Effects of Soldering on High Precision IC Temperature Sensors

Introduction

When within recommended operating conditions, every IC temperature sensor has some small range of expected outputs for a given fixed temperature. This range is what is referred to in temperature sensor data sheets as device accuracy. For example, the TMP117 ultra-high accuracy digital temperature sensor at 25°C has an output expected to be within ±100m°C of 25°C. Even with the TMP117's extremely fine temperature resolution of 7.8125m°C, this range is only around 26 possible digital outputs. This means that all TMP117 sensors should output one of these 26 values when the temperature of the die is assured to be 25°C.

Attaining this level of accuracy across a wide-temperature range requires not only a detailed understanding of analog CMOS design, parasitics, and calibration, but also considerations for the mechanical and thermal environment that the die of the device will be sensing in. With such high levels of sensitivity, it should come as no surprise that improper device soldering can produce some amount of unpredictable behavior. This document covers the findings on how this stress from soldering an IC manifests itself on the TMP117. The goal being to inform tradeoffs between absolute accuracy and mechanical stability that come with soldering the thermal pad of the device. Specifically, it will cover the phenomenon of *solder-shift*, which refers to the shift in device accuracy post-soldering.

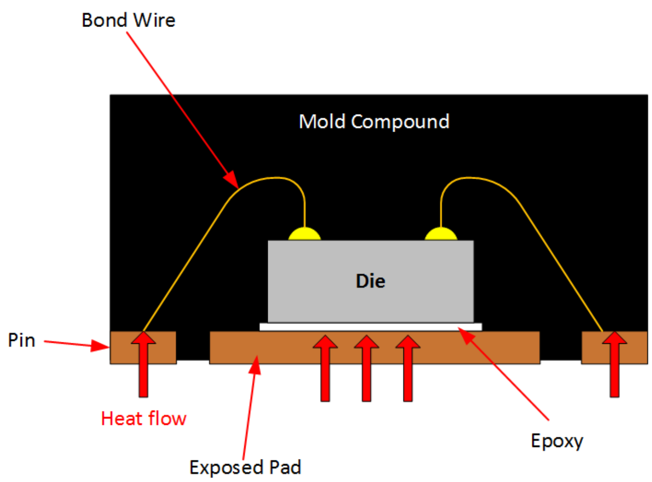

Figure 1. Cross Section of WSON (TMP117DRV) Package Showing Heat Transfer

Solder-Shift

The term solder-shift refers to the loss in absolute accuracy of a temperature sensor due in most cases to the soldering of the thermal pad. Using the example of the TMP117 again, a device at exactly 25ºC without the thermal pad soldered down may output code number 20 of the expected 26 values, and it will do so reliably within ±1 code based on the TMP117's typical ±1 LSB of repeatability. If the same device then had the thermal pad soldered down, it cannot be expected to output code number 20 at 25ºC. Instead the device accuracy will most likely shift, even possibly outside the ±100m°C expected range. This shift in accuracy has not been measured for a wide array of temperature sensors, but where it has been measured, typical shifts are only on the order of 10's of m°C. This makes solder-shift an effect that is virtually undetectable in all but the most precise devices. However, for the TMP117, the resolution and precision of the device make the solder-shift effect reliably measurable.

Figure 1, taken from the *Temperature Sensors: PCB Guidelines for Surface Mount Devices* (SNOA967), shows a cross section of a die inside a WSON package, just like the one used for the TMP117DRV. The die itself is adhered to an exposed pad, sometimes referred to as the Die Attach Pad (DAP), using an epoxy to allow for efficient heat transfer between the surface of the PCB and the sensor. Due to this contact, when the thermal pad is soldered to the PCB, some amount of mechanical stress from the hardening of the solder is also applied to the die.

Findings

To try and quantify the important effect of this stress, a large collection samples of TMP117DRV were first attached to a 32-mil thick FR4 board without the thermal pad being attached. The accuracy of these devices was then measured in an oil bath, using 8 sample averaging in a 1-Hz conversion cycle. The devices were then resoldered, this time including the thermal pad, and the process was repeated. Figure 2 shows the results of the shift in accuracy from this experiment.

These tests only provide a good expectation of how going through a single process may affect one kind of sensor. There are many different factors, such as solder temperature or material, that may affect the final accuracy shift results. The primary takeaway from this experiment should be that the shift in error from soldering can be significant enough to cause issues in high-accuracy applications, and that the nature of this shift is not easily predictable. For this reason, TI recommends avoiding soldering the thermal pad of the TMP117 whenever possible.

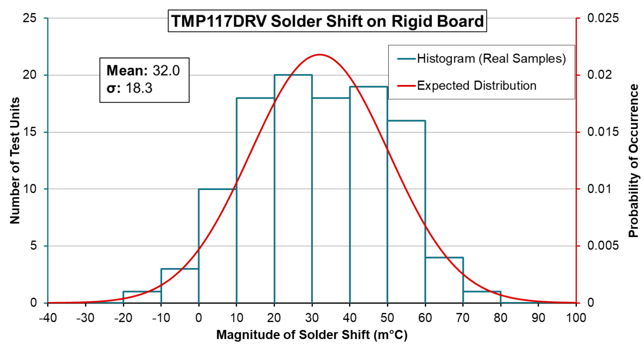

Figure 2. Test Results for Soldering TMP117DRV to a Rigid Board. The Magnitude of Solder Shift was Around 32m°C on Average.

Solder Shift on Flex PCBs

The primary cause of solder shift is mechanical stress from the board to the die, therefore the use of flexible boards might be expected to reduce the magnitude of stress on the device. Figure 3 shows the results of a comparison done on both 6-mil and 12-mil flex boards for the TMP117. Unlike the previous test, the initial accuracy of the part was first evaluated in an IC socket, then the parts were attached to the flex PCB either with or without the thermal pad soldered.

For both 6-mil and 12-mil flex PCBs, the distribution of the accuracy shift are similar with or without the DAP soldered. The average shift is also significantly lower, leading to the conclusion that soldering of the thermal pad does not have a significant effect on device accuracy for flexible boards under 12 mil of thickness. This data should be taken with a grain of salt however, as sample size for each board type was not large enough to be conclusive, and the details of the soldering process are also important factors.

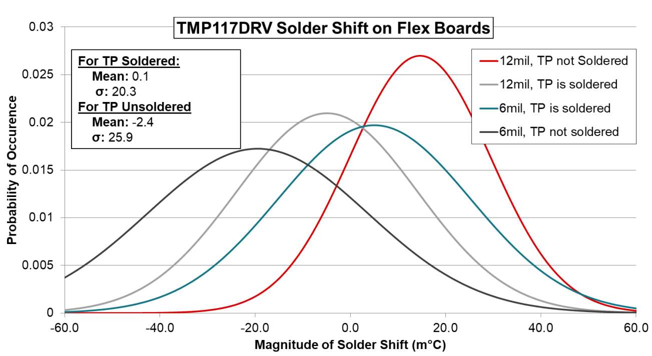

Figure 3. Solder Shift on 12-mil and 6-mil Flex Boards When Compared to Readings Within an IC Socket.

Thermal Response

In applications where the shift in accuracy can be tolerated, attaching the thermal pad of the device can often provide faster thermal response and better mechanical stability. In terms of thermal response, there is no significant change in response time when the sensor is in a fluid medium, regardless of whether or not the thermal pad is soldered. However, the response time in moving or still air was noticeably improved after attaching the thermal pad. The determination of this is discussed in detail in the *Wearable Temperature Sensing Layout Considerations Optimized for Thermal Response* (SNIA021).

Conclusion

As IC temperature sensor accuracy begins to enter the range of 10's of m°C, many previously negligible effects must be considered. This tech note discussed the phenomenon of solder-shift. The mechanical stress on the die from the hardening of solder on the thermal pad often manifests as a shift in error for temperature sensors. The accuracy testing on the TMP117 measured both before and after the thermal pad was soldered onto the device found that the magnitude of temperature shift from soldering is non-negligible. In flex board applications with thickness under 12 mils, however, initial testing shows that solder shift caused by the connecting the DAP appears to be less significant. In general, TI recommends not soldering the DAP of high-precision temperature sensors, for conductivity purposes thermally conductive underfills can aid in reducing response time.

Table 1. Device Recommendations

Device	Description
TMP117	±0.1°C Accurate Digital Temperature Sensor with Integrated NV Memory , Digital 16-bit output via I²C and SMBus™
LMT70	±0.1°C Precision Analog Temperature Sensor, low-power, fast response
TMP112	1.4V-Capable ±0.5°C Accuracy Digital Temperature Sensor

Table 2. Related Documentation

Document Type	Description
Application Report	Wearable Temperature Sensing Layout Considerations Optimized for Thermal Response
Application Report	Temperature Sensors: PCB Guidelines for Surface Mount Devices
Application Report	Precise Temperature Measurements With TMP116

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