

## MAX86150

# Integrated Photoplethysmogram and Electrocardiogram Bio-Sensor Module For Mobile Health

### General Description

The MAX86150 is an integrated electrocardiogram, pulse oximeter, heart rate monitor sensor module. It includes internal LEDs, photodetectors, IR sensor and low-noise electronics with ambient light rejection. Maxim's proprietary technology also includes robust algorithms to give meaningful outputs to the user with minimal additional design required. The MAX86150 helps ease design-in to mobile and wearable devices.

The MAX86150 operates on a 1.8V supply voltage with a separate power supply for the internal LEDs. Communication to and from the module is entirely through a standard I<sup>2</sup>C-compatible interface. The module can be shut down through software with near zero standby current, allowing the power rails to remain powered at all times.

### Applications

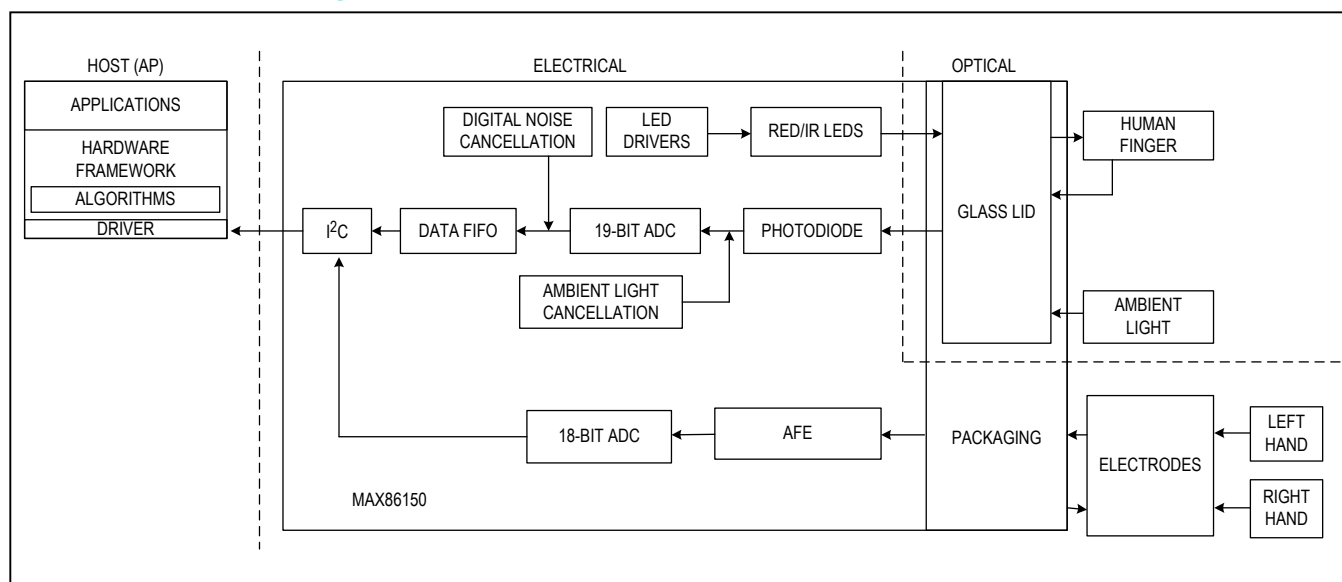
- Smartphones
- Tablets
- Wearable Devices
- Fitness Assistant Devices

### Benefits and Features

- Electrocardiogram (ECG) Optimized for Dry Electrode Operation
- Reflective Heart Rate Monitor and Medical-Grade Pulse Oximeter
- Miniature 3.3mm x 5.6mm x 1.3mm 22-pin Optical Module
  - Optical-Grade Glass for Long-Term Optimal and Robust Performance
- Ultra-Low Power Operation for Mobile Devices
  - Ultra-Low Shutdown Current (0.7μA Typical)
- Robust Motion Artifact Resilience (Heart Rate Monitor)
  - High SNR and Robust Motion Rejection Algorithm
- -40°C to +85°C Operating Temperature Range

Ordering Information appears at end of data sheet.

### Simplified Block Diagram



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**Absolute Maximum Ratings**

V <sub>DD_ANA</sub> to GND_ANA.....	-0.3V to +2.2V	Output Short-Circuit Duration.....	Continuous
V <sub>DD_DIG</sub> to GND DIG.....	-0.3V to +2.2V	Continuous Input Current Into Any Pin	
V <sub>DD_ANA</sub> to V <sub>DD_DIG</sub> .....	V <sub>DD_DIG</sub> - 0.3V to	(except LED_DRVx pins).....	±20mA
	V <sub>DD_DIG</sub> + 0.3V	Continuous Power Dissipation	
GND_ANA to GND_DIG.....	GND_DIG - 0.3V to	(derate 5.5mW/°C above +70°C).....	440mW
	GND_DIG + 0.3V	SDA, SCL, INTB, GPIO to GND_ANA.....	-0.3V to +6.0V
PGND to GND_ANA.....	-0.3V to +0.3V	OESIP (derate 5.5mW/°C above +70°C).....	-40°C to 85°C
LED_DRVx, V <sub>LED</sub> to PGND.....	-0.3V to +6.0V	Operating Temperature Range.....	-40°C to +85°C
ECG_P, ECG_N, ECG_C to GND_ANA.....	-0.3V to +2.2V	Junction Temperature.....	+150°C
C1_P, C1_N to GND_ANA.....	-0.3V to +2.2V	Storage Temperature Range.....	-40°C to +105°C
IDRV_P, IDRV_N to GND_ANA.....	-0.3V to +2.2V	Soldering Temperature (reflow).....	+260°C
V <sub>REF</sub> to GND_ANA.....	-0.3V to +2.2V		

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

**Package Information**

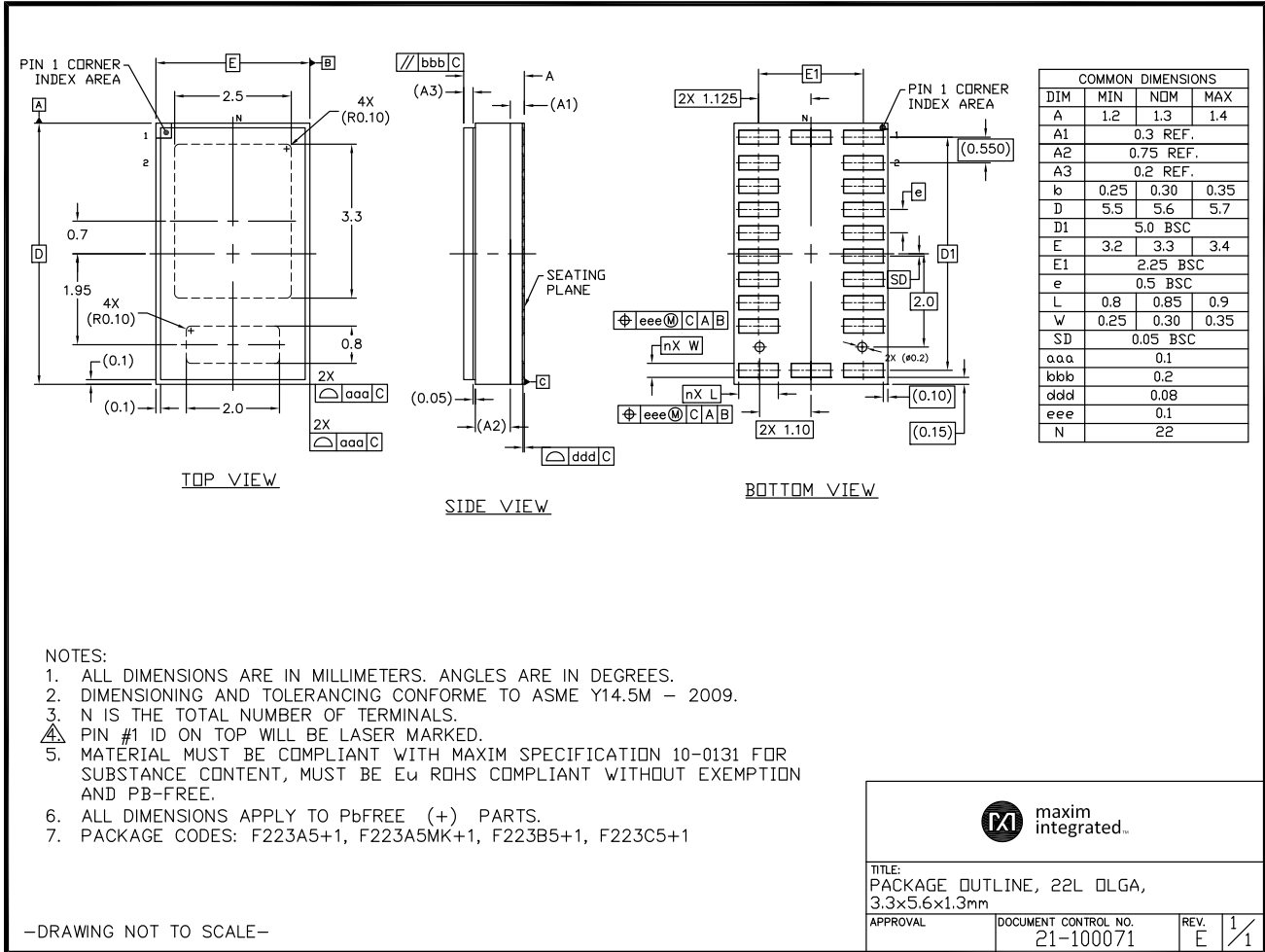
PACKAGE CODE	F223A5+1
Outline Number	<a href="#">21-100071</a>
Land Pattern Number	<a href="#">90-100024</a>
<b>Thermal Resistance, Single Layer Board:</b>	
Junction-to-Ambient (θ <sub>JA</sub> )	N/A
Junction-to-Case Thermal Resistance (θ <sub>JC</sub> )	N/A
<b>Thermal Resistance, Four Layer Board:</b>	
Junction-to-Ambient (θ <sub>JA</sub> )	180°C/W
Junction-to-Case Thermal Resistance (θ <sub>JC</sub> )	150°C/W

For the latest package outline information and land patterns (footprints), go to [www.maximintegrated.com/packages](http://www.maximintegrated.com/packages). Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

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).

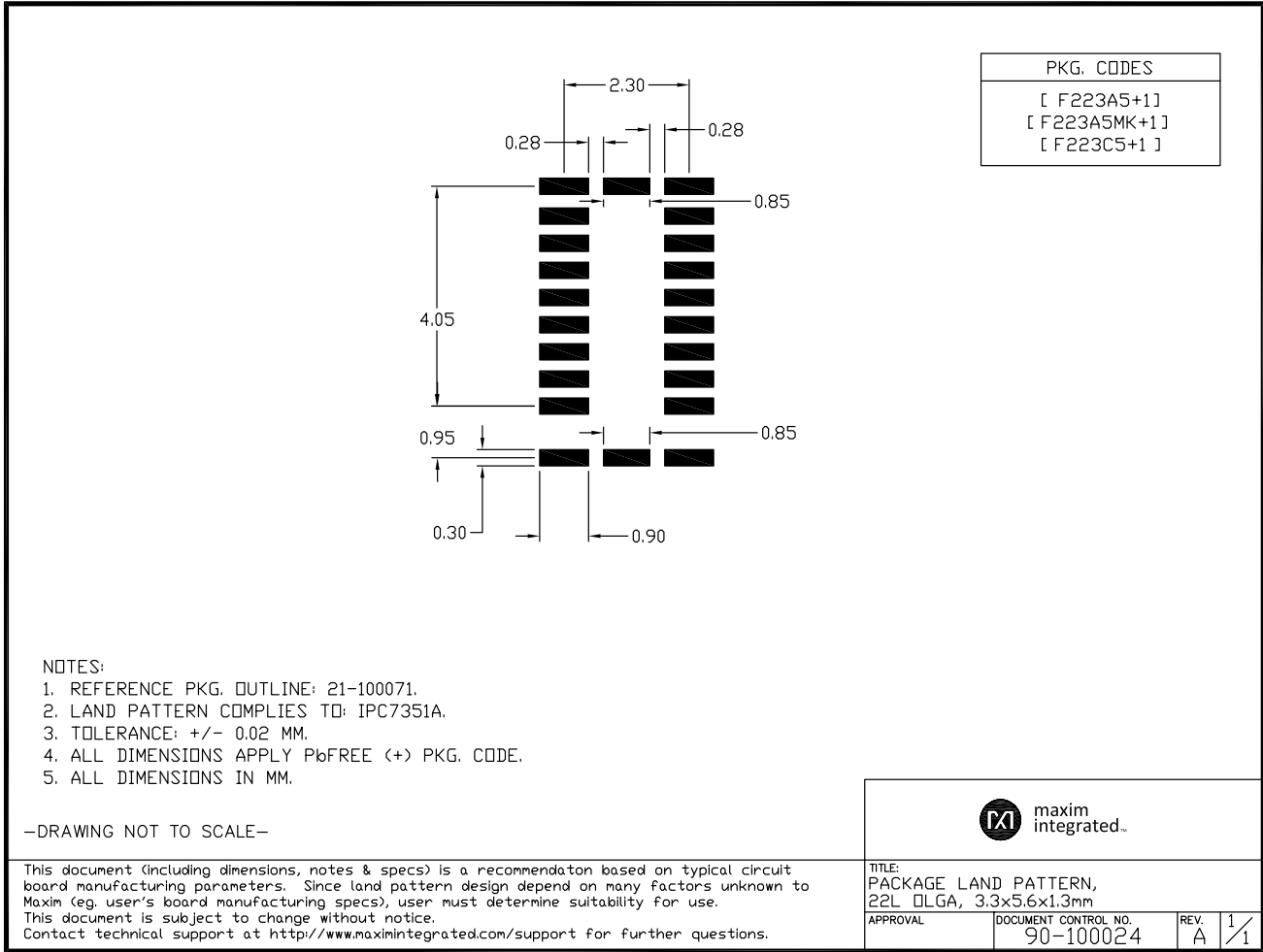
Package Information (continued)

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## Electrical Characteristics

( $V_{DD\_ANA} = V_{DD\_DIG} = 1.8V$ ,  $V_{LED} = 3.3V$ ,  $V_{GND\_ANA} = V_{GND\_DIG} = V_{PGND} = 0V$ ,  $T_A = +25^\circ C$ , min/max are from  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>POWER SUPPLY</b>						
Power Supply Voltage	$V_{DD}$	Guaranteed by RED and IR count tolerance	1.7	1.8	2.0	V
LED Supply Voltage	$V_{LED}$	Guaranteed by PSRR of LED driver	3.1	3.3	5	V
$V_{DD}$ Supply Current	$I_{DD}$	Heart rate/SpO <sub>2</sub> mode; PW = 50 $\mu$ s; SPS = 100; LED driver = 0mA		400	750	$\mu$ A
		Heart rate/SpO <sub>2</sub> mode; PW = 50 $\mu$ s; SPS = 10; LED driver = 0mA		400		
		ECG mode, SPS = 200		340	750	
$V_{LED}$ Supply Current	$I_{LED}$	Heart rate mode; PW = 50 $\mu$ s; SPS = 100, LED driver = 0mA		0.03	1	$\mu$ A
		Heart rate mode; PW = 50 $\mu$ s; SPS = 100, LED driver = 50mA		350		
		Heart rate mode; PW = 50 $\mu$ s; SPS = 10, LED driver = 50mA		50		
	$I_{LED}$	SpO <sub>2</sub> mode; PW = 50 $\mu$ s; SPS = 100, LED driver = 50mA		750		
$I_{LED}$	SpO <sub>2</sub> mode; PW = 50 $\mu$ s; SPS = 10; LED driver = 50mA		80			
$V_{DD}$ Current in Shutdown		$T_A = +25^\circ C$		0.5	12	$\mu$ A
$V_{LED}$ Current in Shutdown		$T_A = +25^\circ C$		0	1	$\mu$ A
Internal Voltage Reference (Note 6)	$V_{REF}$	Bypass to GND with 1 $\mu$ F	1.192	1.204	1.215	V
<b>PULSE OXIMETRY/HEART RATE SENSOR CHARACTERISTICS</b>						
ADC Resolution		LED2_PA		19		bits
Red ADC Count (Note 2)	RED_C	Proprietary ATE setup, LED2_PA = 0x16, PW = 50 $\mu$ S, SPS = 100, $T_A = +25^\circ C$	120,072	140,072	160,072	Counts
IR ADC Count (Note 2)	IR_C	Proprietary ATE setup, LED1_PA = 0x16, PW = 50 $\mu$ S, SPS = 100, $T_A = +25^\circ C$	136,072	156,072	176,072	Counts
Dark Current Counts	DC_C	ALC = ON, LED2_PA = LED1_PA = 0x00, PW = 50 $\mu$ S, SPS = 100, PPG_ADC_ RGE[1:0] = 8 $\mu$ A, $T_A = +25^\circ C$		0.0004	0.01	% of FS
RED/IR ADC Count - PSRR (VDD)	PSRR_VDD	Proprietary ATE setup, 1.7V < $V_{DD}$ < 2.0V, LED1_PA = 0x16, LED2_PA = 0x16, PW = 50 $\mu$ S, SPS = 100, $T_A = +25^\circ C$		0.05	0.5	% of FS
RED/IR ADC Count—PSRR (LED Driver Outputs)	PSRR_LED	Proprietary ATE setup, 3.1V < $V_{LED}$ < 5V, LED1_PA = 0x16, LED2_PA = 0x16, PW = 50 $\mu$ S, SPS = 100, $T_A = +25^\circ C$		0.05	0.5	% of FS
ADC Clock Frequency	CLK		9.633	9.8304	10.027	MHz



**Electrical Characteristics (continued)**

( $V_{DD\_ANA} = V_{DD\_DIG} = 1.8V$ ,  $V_{LED} = 3.3V$ ,  $V_{GND\_ANA} = V_{GND\_DIG} = V_{PGND} = 0V$ ,  $T_A = +25^\circ C$ , min/max are from  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>IR LED (LED1) CHARACTERISTICS (Note 3)</b>						
LED Peak Wavelength	$\lambda_P$	$I_{LED} = 20mA$ , $T_A = +25^\circ C$	870	880	900	nm
<b>RED LED (LED2) CHARACTERISTICS (Note 3)</b>						
LED Peak Wavelength	$\lambda_P$	$I_{LED} = 20mA$ , $T_A = +25^\circ C$	650	660	670	nm
<b>LED DRIVERS</b>						
LED Current Resolution				8		bits
LED Drive Current	$I_{LED}$	LEDx_RGE[1:0] = 01		100		mA
<b>ECG (Note 4)</b>						
ADC Resolution				18		bits
Gain		$V_{IN} = \pm 10mVDC$ , $T_A = +25^\circ C$ , $V_{DIFF} = 0mV$ (Note 5)	72	76	80	V/V
Gain Error		$V_{IN} = 20mV_{P-P}$ , $f = 84Hz$ , $V_{DIFF} = \pm 400mV$ , $T_A = +25^\circ C$ , error-specified w.r.t. $V_{DIFF} = 0mV$			2.2	%
DC Differential Input Range		$V_{IN} = 20mV_{P-P}$ , $f = 84Hz$ , gain error < 3%, $T_A = +25^\circ C$ , error-specified w.r.t. $V_{DIFF} = 0mV$	-400		+400	mV
CMRR		Balanced Inputs, 60Hz with $\pm 300mV$ differential DC offset, per AAMI/IEC standard, lead biasing enabled		136		dB
		51k $\Omega$ // 47nF imbalance, 60Hz with $\pm 300mV$ differential DC offset, per AAMI/IEC standard, lead biasing enabled		78		dB
DC CMRR		Gain = 76V/V, input pins tied together (no electrodes), $0.2V < V_{IN} < 1.0V$	80	120		dB
DC PSRR		Gain = 76V/V, input pins tied together (no electrodes), $1.7V < V_{DD} < 2.0V$	70	100		
AC PSRR		ECG_P/N tied together, AC signal at 60Hz, $10mV_{P-P}$ to $V_{DD}$ , lead bias disabled		95		dB
Input Impedance		ECG_P or ECG_N to GND, DC, lead biasing enabled		100		M $\Omega$
Input Referred Noise		Gain = 76V/V, inputs tied together on chip, SPS = 400, 0.5Hz to 100Hz		0.76		$\mu V_{RMS}$

**Electrical Characteristics (continued)**

( $V_{DD\_ANA} = V_{DD\_DIG} = 1.8V$ ,  $V_{LED} = 3.3V$ ,  $V_{GND\_ANA} = V_{GND\_DIG} = V_{PGND} = 0V$ ,  $T_A = +25^\circ C$ , min/max are from  $T_A = -40^\circ C$  to  $+85^\circ C$ , unless otherwise noted.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>DIGITAL CHARACTERISTICS (SDA, SCL, INT)</b>						
Output Low Voltage SDA, INTB	$V_{OL}$	$I_{SINK} = 6mA$			0.4	V
I <sup>2</sup> C Input Voltage Low	$V_{IL\_I2C}$	SDA, SCL			0.4	V
I <sup>2</sup> C Input Voltage High	$V_{IH\_I2C}$	SDA, SCL	1.4			V
Input Hysteresis (Note 3)	$V_{HYS}$	SDA, SCL		200		mV
Input Capacitance (Note 3)	$C_{IN}$	SDA, SCL		10		pF
Input Leakage Current	$I_{IN}$	$V_{IN} = 0V$ , $T_A = +25^\circ C$ (SDA, SCL)		0.01	1	$\mu A$
		$V_{IN} = V_{DD}$ , $T_A = +25^\circ C$ (SDA, SCL)		0.01	1	
<b>I<sup>2</sup>C TIMING CHARACTERISTICS (SDA, SCL) (Note 3, Figure 1)</b>						
I <sup>2</sup> C Write Address				BC		Hex
I <sup>2</sup> C Read Address				BD		Hex
Serial Clock Frequency	$f_{SCL}$		0		400	kHz
Bus Free Time Between STOP and START Conditions	$t_{BUF}$		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		900	ns
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	$t_{SP}$		0		50	ns
Bus Capacitance	$C_B$				400	pF
SDA and SCL Receiving Rise Time	$t_R$		20 + 0.1 $C_B$		300	ns
SDA and SCL Receiving Fall Time	$t_F$		20 + 0.1 $C_B$		300	ns
SDA Transmitting Fall Time	$t_F$		20 + 0.1 $C_B$		300	ns

**Electrical Characteristics (continued)**

( $V_{DD\_ANA} = V_{DD\_DIG} = 1.8V$ ,  $V_{LED} = 3.3V$ ,  $V_{GND\_ANA} = V_{GND\_DIG} = V_{PGND} = 0V$ ,  $T_A = +25^{\circ}C$ , min/max are from  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted.) (Note 1)

- Note 1:** 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 2:** Specifications are guaranteed by Maxim Integrated's bench characterization and by 100% production test using proprietary ATE setup and conditions.
- Note 3:** For design guidance only. Not production tested.
- Note 4:** Test conditions:  $SPS = 1600Hz$ ,  $ECG\_ADC\_OSR[1:0] = 00$  ( $OSR = 16$ ),  $ECG\_ADC\_CLK = 0$  (25.6kHz),  $IA\_GAIN[1:0] = 01$  ( $IA\_GAIN = 9.5$ ), and  $PGA\_ECG\_GAIN[1:0] = 11$  ( $PGA\_GAIN = 8$ ), unless otherwise noted.
- Note 5:** For measurements with DC difference as input, the highpass filter function is disabled.
- Note 6:** Internal reference only.

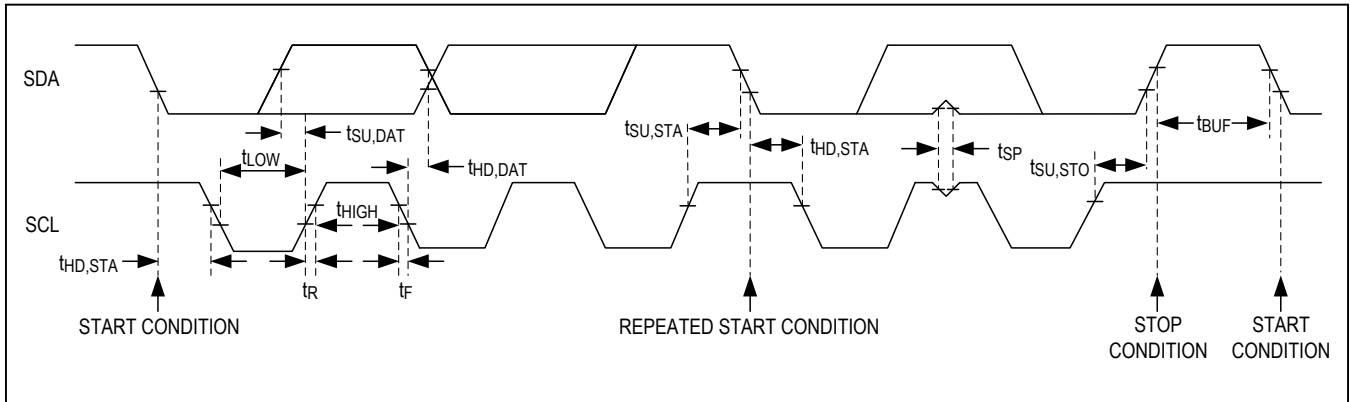
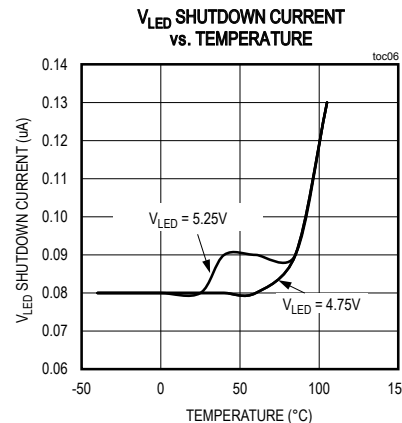
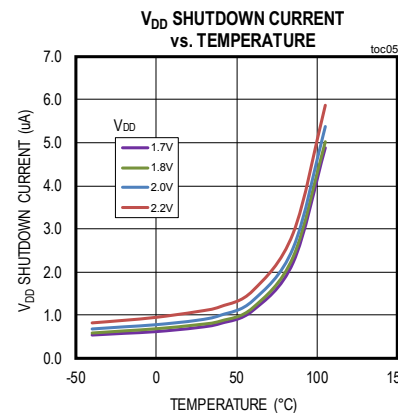
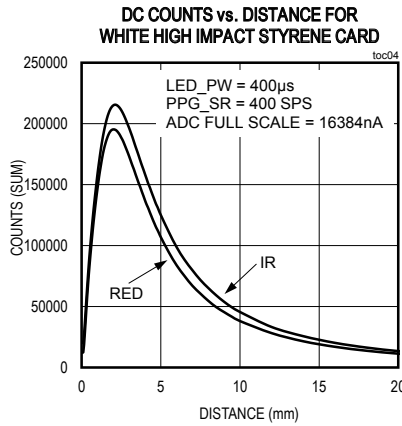
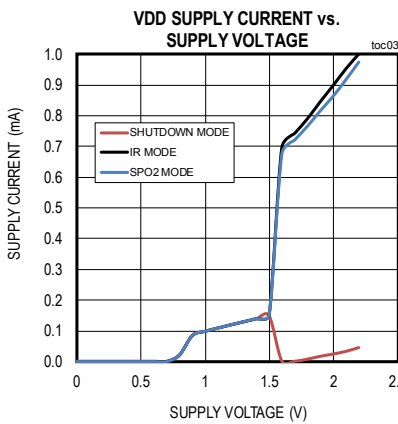
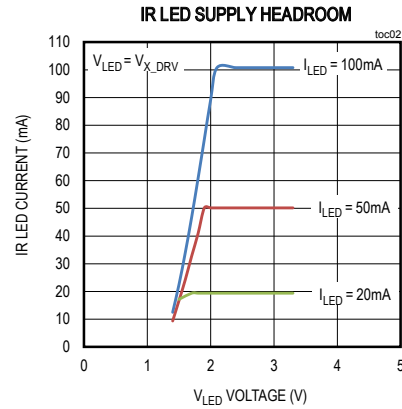
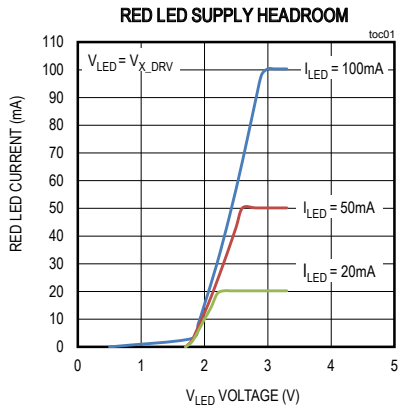


Figure 1. I2C-Compatible Interface Timing Diagram

Typical Operating Characteristics

(T<sub>A</sub> = +25°C, unless otherwise noted.)

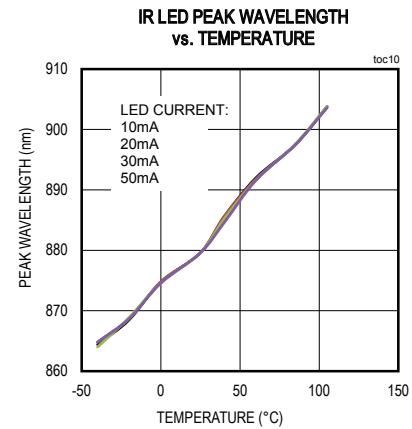
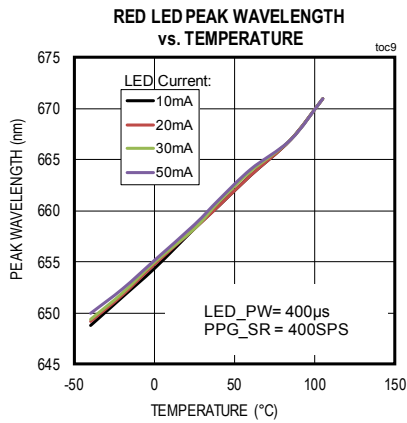
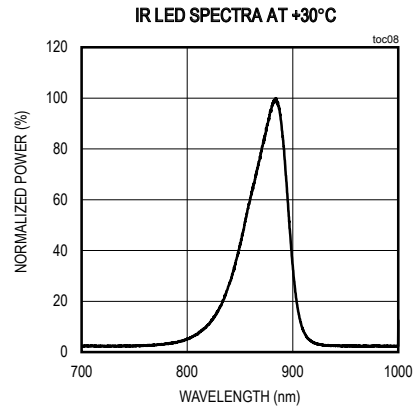
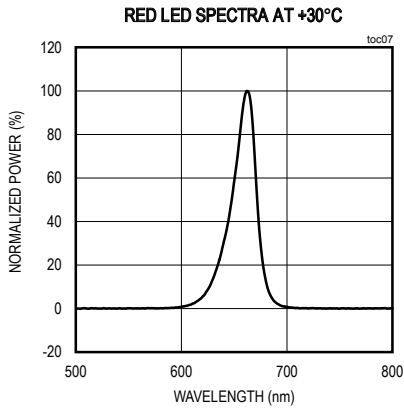
Photoplethysmogram (PPG)



Typical Operating Characteristics (continued)

(T<sub>A</sub> = +25°C, unless otherwise noted.)

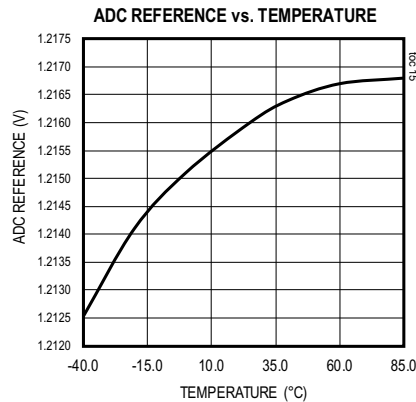
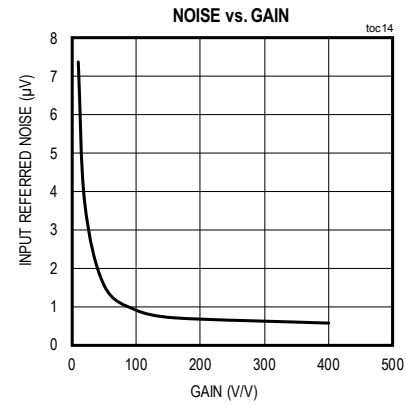
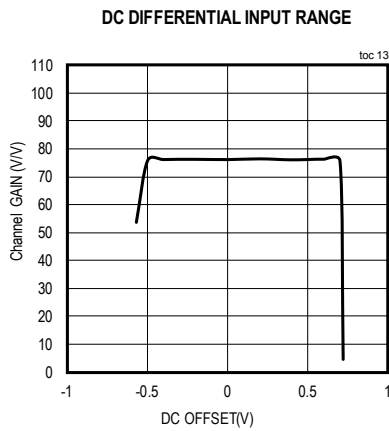
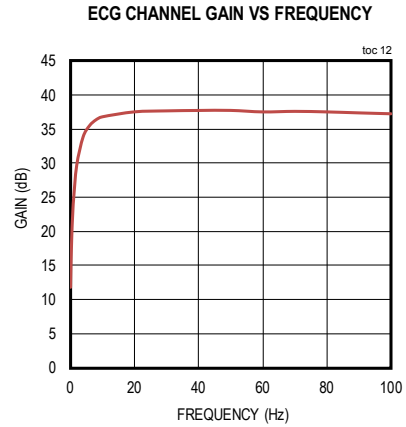
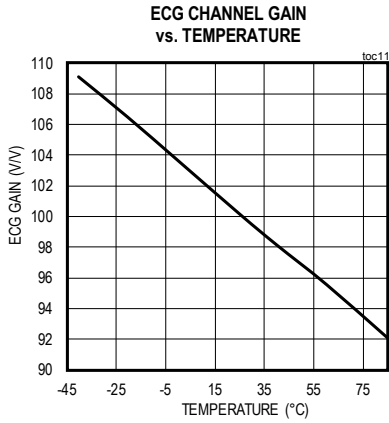
Photoplethysmogram (PPG)



Typical Operating Characteristics (continued)

(T<sub>A</sub> = +25°C, unless otherwise noted.)

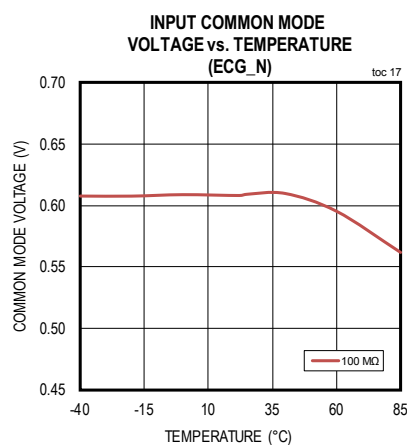
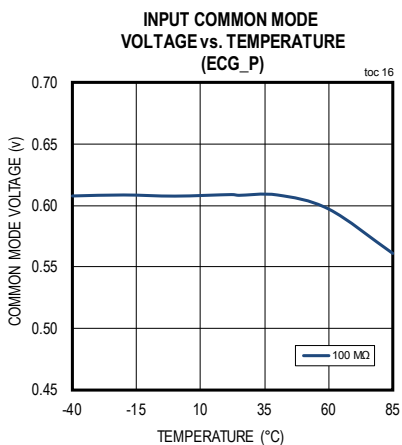
Electrocardiogram (ECG)



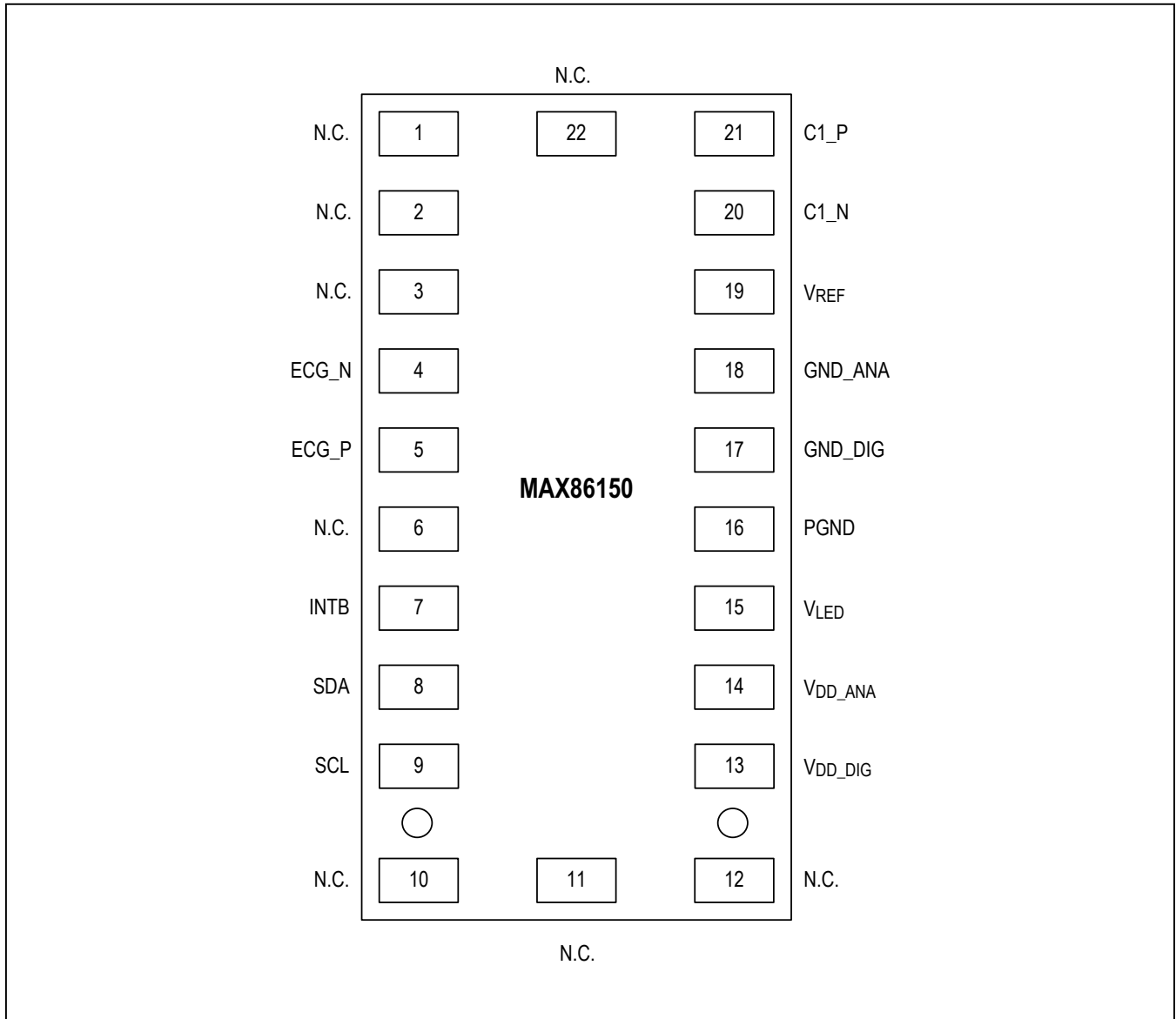
Typical Operating Characteristics (continued)

(T<sub>A</sub> = +25°C, unless otherwise noted.)

Electrocardiogram (ECG)



Pin Configuration

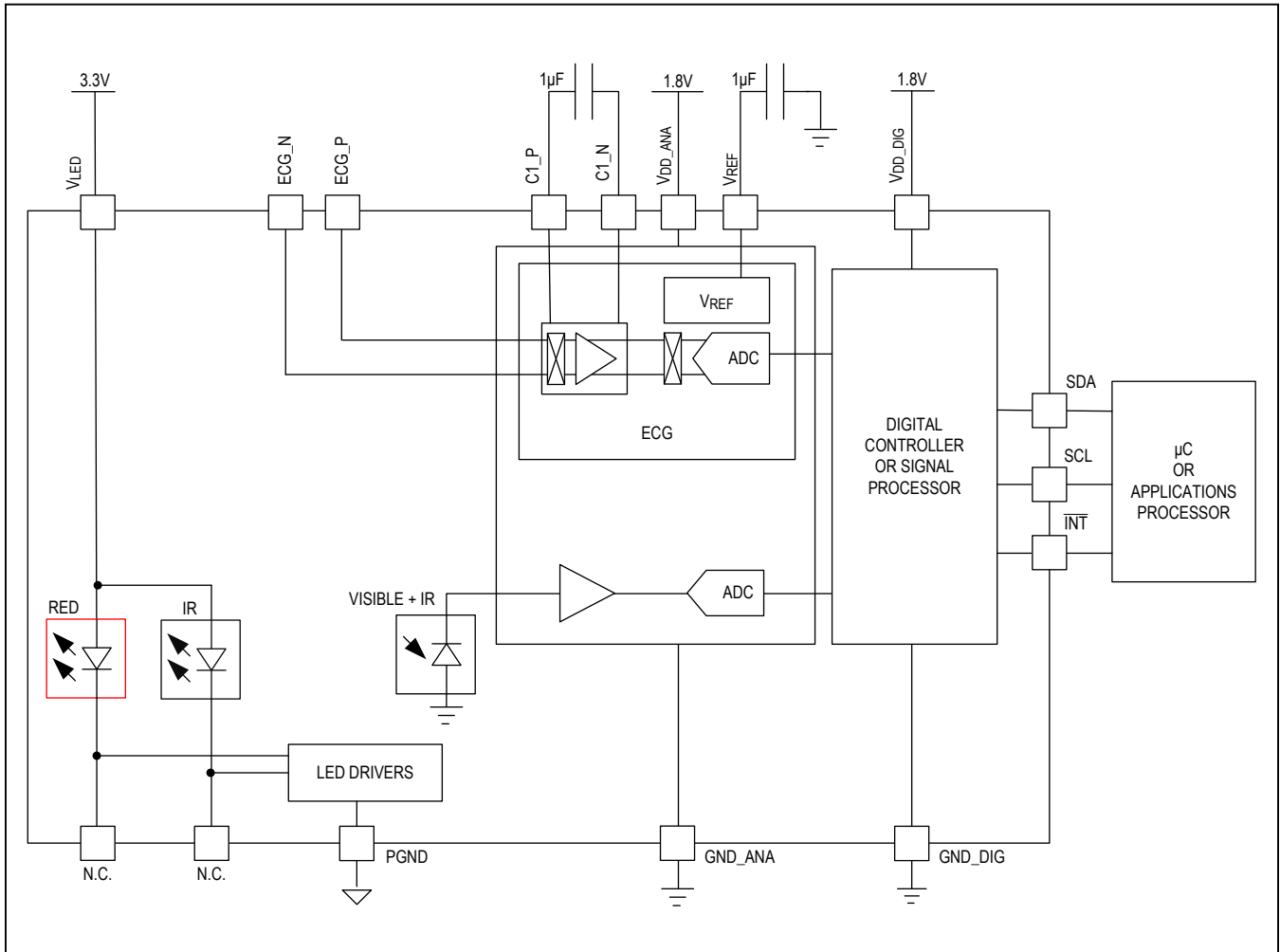




## Pin Description

PIN	NAME	FUNCTION
<b>N.C.</b>		
1–3, 6, 10–12, 22	N.C.	No Connection. Connect to an unconnected PCB pad for mechanical stability. N.C. pin should not be connected to any signal, power, or ground pins.
<b>ECG</b>		
5	ECG_P	Positive ECG Electrode
4	ECG_N	Negative ECG Electrode
21	C1_P	Capacitor for ECG HPF. Connect to C1_N through a 1 $\mu$ F capacitor.
20	C1_N	Capacitor for ECG HPF. Connect to C1_P through a 1 $\mu$ F capacitor.
<b>CONTROL INTERFACE</b>		
8	SDA	I <sup>2</sup> C Data
9	SCL	I <sup>2</sup> C Clock
7	INTB	Open-Drain Interrupt
<b>POWER</b>		
13	V <sub>DD_DIG</sub>	Digital Logic Supply. Connect to externally regulated supply. Bypass to GND <sub>DIG</sub> .
17	GND <sub>DIG</sub>	Digital Logic and Digital Pad Return. Connect to GND.
14	V <sub>DD_ANA</sub>	Analog Supply. Connect to externally regulated supply. Bypass to GND <sub>ANA</sub> .
18	GND <sub>ANA</sub>	Analog Power Return. Connect to GND.
15	V <sub>LED</sub>	LED Power Supply Input. Connect to external battery supply. Bypass to PGND.
16	PGND	LED Power Return. Connect to GND.
<b>REFERENCE</b>		
19	V <sub>REF</sub>	Internal Reference Decoupling Point. Bypass to GND <sub>ANA</sub> .

Functional Diagrams



Detailed Description

The MAX86150 is a electrocardiogram, pulse oximetry, and heart rate sensor system solution module designed for the demanding requirements of mobile devices. The MAX86150 maintains a very small total solution size without sacrificing optical or electrical performance. Minimal external hardware components are necessary for integration into a mobile device. The MAX86150 is fully adjustable through software registers, and the digital output data is stored in a 32-deep FIFO within the device. The FIFO allows the MAX86150 to be connected to a microcontroller or processor on a shared bus, where the data is not being read continuously from the MAX86150's registers.

SpO<sub>2</sub> Subsystem

The SpO<sub>2</sub> subsystem in the MAX86150 is composed of ambient light cancellation (ALC), a continuous-time sigma-delta ADC, and proprietary discrete time filter. The ALC has an internal DAC to cancel ambient light and increase the effective dynamic range. The internal ADC is a continuous time oversampling sigma delta converter with 19-bit resolution. The ADC output data rate can be programmed from 10sps (samples per second) to 3200sps. The MAX86150 includes a proprietary discrete time filter to reject 50Hz/60Hz interference and slow moving residual ambient noise.

**LED Driver**

The MAX86150 integrates red and infrared LED drivers to modulate LED pulses for SpO<sub>2</sub> and HR measurements. The LED current can be programmed from 0mA to 100mA with proper V<sub>LED</sub> supply voltage. The LED pulse width can be programmed from 50µs to 400µs to allow the algorithm to optimize SpO<sub>2</sub> and HR accuracy and power consumption based on use cases.

**Proximity Function**

The MAX86150 includes a proximity function to save power and reduce visible light emission when the user's finger is not on the sensor. Proximity function is enabled by setting PROX\_INT\_EN to 1. When the SpO<sub>2</sub> or HR function is initiated, the IR LED is turned on 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), PROX\_INT interrupt is asserted and the part transitions automatically to the normal SpO<sub>2</sub>/HR mode. To reenter PROX mode, a new SpO<sub>2</sub> or HR reading must be initiated (even if the value is the same). The proximity function can be disabled by resetting PROX\_INT\_EN to 0. In that case, when the SpO<sub>2</sub> or HR function is initiated in the FIFO Data Control registers, the SpO<sub>2</sub> or HR mode begins immediately.

**Electrocardiogram (ECG)**

The ECG subsystem in the MAX86150 is designed specifically for mobile applications. It features single-lead

ECG technology that is optimized for dry electrode operation. It comprises Maxim proprietary analog front end (AFE), which includes an 18-bit ADC. Figure 2 shows the ECG Subsystem Block Diagram. The primary function of the AFE is to digitize heart signals. This process is complicated by the need to reject interference from strong RF sources, common-mode line frequency, signals from other muscles, and electrical noise. The electrical connections to the patient must not create a shock hazard or interfere with other equipment that might be connected to the device. The ECG subsystem also includes an on-chip highpass filter, when coupled with the digital lowpass filter implemented in the algorithm, ensures high SNR in real applications. The ADC output data rate can be programmed from 200sps (samples per second) to 3200sps. The output of the ADC is an 18-bit digital representation of the input voltage. Each data sample takes three bytes in the FIFO, and the data is right-justified and in bipolar two's-complement format.

To calculate the equivalent differential input voltage of the ADC, the formula is as follows:

$$V\_INPUT = ADC\_CODE \times 12.247\mu V/IA\_GAIN/PGA\_GAIN$$

where ADC\_CODE is converted to a bipolar integer decimal format, which can be positive or negative. Note that only one gain setting, IA\_GAIN = 9.5 and PGA\_GAIN = 8, is trimmed to a tight tolerance at the factory, and the other gains are typical expected values only.

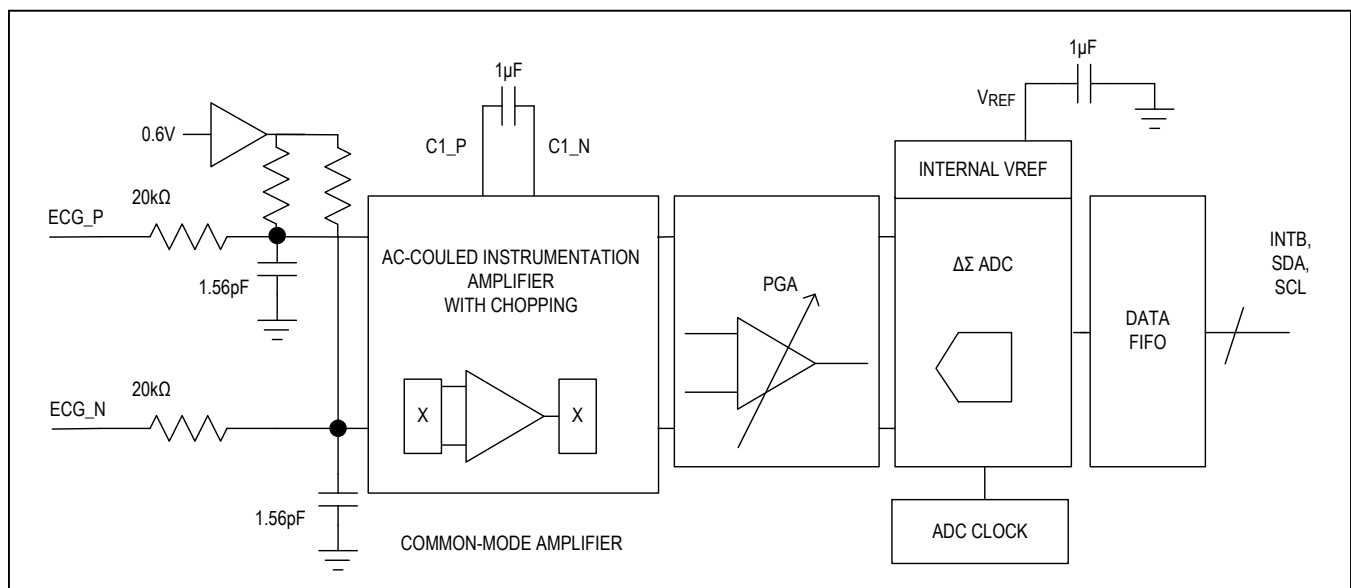


Figure 2. MAX86150 ECG Subsystem Block Diagram

## Register Map

ADDRESS	NAME	MSB							LSB	
<b>Status Registers</b>										
0x00	Interrupt Status 1[7:0]	A_FULL_	PPG_RDY_	ALC_OVF_	PROX_INT_	—	—	—	PWR_RDY_	
0x01	Interrupt Status 2[7:0]	VDD_OOR_	—	—	—	—	ECG_RDY	—	—	
0x02	Interrupt Enable 1[7:0]	A_FULL_EN_	PPG_RDY_EN_	ALC_OVF_EN_	PROX_INT_EN_	—	—	—	—	
0x03	Interrupt Enable 2[7:0]	VDD_OOR_EN_	—	—	—	—	ECG_RDY_EN	—	—	
<b>FIFO Registers</b>										
0x04	FIFO Write Pointer[7:0]	—	—	—	FIFO_WR_PTR_[4:0]					
0x05	Overflow Counter[7:0]	—	—	—	OVF_COUNTER_[4:0]					
0x06	FIFO Read Pointer[7:0]	—	—	—	FIFO_RD_PTR_[4:0]					
0x07	FIFO Data Register[7:0]	FIFO_DATA_[7:0]								
0x08	FIFO Configuration[7:0]	—	A_FULL_CLR_	A_FULL_TYPE_	FIFO_ROLLS_ON_FULL_	FIFO_A_FULL_[3:0]				
<b>FIFO Data Control</b>										
0x09	FIFO Data Control Register 1[7:0]	FD2_[3:0]				FD1_[3:0]				
0x0A	FIFO Data Control Register 2[7:0]	FD4_[3:0]				FD3_[3:0]				
<b>System Control</b>										
0x0D	System Control[7:0]	—	—	—	—	—	FIFO_EN_	SHDN_	RESET_	
<b>PPG Configuration</b>										
0x0E	PPG Configuration 1[7:0]	PPG_ADC_RGE_[1:0]		PPG_SR_[3:0]				PPG_LED_PW_[1:0]		
0x0F	PPG Configuration 2[7:0]	—	—	—	—	—	SMP_AVE_[2:0]			
0x10	Prox Interrupt Threshold[7:0]	PROX_INT_THRESH_[7:0]								
<b>LED Pulse Amplitude</b>										
0x11	LED1 PA[7:0]	LED1_PA_[7:0]								
0x12	LED2 PA[7:0]	LED2_PA_[7:0]								
0x14	LED Range[7:0]	—	—	—	—	LED2_RGE_[7:0]		LED1_RGE_[7:0]		
0x15	LED PILOT PA[7:0]	PILOT_PA_[7:0]								

ECG Configuration								
0x3C	ECG Configuration 1[7:0]	—	—	—	—	—	ECG_ADC_CLK_	ECG_ADC_OSR_[1:0]
0x3E	ECG Configuration 3[7:0]	—	—	—	—	PGA_ECG_GAIN_[1:0]		IA_GAIN_[1:0]

Part ID		
0xFF	Part ID[7:0]	PART_ID_[7:0]

**Interrupt Status 1 (0x00)**

BIT	7	6	5	4	3	2	1	0
Field	A_FULL	PPG_RDY	ALC_OVF	PROX_INT	—	—	—	PWR_RDY
Reset	0x0	0x0	0x0	0x0	—	—	—	0x0
Access Type	Read Only	Read Only	Read Only	Read Only	—	—	—	Read Only

A\_FULL: FIFO Almost Full Flag

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that the FIFO buffer overflows the threshold set by FFIFO_A_FULL[3:0] on the next sample. This bit is cleared when the Interrupt Status 1 register is read. It is also cleared when FIFO_DATA register is read, if A_FULL_CLR = 1

PPG\_RDY: New PPG FIFO Data Ready

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	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

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	This interrupt triggers when the ambient light cancellation function of the SpO <sub>2</sub> /HR photodiode has reached its maximum limit due to overflow, 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 interrupt

If PROX\_INT is masked then the prox mode is disabled and the select PPG begins immediately. This bit is cleared when the Interrupt Status 1 Register is read.

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that the proximity threshold has been crossed when in proximity mode.

PWR\_RDY: Power Ready Flag

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that VBATT went below the UVLO threshold. This bit is not triggered by a soft reset. This bit is cleared when Interrupt Status 1 Register is read.

#### Interrupt Status 2 (0x01)

BIT	7	6	5	4	3	2	1	0
Field	VDD_OOR	—	—	—	—	ECG_RDY	—	—
Reset	0x0	—	—	—	—	0x0	—	—
Access Type	Read Only	—	—	—	—	Read Only	—	—

VDD\_OOR: VDD Out-of-Range Flag

This flag checks if the VDD\_ANA supply voltage is outside supported range.

VALUE	ENUMERATION	DECODE
0	OFF	VDD_ANA between range.
1	ON	Indicated that VDD_ANA is greater than 2.05V or less than 1.65V. This bit is automatically cleared when the Interrupt Status 2 register is read. The detection circuitry has a 10ms delay time and continues to trigger as long as the VDD_ANA is out of range.

ECG\_RDY: New ECG FIFO Data Ready

This flag checks if the VDD\_ANA supply voltage is outside supported range.

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that the ECG ADC has finished it's existing conversion.

**Interrupt Enable 1 (0x02)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	A_FULL_EN	PPG_RDY_EN	ALC_OVF_EN	PROX_INT_EN	—	—	—	—
<b>Reset</b>	0x0	0x0	0x0	0x0	—	—	—	—
<b>Access Type</b>	Write, Read	Write, Read	Write, Read	Write, Read	—	—	—	—

A\_FULL\_EN: FIFO Almost Full Flag Enable

VALUE	ENUMERATION	DECODE
0	OFF	A_FULL interrupt is disabled
1	ON	A_FULL interrupt is enabled

PPG\_RDY\_EN: New PPG FIFO Data Ready Interrupt enable

VALUE	ENUMERATION	DECODE
0	OFF	PPG_RDY interrupt is disabled
1	ON	PPG_RDY interrupt is enabled.

ALC\_OVF\_EN: Ambient Light Cancellation (ALC) Overflow Interrupt Enable

The ALC\_OVF flag is triggered when the HRM/SpO<sub>2</sub> photodiode has reached its maximum limit due to overflow. At this point, the ADC output is affected by the ambient light.

VALUE	ENUMERATION	DECODE
0	OFF	ALC_OVF interrupt is disabled
1	ON	ALC_OVF interrupt is enabled

PROX\_INT\_EN: Proximity Interrupt Enable

When the SpO<sub>2</sub> or HR function is initiated, the IR LED is turned on 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), PROX\_INT interrupt is asserted and the part transitions automatically to the normal SpO<sub>2</sub>/HR mode.

VALUE	ENUMERATION	DECODE
0	OFF	PROX_INT interrupt is disabled
1	ON	PROX_INT interrupt is enabled

**Interrupt Enable 2 (0x03)**

BIT	7	6	5	4	3	2	1	0
Field	VDD_OOR_EN	—	—	—	—	ECG_RDY_EN	—	—
Reset	0x0	—	—	—	—	0x0	—	—
Access Type	Write, Read	—	—	—	—	Write, Read	—	—

VDD\_OOR\_EN: VDD Out-of-Range Indicator Enable

VALUE	ENUMERATION	DECODE
0	OFF	Disables the VDD_OVR interrupt
1	ON	Enables the VDD_OVR interrupt

ECG\_RDY\_EN: New ECG FIFO Data Ready Interrupt Enable

VALUE	ENUMERATION	DECODE
0	OFF	ECG_RDY interrupt is disabled
1	ON	ECG_RDY interrupt is enabled

**FIFO Write Pointer (0x04)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	FIFO_WR_PTR[4:0]				
Reset	—	—	—	0x00				
Access Type	—	—	—	Write, Read				

FIFO\_WR\_PTR: FIFO Write Pointer

This points to the location where the next sample is written. This pointer advances for each sample pushed on to the FIFO.



**Overflow Counter (0x05)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	OVF_COUNTER[4:0]				
Reset	—	—	—	0x00				
Access Type	—	—	—	Read Only				

OVF\_COUNTER: FIFO Overflow Counter

When FIFO is full, any new samples result in new or old samples getting lost depending on FIFO\_ROLLS\_ON\_FULL. OVF\_COUNTER counts the number of samples lost. It saturates at 0x1F.

**FIFO Read Pointer (0x06)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	FIFO_RD_PTR[4:0]				
Reset	—	—	—	0x00				
Access Type	—	—	—	Write, Read				

FIFO\_RD\_PTR: 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. This allows rereading (or retrying) samples from the FIFO.

**FIFO Data Register (0x07)**

BIT	7	6	5	4	3	2	1	0
Field	FIFO_DATA[7:0]							
Reset	0x00							
Access Type	Write, Read							

FIFO\_DATA: FIFO Data Register

This is a read-only register and is used to get data from the FIFO. See [FIFO Description](#) for more details.

**FIFO Configuration (0x08)**

BIT	7	6	5	4	3	2	1	0
Field	—	A_FULL_CLR	A_FULL_TYPE	FIFO_ROLLS_ON_FULL	FIFO_A_FULL[3:0]			
Reset	—	0x0	0x0	0x0	0xF			
Access Type	—	Write, Read	Write, Read	Write, Read	Write, Read			

A\_FULL\_CLR: FIFO Almost Full Interrupt Options

This defines whether the A-FULL interrupt should get cleared by FIFO\_DATA register read.

VALUE	ENUMERATION	DECODE
0	RD_DATA_NOCLR	A_FULL interrupt does not get cleared by FIFO_DATA register read. It gets cleared by status register read.
1	RD_DATA_CLR	A_FULL interrupt gets cleared by FIFO_DATA register read or status register read.

A\_FULL\_TYPE: FIFO Almost Full Flag Options

This defines the behavior of the A\_FULL interrupt.

VALUE	ENUMERATION	DECODE
0	AFULL_RPT	A_FULL interrupt gets asserted when the a_full condition is detected. It is cleared by status register read, but re-asserts for every sample if the a_full condition persists.
1	AFULL_ONCE	A_FULL interrupt gets asserted only when the a_full condition is detected. The interrupt gets cleared on status register read, and does not re-assert for every sample until a new a-full condition is detected.

**FIFO\_ROLLS\_ON\_FULL: FIFO Rolls on Full Options**

This bit controls the behavior of the FIFO when the FIFO becomes completely filled with data.

When the device is in PROX mode, the FIFO always rolls on full.

- Push to FIFO is enabled when FIFO is full if FIFO\_ROLLS\_ON\_FULL = 1 and old samples are lost. Both FIFO\_WR\_PTR and FIFO\_RD\_PTR increment for each sample after the FIFO is full.
- Push to FIFO is disabled when FIFO is full if FIFO\_ROLLS\_ON\_FULL = 0 and new samples are lost. FIFO\_WR\_PTR does not increment for each sample after the FIFO is full.

VALUE	ENUMERATION	DECODE
0	OFF	The FIFO stops on full.
1	ON	The FIFO automatically rolls over on full.

**FIFO\_A\_FULL: FIFO Almost Full Value**

These bits indicate how many new samples can be written to the FIFO before the interrupt is asserted. For example, if set to 0xF, the interrupt triggers when there is 17 empty space left (15 data samples), and so on.

FIFO_A_FULL<3:0>	FREE SPACE BEFORE INTERRUPT	# OF SAMPLES IN FIFO
0000	0	32
0001	1	31
0010	2	30
0011	3	29
----	----	----
1110	14	18
1111	15	17

**FIFO Data Control Register 1 (0x09)**

BIT	7	6	5	4	3	2	1	0
<b>Field</b>	FD2[3:0]				FD1[3:0]			
<b>Reset</b>	0x0				0x0			
<b>Access Type</b>	Write, Read				Write, Read			

**FD2: FIFO Data Time Slot 2**

These bits set the data type for element 2 of the FIFO.

The FIFO can hold up to 32 samples. Each sample can hold up to four elements and each element is 3 bytes wide. The data type that gets stored in the 3 bytes is configured by FD1, FD2, FD3 and FD4 according to the following table. For restriction on data type sequences, see the [FIFO Description](#) section.

FD2[3:0]	DATA TYPE	FD2[3:0]	DATA TYPE	FD2[3:0]	DATA TYPE	FD2[3:0]	DATA TYPE
0000	None	0100	Reserved	1000	Reserved	1100	Reserved
0001	PPG_LED1	0101	Pilot LED1	1001	ECG	1101	Reserved
0010	PPG_LED2	0110	Pilot LED2	1010	Reserved	1110	Reserved
0011	Reserved	Reserved	Pilot LED3	1011	Reserved	1111	Reserved

**FD1: FIFO Data Time Slot 1**

These bits set the data type for element 1 of the FIFO.

The FIFO can hold up to 32 samples. Each sample can hold up to four elements and each element is 3 bytes wide. The data type that gets stored in the 3 bytes is configured by FD1, FD2, FD3 and FD4 according to the following table. For restriction on data type sequences, see the [FIFO Description](#) section.

FD1[3:0]	DATA TYPE	FD1[3:0]	DATA TYPE	FD1[3:0]	DATA TYPE	FD1[3:0]	DATA TYPE
0000	None	0100	Reserved	1000	Reserved	1100	Reserved
0001	PPG_LED1	0101	Pilot LED1	1001	ECG	1101	Reserved
0010	PPG_LED2	0110	Pilot LED2	1010	Reserved	1110	Reserved
0011	Reserved	0111	Reserved	1011	Reserved	1111	Reserved

**FIFO Data Control Register 2 (0x0A)**

BIT	7	6	5	4	3	2	1	0
Field	FD4[3:0]				FD3[3:0]			
Reset	0x0				0x0			
Access Type	Write, Read				Write, Read			

**FD4: FIFO Data Time Slot 4**

These bits set the data type for element 4 of the FIFO.

The FIFO can hold up to 32 samples. Each sample can hold up to four elements and each element is 3 bytes wide. The data type that gets stored in the 3 bytes is configured by FD1, FD2, FD3 and FD4 according to the following table. For restriction on data type sequences, see the [FIFO Description](#) section.

FD4[3:0]	DATA TYPE	FD4<3:0>	DATA TYPE	FD4<3:0>	DATA TYPE	FD4<3:0>	DATA TYPE
0000	None	0100	Reserved	1000	Reserved	1100	Reserved
0001	PPG_LED1	0101	Pilot LED1	1001	ECG	1101	Reserved
0010	PPG_LED2	0110	Pilot LED2	1010	Reserved	1110	Reserved
0011	Reserved	0111	Reserved	1011	Reserved	1111	Reserved

**FD3: FIFO Data Time Slot 3**

These bits set the data type for element 3 of the FIFO.

The FIFO can hold up to 32 samples. Each sample can hold up to four elements and each element is 3 bytes wide. The data type that gets stored in the 3 bytes is configured by FD1, FD2, FD3 and FD4 according to the following table. For restriction on data type sequences please refer to the [FIFO Description](#) section.

FD3[3:0]	DATA TYPE	FD3<3:0>	DATA TYPE	FD3<3:0>	DATA TYPE	FD3<3:0>	DATA TYPE
0000	None	0100	Reserved	1000	Reserved	1100	Reserved
0001	PPG_LED1	0101	Pilot LED1	1001	ECG	1101	Reserved
0010	PPG_LED2	0110	Pilot LED2	1010	Reserved	1110	Reserved
0011	Reserved	0111	Reserved	1011	Reserved	1111	Reserved

**System Control (0x0D)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	—	—	FIFO_EN	SHDN	RESET
Reset	—	—	—	—	—	0x0	0x0	0x0
Access Type	—	—	-	—	—	Write, Read	Write, Read	Write, Read

FIFO\_EN: FIFO Enable

VALUE	ENUMERATION	DECODE
0	OFF	Push to FIFO is disabled, but the read and write pointers and the data in the FIFO are all held at their values before FIFO_EN is set to 0.
1	ON	The FIFO is enabled. When this bit is set the FIFO is flushed of all old data and the new samples start loading from pointer zero.

SHDN: Shutdown Control

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.

VALUE	ENUMERATION	DECODE
0	OFF	The part is in normal operation. No action taken.
1	ON	The part can be put into a power-save mode by writing a '1' to this bit. While in this mode all registers remain accessible and retain their data. ADC conversion data contained in the registers are previous values. Writable registers also remain accessible in shutdown. All interrupts are cleared. In this mode the oscillator is shutdown and the part draws minimum current. If this bit is asserted during a active conversion then the conversion completes before the part shuts down.

RESET: Reset Control

When this bit is set The part under-goes a forced power-on-reset sequence. All configuration, threshold and data registers including distributed registers are reset to their power-on-state. This bit then automatically becomes '0' after the reset sequence is completed.

VALUE	ENUMERATION	DECODE
0	OFF	The part is in normal operation. No action taken.
1	ON	The part under-goes a forced power-on-reset sequence. All configuration, threshold and data registers including distributed registers are reset to their power-on-state. This bit then automatically becomes '0' after the reset sequence is completed.

**PPG Configuration 1 (0x0E)**

BIT	7	6	5	4	3	2	1	0
Field	PPG_ADC_RGE[1:0]		PPG_SR[3:0]			PPG_LED_PW[1:0]		
Reset	0x0		0x0			0x0		
Access Type	Write, Read		Write, Read			Write, Read		

PPG\_ADC\_RGE: SpO<sub>2</sub> ADC Range Control

These bits set the ADC range of the SPO2 sensor as shown in the table below.

PPG_ADC_RGE<1:0>	LSB [PA]	FULL SCALE [NA]
00	7.8125	4096
01	15.625	8192
10	31.25	16384
11	62.5	32768

PPG\_SR: SpO<sub>2</sub> Sample Rate Control

SpO<sub>2</sub> Sample Rate Control

These bits set the effective sampling rate of the PPG sensor as shown in the table below.

Note: If a sample rate is set can not be supported by the selected pulse width and LED mode then the highest available sample rate will be automatically set. The user can read back this register to confirm the sample rate.

PPG_SR<3:0>	SAMPLES PER SECOND	PULSES PER SAMPLE, N
0000	10	1
0001	20	1
0010	50	1
0011	84	1
0100	100	1
0101	200	1
0110	400	1
0111	800	1
1000	1000	1
1001	1600	1
1010	3200	1
1011	10	2
1100	20	2
1101	50	2
1110	84	2
1111	100	2

**Maximum Sample rates Supported for all the Pulse Widths and Number of LEDs:**

NUMBER OF ADC CONVERSIONS PER SAMPLE	PPG_LED_PW = 0 (50US)	PPG_LED_PW = 1 (100US)	PPG_LED_PW = 2 (200US)	PPG_LED_PW = 3 (400US)
1 LED, N=1	3200	1600	1000	1000
2 LED, N=1	1600	800	800	400
1 LED, N=2	100	100	100	100
2 LED, N=2	100	100	100	84

PPG\_LED\_PW: LED Pulse Width Control

These bits set the pulse width of the LED drivers and the integration time of PPG ADC as shown in the table below.

PPG_LED_PW<1:0>	PULSE WIDTH [µS]	INTEGRATION TIME [µS]	RES BITS
00	50	50	19
01	100	100	19
10	200	200	19
11	400	400	19

**PPG Configuration 2 (0x0F)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	—	—	SMP_AVE[2:0]		
Reset	—	—	—	—	—	0x0		
Access Type	—	—	—	—	—	Write, Read		

SMP\_AVE: Sample Averaging Options

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.

These bits set the number of samples that are averaged on chip before being written to the FIFO.

SMP_AVE[2:0]	SAMPLE AVERAGE
000	1 (no averaging)
001	2
010	4
011	8
100	16
101	32
110	32
111	32



**Prox Interrupt Threshold (0x10)**

<b>BIT</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
<b>Field</b>	PROX_INT_THRESH[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Write, Read							

PROX\_INT\_THRESH: Proximity Mode Interrupt Threshold

This register sets the IR ADC count that triggers the beginning of HR or SpO<sub>2</sub> mode. The threshold is defined as the 8 MSB bits 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.

**LED1 PA (0x11)**

<b>BIT</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
<b>Field</b>	LED1_PA[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Write, Read							

LED1\_PA: LED 1 (IR) Current Pulse Amplitude.

These bits set the nominal current pulse amplitude of LED 1 as shown in the table below.

<b>LED1_RGE[1:0]</b>	<b>00 (50MA)</b>	<b>01 (100MA)</b>
LED1_PA[7:0]	LED Current [mA]	LED Current [mA]
00000000	0	0
00000001	0.2	0.4
00000010	0.4	0.8
00000011	0.6	1.2
.....		
11111100	50.4	100.8
11111101	50.6	101.2
11111110	50.8	101.6
11111111	51	102
LSB	0.2	0.4

**LED2 PA (0x12)**

<b>BIT</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
<b>Field</b>	LED2_PA[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Write, Read							

LED2\_PA: LED 2 (RED) Current Pulse Amplitude

These bits set the nominal current pulse amplitude of LED 2 as shown in the table below.

<b>LED2_RGE[1:0]</b>	<b>00(50mA)</b>	<b>01(100mA)</b>
LED2_PA[7:0]	LED Current[mA]	LED Current[mA]
00000000	0	0
00000001	0.2	0.4
00000010	0.4	0.8
00000011	0.6	1.2
.....		
11111100	50.4	100.8
11111101	50.6	101.2
11111110	50.8	101.6
11111111	51	102
LSB	0.2	0.4

**LED Range (0x14)**

<b>BIT</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
<b>Field</b>	—	—	—	—	LED2_RGE[1:0]		LED1_RGE[1:0]	
<b>Reset</b>	—	—	—	—	0x00		0x00	
<b>Access Type</b>	—	—	—	—	Write, Read		Write, Read	

LED2\_RGE: LED 2 Current Control

Range selection of the LED current. Refer to LED2\_PA[7:0] for more details.

<b>LED2_RGE&lt;1:0&gt;</b>	<b>LED CURRENT (mA)</b>
00	50
01	100
10	Not Applicable
11	Not Applicable

LED1\_RGE: LED 1 Current Control

Range selection of the LED current. Refer to LED1\_PA[7:0] for more details.

<b>LED1_RGE&lt;1:0&gt;</b>	<b>LED CURRENT (mA)</b>
00	50
01	100
10	Not Applicable
11	Not Applicable

**LED PILOT PA (0x15)**

<b>BIT</b>	<b>7</b>	<b>6</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>0</b>
<b>Field</b>	PILOT_PA[7:0]							
<b>Reset</b>	0x00							
<b>Access Type</b>	Write, Read							

PILOT\_PA: Proximity Mode LED Pulse Amplitude.

The purpose of PILOT\_PA[7:0] is to set the LED power during the PROX mode, as well as in Multi-LED mode. These bits set the current pulse amplitude for the pilot mode as shown in the table below.

When LED x is used, the respective LEDx\_RGE<1:0> is used to control the range of the LED driver in conjunction with PILOT\_PA[7:0]. For instance, if LED1 is used in the PILOT mode, then, LED1\_RGE[1:0] together with PILOT\_PA[7:0] will be used to set the LED1 current.

<b>LEDX_RGE[1:0]</b>	<b>00 (50mA)</b>	<b>01 (100mA)</b>
PILOT_PA[7:0]	LED Current[mA]	LED Current[mA]
00000000	0	0
00000001	0.2	0.4
00000010	0.4	0.8
00000011	0.6	1.2
.....		
11111100	50.4	100.8
11111101	50.6	101.2
11111110	50.8	101.6
11111111	51	102
LSB	0.2	0.4

**ECG Configuration 1 (0x3C)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	—	—	ECG_ADC_CLK	ECG_ADC_OSR[1:0]	
Reset	—	—	—	—	—	0x0	0x0	
Access Type	—	—	—	—	—	Write, Read	Write, Read	

ECG\_ADC\_OSR: ECG ADC Oversampling Ratio

These bit sets the over sampling ratio (OSR) of the ECG ADC. ECG\_ADC\_OSR<1:0> together with the ADC clock frequency (ECG\_ADC\_CLK) set the ECG sample rate.

{ECG_ADC_CLK, ECG_ADC_OSR[1:0]}	ECG SAMPLE RATE	FILTER BANDWIDTH (70%)	FILTER BANDWIDTH (90%)	UNITS
000	1600	420	232	Hz
001	800	210	116	Hz
010	400	105	58	Hz
011	200	52	29	Hz
100	3200	840	464	Hz
101	1600	420	232	Hz
110	800	210	116	Hz
111	400	105	58	Hz

**ECG Configuration 3 (0x3E)**

BIT	7	6	5	4	3	2	1	0
Field	—	—	—	—	PGA_ECG_GAIN[1:0]		IA_GAIN[1:0]	
Reset	—	—	—	—	0x0		0x2	
Access Type	—	—	—	—	Write, Read		Write, Read	

**PGA\_ECG\_GAIN: ECG PGA Gain Options**

These bit set the gain of the ECG PGA as shown below.

PGA_ECG_GAIN<1:0>	GAIN	UNITS
00	1	V/V
01	2	V/V
10	4	V/V
11	8	V/V

**IA\_GAIN: Instrumentation Amplifier Gain Options**

These bit set the gain of the Instrumental Amplifier (IA) AFE as shown below.

IA_GAIN<1:0>	GAIN	UNITS
00	5	V/V
01	9.5	V/V
10	20	V/V
11	50	V/V

**Part ID (0xFF)**

BIT	7	6	5	4	3	2	1	0
Field	PART_ID[7:0]							
Reset	0x1E							
Access Type	Read Only							

**PART\_ID: Part Identifier**

This register stores the Part identifier for the chip.

**Applications Information**

**Power Sequencing and Requirements**

**Power-Up Sequencing**

It is recommended to power the  $V_{DD\_ANA}$  supply first, followed by the  $V_{DD\_DIG}$  and the  $\overline{LED}$  power supplies ( $V_{LED}$ ).  $V_{DD\_ANA}$  and  $V_{DD\_DIG}$  can be powered on at the same time. The interrupt and I<sup>2</sup>C pins can be pulled up to an external voltage even when the power supplies are not powered up.

After the power is established, an interrupt occurs to alert the system that the sensor is ready for operation. Reading the I<sup>2</sup>C interrupt register clears the interrupt, as shown in the [Figure 3](#).

**Power-Down Sequencing**

The sensor is designed to be tolerant of any power-supply sequencing on power-down.

**I<sup>2</sup>C Interface**

The MAX86150 features an I<sup>2</sup>C/SMBus-compatible, 2-wire serial interface consisting of a serial data line (SDA) and a serial clock line (SCL). SDA and SCL facilitate communication between the MAX86150 and the master at clock rates up to 400kHz. The master generates SCL

and initiates data transfer on the bus. The master device writes data to the MAX86150 by transmitting the proper slave address followed by data. Each transmit sequence is framed by a START (S) or REPEATED START (Sr) condition and a STOP (P) condition. Each word transmitted to the MAX86150 is 8 bits long and is followed by an acknowledge clock pulse. A master reading data from the MAX86150 transmits the proper slave address followed by a series of nine SCL pulses.

The MAX86150 transmits data on SDA in sync with the master-generated SCL pulses. The master acknowledges receipt of each byte of data. Each read sequence is framed by a START (S) or REPEATED START (Sr) condition, a not acknowledge, and a STOP (P) condition. SDA operates as both an input and an open-drain output. A pullup resistor, typically greater than 1000Ω, is required on SDA. SCL operates only as an input. A pullup resistor, typically greater than 1000Ω, is required on SCL if there are multiple masters on the bus, or if the single master has an open-drain SCL output. Series resistors in line with SDA and SCL are optional. Series resistors protect the digital inputs of the MAX86150 from high-voltage spikes on the bus lines and minimize crosstalk and undershoot of the bus signals.

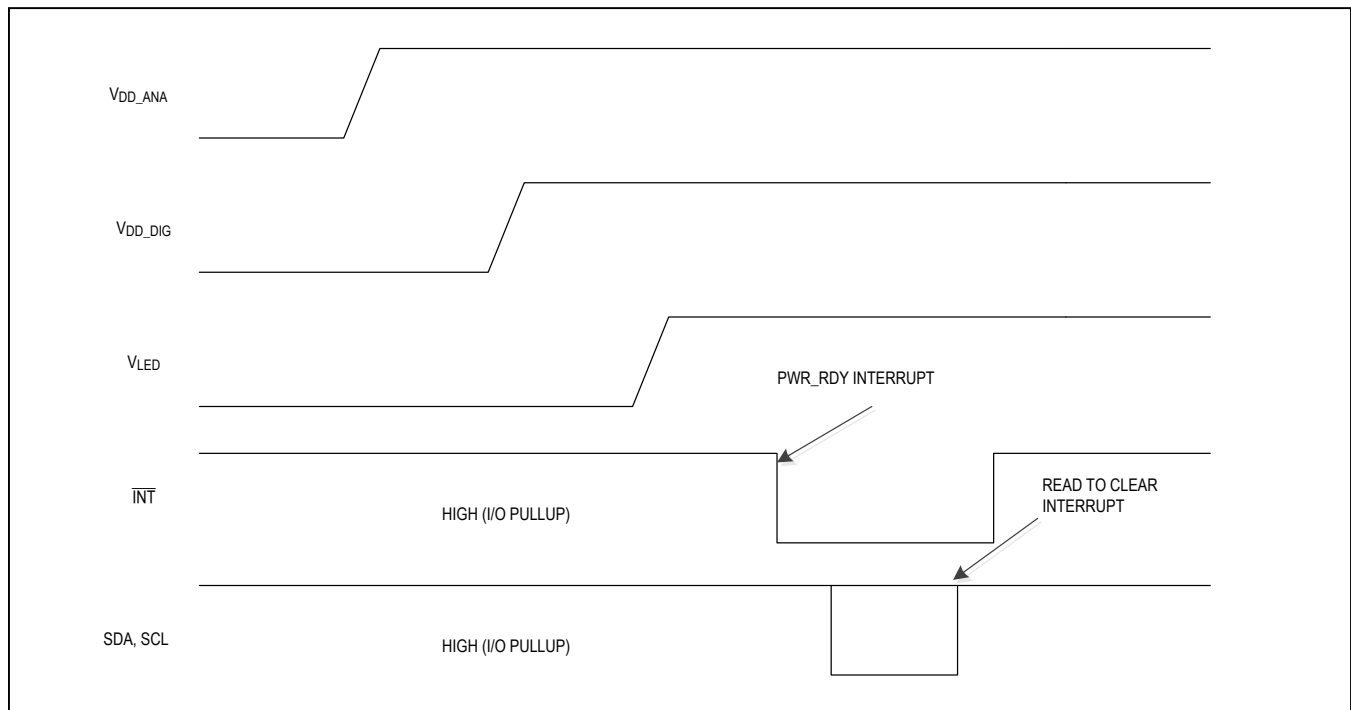


Figure 3. Power-Up Sequence of the Power Supply Rails

**Bit Transfer**

One data bit is transferred during each SCL cycle. The data on SDA must remain stable during the high period of the SCL pulse. Changes in SDA while SCL is high are control signals. See the [START and STOP Conditions](#) section.

**START and STOP Conditions**

SDA and SCL idle high when the bus is not in use. A master initiates communication by issuing a START condition. A START condition is a high-to-low transition on SDA with SCL high. A STOP condition is a low-to-high transition on SDA while SCL is high. A START condition from the master signals the beginning of a transmission to the MAX86150. The master terminates transmission, and frees the bus, by issuing a STOP condition. The bus remains active if a REPEATED START condition is generated instead of a STOP condition. [Figure 4](#) shows the START, STOP, and REPEATED START of the I<sup>2</sup>C conditions

**Early STOP Conditions**

The MAX86150 recognizes a STOP condition at any point during data transmission except if the STOP condition occurs in the same high pulse as a START condition. For proper operation, do not send a STOP condition during the same SCL high pulse as the START condition.

**Slave Address**

A bus master initiates communication with a slave device by issuing a START condition followed by the 7-bit slave ID. When idle, the MAX86150 waits for a START condition followed by its slave ID. The serial interface compares each slave ID bit by bit, allowing the interface to power down and disconnect from SCL immediately if an incorrect slave ID is detected. After recognizing a START condition followed by the correct slave ID, the MAX86150 is programmed to accept or send data. The LSB of the slave ID word is the read/write (R/W) bit. R/W indicates whether the master is writing to or reading data from the MAX86150 (R/W = 0 selects a write condition, R/W = 1 selects a read condition). After receiving the proper slave ID, the MAX86150 issues an ACK by pulling SDA low for one clock cycle.

The MAX86150 slave ID consists of seven fixed bits, B7–B1 (set to 0b1011110). The most significant slave ID bit (B7) is transmitted first, followed by the remaining bits.

B7	B6	B5	B4	B3	B2	B1	B0	WRITE ADDRESS	READ ADDRESS
1	0	1	1	1	1	0	RW	0xBC	0xBD

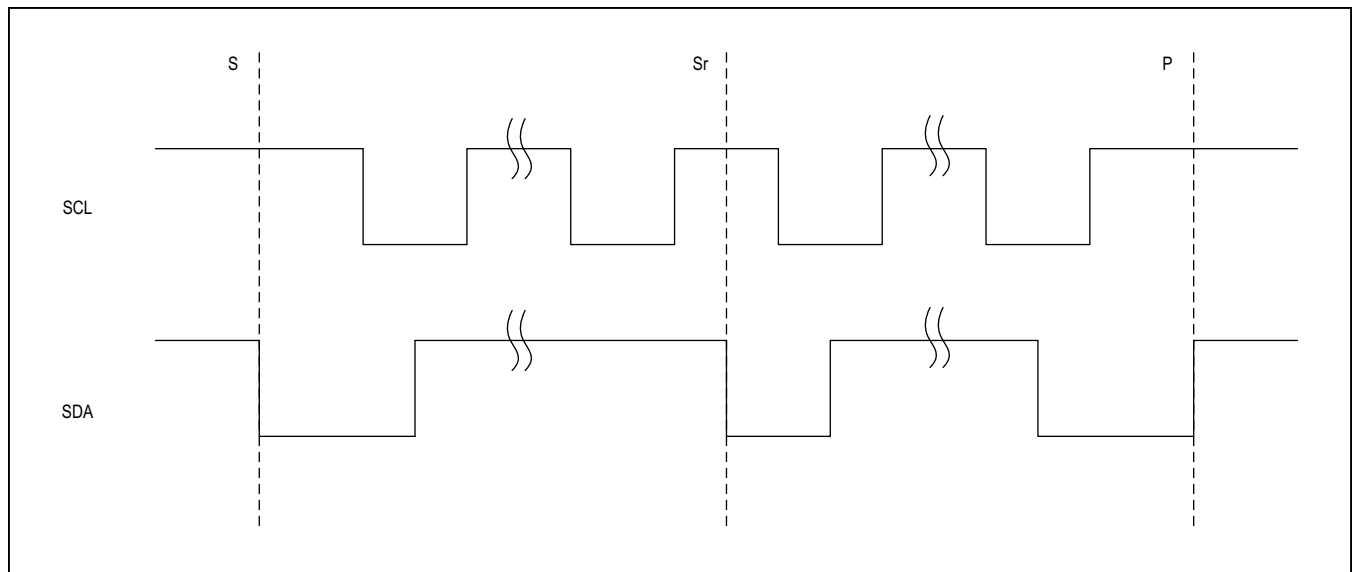


Figure 4: START, STOP, and REPEATED START Conditions





**Read Data Format**

For the read operation, two I<sup>2</sup>C operations must be performed. First, the slave ID byte is sent followed by the I<sup>2</sup>C register that you wish to read. Then a REPEAT START (Sr) condition is sent, followed by the read slave ID. The MAX86150 then begins sending data beginning with the register selected in the first operation. The read pointer increments automatically, so the MAX86150 continues sending data from additional registers in sequential order until a STOP (P) condition is received. The exception to this is the FIFO\_DATA register, at which the read pointer no longer increments when reading additional bytes. To read

the next register after FIFO\_DATA, an I<sup>2</sup>C write command is necessary to change the location of the read pointer.

Figure 7 and Figure 8 show the process of reading one byte or multiple bytes of data respectively.

An initial write operation is required to send the read register address.

Data is sent from registers in sequential order, starting from the register selected in the initial I<sup>2</sup>C write operation. If the FIFO\_DATA register is read, the read pointer does not automatically increment, and subsequent bytes of data contain the contents of the FIFO.

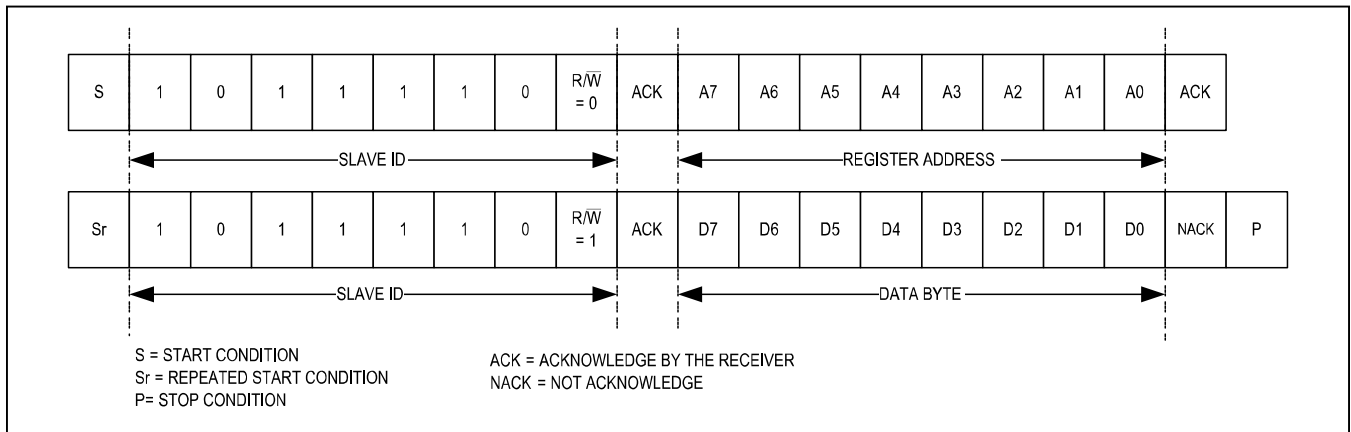


Figure 7. Reading One Byte of Data from MAX86150

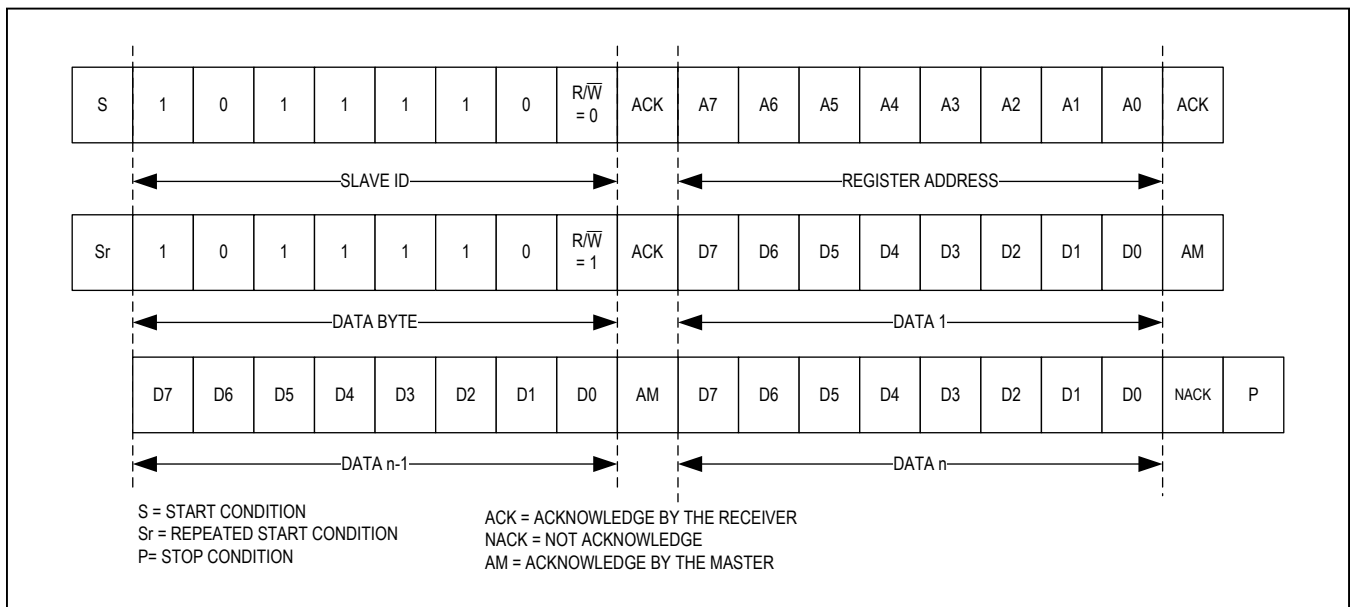


Figure 8. Reading Multiple Bytes of Data from the MAX86150

**FIFO Description**

**Overview**

The FLEX FIFO is designed to support configurable number of elements. So the number of elements in each sample is configurable. All elements are of same width, but can be interpreted differently, depending on how the FIFO data is configured. MS bits of any element that is smaller than this width is padded with zeroes. Reading FIFO through the I<sup>2</sup>C returns only the active FIFO data corresponding to the current configuration.

The design is also scalable to support any:

- Element width in number of bits
- Sample length in number of elements
- FIFO depth in number of samples

Each sample comprises of up to four elements. The actual number of elements in a sample depends on:

- FIFO Data Control Register 1
- FIFO Data Control Register 2

**FIFO Data Types**

**FIFO Data Control Registers**

Table 1 shows the FIFO Data Control registers that are used for enabling any of the PPG modes (e.g., HR, SpO<sub>2</sub>, etc), ECG mode.

FD1, FD2, FD3, and FD4 (FDx[3:0]) are configured as shown in the Table 2 to hold data as programmed. It also shows the format of the data in the FIFO.

**Table 1. FIFO Data Control registers**

ADDRESS	REGISTER NAME	HARDWIRED VALUE	B7	B6	B5	B4	B3	B2	B1	B0
0x09	FIFO Data Configuration Register 1	00	FD2[3:0]				FD1[3:0]			
0x0A	FIFO Data Configuration Register 2	00	FD4[3:0]				FDS3[3:0]			

**Table 2. FDx Format Configurations**

FDX[3:0]	DATA TYPE	FIFO CONTENT OR DATA DESCRIPTION	NOTE
0000	None	N/A	
0001	PPG	PPG_DATA[18:0] for LED1 (IR)	MS bits should be masked
0010	PPG	PPG_DATA[18:0] for LED2 (Red)	MS bits should be masked
0011	Reserved	Reserved	
0100	Reserved	Reserved	
0101	PPG	PPG_DATA[18:0] for Pilot LED1 (IR)	MS bits should be masked
0110	PPG	PPG_DATA[18:0] for Pilot LED2 (Red)	MS bits should be masked
0111	Reserved	Reserved	
1000	Reserved	Reserved	
1001	ECG	ECG_DATA[17:0]	MS bits padded with zeroes
1010	Reserved	Reserved	
1011	Reserved	Reserved	
1100	Reserved	Reserved	
1101	Reserved	Reserved	
1110	Reserved	Reserved	
1111	Reserved	Reserved	

If a configuration uses only one element, FD2, FD3, and FD4 are programmed as zeroes, and FD1 is programmed to the required data type.

- If a configuration uses only two elements, FD3 and FD4 are programmed as zeroes, and FD1 and FD2 are programmed to the required data types.
- If a configuration uses only three elements, FD4 is programmed as zeroes, and FD1, FD2, and FD3 are programmed to the required data types.

- If a configuration uses all four elements, FD1, FD2, FD3, and FD4 are programmed to the required data types.

PPG data is left justified as shown in [Table 3](#). In other words, the MSB bit is always in the bit 18 position regardless of ADC resolution setting, and the LSBs are padded with '0'. FIFO\_DATA[23:19] are don't care and should be masked.

ECG Data is right justified, FIFO\_DATA[23:18] are always padded with '0'.

**Table 3. FIFO Data Format**

ADC Resolution	FIFO_DATA																							
	BYTE 1						BYTE 2						BYTE 3											
	FIFO_DATA[23]	FIFO_DATA[22]	FIFO_DATA[21]	FIFO_DATA[20]	FIFO_DATA[19]	FIFO_DATA[18]	FIFO_DATA[17]	FIFO_DATA[16]	FIFO_DATA[15]	FIFO_DATA[14]	FIFO_DATA[13]	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]
PPG (19-bit)	x	x	x	x	x																			
ECG (18-bit)	0	0	0	0	0	0																		

PPG elements are stored first, followed by ECG, as shown in the examples below:

*Example 1: Configurations for 3 elements: PPG (LED 1) + PPG (LED2) + ECG*

FD1[3:0]	FD2[3:0]	FD3[3:0]	FD4[3:0]
0001 (PPG)	0010 (PPG)	1001 (ECG)	0000 (None)

*Example 2: Configurations for 2 elements: PPG (LED 2) + ECG*

FD1[3:0]	FD2[3:0]	FD3[3:0]	FD4[3:0]
0010 (PPG)	1001 (ECG)	0000 (None)	0000 (None)

*Example 3: Configurations for 2 elements: PPG (LED 1) + PPG (LED2)*

FD1[3:0]	FD2[3:0]	FD3[3:0]	FD4[3:0]
0001 (PPG)	0010 (PPG)	0000 (None)	0000 (None)

*Example 4: Configurations for 1 element: ECG*

FD1[3:0]	FD2[3:0]	FD3[3:0]	FD4[3:0]
1001 (ECG)	0000 (None)	0000 (None)	0000 (None)

*Example 5: Configurations for 1 element: PPG (LED 1)*

FD1[3:0]	FD2[3:0]	FD3[3:0]	FD4[3:0]
0001 (PPG)	0000 (None)	0000 (None)	0000 (None)

**Table 4. Sample of FIFO Data Index**

INDEX WITHIN A SAMPLE	FIFO_DATA[23:0]
0	FD1 data, if enabled
1	FD2 data, if enabled
2	FD3 data, if enabled
3	FD4 data, if enabled

A sample in the FIFO is shown in [Table 4](#).

**FIFO Handling**

Only the elements corresponding to the active FIFO data are pushed onto the FIFO, and only these are read through the I<sup>2</sup>C. The unused FIFO data are not read through the I<sup>2</sup>C, so they are don't care and not padded with zeroes.

The FIFO handling registers are shown in [Table 5](#).

Write Pointer to the FIFO, FIFO\_WR\_PTR[4:0]:  
This points to the location where the next sample will be written. This pointer advances for each sample pushed on to the FIFO.

Read Pointer to the FIFO, FIFO\_RD\_PTR[4:0]:  
This points to the location from where the AP 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 AP can also write to this pointer after reading

the samples. This allows rereading (or retrying) samples from the FIFO.

FIFO Data Read, FIFO\_DATA[7:0]:

This is a read-only register and is used to get data from the FIFO. Reading FIFO\_DATA register does not automatically increment the register address. So burst reading this register, reads the same address over and over. The length of a sample is determined by the number of active elements in the sample. Each element is three bytes long. In order to read one complete sample the FIFO\_DATA register has to be read N times, where

$$N = (\text{Number of active elements}) * (\text{Number of bytes, 3})$$

**Reading from the FIFO**

Normally, reading registers from the I<sup>2</sup>C interface auto-increments the register address pointer, so that all the registers can be read in a burst read without an I<sup>2</sup>C restart event. In this case, 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.

FIFO\_RD\_PTR advances only after burst reading the entire sample.

**Table 5. FIFO Handling Registers**

AD-DRESS	REGISTER NAME	HARD-WIRED VALUE	B7	B6	B5	B4	B3	B2	B1	B0
0x04	FIFO Write Pointer	00				FIFO_WR_PTR[4:0]				
0x05	Overflow Counter	00				OVF_COUNTER[4:0]				
0x06	FIFO Read Pointer	00				FIFO_RD_PTR[4:0]				
0x07	FIFO Data Register	00	FIFO_DATA[7:0]							
0x08	FIFO Configuration	00		A_FULL_CLR	A_FULL_TYPE	FIFO_ROLLS_ON_FULL	FIFO_A_FULL[3:0]			

Each sample is read from the FIFO in the following order, when all **four** Elements are active ([Table 6](#)).

**Table 6. FIFO Sample Elements Order with four active elements**

			FIFO_RD_PTR[4:0]
n Sample:	1st read	Element 1[23:16]	n
	2nd read	Element 1[15:8]	n
	3rd read	Element 1[7:0]	n
	4th read	Element 2[23:16]	n
	5th read	Element 2[15:8]	n
	6th read	Element 2[7:0]	n
	7th read	Element 3[23:16]	n
	8th read	Element 3[15:8]	n
	9th read	Element 3[7:0]	n
	10th read	Element 4[23:16]	n
	11th read	Element 4[15:8]	n
	12th read	Element 4[7:0]	n
n+1 Sample:	13th read	Element 1[23:16]	n+1
	14th read	Element 1[15:8]	n+1
	15th read	Element 1[7:0]	n+1
	16th read	Element 2[23:16]	n+1
	17th read	Element 2[15:8]	n+1
	18th read	Element 2[7:0]	n+1
	19th read	Element 3[23:16]	n+1
	20th read	Element 3[15:8]	n+1
	21st read	Element 3[7:0]	n+1
	22nd read	Element 4[23:16]	n+1
	23rd read	Element 4[15:8]	n+1
	24th read	Element 4[7:0]	n+1
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.

Each sample is read from the FIFO in the following order, when any **two** Elements are active (Table 7).

**Table 7. FIFO Sample Elements Order with two active elements**

			FIFO_RD_PTR[4:0]
n Sample:	1st read	Element 1[23:16]	n
	2nd read	Element 1[15:8]	n
	3rd read	Element 1[7:0]	n
	4th read	Element 2[23:16]	n
	5th read	Element 2[15:8]	n
	6th read	Element 2[7:0]	n
n+1 Sample:	7th read	Element 1[23:16]	n+1
	8th read	Element 1[15:8]	n+1
	9th read	Element 1[7:0]	n+1
	10th read	Element 2[23:16]	n+1
	11th read	Element 2[15:8]	n+1
	12th read	Element 2[7:0]	n+1
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.

Enable Push on FIFO FULL, FIFO\_ROLLS\_ON\_FULL: This bit determines whether samples get pushed on to the FIFO when it is full. If push is enabled when FIFO is full, old samples are lost. Otherwise, new samples are lost.

Overflow counter, OVF\_COUNTER[4:0]: When the FIFO is full, samples are lost. OVF\_COUNTER counts the number of samples lost. It saturates at 0x1F. When a complete sample is popped from the FIFO (when the read pointer advances), and OVF\_COUNTER is reset to zero.

FIFO Almost Full Counter, FIFO\_AFULL\_COUNT[3:0]: This determines the amount of space available in the FIFO, to declare that it is almost full.

FIFO Almost Full status, and Interrupt Enable, A\_FULL and MSK\_A\_FULL: When the FIFO is almost full, the almost full interrupt is asserted if it is enabled by the MSK\_A\_FULL bit. This prompts the AP to read some samples before the FIFO gets full. A\_FULL bit is cleared when the status register is read.

The AP reads the FIFO\_WR\_PTR and FIFO\_RD\_PTR to calculate the number of samples available in the FIFO, and read as many samples as it needs up to a maximum of available samples. The AP can then choose to write the new read pointer to the FIFO\_RD\_PTR register. If necessary to retry, the AP updates the FIFO\_RD\_PTR register with appropriate value.

Example: Following is an example of the pseudo code:

First transaction: Get the FIFO\_WR\_PTR and FIFO\_RD\_PTR:

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

AP evaluates the number of samples to be read from the FIFO:

```
If OVF_COUNTER is zero,
NUM_AVAILABLE_SAMPLES = FIFO_WR_PTR -
FIFO_RD_PTR
(Note: pointer wrap around should be taken into
account)
If OVF_COUNTER is non-zero some samples are
lost, and
NUM_AVAILABLE_SAMPLES = 32
NUM_SAMPLES_TO_READ = < less than or equal
to NUM_AVAILABLE_SAMPLES >
```

Next 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 Data_Item1[23:16];
  Read FIFO_DATA;
  Save Data_Item1[15:8];
  Read FIFO_DATA;
  Save Data_Item1[7:0];
  Read FIFO_DATA;
  Save Data_Item2[23:16];
  Read FIFO_DATA;
  Save Data_Item2[15:8];
  Read FIFO_DATA;
  Save Data_Item2[7:0];
  Read FIFO_DATA;
  Save Data_Item3[23:16];
  Read FIFO_DATA;
  Save Data_Item3[15:8];
  Read FIFO_DATA;
  Save Data_Item3[7:0];
}
STOP;

```

Next transaction: Write to FIFO\_RD\_PTR register. If the previous transaction was successful, FIFO\_RD\_PTR points to the next sample in the FIFO, and this transaction is not necessary. Otherwise, the AP updates the FIFO\_RD\_PTR appropriately to New\_FIFO\_RD\_PTR, so that the samples are reread.

```

START;
Send device address + write mode
Send address of FIFO_RD_PTR;
Write New_FIFO_RD_PTR;
STOP;

```

### FIFO Flush

The FIFO gets flushed if FIFO\_EN = 1, and if any of the following conditions are met:

- I<sup>2</sup>C write to any of the PPG Configuration registers
- I<sup>2</sup>C write to any of the ECG Configuration registers
- I<sup>2</sup>C write to any of the FIFO Data Control registers
- At the rising edge of FIFO\_EN
- Enter and exit PROX mode

When the FIFO gets flushed, FIFO\_WR\_PTR and FIFO\_RD\_PTR are reset to zero, and the contents of the FIFO are lost.

If FIFO contents should not be lost, set FIFO\_EN = 0, before writing to any of the registers listed above.

Note: FIFO\_EN bit is in the System Control register. Data is pushed to the FIFO, when FIFO\_EN = 1. When FIFO\_EN = 0, push to FIFO is disabled, but it holds the status of the FIFO (FIFO pointers and the actual data).

### FIFO Organization

[Figure 9](#) shows how the samples are organized in the FIFO when all four elements in a sample are active.

[Figure 10](#) shows how the samples are organized in the FIFO when only two elements in a sample are active.

FIFO POINTERS[4:0]	I <sup>2</sup> C BYTE			RAM PHYSICAL ADDRESS[6:0]
	1 23 ..... 16	2 15 ..... 8	3 7 ..... 0	
0x00	ELEMENT 1, SAMPLE N			0x00
	ELEMENT 2, SAMPLE N			0x01
	ELEMENT 3, SAMPLE N			0x02
	ELEMENT 4, SAMPLE N			0x03
0x01	ELEMENT 1, SAMPLE N+1			0x04
	ELEMENT 2, SAMPLE N+1			0x05
	ELEMENT 3, SAMPLE N+1			0x06
	ELEMENT 4, SAMPLE N+1			0x07
0x02	ELEMENT 1, SAMPLE N+2			0x08
	ELEMENT 2, SAMPLE N+2			0x09
	ELEMENT 3, SAMPLE N+2			0x0A
	ELEMENT 4, SAMPLE N+2			0x0B
⋮	⋮	⋮	⋮	⋮
0x1F	ELEMENT 1, SAMPLE N+31			0x7C
	ELEMENT 2, SAMPLE N+31			0x7D
	ELEMENT 3, SAMPLE N+31			0x7E
	ELEMENT 4, SAMPLE N+31			0x7F

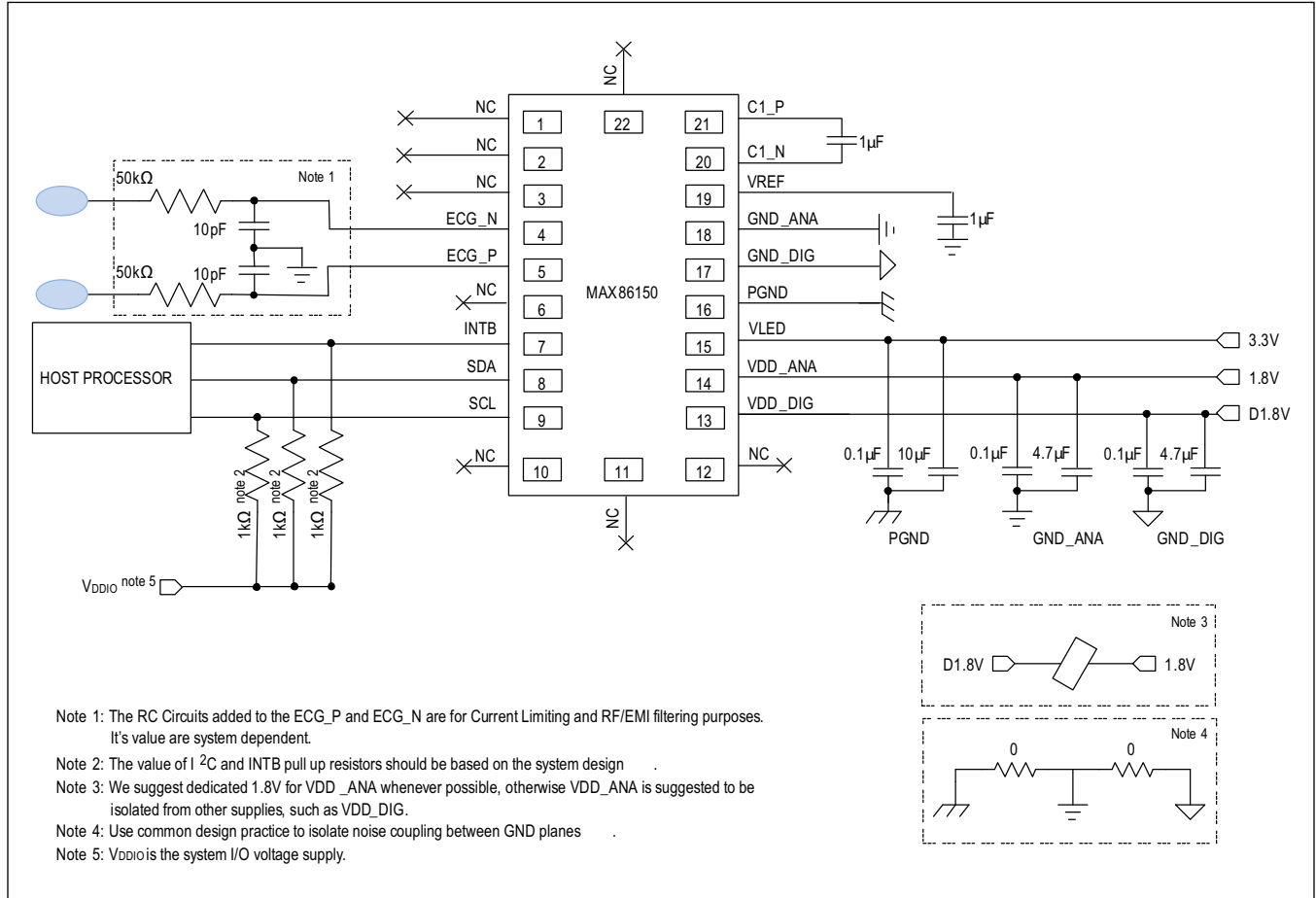
Figure 9. Example of FIFO Organization with Four Active Elements



FIFO POINTERS[4:0]	I <sup>2</sup> C BYTE 1    I <sup>2</sup> C BYTE 2    I <sup>2</sup> C BYTE 3			RAM PHYSICAL ADDRESS[6:0]
	23 ..... 16	15 ..... 8	7 ..... 0	
0x00	ELEMENT 1, SAMPLE N			0x00
	ELEMENT 2, SAMPLE N			0x01
	NOT	USED		0x02
	NOT	USED		0x03
0x01	ELEMENT 1, SAMPLE N+1			0x04
	ELEMENT 2, SAMPLE N+1			0x05
	NOT	USED		0x06
	NOT	USED		0x07
0x02	ELEMENT 1, SAMPLE N+2			0x08
	ELEMENT 2, SAMPLE N+2			0x09
	NOT	USED		0x0A
	NOT	USED		0x0B
⋮	⋮	⋮	⋮	
0x1F	ELEMENT 1, SAMPLE N+31			0x7C
	ELEMENT 2, SAMPLE N+31			0x7D
	NOT	USED		0x7E
	NOT	USED		0x7F

Figure 10. Example of FIFO Organization with Two Active Elements

Typical Application Circuit



Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX86150EFF+T	-40°C to +85°C	22-Lead OESIP

+Denotes a lead(Pb)-free/RoHS-compliant package.  
T = Tape-and-reel.

## Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	12/15	Initial release	—
1	11/16	General updates and typo corrections	1–47

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