

Hearables Body Temperature Monitor Flex PCB Strip Reference Design



Description

This reference design demonstrates using the TMP117 to measure accurate body temperature through the ear from a hearable design. This design implements two TMP117 devices on a small flexible that is suitable for hearable devices. Two temperature sensors are integrated onto the design to compensate for system or ambient temperature changes that can affect the accuracy of the body temperature measurements.

Resources

TIDA-060034	Design Folder
TMP117	Product Folder

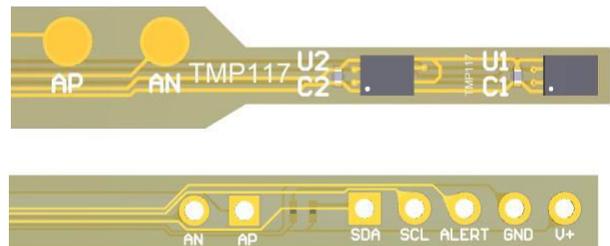
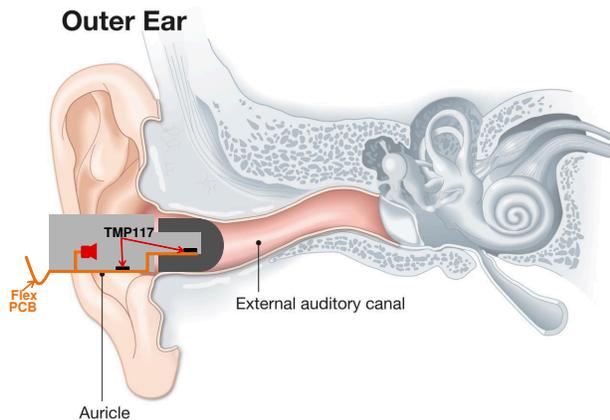
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Features

- TMP117: ± 0.1 °C max, 3.5 μ A Ultra-low Power Temperature Sensor
 - TMP117 #1 In-Ear Membrane Temperature
 - TMP117 #2 System/Ambient Temperature
- Integrated Speaker Soldering Pads and Audio Input Connection
- Thin-Film Flexible Material
- Breakout for Connection to External MCU

Applications

- [Headset, Headphone, and Earbuds](#)
- [Hearing Aid](#)



1 System Description

With the increasing demand for health data collection, the need for accurate body temperature monitoring has become very desirable. Tracking body temperature trends has been used to indicate potential illnesses, disruptions in sleep cycles, athletes' recovery status, and other health trends.

While oral and rectal measurements are common and accurate methods of measuring body temperature, they are extremely intrusive. A less intrusive method to measure accurate body temperature is through the ear via the tympanic membrane. Measuring body temperature through the ear has been a common practice for decades and integrating high-accurate temperature sensors into hearable devices, such as earbuds or hearing aids, can be used to do the same.

Hearable devices are in close proximity to the tympanic membrane and can create a seal in the ear canal making a practical environment to get consistent temperature measurements relative to one's body temperature. Headphones, earbuds, and hearing aids are designed to be very comfortable so they can be worn for hours and sometimes days continuously. This allows for continuous tracking of an individual's temperature and can establish trends of normal temperatures and any deviations from normal which could indicate potential infections, hormonal shifts, or diseases.

The TMP117 high-accuracy, low-power, digital temperature sensor can send 16-bit digital temperature data through I²C to a microcontroller. Since the surrounding electronic system and ambient temperature can create different offsets in the temperature reading, a second TMP117 can be used to adjust for thermal gradients between the body temperature and these environmental temperatures.

This hearable design integrates two TMP117 temperature sensors; one for measuring the in-ear temperature (main sensor), and another for system and ambient temperature sensing (secondary sensor). The reference design is on an extremely low profile thin-film flex cable making it easily integrated into a hearable device and features breakout headers and speaker soldering pads to support different MCUs, power supplies, and speakers.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Operating power supply range	1.8-5.5 V	TMP117 supply range
TMP117: Operating Temperature	-55 °C to 150 °C	
TMP117:Temperature Accuracy	0.1 °C from -20.0 to 50 °C	Exceeds requirements for human body temperature measurements
Form Factor	2-layer flexible PCB	

2 System Overview

2.1 Block Diagram

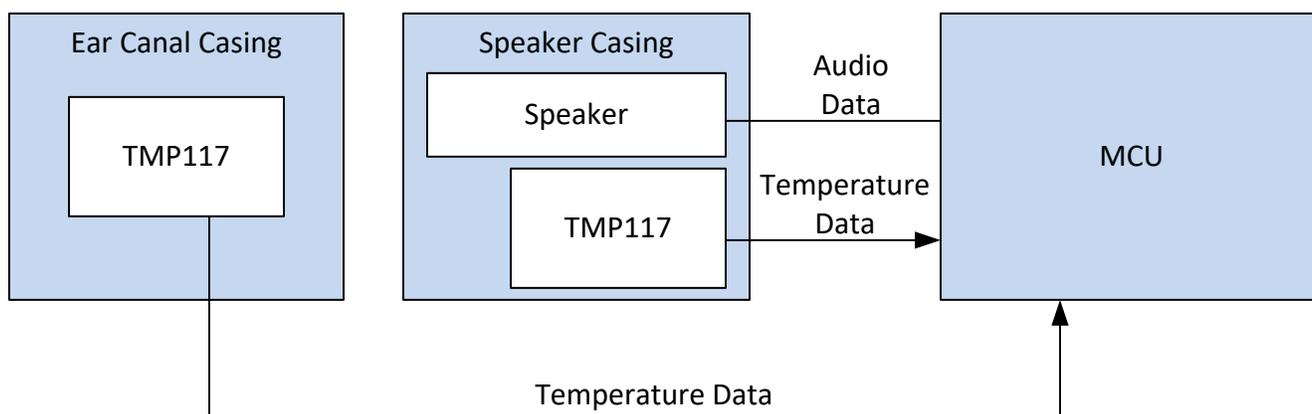


Figure 2-1. TIDA-060034 Block Diagram

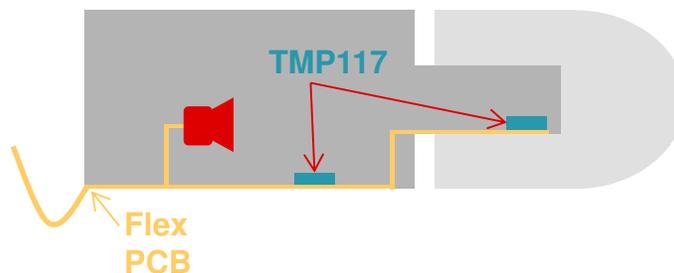


Figure 2-2. TIDA-060034 System Diagram

2.2 Design Considerations

There are a few important design considerations to implement to achieve accurate body temperature measurements. The most important design consideration is that the main sensor should be placed as close to the tympanic membrane of the ear and isolated from other heat sources such as ambient temperature or heat from the system. Secondly, other electrical components that generate heat such as batteries or microprocessors should be placed far from the main sensor. This is to minimize the heat transfer that can cause temperature errors to the main sensor. The hearable casing should also create a tight seal of the ear canal to limit temperature error from the ambient air. The secondary sensor should be placed by any heat source that can create a temperature error on the main sensor. This is to calibrate and correlate temperature affects from those heat sources.

2.3 Highlighted Products

The Hearables Body Temperature Monitor Flex PCB Strip Reference Design features the following device:

2.3.1 TMP117 – High-accuracy, low-power, digital temperature sensor

The TMP117 is a low-power, high-precision temperature sensor that provides a 16-bit temperature result, with a resolution of 7.8125 m°C and an accuracy of up to ± 0.1 °C with no calibration. The TMP117 operates from 1.8 V to 5.5 V, consuming 3.5 μ A typically, and comes in a 1.53 mm \times 1.00 mm DSBGA package. This small package allows for easy integration into small hearable devices as well as fast thermal response times. The device also features integrated EEPROM, and a temperature offset register which can be used for single-point calibration.

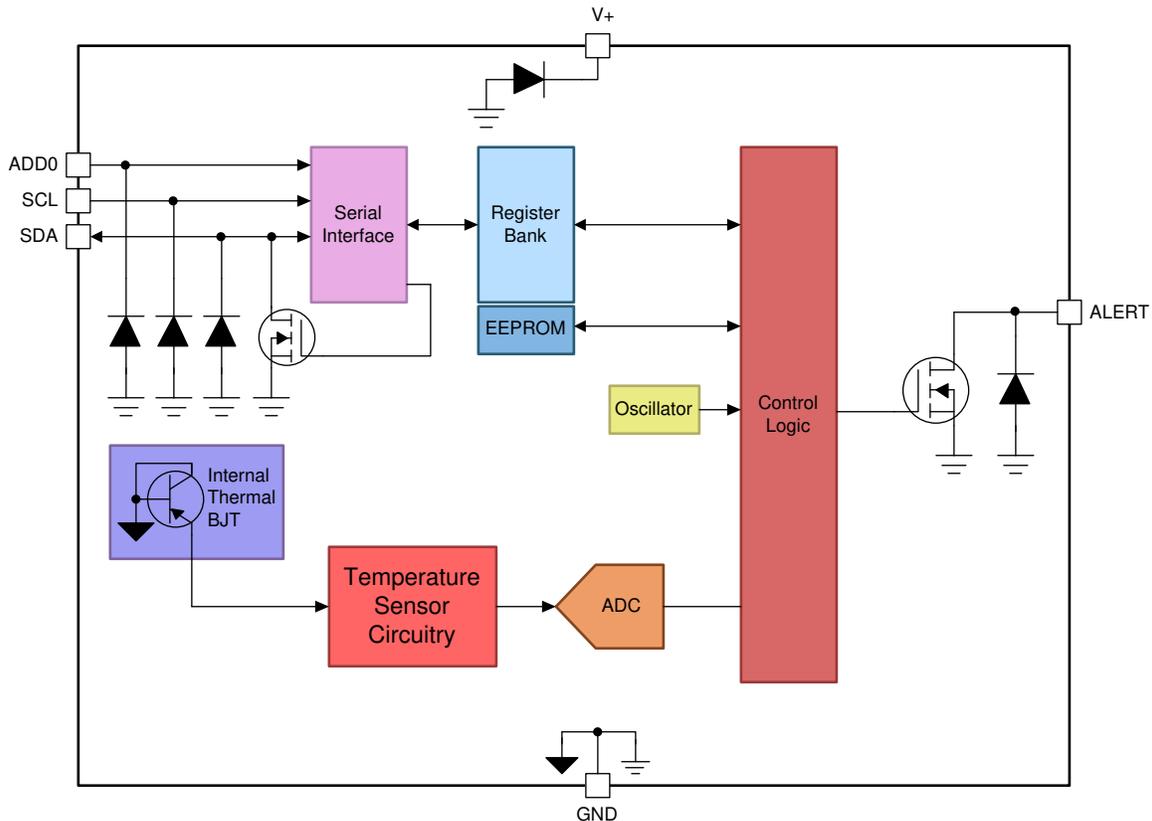


Figure 2-3. TMP117 Internal Block Diagram

2.3.2 System Design Theory

This design features headers to connect an MCU for communication to the TMP117 devices and inputs to a speaker as shown in Figure 2-4. There are also integrated speaker soldering pads towards the end to solder on a small speaker as shown in Figure 2-5. The two TMP117 are used to collect temperature data determine body temperature of the user.



Figure 2-4. MCU and Speaker Input Headers

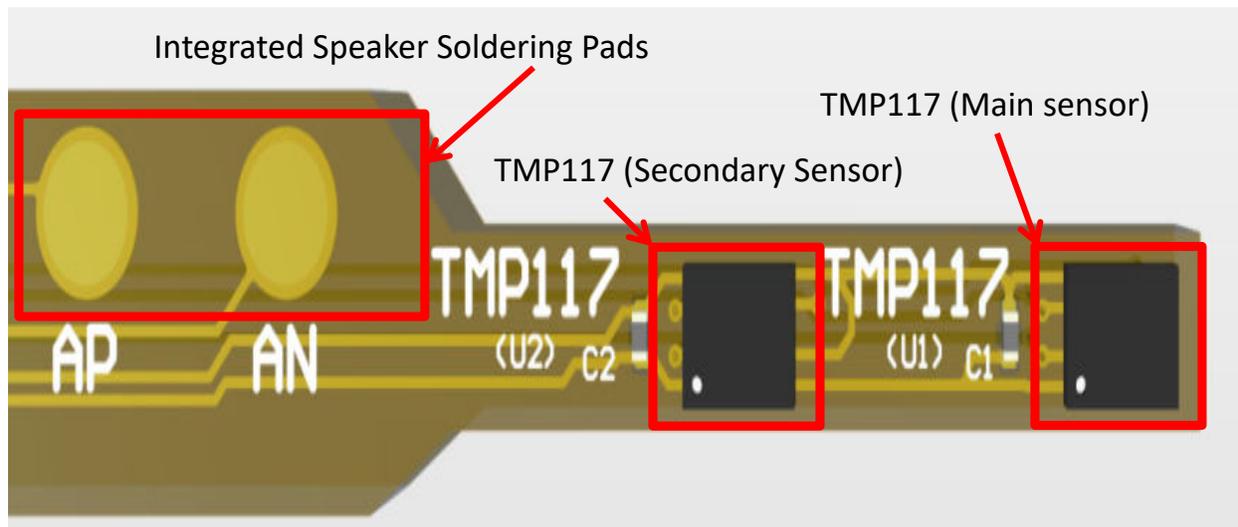


Figure 2-5. Integrated Speaker Soldering pads and TMP117 devices

2.3.2.1 System Accuracy

Table 2-1 shows a summary of specified accuracy of the TMP117. However, the designer must also consider the temperature offset caused by the integration of the device into a design for total system accuracy. A single-point calibration can be performed to negate a consistent temperature offset error in the system. This offset value can be stored in the temperature offset register of the TMP117.

Table 2-1. TMP117 Max Accuracy

TEMPERATURE RANGE	MAX ACCURACY °C
-20 °C to 50 °C	±0.1 °C
-40 °C to 70°C	±0.15 °C
-40 °C to 100°C	±0.2 °C

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware

The hearable flex board and a separate MCU are needed to test the design. The headers for the MCU were made to align with the headers on the TMP117EVM. The TMP117EVM can be broken into two sections: one with the TMP117 and the other with the USB2ANY as shown in Figure 3-1.

The USB2ANY portion can be used to communicate to both TMP117 devices using the [TMP117DualSensor_GUI](#) which can be found at the [Texas Instruments Gallery](#). The main sensor's 7-bit I²C address is 0x49 and the secondary sensor's 7-bit I²C address is 0x48.

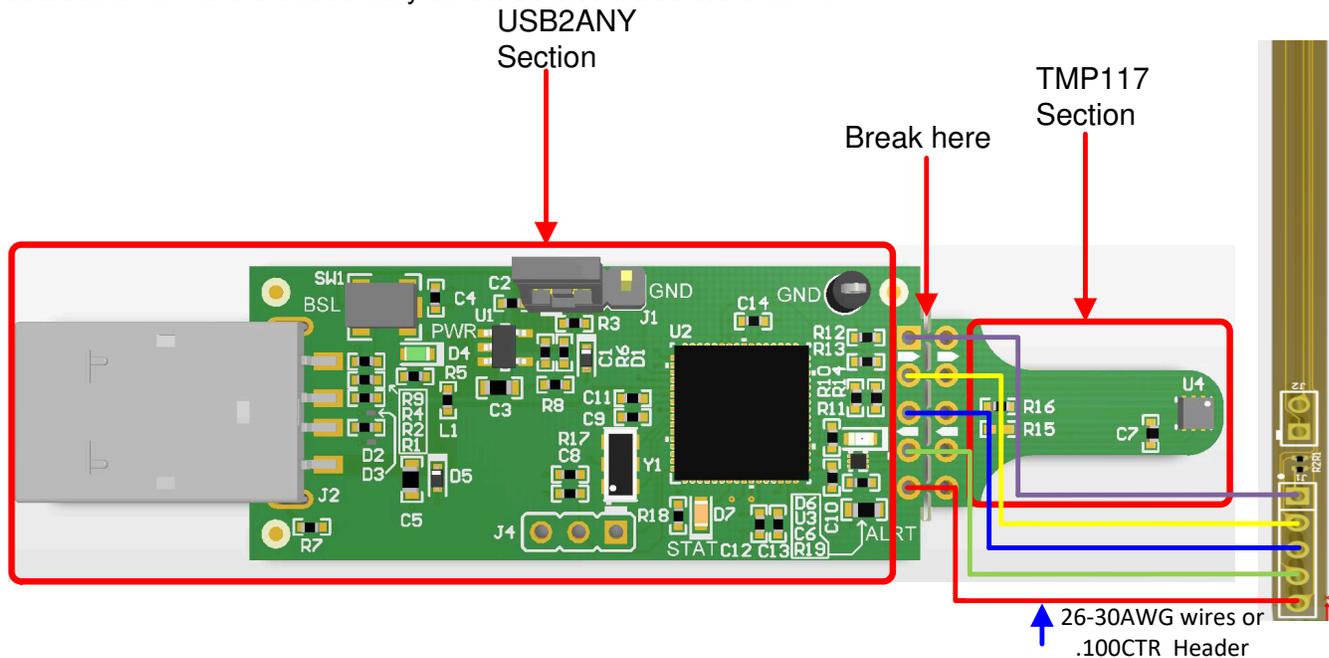


Figure 3-1. Connecting to TMP117EVM

3.2 Software

The [TMP117DualSensor_GUI](#) can be used to communicate with both TMP117 devices using a USB2ANY. The [SysConfig](#) tool can be used to write basic C code to configure, read, and write to the TMP117 devices. This code can be imported into and ran on the [Code Composer Studio](#).

3.2.1 SysConfig

To use the SysConfig tool go to the [TI SysConfig](#) page. This navigates to the home screen of SysConfig tool shown in Figure 3-2. Next, on the Software Product drop-down menu, select *Sensor & Signal Chain Code Studio*. Then select *Other* in the Device drop-down menu, and then click *Start*. The configuration screen shown in Figure 3-3 appears.

From this screen, click the + icon in the first section next to the TMP117. To communicate to both devices on the reference design add two TMP117 devices. The address of one of the devices will need to be updated to address 0x49 in the device address drop-down menu.

Next, the settings of the TMP117 devices can be adjusted using in the configuration drop-down menus. The generated code will reflect the settings from these drop-down menus.

Lastly, use the Save icons to save the files.

Welcome To **SysConfig**

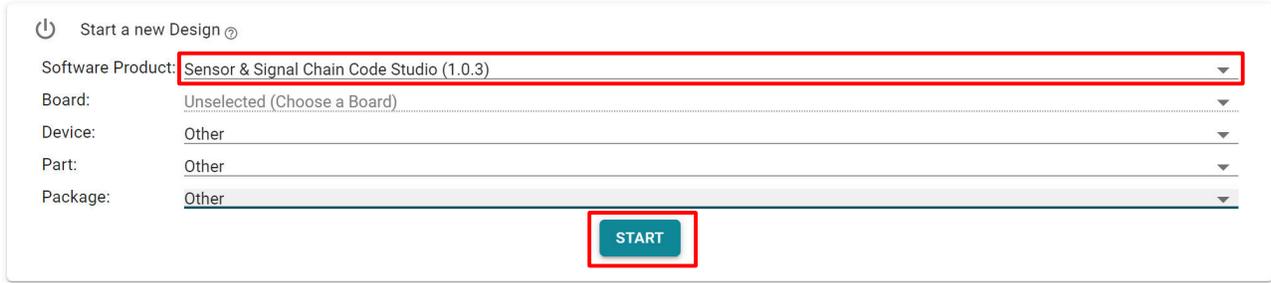


Figure 3-2. SysConfig Home Page

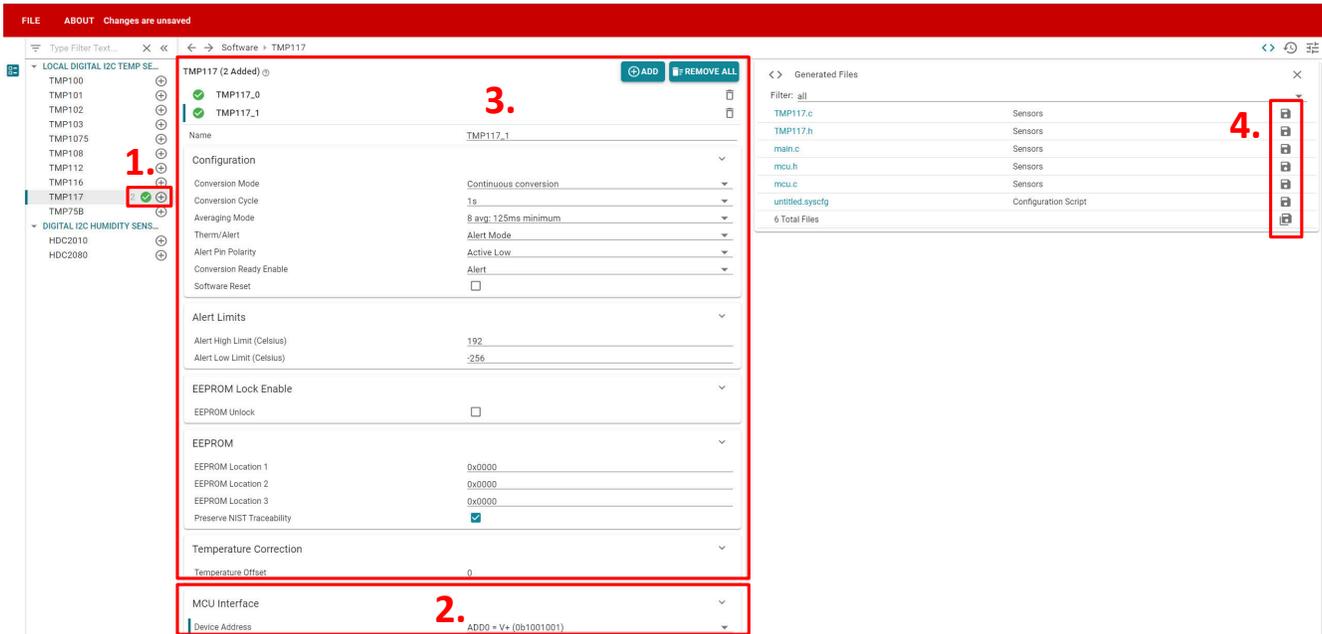


Figure 3-3. SysConfig Configuration Page

3.2.2 Graphical User Interface (GUI)

The EVM software is tested on the Microsoft Windows 7 and 10 operating system (OS). The software also functions on other Windows operating systems. This [hyperlink](#) will bring to TI Cloud where a common repository of all published applications using GUI Composer framework. The applications can be run directly from Gallery with minimal install.

3.2.2.1 Launching and Running the Software

First, connect the TMP117EVM to a USB port on a PC. The TMP117EVM is recognized by the host as a generic human interface device (HID), so there is no proprietary driver required to install on your PC. It shows the typical response to connecting the USB-to-I²C converter board to a PC USB port for the first time as shown in [Figure 3-4](#). Typically, the computer responds with a Found New Hardware, USB device pop-up dialog. The pop-up window then typically changes to *Found New Hardware, USB Human Interface Device*. This pop-up window indicates that the device is ready to be used. The USB-to-I²C Converter uses the human interface device drivers that are part of the Microsoft Windows® operating system.



Figure 3-4. USB Ready

Next, connect directly to the gallery by clicking [this link](#). It requires log on user account privileges to use the online version, as well as, installation of the applications.

On the top middle of the gallery main page, navigating to the Search field, enter *TMP117DualSensor_GUI* shown in [Figure 3-5](#).

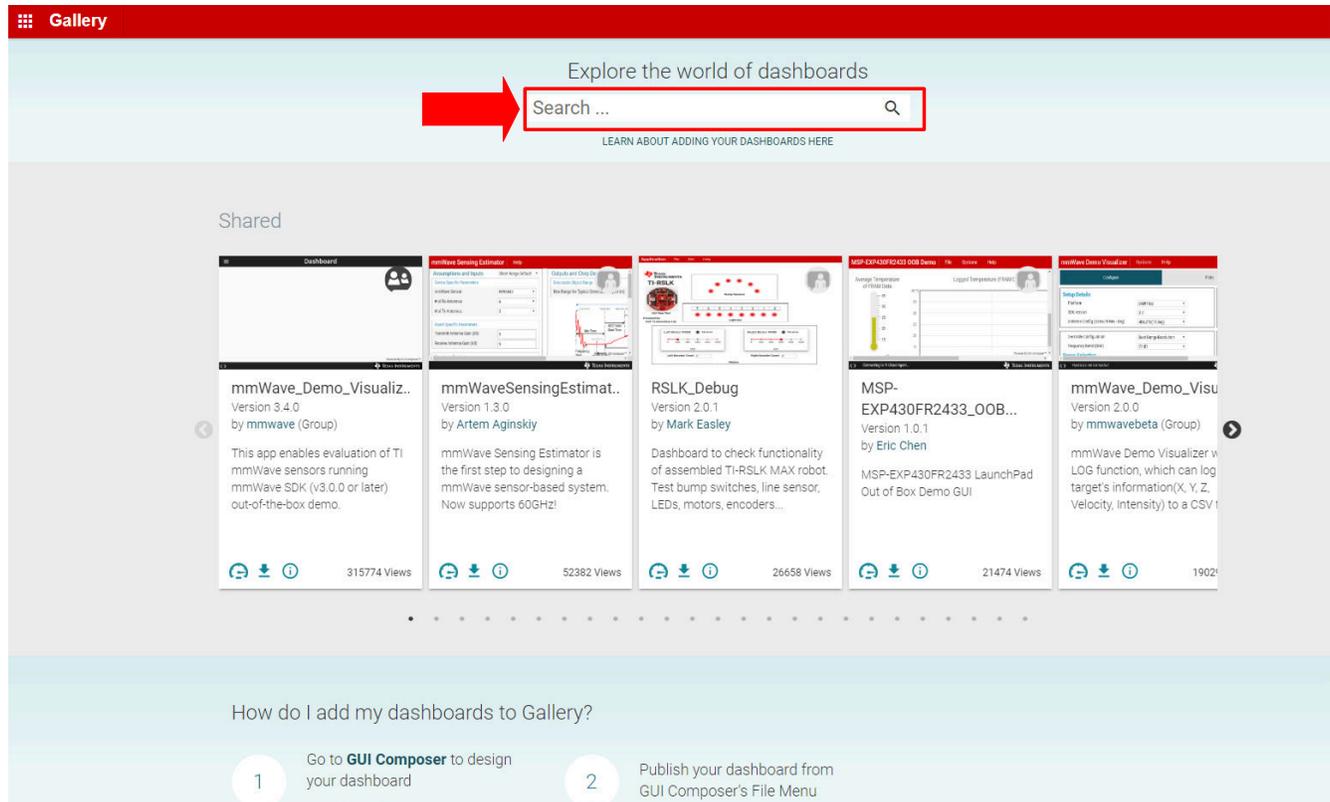


Figure 3-5. Gallery Home Page

Click the *TMP117DualSensor_GUI* icon. Users may be prompted to download and install the browser extension for the Firefox or Chrome and TI Cloud Agent Application for the first time. Click Agree and Proceed.

Follow the steps to install the browser extension and TI Cloud Agent Applications in [Figure 3-6](#).

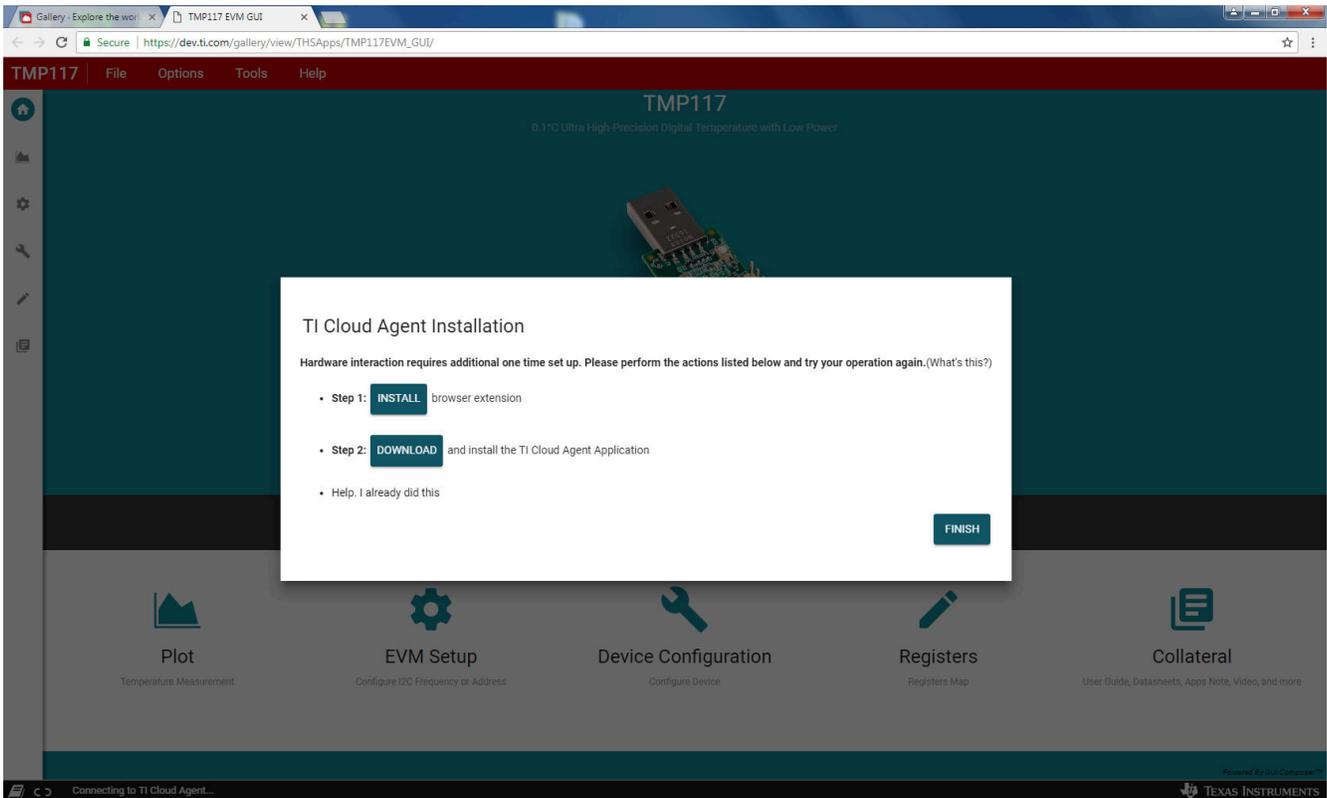


Figure 3-6. TI Cloud Agent Pop up

After installing TI Cloud Agent Applications The TMP117DualSensor_GUI should automatically initialize and connect to the HID port.

A successful connection will show *HARDWARE CONNECTED* on the bottom of the GUI status indicator as shown in Figure 3-7. If there is a connection problem, verify if the TMP117EVM has an established connection with the PC. A failed connection will show as *HARDWARE NOT CONNECTED* shown in Figure 3-8.



Figure 3-7. Hardware Connected



Figure 3-8. Hardware Not Connected

3.2.2.2 Using the GUI

The GUI consists of six tabs, Home, Data Capture, EVM Setup, Device Configuration, Registers, and Collateral. Launching the GUI takes you to the Home tab. There you can navigate between different tabs using the buttons towards the bottom or the tab bar on the left side which is available on all tabs.

3.2.2.2.1 Home Tab

When the TMP117DualSensor_GUI is launched, the Home page will be appeared as shown in Figure 3-9. There are two ways to navigate between tabs. On the bottom half of the Home page contains icons where it links to the five other GUI pages. The icons are identical features to those locked in the left-most border of the TMP117DualSensor_GUI. If TMP117EVM is powered and connected to the PC that has the correct firmware loaded, the Hardware Connected will appear at the left corner of the status bar as well as the connected icon shows solid.

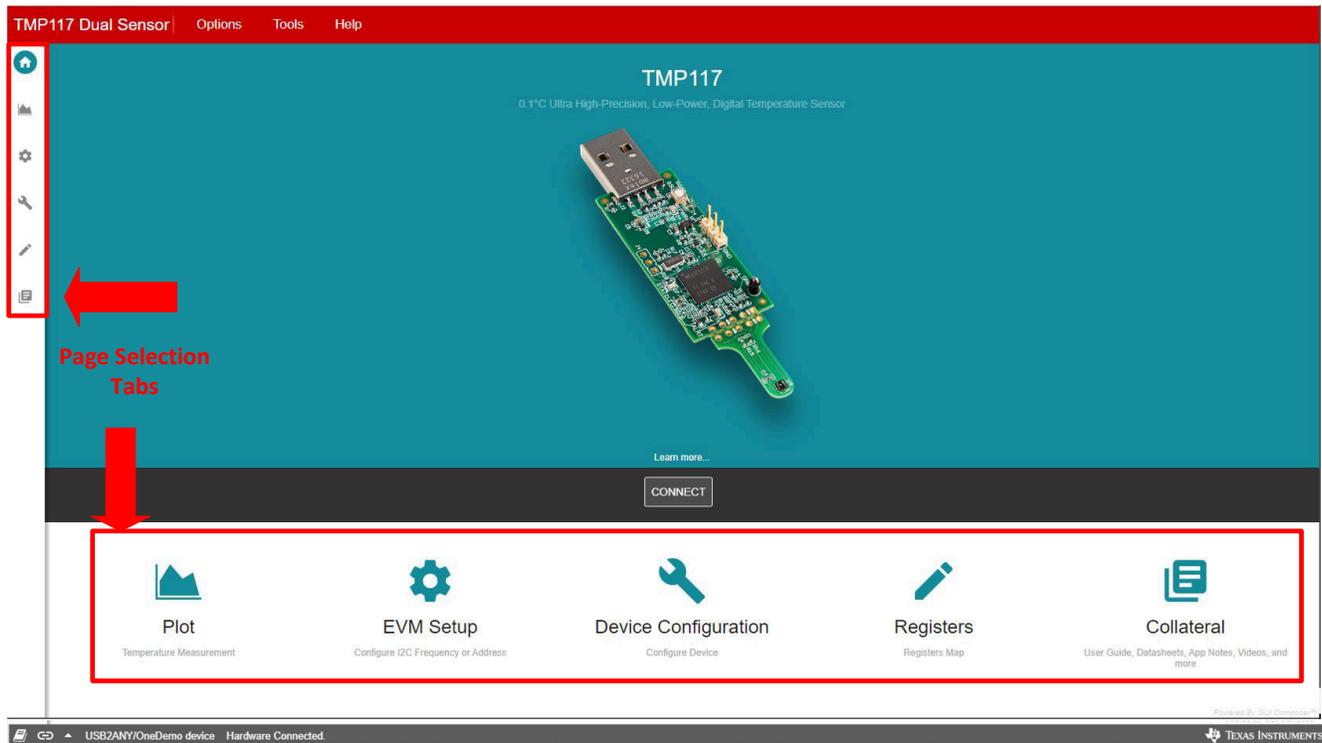


Figure 3-9. Home Tab

3.2.2.2.2 Data Capture Tab

The Data Capture tab provides a graph with the temperature results as well as other features as shown in [Figure 3-10](#). The temperature result will be fetched automatically according to the conversion cycle setting bits in the configuration register. The register data is converted into a human readable format for the GUI and displayed.

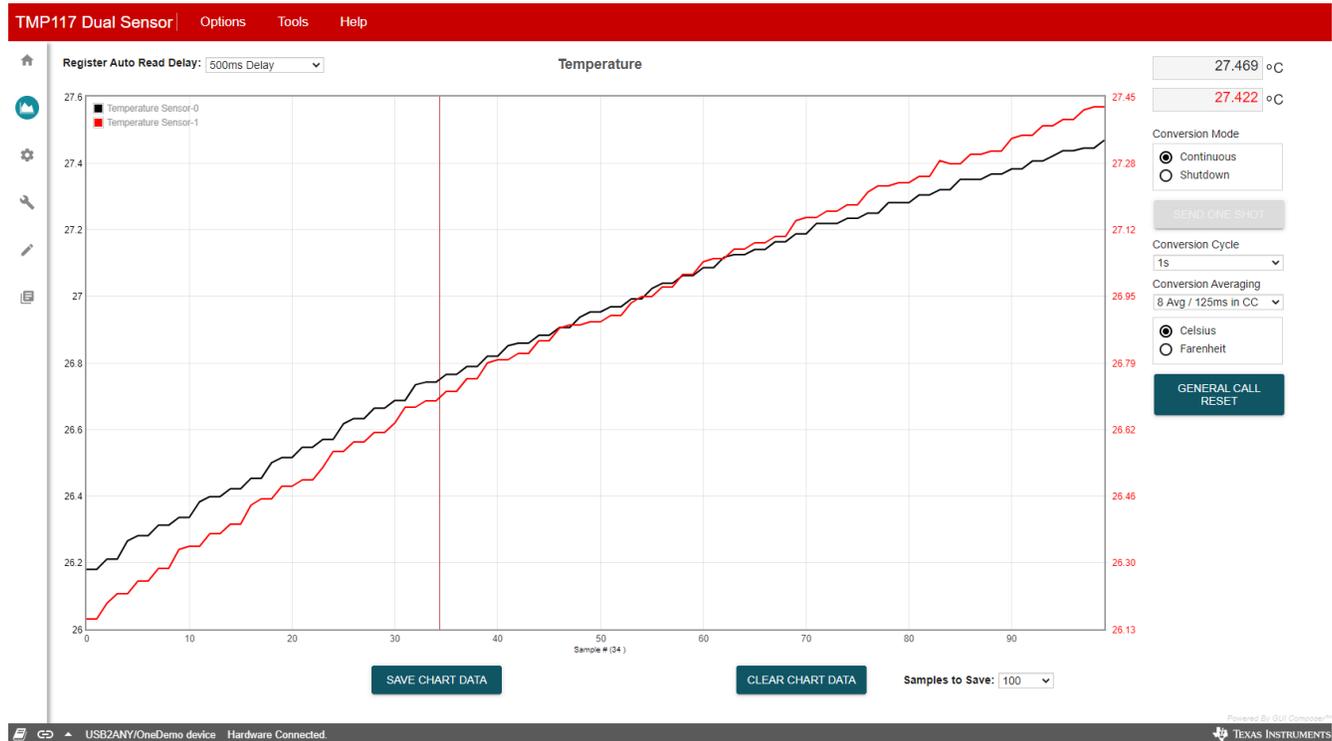


Figure 3-10. Data Capture Tab

- **Clear Chart** erases the contents of the Temperature Chart box
- **Save Chart** prompts for a file name, and then saves the contents of the current temperature graph box to a .csv file.
- **Current Value** shows the current temperatures of the TMP117 devices on the top right.
- **Celsius or Fahrenheit** chooses the unit that the temperature is displayed.
- **One Shot** is available on the Data Capture tab. The One Shot button writes to the TMP117 configuration register with the one-shot in conversion mode. This setting initiates a temperature conversion within the TMP117 device that updates the temperature result registers when the radio button is selected. After the one-shot conversion finishes, the device goes into shutdown.
- **Continuous** performs the temperature conversion continuously when the MOD[1:0] bits are configured in the configuration register to 00. Each temperature conversion consists of an active conversion period followed by a standby period based on the time of the conversion cycle and conversion averaging configuration.

3.2.2.2.3 EVM Setup Tab

The EVM Setup tab shown in [Figure 3-11](#) is where the I²C settings are set and firmware version and Device ID can be read. It is necessary to configure the TMP117 slave address as 0x48 and 0x49 for communication with the reference design.

- **Alert High and Low Limit Register** can be set by entering the value in °C or °F based on °C/°F control on the Data Capture tab that stores the high and low limits for comparison with the temperature result.
- **Offset Temperature** programs the offset temperature to compensate and improve the system error. This register will be cleared when powered down unless the LOCK is set.
- **Firmware Read** checks the firmware revision on the MSP430F5528 microcontroller.

I²C Configuration changes the bus frequency and slave address.

- **Device ID** automatically read device identification.
- **Software Reset** performs a software reset on the TMP117 devices by issuing a general call. After, the software reset, the values displayed in the EVM software may be out of sync with the device register contents. To sync register contents after TMP117 reset, click "Read All" in the Registers tab page.

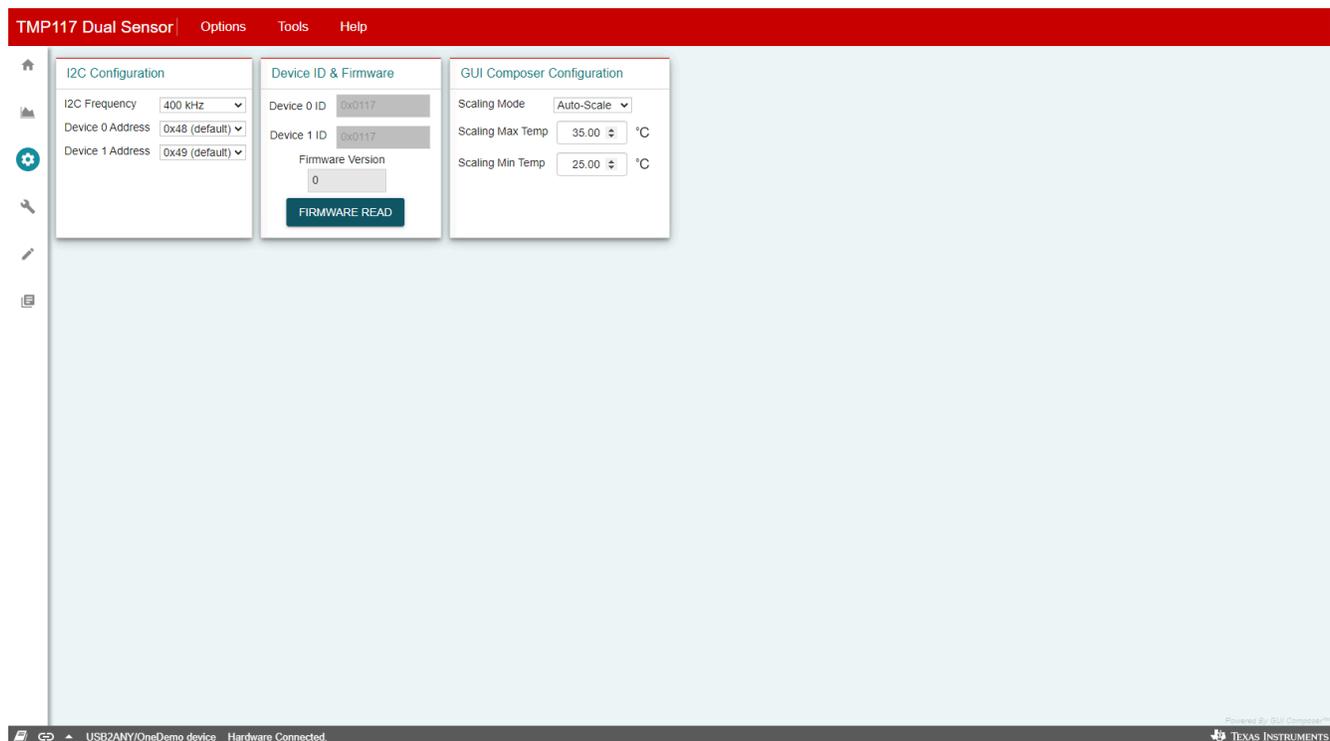


Figure 3-11. EVM Setup Page

3.2.2.2.4 Configuration Tab

The Device Configuration allows users to configure the devices' setting as shown in [Figure 3-12](#).

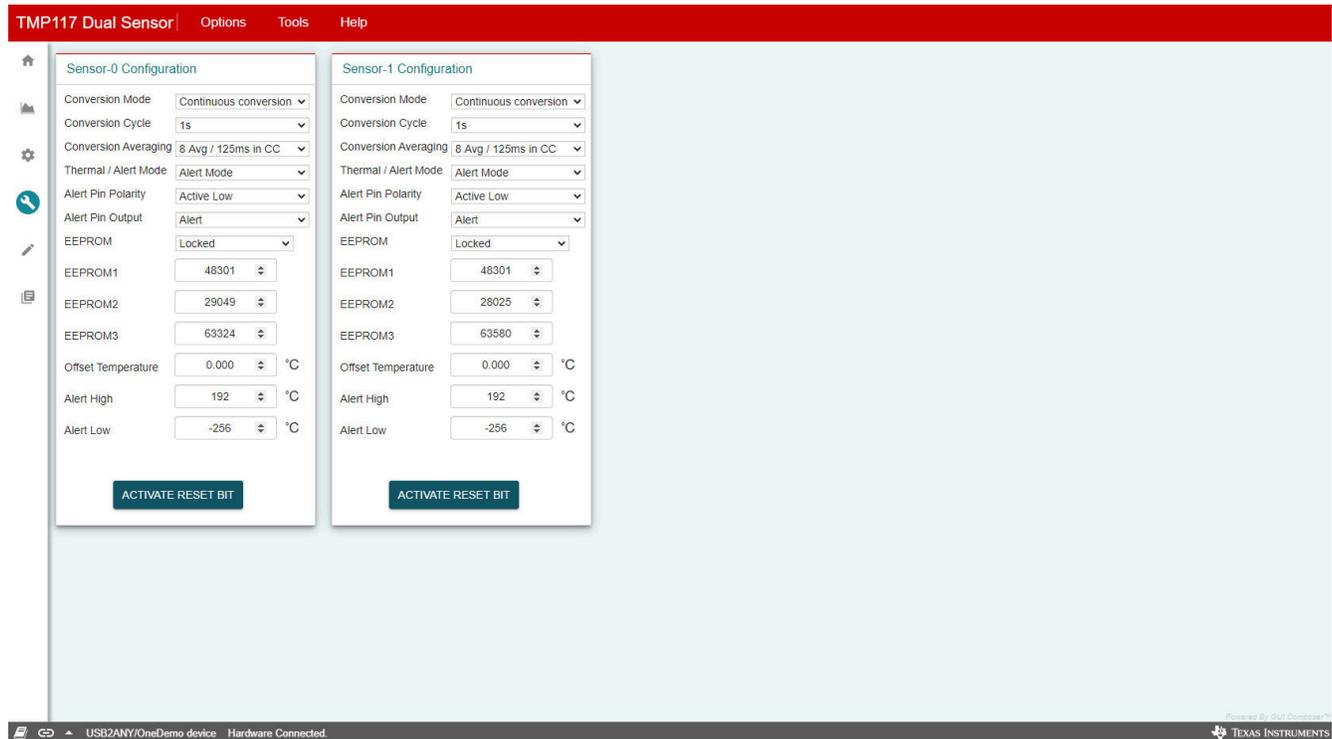


Figure 3-12. Configuration Tab

- **Configuration register** can be set to desired values by selecting the drop-down menu.
- **Non-volatile memory** can be programmed by entering the value at the EEPROMx boxes. Then use the EEPROM dropdown menu to lock the value. This LOCK bit will also lock the value of the offset temperature register.
- **Alert High and Low Limit register** can be set by entering the value in °C/°F. In Fahrenheit mode, it converts Fahrenheit to Celsius before it sends to the TMP117.
- **Status indicator** displays the outputs based on the status bits.
- **Temperature** displays the current temperature of the TMP117.
- **Offset Temperature** programs the offset temperature to compensate and improve the system error. This register will be cleared when powered down unless the LOCK is set.

3.2.2.2.5 Register Tab

The Register Map page, shown in Figure 3-13, allows low-level access to all I²C registers of the TMP117 devices and provides access to the registers raw data of the TMP117, performing read and writes commands. Clicking the question mark to the right of the Register Name brings up an extraction short version from the data sheet describing that register. Clicking on a specific Register Name populates the Field View to on the right side of the screen. The Field View describes each bit field within that register. Changes to the configuration page are mirrored here, and vice versa.

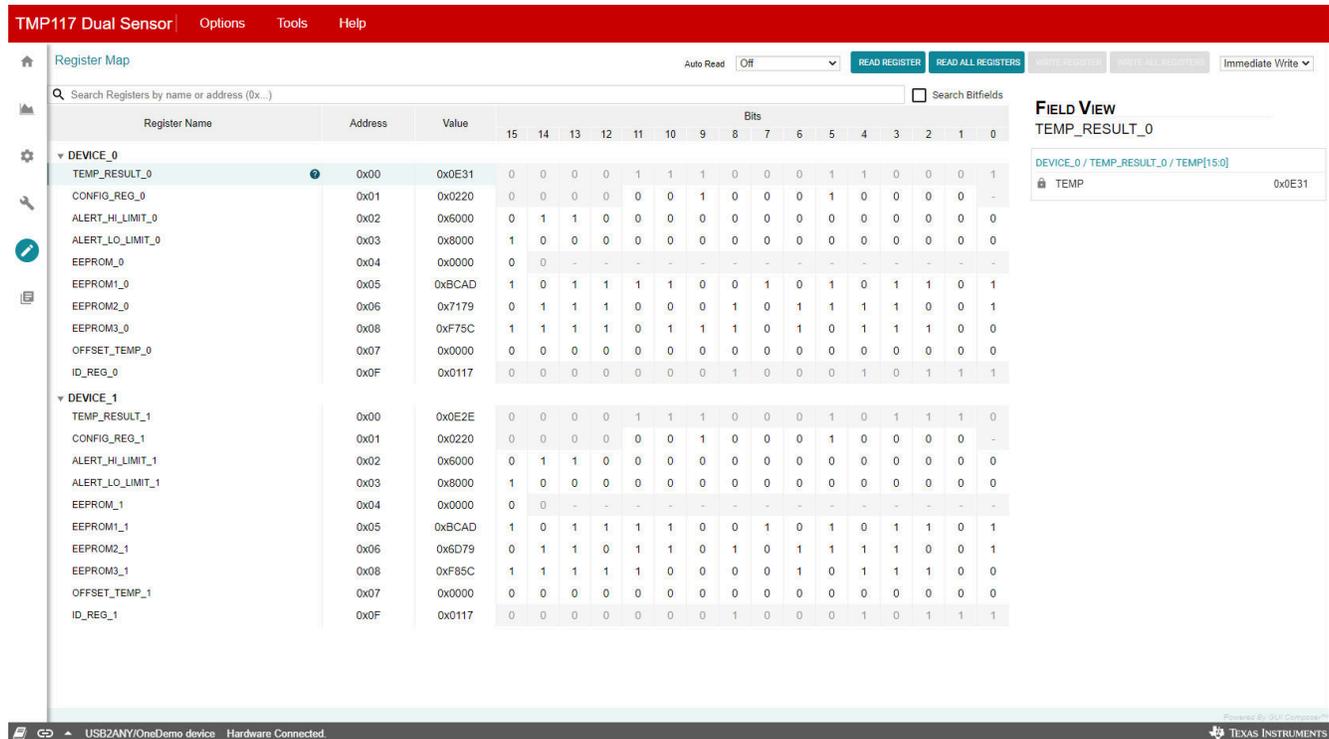


Figure 3-13. Register Tab

- **Read Registers** performs one single read for the selected register.
- **Read All Registers** performs a read for all registers contents.
- **Auto Read** sets the desired time frame fetching each data.

3.2.2.2.6 Collateral Tab

The last page of the GUI is the Collateral page, shown in [Figure 3-14](#), which contains links to web documents pertinent to the TMP117 and its EVM. The page is divided into four sections: (1) User Guide, (2) Data sheet, (3) Application Notes, (4) Video.

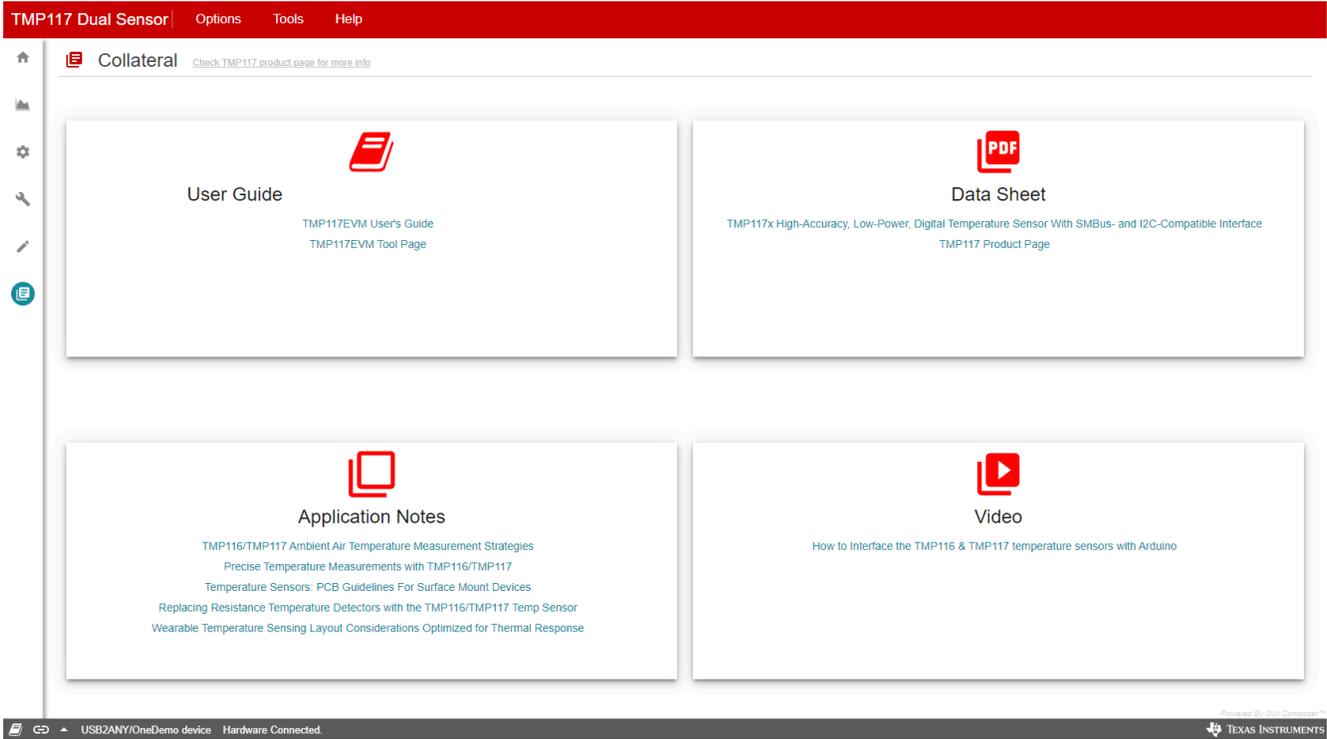


Figure 3-14. Collateral Page

3.3 Testing and Results

This data was collected on one subject to show proof of concept. Since each design will vary with regards to shape, size, self-heating, and other factors a statistically large sample size would have to be taken for a specific design to develop a scalable algorithm. For information on a commercially available algorithm and potential intellectual property rights related to system-level designs, contact WBD101 at their [website](#).

3.3.1 Test Setup

3.3.1.1 System Accuracy

Accuracy of the hearables body temperature monitor flex PCB strip was tested using a stirred oil bath and a calibrated probe. During accuracy testing, one of the flexible strips is submerged in a liquid oil bath and powered through an external 3.3 V supply. The bath is then moved through various points in the human body temperature range, and multiple readings are taken to correlate with the calibrated probe. The accuracy of the TMP117 is specified to be ± 0.1 °C within the typically human body temperature range.

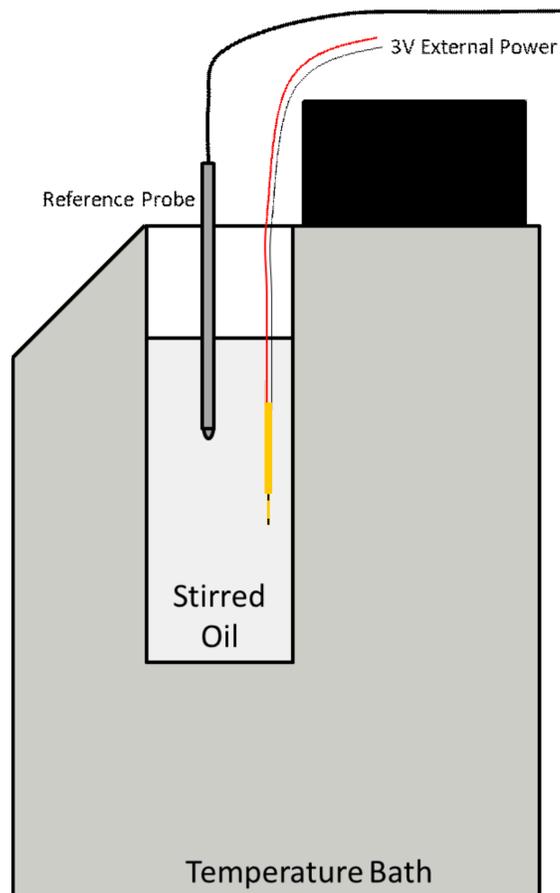


Figure 3-15. Accuracy Test Setup

3.3.2 Test Results

In total, 5 strips were tested for accuracy within the liquid oil-bath. The results are shown in [Figure 3-16](#). The strips were assessed to be well within the accuracy specifications with no additional calibration applied. For finished products packaging must be included during accuracy testing to ensure total system accuracy.

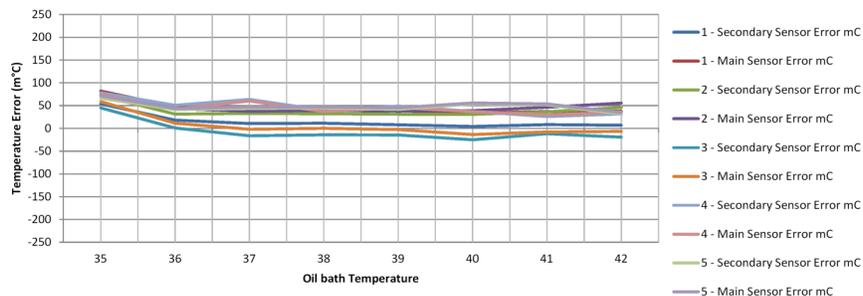


Figure 3-16. Accuracy Test Results

Tympanic Thermometer vs. Hearable Design

Core body temperature data was collected using the hearable reference design and compared to temperature data collected by a commercial tympanic thermometer. First, the hearable reference design was placed in a closed earbud casing. The casing was then placed inside the subject's ear across the normal human body temperature range. After the temperature reading settled, a tympanic thermometer was used to get a reference temperature.

The data was then correlated using a linear fit model and 3rd order polynomial model. The linear fit model resulted in an error between ± 0.1 °C across the temperature range and correlated the two temperature readings with an R^2 value of 0.9738. Figure 3-17 shows the fit models used to correlate the two temperature sets. Figure 3-18 shows the temperature error between the two sets using the linear model.

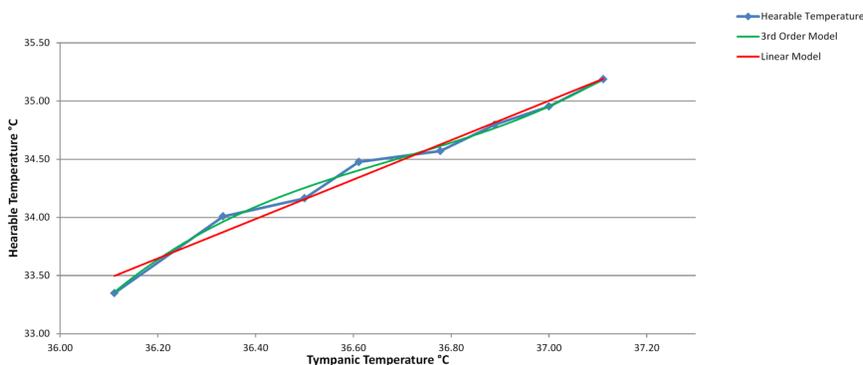


Figure 3-17. Hearable Design Temperature vs. Tympanic Thermometer

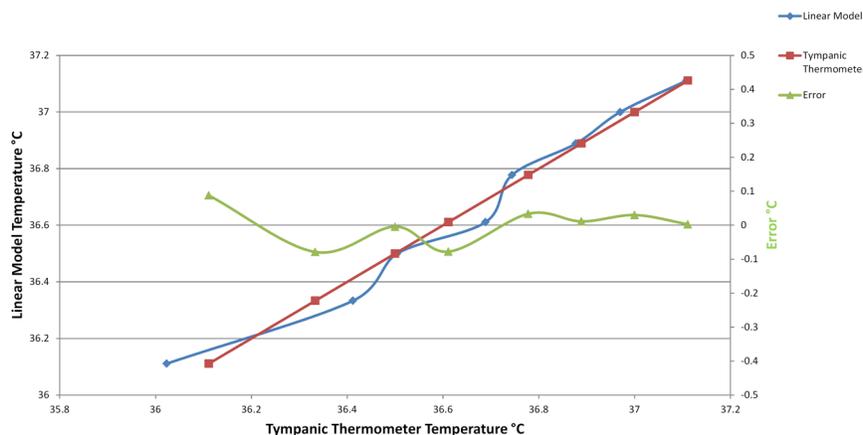


Figure 3-18. Linear Model vs .Tympanic Thermometer

Similarly, the 3rd order polynomial model resulted in an error between ± 0.075 °C across the temperature range and correlated the two temperature readings with an R^2 value of 0.9925. Figure 3-19 shows the temperature error between the two sets using the 3rd order model.

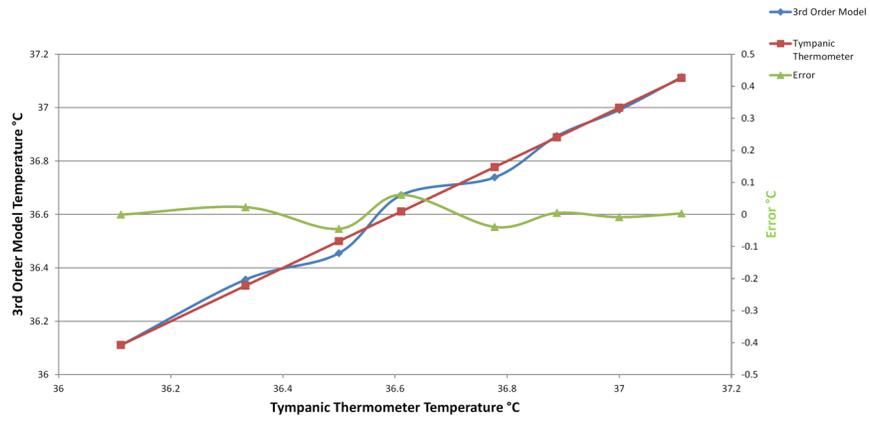


Figure 3-19. 3rd Order Model vs. Tympanic Thermometer

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at [TIDA-060034](#).

4.1.2 BOM

To download the bill of materials (BOM), see the design files at [TIDA-060034](#).

4.2 Tools and Software

4.2.1 PCB Layout Recommendations

The Hearables Body Temperature Monitor Flex PCB Strip was designed with a thin 2-layer flex PCB with a minimalistic profile. This is to allow for easy integration into small wearable devices as well as to have a fast thermal response time. For general recommendations for flex PCB designs, designers should consult with the flex board manufacturer. It is important that this aspect be considered to minimize potential damage to the board traces. While this design does not integrate any stiffener to maximize flexibility, a stiffener should be used on portions that are not intended to bend. The routing of the TMP117 devices was intended to keep the minimal width of the flex board while still being able to access all functions of the device. Small 01005 size decoupling capacitors were also used to keep the minimal profile. [Figure 4-1](#) shows the routing of the TMP117 devices on the flex board.

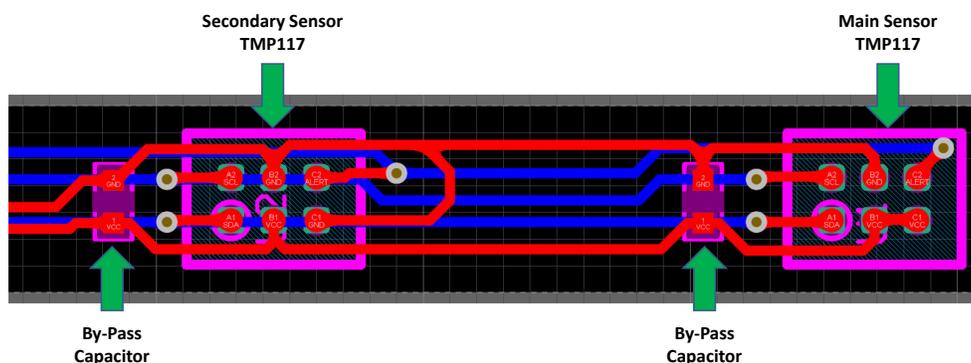


Figure 4-1. TMP117 Layout

4.2.2 Software Files

To download the software files, see the design files at [TIDA-060034](#).

4.3 Documentation Support

1. Texas Instruments, [TMP117 High-accuracy, low-power, digital temperature sensor](#) data sheet.

4.4 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (November 2020) to Revision A (March 2021)	Page
<ul style="list-style-type: none">Updated <i>For information on a commercially available algorithm contact WBD101 at their website.</i> to <i>For information on a commercially available algorithm and potential intellectual property rights related to system-level designs, contact WBD101 at their website.....</i>	16

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