

Bluetooth®-Enabled, High-Accuracy Skin Temperature Measurement Flex PCB Patch Reference Design



Description

This reference design demonstrates highly accurate sensing of skin temperature using the TMP119 high-precision digital temperature sensor with the CC2340R5 wireless MCU. This design guide provides design guidance for skin temperature measurement in medical and wearable applications along with an evaluation software and smart device application.

Resources

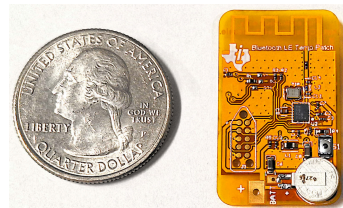
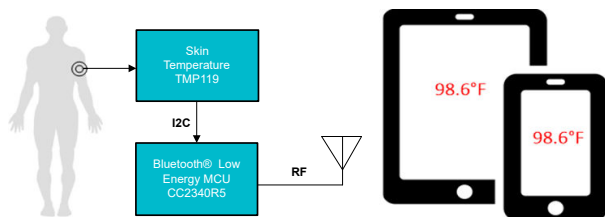
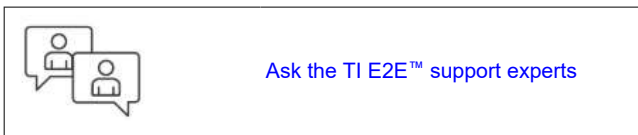
TIDA-01624	Design Folder
TMP119	Product Folder
CC2340R5	Product Folder

Features

- High-accuracy ($\pm 0.08^{\circ}\text{C}$) human body temperature measurement
- 2.4GHz wireless MCU with Bluetooth® Low Energy 5.3
- Integrated PCB antenna
- Flexible PCB design
- Up to two years of shelf life plus five days of active time with a 5.5mAh coin-cell battery
- iOS® and Google Play® apps for device monitoring

Applications

- [Medical sensor patches](#)
- [Wearable fitness and activity monitor](#)



1 System Description

With the need to integrate sensors into newer wireless and cloud applications, the Bluetooth-enabled, high-accuracy skin temperature measurement flex patch provides a wireless answer for receiving high-accuracy skin temperature measurements on a Bluetooth-capable device, such as a smart phone or tablet.

Through direct contact with the skin, the TMP119 high-accuracy, low-power, digital temperature sensor can send 16-bit digital output data through the I²C to a CC2340R5 SimpleLink™ Bluetooth Low Energy wireless microcontroller (MCU). After collecting this data, the CC2340R5 can use Bluetooth protocol to transmit the data to a Bluetooth-connected device.

The patch is designed to operate with a 3V coin cell battery, requiring very low power consumption of the design components. For testing and demonstration purposes, the designer can use the large contact pads of the device to receive external power from other sources when a battery is not connected.

There are two primary modes of operation for the patch: active and inactive mode. When the patch is inactive, the CC340R5 enters a complete shutdown state and the TMP119 is powered down. This mode allows a multiple year shelf life for the patch without a significant depletion of stored energy in the battery. When the designer presses the wake-up switch, the flex patch enters active mode and the TMP119 begins reading and auto-advertising temperature data the CC2340R5 Bluetooth Low Energy device can receive.

In healthcare applications, reuse or extended use of monitoring patches can pose risks to patient health due to hygiene concerns. An alternative for temperature-monitoring systems is to use a removable covering that can be disposed of after use. This is common in designs of probe-type thermometers for oral temperature measurements. If this method is used, the system and these covers must be characterized as the final design. For probes, the designer can modify the software to move between active and inactive mode, but an MCU must be in the probe to use Bluetooth communication protocol under this modification.

1.1 Key System Specifications

Table 1-1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Operating power supply range	1.71V to 3.8V	Limited by CC2340R5 and TMP119 supply range
Operating temperature	-40°C to +125°C	Limited by operating range of CC2340R5
Temperature accuracy	±0.08°C (maximum) from 0°C to +45°C	Exceed requirements for human body temperature measurements
RF range	> 10m	Bluetooth Low Energy 5.3
Form factor	2-layer flexible PCB	

2 System Overview

2.1 Block Diagram

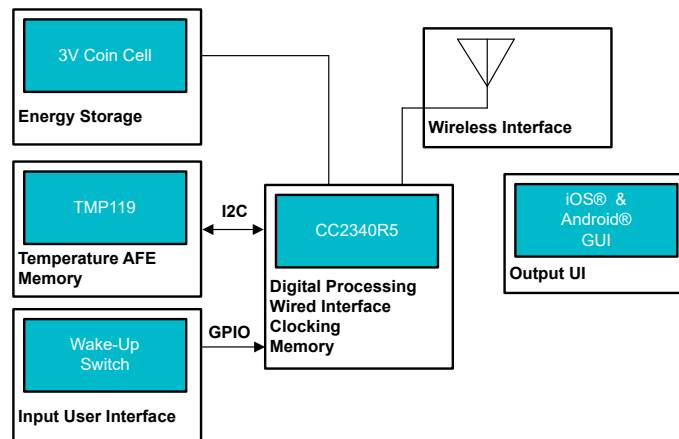


Figure 2-1. TIDA-01624 Block Diagram

2.2 Design Considerations

Carefully consider the placement of the patch to make sure that the temperature reading is aligned with the expected results. The average temperature reading of an oral thermometer in a healthy adult is 98.6°F (37°C), but measurements taken from other areas of the body differ in temperature. For example, a temporal thermometer reads a temperature that can be up to one degree (1°F) lower than that of an oral thermometer.

The crucial distinction here is between *core temperature* and *skin temperature*. The primary goal of this design is to demonstrate effective techniques for the measurement of skin temperature. The temperature at the surface of a patient's skin is not normally identical to the patient's core temperature. The most accurate methods of obtaining core temperature are internal, such as with oral or rectal thermometers. In certain applications, such as long-term patient monitoring in the incubator of a neonatal intensive care unit (NICU), skin temperature monitoring is often the only practical method. Skin temperature can also be used in conjunction with other parameters in applications such as fitness trackers and heart-rate monitors.

When using skin temperature to try and obtain a measurement close to core temperature, the preferred sites are traditionally the underarm (axillary) or the forehead (temporal). The form factor of this patch demonstrates a generic circular form that can be used anywhere on the skin. For axillary measurements, extending the TMP119 away from the primary portion of the board to allow the RF antenna to be exposed on one side while the sensor is enclosed underneath the user's arm can be desirable.

The effective Bluetooth range of the design depends on many factors, such as walls and objects between the patch and the smart device. When worn; however, the primary source of signal loss is likely the patch wearer. To improve the range, the CC2340R5 can be programmed to increase the Bluetooth output power, but this decreases the battery life of the patch. Under normal operation, the patch is powered by a 3V coin cell; therefore, low-power Bluetooth modes are recommended to extend the operating time for this design. As characterized, this design uses the maximum output power of the CC2340R5 to attain a longer range. Alternatively, antenna and pi-network matching can be performed while the device is worn to increase the signal range without increasing the output power level of the CC2340R5.

2.3 Highlighted Products

The *Bluetooth-Enabled High-Accuracy Skin Temperature Measurement Flex PCB Patch* features the following devices:

- **TMP119** – High-accuracy, low-power, digital temperature sensor
- **CC2340R5** – SimpleLink™ 32-bit Arm® Cortex®-M0+ 2.4GHz wireless MCU

2.3.1 TMP119

The TMP119 is a low-power, high-precision temperature sensor that provides a 16-bit temperature result, with a resolution of $7.8125\text{m}^\circ\text{C}$ and an accuracy of up to $\pm 0.08^\circ\text{C}$ with no calibration. The TMP119 operates from 1.7V to 5.5V, consuming $3.5\mu\text{A}$ typically, and comes in a $0.95\text{mm} \times 1.488\text{mm}$ DSBGA package. The device also features integrated EEPROM, and a temperature offset register which can contain single-point calibration data.

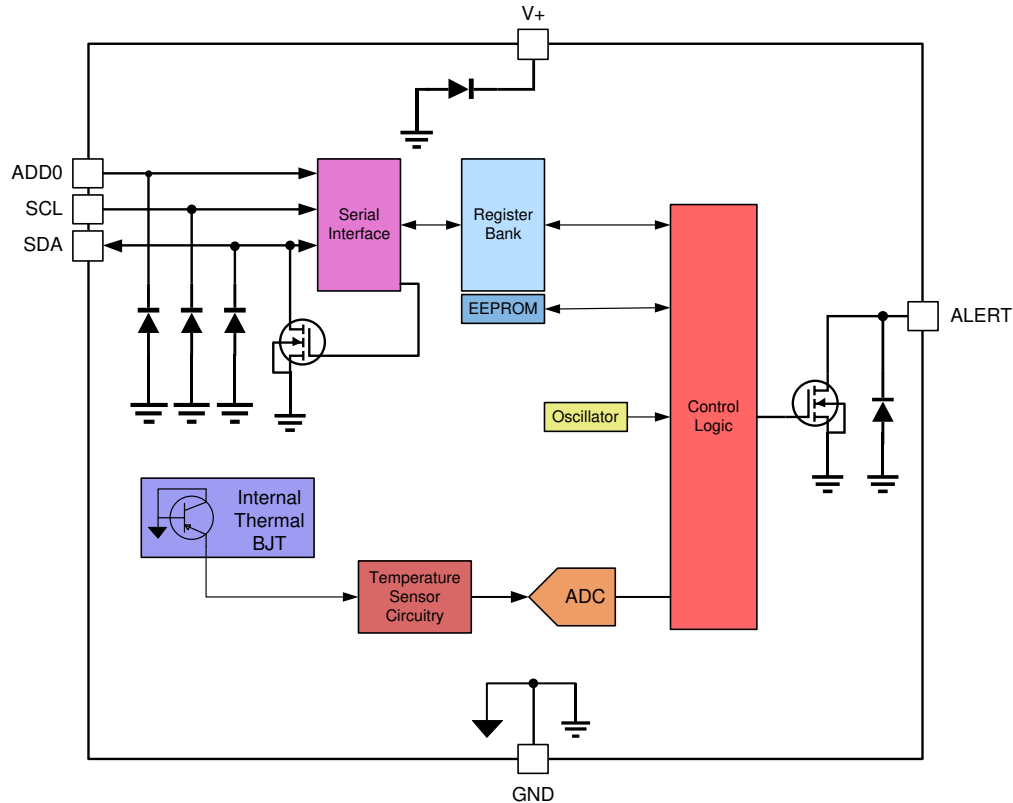


Figure 2-2. TMP119 Internal Block Diagram

2.3.2 CC2340R5

The CC2340Rx SimpleLink™ family of devices are 2.4GHz wireless microcontrollers (MCUs), targeting Bluetooth® 5.3 Low Energy, Zigbee®, Thread, and Proprietary 2.4GHz applications. These devices are optimized for low-power wireless communication for medical applications. Highlighted features of this device include:

- Fully qualified Bluetooth 5.3 software protocol stack included with the [SimpleLink™ Low Power F3 software development kit \(SDK\)](#)
- Ultra-low standby current less than 0.71µA with RTC operational and full RAM retention that enables significant battery life extension, especially for applications with longer sleep intervals
- Integrated balun for reduced bill-of-material (BOM) board layout
- Excellent radio sensitivity and robustness (selectivity and blocking) performance for Bluetooth Low Energy (−102dBm for 125kbps LE Coded PHY, with integrated balun)

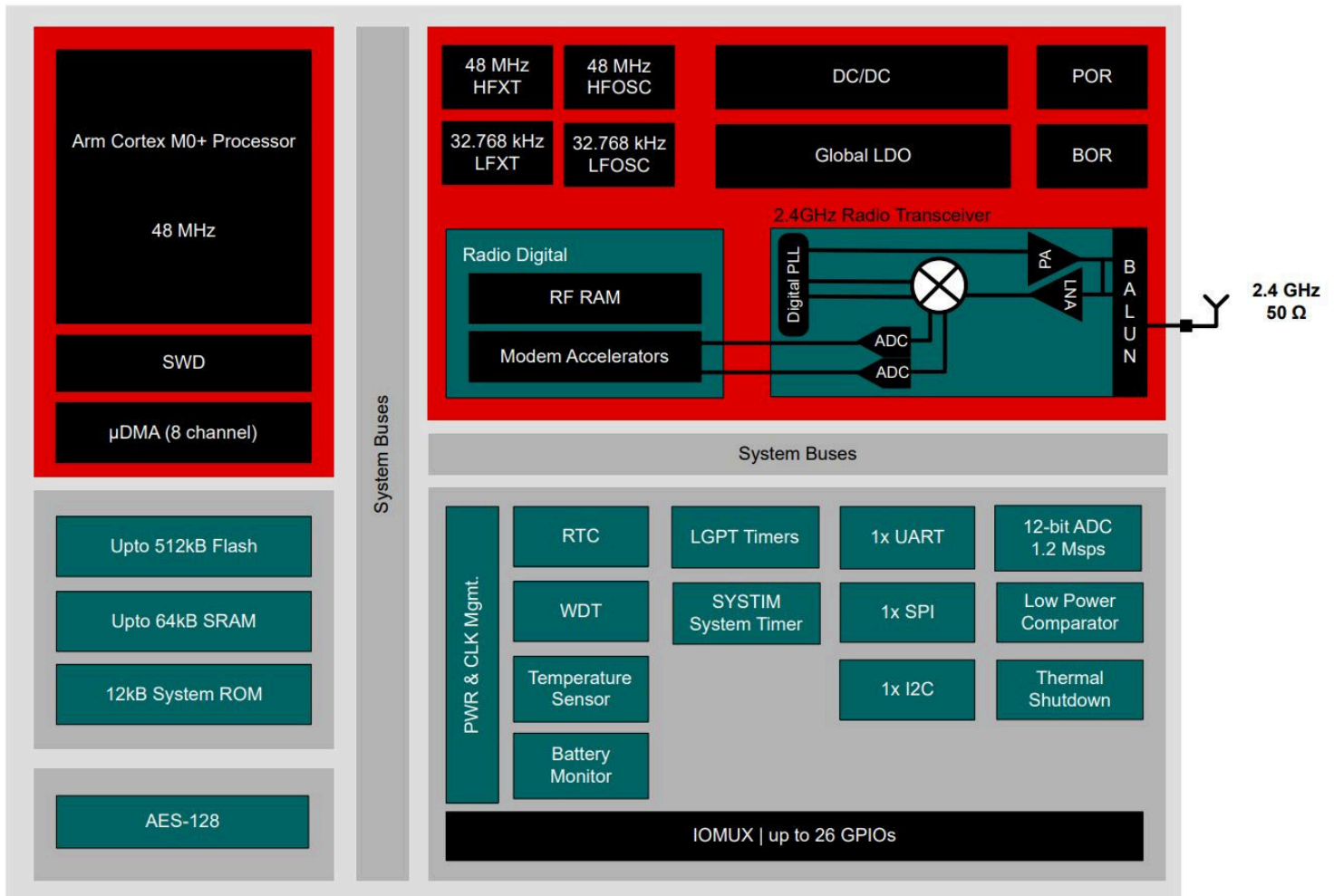


Figure 2-3. CC2340R5 Block Diagram

2.4 System Design Theory

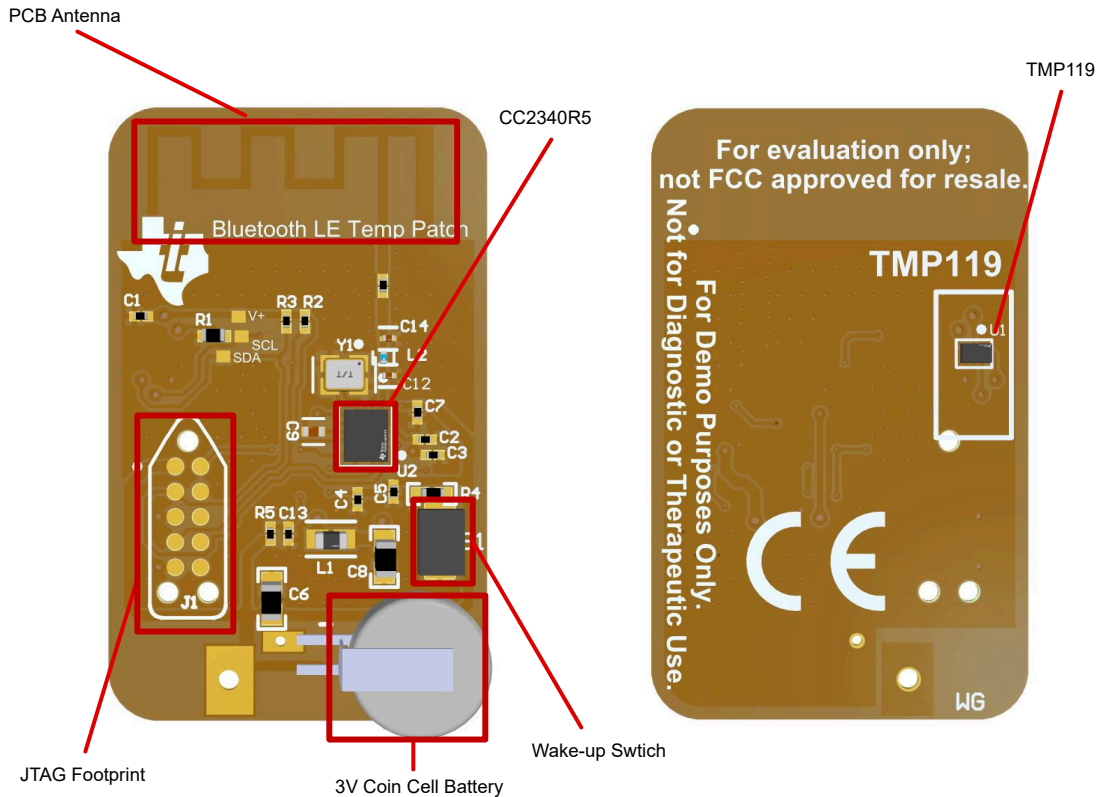


Figure 2-4. Key Features in Design Layout

The system design requirements for wearable patches can vary in certain applications. The requirements considered for this design include:

- Shelf life
- Active life
- Range
- Wearer comfort
- System accuracy

2.4.1 Shelf Life and Active Life

The power budget for this design is based on the shelf life (inactive state) and active life (active state) requirements for the design. In the Bluetooth-enabled high-accuracy skin temperature flex patch, the CC2340R5 is configured in shutdown mode until the tactile switch (S1) is pressed and triggers the patch to wake up. Due to the overall low current consumption for the TMP119, the temperature sensor is powered using one of the CC2340R5 GPIOs. This reduces the total design shutdown current by removing the shutdown current of the temperature sensor from consideration. Thus, the current consumption of the design in shutdown mode is now limited to 165nA, which is primarily from the CC2340R5 MCU. As a result, the overall shelf life for this design is expected to be at least two years. This life span is limited by the typical shelf life of the battery and not by the charge storage. If using an alternate power source, shelf-life can change accordingly.

For active lifetime requirements, temperature patches can be expected to operate for up to a few days after the patches are attached to a wearer. Current consumption can be reduced by limiting the frequency of measurement, and by transmitting temperature data alongside the auto-advertisement pulse. [Section 3.2.2.1](#) shows the current consumption results for the Bluetooth-enabled high-accuracy skin temperature flex patch. If the patch is active but not connected to the wearer, the patch can auto-advertise up to four times a second, measure temperature at 1 second intervals, and has an expected run time greater than 10 days. When connected, the active lifetime is expected to be around 1 day. Therefore, under normal circumstances, the patch remains in advertising mode most of the time and connects only as needed.

2.4.2 Wearer Comfort

This design uses a 2-layer flex PCB to reduce thermal mass and maximize board flexibility. The primary benefit of flexibility is the ease and comfort for the wearers, which improves the likelihood that the patch remains static on the patient. Keep regions such as the RF portion that require solid ground planes as small as possible to minimize the portion of the board that feels rigid to the wearer. Wearer comfort cannot be quantified, so considering this factor in the design of any final products is important. Enclosing a final system in soft-gauze or various types of bandages to pad between the board and the wearer is an option. If this is done, take care to make sure that the thermal path between the TMP119 and the wearer's skin is still optimized for response time and accuracy. The final product must also be characterized with the expected packaging included. The recommendations listed in the [Layout Considerations for Wearable Temperature Sensing](#) and [Design Challenges of Wireless Patient Temperature Monitors](#) application briefs can help the designer improve system response time and accuracy.

2.4.3 System Accuracy

For compliance under the ISO-80601 and ASTM E1112 medical standards for intermittent patient temperature monitors, system accuracy must be verified using a liquid bath and a highly accurate reference. [Table 2-1](#) shows a summary of these accuracy requirements as specified by ASTM E1112. The TMP119 is designed to exceed these requirements, but 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 around the center of the desired range can provide accuracy within most systems, and this offset correction can be stored within the temperature offset register of the TMP119.

If an offset is necessary in production systems, the designer must test a statistically significant sample of the final product to determine the best offset for the TMP119, or plan to perform a calibration during manufacturing.

**Table 2-1. Temperature Accuracy Requirements
Under ASTM E1112**

TEMPERATURE (°C)	MAXIMUM ERROR (°C)
< 35.8	± 0.3
35.8–37	± 0.2
37.0–39.0	± 0.1
39.0–41.0	± 0.2
> 41.0	± 0.3

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware and Software

Unless otherwise noted, the design was implemented and tested with the following battery specifications:

- Voltage: 3.0V
- Minimum capacity: 5.5mAh
- Maximum continuous discharge rate: 0.25mA

3.1.1 Hardware

A computer and JTAG programmer are required to program the device. A smart phone or tablet (Android or iOS) are required to communicate with the device when in use.

3.1.2 Software

The design has an embedded firmware that must be programmed to the patch. To compile and load the embedded firmware, the following software is required:

- [Code Composer Studio™](#)
- [SIMPLELINK-LOWPOWER-F3-SDK](#) — SimpleLink™ Low Power F3 software development kit (SDK) for the CC23xx devices

To view the temperature from the patch or connect to the patch, the following application is required on an Android or iOS-enabled smart phone or tablet.

- [SimpleLink™ Connect](#)

3.1.2.1 Reading From the Patch

This section lists the steps on how to read the patch and navigate through the TI SimpleLink™ Connect App. Reading from a patch requires a nearby smartphone and a power-source for the device. [Figure 3-1](#) to [Figure 3-5](#) show how to navigate the TI SimpleLink™ Connect App.

1. On start-up, *TI SimpleLink™ Connect App* defaults to search for all Bluetooth Low Energy connections (see [Figure 3-1](#)). To more quickly find the temperature patch named *TI BLE HT Profile*, touch the three dots and then select the filter and sort options page.

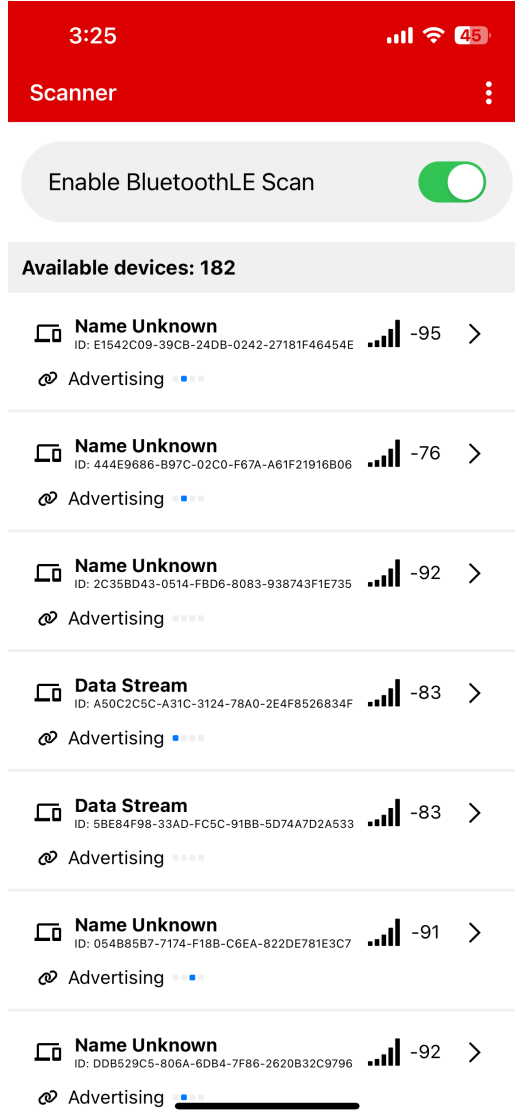


Figure 3-1. Searching For All Bluetooth Connections

2. Switch the *App name* toggle to on and enter "TI"

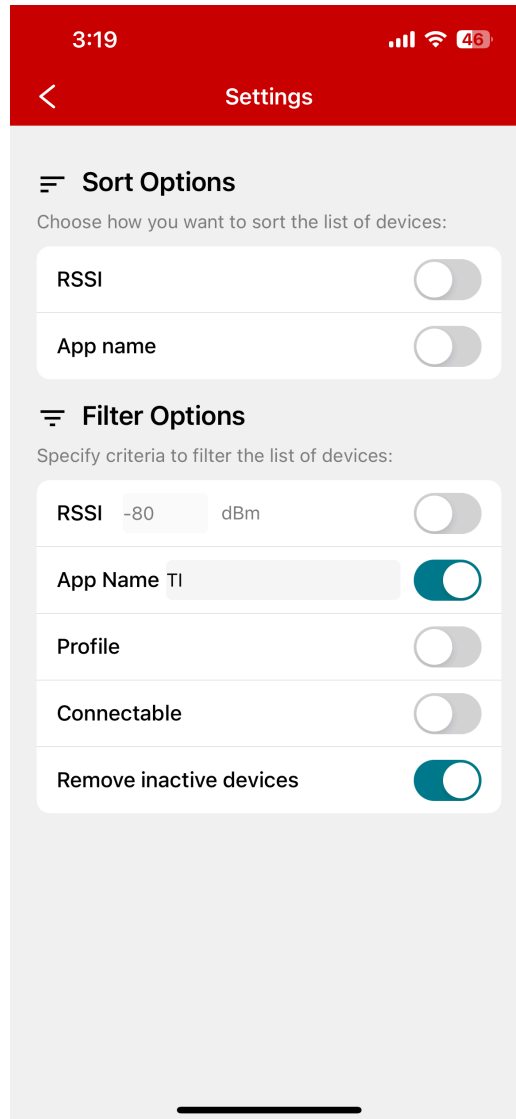


Figure 3-2. Filtering Settings

- Return to the *Searching Bluetooth Connections Page* and select *TI BLE HT Profile* by pressing the *greater than >* button.

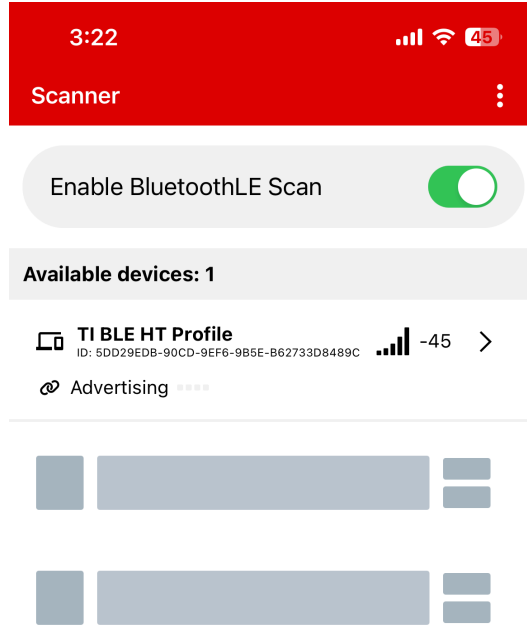


Figure 3-3. Searching Bluetooth Connections Page

4. Click the *Health Thermometer* selection.

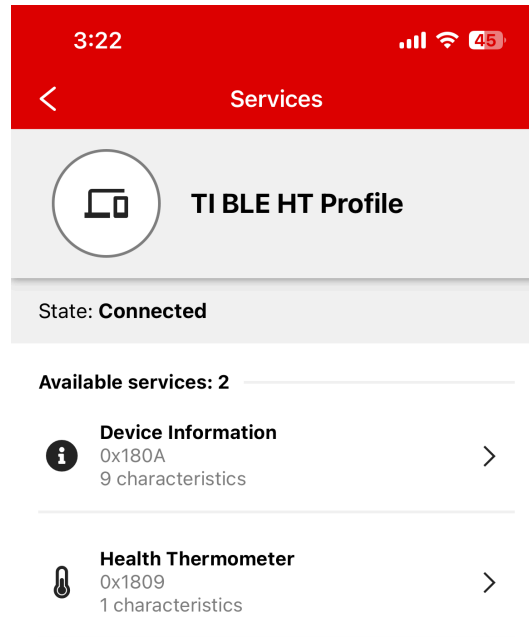


Figure 3-4. TI BLE HT Profile Main Page

- Set the polling interval to 5 seconds and turn on enable indications.

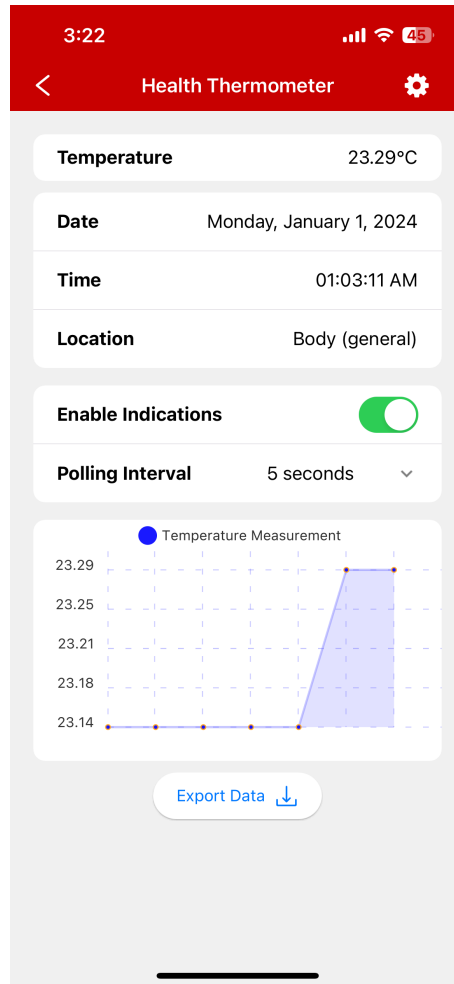


Figure 3-5. Health Thermometer Data Stream Page

3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Current Consumption and Life Span

The current consumption of the device was tested by connecting the power pads on the wireless patch to a DC power analyzer capable of measuring currents in the nA range at fast intervals over time. For the current consumption test during initialization, the current consumption was measured as soon as the pads on the wireless patch were connected to the power analyzer. The measurement spanned the full start-up sequence, and the average current was taken. The power analyzer then remained connected and measuring while the device cycled between advertising and connected active modes. The average and peak current consumption during active mode were taken since both are relevant for battery selection considerations.

3.2.2 Test Results

Section [Section 3.2.2.1](#) explains the results of the testing performed on the patch.

3.2.2.1 Current Consumption and Lifespan

[Figure 3-6](#), [Figure 3-7](#), and [Figure 3-8](#) show the current consumption of the patch under various settings. [Table 3-1](#) summarizes the results. In the final design, the patch was configured to auto-advertise every 5 seconds, and read temperature every 5 seconds. The connection interval is determined by the mobile device connected, but the device was only allowed to connect for 1% of the active time. The remaining 99% of the active time, the device was placed in advertising mode.

[Equation 1](#) shows how to estimate the patch power consumption over a lifetime. [Equation 2](#) shows the test example calculation with two years of shelf life and five days of active time, divided into 99% advertising mode and 1% connection mode. Using the average currents measured during testing and the mentioned testing parameters, was calculated that the device consumes 4.86mAh of battery charge. This is less than the battery capacity of 5.5mAh.

$$Q_{\text{Battery}} = I_{\text{Shelf}} \times T_{\text{Shelf}} + (I_{\text{Advertise}} \times P_{\text{Advertise}} + I_{\text{Connected}} \times P_{\text{Connected}}) \times T_{\text{Active}} \quad (1)$$

where

- Q_{Battery} is the charge consumed from the battery (in mAh)
- I_{Shelf} is the current consumption during device shutdown (in mA)
- T_{Shelf} is the time the patch spends in device shutdown (in hours)
- $I_{\text{Advertise}}$ is the average current consumption when the patch is active and in advertising mode (in mA)
- $P_{\text{Advertise}}$ is the percentage of time the patch is active and in advertising mode (out of 1)
- $I_{\text{Connected}}$ is the average current consumption when the patch is active and in connection mode (in mA)
- $P_{\text{Connected}}$ is the percentage of time the patch is active and in connection mode (out of 1)
- T_{Active} is the time the patch spends in active mode after shutdown (in hours)

$$4.86\text{mAh} = 0.000165 \times 17520 + (0.0143 \times 0.99 + 0.227 \times 0.01) \times 120 \quad (2)$$

Table 3-1. Average Current Consumption

CONDITION	MEASURED CURRENT DRAW	ASSOCIATED FIGURE
Initialization (Start-up)	3.3mA (Avg) for 75ms	Figure 3-6
Advertising	9.6mA (Peak)	Figure 3-7
Advertising	14.3µA (Avg)	Figure 3-7
Connected	7.6mA (Peak)	Figure 3-8
Connected	227.7µA (Avg)	Figure 3-8

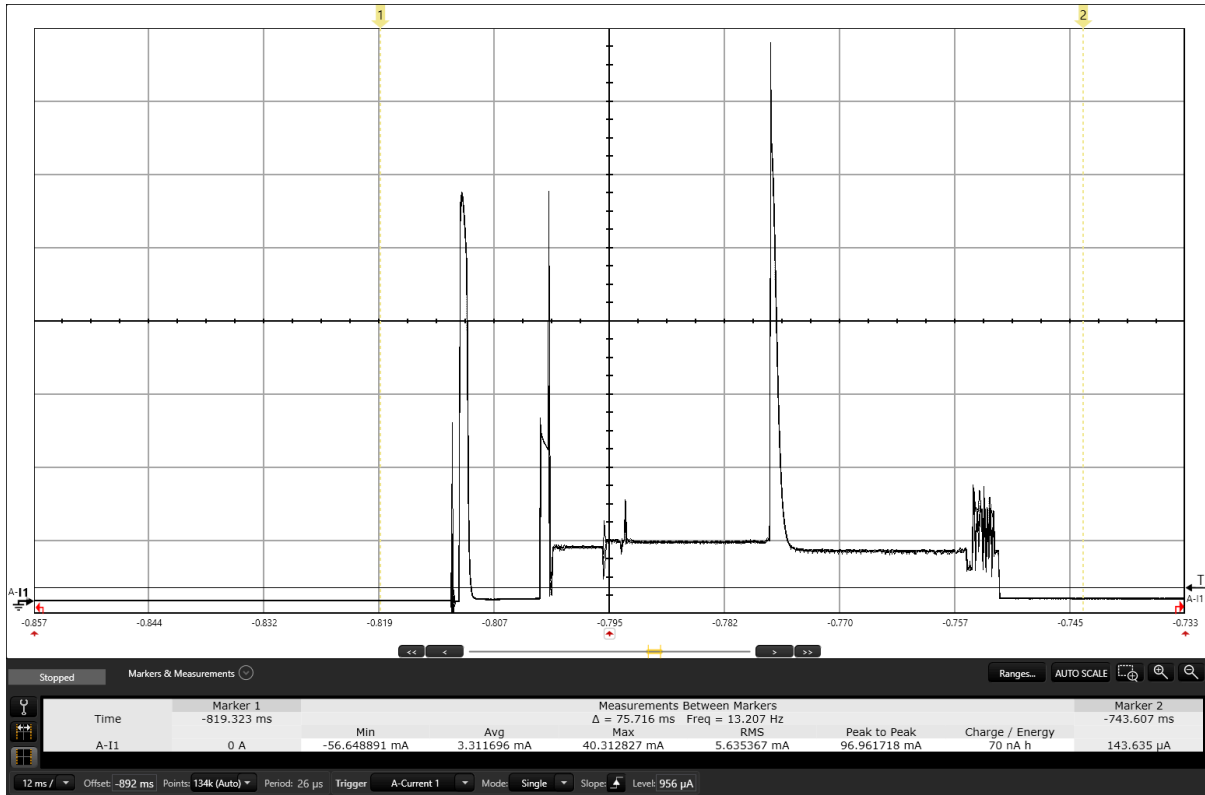


Figure 3-6. Start-Up Current Consumption



Figure 3-7. Average Current for 1s Auto-Advertisement

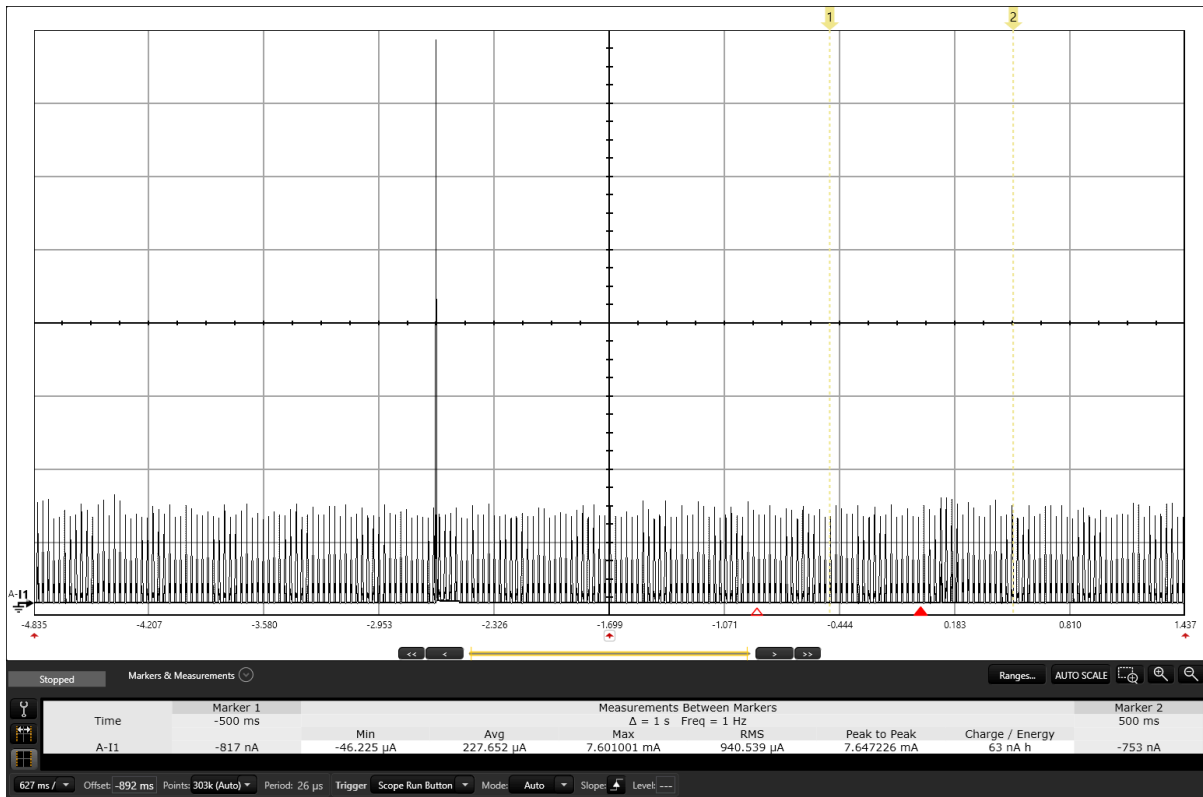


Figure 3-8. Average Current Consumption When Connected to a Smart Device

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [TIDA-01624](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-01624](#).

4.3 PCB Layout Recommendations

The layout for the flex PCB patch was done on a two-layer board, with the intention of maximizing overall board flexibility. Higher numbers of layers likely limit the bending radius of the board and affects wearer comfort. For general recommendations for flex PCBs, consult with the desired manufacturer of the flex board. These boards are extremely thin, therefore the boards can be sensitive to heat applied during the process of soldering or reflow. It is important that this aspect be considered to minimize potential damage to the board traces. If reliability is a concern, consider applying a semi-rigid design form factor by applying a stiffener to portions of the board not intended to bend.

4.3.1 Layout Considerations for the CC2340R5

The CC2340R5, along with the RF matching network and antenna, requires a large copper pour on the bottom layer of the board to provide a low impedance path to ground. In a two-layer design, this means that mainly only the top layer is available to route signals to and from the CC2340R5. Take care to make sure that the necessary bypass components are still placed as close to the IC as possible. Multiple vias underneath the CC2340R5 provide a low impedance path to ground for the device. [Figure 4-1](#) shows the CC2340R5 WCSP footprint and wiring on the flex PCB.

Remember to consider the width of the signal traces to the balun and RF antenna in two-layer design cases. With the most rigid PCBs, it is often possible to find reasonable width traces that provide matching to design impedances. In the case of a 2-layer design, the thickness of the board, the PCB design rules, and the desired cost of the boards limits the maximum characteristic impedance of these traces. If matching is not possible, TI recommends keeping these traces as short as possible. Additionally, a pi-type matching network using 0201 footprints was left to allow matching with lumped elements. Perform RF impedance matching with the patch adhered to the skin of a wearer to emulate the environment of use.

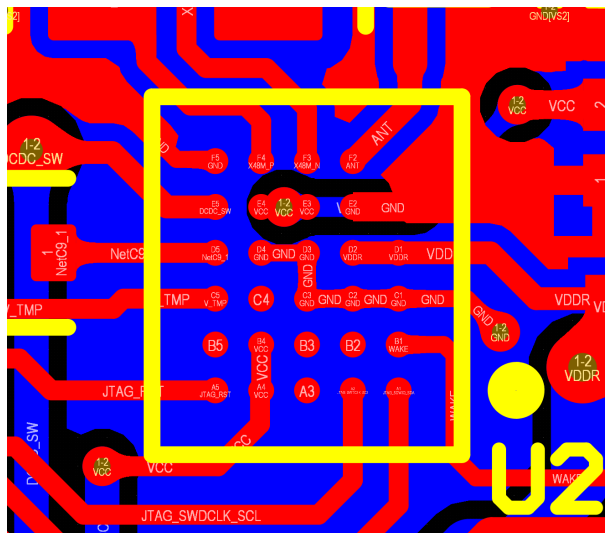


Figure 4-1. CC2340R5 Routing on 2-Layer Flex Patch With Ground Plane Shown in Blue

4.3.2 Layout Considerations for the TMP119

4.3.2.1 WCSP (YBG) Package

The *Bluetooth-Enabled High-Accuracy Skin Temperature Measurement Flex PCB Patch* uses the TMP119AIYBGR to demonstrate one potential technique for measuring skin temperature. In this design, the WCSP version of the TMP119 has the coated backside placed directly against the skin of the wearer, and heat is conducted from the skin directly to the TMP119. In an end system that uses this technique the TMP119 can be covered in a soft over-molding to protect the device from damage. Figure 4-2 shows the TMP119 is located on the skin side of the patch.



Figure 4-2. TMP119AIYBGR Layout in PCB Editor

This technique can be modified for applications that use enclosures but still want to measure skin temperature such as smartwatches or earbuds. The TMP119 can be placed against a metal contact to conduct heat from the wearer's skin, as shown in Figure 4-3. Alternatively, the underside of the device can be used to transfer heat as shown in Figure 4-4. If using the underside of the package, consider using a board stiffener made of a bio-compatible and thermally conductive material such as stainless steel.

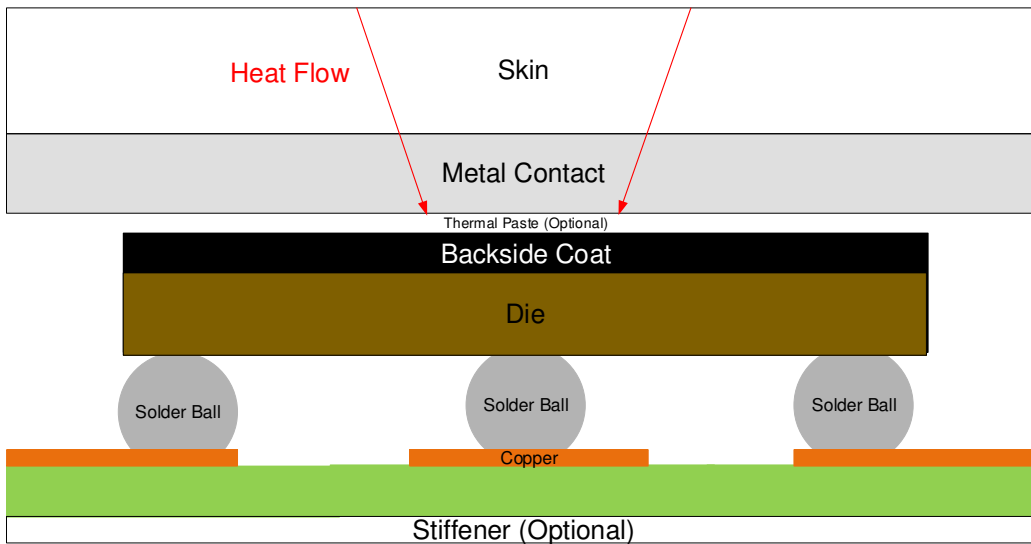


Figure 4-3. Example Stack-up for External Case Sensing Using Top Side of TMP119 in WCSP Package

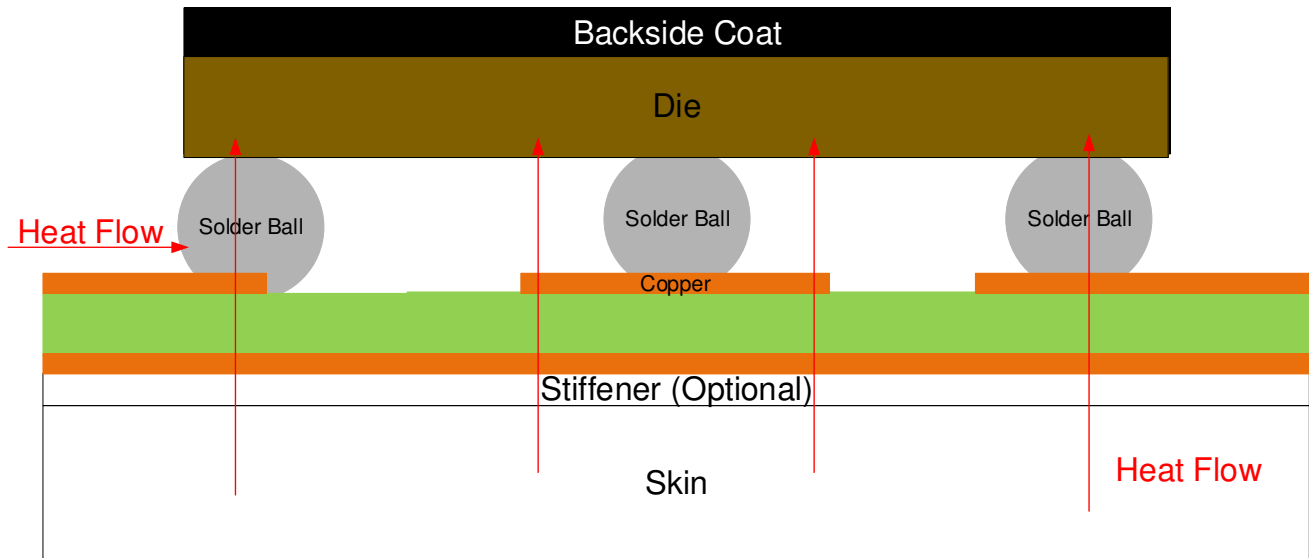


Figure 4-4. Example Stackup for Sensing From Underside of TMP119 in WCSP Package

4.3.3 Layout Prints

To download the layer plots, see the design files at [TIDA-01624](#).

4.4 Altium Project

To download the Altium project files, see the design files at [TIDA-01624](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [TIDA-01624](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [TIDA-01624](#).

4.7 Related Documentation

1. Texas Instruments, [TMP119 High-Accuracy, Low-Power, Digital Temperature Sensor With SMBus™- and I²C-Compatible Interface Data Sheet](#)
2. Texas Instruments, [Layout Considerations for Wearable Temperature Sensing Application Brief](#)
3. Texas Instruments, [Design Challenges of Wireless Patient Temperature Monitors Application Brief](#)
4. Texas Instruments, [Precise Temperature Measurements With the TMP116 and TMP117 Application Report](#)

4.8 Trademarks

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4.9 Revision History

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

Changes from Revision A (May 2020) to Revision B (December 2024)	Page
<ul style="list-style-type: none"> • Changed supported devices from TMP117 to TMP119 and CC2640R2F to CC2340R5 throughout the design guide. • Updated the numbering format for tables, figures, and cross-references throughout the document. 	1

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