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# MAX30101

# High-Sensitivity Pulse Oximeter and Heart-Rate Sensor for Wearable Health

## General Description

The MAX30101 is an integrated pulse oximetry and heart-rate monitor module. It includes internal LEDs, photodetectors, optical elements, and low-noise electronics with ambient light rejection. The MAX30101 provides a complete system solution to ease the design-in process for mobile and wearable devices.

The MAX30101 operates on a single 1.8V power supply and a separate 5.0V power supply for the internal LEDs. Communication is through a standard I<sup>2</sup>C-compatible interface. The module can be shut down through software with zero standby current, allowing the power rails to remain powered at all times.

## Applications

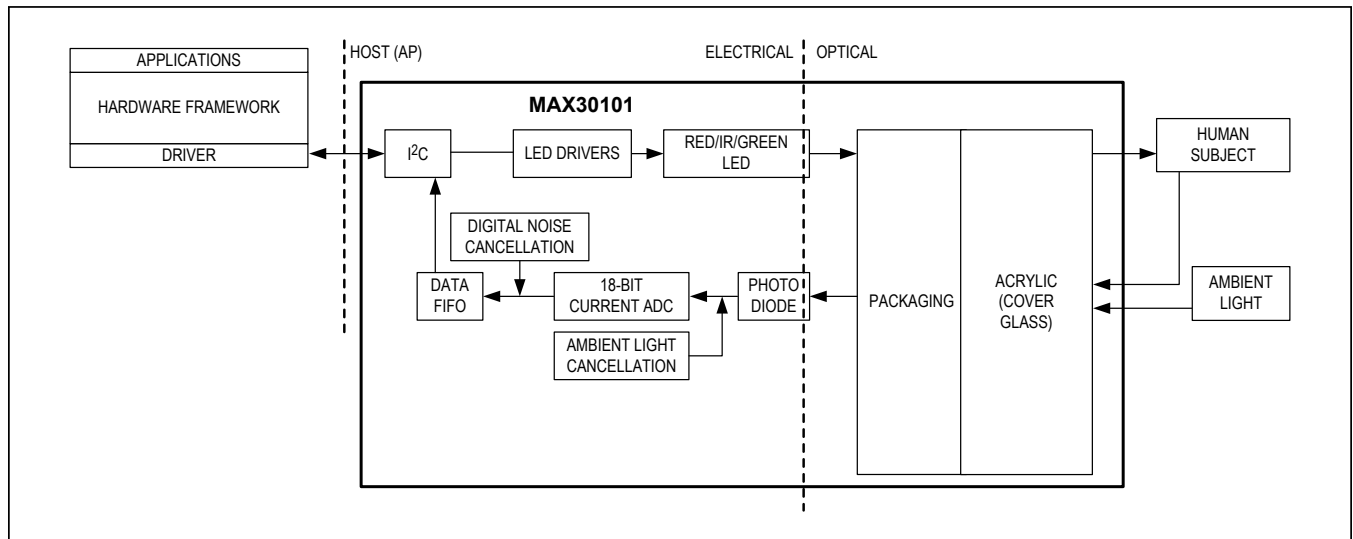
- Wearable Devices
- Fitness Assistant Devices

## Benefits and Features

- Heart-Rate Monitor and Pulse Oximeter Sensor in LED Reflective Solution
- Tiny 5.6mm x 3.3mm x 1.55mm 14-Pin Optical Module
  - Integrated Cover Glass for Optimal, Robust Performance
- Ultra-Low Power Operation for Mobile Devices
  - Programmable Sample Rate and LED Current for Power Savings
  - Low-Power Heart-Rate Monitor (< 1mW)
  - Ultra-Low Shutdown Current (0.7µA, typ)
- Fast Data Output Capability
  - High Sample Rates
- Robust Motion Artifact Resilience
  - High SNR
- -40°C to +85°C Operating Temperature Range

*Ordering Information appears at end of data sheet.*

## System Diagram



**Absolute Maximum Ratings**

V <sub>DD</sub> to GND .....	-0.3V to +2.2V	Continuous Power Dissipation (T <sub>A</sub> = +70°C)
GND to PGND .....	-0.3V to +0.3V	OESIP (derate 5.5mW/°C above +70°C) .....
X_DRV, V <sub>LED+</sub> to PGND .....	-0.3V to +6.0V	.....440mW
All Other Pins to GND .....	-0.3V to +6.0V	Operating Temperature Range .....
Output Short-Circuit Current Duration .....	Continuous	-40°C to +85°C
Continuous Input Current into Any Terminal .....	±20mA	Junction Temperature .....
		+90°C
		Soldering Temperature (reflow) .....
		+260°C
		Storage Temperature Range .....
		-40°C to +105°C

**Package Thermal Characteristics (Note 1)**

OESIP

Junction-to-Ambient Thermal Resistance (θ <sub>JA</sub> ) .....	180°C/W	Junction-to-Case Thermal Resistance (θ <sub>JC</sub> ) .....	150°C/W
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**Note 1:** Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to [www.maximintegrated.com/thermal-tutorial](http://www.maximintegrated.com/thermal-tutorial).

**Electrical Characteristics**

(V<sub>DD</sub> = 1.8V, V<sub>IR\_LED+</sub> = V<sub>R\_LED+</sub> = V<sub>G\_LED+</sub> = 5.0V, T<sub>A</sub> = +25°C, min/max are from T<sub>A</sub> = -40°C to +85°C, unless otherwise noted. Typical values are at T<sub>A</sub> = 25°C.) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>POWER SUPPLY</b>						
Power-Supply Voltage	V <sub>DD</sub>	Guaranteed by RED and IR count tolerance	1.7	1.8	2.0	V
LED Supply Voltage R_LED+, IR_LED+, or G_LED+ to PGND	V <sub>LED+</sub>	Guaranteed by PSRR of LED driver (R_LED+ and IR_LED+ only)	3.1	3.3	5.25	V
Supply Current	I <sub>DD</sub>	SpO <sub>2</sub> and HR mode, PW = 215µs, 50sps		600	1100	µA
		IR only mode, PW = 215µS, 50sps		600	1100	
Supply Current in Shutdown	I <sub>SHDN</sub>	T <sub>A</sub> = +25°C, MODE = 0x80		0.7	2.5	µA
<b>PULSE OXIMETRY/HEART-RATE SENSOR CHARACTERISTICS</b>						
ADC Resolution				18		bits
Red ADC Count (Note 3)	REDC	RED_PA = 0x0C, LED_PW = 0x01, SPO2_SR = 0x05, ADC_RGE = 0x00, T <sub>A</sub> = +25°C		65536		Counts
IR ADC Count (Note 3)	IRC	IR_PA = 0x0C, LED_PW = 0x01, SPO2_SR = 0x05, ADC_RGE = 0x00, T <sub>A</sub> = +25°C		65536		Counts
Green ADC Count (Note 3)	GRNC	GRN_PA = 0x24, LED_PW = 0x11, SPO2_SR = 0x05, ADC_RGE = 0x00, T <sub>A</sub> = +25°C		65536		Counts
SNR IR LED	SNR <sub>IR</sub>	White card loop-back, LED_PW = 0x11, ADC_RGE = 0x10, T <sub>A</sub> = 25°C		89	300	dB
SNR Red LED	SNR <sub>RED</sub>	White card loop-back, LED_PW = 0x11, ADC_RGE = 0x10, T <sub>A</sub> = 25°C		88.9	300	dB
SNR Green LED	SNR <sub>GREEN</sub>	White card loop-back, LED_PW = 0x11, ADC_RGE = 0x01, T <sub>A</sub> = 25°C		80.4		dB

**Electrical Characteristics (continued)**

( $V_{DD} = 1.8V$ ,  $V_{IR\_LED+} = V_{R\_LED+} = V_{G\_LED+} = 5.0V$ ,  $T_A = +25^{\circ}C$ , min/max are from  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted. Typical values are at  $T_A = 25^{\circ}C$ .) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Dark Current Count	LED_DCC	RED_PA = IR_PA = 0x00, LED_PW = 0x03, SPO2_SR = 0x01 ADC_RGE = 0x02		30	128	Counts
				0.01	0.05	% of FS
DC Ambient Light Rejection (Note 4)	ALR	ADC counts with finger on sensor under direct sunlight (100K lux), ADC_RGE = 0x3, LED_PW = 0x03, SPO2_SR = 0x01	Red LED	2		Counts
			IR LED	2		Counts
ADC Count—PSRR ( $V_{DD}$ )	PSRR $V_{DD}$	1.7V < $V_{DD}$ < 2.0V, LED_PW = 0x00, SPO2_SR = 0x05 $T_A = +25^{\circ}C$		0.25	1	% of FS
		Frequency = DC to 100kHz, 100mV <sub>P-P</sub>		10		LSB
ADC Count—PSRR (LED Driver Outputs)	PSRR <sub>LED</sub>	3.6V < R_LED+, IR_LED+, GRN_LED+ < 5.0V, $T_A = +25^{\circ}C$		0.05	1	% of FS
		Frequency = DC to 100kHz, 100mV <sub>P-P</sub>		10		LSB
ADC Clock Frequency	CLK		10.2	10.48	10.8	MHz
ADC Integration Time (Note 4)	INT	LED_PW = 0x00		69		μs
		LED_PW = 0x01		118		
		LED_PW = 0x02		215		
		LED_PW = 0x03		411		
Slot Timing (Timing Between Sequential Channel Samples; e.g., Red Pulse Rising Edge To IR Pulse Rising Edge)	INT	LED_PW = 0x00		427		μs
		LED_PW = 0x01		525		
		LED_PW = 0x02		720		
		LED_PW = 0x03		1107		
<b>COVER GLASS CHARACTERISTICS (Note 4)</b>						
Hydrolytic Resistance Class		Per DIN ISO 719		HGB 1		
<b>IR LED CHARACTERISTICS (Note 4)</b>						
LED Peak Wavelength	$\lambda_P$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$	870	880	900	nm
Full Width at Half Max	$\Delta\lambda$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$		30		nm
Forward Voltage	$V_F$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$		1.4		V
Radiant Power	$P_O$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$		6.5		mW
<b>RED LED CHARACTERISTICS (Note 4)</b>						
LED Peak Wavelength	$\lambda_P$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$	650	660	670	nm
Full Width at Half Max	$\Delta\lambda$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$		20		nm
Forward Voltage	$V_F$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$		2.1		V
Radiant Power	$P_O$	$I_{LED} = 20mA$ , $T_A = +25^{\circ}C$		9.8		mW

**Electrical Characteristics (continued)**

( $V_{DD} = 1.8V$ ,  $V_{IR\_LED+} = V_{R\_LED+} = V_{G\_LED+} = 5.0V$ ,  $T_A = +25^{\circ}C$ , min/max are from  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted. Typical values are at  $T_A = 25^{\circ}C$ .) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>GREEN LED CHARACTERISTICS (Note 4)</b>						
LED Peak Wavelength	$\lambda_P$	$I_{LED} = 50mA$ , $T_A = +25^{\circ}C$	530	537	545	nm
Full Width at Half Max	$\Delta\lambda$	$I_{LED} = 50mA$ , $T_A = +25^{\circ}C$		35		nm
Forward Voltage	$V_F$	$I_{LED} = 50mA$ , $T_A = +25^{\circ}C$		33		V
Radiant Power	$P_O$	$I_{LED} = 50mA$ , $T_A = +25^{\circ}C$		17.2		mW
<b>PHOTODETECTOR CHARACTERISTICS (Note 4)</b>						
Spectral Range of Sensitivity	$\lambda > 30\% QE$	QE: Quantum Efficiency	640		980	nm
Radiant Sensitive Area	A			1.36		mm <sup>2</sup>
Dimensions of Radiant Sensitive Area	L x W			1.38x0.98		mm x mm
<b>INTERNAL DIE TEMPERATURE SENSOR</b>						
Temperature ADC Acquisition Time	$T_T$	$T_A = +25^{\circ}C$		29		ms
Temperature Sensor Accuracy	$T_A$	$T_A = +25^{\circ}C$		$\pm 1$		$^{\circ}C$
Temperature Sensor Minimum Range	$T_{MIN}$			-40		$^{\circ}C$
Temperature Sensor Maximum Range	$T_{MAX}$			85		$^{\circ}C$
<b>DIGITAL INPUTS (SCL, SDA)</b>						
Input Logic-Low Voltage	$V_{IL}$				$0.3 \times V_{DD}$	V
Input Logic-High Voltage	$V_{IH}$		$0.7 \times V_{DD}$			V
Input Hysteresis	$V_{HYS}$			$0.5 \times V_{DD}$		V
Input Leakage Current	$I_{IN}$			$\pm 0.1$	$\pm 1$	$\mu A$
Input Capacitance	$C_{IN}$			10		pF
<b>DIGITAL OUTPUTS (SDA, INT)</b>						
Output Low Voltage	$V_{OL}$	$I_{SINK} = 3mA$			0.4	V
<b>I<sup>2</sup>C TIMING CHARACTERISTICS</b>						
I <sup>2</sup> C Write Address				AE		Hex
I <sup>2</sup> C Read Address				AF		Hex
SCL Clock Frequency	$f_{SCL}$	Lower limit not tested	0		400	kHz
Bus Free Time Between STOP and START Condition	$t_{BUF}$		1.3			$\mu s$
Hold Time (Repeated) START Condition	$t_{HD,STA}$		0.6			$\mu s$
SCL Pulse-Width Low	$t_{LOW}$		1.3			$\mu s$
SCL Pulse-Width High	$t_{HIGH}$		0.6			$\mu s$
Setup Time for a Repeated START Condition	$t_{SU,STA}$		0.6			$\mu s$
Data Hold Time	$t_{HD;DAT}$		0		0.9	$\mu s$
Data Setup Time	$t_{SU;DAT}$		100			ns
Setup Time for STOP Condition	$t_{SU;STO}$		0.6			$\mu s$
Pulse Width of Suppressed Spike	$t_{SP}$				50	ns

Electrical Characteristics (continued)

( $V_{DD} = 1.8V$ ,  $V_{IR\_LED+} = V_{R\_LED+} = V_{G\_LED+} = 5.0V$ ,  $T_A = +25^\circ C$ , min/max are from  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted. Typical values are at  $T_A = 25^\circ C$ .) (Note 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Bus Capacitance	$C_b$				400	pF
SDA and SCL Receiving Rise Time	$T_r$	(Note 5)	20		300	ns
SDA and SCL Receiving Fall Time	$t_{Rf}$	(Note 5)	$20 \times V_{DD}/5.5$		300	ns
SDA Transmitting Fall Time	$t_{of}$		$20 \times V_{DD}/5.5$		250	ns

- Note 2:** All devices are 100% production tested at  $T_A = +25^\circ C$ . Specifications over temperature limits are guaranteed by Maxim Integrated's bench or proprietary automated test equipment (ATE) characterization.
- Note 3:** Specifications are guaranteed by Maxim Integrated's bench characterization and by 100% production test using proprietary ATE setup and conditions.
- Note 4:** For design guidance only. Not production tested.
- Note 5:** These specifications are guaranteed by design, characterization, or I<sup>2</sup>C protocol.

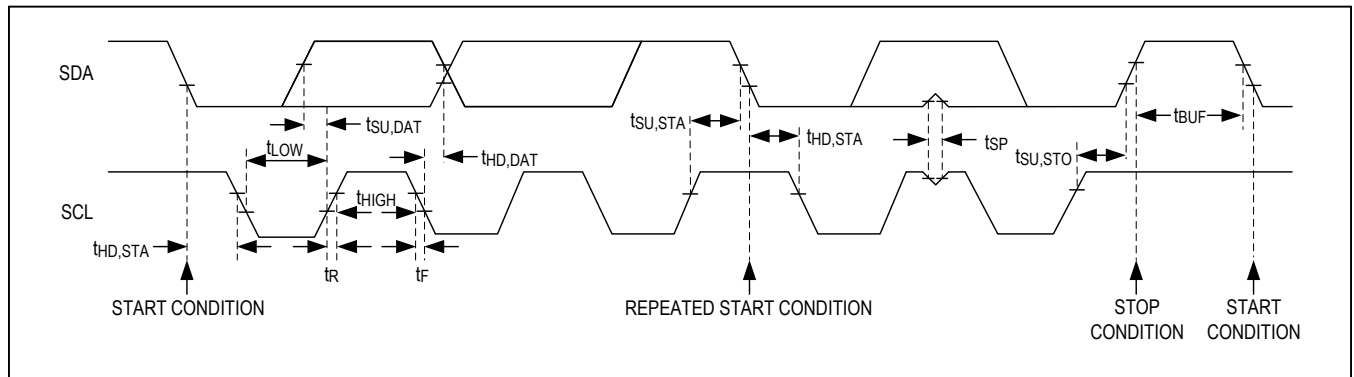
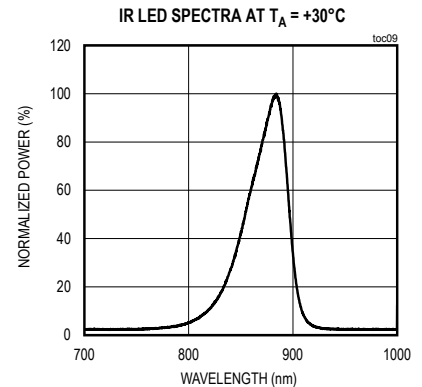
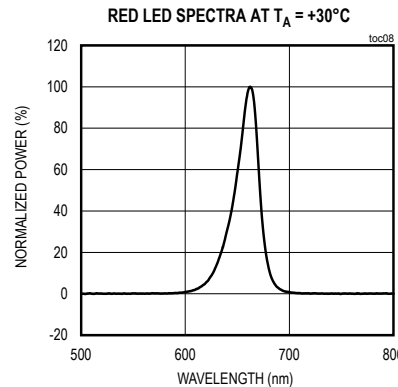
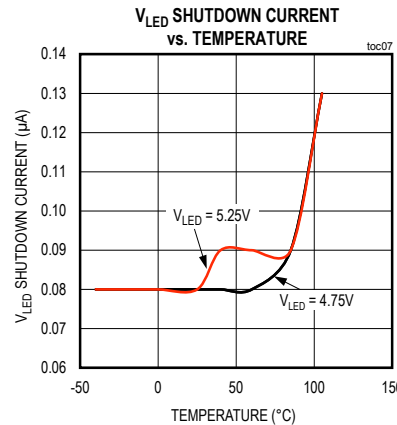
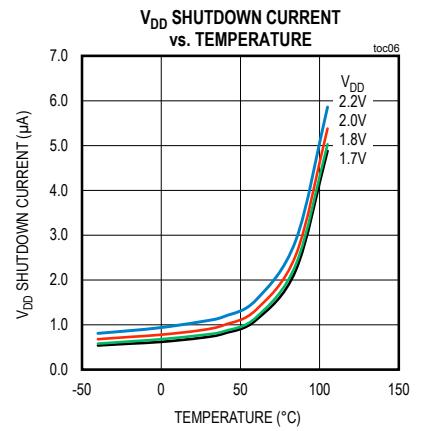
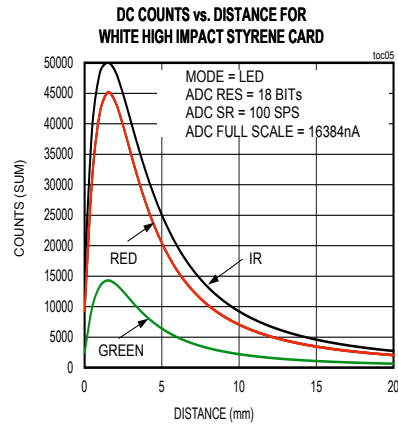
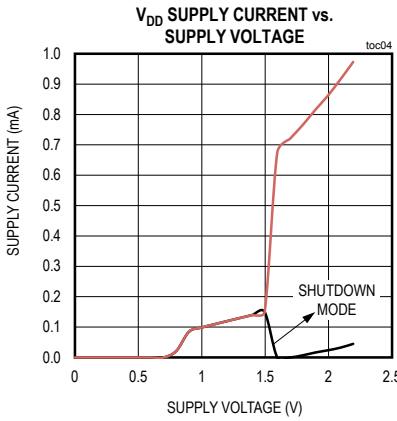
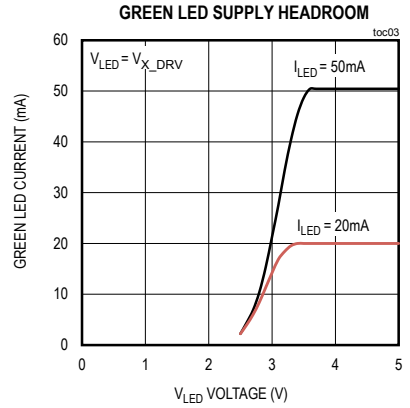
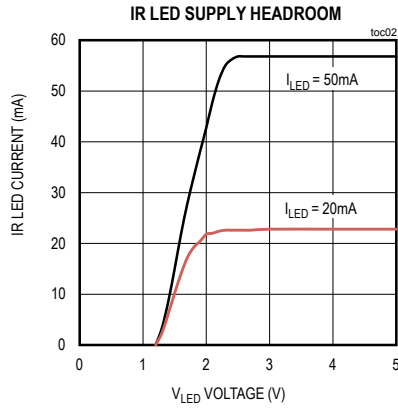
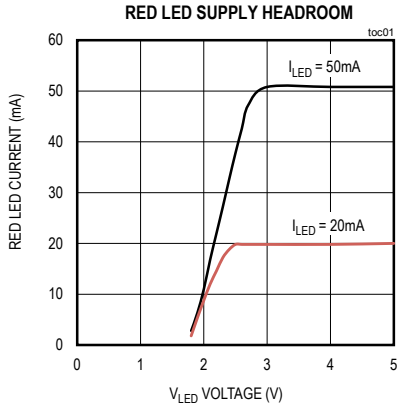


Figure 1. I<sup>2</sup>C-Compatible Interface Timing Diagram

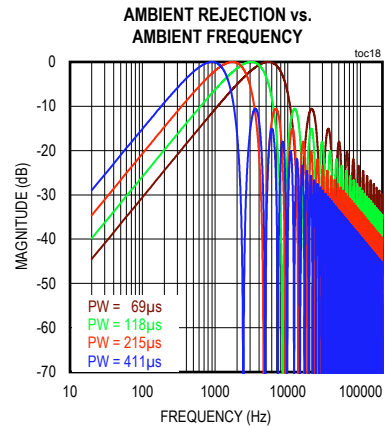
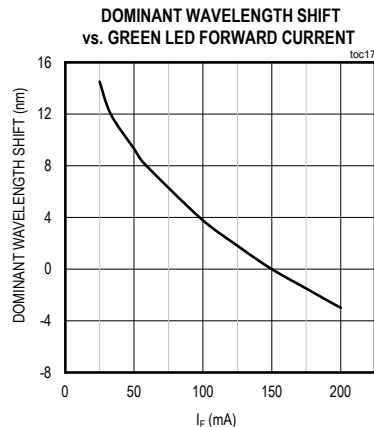
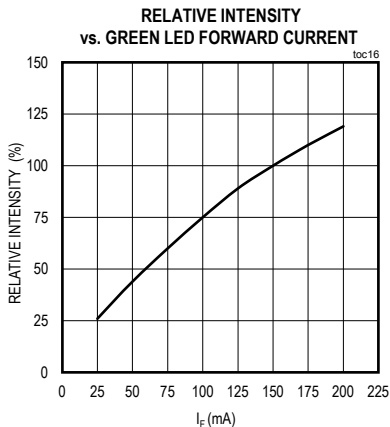
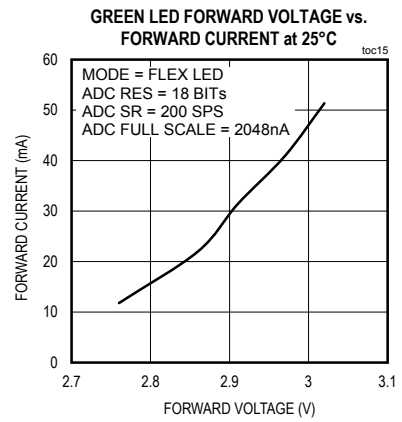
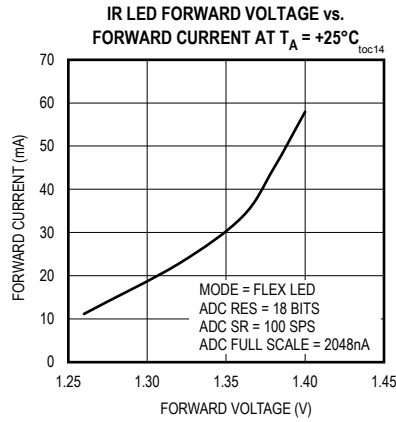
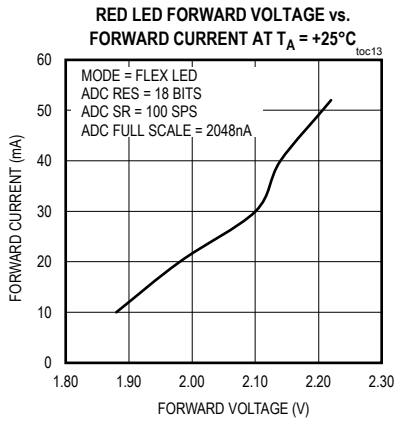
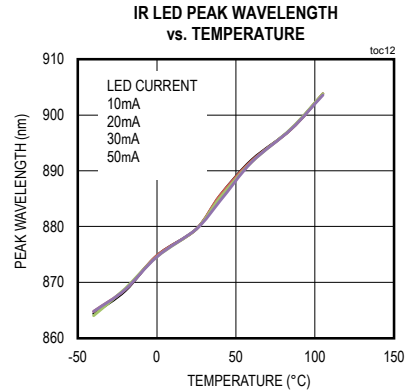
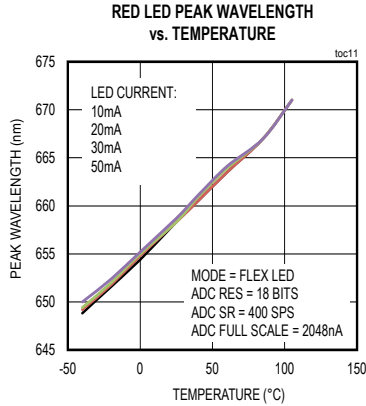
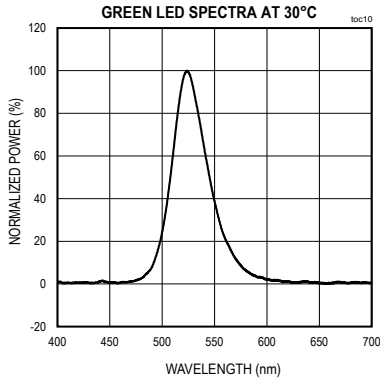
Typical Operating Characteristics

( $V_{DD} = 1.8V$ ,  $V_{LED+} = 5.0V$ ,  $T_A = +25^\circ C$ ,  $\overline{RST}$ , unless otherwise noted.)



Typical Operating Characteristics (continued)

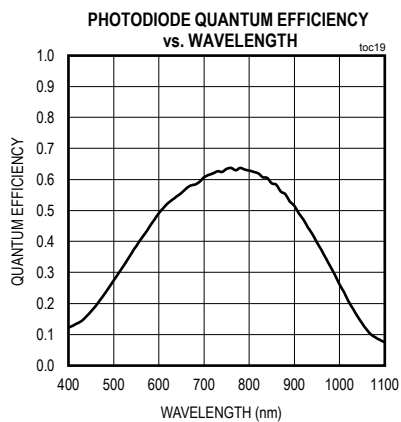
( $V_{DD} = 1.8V$ ,  $V_{LED+} = 5.0V$ ,  $T_A = +25^{\circ}C$ ,  $\overline{RST}$ , unless otherwise noted.)



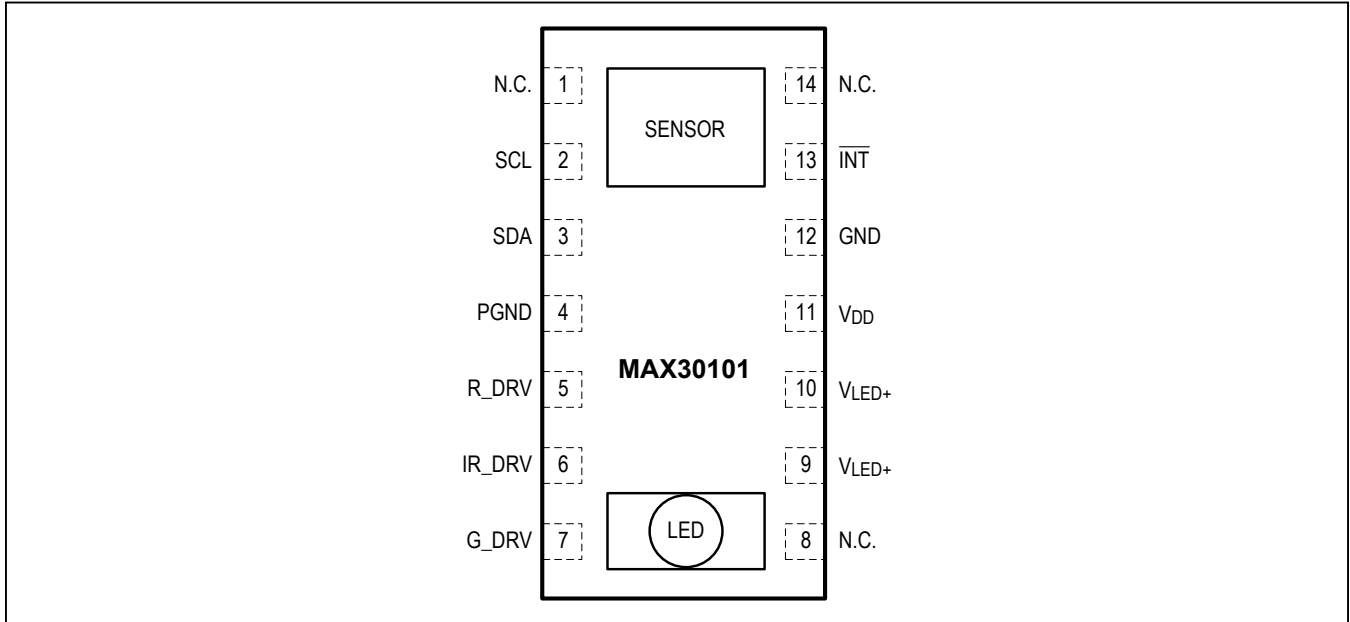


Typical Operating Characteristics (continued)

( $V_{DD} = 1.8V$ ,  $V_{LED+} = 5.0V$ ,  $T_A = +25^{\circ}C$ ,  $\overline{RST}$ , unless otherwise noted.)



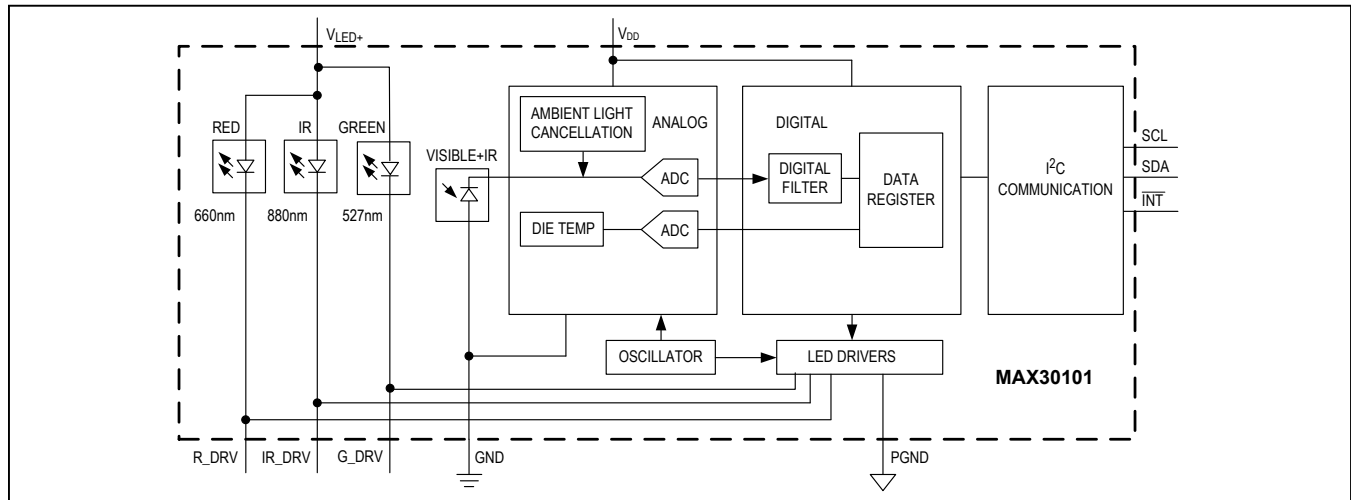
Pin Configuration



Pin Description

PIN	NAME	FUNCTION
1, 8, 14	N.C.	No Connection. Connect to PCB pad for mechanical stability.
2	SCL	I <sup>2</sup> C Clock Input
3	SDA	I <sup>2</sup> C Clock Data, Bidirectional (Open-Drain)
4	PGND	Power Ground of the LED Driver Blocks
5	R_DRV	Red LED Driver.
6	IR_DRV	IR LED Driver.
7	G_DRV	Green LED Driver.
9	V <sub>LED+</sub>	LED Power Supply (anode connection). Use a bypass capacitor to PGND for best performance.
10	V <sub>LED+</sub>	
11	V <sub>DD</sub>	Analog Power Supply Input. Use a bypass capacitor to GND for best performance.
12	GND	Analog Ground
13	INT	Active-Low Interrupt (Open-Drain). Connect to an external voltage with a pullup resistor.

## Functional Diagram



## Detailed Description

The MAX30101 is a complete pulse oximetry and heart-rate sensor system solution module designed for the demanding requirements of wearable devices. The MAX30101 maintains a very small solution size without sacrificing optical or electrical performance. Minimal external hardware components are required for integration into a wearable system.

The MAX30101 is fully adjustable through software registers, and the digital output data can be stored in a 32-deep FIFO within the IC. The FIFO allows the MAX30101 to be connected to a microcontroller or processor on a shared bus, where the data is not being read continuously from the MAX30101's registers.

### SpO<sub>2</sub> Subsystem

The SpO<sub>2</sub> subsystem contains ambient light cancellation (ALC), a continuous-time sigma-delta ADC, and proprietary discrete time filter. The ALC has an internal Track/Hold circuit to cancel ambient light and increase the effective dynamic range. The SpO<sub>2</sub> ADC has a programmable full-scale ranges from 2μA to 16μA. The ALC can cancel up to 200μA of ambient current.

The internal ADC is a continuous time oversampling sigma-delta converter with 18-bit resolution. The ADC sampling rate is 10.24MHz. The ADC output data rate can be programmed from 50sps (samples per second) to 3200sps.

### Temperature Sensor

The MAX30101 has an on-chip temperature sensor for calibrating the temperature dependence of the SpO<sub>2</sub> subsystem. The temperature sensor has an inherent resolution 0.0625°C.

The device output data is relatively insensitive to the wavelength of the IR LED, where the red LED's wavelength is critical to correct interpretation of the data. An SpO<sub>2</sub> algorithm used with the MAX30101 output signal can compensate for the associated SpO<sub>2</sub> error with ambient temperature changes.

### LED Driver

The MAX30101 integrates red, green, and IR LED drivers to modulate LED pulses for SpO<sub>2</sub> and HR measurements. The LED current can be programmed from 0 to 50mA with proper supply voltage. The LED pulse width can be programmed from 69μs to 411μs to allow the algorithm to optimize SpO<sub>2</sub> and HR accuracy and power consumption based on use cases.

### Proximity Function

The device includes a proximity function to save power and reduce visible light emission when the user's finger is not on the sensor. When the SpO<sub>2</sub> or HR function is initiated (by writing the MODE register), the IR LED is activated in proximity mode with a drive current set by the PILOT\_PA register. When an object is detected by exceeding the IR ADC count threshold (set in the PROX\_INT\_THRESH register), the part transitions automatically to the normal SpO<sub>2</sub>/HR Mode. To reenter PROX mode, the MODE register must be rewritten (even if the value is the same).

The proximity function can be disabled by resetting PROX\_INT\_EN to 0. In this case, the SpO<sub>2</sub> or HR mode begins immediately.

Register Maps and Descriptions

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
<b>STATUS</b>											
Interrupt Status 1	A_FULL	PPG_RDY	ALC_OVF	PROX_INT				PWR_RDY	0x00	0x00	R
Interrupt Status 2							DIE_TEMP_RDY		0x01	0x00	R
Interrupt Enable 1	A_FULL_EN	PPG_RDY_EN	ALC_OVF_EN	PROX_INT_EN					0x02	0x00	R/W
Interrupt Enable 2							DIE_TEMP_RDY_EN		0x03	0x00	R/W
FIFO											
FIFO Write Pointer				FIFO_WR_PTR[4:0]					0x04	0x00	R/W
Overflow Counter				OVF_COUNTER[4:0]					0x05	0x00	R/W
FIFO Read Pointer				FIFO_RD_PTR[4:0]					0x06	0x00	R/W
FIFO Data Register	FIFO_DATA[7:0]								0x07	0x00	R/W
<b>CONFIGURATION</b>											
FIFO Configuration	SMP_AVE[2:0]			FIFO_ROLL_OVER_EN	FIFO_A_FULL[3:0]				0x08	0x00	R/W
Mode Configuration	SHDN	RESET				MODE[2:0]			0x09	0x00	R/W
SpO <sub>2</sub> Configuration	0 (Reserved)	SPO2_ADC_RGE [1:0]		SPO2_SR[2:0]			LED_PW[1:0]		0x0A	0x00	R/W
RESERVED									0x0B	0x00	R/W
LED Pulse Amplitude	LED1_PA[7:0]								0x0C	0x00	R/W
	LED2_PA[7:0]								0x0D	0x00	R/W
	LED3_PA[7:0]								0x0E	0x00	R/W
RESERVED									0x0F	0x00	R/W
Proximity Mode LED Pulse Amplitude	PILOT_PA[7:0]								0x10	0x00	R/W
Multi-LED Mode Control Registers	SLOT2[2:0]				SLOT1[2:0]				0x11	0x00	R/W
	SLOT4[2:0]				SLOT3[2:0]				0x12	0x00	R/W

## Register Maps and Descriptions (continued)

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
RESERVED									0x13–0x17	0xFF	R/W
RESERVED									0x18–0x1E	0x00	R
<b>DIE TEMPERATURE</b>											
Die Temp Integer	TINT[7:0]								0x1F	0x00	R
Die Temp Fraction					TFRAC[3:0]				0x20	0x00	R
Die Temperature Config								TEMP_EN	0x21	0x00	R
RESERVED									0x22–0x2F	0x00	R/W
<b>PROXIMITY FUNCTION</b>											
Proximity Interrupt Threshold	PROX_INT_THRESH[7:0]								0x30	0x00	R/W
<b>PART ID</b>											
Revision ID	REV_ID[7:0]								0xFE	0XX*	R
Part ID	PART_ID[7]								0xFF	0x15	R

\*XX denotes a 2-digit hexadecimal number (00 to FF) for part revision identification. Contact Maxim Integrated for the revision ID number assigned for your product.

**Interrupt Status (0x00–0x01)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
Interrupt Status 1	A_FULL	PPG_RDY	ALC_OVF	PROX_INT				PWR_RDY	0x00	0x00	R
Interrupt Status 2							DIE_TEMP_RDY		0x01	0x00	R

Whenever an interrupt is triggered, the MAX30101 pulls the active-low interrupt pin into its low state until the interrupt is cleared.

**A\_FULL: FIFO Almost Full Flag**

In SpO<sub>2</sub> and HR modes, this interrupt triggers when the FIFO write pointer has a certain number of free spaces remaining. The trigger number can be set by the FIFO\_A\_FULL[3:0] register. The interrupt is cleared by reading the Interrupt Status 1 register (0x00).

**PPG\_RDY: New FIFO Data Ready**

In SpO<sub>2</sub> and HR modes, this interrupt triggers when there is a new sample in the data FIFO. The interrupt is cleared by reading the Interrupt Status 1 register (0x00), or by reading the FIFO\_DATA register.

**ALC\_OVF: Ambient Light Cancellation Overflow**

This interrupt triggers when the ambient light cancellation function of the SpO<sub>2</sub>/HR photodiode has reached its maximum limit, and therefore, ambient light is affecting the output of the ADC. The interrupt is cleared by reading the Interrupt Status 1 register (0x00).

**PROX\_INT: Proximity Threshold Triggered**

The proximity interrupt is triggered when the proximity threshold is reached, and SpO<sub>2</sub>/HR mode has begun. This lets the host processor know to begin running the SpO<sub>2</sub>/HR algorithm and collect data. The interrupt is cleared by reading the Interrupt Status 1 register (0x00).

**PWR\_RDY: Power Ready Flag**

On power-up or after a brownout condition, when the supply voltage  $V_{DD}$  transitions from below the undervoltage lockout (UVLO) voltage to above the UVLO voltage, a power-ready interrupt is triggered to signal that the module is powered-up and ready to collect data.

**DIE\_TEMP\_RDY: Internal Temperature Ready Flag**

When an internal die temperature conversion is finished, this interrupt is triggered so the processor can read the temperature data registers. The interrupt is cleared by reading either the Interrupt Status 2 register (0x01) or the TFRAC register (0x20).

The interrupts are cleared whenever the interrupt status register is read, or when the register that triggered the interrupt is read. For example, if the SpO<sub>2</sub> sensor triggers an interrupt due to finishing a conversion, reading either the FIFO data register or the interrupt register clears the interrupt pin (which returns to its normal HIGH state). This also clears all the bits in the interrupt status register to zero.

### Interrupt Enable (0x02-0x03)

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
Interrupt Enable 1	A_FULL_EN	PPG_RDY_EN	ALC_OVF_EN	PROX_INT_EN					0x02	0x00	R/W
Interrupt Enable 2							DIE_TEMP_RDY_EN		0x03	0x00	R/W

Each source of hardware interrupt, with the exception of power ready, can be disabled in a software register within the MAX30101 IC. The power-ready interrupt cannot be disabled because the digital state of the module is reset upon a brownout condition (low power supply voltage), and the default condition is that all the interrupts are disabled. Also, it is important for the system to know that a brownout condition has occurred, and the data within the module is reset as a result.

The unused bits should always be set to zero for normal operation.

### FIFO (0x04–0x07)

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
FIFO Write Pointer				FIFO_WR_PTR[4:0]					0x04	0x00	R/W
Over Flow Counter				OVF_COUNTER[4:0]					0x05	0x00	R/W
FIFO Read Pointer				FIFO_RD_PTR[4:0]					0x06	0x00	R/W
FIFO Data Register	FIFO_DATA[7:0]								0x07	0x00	R/W

#### FIFO Write Pointer

The FIFO Write Pointer points to the location where the MAX30101 writes the next sample. This pointer advances for each sample pushed on to the FIFO. It can also be changed through the I<sup>2</sup>C interface when MODE[2:0] is 010, 011, or 111.

#### FIFO Overflow Counter

When the FIFO is full, samples are not pushed on to the FIFO, samples are lost. OVF\_COUNTER counts the number of samples lost. It saturates at 0xF. When a complete sample is “popped” (i.e., removal of old FIFO data and shifting the samples down) from the FIFO (when the read pointer advances), OVF\_COUNTER is reset to zero.

#### FIFO Read Pointer

The FIFO Read Pointer points to the location from where the processor gets the next sample from the FIFO through the I<sup>2</sup>C interface. This advances each time a sample is popped from the FIFO. The processor can also write to this pointer after reading the samples to allow rereading samples from the FIFO if there is a data communication error.

**FIFO Data Register**

The circular FIFO depth is 32 and can hold up to 32 samples of data. The sample size depends on the number of LED channels (a.k.a. channels) configured as active. As each channel signal is stored as a 3-byte data signal, the FIFO width can be 3 bytes, 6 bytes, 9 bytes, or 12 bytes in size.

The FIFO\_DATA register in the I<sup>2</sup>C register map points to the next sample to be read from the FIFO. FIFO\_RD\_PTR points to this sample. Reading FIFO\_DATA register, does not automatically increment the I<sup>2</sup>C register address. Burst reading this register, reads the same address over and over. Each sample is 3 bytes of data per channel (i.e., 3 bytes for RED, 3 bytes for IR, etc.).

The FIFO registers (0x04–0x07) can all be written and read, but in practice only the FIFO\_RD\_PTR register should be written to in operation. The others are automatically incremented or filled with data by the MAX30101. When starting a new SpO<sub>2</sub> or heart rate conversion, it is recommended to first clear the FIFO\_WR\_PTR, OVF\_COUNTER, and FIFO\_RD\_PTR registers to all zeroes (0x00) to ensure the FIFO is empty and in a known state. When reading the MAX30101 registers in one burst-read I<sup>2</sup>C transaction, the register address pointer typically increments so that the next byte of data sent is from the next register, etc. The exception to this is the FIFO data register, register 0x07. When reading this register, the address pointer does not increment, but the FIFO\_RD\_PTR does. So the next byte of data sent represents the next byte of data available in the FIFO.

Entering and exiting the proximity mode (when PROX\_INT\_EN = 1) clears the FIFO by setting the write and read pointers equal to each other.

**Reading from the FIFO**

Normally, reading registers from the I<sup>2</sup>C interface autoincrements the register address pointer, so that all the registers can be read in a burst read without an I<sup>2</sup>C start event. In the MAX30101, this holds true for all registers except for the FIFO\_DATA register (register 0x07).

Reading the FIFO\_DATA register does not automatically increment the register address. Burst reading this register reads data from the same address over and over. Each sample comprises multiple bytes of data, so multiple bytes should be read from this register (in the same transaction) to get one full sample.

The other exception is 0xFF. Reading more bytes after the 0xFF register does not advance the address pointer back to 0x00, and the data read is not meaningful.

**FIFO Data Structure**

The data FIFO consists of a 32-sample memory bank that can store GREEN, IR, and RED ADC data. Since each sample consists of three channels of data, there are 9 bytes of data for each sample, and therefore 288 total bytes of data can be stored in the FIFO.

The FIFO data is left-justified as shown in Table 1; in other words, the MSB bit is always in the bit 17 data position regardless of ADC resolution setting. See Table 2 for a visual presentation of the FIFO data structure.

**Table 1. FIFO Data is Left-Justified**

ADC Resolution	FIFO_DATA[17]	FIFO_DATA[16]	...	FIFO_DATA[12]	FIFO_DATA[11]	FIFO_DATA[10]	FIFO_DATA[9]	FIFO_DATA[8]	FIFO_DATA[7]	FIFO_DATA[6]	FIFO_DATA[5]	FIFO_DATA[4]	FIFO_DATA[3]	FIFO_DATA[2]	FIFO_DATA[1]	FIFO_DATA[0]
18-bit	█	█		█	█	█	█	█	█	█	█	█	█	█	█	█
17-bit	█	█		█	█	█	█	█	█	█	█	█	█	█	█	█
16-bit	█	█		█	█	█	█	█	█	█	█	█	█	█	█	█
15-bit	█	█		█	█	█	█	█	█	█	█	█	█	█	█	█



**FIFO Data Contains 3 Bytes per Channel**

The FIFO data is left-justified, meaning that the MSB is always in the same location regardless of the ADC resolution setting. FIFO DATA[18] – [23] are not used. Table 2 shows the structure of each triplet of bytes (containing the 18-bit ADC data output of each channel).

Each data sample in SpO<sub>2</sub> mode comprises two data triplets (3 bytes each). To read one sample, requires an I<sup>2</sup>C read command for each byte. Thus, to read one sample in SpO<sub>2</sub> mode, requires 6 I<sup>2</sup>C byte reads. To read one sample with three LED channels requires 9 I<sup>2</sup>C byte reads. The FIFO read pointer is automatically incremented after the first byte of each sample is read.

**Write/Read Pointers**

Write/Read pointers are used to control the flow of data in the FIFO. The write pointer increments every time a new sample is added to the FIFO. The read pointer is incremented every time a sample is read from the FIFO. To reread a sample from the FIFO, decrement its value by one and read the data register again.

The FIFO write/read pointers should be cleared (back to 0x00) upon entering SpO<sub>2</sub> mode or HR mode, so that there is no old data represented in the FIFO. The pointers are automatically cleared if V<sub>DD</sub> is power-cycled or V<sub>DD</sub> drops below its UVLO voltage.

**Table 2. FIFO Data (3 Bytes per Channel)**

BYTE 1							FIFO_ DATA[17]	FIFO_ DATA[16]
BYTE 2	FIFO_ DATA[15]	FIFO_ DATA[14]	FIFO_ DATA[13]	FIFO_ DATA[12]	FIFO_ DATA[11]	FIFO_ DATA[10]	FIFO_ DATA[9]	FIFO_ DATA[8]
BYTE 3	FIFO_ DATA[7]	FIFO_ DATA[6]	FIFO_ DATA[5]	FIFO_ DATA[4]	FIFO_ DATA[3]	FIFO_ DATA[2]	FIFO_ DATA[1]	FIFO_ DATA[0]

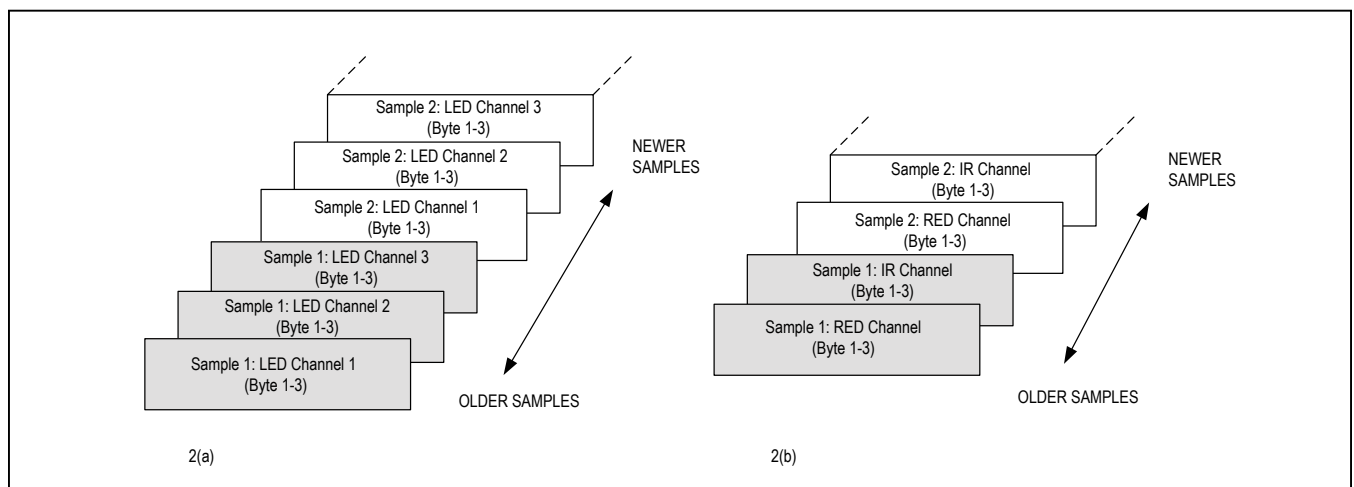


Figure 2a and 2b. Graphical Representation of the FIFO Data Register. The left shows three LEDs in multi-LED mode, and the right shows IR and Red only in SpO<sub>2</sub> Mode.

**Pseudo-Code Example of Reading Data from FIFO**

First transaction: Get the FIFO\_WR\_PTR:

```
START;
Send device address + write mode
Send address of FIFO_WR_PTR;
REPEATED_START;
Send device address + read mode
Read FIFO_WR_PTR;
STOP;
```

The central processor evaluates the number of samples to be read from the FIFO:

```
NUM_AVAILABLE_SAMPLES = FIFO_WR_PTR - FIFO_RD_PTR
(Note: pointer wrap around should be taken into account)
NUM_SAMPLES_TO_READ = < less than or equal to NUM_AVAILABLE_SAMPLES >
```

Second transaction: Read NUM\_SAMPLES\_TO\_READ samples from the FIFO:

```
START;
Send device address + write mode
Send address of FIFO_DATA;
REPEATED_START;
Send device address + read mode
for (i = 0; i < NUM_SAMPLES_TO_READ; i++) {
Read FIFO_DATA;
Save LED1[23:16];
Read FIFO_DATA;
Save LED1[15:8];
Read FIFO_DATA;
Save LED1[7:0];
Read FIFO_DATA;
Save LED2[23:16];
Read FIFO_DATA;
Save LED2[15:8];
Read FIFO_DATA;
Save LED2[7:0];
Read FIFO_DATA;
Save LED3[23:16];
Read FIFO_DATA;
Save LED3[15:8];
Read FIFO_DATA;
Save LED3[7:0];
Read FIFO_DATA;
}
STOP;
```

START;  
 Send device address + write mode  
 Send address of FIFO\_RD\_PTR;  
 Write FIFO\_RD\_PTR;  
 STOP;

Third transaction: Write to FIFO\_RD\_PTR register. If the second transaction was successful, FIFO\_RD\_PTR points to the next sample in the FIFO, and this third transaction is not necessary. Otherwise, the processor updates the FIFO\_RD\_PTR appropriately, so that the samples are reread.

**FIFO Configuration (0x08)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
FIFO Configuration	SMP_AVE[2:0]			FIFO_ROL LOVER_EN	FIFO_A_FULL[3:0]			0x08	0x00	R/W	

**Bits 7:5: Sample Averaging (SMP\_AVE)**

To reduce the amount of data throughput, adjacent samples (in each individual channel) can be averaged and decimated on the chip by setting this register.

**Table 3. Sample Averaging**

SMP_AVE[2:0]	NO. OF SAMPLES AVERAGED PER FIFO SAMPLE
000	1 (no averaging)
001	2
010	4
011	8
100	16
101	32
110	32
111	32

**Bit 4: FIFO Rolls on Full (FIFO\_ROLLOVER\_EN)**

This bit controls the behavior of the FIFO when the FIFO becomes completely filled with data. If FIFO\_ROLLOVER\_EN is set (1), the FIFO Address rolls over to zero and the FIFO continues to fill with new data. If the bit is not set (0), then the FIFO is not updated until FIFO\_DATA is read or the WRITE/READ pointer positions are changed.

**Bits 3:0: FIFO Almost Full Value (FIFO\_A\_FULL)**

This register sets the trigger for the FIFO\_A\_FULL interrupt. For example, if set to 0x0F, the interrupt triggers when there is 17 empty space left (15 data samples), and so on.

FIFO_A_FULL[3:0]	ALMOST FULL INTERRUPT TRIGGER (NO. OF SAMPLES IN THE FIFO)
0x0h	0
0x1h	1
0x2h	2
0x3h	3
...	...
0xFh	15

**Mode Configuration (0x09)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
Mode Configuration	SHDN	RESET				MODE[3:0]			0x09	0x00	R/W

**Bit 7: Shutdown Control (SHDN)**

The part can be put into a power-save mode by setting this bit to one. While in power-save mode, all registers retain their values, and write/read operations function as normal. All interrupts are cleared to zero in this mode.

**Bit 6: Reset Control (RESET)**

When the RESET bit is set to one, all configuration, threshold, and data registers are reset to their power-on-state through a power-on reset. The RESET bit is cleared automatically back to zero after the reset sequence is completed.

**Note:** Setting the RESET bit does not trigger a PWR\_RDY interrupt event.

**Bits 2:0: Mode Control**

These bits set the operating state of the MAX30101. Changing modes does not change any other setting, nor does it erase any previously stored data inside the data registers.

**Table 4. Mode Control**

MODE[2:0]	MODE	ACTIVE LED CHANNELS
000	Do not use	
001	Do not use	
010	Heart Rate mode	Red only
011	SpO2 mode	Red and IR
100–110	Do not use	
111	Multi-LED mode	Green, Red, and/or IR

**SpO<sub>2</sub> Configuration (0x0A)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
SpO <sub>2</sub> Configuration		SPO2_ADC_RGE<1:0>		SPO2_SR[2:0]			LED_PW[2:0]		0x0A	0x00	R/W

**Bits 6:5: SpO<sub>2</sub> ADC Range Control**

This register sets the SpO<sub>2</sub> sensor ADC's full-scale range as shown in [Table 5](#).

**Table 5. SpO<sub>2</sub> ADC Range Control (18-Bit Resolution)**

SPO2_ADC_RGE[1:0]	LSB SIZE (pA)	FULL SCALE (nA)
00	7.81	2048
01	15.63	4096
02	31.25	8192
03	62.5	16384

**Bits 4:2: SpO<sub>2</sub> Sample Rate Control**

These bits define the effective sampling rate with one sample consisting of one IR pulse/conversion and one RED pulse/conversion.

The sample rate and pulse width are related in that the sample rate sets an upper bound on the pulse width time. If the user selects a sample rate that is too high for the selected LED\_PW setting, the highest possible sample rate is programmed instead into the register.

**Table 6. SpO<sub>2</sub> Sample Rate Control**

SPO2_SR[2:0]	SAMPLES PER SECOND
000	50
001	100
010	200
011	400
100	800
101	1000
110	1600
111	3200

See [Table 11](#) and [Table 12](#) for Pulse Width vs. Sample Rate information.

**Bits 1:0: LED Pulse Width Control and ADC Resolution**

These bits set the LED pulse width (the IR, Red, and Green have the same pulse width), and therefore, indirectly sets the integration time of the ADC in each sample. The ADC resolution is directly related to the integration time.

**Table 7. LED Pulse Width Control**

LED_PW[1:0]	PULSE WIDTH (μs)	ADC RESOLUTION (bits)
00	69 (68.95)	15
01	118 (117.78)	16
10	215 (215.44)	17
11	411 (410.75)	18

**LED Pulse Amplitude (0x0C–0x10)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
LED Pulse Amplitude	LED1_PA[7:0]								0x0C	0x00	R/W
	LED2_PA[7:0]								0x0D	0x00	R/W
LED Pulse Amplitude	LED3_PA[7:0]								0x0E	0x00	R/W
RESERVED									0x0F	0x00	R/W
Proximity Mode LED Pulse Amplitude	PILOT_PA[7:0]								0x10	0x00	R/W

These bits set the current level of each LED as shown in [Table 8](#).

**Table 8. LED Current Control**

LEDx_PA [7:0], RED_PA[7:0], IR_PA[7:0], or G_PA[7:0]	TYPICAL LED CURRENT (mA)*
0x00h	0.0
0x01h	0.2
0x02h	0.4
...	...
0x0Fh	3.1
...	...
0x1Fh	6.4
...	...
0x3Fh	12.5
...	...
0x7Fh	25.4
...	...
0xFFh	50.0

\*Actual measured LED current for each part can vary significantly due to the trimming methodology.

The purpose of PILOT\_PA[7:0] is to set the LED power during the proximity mode, as well as in Multi-LED mode.

### Multi-LED Mode Control Registers (0x11–0x12)

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
Multi-LED Mode Control Registers			SLOT2[2:0]			SLOT1[2:0]			0x11	0x00	R/W
			SLOT4[2:0]			SLOT3[2:0]			0x12	0x00	R/W

In multi-LED mode, each sample is split into up to four time slots, SLOT1 through SLOT4. These control registers determine which LED is active in each time slot, making for a very flexible configuration.

**Table 9. Multi-LED Mode Control Registers**

SLOTx[2:0] Setting	WHICH LED IS ACTIVE	LED PULSE AMPLITUDE SETTING
000	None (time slot is disabled)	N/A (Off)
001	LED1 (RED)	LED1_PA[7:0]
010	LED2 (IR)	LED2_PA[7:0]
011	LED3 (GREEN)	LED3_PA[7:0]
100	None	N/A (Off)
101	LED1 (Red)	PILOT_PA[7:0]
110	LED2 (IR)	PILOT_PA[7:0]
111	LED3 (GREEN)	PILOT_PA[7:0]

Each slot generates a 3-byte output into the FIFO. One sample comprises all active slots, for example if SLOT1 and SLOT2 are non-zero, then one sample is  $2 \times 3 = 6$  bytes. If SLOT1 through SLOT3 are all non-zero, then one sample is  $3 \times 3 = 9$  bytes.

The slots should be enabled in order (i.e., SLOT1 should not be disabled if SLOT2 or SLOT3 are enabled).

**Temperature Data (0x1F–0x21)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
Temp_Integer	TINT[7]								0x1F	0x00	R/W
Temp_Fraction					TFRAC[3:0]				0x20	0x00	R/W
Die Temperature Config								TEMP_EN	0x21	0x00	R

**Temperature Integer**

The on-board temperature ADC output is split into two registers, one to store the integer temperature and one to store the fraction. Both should be read when reading the temperature data, and the equation below shows how to add the two registers together:

$$T_{\text{MEASURED}} = T_{\text{INTEGER}} + T_{\text{FRACTION}}$$

This register stores the integer temperature data in 2's complement format, where each bit corresponds to 1°C.

**Table 10. Temperature Integer**

REGISTER VALUE (hex)	TEMPERATURE (°C)
0x00	0
0x00	+1
...	...
0x7E	+126
0x7F	+127
0x80	-128
0x81	-127
...	...
0xFE	-2
0xFF	-1

**Temperature Fraction**

This register stores the fractional temperature data in increments of 0.0625°C. If this fractional temperature is paired with a negative integer, it still adds as a positive fractional value (e.g., -128°C + 0.5°C = -127.5°C).

**Temperature Enable (TEMP\_EN)**

This is a self-clearing bit which, when set, initiates a single temperature reading from the temperature sensor. This bit clears automatically back to zero at the conclusion of the temperature reading when the bit is set to one in HR or SpO2 mode.



**Proximity Mode Interrupt Threshold (0x30)**

REGISTER	B7	B6	B5	B4	B3	B2	B1	B0	REG ADDR	POR STATE	R/W
Proximity Interrupt Threshold	PROX_INT_THRESH[7:0]								0x30	0x00	R/W

This register sets the IR ADC count that will trigger the beginning of HR or SpO2 mode. The threshold is defined as the 8 MSBs of the ADC count. For example, if PROX\_INT\_THRESH[7:0] = 0x01, then an ADC value of 1023 (decimal) or higher triggers the PROX interrupt. If PROX\_INT\_THRESH[7:0] = 0xFF, then only a saturated ADC triggers the interrupt.

**Applications Information**

**Sampling Rate and Performance**

The maximum sample rate for the ADC depends on the selected pulse width, which in turn, determines the ADC resolution. For instance, if the pulse width is set to 69µs then the ADC resolution is 15 bits, and all sample rates are selectable. However, if the pulse width is set to 411µs, then the samples rates are limited. The allowed sample rates for both SpO2 and HR Modes are summarized in the [Table 11](#) and [Table 12](#):

**Power Considerations**

The LED waveforms and their implication for power supply design are discussed in this section.

The LEDs in the MAX30101 are pulsed with a low duty cycle for power savings, and the pulsed currents can cause ripples in the V<sub>LED+</sub> power supply. To ensure these pulses do not translate into optical noise at the LED outputs, the power supply must be designed to handle these. Ensure that the resistance and inductance from the power supply (battery, DC/DC converter, or LDO) to the pin is much smaller than 1Ω, and that there is at least 1µF of power supply bypass capacitance to a good ground plane. The capacitance should be located as close as physically possible to the IC.

**Table 11. SpO2 Mode (Allowed Settings)**

SAMPLES PER SECOND	PULSE WIDTH (µs)			
	69	118	215	411
50	O	O	O	O
100	O	O	O	O
200	O	O	O	O
400	O	O	O	O
800	O	O	O	
1000	O	O		
1600	O			
3200				
Resolution (bits)	15	16	17	18

**Table 12. HR Mode (Allowed Settings)**

SAMPLES PER SECOND	PULSE WIDTH (µs)			
	69	118	215	411
50	O	O	O	O
100	O	O	O	O
200	O	O	O	O
400	O	O	O	O
800	O	O	O	O
1000	O	O	O	O
1600	O	O	O	
3200	O			
Resolution (bits)	15	16	17	18

**SpO<sub>2</sub> Temperature Compensation**

The MAX30101 has an accurate on-board temperature sensor that digitizes the IC's internal temperature upon command from the I<sup>2</sup>C master. The temperature has an effect on the wavelength of the red and IR LEDs. While the device output data is relatively insensitive to the wavelength of the IR LED, the red LED's wavelength is critical to correct interpretation of the data.

Table 13 shows the correlation of red LED wavelength versus the temperature of the LED. Since the LED die heats up with a very short thermal time constant (tens of microseconds), the LED wavelength should be calculated according to the current level of the LED and the temperature of the IC. Use Table 13 to estimate the temperature.

**Red LED Current Settings vs. LED Temperature Rise**

Add this to the module temperature reading to estimate the LED temperature and output wavelength. The LED temperature estimate is valid even with very short pulse widths, due to the fast thermal time constant of the LED.

**Interrupt Pin Functionality**

The active-low interrupt pin pulls low when an interrupt is triggered. The pin is open-drain, which means it normally requires a pullup resistor or current source to an external voltage supply (up to +5V from GND). The interrupt pin is not designed to sink large currents, so the pullup resistor value should be large, such as 4.7kΩ.

**Table 13. RED LED Current Settings vs. LED Temperature Rise**

RED LED CURRENT SETTING	RED LED DUTY CYCLE (% OF LED PULSE WIDTH TO SAMPLE TIME)	ESTIMATED TEMPERATURE RISE (ADD TO TEMP SENSOR MEASUREMENT) (°C)
0001 (0.2mA)	8	0.1
1111 (50mA)	8	2
0001 (0.2mA)	16	0.3
1111 (50mA)	16	4
0001 (0.2mA)	32	0.6
1111 (50mA)	32	8