Benchmark™ Biometric Sensor System for Wearable Devices

Features

- Market-Leading optical heart rate (HR) measurement, HR zone, HR recovery, resting HR, step rate / count, distance cycling cadence, calories, VO2, activity recognition (running/lifestyle), at-rest R-R interval (RRi*) and Heart Rate Variability (HRV). Not characterized for high- or best-precision RRi measurement.

  *Note: Sensor measures P-P interval which correlates with RRi, see Valencell Heart Rate Variability Review for more information
- Single Benchmark™ module simplifies system integration
- Sensor module contains processor, LED, detector, and accelerometer mounted to an IR-filtering window assembly optimized for sensor system accuracy
- PerformTek™ Low-Power ARM® Cortex® processor performs sensor data processing and provides a communication interface to the system host processor.

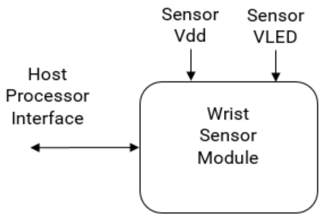
Figure 1: Benchmark™ Wrist 1.2 Sensor

- Wrist Sensor Dimensions: (19.5 x 14.5 x 3.25) mm
- Sensor Weight 0.85 grams
- 400 kHz I2C or 57.6 kbps UART Interface
- Sensor V_{DD}: 1.8 VDC to 3.3 VDC
- Sensor V_{LED}: 5 VDC
- V_{LED} Current: 0.52 mA Continuous Average
- V_{DD} Current: 1.51 mA average operating; 5 uA in Standby, 1 mA in Idle
- Field updatable processor firmware
- Patented optomechanical designs
- 100% factory-tested optical and sensor performance
- Additional design and test services available upon request

Description

The PerformTek™ powered Benchmark™ Wrist 1.2 Sensor System is the next-generation biometric wearable sensor technology developed by Valencell, Inc. This sensor helps you quickly develop your own biometric products. The modular design brings together the best available parts of a successful biometric sensor system in a smaller form factor and includes emitter/detector sensor electronics in an optimized optical package with a processor that is pre-programmed with Valencell's PerformTek™ advanced biometric algorithms.

Figure 2: Benchmark™ Wrist 1.2 Simplified Block Diagram



Applications

- Wearable Devices
- Lifestyle / Activity Bands
- Smart Watches
- Wrist, Forearm, and Upper Arm Bands for Sports
- Helmets and Headbands

Reference Documentation

Table 1: Related Documents

Document	Title
000638	PerformTek™ Interface Protocol Document
000964	PerformTek™ User Guide
000832	PerformTek™ Wrist Integration Guide
000827	Benchmark™ BW1.2 Sensor 3D CAD models
001113	Valencell Heart Rate Variability Review

Change Record

Table 2: Change Record

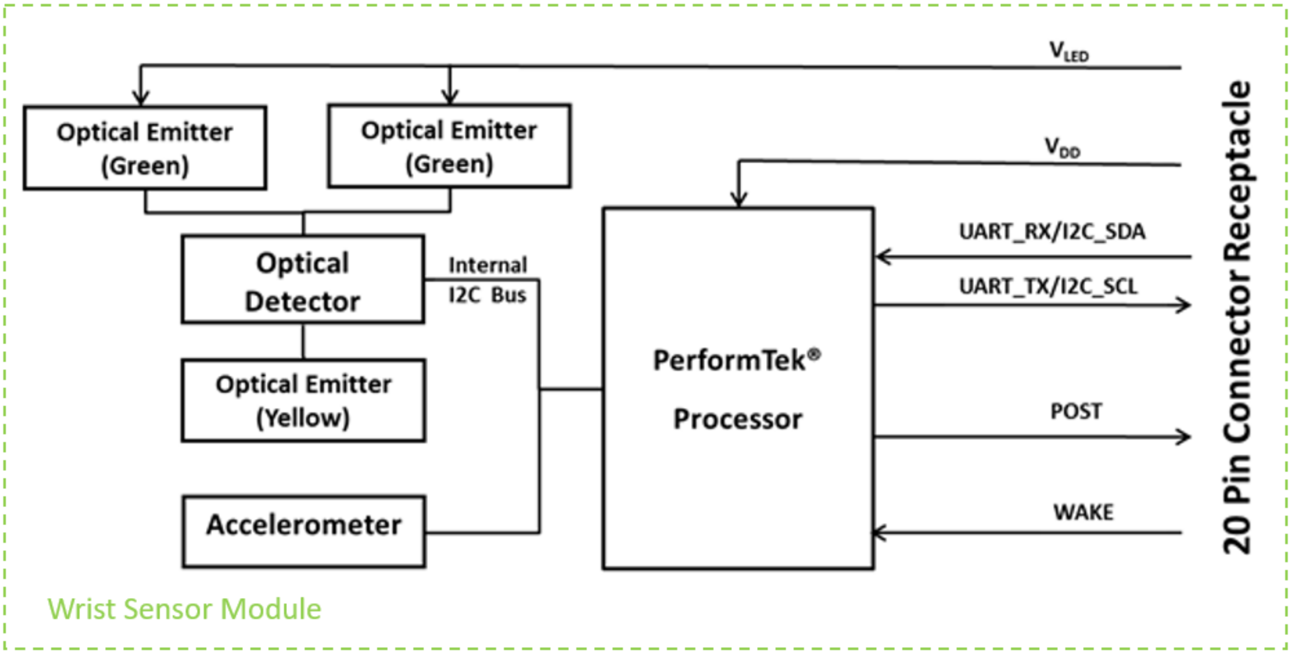
Author	Revision	Date	Description of change(s)
MEP	2.00	09MAY2017	Release under new format with re-defined supported features and power requirements

Table of Contents

1 Block Diagram / System Overview

Figure 3 shows how the Benchmark™ Wrist 1.2 Biometric Sensor components work together.

Figure 3: Benchmark™ Wrist 1.2 Functional Block Diagram



On the left of the diagram, the sensor module circuit board contains a digital optical detector system, three LEDs, and an accelerometer. The detector, LEDs, and accelerometer work together to collect biometric information via reflected light and movement from the wearer. The integrated PerformTek™ processor controls the sensing devices over the internal I2C bus.

The integrated PerformTek™ processor collects the sensor data and runs Valencell's patent protected algorithms to convert the raw measurements into biometric values such as heart rate or cadence and processes those values further into higher level user assessments like calories burned. In addition, sensor module diagnostics such as signal quality, error codes, and serial number ID are available. This information is available to the Host processor via the Host Interface.

The Host Interface is shown on the right side of the diagram. Control lines for interfacing the host processor with the PerformTek™ processor include UART or I2C, Power-On Self-Test (POST), and a Wake-from-Standby line (WAKE).

2 Sensor Pin Descriptions

2.1 Sensor Pinout

Table 3 and Figure 4 show the pinout for the Wrist sensor. Figure 5 shows an image of the BW1.2 Sensor Connector Orientation.

Table 3: Sensor Connector Pinout

Pin	Name	I/O	Description
1	GND	Power	Ground / Reference Voltage
2	GND	Power	Ground / Reference Voltage
3	V_{DD}	Power	Power supply to sensor module sections other than LEDs.
4	V_{DD}	Power	Power supply to sensor module sections other than LEDs.
5	V_{LED}	Power	Power supply to LEDs on module.
6	V_{LED}	Power	Power supply to LEDs on module.
7	NC	-	Do not connect
8	POST	I/O	This pin serves two functions: 1. Power-On Self Test Output: This pin will present a logic high after the power up process has successfully completed. 2. Bootloader Mode Input: Driving the POST pin high during boot up puts the device into bootloader mode. The POST pin should not be biased during normal operation.
9	GND	Power	Ground / Reference Voltage
10	GND	Power	Ground / Reference Voltage
11	GND	Power	Ground / Reference Voltage

Pin	Name	I/O	Description
12	GND	Power	Ground / Reference Voltage
13	UART_RX / I^2C_SDA	I/O	Host interface pin configured as either UART RX (processor input) or I2C SDA depending on the selected communication protocol. A pull-up resistor should be added for I2C operation. Connect this pin to the host processor. A series zero ohm resistor should be added to this signal to enable Valencell debug support.
14	WAKE	Input	Wakeup signal from host processor. A low-to-high transition on this pin will wake the processor from Standby Note: The processor will not enter Standby if this signal is not low.
15	UART_TX / I^2C_SCL	I/O	Host interface pin configured as either UART TX (processor output) or I2C SCL depending on the selected communication protocol. A pull-up resistor should be added for I2C operation. Connect this pin to the host processor. A series zero ohm resistor should be added to this signal to enable Valencell debug support.
16	NC	-	Do not connect
17	NC	-	Do not connect
18	NC	-	Do not connect
19	GND	Power	Ground / Reference Voltage
20	GND	Power	Ground / Reference Voltage

2.2 Sensor Connector Description

The sensor interface utilizes a Hirose BM20B(0.6)-20DS-0.4V(51) connector as shown below. A Hirose BM20B(0.6)-20DP-0.4V(51) or equivalent connector should be used on the system host side to interface to it.

Figure 4: Benchmark™ Wrist 1.2 Connector

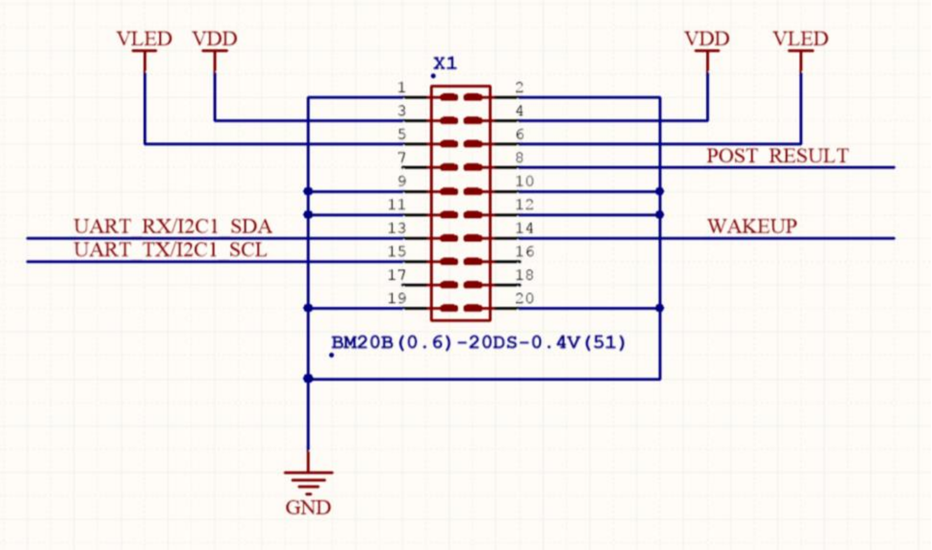
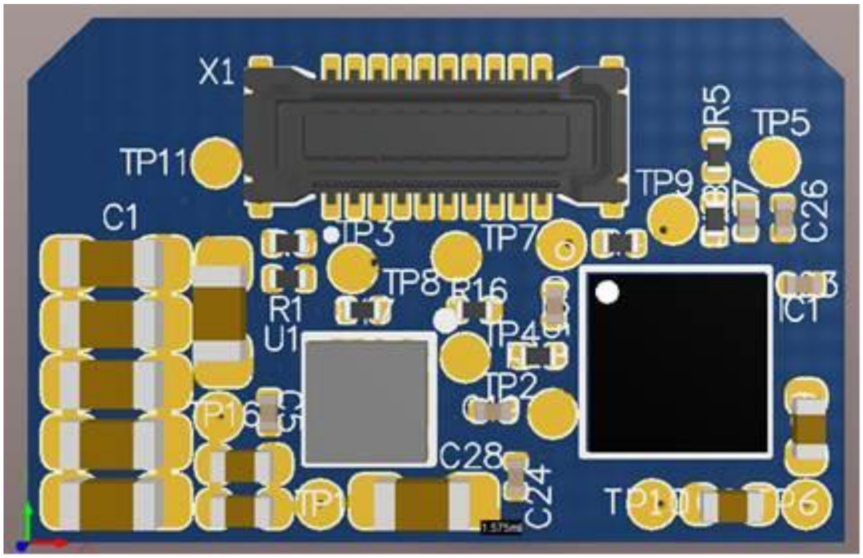


Figure 5: Benchmark™ Wrist 1.2 Sensor Connector Orientation



3 Sensor Electrical Characteristics

Table 4: Recommended Operating Conditions for Sensor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
V_{LED} Supply Voltage	V_{LED}	Min and Max are inclusive of V_{LED} ripple requirement	4.875	5.0	5.50	VDC
V_{LED} ripple voltage_30k	V_{ripple_10}	Sensor system active: 0 to 30 kHz Ripple	-	-	250	mV_{pp}
V_{LED} ripple voltage_100M	V_{ripple_100}	Sensor system active: >30 kHz to 100 MHz Ripple	-	-	100	mV_{pp}
V_{DD} Supply Voltage[1]	V_{DD}	Min and Max are inclusive of V_{DD} ripple requirement	1.76	1.8	3.6	VDC
V_{DD} ripple voltage_10	V_{ripple_10}	Sensor system active: 0 to 10 MHz Ripple	-	-	50	mV_{pp}
Operating Temperature	-	Device operating in Standby, Idle, or Active Modes	-10	25	50	°C

Note 1: V_{DD} must reach or exceed 1.80 VDC on startup to ensure that the sensors internal Power-On Reset appropriately de-asserts and must stay above 1.76 VDC during operation to avoid Power-Down Reset Assertion. Please contact Valencell for more details if needed.

Table 5: Operating Characteristics of Sensor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
I_{LED} Sensor Standby and Idle Modes	-	System is in Standby mode	-	3	-	µA
I_{DD} Standby Mode	I_{STBY}	System is in Standby mode (Sensor is in lowest-power mode with power applied)	-	5	-	µA
I_{DD} Idle Mode	I_{IDLE}	System is in Idle mode (sensor is active but not collecting data)	-	0.95	-	mA

Parameter	Symbol	Conditions	Min	Typ	Max	Units
I_{DD} Active Mode with Standard-Precision RRi[1]	-	System is in Active mode and operating at standard RRi sampling rate	-	1.64 to 2.09	--	mA
I_{DD} Active Mode with High-Precision RRi[1,2]	-	System is in Active mode and operating at fast RRi sampling rate	-	2.45 to 2.90	-	mA
I_{DD} Active Mode with Best-Precision RRi[1,2]	-	System is in Active mode and operating at fastest RRi sampling rate	-	3.41 to 3.86	-	mA
I_{LED} Sensor Active Mode with Standard-Precision RRi	-	System is in Active mode and operating at standard RRi sampling rate	-	0.518	0.65	mA
I_{LED} Sensor Active Mode with High-Precision RRi		System is in Active mode and operating at fast RRi sampling rate	-	2.59	3.25	mA
I_{LED} Sensor Active Mode Best-Precision RRi		System is in Active mode and operating at fastest RRi sampling rate	-	5.18	6.5	mA
I_{LED} LED Pulse Current	-	System is in Active mode	-	18	23	mA
I_{DD} Processor Pulse Current	-	System is in Active mode	-	10	-	mA
Start-up time before POST response	t_{POST}	On Start-up, time measured after V_{DD} equal to or above 1.8V	-	40	150	ms

Note 1: Typical range depends on if an external crystal is utilized or not. The crystal will increase precision but will also increase power consumption.

Note 2: High- and Best-Precision operation and current draw applies to RRi only. Best-precision heart rate monitoring is available in standard Active Mode. See PerformTek™ Interface Protocol Document for more details.

Absolute limits are provided below. If these limits are exceeded, permanent device damage may occur. Additionally, if the sensor is exposed to these limits for an extended period of time, the sensor reliability may be impacted.

Table 6: Sensor Absolute Maximum Limits

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Operating Temperature	-	Device operating in Standby, Idle, or Active Modes – performance not guaranteed	-20	-	70	ºC
Storage Temperature	-	Device powered off, device will require time to equalize with normal operating temperature after exposure to limits of storage temperature	-50	-	85	ºC
ESD Rating	-	Human Body Model[1]	-	-	2	kV

Note 1: The sensor module is designed to support system level ESD compliance testing up to 4 kV contact and 8 kV air discharges; however, ESD protection for the standalone sensor module is intended only to protect the sensor during normal handling in a typical electronic manufacturing environment with typical ESD protection in place.

4 PerformTek™ Sensor Connections and Interface Features

- Host Interface – UART / I2C

The Host Interface that connects the system processor to the PerformTek™ processor supports both I2C and UART communications with an automatic communication protocol (AutoComms) feature. With this feature, the processor monitors its UART_TX pin by applying a weak pull-down to this pin and then reading its status. If the pin is pulled high, it enters I2C communications mode, and if the pin is low, it enters UART communications mode.

Figure 6: AutoComms Compatible Signal Configuration – UART

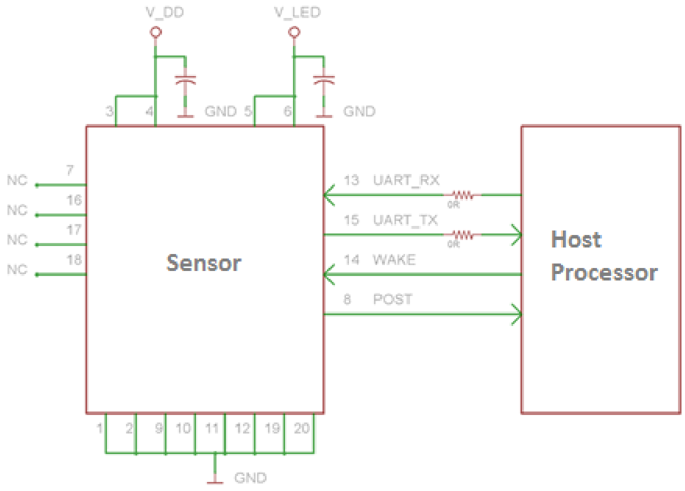
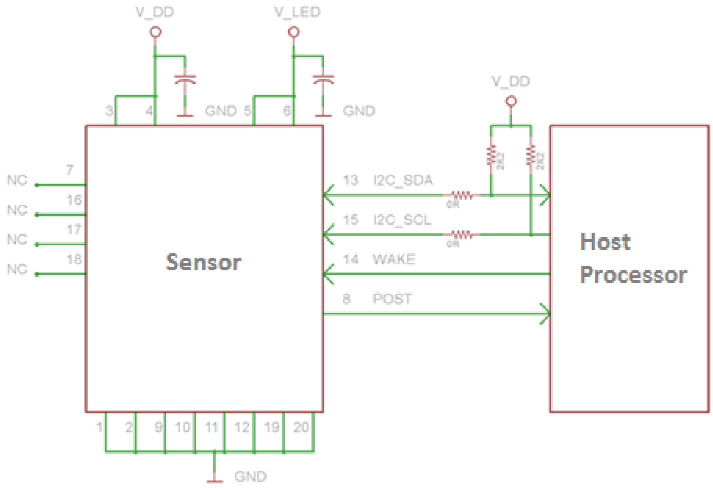


Figure 7: AutoComms Compatible Signal Configuration – I2C



For proper AutoComms functionality, follow these steps:

1. For a UART interface, no biasing should be added to the communication lines. For I2C, typical pull-up resistor values should be used.
2. During PerformTek™ processor bootup, the communication lines should not be driven by the host processor until either the POST pin goes high or t_{POST} as defined in Table 5 has elapsed.

For UART host communications, the UART_RX pin is the receive line for data sent to the module from the host processor and the UART_TX pin is the transmit line from the sensor module to the host. The port settings are 57.6 kpbs, 8, N, 1. There is no hardware or software flow control.

For I2C host communications, the I2C_SDA line is the data line and I2C_SCL line is the clock line. The sensor module acts as an I2C slave with a 400 kHz bus speed and an I2C address of 0x44.
For information about the UART or I2C communication protocols, see the PerformTek™ Interface Protocol Document.

- Host Interface – POST (Power-On Self-Test)

Once V_{DD} power is applied, the on-board processor will attempt to initialize all components on the module. This startup time is defined by t_{POST} in Table 5. If startup is successful, the POST pin will assert high, otherwise, the pin will stay low. If the POST pin is not utilized, the Max time for t_{POST} should be observed before interaction with the PerformTek™ processor begins.

Diagnostic information associated with the POST pin is stored in the sensor module's registers and can be read via the UART/ I2C Host Interface. As part of the POST, the PerformTek™ processor tests communications with the sensor peripherals and exercises the axes of the accelerometer while checking for a response within bounds. If a failure is detected but the processor can still communicate, the POST will still assert high. To ensure correct system operation, the POST register should be examined at startup. Refer to the PerformTek™ Interface Protocol Document for further information on the POST and other diagnostic registers.

- Host Interface – WAKE

WAKE is an input to the module used to bring the module out of Standby mode. Raising this pin from Low to High will return the module to an awake state, ready for communication.
Note that lowering WAKE does not put the module into Standby mode. Standby mode is entered via a command over the UART/ I2C module communications. WAKE pin should be lowered before issuing the Standby command.

- Firmware Updates

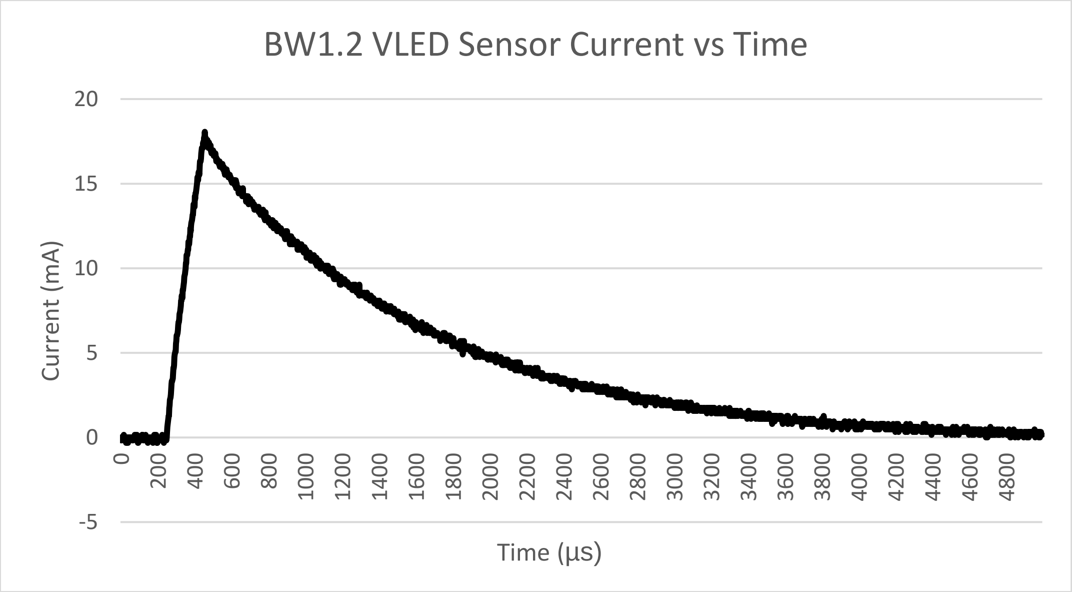
The PerformTek™ processor supports in-field firmware updates via the Host Interface. Driving the PerformTek™ processor's POST pin high during boot up puts the device into bootloader mode. The POST pin should not be biased during normal operation. Refer to the PerformTek™ User Guide for further information on this feature.

5 Sensor Power Supply Design Guidelines

5.1 Power Supply Loading

The system power supply or supplies should be designed to meet the requirements in Section 3 during transients on both V_{LED} and V_{DD}. Peak V_{LED} current will be periodic where the peaks will occur every 40 ms). A typical current peak profile for sensor V_{LED} is shown Figure 8.

Figure 8: Typical Benchmark™ BW1.2 Sensor V_{LED} Current Pulse



The V_{LED} current profile shown here and the V_{LED} and V_{DD} current peaks listed in Section 3 are based on measured system performance. V_{DD} current peaks are of smaller amplitude and much smaller duration than V_{LED} current peaks. Actual peak V_{DD} current profiles and average processor power numbers will vary depending on how the PerformTek™ features are used within the system. Because of this, Valencell recommends testing our sensors in a manner representative of their intended use as early as possible in the design cycle. To facilitate this, Valencell supplies development kits that support early prototyping and power measurement.

5.2 Power Supply Sequencing

The system V_{LED} supply should come up at the same time or before the V_{DD} supply to ensure correct sensor operation. This requirement is met if V_{LED} = 1.4 V (0.77 x V_{DD}) at the same time or before V_{DD} = 1.8 V on initial power up.

6 Sensor Optical-Mechanical Integration

The optical lens system is a critical component of the sensor module, ensuring good optical coupling from the emitters and sensors to the user's skin. This is necessary for accurate measurement. The lens frame is an overmolded PC/ABS opaque frame onto an optical grade film lens. The PCB and opto-mechanical lens is tested as an assembly and should not be disassembled.

Figure 9: BW 1.2 Sensor Module Drawing

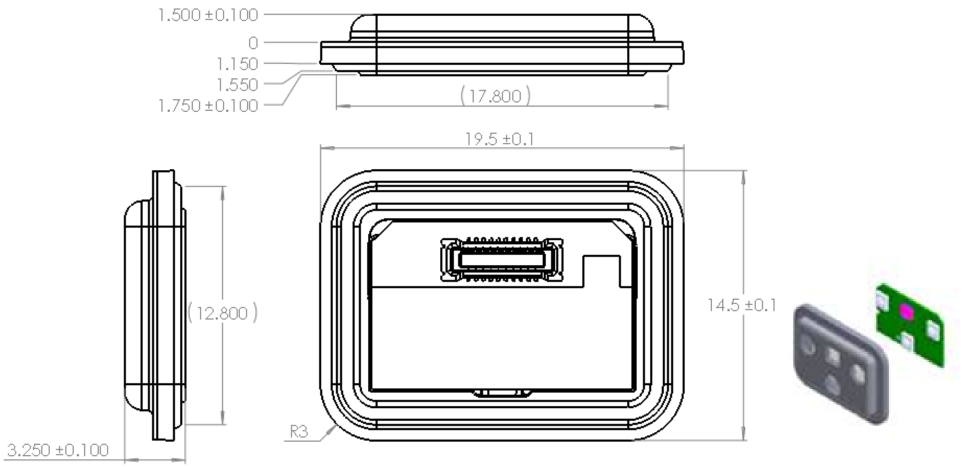
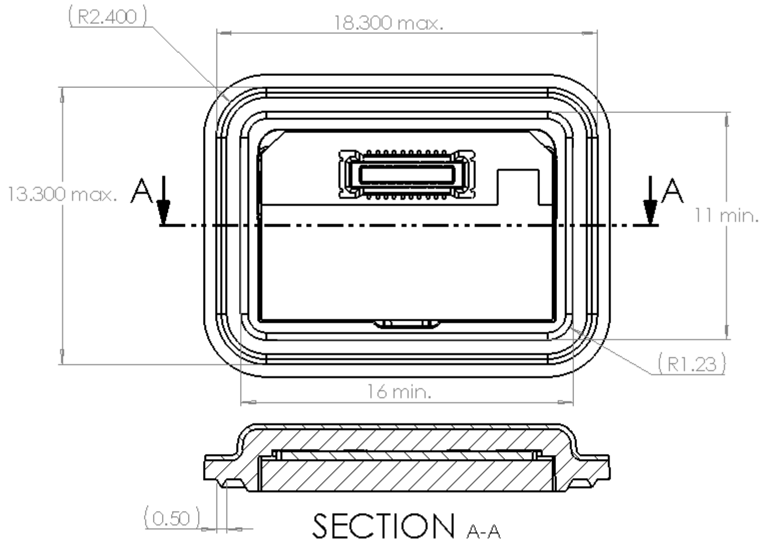


Figure 10: BW 1.2 Cross-Section Drawing



There is an ultrasonic weld rib that is designed along the inner edge of the lens frame, as shown in Figure 9 and Figure 10. This weld rib is used to ensure a good seal using ultrasonic welding to the customer's plastic enclosure bottom. For ultrasonic welding design and process guidelines as well as 3D CAD models of the sensor module, please contact Valencell.

The mechanical design has been optimized to reduce the impact of the sensor module on industrial design, especially in total sensor height when built into the device housing. It is designed for easy integration into the bottom shell of a wristband, wristwatch, or armband with part of the module protruding into the interior of the wrist product (~1 mm), and part protruding from the bottom of the wrist product (1.5mm). This design balance provides optimal sensor accuracy with minimal disruption to other components of the interior of the product design.

For additional capture feature design and adhesive process guidelines and more complete details on sensor integration refer to the Benchmark™ Wrist Sensor Integration Guide and BW1.2 Sensor 3D CAD models.

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7 Processor Communication Interface Example

An example of the processor communications interface protocol is described in short detail below. Simple packet based commands are used to Get or Set measurement readings or parameters, or to control the PerformTek™ processor. For a full description of the interface protocol, please refer to the 000638 Valencell PerformTek™ Interface Protocol document.

- Command: Get(0x08)

The GET command issues requests for parameters and measured values from the PerformTek™ output registers. The purpose of these register values can range from declarations about the firmware features to the most recently calculated value for heart rate.

Following is an example of a GET command that requests three values (heart rate, step rate, and calories):

PerformTek™ Start	Byte Count	GET Command	BPM Request	SPM Request	CALS Request
0x44	0x04	0x08	0x20	0x30	0x42

- Command: Set (0x04)

The SET command writes configuration values to PerformTek™ registers. The purpose of these register values can range from declarations about the capability of the application, to information needed by the algorithms about the user.

Here is an example of a typical SET command that sends three user information parameters (age, gender, and weight):

PerformTek™ Start	Byte Count	SET Command
0x44	0x0A	0x04

. . .

. . .

age	34.5 years old		gender	female		weight	140 lbs	
0x10	0x01	0x9E	0x11	0x00	0x00	0x12	0x02	0x7B

Other interface commands control PerformTek™ processor operation. Full specifications of the API are available.

8 Sensor Ordering Guide

Part Number	Description
000945	Benchmark™ Ear 2.0
000915	Benchmark™ Ear 1.2
001034	Benchmark™ Wrist 2.0
000954	Benchmark™ Wrist 1.2

9 Incoming QC Module Test Fixture

Benchmark™ sensors are 100% optically tested at the factory using a Valencell-designed VIPER test fixture. As an option, these VIPER test fixtures are available for customers to use as part of their incoming inspection process. The test fixtures are available for purchase – please contact Valencell for pricing, availability, and additional details.

10 Valencell Product Development Design and Test Services

Valencell has years of experience helping customers bring accurate biometric hearable and wearable devices to market. Much of our experience has been captured in application notes and in the integration and user guides, but additional design and test support is available upon request to help reduce your time to market and lower your technical development risks. Our support can span all stages of the product development process, from concept development through mass production and marketing. Design support examples include assisting with placement and mechanical integration of the sensor module within the product being worn; product fit and comfort; power-supply design; and audio design considerations for hearable designs.

Additionally, product performance should be backed by a solid test plan. Valencell has a sophisticated exercise and sport physiology test lab where products using our sensors are tested for proper performance. Our biometric sensors have been tested on thousands of test subjects with the statistical analysis done in a way that conforms to medical and sports journal publication standards. Testing is carried out both indoors and outdoors under many different activities with pools of subjects that have different skin tones, weight, hair, and fitness levels. Results from our sensor tests can be seen in the form of technical white papers on the Valencell website here: www.valencell.com/white-papers. Valencell Labs is located in the U.S. where there is a good diversity of test subjects. Our lab can validate the accuracy and performance of your product design and provide a statistical analysis as part of a design feedback report along with suggestions to improve the product design. This type of testing is the best and only way to know how well your product will perform when introduced into the market.

For more information about our support options, please contact Valencell.

11 Contact Information

For additional information please contact:

Sales Support: benchmark@valencell.com

Technical Support: support@valencell.com

Valencell, Inc.
4601 Six Forks Rd. Suite 103
Raleigh, NC 27609
www.valencell.com

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