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MAX30110

Optimized Pulse-Oximeter and Heart Rate AFE for Wearable Health

General Description

The MAX30110 is a complete optical pulse oximetry and heart rate detection integrated analog front-end. The MAX30110 has a high-resolution, optical readout signal-processing channel with built-in ambient light cancellation, as well as high-current LED driver DACs, to form a complete optical readout signal chain. With external LED(s) and photo diode(s), the MAX30110 offers the lowest power, highest performance heart rate detection solution for wrist applications.

The MAX30110 operates on a 1.8V main supply voltage, with a separate 3.1V to 5.25V LED driver power supply. The device supports a standard SPI compatible interface, as well as shutdown modes through the software with near-zero standby current, allowing the power rails to remain powered at all times.

Applications

- Wrist-Worn Wearable Devices
- In-Ear Wearable Devices
- SpO₂ Monitoring Devices
- Fitness Wearable Devices

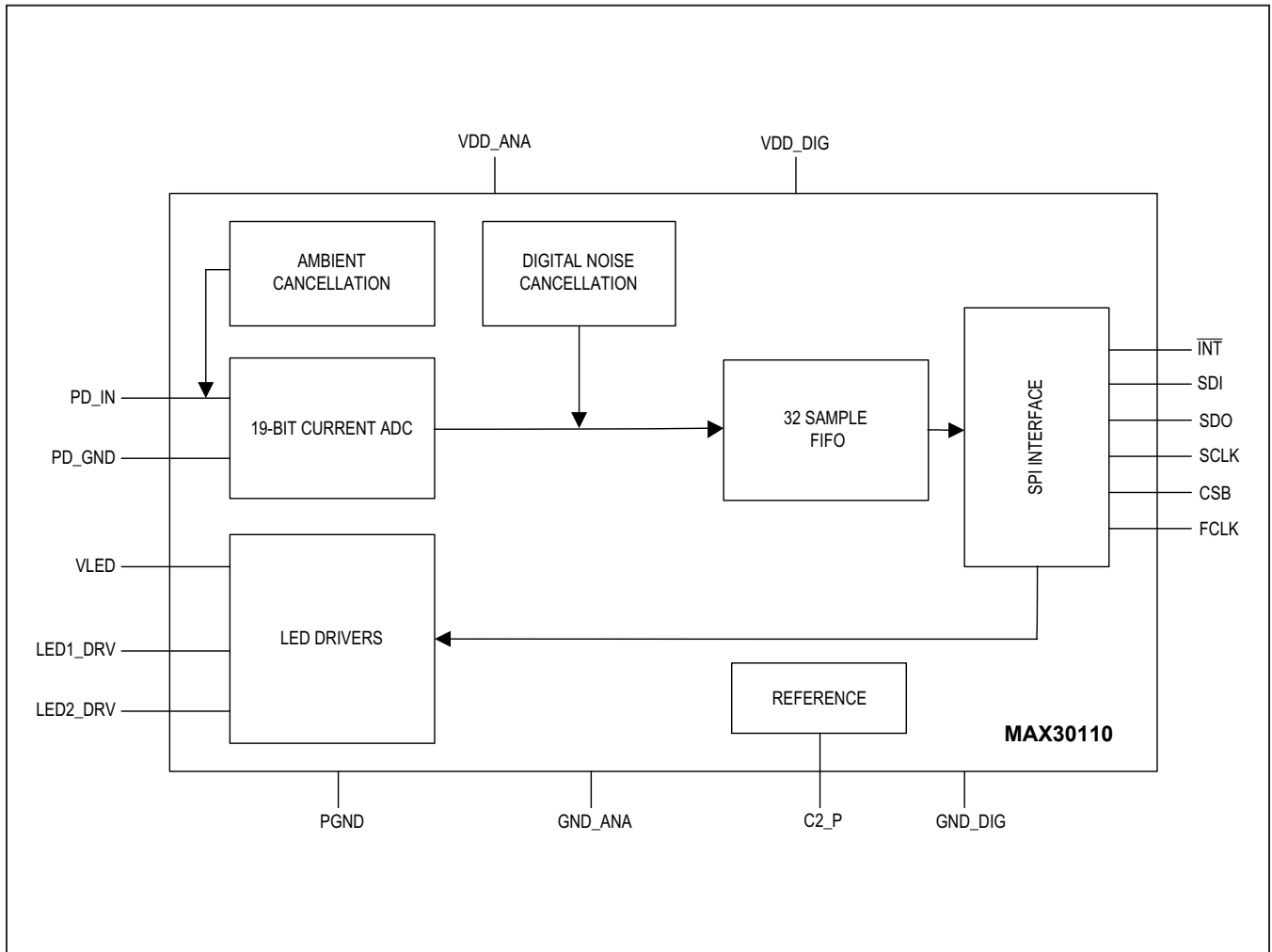
Benefits and Features

- Reflective or Transmissive Heart Rate, Heart Rate Variability, or SpO₂ Monitoring
- Transmit Section
 - Two 8-bit LED Current DACs
 - Four Current Ranges 50mA, 100mA, 150mA, 200mA
 - Low Noise Current Sources for High Peak Transmit to Receive Dynamic Range
 - Low 160mV Dropout to Support Direct Drive From Rechargeable Li Battery
 - High Output Impedance and High Supply Rejection to Support Unregulated Supply or Direct Drive From Boost Switcher Supply

- Receive Section
 - 19-bit Optical ADC Path to Support the Lowest Perfusions Situations
 - Low 25pA-RMS Input Referred Noise to Minimize LED Power Under Most Conditions
 - High Ambient Light Input Range of 200μA and to Support Extraction of HRM Signal in the Most Adverse Lighting Conditions
 - Built-in Front And Back-End Ambient Light Cancellation, Improving Rejection and Eliminating System Complexity of Dealing with Ambient Light
 - Short Exposure Pulse Widths of 52μs, 104μs, 206μs, 417μs for Efficient Uses of LED Light
 - Multiple Sample Rate Options from 20sps to 3.2ksps
- Ultra-Low-Power Operation for Mobile and Body-Wearable Device
 - Dynamic Power-Down Modes to 100sps for Low-Power Consumption
 - Full AFE Power Consumption of Less Than 25μA (Typ) at 25sps
 - Large 32 Sample FIFO to Support Batch Processing in the Microcontroller
 - Variety of System Monitors Mappable to Interrupts to Off-Load System Monitoring Functions From the Microcontroller
 - Low Shutdown Current = 1.4μA (typ)
- SPI Interface
 - Supports a Single 1.8V Supply with Separate 3.1V to 5.25V LED Supply
 - Miniature 2.8mm x 2.0mm, 6x4, 0.4mm Ball Pitch WLP Package
 - -40°C to +85°C Operating Temperature Range

[Ordering Information](#) appears at end of data sheet.

Simplified Block Diagram



Absolute Maximum Ratings

VDD_ANA to GND_ANA	-0.3V to +2.2V	All other pins to GND_ANA	-0.3V to +2.2V
VDD_DIG to GND_ANA	-0.3V to +2.2V	Output Short-Circuit Duration	Continuous
VDD_ANA to VDD_DIG	-0.3V to +0.3V	Continuous Input Current Into Any Pin	
PGND to GND_ANA	-0.3V to +0.3V	(except LEDx_DRV Pins)	±20mA
GND_DIG to GND_ANA	-0.3V to +0.3V	Continuous Power Dissipation, WLP	
VLED to PGND	-0.3V to +6.0V	(T _A = +70°C, derate 5.5mW/°C above +70°C)	440mW
LED1_DRV to PGND	-0.3V to V _{LED} + 0.3V	Operating Temperature Range	-40°C to +85°C
LED2_DRV to PGND	-0.3V to V _{LED} + 0.3V	Storage Temperature Range	-40°C to +105°C
PD_GND to GND_ANA	Internally Shorted	Soldering Temperature (reflow)	+260°C
SDO, SDI, CSB, SCLK to GND_ANA	-0.3V to +6.0V		

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

24-Bump WLP

PACKAGE CODE	W241C2+1
Outline Number	21-100088
Land Pattern Number	Refer to Application Note 1891
THERMAL RESISTANCE, FOUR-LAYER BOARD:	
Junction to Ambient (θ _{JA})	49°C/W

For the latest package outline information and land patterns (footprints), go to 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.

Electrical Characteristics

(V_{DD} = VDD_ANA = VDD_DIG = 1.8V, V_{LED} = 3.3V, C_{LOAD} = 10pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1))

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
POWER SUPPLY							
Power Supply Voltage	V _{DD}	Guaranteed by V _{DD} DC PSR		1.7	1.8	2.0	V
LED Supply Voltage	V _{LED}	Guaranteed by V _{LED} DC PSR		3.1	3.3	5.25	V
V _{DD} Supply Current	I _{DD}	Low Power = Off, LED1 or LED2 (FD1 = 0x01 or FD1 = 0x02, PPG_TINT = 0x0, LP_MODE = 0x0), Note 2	Sample Rate = 100sps, single pulse (PPG_SR = 0x4)		241	308	μA
		Low Power = On, LED1 or LED2 (FD1 = 0x01 or FD1 = 0x02, PPG_TINT = 0x0, LP_MODE = 0x1), Note 2	Sample Rate = 100sps, single pulse (PPG_SR = 0x4)		72		
			Sample Rate = 50sps, single pulse (PPG_SR = 0x2)		40		
			Sample Rate = 25sps, single pulse (PPG_SR = 0x1)		24	45	
			Sample Rate = 50sps, dual pulse (PPG_SR = 0xD)		94		
	I _{DD}		Sample Rate = 25sps, dual pulse (PPG_SR = 0xC)		51		μA

Electrical Characteristics (continued)

(V_{DD} = VDD_ANA = VDD_DIG = 1.8V, V_{LED} = 3.3V, C_{LOAD} = 10pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.) (Note 1))

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
V _{LED} Supply Current	I _{LED}	Low Power = On, LED1 or LED2, LED driver 0mA (FD1 = 0x01 or FD1 = 0x02, PPG_TINT = 0x0, LP_MODE = 0x1, LEDx_DRV = 0x00)	Sample Rate = 100sps, single pulse (PPG_SR = 0x4)		0.1	±1	μA
		Low Power = On, LED1 or LED2, LED driver full scale (FD1 = 0x01 or FD1 = 0x02, PPG_TINT = 0x0, LP_MODE = 0x1, LEDx_DRV = 0xFF)	Sample Rate = 100sps, single pulse (PPG_SR = 0x4)		308		
			Sample Rate = 50sps, single pulse (PPG_SR = 0x2)		155		
			Sample Rate = 25sps, single pulse (PPG_SR = 0x1)		74	110	
		Low Power = On, LED1 and LED2, LED driver full scale (FD1 = 0x1, FD2 = 0x2, FD3 = 0x0, PPG_TINT = 0x0, LP_MODE = 0x1, LEDx_DRV = 0xFF)	Sample Rate = 100sps, single pulse (PPG_SR = 0x4)		616		μA
			Sample Rate = 50sps, single pulse (PPG_SR = 0x2)		304		
			Sample Rate = 25sps, single pulse (PPG_SR = 0x1)		149		
		V _{DD} Current in Shutdown		T _A = +25°C, Note 2			1.6
V _{LED} Current in Shutdown		T _A = +25°C				1	μA
V _{DD} Undervoltage Interrupt Threshold		T _A = +25°C			1.64		V
V _{DD} Overvoltage Interrupt Threshold		T _A = +25°C			2.0		V
OPTICAL RECEIVE CHANNEL							
ADC Resolution					19		bits
ADC Full-Scale Input Current		PPG_ADC_RGE = 0x0			6.0		μA
ADC Full-Scale Input Current (Including DC Offset DAC)		PPG_ADC_RGE = 0x1			12.0		μA
		PPG_ADC_RGE = 0x2			24.0		
		PPG_ADC_RGE = 0x3			48.0		
ADC Integration Time	t _{PPG_TINT}	LED_SETLNG = 0x3	PPG_TINT = 0x0		52		μs
			PPG_TINT = 0x1		104		
			PPG_TINT = 0x2		208		
			PPG_TINT = 0x3		417		

Electrical Characteristics (continued)

($V_{DD} = V_{DD_ANA} = V_{DD_DIG} = 1.8V$, $V_{LED} = 3.3V$, $C_{LOAD} = 10pF$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^\circ C$.) (Note 1))

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Minimum PPG Sample Rate		PPG_SR = 0x0			20		sps
Maximum PPG Sample Rate		PPG_SR = 0xA			3200		sps
Sample Rate Error		From nominal as indicated in the PPG_SR table		-2		+2	%
DC Ambient Light Input Range	ALR	$T_A = +25^\circ C$			200		μA
Total Integrated Input Referred Noise Current		PPG_ADC_RGE = 0x0, $T_A = +25^\circ C$	PPG_TINT = 0x0		71		pArms
			PPG_TINT = 0x1		50		
			PPG_TINT = 0x2		35		
			PPG_TINT = 0x3		25		pArms
Maximum Photodiode Input Capacitance					1000		pF
Transmit and Receive Channel V_{DD} DC PSR		Loopback test, exposure current = 1.6 μA nominal, PPG_TINT = 0x3, $V_{LED} = 3.3V$, $V_{DD} = 1.7V$ to 2.0V	PPG_ADC_RGE = 0x0		2420		LSB/V
			PPG_ADC_RGE = 0x1		2010		
			PPG_ADC_RGE = 0x2		1790		
			PPG_ADC_RGE = 0x3		1664		
LED TRANSMIT DRIVER							
LED Current Resolution					8		Bits
Driver DNL					1		LSB
Driver INL					1		LSB
Full-Scale LED Current	I_{LED}	LEDx_PA = 0xFF	LEDx_RGE = 0x0	45	50	55	mA
			LEDx_RGE = 0x1		100		
			LEDx_RGE = 0x2		150		
	I_{LED}	LEDx_PA = 0xF2, LEDx_RGE = 0x3		190			
	I_{LED}	LEDx_PA = 0xFF, LEDx_RGE = 0x3 (Note 3)		200			mA
Minimum Output Voltage		LEDx_PA = 0xFF, $V_{DD} = 1.8V$, $V_{LED} = 3.3V$, 95% of the desired LED current	LEDx_RGE = 0x0		0.16	0.25	V
			LEDx_RGE = 0x1		0.32		
			LEDx_RGE = 0x2		0.49		
		LEDx_RGE = 0x3, LEDx_PA = 0xF2, $V_{DD} = 1.8V$, $V_{LED} = 3.3V$, 95% of the desired LED current		0.64			

Electrical Characteristics (continued)

($V_{DD} = V_{DD_ANA} = V_{DD_DIG} = 1.8V$, $V_{LED} = 3.3V$, $C_{LOAD} = 10pF$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$.) (Note 1))

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	
Transmit Driver V_{LED} DC PSR		LEDx_PA = 0xFF, $V_{DD} = 1.8V$, $V_{LEDx_DRV} = 0.9V$, $V_{LED} = 3.1V$ to $5.25V$	LEDx_RGE = 0x0	-0.9	-0.04	+0.9	mA/V
			LEDx_RGE = 0x1		-0.06		
			LEDx_RGE = 0x2		-0.02		
		LEDx_PA = 0xF2, $V_{DD} = 1.8V$, $V_{LEDx_DRV} = 0.9V$, $V_{LED} = 3.1V$ to $5.25V$	LEDx_RGE = 0x3		-0.025		
Transmit Driver V_{DD} DC PSR		LEDx_PA = 0xFF, $V_{LED} = 3.3V$, $V_{LEDx_DRV} = 0.9V$, $V_{DD} = 1.7V$ to $2.0V$	LEDx_RGE = 0x0	-4	± 0.08	+4	mA/V
			LEDx_RGE = 0x1		0.14		mA/V
			LEDx_RGE = 0x2		0.16		mA/V
		LEDx_PA = 0xF2, $V_{LED} = 3.3V$, $V_{LEDx_DRV} = 0.9V$, $V_{DD} = 1.7V$ to $2.0V$	LEDx_RGE = 0x3		0.02		mA/V
LED Driver Compliance Interrupt	LED _{COMP}	LEDx_RGE = 0x0, LED1_DRV only		170		mV	
DIGITAL/I/O CHARACTERISTICS							
Output High Voltage	V_{OH}	SDO, \overline{INT} , $I_{SOURCE} = 2mA$	$V_{DD} - 0.4$			V	
Output Low Voltage	V_{OL}	SDO, \overline{INT} , $I_{SINK} = 2mA$	0.4			V	
Input Voltage Low	V_{ILI}	SDI, SCLK, CSB, FCLK	$0.3 \times V_{DD}$			V	
Input Voltage High	V_{IH}	SDI, SCLK, CSB, FCLK	$0.7 \times V_{DD}$			V	
Input Hysteresis	V_{HYS}	SDI, SCLK, CSB, FCLK	200			mV	
Pin Capacitance	C_{PIN}	SDI, SCLK, CSB, \overline{INT} (when inactive)	10			pF	
Pin Leakage Current	I_{PIN}	SDA, SCLK, CSB, \overline{INT} (when inactive), $T_A = +25^{\circ}C$	0.01	1		μA	
DIGITAL/SPI TIMING CHARACTERISTICS							
SCLK Frequency	f_{SCLK}		4			MHz	
SCLK Period	t_{CP}		250			ns	
SCLK Pulse Width High	t_{CH}		75			ns	
SCLK Pulse Width Low	t_{CL}		75			ns	
CSB Fall to SCLK Rise Setup Time	t_{CSS0}	to 1st SCLK rising edge	20			ns	
CSB Fall to SCLK Rise Hold Time	t_{CSH0}	Applies to inactive rising edge preceding 1st rising edge	0			ns	
CSB Rise to SCLK Rise Hold Time	t_{CSH1}	Applies to 24th rising edge	500			ns	
SCLK Rise to CSB Fall	t_{CSF}	Applies to 24th rising edge	500			ns	
CSB Pulse Width High	t_{CSPW}		250			ns	

Electrical Characteristics (continued)

($V_{DD} = V_{DD_ANA} = V_{DD_DIG} = 1.8V$, $V_{LED} = 3.3V$, $C_{LOAD} = 10pF$, $T_A = T_{MIN}$ to T_{MAX} , unless otherwise noted. Typical values are at $T_A = +25^{\circ}C$.) (Note 1))

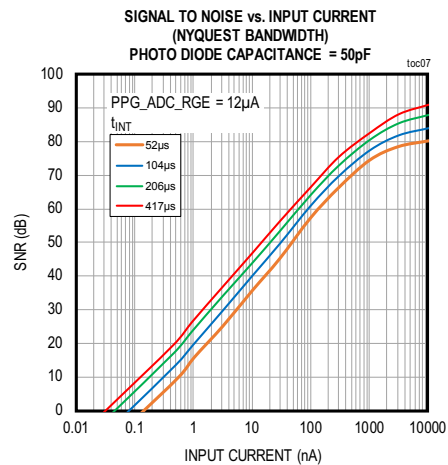
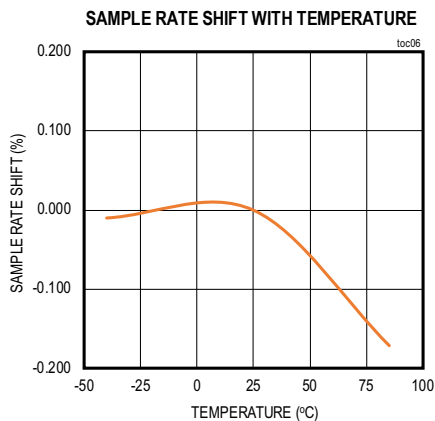
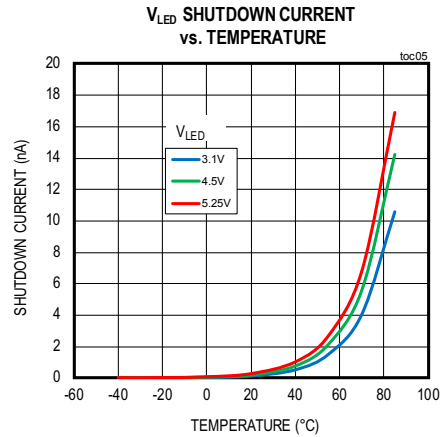
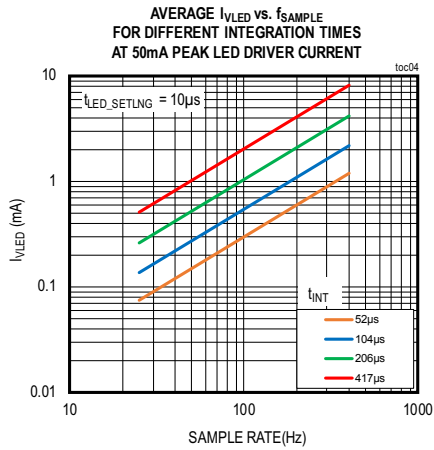
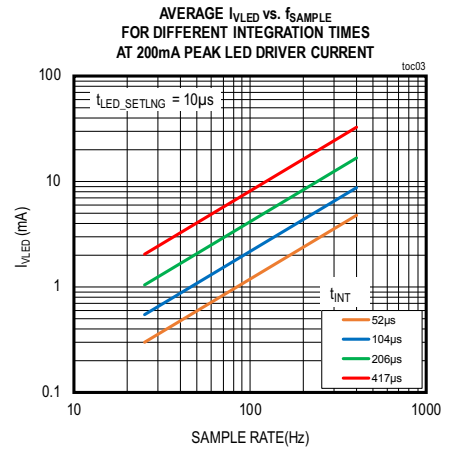
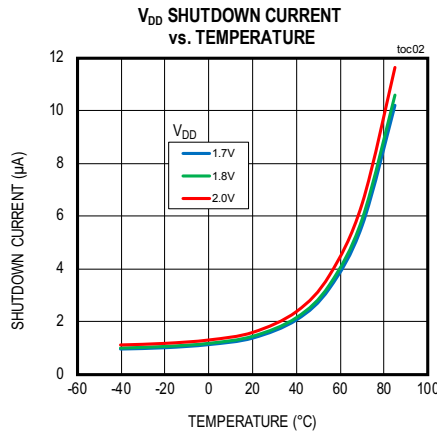
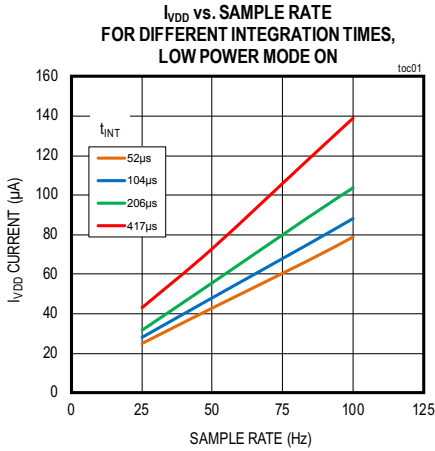
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SDI to SCLK Rise Setup Time	t_{DS}		10			ns
SDI to SCLK Rise Hold Time	t_{DH}		10			ns
SCLK Fall to SDO Transition	t_{DOT}	$C_{LOAD} = 20pF$			20	ns
SCLK Fall to SDO Fall	t_{DOH}	$C_{LOAD} = 0pF$	2			ns
CSB Rise to SDO Hi-Z	t_{DOZ}	Disable Time			20	ns
CSB Fall to SDO Fall	t_{DOE}	Enable time	20			ns
FCLK External Sample Input	f_{FCLK}	External Sample Reference Clock		32.768		kHz
FCLK Pulse Width High	f_{FCLKH}	~50% duty cycle assumed		15.26		μs
FCLK Pulse Width Low	f_{FCLKL}	~50% duty cycle assumed		15.26		μs

Note 1: Limits are 100% tested at $T_A = +25^{\circ}C$. Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization.

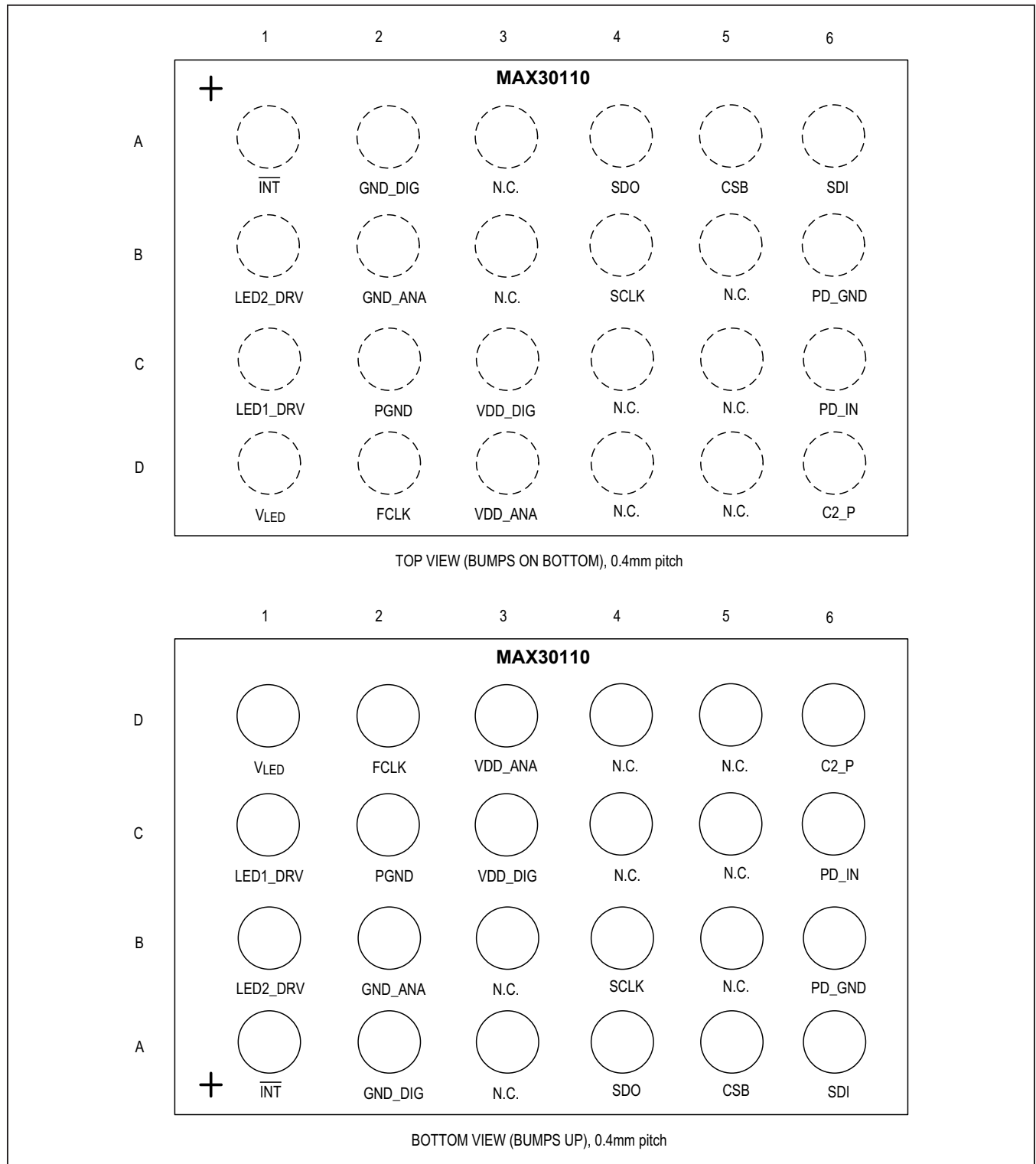
Note 2: Limit assumes that all user-programmable memory is programmed. If user programmable memory is left unprogrammed, currents can exceed the limit shown.

Typical Operating Characteristics

VDD_ANA = VDD_DIG = 1.8V, VLED = 3.3V, GND_ANA = GND_DIG = PGND = 0V, TA = +25°C, min/max are from TA = -40°C to +85°C, unless otherwise noted. (Note 2)



Bump Configurations



Bump Description

PIN	NAME	FUNCTION
POWER		
C3	VDD_DIG	Digital Logic Supply. Connect to externally-regulated supply. Suggest to connect to VDD_ANA.
A2	GND_DIG	Digital Logic and Digital Pad Return. Suggest to connect to common PCB ground.
D3	VDD_ANA	Analog Supply. Connect to externally-regulated supply. Bypass with a 0.1µF as close as possible to bump and a 10µF capacitor to GND_ANA.
B2	GND_ANA	Analog Power Return. Suggest to connect to common PCB ground.
D1	V _{LED}	LED Power Supply Input. Connect to external voltage supply. Bypass with a 10µF capacitor to PGND.
C2	PGND	LED Power Return
CLOCK		
D2	FCLK	Optional External Clock Input. Leave FCLK unconnected/floating, if external clock is not used.
SPI CONTROL INTERFACE		
A1	$\overline{\text{INT}}$	Interrupt. Programmable open-drain interrupt output signal pin (active-low).
A4	SDO	SPI Data Output
A5	CSB	SPI Chip Select
A6	SDI	SPI Data Input
B4	SCLK	SPI Clock
OPTICAL		
C6	PD_IN	Photodiode Cathode Input. Keep traces as short as possible, shield with PD_GND.
B6	PD_GND	Photodiode Anode. Connect to PCB GND plane only at PD_GND pin. Use as shield trace for PD_IN.
C1	LED_DRV1	LED Driver Output 1. Connect the LED cathode to LED_DRV1 output and its anode to the V _{LED} supply.
B1	LED_DRV2	LED Driver Output 2. Connect the LED cathode to LED_DRV2 output and its anode to the V _{LED} supply.
REFERENCE		
D6	C2_P	Internal Reference Decoupling Point. Bypass with a 10µF capacitor to GND_ANA
N.C.		
A3, B3, B5, C4, C5, D4, D5	N.C.	No Connection. Internally connected, leave N.C. unconnected.

Detailed Description

The MAX30110 is a complete optical pulse oximetry and heart-rate-detection, integrated, analog front-end readout circuit designed for the demanding requirements of mobile and wearable devices. Minimal external hardware components are necessary for integration into a mobile device. The MAX30110 is fully adjustable through software registers, with the digital output data being stored in a 32-samples FIFO within the IC.

Optical Subsystem

The optical subsystem in MAX30110 is composed of ambient light cancellation (ALC), a continuous-time, sigma-delta ADC, and proprietary discrete time filter. ALC incorporates a proprietary scheme to cancel ambient-light-generated photo diode current up to 200µA, allowing the sensor to work in high ambient light conditions. The ADC has programmable full-scale ranges of between 6µA and 48µA. The internal ADC is a continuous-time oversampling sigma-delta converter with 19-bit resolution. The ADC output data rate can be programmed from 20sps (samples per second) to 3200sps. The MAX30110 includes a proprietary discrete time filter to reject 50Hz/60Hz interference and changing residual ambient light from the sensor measurements.

MAX30110 supports Dynamic Power-Down mode (Low Power mode) in which the power consumption is decreased between samples. This mode is only supported for sample rates 100sps and below. For more details on the power consumption at each sample rates, please refer to the [Electrical Characteristics](#) table.

LED Driver

The MAX30110 integrates two precision LED-driver-current DACs that modulate LED pulses for both SpO₂ and HR measurements. The LED current DACs have 8-bits of dynamic range with four programmable full-scale ranges of 50mA, 100mA, 150mA, and 200mA. The LED drivers are low-dropout current sources, allowing for low-noise, power-supply independent LED currents to be sourced at the lowest supply voltage possible; thus minimizing LED power consumption. The LED pulse width and the LED settling time can be programmed to allow the algorithms to optimize SpO₂ and HR accuracy at the lowest dynamic power consumption dictated by the application.

SPI Timing

Detailed SPI Timing

The detailed SPI timing is illustrated in [Figure 1](#). The timings indicated are all specified in the [Electrical Characteristics](#) table.

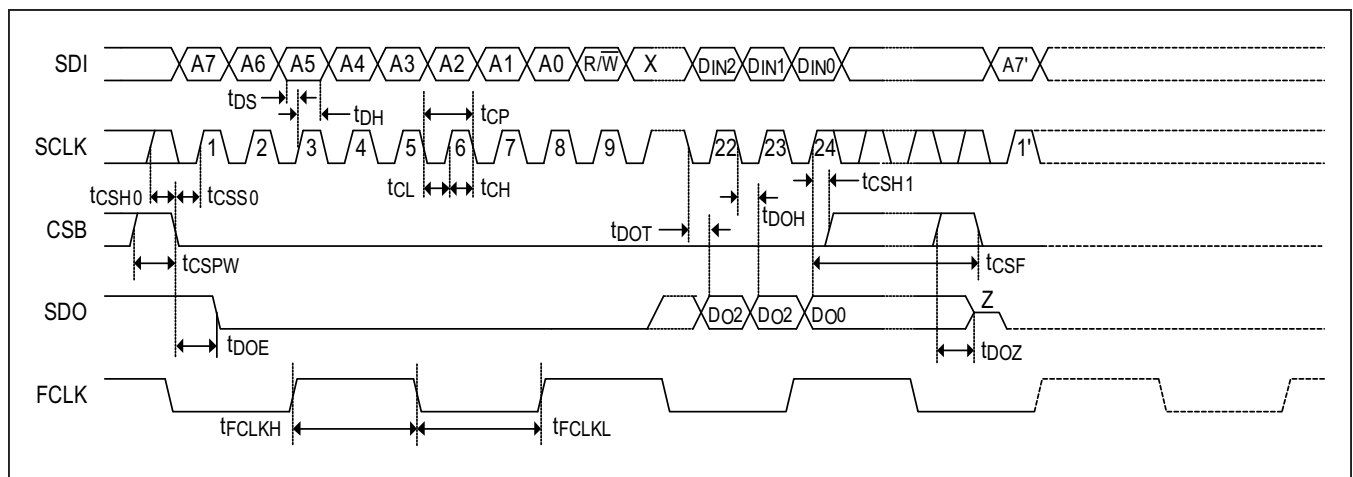


Figure 1. SPI Detailed Timing Diagram

Single-Word SPI Register Read/Write Transaction

The MAX30110 interface is SPI/QSPI/Microwire/DSP compatible. The operation of the SPI interface is shown below. Data is strobed into the MAX30110 on the SCLK rising edge, while clocked-out on the SCLK falling edge. All single-word SPI read and write operations are performed in a 3-byte, 24-cycle SPI instruction framed by a CSB low interval. The content of the SPI operation consists of a one byte register address (A[7:0]), followed by a one-byte command word that defines the transaction as write or read, followed by a single-byte data word, either written to, or read from, the register location provided in the first byte.

Write mode operations will be executed on the 24th SCLK rising edge using the first three bytes of data available. In

write mode, any data supplied after the 24th SCLK rising edge will be ignored. Subsequent writes require CSB to deassert high and then assert low for the next write command. A rising CSB edge precede the 24th rising edge of SCLK by t_{CSA} (detailed SPI timing diagram), will result in the transaction being aborted.

Read mode operations will access the requested data on the 16th SCLK rising edge, and present the MSB of the requested data on the following SCLK falling edge, allowing the μC to latch the data MSB on the 17th SCLK rising edge. Configuration and status registers are available through normal mode readback sequences. FIFO reads must be performed with a burst mode FIFO read (see [SPI FIFO Burst Mode Read Transaction](#)). If more than 24 SCLK rising edges are provided in a normal read sequence, the excess edges will be ignored and the device will read back zeros.

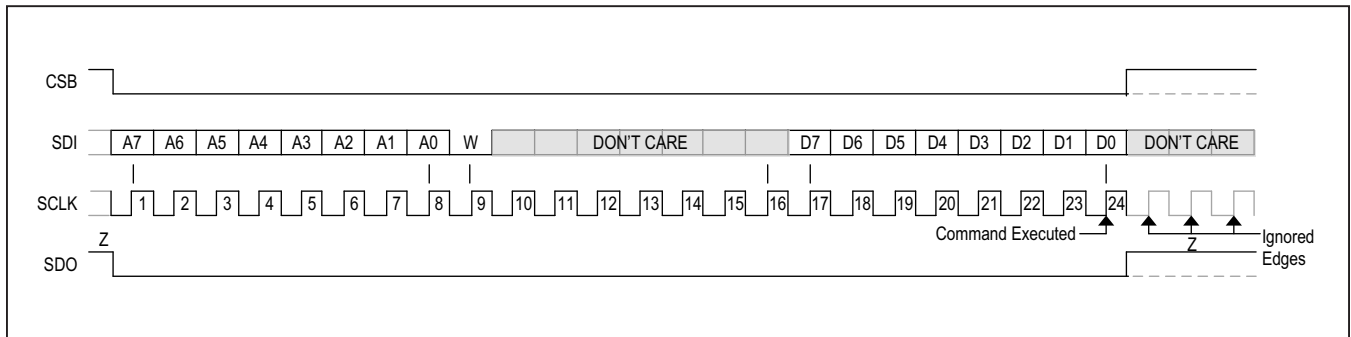


Figure 2: SPI Write Transaction Diagram

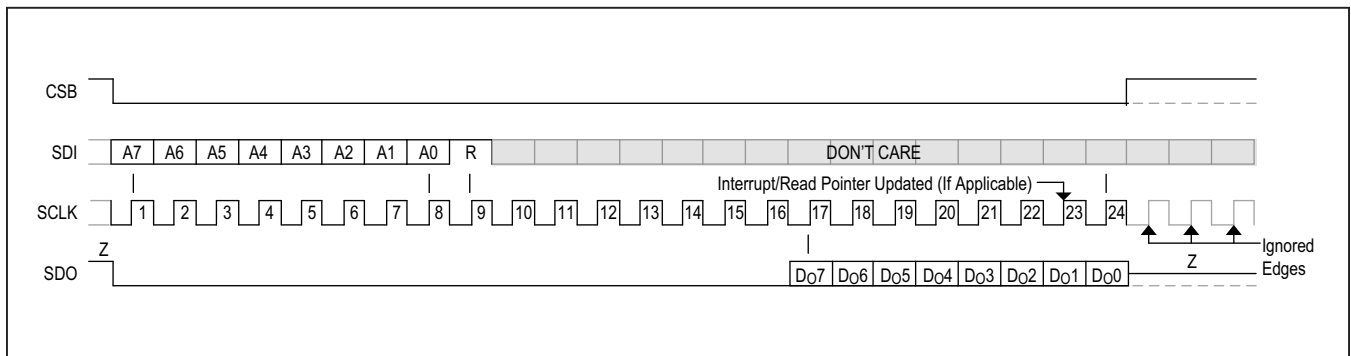


Figure 3: SPI Read Transaction Diagram

SPI FIFO Burst Mode Read Transaction

The MAX30110 provides a FIFO burst read mode to increase data transfer efficiency. The first 16 SCLK cycles operate exactly as described for the normal read mode, the first byte being the register address, the second being a read command. The subsequent SCLKs consist of FIFO data, 24 SCLKs per sample. All Samples in the FIFO should be read with a single FIFO burst read command.

Each FIFO sample consists of 3 bytes per sample and thus requires 24 SCLKs per sample to readout. The first byte (SCLK 16 to 23) consists of both the sub-range DAC value (upper 5 bits, left justified) then the MSBs of the corrected exposure sample (MSB, MSB-1 and MSB-2). The next byte (SCLK 24 to 31) consists of sample bits MSB-3 to MSB-19. The final byte of each sample (SCLK 32 to 40) consists of the sample LSB bits. The number of samples in the FIFO depends on the FIFO configuration and the channels enable. See the [FIFO Configuration](#) section for more details on the FIFO configuration and readout.

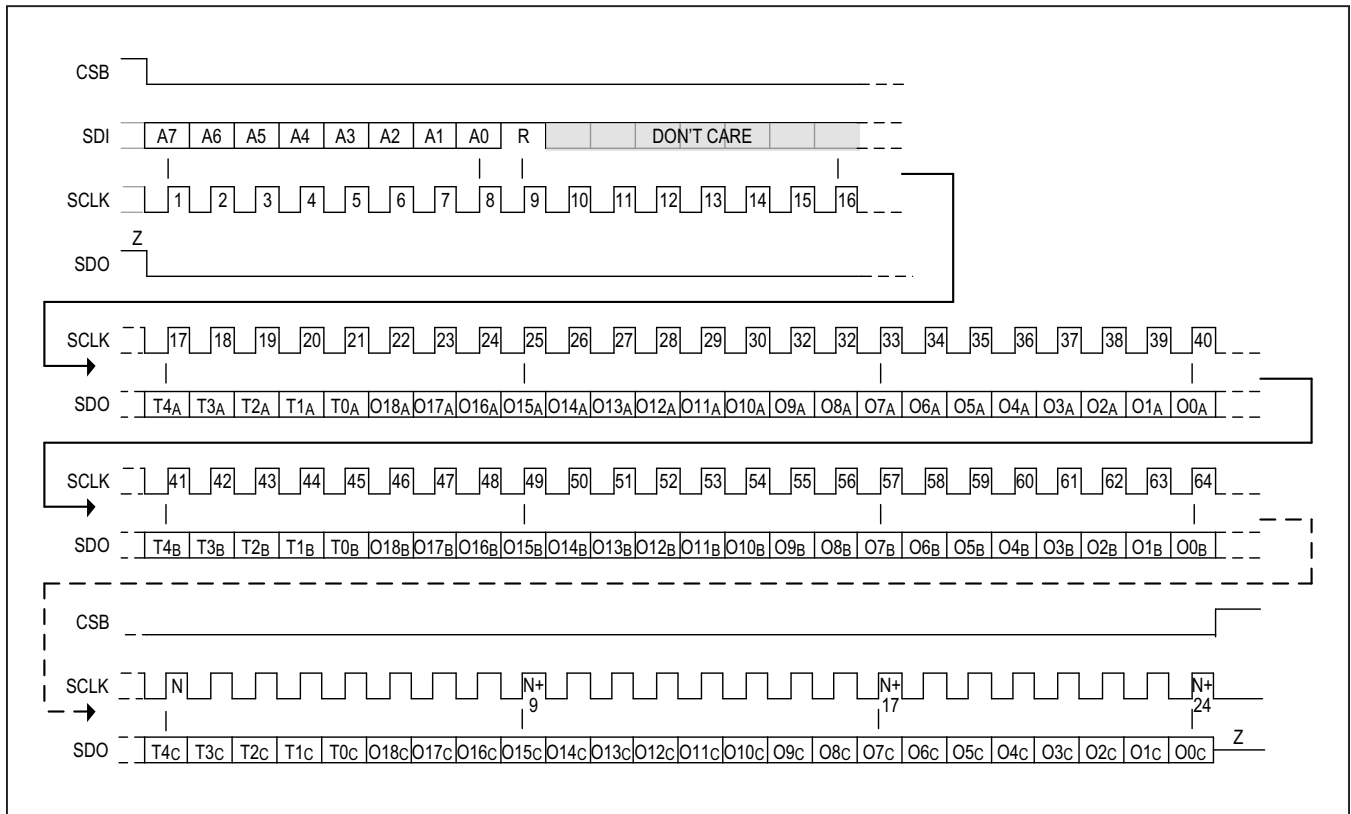


Figure 4. SPI FIFO Burst Mode Transaction Diagram

FIFO Configuration

The FIFO can hold up to 32 samples of data, with each sample comprised of up to 4 data items (time slots). Each data item is 3 bytes. The content of each data item is programmed through register FD1 to FD4 (FIFO data control). These data items are ADC counts from the analog front-end of this device. The FIFO supports the following features:

- Maximum 32 samples (depth)
- Supports up to four data items in each sample
- FIFO roll-on full
- Different interrupt modes based on watermark

There are seven registers that control how the FIFO is configured and read out. These registers are described in [Table 1](#) and [Table 2](#).

FIFO Data Control (Address 0x09 and 0x0A)

The data format in the FIFO, as well as the sequencing of exposures, are controlled by the FIFO Data Control registers through FD1 through FD4. There are four FIFO data items available, each holding up to 32 samples. The exposure sequence cycles through the FIFO data bit fields, starting from FD1 to FD4. The first FIFO data field set to NONE (0000) ends the sequence.

Table 1. FIFO Information, Control and Configuration Registers

ADDRESS	REGISTER NAME	DEFAULT 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	0F	—	FIFO_STAT_CLR	A_FULL_TYPE	FIFO_RO	FIFO_A_FULL[3:0]			
0x09	FIFO Data Control 1	00	FD2[3:0]				FD1[3:0]			
0x0A	FIFO Data Control 2	00	FD4[3:0]				FD3[3:0]			

Table 2: Data Items Type for FIFO Control Registers

FDX[3:0]*	DATA TYPE	FIFO DATA CONTENT	NOTE
0000	NONE	—	—
0001	LED1	PPG_DATA[18:0]	MS bits should be masked
0010	LED2	PPG_DATA[18:0]	MS bits should be masked
0011	Reserved	—	—
0100	Reserved	—	—
0101	PILOT LED1	PPG_DATA[18:0]	MS bits should be masked
0110	Reserved	—	—
0111	Reserved	—	—
1000	Reserved	—	—
1001	Reserved	—	—
1010	Reserved	—	—
1011	Reserved	—	—
1100	DIRECT_AMBIENT	PPG_DATA[18:0]	MS bits should be masked
1101	LED1 and LED2	PPG_DATA[18:0]	MS bits should be masked
1110	Reserved	—	—
1111	Reserved	—	—

* Note: In FDX, x is 1, 2, 3, or 4 for the corresponding FIFO bank.

Write Pointer (Register 0X04)

FIFO_WR_PTR[4:0] points to the FIFO location where the next sample will be written. This pointer advances for each sample pushed on to the FIFO by the internal conversion process. The write pointer is a 5-bit counter and will wrap around to count 0x00 on the next sample after count 0x1F.

Overflow Counter (Register 0X05)

OVF_COUNTER[4:0] logs the number of samples lost if the FIFO is not read in a timely fashion. This counter holds at count value 0x1F. When a complete sample is popped from the FIFO (when the read pointer advances), and OVF_COUNTER is reset to zero. This counter is essentially a debug tool. It should be read immediately before reading the FIFO in order to check if an overflow condition has occurred.

Read Pointer (Register 0X06)

FIFO_RD_PTR[4:0] points to the location from where the next sample from the FIFO will be read through the interface. This advances each time a sample is read from the FIFO. The read pointer can be both read and written to. This allows a sample to be reread from the FIFO if it has not already been overwritten. The read pointer is updated from a 5-bit counter and will wrap around to count 0x00 from count 0x1F.

FIFO Data (Register 0X07)

FIFO_DATA[7:0] is a read-only register used to retrieve data from the FIFO. The format and data type of the data stored in the FIFO is determined by the FIFO data control register. Readout from the FIFO follows a progression defined by the FIFO data control register as well. This configuration is best illustrated by a few examples.

Assume it is desired to perform an SpO₂ measurement simultaneously with monitoring the ambient level on the photodiode to adjust the IR and red LED intensity. To perform this measurement, config the following registers,

FIFO Data Control field

```
FD1[3:0] = 0x1 (LED1)
FD2[3:0] = 0x2 (LED2)
FD3[3:0] = 0xC (DIRECT_AMBIENT)
FD4[3:0] = 0x0 (NONE)
```

PPG Configuration

```
PPG_ADC_RGE[1:0] (Gain Range Control)
PPG_SR[3:0] (Sample Rate Control)
PPG_TINT[1:0] (Integration Time)
```

LED Pulse Amplitude

```
LED1_PA[7:0] (LED1 Current Pulse Amplitude)
LED2_PA[7:0] (LED2 Current Pulse Amplitude)
```

When done so the sample sequence and the data format in the FIFO will follow the following time/location sequence.

```
LED1 sample 1
LED2 sample 1
DIRECT_AMBIENT sample 1
LED1 sample 2
LED2 sample 2
DIRECT_AMBIENT sample 2
.
.
.
LED1 sample n
LED2 sample n
DIRECT_AMBIENT sample n
```

where:

LED1 sample x = ambient light corrected photodiode ADC count exposure data from LED1 for the sample x

LED2 sample x = ambient light corrected photodiode ADC count exposure data from LED2 for the sample x

DIRECT_AMBIENT sample x = direct ambient sample x

n is the number of samples in the FIFO, which can be up to 32 samples.

For a second example, assume it is desired to pulse LED1 and LED2 simultaneously while also monitoring the ambient level. In this case set the following registers,

FIFO Data Control field

```
FD1[3:0] = 0xD (LED1 & LED2)
FD2[3:0] = 0xC (DIRECT_AMBIENT)
FD3[3:0] = 0x0 (NONE)
FD4[3:0] = 0x0 (NONE)
```

The sequencing in the FIFO will then be,

```
LED1 and LED2 sample1
DIRECT_AMBIENT sample 1
LED1 and LED2 sample2
DIRECT_AMBIENT 2
.
.
.
LED1 and LED2 sample n
DIRECT_AMBIENT n
```

where:

LED1 and LED2 sample x = ambient light corrected photodiode ADC count exposure data when both LED1 and LED2 are active simultaneously

DIRECT_AMBIENT sample x = direct ambient corrected sample x

The number of bytes of active data samples is given by: 3 x K x N

where:

K = the number of active sampled channels as defined in the FIFO_Data_Control register 0x09 and 0x0A

N = the number of active data samples in the FIFO

The number of active data samples in the FIFO is directly readable by subtracting the FIFO_RD_PTR[4:0] from the FIFO_WR_PTR[4:0], and taking wrap around of the pointers into consideration. It is typically controlled in the system by generating an interrupt on the INT line when the FIFO reaches a watermark level computed from the FIFO_A_FULL[3:0] field in the FIFO Configuration register (0x08). In this case, when the active data samples in the FIFO reach a level given by 32 - FIFO_A_FULL[3:0], an A_FULL interrupt is generated.

To calculate the number of active samples when the INT signal is asserted, execute the following pseudo-code:

```
read the OVF_COUNTER register
read the FIFO_WR_PTR register
read the FIFO_RD_PTR register
if (OVF_COUNTER == 0) then //no
overflow occurred
    if (FIFO_WR_PTR > FIFO_RD_PTR) then
        NUM_AVAILABLE_SAMPLES = FIFO_WR_PTR
        - FIFO_RD_PTR
    else
        NUM_AVAILABLE_SAMPLES = FIFO_WR_PTR
        + 32 - FIFO_RD_PTR
    endif
else
    NUM_AVAILABLE_SAMPLES = 32 // over-
flow occurred and data has been lost
endif
```

FIFO data format depends on the data type being stored. Optical data, whether ambient-corrected LED exposure, ambient-corrected proximity, or direct ambient-sampled data is as shown in Table 3. The ADC data is left-justified at FIFO_DATA[18] and the MSBs (FIFO_DATA[23:18]) are don't care and should be masked as shown in Table 3. In other words, the MSB bit of the ADC data is always in the bit 18 position.

The ADC resolution is set by the PPG_LED_PW[1:0] in the PPG Configuration 1 Register. This field generates an ADC resolution of 19, 18, 17, or 16 bits and is tied to the selected integration time of 417µs, 206µs, 104µs, or 52µs, respectively. In lower ADC resolutions, the unused LSBs should be masked.

Table 3. Integration Pulse Width, Resulting ADC Resolution, and FIFO Data Format

Integration Pulse Width	ADC Res	FIFO DATA FORMAT (FIFO_DATA[23:0])																								
		ADC Value																								
		F23	F22	F21	F20	F19	F18	F17	F16	F15	F14	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2	F1	F0	
417µs	19-bits	X	X	X	X	X	018	017	016	015	014	013	012	011	010	09	08	07	06	05	04	03	02	01	00	
206µs	18-bits	X	X	X	X	X	018	017	016	015	014	013	012	011	010	09	08	07	06	05	04	03	02	01	X	
104µs	17-bits	X	X	X	X	X	018	017	016	015	014	013	012	011	010	09	08	07	06	05	04	03	02	X	X	
52µs	16-bits	X	X	X	X	X	018	017	016	015	014	013	012	011	010	09	08	07	06	05	04	03	X	X	X	

FIFO Almost Full (Watermark)

The FIFO_A_FULL[3:0] register in the FIFO_Configuration register (0x08) determines when the A_FULL bit in the Interrupt_Status 1 register (0x00) gets asserted. The FIFO is almost full when it has 32 minus FIFO_A_FULL[3:0] samples. Then, if A_FULL_EN mask bit in the Interrupt_Enable 1 register (0x02) is set, the A_FULL bit in the Interrupt_Status 1 will be set and routed to the \overline{INT} pin on the MAX30110 interface. This condition prompts the Application Processor to read samples from the FIFO before it gets filled. The A_FULL bit is cleared and \overline{INT} is deasserted when the status register is read, or when the FIFO_DATA register (0x07) is read and FIFO_STAT_CLR (0x08) bit is set.

When the application processor receives an interrupt, there are at least 32 minus FIFO_A_FULL[3:0] samples available in the FIFO. It is not necessary to read the FIFO_WR_PTR and FIFO_RD_PTR registers. The Application Processor may read all the available samples in the FIFO, or only a portion of it. At high sample rates, it is recommended that only a portion of the available samples are read on an A_FULL interrupt, to ensure that FIFO reading does not happen when the next sample conversion is in progress. The remaining samples will be read on the next interrupt.

If the A_FULL interrupt is not enabled, the Application Processor has to read the FIFO in polling mode. In this mode the Application Processor has to read the FIFO_WR_PTR and FIFO_RD_PTR registers to calculate the number of samples available in the FIFO, and then decide how many samples to read. However, polling mode is not recommended, because in this mode an interface transaction will inevitably overlap an optical sample, potentially adding noise to the optical data. Because of this concern, the interface transaction should occur during the dead time between optical samples to avoid adding additional noise.

FIFO_RO (FIFO Rollover)

The FIFO_RO bit in the FIFO_Configuration register (0x08) 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. If FIFO_RO is not set, the new sample is dropped and the FIFO is not updated.

A_FULL_TYPE

The A_FULL_TYPE bit defines the behavior of the A_FULL interrupt. If the A_FULL_TYPE bit is set low, the A_FULL interrupt gets asserted when the A_FULL condition is detected and cleared by status register read, but reasserts for every sample if the A_FULL condition persists.

If A_FULL_TYPE bit is set high, the 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_STAT_CLR

The FIFO_STAT_CLR bit defines whether the A-FULL interrupt should get cleared by FIFO_DATA register read. If FIFO_STAT_CLR is set low, A_FULL and DATA_RDY interrupts do not get cleared by FIFO_DATA register read but get cleared by status register read. If FIFO_STAT_CLR is set high, A_FULL and DATA_RDY interrupts get cleared by a FIFO_DATA register read or a status register read.

Optical Timing

The AFE can be configured to make a variety of measurements which involves the following options:

- LED1
- LED2
- LED1 + LED2
- Direct Ambient Measurement

For more details on the available modes, please refer to [FIFO Configuration](#) section.

The “LED Ambient Sample” is integrated without turning on the LED, while “LED Exposure Sample” is integrated with LED illumination driven by the on-chip LED driver. Each “LED Exposure Sample” output is then compensated by the “LED Ambient Sample” at the front-end before the ADC conversion. The final FIFO exposure value for each LED mode represents an ambient corrected LED exposure signal.

The controller is also configurable to measure direct ambient level for every exposure sample. The direct ambient measurement can be used to adjust the LED drive level to compensate for increased noise levels when high interfering ambient signals are present.

The following optical timing diagrams illustrate the possible measurement configurations.

Sequential LED1 and LED2 Pulsing with Direct Ambient Sampling

The optical timing diagram in [Figure 5](#) illustrates the optical timing when both LED1 and LED2 are enabled to pulse sequentially followed by a direct ambient measurement. This timing mode is an example of when measuring SpO₂ with IR and red LEDs. The converted values of the optical measurements made by each LED followed by the converted direct ambient value will appear successively in the FIFO.

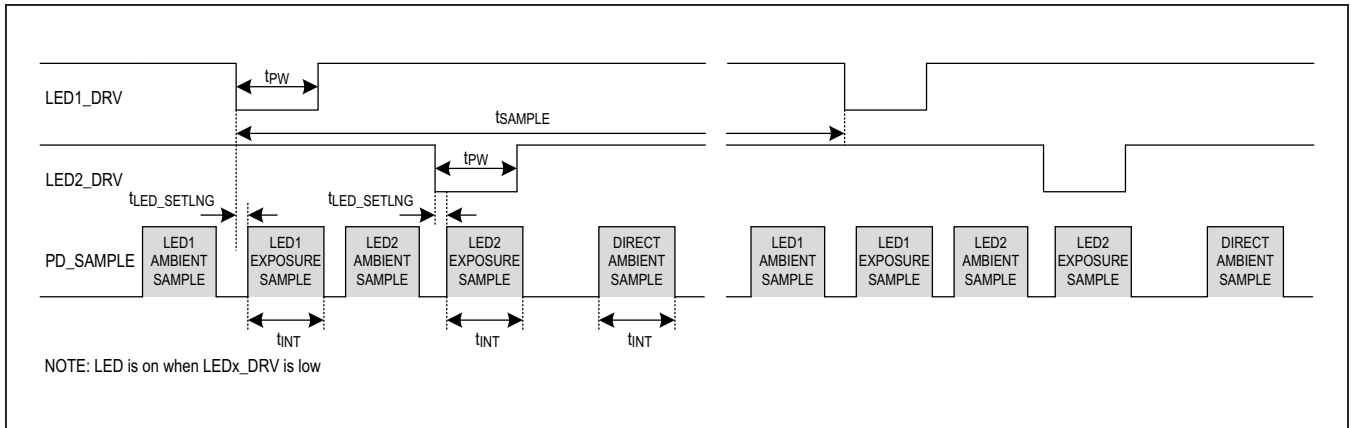


Figure 5. Timing for LED1 and LED2 Firing with Direct Ambient Sampling

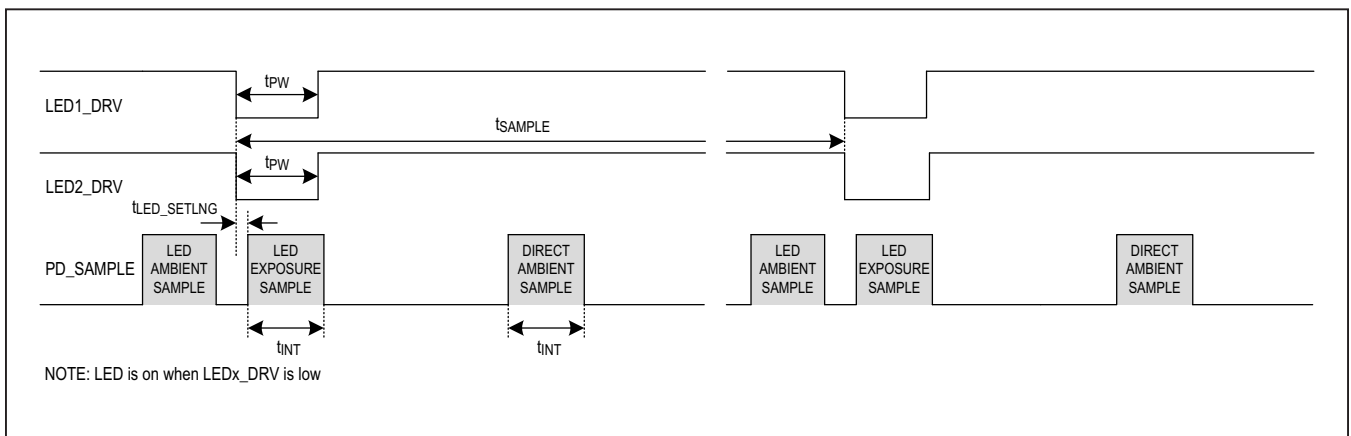


Figure 6. Timing for Dual LED Pulsing with Direct Ambient Sampling

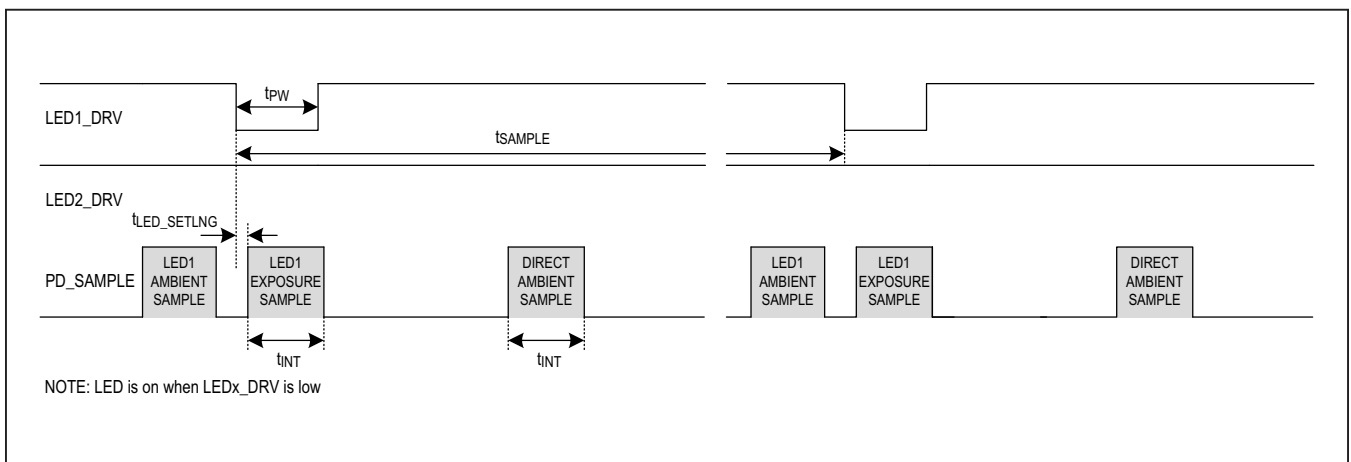


Figure 7. Timing for LED1 Pulsing with Direct Ambient Sampling

Dual LED Pulsing with Direct Ambient Sampling

The optical timing diagram in [Figure 6](#) represents both LED1 and LED2 pulsing simultaneously with direct ambient sampling enabled. This timing mode would be used when heart rate is being measured with two green LEDs. In this mode, a single optical sampled value followed by the ambient sampled value will appear in successive the FIFO locations.

LED1 Pulsing with Direct Ambient Sampling

The optical timing diagram in [Figure 7](#) represents only LED1 pulsing during the data sampling time with direct ambient sampling enabled. This timing mode would be used when heart rate is being measured with a single green LED. In this mode a single optical sampled value followed by the ambient sampled value will appear successively in the FIFO.

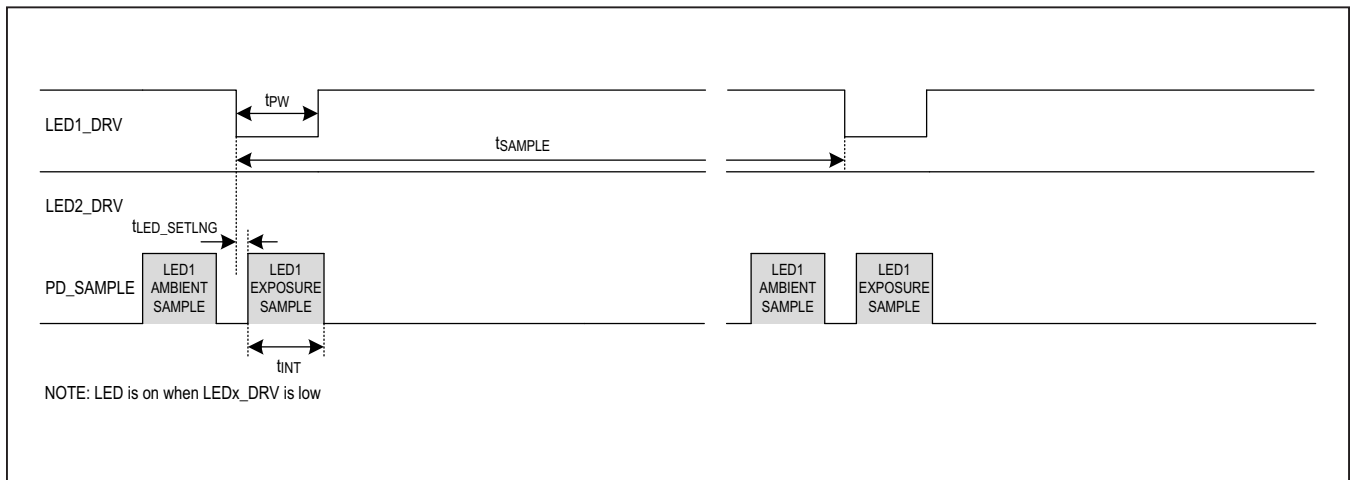


Figure 8: Timing for LED1 Pulsing with No Ambient Sampling

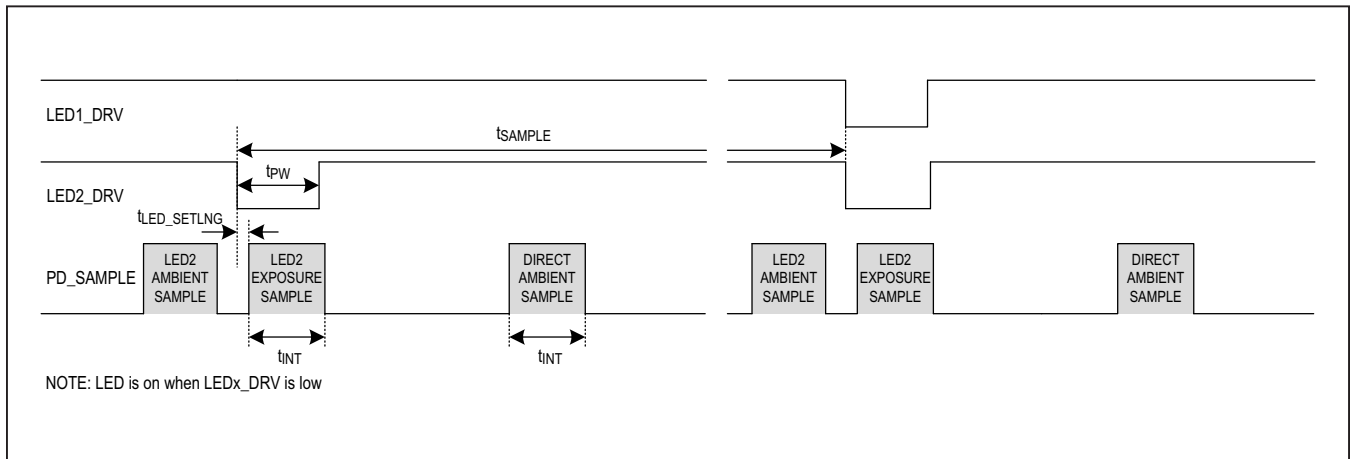


Figure 9: Timing for LED2 Pulsing with Direct Ambient Sampling

LED1 Pulsing with No Ambient Sampling

The optical timing diagram in [Figure 8](#) represents only LED1 pulsing during the data sampling time with no direct ambient sampling enabled. This timing mode would be used when heart rate is being measured with a single green LED. In this mode a single optical sampled value will appear successively in the FIFO.

LED2 Pulsing with Direct Ambient Sampling

The optical timing diagram in [Figure 9](#) represents only LED2 firing during the data sampling time with direct

ambient sampling enabled. This timing mode would be used when heart rate is being measured with a single green LED. In this mode a single optical sampled value followed by the ambient sampled value will appear successively in the FIFO.

LED2 Pulsing with No Ambient Sampling

The optical timing diagram in [Figure 10](#) represents only LED2 firing during the data sampling time with no direct ambient sampling enabled. This timing mode would be used when heart rates is being measured with a single

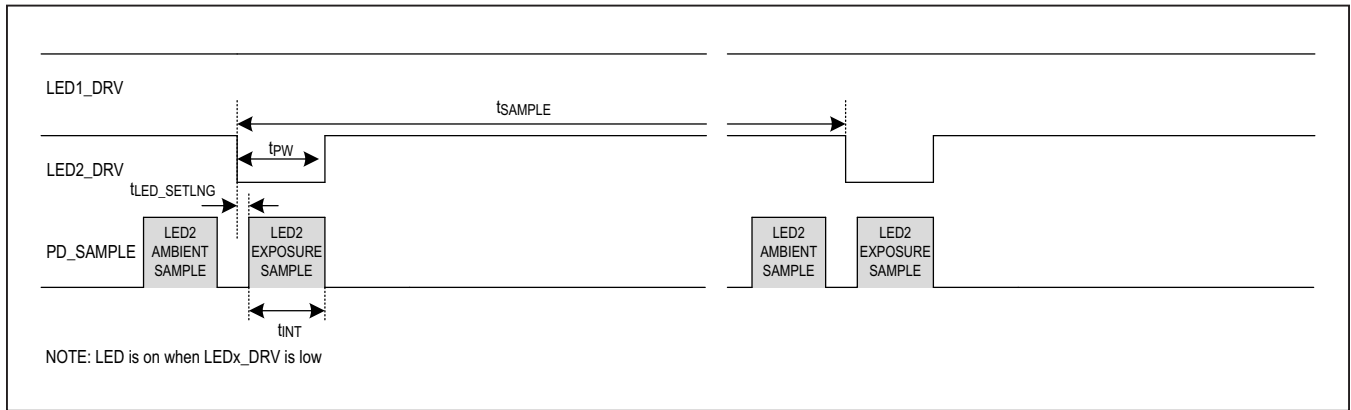


Figure 10: Timing for LED2 Pulsing with No Ambient Sampling

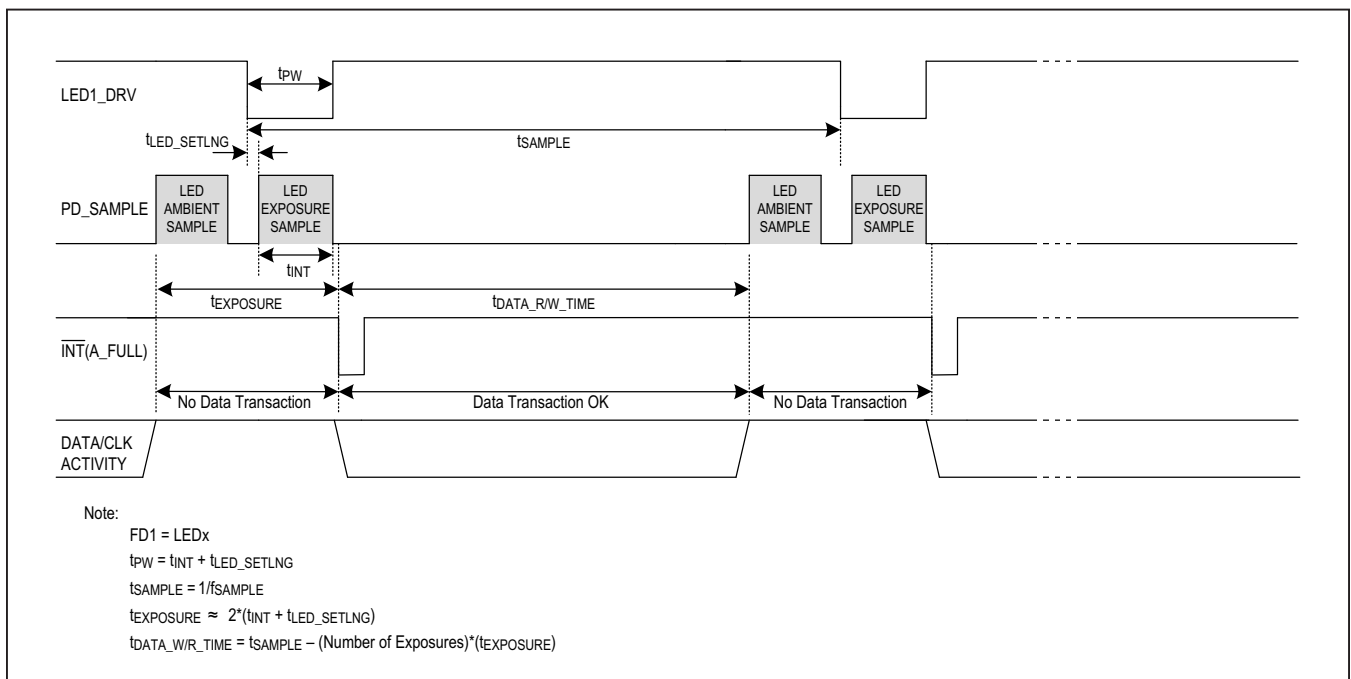


Figure 11. Readout Window for FIFO Read

green LED. In this mode, a single optical sampled value will appear successively in the FIFO.

FIFO Data Read Synchronization

Activity on the interface pins can bounce the on-chip GND potential, disturbing an optical sample, resulting in higher noise. Therefore, during a FIFO read event, it is recommended to time the FIFO read to occur between optical samples. This can be accomplished by reading the FIFO when the FIFO_A_FULL interrupt occurs and then limit the number of samples in the FIFO to those that can be read out during the time between samples. [Figure 11](#) illustrates how to place this read relative to the FIFO_A_FULL interrupt and the chosen sample rate, integration pulse width and LED settling time.

Proximity Function

The MAX30110 features proximity mode, which could significantly reduce energy consumption and extend battery life. In proximity mode, LED1 is pulsing at a lower current. When an object is present, the ADC count will exceed the preset threshold (PROX_INT_THRESH) and trigger the interrupt (PROX_INT). This functionality is only available when the FD1 timing slot is assigned to LED1. To use this function, it is necessary to set four register/bit fields correctly. These variables are the normal state LED current on LED1, LED1_PA (0x11), the proximity LED current, LED_PILOT_PA (0x15), the threshold code, PROX_INT_THRESH (0x10) and the proximity mode enable bit (Interrupt Enable1 (0x02, bit 4). Note that the threshold value is the code in register PROX_INT_THRESH (0x10) times 2048.

If the proximity feature is enabled, it will be switched to proximity mode when the LED1 ADC count drops below the threshold code, PROX_INT_THRESH(0x10). At this point, the LED1 drive current will be set from LED1_PA(0x11) to LED_PILOT_PA(0x15). Note that the threshold value is the code in register PROX_INT_THRESH (0x10) times 2048. This drop in LED current should generate sufficient hysteresis to guarantee that the MAX30110 does not toggle back and forth between proximity and normal mode operation.

Once in proximity mode, the MAX30110 will return to normal operating mode when the ADC count generated by the current programmed into the LED_PILOT_PA (0x15) register passes above the threshold in the PROX_INT_THRESH (0x10) register. When this occurs the LED1 current will increase to the value assigned in LED1_PA (0x11) register, again providing sufficient hysteresis to guarantee a clean transition. Note that the threshold value is the code in register PROX_INT_THRESH (0x10) times 2048.

It is necessary to experiment with the specific optical geometry when configuring the proximity function. As a means of a starting point of this experimental work, it is recommended that the LED_PILOT_PA (0x15) register be set to about 1/10th the value of the LED1_PA (0x11) register. It is also recommended that the PROX_INT_THRESH (0x10) be set to roughly mid-way between the output code produced by the values of LED1_PA (0x11) and LED_PILOT_PA (0x15) when the optical device is correctly mounted to a subject.

Register Map

User Register Map

ADDRESS	NAME	MSB							LSB
STATUS									
0x00	Interrupt Status 1[7:0]	A_FULL	PPG_RDY	ALC_OVF	PROX_INT	LED_COMPB	-	-	PWR_RDY
0x01	Interrupt Status 2[7:0]	VDD_OOR	-	-	-	-	-	-	-
0x02	Interrupt Enable 1[7:0]	A_FULL_EN	PPG_RDY_EN	ALC_OVF_EN	PROX_INT_EN	LED_COMPB_EN	-	-	-
0x03	Interrupt Enable 2[7:0]	VDD_OOR_EN	-	-	-	-	-	-	-
FIFO									
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]	-	FIFO_STAT_CLR	A_FULL_TYPE	FIFO_RO	FIFO_A_FULL[3:0]			

User Register Map continued

FIFO DATA CONTROL									
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]				
SYSTEM CONTROL									
0x0D	System Control[7:0]	-	-	-	FCLK_CTRL	LP_MODE	FIFO_EN	SHDN	RESET
PPG CONFIGURATION									
0x0E	PPG Configuration 1[7:0]	PPG_ADC_RGE[1:0]		PPG_SR[3:0]			PPG_TINT[1:0]		
0x0F	PPG Configuration 2[7:0]	-	-	-	LED_SETLNG[1:0]	SMP_AVE[2:0]			
0x10	Prox Interrupt Threshold[7:0]	PROX_INT_THRESH[7:0]							
LED PULSE AMPLITUDE									
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[1:0]	LED1_RGE[1:0]		
0x15	LED PILOT PA[7:0]	PILOT_PA[7:0]							
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	LED_COMPB	-	-	PWR_RDY
Reset	0x0	0x0	0x0	0x0	0x0	-	-	0x0
Access Type	Read Only	Read Only	Read Only	Read Only	Read Only	-	-	Read Only

A_FULL

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that the FIFO buffer will overflow the threshold set by FIFO_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

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	In LED1 and/or LED2 modes, this interrupt triggers if PPG_RDY_EN is set to 1, when there is a new sample in the data FIFO. The interrupt is cleared by reading the Interrupt Status 1 register (0x00). It is also cleared by reading the FIFO_DATA register if A_FULL_CLR is set to 1.

ALC_OVF

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	This interrupt triggers when the ambient light cancellation function of the PPG 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

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that the proximity threshold has been crossed when in proximity mode. If PROX_INT is masked then the prox mode is disabled and the selected PPG mode begins immediately. This bit is cleared when the Interrupt Status 1 Register is read.

LED_COMPB

LED1 is not voltage compliant meaning that $V_{LED1} < 160\text{mV}$ while LED1 pulses. At the end of each sample, if the LED1 Driver is not voltage compliant, LED_COMPB interrupt is asserted if LED_COMPB_EN is set to 1. The interrupt is cleared when the status register is read.

VALUE	ENUMERATION	DECODE
0	COMPLIANT	LED1 driver voltage is in compliance
1	NOT_COMPLIANT	LED1 driver voltage is not in compliance

PWR_RDY

VALUE	ENUMERATION	DECODE
0	OFF	Normal Operation
1	ON	Indicates that VDD_DIG went below the 1.55V under voltage lockout threshold. This bit is also set upon 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	–	–	–	–	–	–	–
Reset	0x0	–	–	–	–	–	–	–
Access Type	Read Only	–	–	–	–	–	–	–

VDD_OOR

This is an indicator to check if the VDD_ANA supply voltage is within supported range.

VALUE	ENUMERATION	DECODE
0	OFF	VDD_ANA within supported range.
1	ON	Indicates 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 will continue to trigger as long as the VDD_ANA is out of range.