Application Note

Under-Component Monitoring With Ultra-Small Temperature Sensors

TEXAS INSTRUMENTS

ABSTRACT

Accurate processor and component temperature monitoring is critical in applications where temperature compensation is needed, or where operation around the system temperature limits is required. Higher sensing accuracy in these kinds of use-cases directly affects the quality or uptime of the system. The new ultra-thin TMP114, and TMP144 digital temperature sensors from TI provide another option to achieve high-accuracy component temperature monitoring, without calibration, and without additional board space, by placing the IC themselves underneath critical components. This note introduces the idea of under-component temperature monitoring, and briefly compares it to other potential temperature sensing layouts.

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1 Introduction

When monitoring temperature of critical components for a system, greater accuracy results in better information feedback to temperature control loops, whether they are for compensation or for safety shutdown performance. In the case of monitoring processor or MCU temperature, designers often include a thermal diode pin, which allows for an external temperature monitoring IC to measure the internal temperature of the die. This method works well when both an internal diode is available, and when the diode is well constructed and has an over-temperature behavior which closely follows that of a standard BJT.

In some cases however, an integrated diode is not designed in, or the overtemperature characteristics render it either unusable or of very-poor quality for temperature detection. In such instances a designer can choose to use the internal temperature sensor of their processor if one is available. The primary drawback of the included sensing element in most modern processors is the extremely low accuracy, typically on the order of ± 5 to 10 °C.

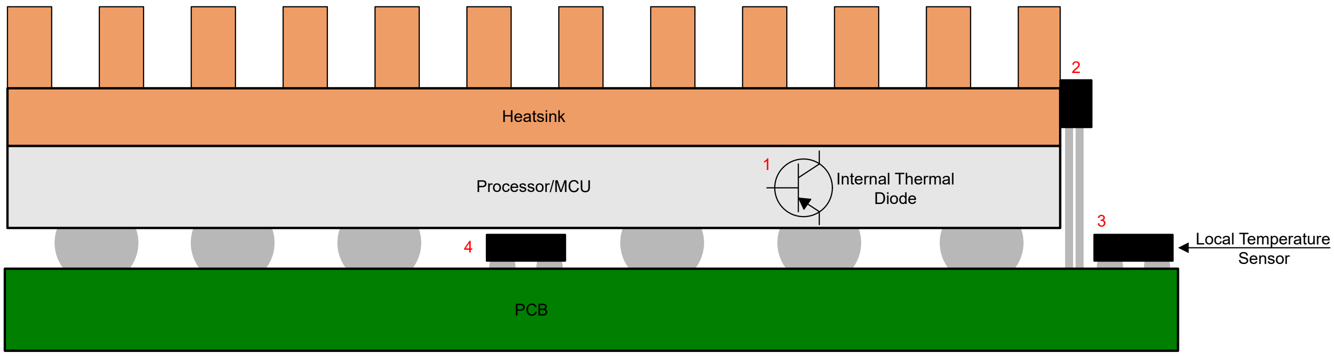

Figure 1-1. SMT Processor Temperature Measurement Options

A better alternative is to use an external integrated temperature sensor or thermistor, to provide the best possible accuracy. Figure 1-1 shows several potential options for measuring the temperature of a processor. Option 1, is to use the internal diode or temperature sensor. In option 2, the sensor, either in a through-hole type package, a probe, or on a flex cable, is affixed to a heat sink using a thermal epoxy. A common variant of this is to place the sensor directly into a machined or drilled hole of a processor heat sink. Option 3 is to place a temperature sensor (IC or thermistor) elsewhere on the PCB, as close as possible to the Processor/MCU. Finally option 4, is to place a temperature sensor directly under the component you want to monitor. Previously, option 4 was only really feasible in applications which included a socket that provided adequate vertical clearance. The newest ultra-thin temperature sensor offerings from TI are discussed and can enable this method even in applications where the component is surface mounted.

2 Heat Sink Temperature Sensor Monitoring

As shown in option 2 of Figure 1-1, a common method of tracking critical component temperature is to capture the temperature of a heat sink contacting the device to be monitored. Mechanically the sensors in these applications can either be attached to the heat sink with an epoxy, clip, or a bolt if the package permits. The equivalent thermal circuit for this method is shown in Figure 2-1, where the $R_{ΘJC(top)}$ is the thermal resistance from the junction of the processor/MCU to the top of the device.

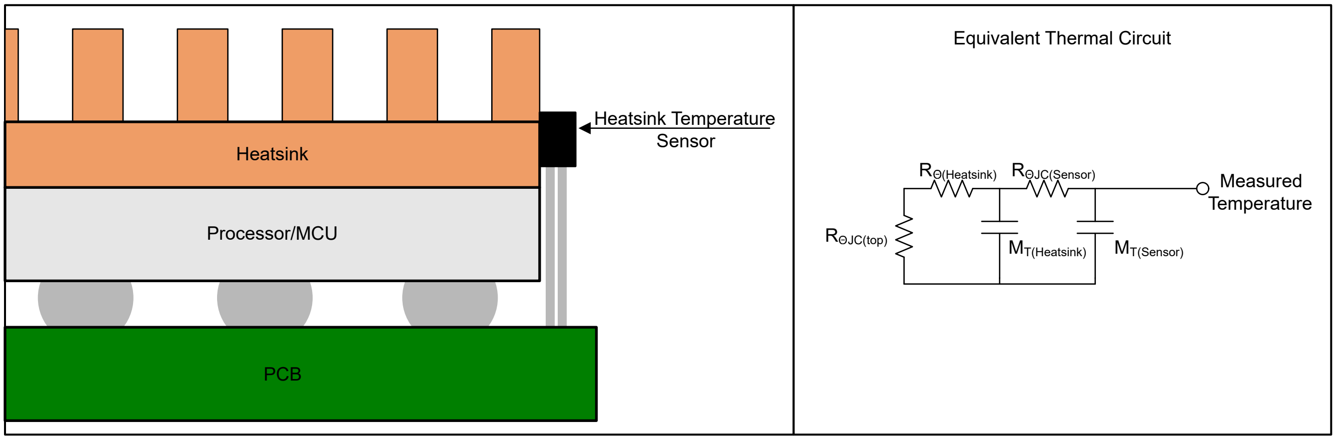

Figure 2-1. Equivalent Thermal Circuit for Heat Sink Temperature Sensing

When using this style of temperature monitoring, the measured temperature at the sensor will lag the actual processor temperature significantly due to the relatively large thermal mass of the heat sink. This additional thermal mass can slow system response to sudden changes in component temperature and can allow for component damage. Additionally, the contact between the heat sink, sensor, and processor will eventually degrade due to breakdown of the contact adhesives from time and temperature cycling. Component temperature in these types of sensing applications can still be successfully monitored with enough due-diligence in system characterization, to provide sufficient safety margin for these extreme cases.

3 Component Temperature Monitoring With Adjacent PCB Placement

The simplest and most common method of monitoring a critical component's temperature is to place a temperature sensor directly next to the component, and allow heat to conduct via the PCB and traces to the temperature sensing IC or thermistor. While this method is extremely cheap and simple, the temperature sensor will be vulnerable to thermal interference from ambient temperature and heat from other components on the PCB. The heat radiated from the critical component can also decay very quickly when the temperature differential between the component and ambient is very high. Figure 3-1 shows this in thermal simulation, using the TMP116 temperature sensor placed on a board near a roughly 100 °C heat source.

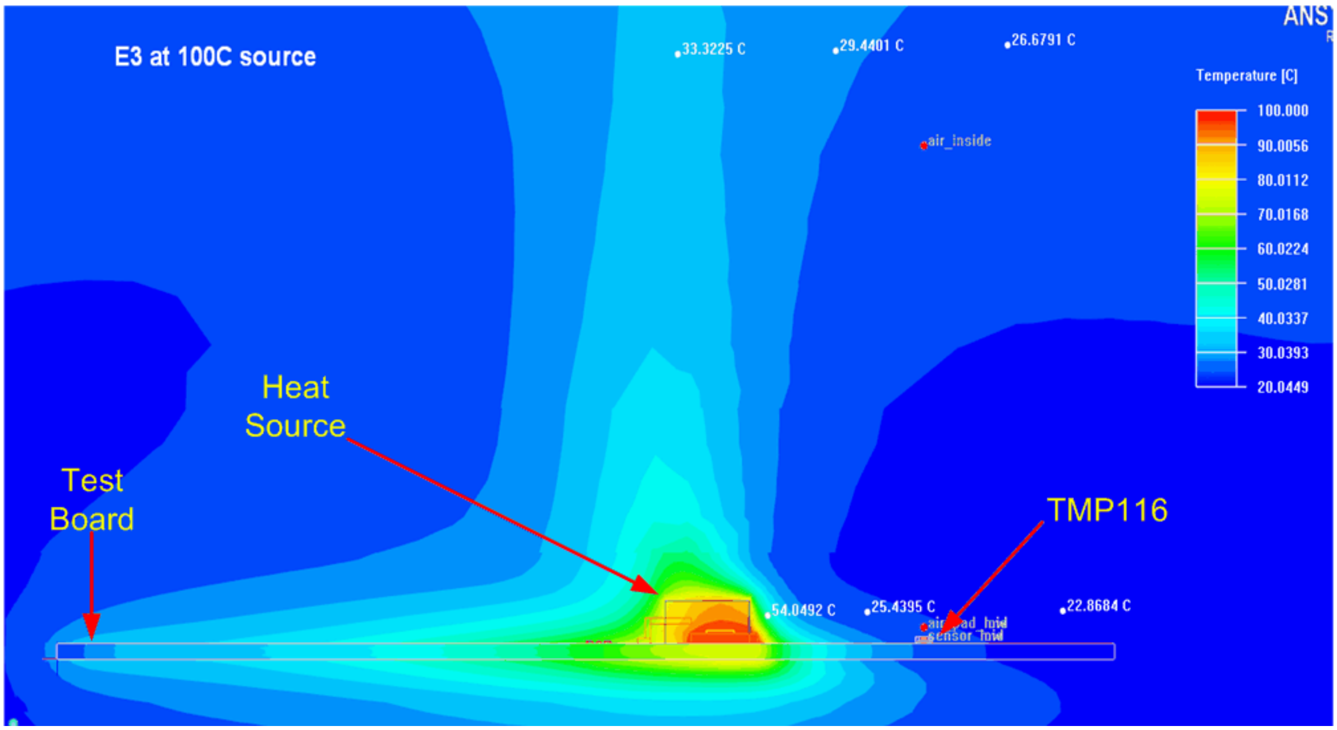

Figure 3-1. Thermal Simulation of TMP116 near 100C Heat Source

As shown, the quality of temperature data will decline rapidly as distance between the sensor and component increases.

4 Under-Component Temperature Monitoring

Figure 4-1 shows a thermal capture of the AWR2243BOOST evaluation module (EVM) mounted onto the DCA1000EVM for data capture. The *HI* temperature reading shows the AWR2243 has reached a temperature of about 51.5 °C, and is therefore operating at a moderate load. The *LO* value displayed is the ambient temperature of around 22.9 °C, and the board temperature as measured by the thermal camera is at 41.9 °C.

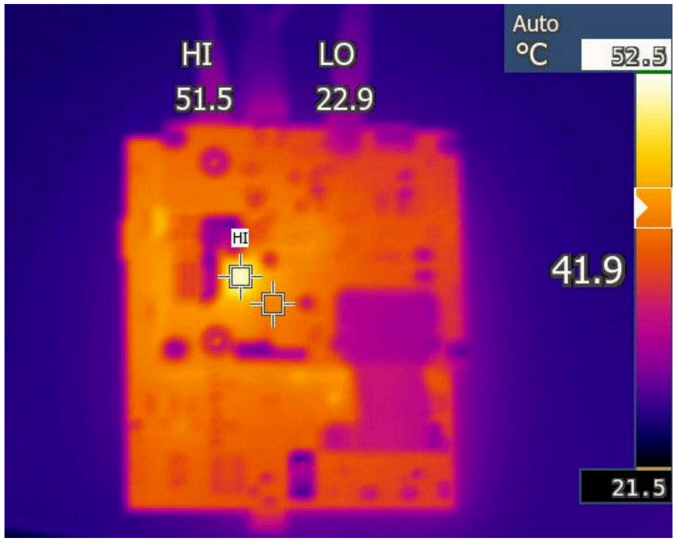

Figure 4-1. Thermal Capture of AWR2243BOOST Under Moderate Load

Unlike the simulation example shown in Figure 3-1, the heat source here has only a temperature differential from ambient of less than 30 °C, and yet the temperature of the board immediately adjacent to the AWR2243 has already dropped by nearly 10 degrees. It should be evident from this that in order to use an external sensor to accurately monitor the temperature of certain components, it is going to be necessary to get the sensor as close as possible to the device to be monitored.

4.1 Ultra-Thin Temperature Sensors

To aid in our goal of reducing the physical and thermal distance between the sensor and critical components, the new TMP114 and TMP144 temperature sensors from TI are available in a small-footprint, and ultra-thin, 0.15mm height YMT package. This makes them uniquely suited for under-component temperature sensing applications. These DSBGA package devices have only a thin-backside coating between them and the die, allowing for extremely low $R_{\Theta JC(top)}$ thermal resistances. This means that heat can conduct easily through the top of the package to the sensing element located in the silicon die. In terms of overall footprint, the TMP114 and TMP144 temperature sensors are only 0.758mm x 0.758mm and 0.76mm x 0.96mm respectively, ensuring they are small enough to easily place and route.

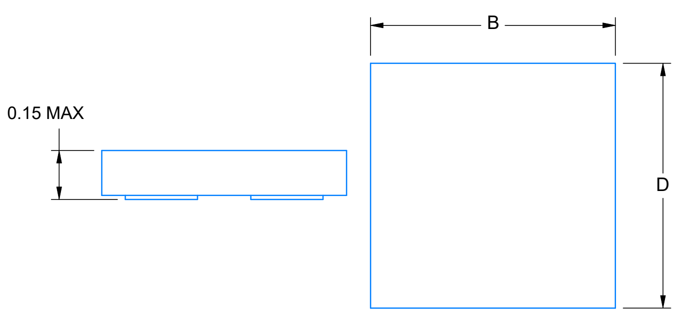

Figure 4-2. TMP144 and TMP144 YMT Package Drawing

4.2 Designing an Under-Component Layout With the TMP114 Temperature Sensor

Figure 4-3 shows a 3D rendering of the TMP114 temperature sensor underneath the IWR6843 integrated single-chip mmWave sensor. The IWR6843 mmWave sensor was selected for under-component sensing here because of the footprint, available vertical clearance, and integrated self-calibration over temperature.

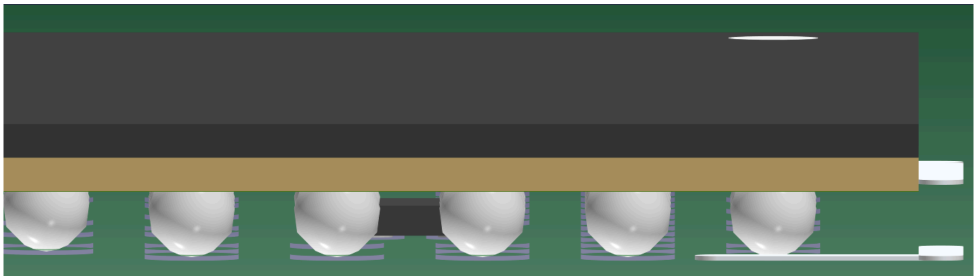

Figure 4-3. Board Rendering of TMP114 Temperature Sensor Underneath IWR6843 Sensor

When deciding if an under-component approach is appropriate, one of the most important factors is that there is room in the footprint for the sensor to be placed. Not all components and processors meet this requirement; therefore, use another method of temperature monitoring. The IWR6843; however, is available in a Flip Chip Chip-Scale Package (FCCSP) which includes adequate spacing between the solder balls for the TMP114 temperature sensor footprint as shown in Figure 4-4.

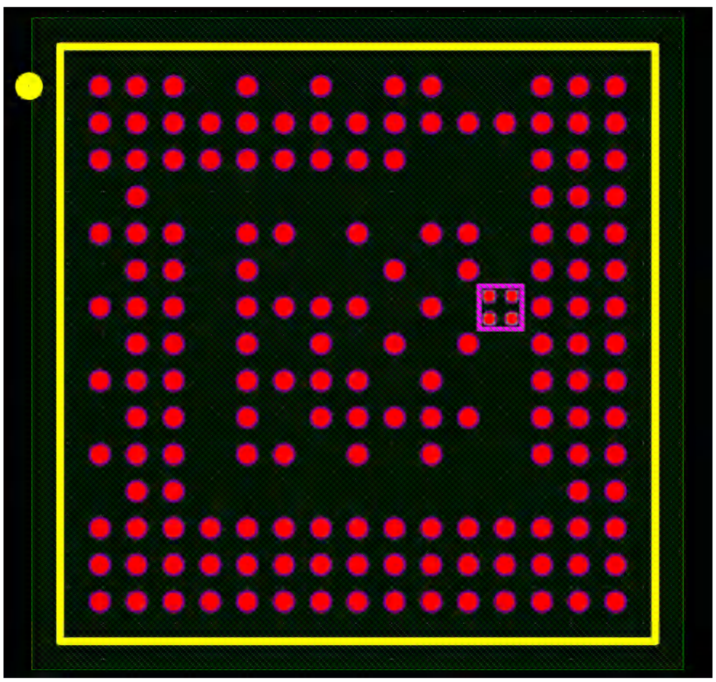

Figure 4-4. IWR6843 and TMP114 Footprints Rendered in PCB Editor

Vertical clearance must also be enough for the sensor to fit entirely. With the IWR6843, there is plenty of vertical clearance due to the height of the solder balls being much higher than the height of the TMP114 temperature sensor package.

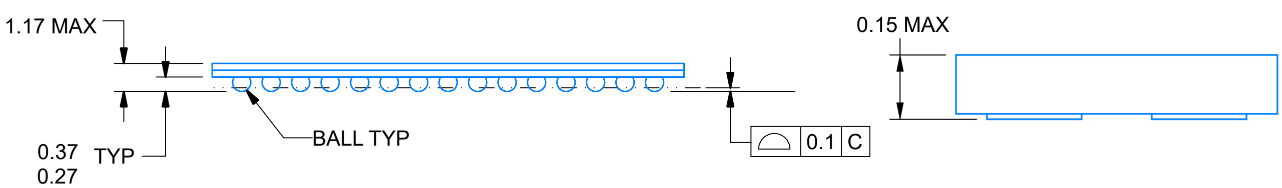

Figure 4-5. TMP114, TMP144, and IWR6843 Vertical Dimensions

There are several tradeoffs to this kind of temperature sensing placement. For instance, an under-component strategy for temperature sensing can increase board cost, because smaller diameter in-pad vias are required to route the communication lines from the temperature sensor. When placing the sensor under a leaded package component, additional cost can still be seen if a lower minimum trace width is required for routing. Assembly costs can also be higher, as a second reflow is needed to allow the sensor to be placed first, followed by the component to be placed on top.

4.3 Under-Component Experimental Results

To further explore the topic of under-component temperature monitoring and test for accuracy and response time, a TMP114 temperature sensor was placed underneath the IWR6843 mmWave sensor on the IWR6843ISK evaluation board. The board layout files were modified to add the TMP114 temperature sensor footprint and then route the communication and power traces out to a header. This was to make sure that the operation of the radar board is not interrupted.

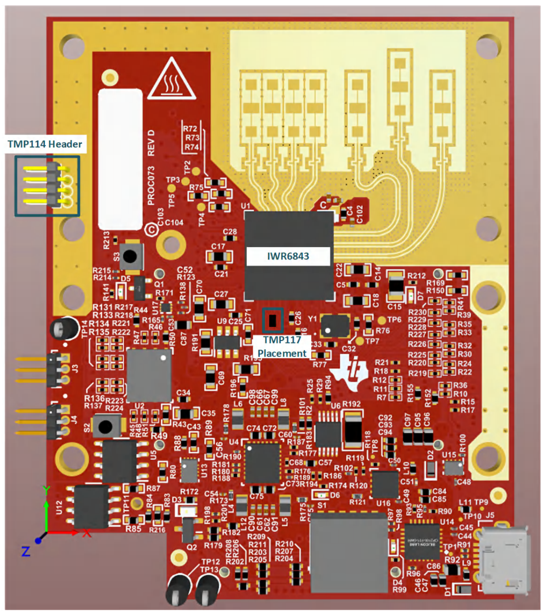

Figure 4-6. IWR6843ISK Evaluation Module

Correct operation of the modified radar board was confirmed using the MMWAVE Out of Box Demo. An xray image was also used to collect more information about the placement of the TMP114 temperature sensor underneath the IWR6843 mmWave sensor.

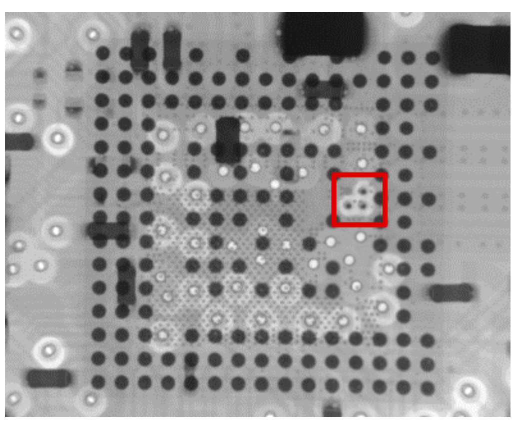

Figure 4-7. Xray Image of IWR6843 with TMP114 Temperature Sensor Underneath

To compare the performance of the under-component TMP114 temperature sensor, a TMP117 temperature sensor was placed next to the radar processor. This was designed so that both sensors can be interfaced with an MSP430 microcontroller to read back temperature data in the same 500-ms interval.

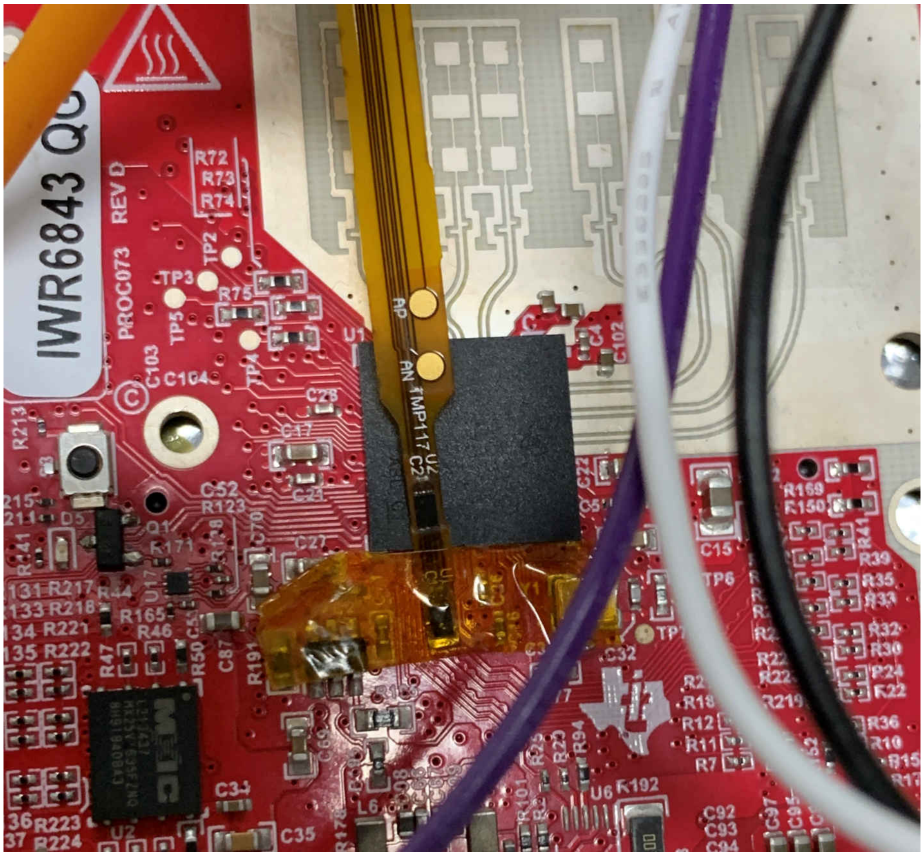

Figure 4-8. TMP114 and TMP117 Temperature Sensor Testing Setup

The temperature rise as the IWR6843 mmWave sensor begins heating up can be seen in Figure 4-9, which shows the difference in thermal response and accuracy between the two devices. On average, the TMP117 temperature sensor measures 3.6°C below the TMP114 temperature sensor as the processor temperature increases. Additionally, the TMP114 temperature sensor is able to respond to the temperature rise much more rapidly, and this increase in thermal response time shows the effectiveness of this type of sensor placement. Table 4-1 shows how quickly each device reached 30°C, as well as each measurement at the end of the test run. Especially in systems that rely on over- or undertemperature shutdown mechanisms, fast thermal response, and higher accuracy can keep systems running longer by avoiding unnecessary shutdowns.

Table 4-1. Comparison of Thermal Response

Temperature Sensor	Time to Reach 30 °C	Temperature After 152.9 Seconds
TMP114	47.6 seconds	37.2109°C
TMP117	87.1 seconds	33.2421°C

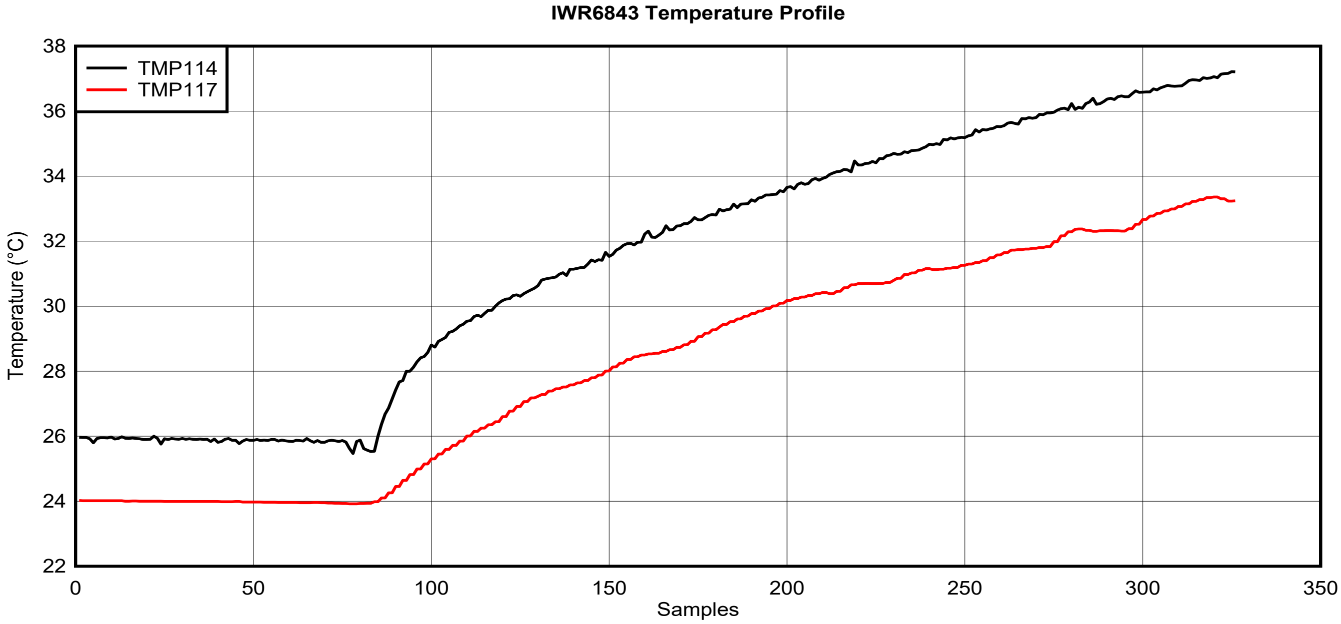

Figure 4-9. TMP114 and TMP117 Temperature Comparison

5 Summary

High accuracy component temperature monitoring is essential in both applications where temperature compensation is needed, or where a system requires safety shutoff limits. This type of component specific temperature monitoring can be done very well with an ultra-thin integrated temperature sensor such as the TMP114 or TMP144 temperature sensors, which can be placed underneath a device to provide the closest possible proximity and by extension, the best temperature correlation.

This style of design can respond more quickly to sudden temperature changes than a heat sink mounted sensor, and returns more accurate results than a sensor placed adjacent to the device to be monitored. Under-component temperature monitoring can be considered when the board layout is space-constrained and the component to be monitored has adequate clearance for the sensor.

6 References

For related documentation, see the following:

- Texas Instruments, *TMP114 Ultra-Thin, 1.2-V to 1.8-V Supply, High Accuracy Digital Temperature Sensor with I^2C Interface* data sheet
- Texas Instruments, *TMP144 Low-Power, Digital Temperature Sensor With SMAART Wire™ / UART Interface* data sheet
- Texas Instruments, *AWR2243 Evaluation Module (AWR2243BOOST) mmWave Sensing Solution* user's guide.
- Texas Instruments, *60GHz mmWave Sensor EVMs* user's guide
- Texas Instruments, *DCA1000EVM Data Capture Card* user's guide

7 Revision History

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

Changes from Revision * (July 2021) to Revision A (April 2023) **Page**

- Added the TMP117 testing and results...7