Methods to Calibrate Temperature Monitoring Systems

Introduction

Temperature sensors are affected by various environmental effects aside from manufacturing process variations. These include thermal stress, mechanical stress, radiation, humidity, and aging during storage, shipment, and/or assembly that may alter the device's intrinsic characteristics (for example, accuracy and reliability) after it is implemented on the final system. Note that physical placement of the temperature sensor has a significant impact on the device's apparent accuracy relative to the target heat source due to the local temperature gradient. There is a distinction between apparent and intrinsic accuracy. Apparent accuracy can be improved with physical design (for example, PCB design with improved heat transfer characteristics) but intrinsic accuracy is an inherent device characteristic. In addition, external components connected to the temperature sensors (for example, ADC and filters) may have a significant impact on the overall system's intrinsic performance. Both environmental and system electrical factors may require system calibration to achieve traceable system accuracy.

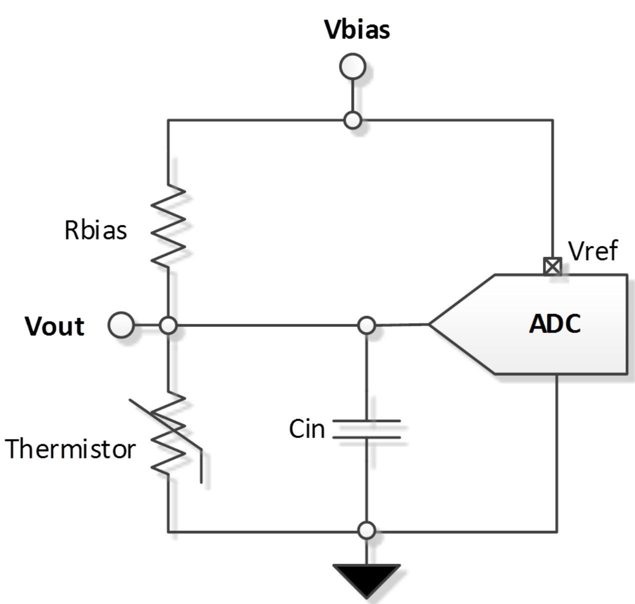

Figure 1. Example Temperature Sensing Circuit With a Thermistor

Analog temperature sensors, such as the TMP236 or NTC thermistors, require an analog-to-digital converter (ADC) to translate voltage to temperature. This affects overall system performance due to error contributions from the ADC. An example thermistor circuit is shown in Figure 1. Unlike an IC temperature sensor, some thermistor applications will require a bias resistor, which will introduce an addition source of error. The system errors arising from the factors discussed typically manifest themselves as system gain and offset errors, which can be reduced to some extent using calibration. For non-linear systems, an additional linearization step may be required depending on the application. The general 3-step process is shown in Figure 2. Note that the figure depicts only the average-value lines. Actual sensor output will have a statistical distribution about the average.

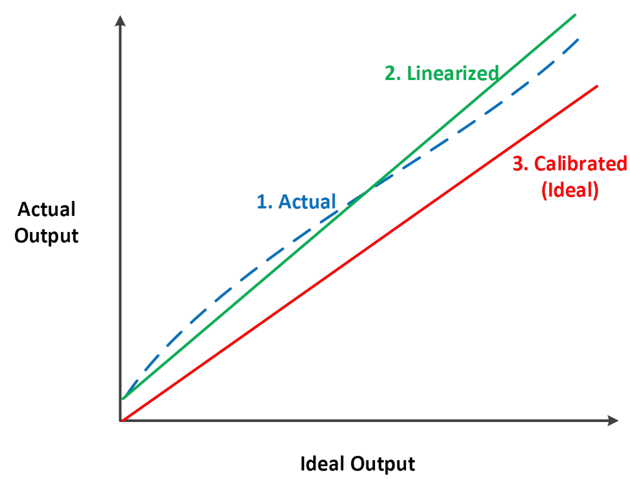

Figure 2. Generalize Three Steps of Temperature Sensor Calibration

System Calibration for Traceability

The system calibration process allows the final assembled measurement system to be compared to a known, traceable measurement standard (for example, the NIST, UL, EN, and so forth) to establish quantifiable measurement uncertainty. In the ideal case, the system response is linear and the system can be easily calibrated with just a simple offset, or gain and offset corrections. However, temperature sensors are not perfectly linear and thus cannot be easily calibrated without linearization. Typically, a non-linear system response requires multipoint linearization using a LUT prior to gain and offset calibration.

Analog Temperature Monitoring Systems

Analog temperature monitoring systems generally require linearization and calibration to achieve a high level of accuracy and traceability. The degree of linearization depends on the linearity of the sensor itself. NTC thermistors, for example, will generally require more system tradeoffs (for example, memory, CPU cycle, and sensitivity) for linearization compared to analog IC temperature sensors (for example, the

TMP236). Specifically, analog IC temperature sensors are typically more linear across a wide temperature range compared to NTC thermistors. Regardless, an additional step of calibration is required to achieve system-level accuracy that is traceable. For a more in-depth discussion on linearization, refer to the document listed in Table 2.

Calibration Methods

For production purposes, some system calibration is performed on a statistically significant number of systems (for example, 30) to determine the appropriate correction coefficients for the total number of systems. This statistical approach limits production cost. In some cases, calibration methods are performed at the production test stage using a single-point room temperature calibration. Multipoint calibration at the production test stage can result in better system accuracy but is more expensive to perform. Thus, multipoint calibration processes are typically applied to specialized systems where the production volume is relatively low. Regardless of the calibration method, the reference probe accuracy and traceability are essential components of calibration.

Zero Calibration Sensors

Unlike analog temperature sensors, TI digital temperature sensors such as TMP117 do not require any additional system linearization or calibration to achieve traceable system accuracy. As shown in Figure 3, a digital sensor is effectively a temperature monitoring system on a chip. These traceable devices are linearized and calibrated in production and this greatly simplifies system implementation. Note that the TMP117 does feature an offset register to enable the end user to calibrate any temperature offset for their system (for example, from physical system temperature gradient).

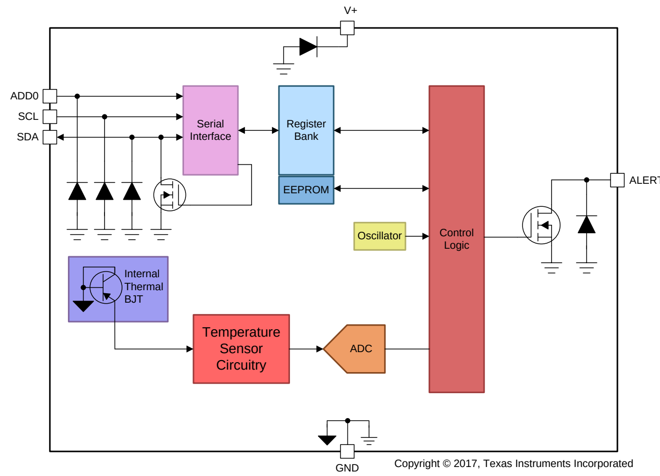

Figure 3. TMP117 Functional Block Diagram

TI Temperature Sensors and Design Tips

To learn more about some of TI temperature sensors, refer to Table 1. The key optimized parameters as well as their trade-offs are listed. To learn more about PCB guidelines, ambient air measurement, or linearization, refer to Table 2.

Table 1. Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
TMP117	Zero calibration and linearization, high accuracy	May have longer read time compared to analog sensors
TMP236	Linear analog output without external bias circuit	May require ADC
TMP390	Zero calibration and linearization, integrated temperature switch	Less features than digital sensors
TMP61	2-pin, small package, linear resistance	May require ADC and bias circuit

Table 2. Related Documentation

Literature Number	Title
SNOA967	Temperature Sensors: PCB Guidelines for Surface Mount Devices
SNOA966	TMP116 Ambient Air Temperature Measurement
SNOAA12	Methods to Reduce Thermistor Linearization Error, Memory, and Power Requirements Over Wide Operating Temperature Ranges

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