DATA PROTOCOL
IOLab

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Indesign, LLC
8225 E 56th Street
Indianapolis, IN 46216
Phone: 317.377.5450
FAX: 317.377.5455
http://www.indesign-llc.com

Document Change Notes

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2	Add sections on sensor data format and make corrections	7/24/2012	Shaun Greene
3	Add overflow bit to payload section and add more sensor data format definitions Add sensor data format for encoder and force gauge Change the sample rate options for some sensors Add packet configuration definition	8/8/2012	Shaun Greene
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5	Changed Sensor IDs to hex, updated the sensor id and key-value designators for the headers, added details for the output configuration and the calibration payload, and sensor data information for the microphone, ambient light, ECG, battery, high gain input, digital inputs, and analog header inputs, and removed the ultrasonic sensor	9/21/2012	Ellen Taylor, Shaun Greene
6	Updated the sample rates for the sensors with an analog interface, added extended range to the buzzer pitches	10/04/2012	Ellen Taylor, Shaun Greene
7	Added extended buzzer range, added 800Hz high speed sampling, added new thermometer sensor. NOT BACKWARD COMPATIBLE with previous versions for data rate of analog sensors or buzzer frequencies	04/11/2013	Shaun Greene
8	Update typos and errors	4/17/2013	Shaun Greene Fritz Kiffmeyer
9	Added the 6-Channel ECG sensor	10/27/2014	Shaun Greene

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1.0 INTRODUCTION

The IOLab system is a "low-cost, easy-to-use, all-purpose handheld device that performs a myriad of functions for both introductory and advanced physics courses."[1] The system consists of a USB dongle (referred to as "dongle") that wirelessly connects to one or two handheld devices (referred to as "remote") to transmit sensor information to a PC for processing and display of the data.

The dongle consists of a single microcontroller that will interface between the RF radio and the USB connection to the PC. The remote consists of two microcontrollers: a sensor microcontroller to interface to the sensors and a radio microcontroller to manage the radio communication.

1.1 PURPOSE

This document details the data protocol that is used in the different microcontrollers and the PC for the IOLab system. This data protocol covers the format of the payload used in the different communication protocols used in the IOLab system.

1.2 DEFINITIONS

- **ACK – acknowledgement**. A packet sent to acknowledge the receipt of a packet.
- **ADC – analog to digital converter**. A device that converts a continuous time analog signal to a discrete time digital representation.
- **ASCII – American Standard Code for Information Interchange**. A character encoding scheme based on the English alphabet using codes to represent text.
- **d, dd, 0xdd – don't care.** When used in place of a number it means that the actual value of the number doesn't matter because it is never used, but a number must still be present.
- **DCS – data checksum**. A value computed from a block of digital data for the purpose of detecting accidental errors that occurred during transmission or storage.
- **EOP – end of packet byte**. A specific byte or character used to identify the end of a packet in serial communication.
- **GPIO – general purpose input/output**. Term given to microcontroller connections that can be used for digital input or output.
- **HCS – header checksum**. A data checksum computed on just the packet header, not the packet payload.
- **LSB – least significant byte.** The byte position of a number or byte-array with the lowest value. Also refers to the right most byte when using positional notation.
- **lsb – least significant bit.** The bit position of a binary integer giving the units value determining if the number is even or odd. Also the right-most bit when using positional notation.

[1] Quoted from an article by Liz Ahlberg, Physical Sciences Editor on October 20, 2011 found at http://news.illinois.edu/ii/11/1020/physics_device.html

- **MSB –most significant byte.** The byte position of a number or byte-array with the highest value. Also refers to the left most byte when using positional notation.
- **msb –most significant bit.** The bit position of a binary integer having the greatest value or represents the sign of the number (positive or negative) in two's compliment signed integers. Also the left-most bit when using positional notation.
- **NAK – negative acknowledgement**. A packet sent as a negative response to the receipt of a packet, or when the receiver is not ready or when the packet data was corrupted.
- **n, nn, 0xnn** – any number. When used in place of a number it means that the actual value of the number is unknown but still important and does get used.
- **PC – personal computer.**
- **RF – radio frequency**. A rate of oscillation in the range of 3kHz to 300GHz which corresponds to the frequency of radio waves and the alternating currents which carry radio signals.
- **SOP – start of packet byte**. A specific byte or character used to identify the start of a packet in serial communications.

1.3 References

- Product Requirements, IOLab System, 1814S01, Revision P4.
- Wireless Protocol, IOLab, 1814E11, Revision 2.
- USB Interface Specification, IOLab, 1814F03, Revision 1
- SPI Communication Protocol, IOLab, 1814F04, Revision P2.

2.0 COMMON STRUCTURES

Some structures appear in multiple places in different protocols. The structures discussed in this section can be used in more than one protocol. By using the same structures in multiple protocols throughout the system the communication will be more efficient because each protocol does not need to translate the data to the next protocol.

2.1 DATA PACKET SENSOR PAYLOAD

The data packet sensor payload is used when sending sensor data samples. The payload of sensor data will always a fixed size, but not all of it is valid- there could be padded bytes at the end to make the payload length equal to the necessary number of bytes.

The sensor data payload is structured as shown here:

# of sensors	sensor id A	length A	data A_0	data A_1	…	data A_n	sensor id B	length B	data B_0	data B_1	…	data B_n	…

Figure 1: Sensor Data Payload Structure

- # of sensors – this byte indicates the number of sensors that are included in this payload.
- Sensor ID A –this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- Length A – this byte contains the number of bytes of meaningful data that belong to the previous sensor ID.
- Data A_n – these bytes are the actual sensor data in the order which they were recorded. See section 4.0 Sensor Data Format for information about how the data for a specific sensor are formatted.
- Sensor ID B – this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- Length B – this byte contains the number of bytes of meaningful data that belong to the previous sensor ID.
- Data B_n – these bytes are the actual sensor data in the order which they were recorded. See section 4.0 Sensor Data Format for information about how the data for a specific sensor are formatted.

2.1.1 Sensor ID Format

The sensor ID is a 1 byte value that represents the identifier number assigned to the sensor or device in the IOLab system. See section 3.0 Sensor IDs & Key-Value Pairs for definitions of specific sensor IDs.

bit #	7	6	5	4	3	2	1	0
name	OVF	ID						
value	0 or 1	unsigned integer between 1 and 127						

Figure 2: Sensor ID Byte Definition

- OVF – Overflow Bit

  0 – Indicates that overflow did not occur (no data was lost) for the included data

  1 – Indicates that data overflowed in the system and that there were samples collected that did not fit into this message and were lost.

- ID – ID value

  Represented as a 7-bit unsigned integer

2.1.2 Sensor Data Byte Allocations

When sensors are configured, space in the payload buffer will be allocated for the worst case amount of data that needs to be stored for a specific sensor configuration. See Section 2.2 Packet Configuration Payload for more information about pre-allocated buffer configurations.

2.1.3 Single Sensor Data Example – Completely Full Data

byte #	0	1	2	3	4	5	6	7	8	9
value	0x01	0x02	0x2F (47)	0x01	0x02	0x03	0x04	0x05	0x06	0x07
meaning	# sensors	sensor id	data length	data 0	data 1	data 2	data 3	data 4	data 5	data 6

byte #	10	11	12	13	14	15	16	17	18	19
value	0x08	0x09	0x0A	0x0B	0x0C	0x0D	0x0E	0x0F	0x10	0x11
meaning	data 7	data 8	data 9	data 10	data 11	data 12	data 13	data 14	data 15	data 16

byte #	20	21	22	23	24	25	26	27	28	29
value	0x12	0x13	0x14	0x15	0x16	0x17	0x18	0x19	0x1A	0x1B
meaning	data 17	data 18	data 19	data 20	data 21	data 22	data 23	data 24	data 25	data 26

byte #	30	31	32	33	34	35	36	37	38	39
value	0x1C	0x1D	0x1E	0x1F	0x20	0x1F	0x1E	0x1D	0x1C	0x1B
meaning	data 27	data 28	data 29	data 30	data 31	data 32	data 33	data 34	data 35	data 36

byte #	40	41	42	43	44	45	46	47	48	49
value	0x1A	0x19	0x18	0x17	0x16	0x15	0x14	0x13	0x12	0x11
meaning	data 37	data 38	data 39	data 40	data 41	data 42	data 43	data 44	data 45	data 46

Figure 3: Single Sensor Data Example - Completely Full Data

2.1.4 Single Sensor Data Example – Partially Full Data

byte #	0	1	2	3	4	5	6	7	8	9
value	0x01	0x02	0x0A (10)	0x01	0x02	0x03	0x04	0x05	0x06	0x07
meaning	# sensors	sensor id	data length	data 0	data 1	data 2	data 3	data 4	data 5	data 6

byte #	10	11	12	13	14	15	16	17	18	19
value	0x08	0x09	0x0A	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	data 7	data 8	data 9	dd	dd	dd	dd	dd	dd	dd

byte #	20	21	22	23	24	25	26	27	28	29
value	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	dd	dd	dd	dd	dd	dd	dd	dd	dd	dd

byte #	30	31	32	33	34	35	36	37	38	39
value	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	dd	dd	dd	dd	dd	dd	dd	dd	dd	dd

byte #	40	41	42	43	44	45	46	47	48	49
value	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	dd	dd	dd	dd	dd	dd	dd	dd	dd	dd

Figure 4: Single Sensor Data Example - Partially Full Data

2.1.5 Two Sensor Data Example – Partially Full Data

byte #	0	1	2	3	4	5	6	7	8	9
value	0x02	0x02	0x0A (10)	0x01	0x02	0x03	0x04	0x05	0x06	0x07
meaning	# sensors	sensor id	data length	data 0	data 1	data 2	data 3	data 4	data 5	data 6

byte #	10	11	12	13	14	15	16	17	18	19
value	0x08	0x09	0x0A	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	data 7	data 8	data 9	data 10	data 11	data 12	data 13	data 14	data 15	data 16

byte #	20	21	22	23	24	25	26	27	28	29
value	0xdd	0xdd	0xdd	0x03	0x05	0xFF	0xFE	0xFD	0xFC	0xFB
meaning	data 17	data 18	data 19	sensor id	data length	data 0	data 1	data 2	data 3	data 4

byte #	30	31	32	33	34	35	36	37	38	39
value	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	data 5	data 6	data 7	data 8	data 9	data 10	data 11	data 12	data 13	data 14

byte #	40	41	42	43	44	45	46	47	48	49
value	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd	0xdd
meaning	data 15	data 16	data 17	data 18	data 19	data 20	data 21	data 22	data 23	data 24

Figure 5: Two Sensor Data Example - Partially Full Data

2.2 Packet Configuration Payload

The get packet configuration payload is used to get the format of the Data Packet Sensor Payload. This payload explains how many bytes of the data packet are allocated for which sensors.

The packet configuration payload is structured as shown here:

# of sensors	sensor id A	length A	sensor id B	length B	…

Figure 6: Packet Configuration Payload Structure

- # of sensors – this byte indicates the number of sensors that are included in this payload.
- Sensor ID A – this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- Length A – this byte contains the fixed number of bytes of the data payload that are allocated for the previous sensor ID.
- Sensor ID B – this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- Length B – this byte contains the fixed number of bytes of the data payload that are allocated for the previous sensor ID.

2.2.1 Packet Configuration Example – Two Sensors

This example demonstrates what the packet configuration would return if the system was configured to give the data packet from Section 2.1.5 Two Sensor Data Example – Partially Full Data.

byte #	0	1	2	3	4
value	0x02	0x02	0x14 (20)	0x03	0x19 (25)
meaning	# sensors	sensor id	data length	sensor id	data length

Figure 7: Packet Configuration Example, Two Sensors

2.2.2 Packet Configuration Example – Six Sensors

This example demonstrates what the packet configuration would return when there are 6 active sensors with space allocated for each.

byte #	0	1	2	3	4	5	6	7	8
value	0x06	0x02	0x0C (12)	0x01	0x0C (12)	0x09	0x08	0x08	0x04
meaning	# sensors	sensor id	data length	sensor id	data length	sensor id	data length	sensor id	data length

byte #	9	10	11	12
value	0x03	0x0C (12)	0x04	0x08
meaning	sensor id	data length	sensor id	data length

Figure 8: Packet Configuration Example, Six Sensors

2.3 OUTPUT CONFIGURATION PAYLOAD

The output configuration payload is used to send configuration information to the sensors that can support an output (as opposed to the input that most sensors use to gather data). The output configuration uses the settings from section 3.0 Sensor IDs & Key-Value Pairs. Look for the “Config Type” column to include “Output” for the possible key-value pairs that are allowed for an output configuration payload.

The output configuration payload is structured as shown in Figure 9 below.

# of pairs	sensor id A	key-value A	sensor id B	key-value B	…

Figure 9

# of pairs	sensor id A	key-value A	sensor id B	key-value B	…

Figure 9: Output Configuration Payload Structure

- # of pairs- this byte indicates the number of sensor id + key-value pairs that are included in the command.
- Sensor ID A – this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- Key-Value A – this byte contains combined key and value setting for the specified sensor. See **Error! Reference source not found.** for valid values.
- Sensor ID B – this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- Key-Value B – this byte contains combined key and value setting for the specified sensor. See **Error! Reference source not found.** for valid values.

***NOTE:* When sending multiple settings for a single sensor, always send the “enable” last in the list of settings.**

2.3.1 Output Configuration Example – One Sensor, One Setting

This example demonstrates what the payload would look like to set a specific key-value for a specific sensor.

byte #	0	1	2
value	0x01	0x18	0x01
meaning	# pairs	sensor id	key-value

Figure 10: Output Configuration Example - One Sensor, One Setting

2.3.2 Output Configuration Example – One Sensor, Multiple Settings

This example demonstrates what the payload would look like to set multiple key-values for a single sensor.

byte #	0	1	2	3	4
value	0x02	0x18	0x25	0x18	0x01
meaning	# pairs	sensor id	key-value	sensor id	key-value

Figure 11: Output Configuration Example - One Sensor, Multiple Settings

2.3.3 Output Configuration Example – Multiple Sensors, Multiple Settings

This example demonstrates what the payload would look like to set multiple key-values for multiple sensors.

byte #	0	1	2	3	4	5	6	7	8
value	0x04	0x18	0x25	0x18	0x01	0x19	0x29	0x19	0x01
meaning	# pairs	sensor id	key-value	sensor id	key-value	sensor id	key-value	sensor id	key-value

Figure 12: Output Configuration, Multiple Sensors, Multiple Settings

2.4 Sensor Calibration Payload

The sensor calibration payload is used to transfer as sensor's calibration information. The structure of the actual calibration data is discussed in the sensor specific data section 4.0 Sensor Data Format. The sensor calibration payload is structured as shown in Figure 13 below.

sensor id	# cal bytes	cal data 1	cal data 2	…

Figure 13: Sensor Calibration Payload Structure

sensor id	# cal bytes	cal data 1	cal data 2	…

Figure 13: Sensor Calibration Payload Structure

- Sensor ID – this byte is the ID number assigned to the sensor to which the data belongs. See Section 2.1.1 Sensor ID Format and Section 3.0 Sensor IDs & Key-Value Pairs for more information about this value.
- # cal bytes- this byte indicates the number of bytes of calibration data that go with this sensor id.
- Cal Data 1 – this is the actual data for the sensor calibration. This data is specific to each sensor.
- Cal Data 2 – this is the actual data for the sensor calibration. This data is specific to each sensor.

2.4.1 Sensor Calibration Payload Example

This example demonstrates what the bytes would look like for a sensor calibration payload.

byte #	0	1	2	3	4	5	6	7	8	9
value	0x04	0x08	0x3D	0x94	0xB5	0x7A	0xC2	0x2E	0x35	0xB0
meaning	sensor id	# cal bytes	cal 1	cal 2	cal 3	cal 4	cal 5	cal 6	cal 7	cal 8

Figure 14: Sensor Calibration Payload Example

3.0 SENSOR IDS & KEY-VALUE PAIRS

Each sensor or device that can be configured in the IOLab remote is given a sensor ID so that it can be identified from the other sensors and devices. This ID is used in configuration and in output settings. **Error! Reference source not found.** lists all of the possible configuration options for each sensor or device in the IOLab remote.

The IOLab system supports two configuration types: sensor and data configurations. Sensor configurations can only be sent when data is not being collected in the system, i.e. data mode is inactive. Output configurations can be sent at any time because they do not affect the sensor data collection.

3.1 SENSOR ID FORMAT

The sensor ID is a 1 byte value that represents the identifier number assigned to the sensor or device in the IOLab system.

bit #	7	6	5	4	3	2	1	0
name	OVF	ID						
value	0 or 1	unsigned integer between 1 and 127						

Figure 15: Sensor ID Byte Definition

- OVF – Overflow Bit

  0 – Indicates that overflow did not occur (no data was lost) for the included data

  1 – Indicates that data overflowed in the system and that there were samples collected that did not fit into this message and were lost.

- ID – ID value

  Represented as a 7-bit unsigned integer

3.2 KEY-VALUE FORMAT

The key-value is a single byte that represents what configuration type (key) and what the configuration should be set to (value).

bit #	7	6	5	4	3	2	1	0
name	KEY			VALUE				
value	unsigned integer between 0 and 7			unsigned integer between 0 and 31				

Figure 16: Key-Value Byte Definition

- KEY – configuration type

  Represented as a 3-bit unsigned integer and corresponds to a configuration type for a specific sensor or device

- VALUE – the value of the configuration type

  Represented as a 5-bit unsigned integer and corresponds to the specific setting for a configuration type of a specific sensor or device.

3.3 SENSOR ID, KEY-VALUE TABLE

The legend in Table 1 explains what the different font colors in the table represent.

Legend
In Use
Not implemented

Table 1: Sensor ID & Key-Value Pairs Legend

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
0x01	Accelerometer (MMA8451Q)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1.56	
					1	6.25	
					2	12.5	
					3	50	
					4	100	default
					5	200	
					6	400	
					7	800	
		2	Resolution (g)	Sensor	0	2	default
					1	4	
					2	8	
		3	Oversampling Mode	Sensor	0	Normal	default
					1	Low Noise Low Power	
					2	High Resolution	
					3	Low Power	
0x02	Magnetometer (MAG3110)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	0.63	
					1	1.25	
					2	2.5	
					3	5	
					4	10	
					5	20	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					6	40	
					7	80	default
0x03	Gyroscope (L3GD20)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	95	default
					1	190	
					2	380	
					3	760	
		2	Resolution (dps)	Sensor	0	250	default
					1	500	
					2	2000	
0x04	Barometer (MPL115A1)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	default
0x05	Ultrasonic	0	Mode	Sensor	0	Disable	
					1	Echo Range	
					2	Direct Range	
		1	Sample Rate (Hz)	Sensor	0	50	
					1	100	default
0x06	Microphone (CMA-4544PF-W)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	minimum respose is 60Hz
					1	10	
					2	50	
					3	100	
					4	200	
					5	400	
					6	800	
					7	2400	default
					8	4800	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					9	6000	
0x07	Ambient Light (APDS-9002)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	max response rate is 250 Hz
					1	10	
					2	50	
					3	100	default
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	
					9	6000	
0x08	Force Gauge (EQ-430L)	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	default
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	
					9	6000	
0x09	Encoder	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	50	
					1	100	default
0x0A	ECG	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					2	50	
					3	100	
					4	200	default
					5	400	
					6	800	
0x0B	Battery	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	default
					1	10	
					2	50	
					3	100	
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	
					9	6000	
0x0C	High Gain Input	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	default
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	
					9	6000	
0x0D	Digital Inputs	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	20	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					3	25	
					2	50	
					3	100	default
0x0F	Header 1	0	Mode	Sensor	0	Disable	
					1	Digital Input	
					2	Digital Output	
		1	Output Value (Output Mode Only)	Sensor, Output	0	Digital Low	default
					1	Digital High	
0x10	Header 2	0	Mode	Sensor	0	Disable	
					1	Digital Input	
					2	Digital Output	
		1	Output Value (Output Mode Only)	Sensor, Output	0	Digital Low	default
					1	Digital High	
0x11	Header 3	0	Mode	Sensor	0	Disable	
					1	Digital Input	
					2	Digital Output	
		2	Output Value (Output Mode Only)	Sensor, Output	0	Digital Low	default
					1	Digital High	
0x12	Header 4	0	Mode	Sensor	0	Disable	
					1	Digital Input	
					2	PWM Output	
		1	Low Frequency (Hz) (PWM Output mode only)	Sensor, Output	0	20	
					1	25	
					2	30	
					3	35	
					4	40	
					5	45	
					6	50	
					7	55	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					8	60	
					9	65	default
					10	70	
					11	75	
					12	80	
					13	85	
					14	90	
					15	95	
					16	100	
					17	150	
					18	200	
					19	250	
					20	300	
					21	350	
					22	400	
					23	450	
					24	500	
					25	600	
					26	700	
					27	800	
					28	900	
					29	1000	
					30	1100	
					31	1200	
		2	Mid Frequency (Hz) (PWM Output mode only)	Sensor, Output	0	1400	
					1	1600	
					2	1800	
					3	2000	
					4	2200	
					5	2400	
					6	2600	
					7	2800	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					8	3000	
					9	3200	default
					10	3400	
					11	3600	
					12	3800	
					13	4000	
					14	4200	
					15	4400	
					16	4600	
					17	4800	
					18	5000	
					19	5500	
					20	6000	
					21	6500	
					22	7000	
					23	7500	
					24	8000	
					25	8500	
					26	9000	
					27	9500	
					28	10000	
					29	10500	
					30	11000	
					31	11500	
		3	High Frequency (Hz) (PWM Output mode only)	Sensor, Output	0	12000	
					1	12500	
					2	13000	
					3	13500	
					4	14000	
					5	14500	
					6	15000	
					7	15500	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					8	16000	
					9	16500	default
					10	17000	
					11	18000	
					12	19000	
					13	20000	
					14	21000	
					15	22000	
					16	23000	
					17	24000	
					18	25000	
					19	26000	
					20	27000	
					21	28000	
					22	29000	
					23	30000	
					24	31000	
					25	32000	
					26	33000	
					27	34000	
					28	35000	
					29	36000	
					30	37000	
					31	37500	
0x13	Header 5	0	Mode	Sensor	0	Disable	
					1	Digital Input	
					2	PWM Output	
		1	Low Frequency (Hz) (PWM Output mode only)	Sensor, Output	0	20	
					1	25	
					2	30	
					3	35	
					4	40	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					5	45	
					6	50	
					7	55	
					8	60	
					9	65	default
					10	70	
					11	75	
					12	80	
					13	85	
					14	90	
					15	95	
					16	100	
					17	150	
					18	200	
					19	250	
					20	300	
					21	350	
					22	400	
					23	450	
					24	500	
					25	600	
					26	700	
					27	800	
					28	900	
					29	1000	
					30	1100	
					31	1200	
		2	Mid Frequency (Hz) (PWM Output mode only)	Sensor, Output	0	1400	
					1	1600	
					2	1800	
					3	2000	
					4	2200	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					5	2400	
					6	2600	
					7	2800	
					8	3000	
					9	3200	default
					10	3400	
					11	3600	
					12	3800	
					13	4000	
					14	4200	
					15	4400	
					16	4600	
					17	4800	
					18	5000	
					19	5500	
					20	6000	
					21	6500	
					22	7000	
					23	7500	
					24	8000	
					25	8500	
					26	9000	
					27	9500	
					28	10000	
					29	10500	
					30	11000	
					31	11500	
		3	High Frequency (Hz) (PWM Output mode only)	Sensor, Output	0	12000	
					1	12500	
					2	13000	
					3	13500	
					4	14000	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					5	14500	
					6	15000	
					7	15500	
					8	16000	
					9	16500	default
					10	17000	
					11	18000	
					12	19000	
					13	20000	
					14	21000	
					15	22000	
					16	23000	
					17	24000	
					18	25000	
					19	26000	
					20	27000	
					21	28000	
					22	29000	
					23	30000	
					24	31000	
					25	32000	
					26	33000	
					27	34000	
					28	35000	
					29	36000	
					30	37000	
					31	37500	
0x14	Header 6	0	Mode	Sensor	0	Disable	
					1	Digital Input	
					2	Digital Output	
		1	Output Value (Output Mode Only)	Sensor, Output	0	Digital Low	default
					1	Digital High	
0x15	Analog 7	0	Mode	Sensor	0	Disable	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	default
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	
					9	6000	
0x16	Analog 8	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	default
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	
					9	6000	
0x17	Header 9	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	default
					4	200	
					5	400	
					6	800	
					7	2400	
					8	4800	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					9	6000	
0x18	Buzzer	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Low Frequency (Hz) (Frequency Mode Only)	Sensor, Output	0	50	
					1	60	
					2	70	
					3	80	
					4	90	
					5	100	
					6	120	
					7	150	
					8	200	
					9	240	default
					10	250	
					11	300	
					12	350	
					13	400	
					14	450	
					15	480	
					16	500	
					17	600	
					18	700	
					19	800	
					20	900	
					21	960	
					22	1000	
					23	1100	
					24	1200	
					25	1300	
					26	1400	
					27	1500	
					28	1600	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					29	1700	
					30	1800	
					31	1900	
		2	High Frequency (Hz) (Frequency Mode Only)	Sensor, Output	0	2000	
					1	2100	
					2	2200	
					3	2300	
					4	2398	
					5	2400	
					6	2402	
					7	2500	
					8	2750	
					9	3000	default
					10	3250	
					11	3500	
					12	3750	
					13	4000	
					14	4250	
					15	4500	
					16	4750	
					17	4798	
					18	4800	
					19	4802	
					20	4900	
					21	5000	
					22	5250	
					23	5500	
					24	5750	
					25	6000	
					26	6250	
					27	6500	
					28	6750	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					29	7000	
					30	7250	
					31	7500	
		3	Low Pitch (Pitch Mode Only)	Sensor, Output	0	C♯1/D♭1	34.6
					1	D1	36.7
					2	D♯1/E♭1	38.9
					3	E1	41.2
					4	F1	43.7
					5	F♯1/G♭1	46.2
					6	G1	49.0
					7	G♯1/A♭1	51.9
					8	A1	55.0
					9	A♯1/B♭1	58.3
					10	B1	61.7
					11	C2 Deep C	65.4
					12	C♯2/D♭2	69.3
					13	D2	73.4
					14	D♯2/E♭2	77.8
					15	E2	82.4
					16	F2	87.3
					17	F♯2/G♭2	92.5
					18	G2	98.0
					19	G♯2/A♭2	103.8
					20	A2	110 (default)
					21	A♯2/B♭2	116.5
					22	B2	123.5
					23	C3 Low C	130.8
					24	C♯3/D♭3	138.6
					25	D3	146.8
					26	D♯3/E♭3	155.6
					27	E3	164.8
					28	F3	174.6
					29	F♯3/G♭3	185.0

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					30	G3	196.0
					31	G♯3/A♭3	207.7
		4	Mid Pitch (Pitch Mode Only)	Sensor, Output	0	A3	220.0
					1	A♯3/B♭3	233.1
					2	B3	246.9
					3	C4 Middle C	261.6
					4	C♯4/D♭4	277.2
					5	D4	293.7
					6	D♯4/E♭4	311.1
					7	E4	329.6
					8	F4	349.2
					9	F♯4/G♭4	370.0
					10	G4	392.0
					11	G♯4/A♭4	415.3
					12	A4 A440	440 (default)
					13	A♯4/B♭4	466.2
					14	B4	493.9
					15	C5 Tenor C	523.3
					16	C♯5/D♭5	554.4
					17	D5	587.3
					18	D♯5/E♭5	622.3
					19	E5	659.3
					20	F5	698.5
					21	F♯5/G♭5	740.0
					22	G5	784.0
					23	G♯5/A♭5	830.6
					24	A5	880.0
					25	A♯5/B♭5	932.3
					26	B5	987.8
					27	C6 Soprano C (High C)	1046.5
					28	C♯6/D♭6	1108.7
					29	D6	1174.7

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					30	D♯6/E♭6	1244.5
					31	E6	1318.5
		5	High Pitch (Pitch Mode Only)	Sensor, Output	0	F6	1396.9
					1	F♯6/G♭6	1480.0
					2	G6	1568.0
					3	G♯6/A♭6	1661.2
					4	A6	1760.0
					5	A♯6/B♭6	1864.7
					6	B6	1975.5
					7	C7 Double high C	2093.0
					8	C♯7/D♭7	2217.5
					9	D7	2349.3
					10	D♯7/E♭7	2489.0
					11	E7	2637.0
					12	F7	2793.8
					13	F♯7/G♭7	2960.0
					14	G7	3136.0
					15	G♯7/A♭7	3322.4
					16	A7	3520.0
					17	A♯7/B♭7	3729.3
					18	B7	3951.1
					19	C8 Eighth octave	4186.0
					20	C#8/Db8	4434.9
					21	D8	4698.6
					22	D#8/Eb8	4978.0
					23	E8	5274.0
					24	F8	5587.7
					25	F#8/Gb8	5919.9
					26	G8	6271.9
					27	G#8/Ab8	6644.9
					28	A8	7040.0
					29	A#8/Bb8	7458.6
					30	B8	7902.1

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					31	C9 Ninth octave	8372.0
		6	Duty Cycle (%)	Sensor, Output	0	0	
					1	3	
					2	6	
					3	9	
					4	12	
					5	15	
					6	18	
					7	21	
					8	25	
					9	28	
					10	31	
					11	34	
					12	37	
					13	40	
					14	43	
					15	46	
					16	50	default
					17	55	
					18	59	
					19	62	
					20	65	
					21	68	
					22	71	
					23	75	
					24	78	
					25	81	
					26	84	
					27	88	
					28	91	
					29	94	
					30	97	
					31	100	
0x19	DAC	0	Mode	Sensor,	0	Disable	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
	(AD5601)			Output	1	DC	
					2	Square	
					3	Triangle	
					4	Sawtooth	
					5	Sine	
		1	Amplitude (Volts) (DC Waveform Only)	Sensor, Output	0	0	
					1	0.1	
					2	0.2	
					3	0.3	
					4	0.4	
					5	0.5	
					6	0.6	
					7	0.7	
					8	0.8	
					9	1	
					10	1.1	
					11	1.2	
					12	1.3	
					13	1.4	
					14	1.5	
					15	1.6	
					16	1.7	
					17	1.8	default
					18	1.9	
					19	2	
					20	2.1	
					21	2.2	
					22	2.3	
					23	2.4	
					24	2.5	
					25	2.7	
					26	2.8	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					27	2.9	
					28	3	
					29	3.1	
					30	3.2	
					31	3.3	
		2	Frequency (Hz) (Non-DC waveform only)	Sensor, Output	0	10	
					1	20	
					2	40	
					3	60	
					4	80	
					5	100	
					6	200	
					7	300	
					8	400	
					9	500	
					10	750	
					11	1000	
					12	1500	
					13	2000	
					14	2500	
					15	3000	
					16	3500	
					17	4000	
					18	4500	
					19	5000	
0x1A	Thermometer	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	default
					3	100	
					4	200	

Sensor ID (Hex)	Sensor Name	Key	Key Name	Config Type	Value	Value Name	Note
					5	400	
		2	Oversampling	Sensor	0	On	default
					1	Off	
0x1B	6-Channel ECG	0	Mode	Sensor	0	Disable	
					1	Enable	
		1	Sample Rate (Hz)	Sensor	0	1	
					1	10	
					2	50	
					3	100	
					4	200	
					5	400	default
					6	800	

4.0 SENSOR DATA FORMAT

Each of the sensors in the IOLab device will gather raw data from the source of the sensor and transmit the data through different protocols with the data ending up at the PC. The data from each sensor arriving at the PC will be formatted as described in this section.

4.1 ACCELEROMETER

An accelerometer sample has 6 bytes formatted as three 16-bit two's-compliment signed integers each representing the acceleration of one of the three three-dimensional Cartesian axes.

byte #	0	1	2	3	4	5
value	X_H	X_L	Y_H	Y_L	Z_H	Z_L
meaning	X axis MSB	X axis LSB	Y axis MSB	Y axis LSB	Z axis MSB	Z axis LSB

Figure 17: Accelerometer Data Sample

4.2 MAGNETOMETER

A magnetometer sample has 6 bytes formatted as three 16-bit two's-compliment signed integers each representing the magnetic flux density of one of the three three-dimensional Cartesian axes.

byte #	0	1	2	3	4	5
value	X_H	X_L	Y_H	Y_L	Z_H	Z_L
meaning	X axis MSB	X axis LSB	Y axis MSB	Y axis LSB	Z axis MSB	Z axis LSB

Figure 18: Magnetometer Data Sample

4.3 GYROSCOPE

A gyroscope sample has 6 bytes formatted as three 16-bit two's-compliment signed integers each representing the angular velocity about one of the three three-dimensional Cartesian axes.

byte #	0	1	2	3	4	5
value	X_H	X_L	Y_H	Y_L	Z_H	Z_L
meaning	X axis MSB	X axis LSB	Y axis MSB	Y axis LSB	Z axis MSB	Z axis LSB

Figure 19: Gyroscope Data Sample

4.4 Barometer

4.4.1 Barometer Sample

A barometer sample has 4 bytes formatted as two 10-bit unsigned integers, right aligned, where the first represents pressure and the second represents temperature compensation.

byte #	0	1	2	3
value	P_H	P_L	T_H	T_L
meaning	Pres MSB	Pres LSB	Temp MSB	Temp LSB

Figure 20: Barometer Data Sample

4.4.1.1 Barometer Bit Definitions

Byte 0

bit #	7	6	5	4	3	2	1	0
name	P_H							
value	pressure							

Byte 1

bit #	7	6	5	4	3	2	1	0
name	P_L		dd					
value	pressure		unused					

Byte 2

bit #	7	6	5	4	3	2	1	0
name	T_H							
value	temperature							

Byte 3

bit #	7	6	5	4	3	2	1	0
name	T_L		dd					
value	temperature		unused					

4.4.2 Barometer Calibration Constants

A barometer calibration constant is used to convert the raw barometer sample into a pressure and temperature measurement. It consists of four 16-bit values whose bits are explained in the barometer datasheet.

byte #	0	1	2	3	4	5	6	7
value	a0_H	a0_L	b1_H	b1_L	b2_H	b2_L	c12_H	c12_L
meaning	a0 MSB	a0 LSB	b1 MSB	b1 LSB	b2 MSB	b1 LSB	c12 MSB	c12 LSB

Figure 21: Barometer Calibration Constants

4.4.2.1 Barometer Calibration Constants Bit Definitions

Byte 0 – coefficient A0 MSB

bit #	7	6	5	4	3	2	1	0
name	S	I_{11}	I_{10}	I_9	I_8	I_7	I_6	I_5
value	sign				integer bits			

Byte 1 – coefficient A0 LSB

bit #	7	6	5	4	3	2	1	0
name	I_4	I_3	I_2	I_1	I_0	F_2	F_1	F_0
value			integer bits				fractional bits	

Byte 2 – B1 MSB

bit #	7	6	5	4	3	2	1	0
name	S	I_1	I_0	F_{12}	F_{11}	F_{10}	F_9	F_8
value	sign	integer bits				fractional bits		

Byte 3 – B1 LSB

bit #	7	6	5	4	3	2	1	0
name	F_7	F_6	F_5	F_4	F_3	F_2	F_1	F_0
value				fractional bits				

Byte 4 – B2 MSB

bit #	7	6	5	4	3	2	1	0
name	S	I_0	F_{13}	F_{12}	F_{11}	F_{10}	F_9	F_8
value	sign	integer			fractional bits			

Byte 5 – B2 LSB

bit #	7	6	5	4	3	2	1	0
name	F_7	F_6	F_5	F_4	F_3	F_2	F_1	F_0
value				fractional bits				

Byte 6 – C12 MSB

bit #	7	6	5	4	3	2	1	0
name	S	F_{12}	F_{11}	F_{10}	F_9	F_8	F_7	F_6
value	sign				fractional bits			

Byte 7 – C12 LSB

bit #	7	6	5	4	3	2	1	0
name	F_5	F_4	F_3	F_2	F_1	F_0	dd	dd
value			fractional bits				unused	

4.5 MICROPHONE

A microphone sample has 2 bytes formatted as a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 22: Microphone Data Sample

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.6 AMBIENT LIGHT

An ambient light sample has 2 bytes formatted as a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 23: Ambient Light Data Sample

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.7 Force Gauge

A force gauge sample has 2 bytes formatted as a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 24: Force Gauge Data Sample

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.8 Encoder

An encoder sample has 2 bytes formatted as a 16-bit two's-compliment signed integer where the sign represents the direction of the encoder (e.g. forwards, backwards) and the magnitude of the sample is the number of steps in that direction.

byte #	0	1
value	E_H	E_L
meaning	Encoder MSB	Encoder LSB

Figure 25: Encoder Data Sample

4.9 ECG

An ECG sample has 6 bytes of data formatted as three channels of 12-bit unsigned integers, right aligned.

byte #	0	1	2	3	4	5
value	A_H	A_L	B_H	B_L	C_H	C_L
meaning	Ch A MSB	Ch A LSB	Ch B MSB	Ch B LSB	Ch C MSB	Ch C LSB

Figure 26: ECG Data Sample

Each channel's data is formatted right aligned as shown here:

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.10 Battery

A battery sample has 2 bytes formatted as 12 a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 27: Battery Data Sample

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

The battery's voltage can be calculated using the following formula.

$$Vbat = \frac{sample * 3\,Volts * 2}{4095}$$

Equation 1: Battery sample to voltage conversion

Where `Vbat` is in volts, `sample` is the value from the battery sample, `3 Volts` is the analog reference used, `2` is the gain correction for the hardware voltage divider, and `4095` is the maximum value the 12-bit ADC can return.

4.11 High Gain Input

A high gain input sample has 2 bytes formatted as a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 28: High Gain Data Sample

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.12 Digital Inputs

A digital input sample has 1 byte formatted as an 8-bit binary flag.

byte #	0
value	S
meaning	digital

Figure 29: Digital Input Data Sample

Sample Bit Representation

bit #	7	6	5	4	3	2	1	0
name	0|1	0|1	0|1	0|1	0|1	0|1	0|1	0|1
value	button 1	button 0	header 6	header 5	header 4	header 3	header 2	header 1

***NOTE:* If the header pin is configured as an output, the value of the corresponding header bit is not valid.**

4.13 Analog 7 through 9 Header Input

An analog header sample has 2 bytes formatted a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 30: Analog Header Data Sample

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.14 Thermometer

4.14.1 Thermometer Sample (oversampling DISABLED)

A thermometer sample has 2 bytes formatted as a 12-bit unsigned integer, right aligned in 16-bits.

byte #	0	1
value	S_H	S_L
meaning	Sample MSB	Sample LSB

Figure 31: Thermometer Data Sample (no oversampling)

4.14.1.1 Thermometer Bit Definitions (no oversampling)

Byte 0

bit #	7	6	5	4	3	2	1	0
name	dd				S_H			
value	unused				sample			

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							

4.14.2 Thermometer Sample (oversampling ENABLED)

When the thermometer oversampling is enabled, the thermometer will be sampled at 400Hz. The data will be read out at whatever the thermometer sample rate is set at. If 400Hz is greater than the selected data rate, the thermometer data will be an accumulation (sum) of 400Hz samples and must be divided in post processing to get the actual raw reading. . The divisor is always the current sample rate / oversampling rate.

$$Oversampling\ Divisor = \frac{Sample\ Rate\ Setting}{Oversampling\ Sample\ Rate}$$

Equation 2: Oversampling divisor

A thermometer sample (with oversampling) has 4 bytes formatted as a single 32-bit unsigned integer, right aligned, which is the sum of the collected samples.

byte #	0	1	2	3
value	T_HM	T_HL	T_LM	T_LL
meaning	Temp_H MSB	Temp_H LSB	Temp_L MSB	Temp_L LSB

Figure 32: Thermometer Data Sample (with oversampling)

4.14.2.1 Thermometer oversampling calculation example

This example uses the thermometer sample rate of 1Hz with oversampling enabled. This means that every second the thermometer reading will be acquired and it will be a sum of 400 samples because the oversampling always runs at 400Hz

byte #	0	1	2	3
value	0x00	0x0C	0x41	0x74
meaning	Temp_H MSB	Temp_H LSB	Temp_L MSB	Temp_L LSB

The thermometer readings is 0x000C4174 which when converted from hex to decimal is 803,188 counts. Since the oversampling always runs at 400Hz and the sample rate is 1Hz the divisor is

$$400 = \frac{1Hz}{400Hz}$$

Therefore the average raw count over the last sample period is

$$\frac{803{,}188}{400} = 2007.97$$

4.14.3 Thermometer Calibration Constants

A thermometer calibration constant is used to convert the raw thermometer sample into a temperature in °C. It consists of two unsigned 16-bit integer values that are used as scaling factors. The first integer is the calibration at 85°C and the second integer is the calibration at 30°C.

byte #	0	1	2	3
value	cal85_H	cal85_L	cal30_H	cal30_L
meaning	cal85 MSB	cal85 LSB	cal30 MSB	cal30 LSB

Figure 33: Thermometer Calibration Constants

4.14.3.1 Thermometer Calibration

The raw thermometer count can be scaled to °C using the two point calibration from the calibration constants.

$$Temp\ (°C) = \left(\frac{CalTemp1\ (°C) - CalTemp2\ (°C)}{Cal@Temp1 - Cal@Temp2} * (RawCount - Cal@Temp2)\right) + CalTemp2\ (°C)$$

Equation 3: Thermometer Temperature Correction

4.14.3.2 Thermometer Calibration Example

Using the raw temperature counts from the example in section 4.14.2.1 and the compensation data below, we can calculate the temperature in °C.

byte #	0	1	2	3
value	0x09	0x7A	0x07	0xF9
meaning	cal85 MSB	cal85 LSB	cal30 MSB	cal30 LSB

When converting from hexadecimal to decimal we get the first calibration point from 85°C is 2426 and the second calibration point from 30°C is 2041. Using the raw count of 2007.97 from above Equation 3 we get:

$$25.28°C = \left(\frac{85°C - 30°C}{2426 - 2041} * (2007.97 - 2041)\right) + 30°C$$

So the actual temperature over the period was 25.28°C.

4.15 6-Channel ECG

A 6-channel ECG sample has 12 bytes of data formatted as six channels of 12-bit unsigned integers, right aligned.

byte #	0	1	2	3	4	5	6	7	8	9	10	11
value	A_H	A_L	B_H	B_L	C_H	C_L	D_H	D_L	E_H	E_L	F_H	F_L
meaning	Ch A MSB	Ch A LSB	Ch B MSB	Ch B LSB	Ch C MSB	Ch C LSB	Ch D MSB	Ch D LSB	Ch E MSB	Ch E LSB	Ch F MSB	Ch F LSB

Figure 34: 6-Channel ECG Data Sample

Each channel's data is formatted right aligned as shown here:

Byte 0

bit #	7	6	5	4	3	2	1	0

name	dd				S_H			
value	unused						sample	

Byte 1

bit #	7	6	5	4	3	2	1	0
name	S_L							
value	sample							