Benchmark Biometric Sensor System for Hearable Devices

Features

- Chest-Strap quality optical heart rate (HR) measurement, HR zone, HR recovery, resting HR, step rate / count, distance cycling cadence, calories, at-rest R-R interval (RRi) and activity recognition (running/lifestyle)
- The Benchmark sensor and PerformTek™ processor minimize space impact to the hearable design and provide design flexibility
- Sensor module contains an LED, optical detector with data conversion circuitry, and an accelerometer mounted to a lens 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

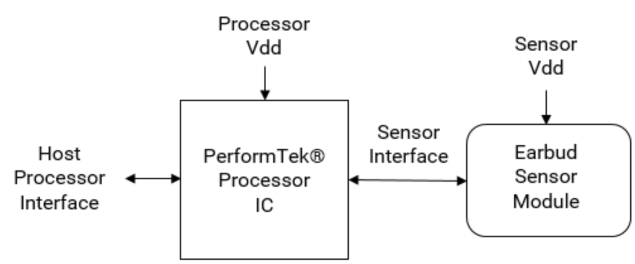
Figure 1: BE4.0 Processor and Sensor with Dime for Scale

- Ear Sensor Dimensions: (10.0 x 4.4 x5.0) mm
- Processor: CSP-49, 0.35 mm pitch,
- (2.56 x 2.59 x 0.45) mm
- Sensor Weight 0.175 grams
- 400 kHz I2C or 57.6 kbps UART interface
- Processor VDD: 1.8 VDC to 3.3 VDC
- Sensor VDD(SENSE): 3.3 VDC
- V_{DD} Current: 255 µA standard operating; 142 uA Standby, and Idle modes
- $V_{DD(SENSE)}$ Current: 0.2 mA standard operating
- Field updatable processor firmware
- Patented optomechanical designs
- 100% factory-tested optical and sensor performance

Description

The PerformTek powered Benchmark Ear 4.0 (BE4.0) Sensor System is an update to the BE2.0 biometric sensor technology developed by Valencell, Inc. to integrate a lower power processor. 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: BE4.0 Simplified Block Diagram



Applications

- In-canal or in-concha wired or wireless headphones
- Hearing aids
- Mono Bluetooth headsets
- Wireless smart audio assistants

Reference Documentation

Table 1: Related Documents

Document	Title
000638	PerformTek Interface Protocol Document
000964	PerformTek User Guide
000532	PerformTek Earbud Integration Guide
000881	Benchmark BE2.0 Sensor Drawing and 3D CAD models
001113	Valencell Heart Rate Variability Review
DS-A2-1p0 (External)	Ambiq Micro Apollo2 MCU Datasheet (Revision 1.0 at time of 001621 Release)

Change Record

Table 2: Change Record

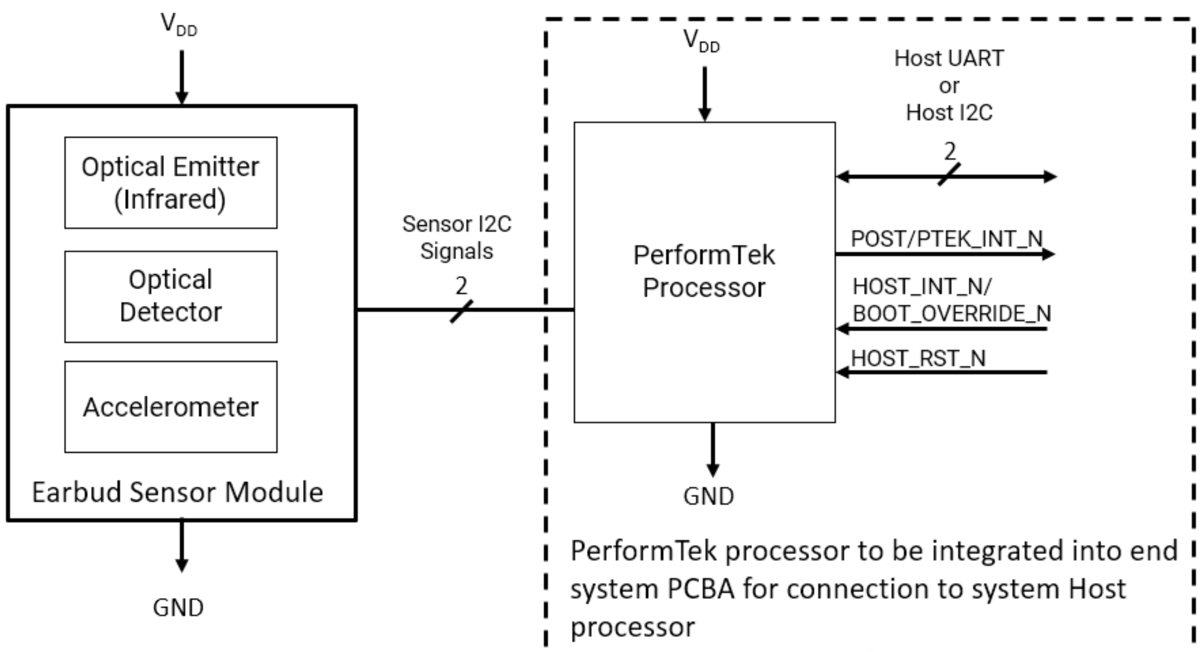
Author	Revision	Date	Description of change(s)
MEP	1.0	05AUG2018	Initial Release

Table of Contents

1 Block Diagram / System Overview

The Benchmark Ear 4.0 Biometric Sensor solution is provided in two pieces, the sensor and the PerformTek processor. Figure 3 shows how these pieces work together and is described below.

Figure 3: Benchmark Ear 4.0 Functional Block Diagram



On the left of the diagram, the sensor module circuit board contains a digital optical detector system, an infrared LED, and an accelerometer. The detector, LED, and accelerometer work together to collect biometric information via reflected light and movement from the wearer. This information is transmitted over the sensor's I2C bus when requested by the PerformTek processor.

The 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 an I2C or UART, power-on self-test / sensor interrupt output (POST / PTEK_INT_N), and sensor interrupt / bootloader mode select input (HOST_INT_N / BOOT_OVERRIDE_N). More details on this interface are provided in Section 4.2. For I2C serial communications with the Host processor, the PerformTek processor acts as the I2C slave role and the Host processor acts as the I2C Master.

2 Pin Descriptions

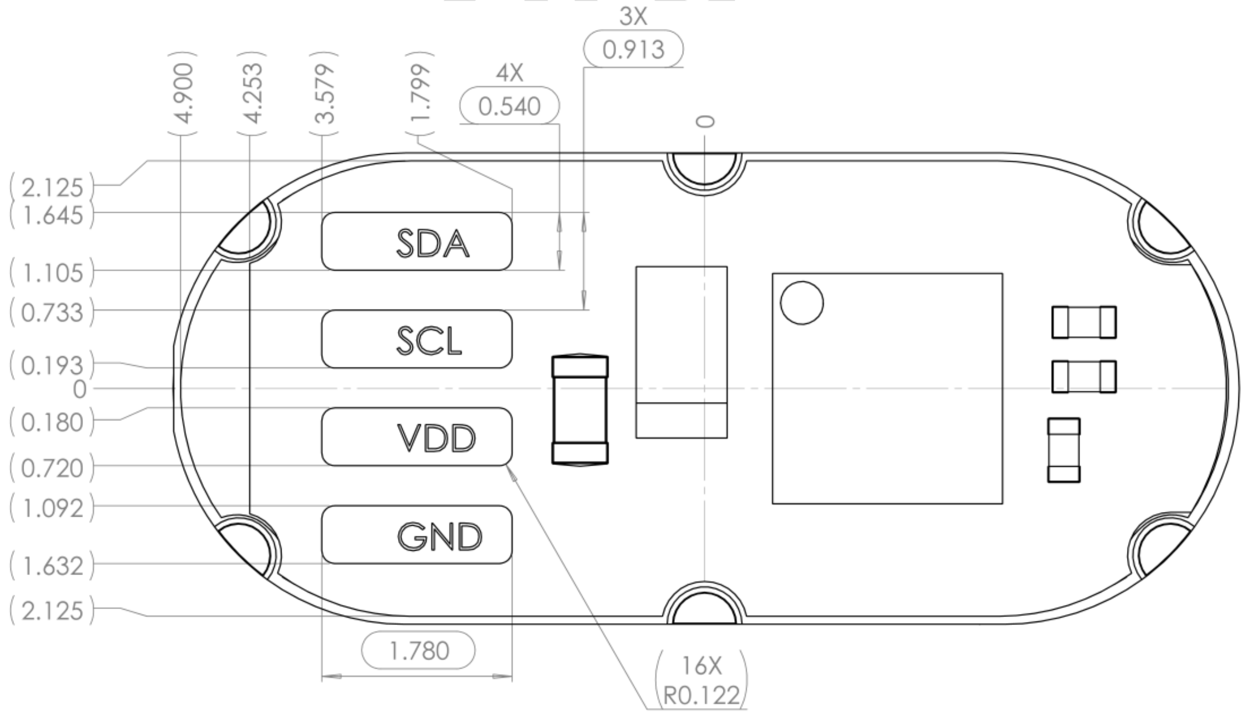
2.1 Sensor Pinout

Table 3 and Figure 4 show the pinout for the Earbud sensor. Solder pads are provided for individual wire or custom flex cable connection.

Table 3: Sensor Pinout

Pin Number	Symbol	Description
1	GND	Connect to system ground / reference plane
2	$V_{DD(SENSE)}$	Sensor 3.3 VDC Power. Connect to sensor supply voltage
3	SENSOR_I2C_SCL	I2C Clock Line. Connect to PerformTek Processor
4	SENSOR_I2C_SDA	I2C Data Line. Connect to PerformTek Processor

Figure 4: BE4.0 Sensor Drawing and Solder Pads



2.2 PerformTek Processor Pin Description

Table 4 provides a description of the pin assignments to the PerformTek processor. See the Ambiq Micro Apollo2 MCU Datasheet for the 49-pin WLCSP processor package information.

Table 4: Processor Pinout

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
PAD0	G7	Input	HOST_I2C_SCL	SLSCL	Host to PeformTek MCU Interface: I2C Clock Note: I2C is one of two supported Host interfaces. Connect the Host to either the I2C or UART interface pins and leave the ununsed Host interface pins unconnected.
PAD1	F5	Input / Output	HOST_I2C _SDA	SLSDA	Host to PerformTek MCU Interface: I2C Data Note: I2C is one of two supported Host interfaces. Connect Host to either the I2C or UART interface pins and leave the ununsed Host interface pins unconnected.
PAD2	E4	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD3	F7	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD4	G1	N/A	N/C	N/A	No Connect - Reserved for Future Use

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
PAD5	E5	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD6	D7	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD7	D5	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD8	F2	Output	SENSOR_I2C_SCL	M1SCL	Sensor Interface: Sensor I2C SCL
PAD9	G3	Input / Output	SENSOR_I2C _SDA	M1SDA	Sensor Interface: Sensor I2C SDA
PAD10	G2	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD11	B3	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD12	B2	N/A	N/C	N/A	No Connect / Reserved for Future Use
PAD13	C2	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD14	B1	Output	HOST_UART_TX	UART1TX	Host to PerformTek MCU Interface: UART TX to Host from MCU Note: UART is one of two supported Host Interfaces. Connect Host to either the I2C or UART interface pins and leave the ununsed Host interface pins unconnected.

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
PAD15	A1	Input	HOST_UART_RX	UART1RX	Host to PerformTek MCU Interface: UART RX from Host to MCU Note: UART is one of two supported Host Interfaces. Connect Host to either the I2C or UART interface pins and leave the ununsed Host interface pins unconnected.
PAD16	C3	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD17	D3	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD18	B4	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD19	A4	Input	N/C	N/A	No Connect - Reserved for Future Use
PAD20	E1	Input	DBG_SWDCK	SWDCK	Serial Wire Debug Clock If space allows it, connect to test point / pad for debug support
PAD21	D6	Input / Output	DBG_SWDIO	SWDIO	Serial Wire Debug Data If space allows it, connect to test point / pad for debug support
PAD22	F4	N/A	N/C	N/A	No Connect - Reserved for Future Use

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
PAD23	C1	Input	HOST_INT_N / BOOT_OVERRIDE_N	GPIO23	Host to PerformTek MCU Interface: This pin serves two functions: 1. HOST_INT_N: A software configurable input 2. BOOT_OVERRIDE_N: May be asserted by the Host processor during the PerformTek processor bootup to enter bootloader mode.
PAD26	E3	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD28	D2	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD29	A3	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD39	E2	Input	N/C	N/A	No Connect - Reserved for Future Use
PAD40	D1	Input	N/C	N/A	No Connect - Reserved for Future Use

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
PAD41	G6	Output	SENSOR_PWR	GPIO41	PerformTek MCU Sensor Interface: SENSOR_PWR High-Side Switch / Power control for the sensor. This pin may be connected directly to sensor $V_{DD(SENSE)}$ to supply sensor power directly if the MCU is powered from 3.3VDC or it may be used to control a load switch. Use of this pin as a power supply for the sensor has an impact on MCU and sensor power supply design. See Section 5 for more details.
PAD44	F1	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD47	E6	N/A	N/C	N/A	No Connect - Reserved for Future Use
PAD48	E7	N/A	N/C	N/A	No Connect - Reserved for Future Use

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
PAD49	F6	Output	POST / PTEK_INT_N	GPIO49	Perform Tek MCU Host Interface: This pin serves two functions: 1. Power-on self-test (POST) output: This pin will present a logic high after the power up process is complete 2. Software configurable output
ADC_VREF	A2	Input	ADC_REF	N/A	No Connect - Reserved for Future Use
nRST	G4	Input	HOST_RST_N	nRST	PerformTek MCU Reset: A logic low input on this pin will reset the processor Connect to system reset and add a capacitor as shown in Figure 5. Note that an external resistor is not required because of the MCU's internal pull-up on this net.
XO	A4	Output	XO	N/A	Crystal oscillator circuit output pin Connect to a 32.768 kHz Crystal
SWC	A7	Output	COREBUCK_SW	N/A	Memory Buck Converter Inductor Switch Node Connect to 2.2 µH Inductor

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
XI	B5	Input	XI	N/A	Crystal oscillator circuit output pin Connect to 32.768 kHz Crystal Note: The crystal input is highly sensitive to external leakage on the XI pin. Therefore, it is recommended to minimize the components on XI and to use low leakage load capacitors. Good quality ceramic capacitors will usually meet this low leakage guideline.
SMM	B7	Output	MEMBUCK_SW	N/A	Memory Buck Converter Inductor Switch Node Connect to 2.2 µH Inductor
VDDC	A6	Input	VDDC	N/A	Core Buck Converter Voltage Output Supply (Input to PerformTek MCU Core). Typical value: 0.7 VDC
VDDF	D4	Input	VDDF	N/A	Memory Buck Converter Voltage Output Supply (Input to PerformTek MCU Memory). Typical value: 0.9 VDC
VDDP	B6, B7	Power	VDDP	N/A	Pad Supply Voltage
VDDA	C5	Power	VDDA	N/A	Analog Supply Voltage
VDDH	G5	Power	VDDH	N/A	Digital Supply Voltage

MCU Pad	Pin / Ball	Direction with respect to MCU	Name	MCU Pad Function Selection	Description
VSSL, VSSA, VSSP	F3, C4, C6	Ground	GND	N/A	Power Input References

3 Electrical Characteristics

3.1 Sensor

Table 5: Recommended Operating Conditions for Sensor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Sensor Supply Voltage	$V_{DD(SENSE)}$	Min and Max are inclusive of V_{DD} ripple requirement	3.2	3.3	3.6	VDC
Sensor ripple voltage_10	V_{ripple_10}	Sensor system active: 0 to 10 MHz Ripple	-	-	50	mV_{pp}
Sensor ripple voltage_100	V_{ripple_100}	Sensor system active: >10 MHz to 100 MHz Ripple	-	-	100	mV_{pp}
Operating Temperature	-	Device operating in Standby, Idle, or Active Modes	-10	25	50	ºC

Table 6: Operating Characteristics of Sensor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Sensor Current OFF Mode	-	No V_{DD} supply given to sensor module	-	0	-	µA
Sensor Current Standby and Idle Modes	-	System is in Standby mode	-	5	32	µA
Sensor Current Active Mode, Standard-Precision RRi	-	System is in Active mode and operating at standard RRi sampling rate	-	0.204	0.240	mA
Sensor Current Active Mode, High-Precision RRi	-	System is in Active mode and operating at fast RRi sampling rate	-	0.965	1.15	mA

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Sensor Current Active Mode, Best-Precision RRi	-	System is in Active mode and operating at fastest RRi sampling rate	-	1.91	2.04	mA
Sensor Pulse Current	I_{pulse}	System is in Active mode	-	TBD (10 to 15)	TBD	mA

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 7: 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 come 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.

3.2 PerformTek Processor

PerformTek-specific and high-level processor characteristics are provided below. See the processor datasheet for more details.

Table 8: Recommended Operating Conditions for PerformTek Processor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
V_{DD} Supply Voltage[1]	V_{DD}	Processor internal Power-On Reset Enabled	1.76	3.3	3.63	V
Voltage on any Pin	V_{INPUT}	Valid input signal voltage	0	-	V_{DD}	V

Note 1: Processor $V_{DD} = V_{DDP} = V_{DDH} = V_{DDA}$

Table 9: Operating Characteristics of PerformTek Processor

Parameter	Symbol	Conditions	Min	Typ	Max	Units
I_{DD} Standby Mode	I_{STBY}	System is in Standby mode	-	173	-	µA
I_{DD} Idle Mode	-	V_{DD} = 1.8VDC System is in Idle mode	-	173	-	µA
I_{DD} Active Mode with Standard-Precision RRi[1]	-	V_{DD} = 1.8VDC System is in Active mode and operating at standard RRi sampling rate	-	255	-	µA
I_{DD} Active Mode with High-Precision RRi[1]	-	V_{DD} = 1.8VDC System is in Active mode and operating at fast RRi sampling rate	-	457	-	µA
I_{DD} Idle Mode	-	V_{DD} = 3.3VDC System is in Idle mode	-	142	-	µA
I_{DD} Active Mode with Standard-Precision RRi[1]	-	V_{DD} = 3.3VDC System is in Active mode and operating at standard RRi sampling rate	-	255	-	µA

Parameter	Symbol	Conditions	Min	Typ	Max	Units
I_{DD} Active Mode with High-Precision RRi[1]	-	V_{DD} = 3.3VDC System is in Active mode and operating at fast RRi sampling rate	-	509	-	μA
I_{DD} Processor Pulse Current[2]	I_{pulse}	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	-	TBD	-	ms

Note 1: High-Precision operation and current draw applies to RRi only. Best-precision heart rate monitoring is available in standard Active Mode.

Note 2: Estimate only. Processor pulse current will be dependent on local decoupling design and layout

4 PerformTek Processor Integration

4.1 PerformTek Processor Schematic

The included PerformTek processor is implemented on an Ambiq Micro Apollo2 processor. This processor provides significant power savings from Ambiq's patented Subthreshold Power Optimized Technology (SPOT). This is an ARM Cortex-M4 based processor and is provided in a 49-pin Chip Scale Package (CSP)

The processor is programmed by Valencell, Inc. with PerformTek custom firmware and algorithms. To interface with this programmed processor, please use the schematic diagram shown in Figure 5, the recommended component list in Table 10, and the associated interface descriptions that follow. For additional electrical and physical specifications for this processor, consult the Apollo2 datasheet and associated documentation available at https://ambiqmicro.com or contact your local Ambiq Micro sales representative.

Figure 5: Processor Connection Schematic (Both I2C and UART Host Connections Shown)

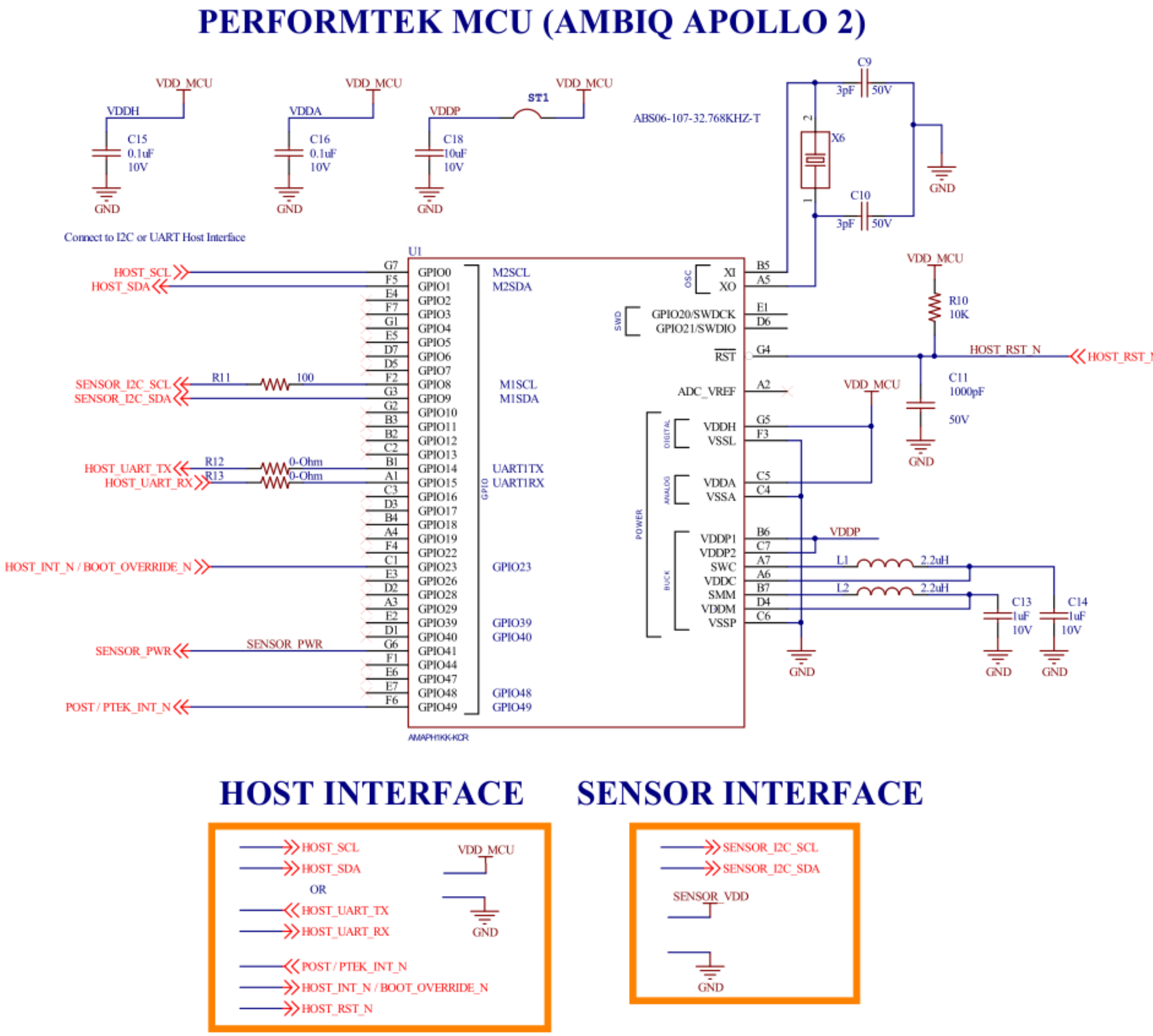


Table 10: Recommended Supporting Components

Description	Manufacturer	Manufacturer Part Number
2.2 µH Buck Supply Inductors	Taiyo Yuden Bourns	MBKK1608T2R2M (0603) package) SRN2010TA-2R2M (0806 package)
32 kHz Crystal	KDS Abracon	DST1610A 32.768kHz (1.6x1.0x0.5 mm) ABS06-107-32.768KHZ-T (2.0x1.2x0.6 mm)

4.2 PerformTek Processor Connections

Host Interface – UART / I2C

The Host interface that connects the system processor to the PerformTek processor supports both I2C and UART communications. Either I2C or UART should be connected to the Host since only one interface can be used at a time. The PerformTek processor will automatically detect the active interface. On boot up, the PerformTek processor will scan both communications ports until activity is detected on one of them. For optimal power savings, it is recommended to exercise one of the ports so that the PerformTek processor can shut down the unused port. Additionally, no external pull-up resistors are required for correct operation of the PerformTek MCU I2C port, since it provides internal pull-ups. If pull-ups are required for other devices on the I2C bus while the PerformTek MCU is powered off or in reset, external pull-up resistors may be added. If external pull-ups are added, the interface will consume additional power through the external resistors.

For UART Host communications, the HOST_UART_RX pin is the receive line for data sent to the module from the Host processor and the HOST_UART_TX pin is the transmit line from the sensor module to the Host. The port settings are 57.6 kbps, 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 device with up to 400KHz bus speed and a 7-bit I2C address of 0x45. This interface has been updated from previous generations of the PerformTek I2C interface to support the Ambiq lower power interface. For more information about the UART or I2C communication protocols or to see more details on updates associated with the I2C interface, see the PerformTek Interface Protocol Document.

Host Interface – POST / PTEK_INT_N

Once V_{DD} power is applied, the processor will attempt to initialize all components on the module. This startup time is defined by t_{POST} in Table 9. If startup is successful, the POST / PTEK_INT_N 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 this 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_RESULTS register should be examined at startup.

After successful bootup and assertion of the POST status, the POST / PTEK_INT_N provides software configurable interrupt output functionality from the PerformTek processor to the Host.

Refer to the PerformTek Interface Protocol Document for further information on the POST, other diagnostic registers, and interrupt configuration.

Host Interface – HOST_INT_N / BOOT_OVERRIDE_N

Upon application of V_{DD} power or upon release of reset, the PerformTek processor will enter Bootloader mode if HOST_INT_N / BOOT_OVERRIDE_N is asserted low.

During normal operation, HOST_INT_N / BOOT_OVERRIDE_N provides software configurable interrupt input functionality from the Host to the PerformTek processor.

Refer to the PerformTek Interface Protocol Document for further information on Bootloader mode and interrupt configuration.

Host Interface – HOST_RST_N

HOST_RST_N is an active low reset signal connected to the HOST controller to allow it to control reset of the PerformTek processor. Valencell recommends connecting this line to the Host controller as part of a robust system reset strategy. HOST_RST_N should be tied to a decoupling capacitor placed close to the HOST_RST_N processor pin as shown in Figure 5.

Note: Current consumption is undefined while the PerformTek processor is held in reset. HOST_RST_N should not be used as a method to hold the PerformTek processor in a low power state. Removing power from the MCU or placing the MCU in Standby mode is the best method for achieving minimum power consumption when the sensor is not in use.

Crystal Oscillator

A clock reference is required for correct operation of the PerformTek MCU. Valencell recommends a KDS DST1610A 32.768kHz crystal, an Abracon ABS06-107-32.768KHZ-T, or equivalent. Note; for maximum space savings the KDS DST1210A 32.768kHz may also be used but has not been tested by Valencell. See the Apollo2 datasheet and associated documentation for more information on the use of the crystal including additional crystal selection criteria and design guidance.

Inductors

To minimize power consumption, the PerformTek processor uses internal buck regulators to convert VDD to the lower voltages used by the processor. To support this functionality, two external inductors are required along with the capacitors shown in Figure 5. To minimize the impact to the overall processor footprint, Valencell recommends the Taiyo Yuden MBKK1608T2R2M, 2.2 µH 0603 inductor.

Decoupling

The capacitors shown in Figure 5 are necessary to reduce noise and ensure measurement accuracy and proper processor functionality. These capacitors should be placed physically near the V_{DD} pins of the processor.

Firmware Updates

The PerformTek processor supports in-field firmware updates via the Host interface. Driving the PerformTek processor's HOST_INT_N / BOOT_OVERRIDE_N pin high low during boot up puts the device into bootloader mode. Refer to the PerformTek User Guide for further information on this feature.

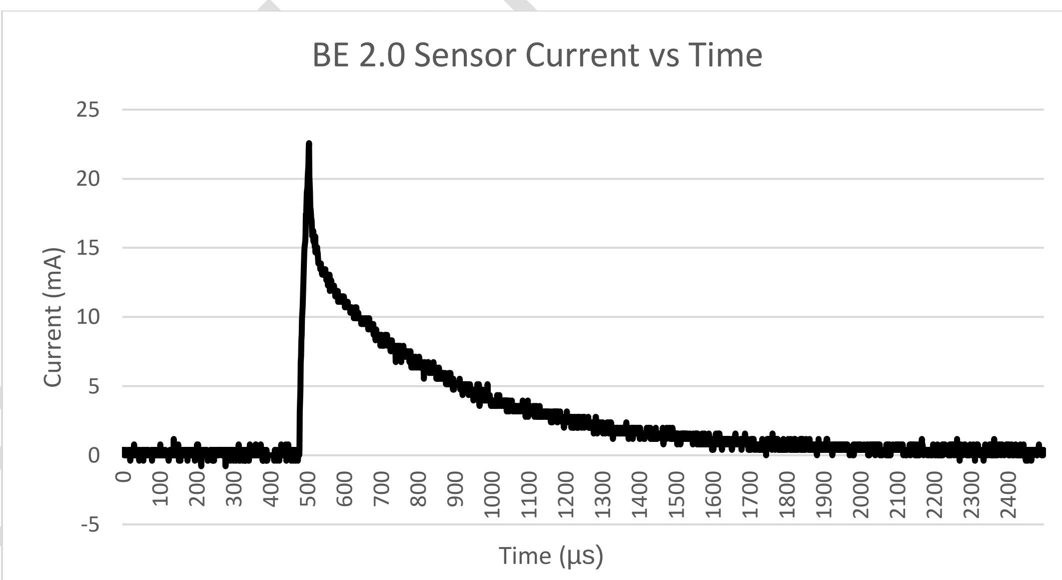
5 Additional Electrical Design Guidelines

5.1 Power Supply Loading

The PerformTek processor and sensor may be supplied from the same rail (V_{DD} and $V_{DD(SENSE)}$ combined) or may be supplied separately. If they are supplied together, care must be taken to ensure that the voltage tolerances and ripple specifications for the sensor are still followed. The system power supply or supplies should be designed to meet the requirements in Section 3 during transients from both the Benchmark sensor and processor. If SENSOR_PWR is used to supply $V_{DD(SENSE)}$, system power supply design and overall layout can still impact power quality, and the design must still be verified to meet all specified power requirements.

Peak $V_{DD(SENSE)}$ current will be periodic where the period of the peaks will depend on the mode of operation Heart Rate and Standard-Precision RRi (40 ms), High-Precision RRi (8 ms), and Best-Precision RRi (4 ms). A typical current peak profile for sensor $V_{DD(SENSE)}$ is shown in Figure 6. Note: As part of the update for BE4.0, the peak current is expected to be reduced. The BE2.0 sensor current profile is shown here for reference.

Figure 6: Typical BE2.0 Sensor Current Pulse



The $V_{DD(SENSE)}$ current profile shown here and the V_{DD} current peak listed in Section 3 are based on measured system performance. Processor V_{DD} current peaks are of smaller amplitude and much smaller duration than $V_{DD(SENSE)}$ current peaks. Actual peak and average V_{DD} processor current peak and average numbers will vary depending on the unique characteristics of the system design and 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 and can provide design support and review services upon request.

5.2 Power Supply Rise Time

The power supplied to the processor's VDDP pin must not exceed a rise time of 2kV/s. This rise time is impacted by the system power supply, bulk capacitance on VDDP and bulk capacitance and loading on the processor's SENSOR_PWR pin. Early testing should be performed with the system power supply design to ensure that this rise time limit is not violated.

5.3 Mixed Voltage Operation

Lowest overall power consumption is achieved when the PerformTek processor operating voltage is minimized. If the supply voltage to the processor is reduced below the specification for the sensor, logic level translation must be implemented for the I2C signals between the sensor and PerformTek processor.

5.4 Audio Quality Design Guidelines

While the Benchmark sensor does not generate any perceptible audible noise on its own, it is possible for system power supply noise or crosstalk from the sensor I2C lines to interfere with audio quality if appropriate system design considerations are not followed. To mitigate potential noise issues, design considerations should include:

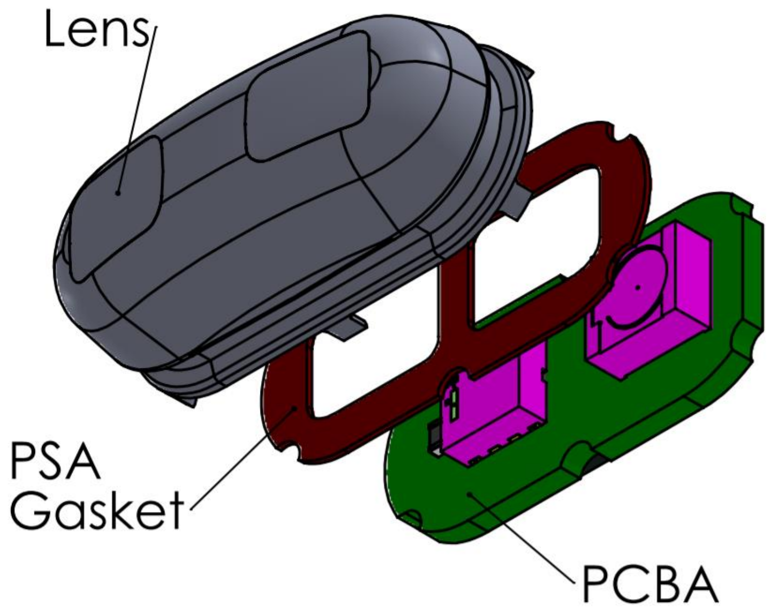
- Good power and ground plane design and decoupling to minimize conducted system noise into sensor and / or audio cabling
- Appropriate audio circuit and system grounding to ensure any coupled noise is either returned to the system reference as appropriate or blocked by appropriate isolation

Isolation of audio circuitry signals from sensor I2C, power, and ground lines to minimize crosstalk (This may be accomplished by a combination of PCB routing and or cable design as appropriate)

6 Sensor Optical-Mechanical Integration

The sensor component is a critical part of the measurement system and is designed to ensure good optical coupling from the emitter and detector to the user's skin. Placement and proper integration of the sensor into the hearable system housing is critical for accurate measurement. The lens frame is a two-shot molded PC opaque frame onto an optical grade PC lens. The PCB and opto-mechanical lens is tested at module production as an assembly and should not be disassembled.

Figure 7: Earbud Sensor Image



The optical lens system is shown in Figure 7. There is a mating rib along the outer edge of the lens frame. This rib is used as a capture feature to ensure a good seal using adhesive to the customer's system enclosure.

The mechanical design has been optimized to reduce the impact of the sensor module on the industrial design, while still maintaining the necessary positioning for sensor accuracy. It is designed for easy integration into the shell of a hearable assembly and the design balance provides optimal sensor accuracy with minimal disruption to other components of the interior of the enclosure design.

For capture feature design and adhesive process guidelines and more complete details on sensor integration refer to the Benchmark Ear Sensor Integration Guide and BE2.0 Sensor 2D and 3D CAD models. Note, the BE2.0 sensor is dimensionally identical to the BE4.0, so the BE2.0 mechanical design files apply to both BE2.0 and BE4.0.

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. For full specifications, consult the PerformTek Interface Protocol document.

8 Benchmark Sensor Ordering Guide

Part Number	Description
000945	Benchmark Ear 2.0
001706	Benchmark Ear 4.0
001701	Benchmark Wearable 4.0
001034	Benchmark Wearable 2.0
000954	Benchmark Wearable 1.2

9 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.

10 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

11 Statements

Valencell reserves the right to make changes to its products or example designs as part of its development program. This document and any other related support materials (collectively, the "Materials") are intended to serve as resources only and users should not rely on them to ensure compliance with any laws or requirements.

Benchmark™ and PerformTek™ technology are not designed or authorized for use in life support, medical, or safety critical applications.

THE MATERIALS ARE PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL VALENCELL, INC., BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE MATERIALS.

No license is granted or implied under any patent or other rights owned by Valencell, Inc., by the publication or transfer of the information contained herein. Unless otherwise stated, words and logos marked with ® or ™ are trademarks registered or owned by Valencell, Inc. Other products, services and names used in this document may have been trademarked by their respective owners.

Patent Notice:
Protected by granted patents and/or patents pending: www.valencell.com/patents
Both Benchmark™ and PerformTek™ and the Benchmark™ and PerformTek™ designs are registered trademarks of Valencell, Inc. and may not be used for any purpose without the express prior written consent of Valencell, Inc.