Measuring Blood Pressure, Heart Rate, and SpO_2 Using MAX32664D – A Quick Start Guide

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Abstract

The MAX32664D is a variant of the MAX32664 sensor-hub family, which is specifically targeted for finger-based measurement of blood pressure, heart rate, and SpO_2. Combined with the MAX30101 pulse oximetry and heart-rate monitor module and powered by Maxim's BPT algorithm, it provides sensors' raw data, as well as calculated systolic and diastolic blood pressure, SpO_2, and heart-rate data to a host device through its I^2C slave interface. This document provides step-by-step instructions that enable a user to communicate with the MAX32664D, and to calibrate, configure, and receive measurement and monitoring data.

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Introduction

The MAX32664D is a variant of the MAX32664 sensor-hub family that enables users to capture raw data, as well as calculated systolic and diastolic blood pressure (BP), SpO_2, and heart-rate data through finger contact. The part is preprogrammed with the firmware, drivers, and algorithm that are required to interface with the MAX30101 sensor device through an I^2C port. The I^2C slave interface is also used for establishing communication with a host microcontroller.

This document provides the instructions necessary to create a sensor data measurement solution with the MAX32664D based on the MAXREFDES220 reference design.

1 Architecture

A typical health-sensing design includes a host microcontroller that communicates with the MAX32664D through the I2C bus. Two GPIO pins are needed to control the reset and the startup in Application or Bootloader mode through the RSTN and multifunction I/O (MFIO) pins. An MFIO pin is also used in Application mode to interrupt the host for I2C communication. The MAX32664D interfaces with the MAX30101 optical sensor through a second I2C bus. The algorithm does not use accelerometer data. **Figure 1** shows the top-level architecture.

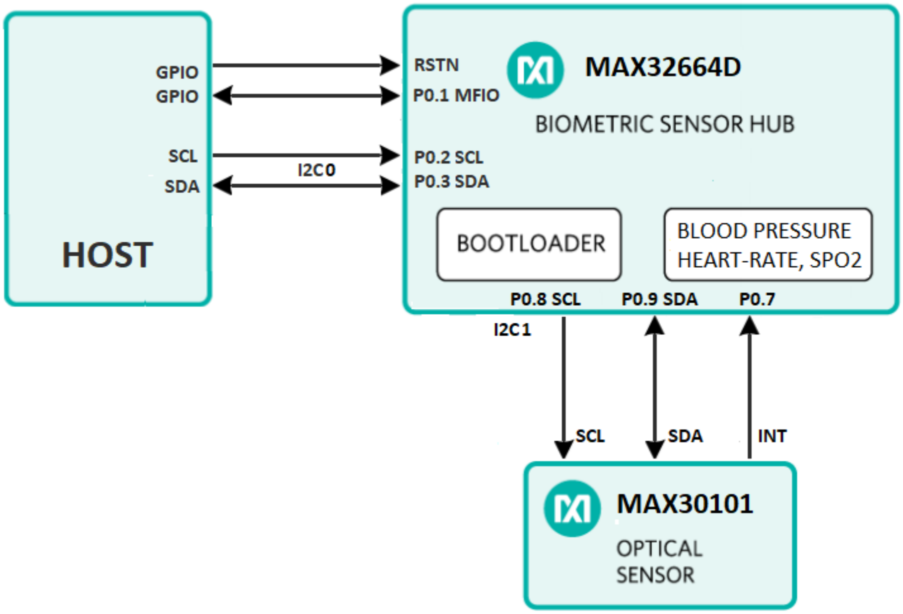

Figure 1. Architecture diagram for health-sensing applications.

1.1 Communicating with MAX32664D

A host should use the I2C bus to communicate with the MAX32664D (slave) using a series of commands. A generic write command includes the following fields:

```
Slave_WriteAddress(1 byte)|Command_Family(1 byte)|Command_Index(1
byte)|Value(multiple bytes)
```

A generic response includes the following fields:

```
Slave_ReadAddress(1 byte)|Status(1 byte)|Value(multiple bytes)
```

`Slave_WriteAddress` and `Slave_ReadAddress` are set to 0xAA and 0xAB respectively.

The read status byte is an indicator of success (0x00) or failure, as shown **Table 1**.

Table 1. Read Status Byte Value

STATUS BYTE VALUE	DESCRIPTION
0x00	SUCCESS. The write transaction was successful.
0x01	ERR_UNAVAIL_CMD. Illegal Family Byte and/or Command Byte was used.
0x02	ERR_UNAVAIL_FUNC. This function is not implemented.
0x03	ERR_DATA_FORMAT. Incorrect number of bytes sent for the requested Family Byte.
0x04	ERR_INPUT_VALUE. Illegal configuration value was attempted to be set.
0x05	ERR_TRY_AGAIN. Device is busy. Try again.
0x80	ERR_BTLDR_GENERAL. General error while receiving/flashing a page during the bootloader sequence.
0x81	ERR_BTLDR_CHECKSUM. Checksum error while decrypting/checking page data.
0x82	ERR_BTLDR_AUTH. Authorization error.
0x83	ERR_BTLDR_INVALID_APP. Application not valid.
0xFF	ERR_UNKNOWN. Unknown Error.

This document provides examples of commands for establishing communication with the MAX32664D. For a complete list of commands and instructions for the I2C interface, see the **MAX32664 User Guide**.

2 Calibration of SpO_2 and Blood Pressure Trending (BPT) Algorithm

2.1 Calibration of SpO_2 Coefficients for Final Product

Due to variations in the physical design and optical shield of the final product, a calibration procedure is required to be performed once in a controlled environment. This procedure is important to ensure the quality of SpO_2 calculation. This step is typically performed in a standard lab with a reference SpO_2 device to determine three calibration coefficients: A, B, and C. The details of the calibration procedure are described in the Maxim **Application Note 6845**.

Once three calibration coefficients are obtained, they need to be loaded to the MAX32664D every time prior to starting the algorithm. But first, they are required to be converted to 32-bit integer format using the following:

- A_{int32} = round (10^5 x a)
- B_{int32} = round (10^5 x b)
- C_{int32} = round (10^5 x c)

For example, the default measured calibration coefficients are:

- a = 1.5958422
- b = -34.659664
- c = 112.68987

They are sent to the MAX32664D in integer format after conversion:

- A_{int32} = round (10^5 x a) = 0x00026F60
- B_{int32} = round (10^5 x b) = 0xFFCB1D12
- C_{int32} = round (10^5 x c) = 0x00ABF37B

The calibration coefficients may be stored in the host flash separately and loaded to the MAX32664D after every reset.

In order to perform the SpO_2 calibration process, the BPT algorithm is started in Estimation mode, as shown in **Table 6**.

Table 4 shows the format of received samples. Typically, R values are needed for the calibration process, as described in Maxim **Application Note 6845**. Note that the algorithm will keep updating R values, even after progress has reached 100%.

2.2 Calibration of BPT Algorithm for a User

A calibration process is required for each user to tune the estimation algorithm. This step is typically done by first measuring subject's systolic and diastolic BP three times using a medically approved device. Next, these three values are provided to the MAX32664D as references and a calibration measurement is performed. This process takes about 1 minute. After the calibration is complete (progress is at 100% and status is 2, as shown in **Table 4**), a calibration vector is generated and stored internally in SRAM. The calibration information is valid as long as the MAX32664D has not restarted and the user has not changed. However, the host is recommended to read the calibration vector, tag and store it in memory (or flash) for a user, and reload it to the MAX32664D prior to future measurements.

The calibration procedure is needed once a month to ensure the accuracy of BP estimation for the current user. **Table 2** shows the sequence of commands for completing BPT calibration.

Table 2. Host Commands—BPT Calibration

	#	HOST COMMAND (HEX)	COMMAND DESCRIPTION	RESPONSE (HEX)
START ALGORITHM	Host initializes MAX32664D in Calibration mode:			
	1.1	AA 50 04 00 00 (if user does not take any BP medication) AA 50 04 00 01 (if user takes BP medication)	Set if the user is on blood pressure medication. THIS STEP IS NOT NEEDED IN FW VER. 40.2.2 AND LATER.	AB 00
	1.2	AA 50 04 05 00	Set if user is in Rest mode. THIS STEP IS NOT NEEDED IN FW VER. 40.2.2 AND LATER.	AB 00
	1.3	AA 50 04 04 5C C2 02 00 E0 7F 02 00 (example data and time)	Set data and time as two 32-bit numbers for YYMMDD and HHMMSS in little-endian format. Provided example is for date:180828, time:163808.	AB 00
	1.4	AA 50 04 01 78 7A 7D (example of three systolic BP references)	Set three systolic calibration values. Provided example is for 120, 122, and 125.	AB 00
	1.5	AA 50 04 02 50 51 52 (example of three diastolic BP references)	Set three diastolic calibration values. Provided example is for 80, 81, and 82.	AB 00
	1.6	Optional: Any other command to change the algorithm settings and configurations (**Table 3**) from default should appear here BEFORE enabling algorithm.		
	1.7	AA 10 00 03	Set output mode to sensor + algorithm data (streamed data will include PPG and algorithm data).	AB 00
	1.8	AA 10 01 0F	Set sensor hub interrupt threshold.	AB 00
	1.9	AA 44 03* 01	Enable AFE (e.g., MAX30101).	AB 00
	1.10	AA 52 04 01	Enable BPT algorithm in Calibration mode.	AB 00
	1.11	Wait for 100ms before sending the next command. Any command to change sensor registers should appear AFTER enabling algorithm or they will be overwritten.		
READING SAMPLES	Host reads samples upon receiving MFIO interrupt by MAX32664D. For BPT calibration, repeat until BPT status is 2 and progress is at 100%. See **Table 4**.			
	2.1	AA 00 00	Read sensor hub status byte: Bit 0: Sensor comm error Bits 1 and 2: Reserved Bit 3: FIFO filled to threshold (DataRdyInt) Bit 4: Output FIFO overflow (FifoOutOvrInt) Bit 5: Input FIFO overflow (FifoInOverInt) Bit 6: Sensor hub busy (DevBusy) Bit 7: Reserved If DataRdyInt is set, proceed to next step.	AB 00 08
	2.2	AA 12 00	Get the number of samples (nn) in the FIFO.	AB 00 nn
	2.3	AA 12 01	Read the data stored in the FIFO; nn samples (23 bytes each) will be read. The format of samples is shown in **Table 4**.	AB 00 data_for_nn_samples
STOP	Host ends the procedure:			
	3.1	AA 44 03* 00	Disable AFE (e.g., MAX30101)*.	AB 00
	3.2	AA 52 04 00	Disable BPT algorithm.	AB 00
	3.3	AA 51 04 03	Read calibration data (824 bytes).	AB 00 [calibration vector]

**Provided indexes are examples for sensors such as the MAX30101 AFE.*

2.3 Algorithm Settings and Configurations

Table 3 shows the settings that are available for the BPT algorithm. To update the algorithm settings, be sure to send the appropriate commands BEFORE enabling the algorithm, as shown in **Table 2**.

Table 3. Configurations and Settings—BPT

FAMILY BYTE	ALGORITHM INDEX	CONFIGURATION INDEX	DESCRIPTION	DEFAULT VALUE
0x50 for write 0x51 for read	0x04	0x00	Blood pressure medication: Set to 1 if the user is on blood pressure medication. Write only. NOT SUPPORTED IN FW VER. 40.2.2 AND LATER.	0x00
		0x01	Three systolic BP calibration values (8-bit unsigned). Write only.	0x78, 0x78, 0x78
		0x02	Three diastolic BP calibration values (8-bit unsigned). Write only.	0x50, 0x50, 0x50
		0x03	BP calibration data. Read 824 bytes of BP calibration data after calibration is complete and store in host memory. Write the stored calibration data prior to running the BPT algorithm.	824 bytes of zeros
		0x04	Set the date and time as two 32-bit unsigned values (little-endian format) in following order: Value 1: Date in YYMMDD decimal form Value 2: Time in HHMMSS decimal form Write only.	0x85, 0xBF, 0x02, 0x00 0x7C, 0xD9, 0x01, 0x00 for date = 180101, time = 12:12:12
		0x05	Non-resting estimation: Set 0 if user is resetting, otherwise 1. NOT SUPPORTED IN FW VER. 40.2.2 AND LATER.	0x0

		0x06	SpO_2 calibration coefficients x 100,000 (12 bytes comprised of three 32-bit signed values)	A = 1.5958422 (0x00026f60)
				B = -34.659664 (0xffcb1d12)
				C = 112.68987 (0x00abf37b)

Table 4. Format of Received Samples—BPT Algorithm

DATA SOURCE	BYTE INDEX	DATA ITEM	NUMBER OF BYTES (MSB FIRST)	DESCRIPTION
MAX30101 (12 Bytes)	0	LED1	3	IR counter
	3	LED2	3	Red counter
	6	LED3	3	N/A
	9	LED4	3	N/A
BPT Algorithm (11 Bytes)	12	BP status	1	Status: No signal: 0 Estimation in progress: 1 Success: 2 Weak signal: 3 Motion: 4 Estimation failure: 5 Calibration partially done: 6
	13	Progress	1	% complete
	14	Heart rate	2	10x heart-rate value
	16	Systolic blood pressure	1	Estimate systolic blood pressure
	17	Diastolic blood pressure	1	Estimate diastolic blood pressure
	18	SpO_2	2	10x SpO_2 value
	20	R	2	1000x actual R value
	22	HR_AboveResting	1	0 - Resting flag, HR ≤95bpm 1 - Non-resting flag, HR > 95bpm

3 Measuring BPT, SpO_2, and Heart Rate on Finger

3.1 Raw Data Collection Mode

For hardware testing purposes, the user may choose to start the MAX32664D to collect raw PPG samples.

3.1.1 Raw Data Collection in Algorithm Mode

In Algorithm mode, AGC may be turned off to collect raw PPG data, as shown in step 1.6 in **Table 5**. In this case, LED currents will not be adjusted automatically; the BPT, SpO_2 and heart-rate measurement algorithm may not converge and should be discarded. Although the algorithm is running, it will not affect the PPG samples. If the reported PPG data is saturated, you can reduce the LED currents as shown. Note that updating MAX30101 registers should appear AFTER enabling the algorithm and the MAX30101, or they will be overwritten during initialization. By setting the output mode to sensor data in step 1.2, only the 12-byte PPG data of the MAX30101 will be reported in received samples.

Table 5. Host Commands—BPT Raw Data Collection

	#	HOST COMMAND (HEX)	COMMAND DESCRIPTION	RESPONSE (HEX)
START ALGORITHM	Host initializes the MAX32664D in Estimation mode:			
	1.1	Optional: Any other command to change the algorithm settings and configurations (**Table 3**) from default should appear here BEFORE enabling algorithm.		
	1.2	AA 10 00 01	Set output mode to sensor data (streamed data will include only PPG data).	AB 00
	1.3	AA 10 01 0F	Set sensor hub interrupt threshold.	AB 00
	1.4	AA 44 03* 01	Enable AFE (e.g., MAX30101).	AB 00
	1.5	AA 52 04 02	Enable BPT algorithm in Estimation mode.	AB 00
	1.6	AA 52 00 00	Disable AGC.	AB 00
	1.7	Wait for 100ms before sending next command. Any command to change sensor registers should appear AFTER enabling algorithm or they will be overwritten.		
	1.8	AA 40 03 0C [7F]	Set MAX30101 LED1 (red) current to half of full scale. Reduce [7F] if signal is saturated.	AB 00
	1.9	AA 40 03 0D [7F]	Set MAX30101 LED2 (IR) current to half of full scale. Reduce [7F] if signal is saturated.	AB 00
READING SAMPLES	Host reads samples upon receiving MFIO interrupt by the MAX32664D. For BPT raw data, repeat as needed to collect PPG counters.			
	2.1	AA 00 00	Read sensor hub status byte: Bit 0: Sensor comm error Bits 1 and 2: Reserved Bit 3: FIFO Filled to threshold (DataRdyInt) Bit 4: Output FIFO overflow (FifoOutOvrInt) Bit 5: Input FIFO overflow (FifoInOverInt) Bit 6: Sensor hub busy (DevBusy) Bit 7: Reserved If DataRdyInt is set, proceed to next step.	AB 00 08
	2.2	AA 12 00	Get the number of samples (nn) in the FIFO.	AB 00 nn
	2.3	AA 12 01	Read the data stored in the FIFO; nn samples (12 bytes each) will be read. The format of samples is shown in **Table 4**.	AB 00 data_for_nn_samples
STOP	Host ends the procedure:			
	3.1	AA 44 03* 00	Disable AFE (e.g., MAX30101).*	AB 00
	3.2	AA 52 04 00	Disable BPT algorithm.	AB 00

**Provided indexes are example for sensors such as the MAX30101 AFE.*

3.2 Algorithm Mode: BPT, SpO_2 and Heart-Rate Estimation

Once calibration of SpO_2 coefficients and BPT is complete, the algorithm can estimate BP, SpO_2 and heart rate. Table 6 shows the list of commands to start the algorithm in Estimation mode.

Table 6. Host Commands—BPT Estimation

	#	HOST COMMAND (HEX)	COMMAND DESCRIPTION	RESPONSE (HEX)
START ALGORITHM	Host initializes the MAX32664D in Estimation mode:			
	1.1	AA 50 04 03 [calibration vector]	Load 824 bytes of BPT calibration vector data as derived in the last step in **Table 2**.	AB 00
	1.2	AA 50 04 00 00 (if user does not take any BP medication) AA 50 04 00 01 (if user takes BP medication)	Set if the user is on BP medication. THIS STEP IS NOT NEEDED IN FW VER. 40.2.2 AND LATER.	AB 00
	1.3	AA 50 04 05 00	Set user in Reset mode. THIS STEP IS NOT NEEDED IN FW VER. 40.2.2 AND LATER.	AB 00
	1.4	AA 50 04 04 5C C2 02 00 E0 7F 02 00 (example data and time)	Set data and time as two 32-bit numbers for YYMMDD and HHMMSS in little-endian format. Provided example is for date:180828, time:163808.	AB 00
	1.5	AA 50 04 06 00 02 6F 60 (example for A) FF CB 1D 12 (example for B) 00 AB F3 7B (example for C)	Set SpO_2 calibration coefficients as described in the document. Provided example for: A = 1.5958422, B = -34.659664, C = 112.68987.	AB 00
	1.6	Optional: Any other command to change the algorithm settings and configurations (**Table 3**) from default should appear here BEFORE enabling algorithm.		
	1.7	AA 10 00 03	Set output mode to sensor + algorithm data (streamed data will include PPG and algorithm data).	AB 00
	1.8	AA 10 01 0F	Set sensor hub interrupt threshold.	AB 00
	1.9	AA 52 00 01	Enable AGC.	AB 00
	1.10	AA 44 03* 01	Enable AFE (e.g., MAX30101).	AB 00
	1.11	AA 52 04 02	Enable BPT algorithm in Estimation mode.	AB 00
	1.12	Wait for 100ms before sending next command. Any command to change sensor registers should appear AFTER enabling algorithm or they will be overwritten.		
READING SAMPLES	Host reads samples upon receiving MFIO interrupt by the MAX32664D. For BPT estimation, repeat until BPT status is 2 and progress is at 100%. For SpO_2 calibration, continue as needed to capture R value. See **Table 4**.			
	2.1	AA 00 00	Read sensor hub status byte: Bit 0: Sensor comm error Bits 1 and 2: Reserved Bit 3: FIFO filled to threshold (DataRdyInt) Bit 4: Output FIFO overflow (FifoOutOvrInt) Bit 5: Input FIFO overflow (FifoInOverInt) Bit 6: Sensor hub busy (DevBusy) Bit 7: Reserved If DataRdyInt is set, proceed to next step.	AB 00 08
	2.2	AA 12 00	Get the number of samples (nn) in the FIFO.	AB 00 nn
	2.3	AA 12 01	Read the data stored in the FIFO; nn samples (23 bytes each) will be read. The format of samples is shown in **Table 4**.	AB 00 data_for_ nn_samples
STOP	Host ends the procedure:			
	3.1	AA 44 03* 00	Disable AFE (e.g., MAX30101).*	AB 00
	3.2	AA 52 04 00	Disable BPT algorithm.	AB 00
	3.3	AA 52 00 00	Disable AGC.	AB 00

**Provided indexes are example for sensors such as the MAX30101 AFE.*

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	4/19	Initial release	—
1	9/19	Updated **Table 4** byte index 20 description	9