor drives one of its own LEDs, the emitted light is reflected on the sensor by a white object, then the SNR is measured on the sensor output. In this way, the SNR accounts for the noise of the readout chain as well as the LED driver circuit and LEDs.

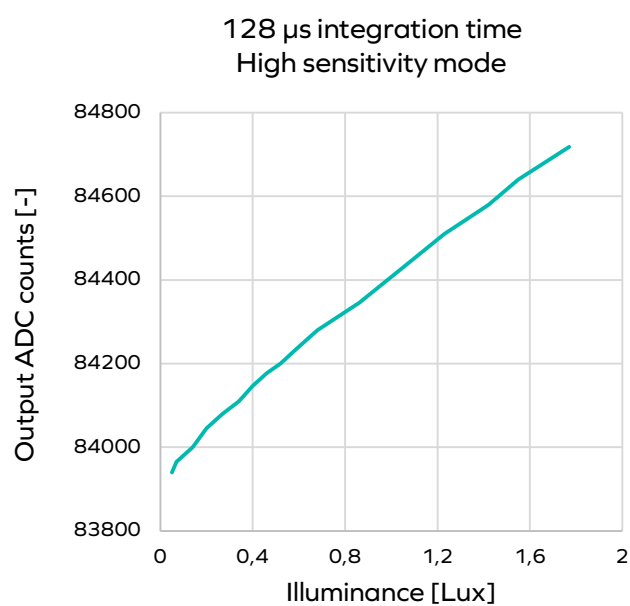
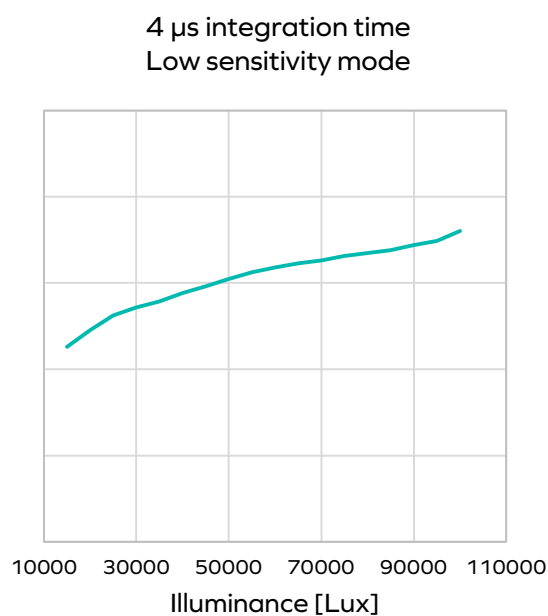
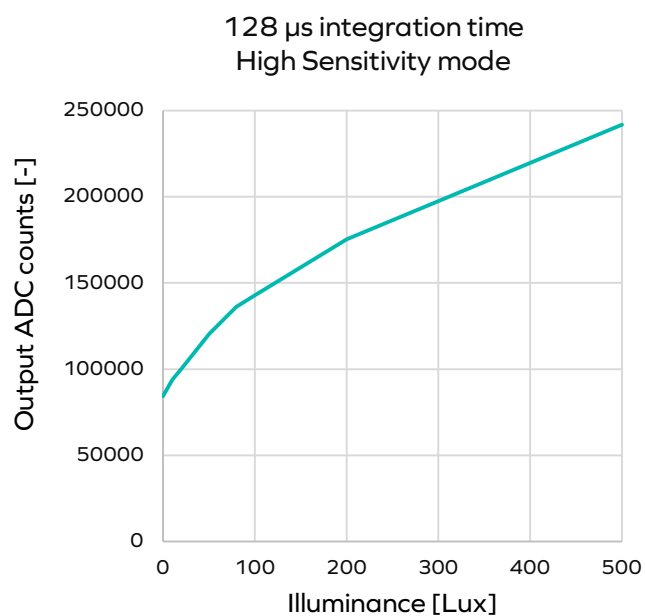


11.2. Proximity sensing

NIR LED and white object
High sensitivity mode, 8 μ s integration, 60 mA peak
current and 1500 lux ambient light

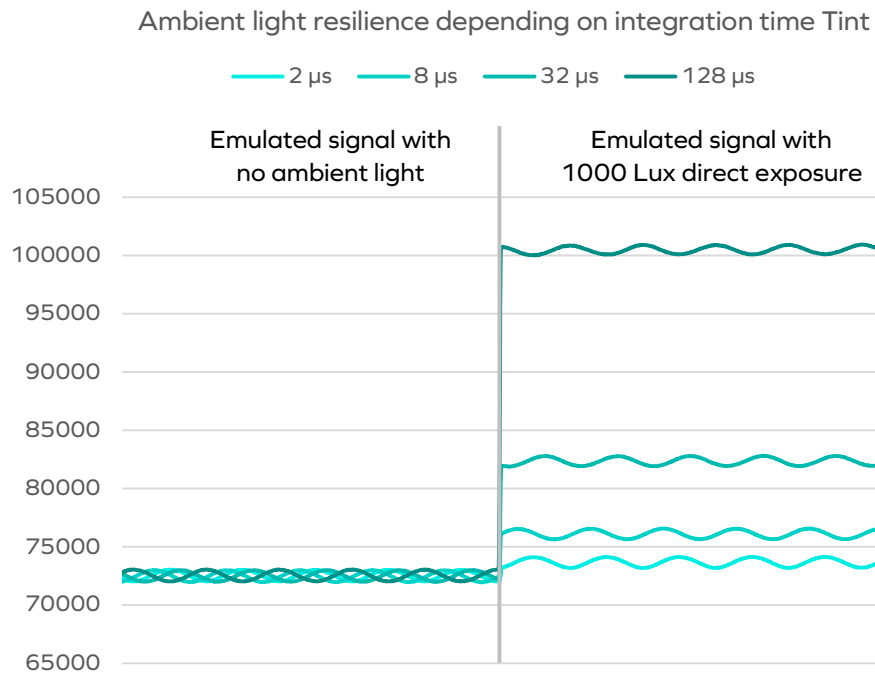


11.3. Ambient light sensing

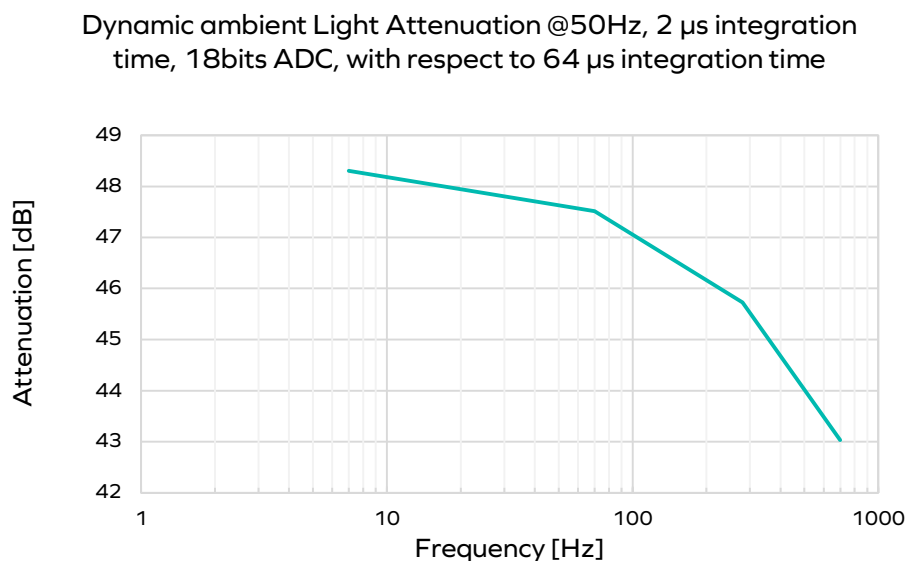


11.4. Ambient light cancelation

The SB140M1 offers the possibility to operate with integration time and LED pulse width from 2 μ s, without impact on the SNR and power consumption. Short integration times are an intrinsic and efficient way to reduce ambient light contribution. The measurement below shows the sensor output when exposed to an emulated PPG signal with no ambient light in one case and under 1000 Lux direct exposure.



The figure below shows how the ambient light attenuation evolves with the modulation frequency of the ambient light. The measured attenuation is shown with respect to an integration time of 64 μ s.



11.5. Power consumption

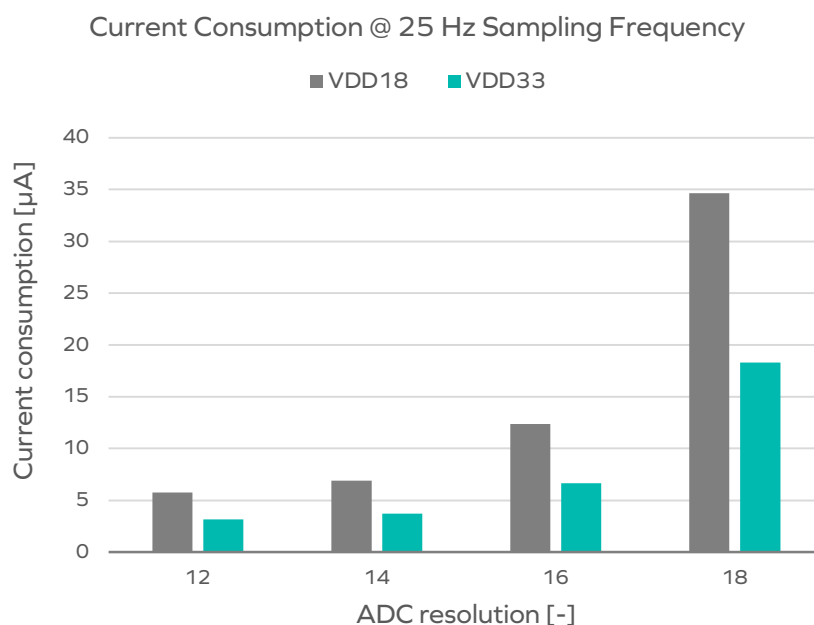


Table 7 Current consumption in [µA] for different ADC resolutions and sampling frequencies

Sampling Frequency [Hz]	Integration time [µs]	ADC resolution				Supply
		12b	14b	16b	18b	
25	64	3.16	3.738	6.635	18.27	VDD33
		5.75	6.88	12.37	34.64	VDD18
	100	2.207	3.736	6.687	18.36	VDD33
		5.75	6.87	12.38	34.6	VDD18
50	64	3.622	4.84	10.66	33.97	VDD33
		6.55	8.909	19.89	63.96	VDD18
	100	3.668	4.89	10.74	34.09	VDD33
		6.53	8.915	19.9	63.81	VDD18

Note that the power consumption is not affected by the integration time.