System Design Heats Up: Temp Sensor Accuracy & Linearity

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As Moore's Law continues to operate, all types of processors exhibit two characteristics: continuously smaller sizes and faster operation. As a result, systems designers continue to pack more features into smaller form factors and thus face increasingly crucial power and thermal management issues. Design teams require temperature sensors with more accuracy and linearity to reduce system costs and increase thermal management system performance.

As one example, cell phone designers can leverage higher accuracy temperature sensors in transmit voltage-controlled oscillator applications (TVCO). The improved temperature sensor results in fewer dropped calls, improves user call quality, and reduces unnecessary power drain from the battery. In another example, inkjet and bubble jet printers use higher accuracy print-head temperature sensing to improve ink flow characteristics.

Thermistors

System Designers can choose from among three different chip-based temperature sensing technologies: Thermistors, Analog Temperature Sensors, and Digital Temperature sensors. The name "thermistor," derived from the phrase "*therm*ally sensitive res*istor*," is a passive semiconductor device in which the electrical resistance varies with temperature. The two types of thermistors are distinguished by their slope coefficient, the more common negative temperature coefficient (NTC) and the positive temperature coefficient (PTC). Although lowest in cost, thermistors suffer from several drawbacks including highly non-linear output, self-heating, and additional thermal system components. Additionally, thermistors are not calibrated at the factory. Thus, the design team must also develop a self-calibration test every time the system powers up, requiring additional design cost, parts, space, and complexity.

[Insert Fig. 1] Thermistor Temperature/Resistance Curve

Non-linear literally means that the relationship between the temperature and the resistance results in a curve (as versus a straight line) such as the one shown in Fig. 1. Moving to the right in the graph, note that there is very little vertical elevation over a wide range of temperature, a defined trait of non-linear temperature sensors. A thermistor therefore requires a separate measurement circuit and the means to convert the non-linear output to meaningful thermal data. In Fig. 2, an ADC converts the continuous thermistor output to digital output. To do so, the ADC relies on a reference chip and an

EEPROM to store the necessary conversion tables. Each of these components adds cost, increases real estate, and adds complexity to manufacturability, all a result of non-linearity.

A thermistor system also requires a higher bit ADC to resolve the narrow output range as the temperature increases. An inadequate number of bits in the specified ADC means that there will not be enough measurement steps to resolve temperature gradients in the shallow slope of the curve at the right of the graph.

[Insert Fig. 2] Thermistor Measurement Circuit

Analog Temperature Sensors

Most U.S. circuit designers would prefer to achieve a temperature resolution of 0.1°F in their thermal management systems, since the Fahrenheit scale is most familiar to them. Recently, new analog sensor products achieve linear output, higher standard accuracy, and simplified thermal system designs.

Analog temperature sensors measure temperature as a function of the output voltage. Like thermistors, analog temperature sensors require an additional thermal management circuit to convert the analog output to digital. Most analog temperature sensors offer +/- 3°C as standard accuracy, with a premium cost for parts with +/- 1°C accuracy. Accuracy for all varieties of temperature sensors is determined by the vendor using sophisticated laboratory measurements. Since most semiconductor analog temperature sensors produce non-linear output (see Fig. 3) and are not factory calibrated, they require much the same circuitry as a thermistor: A 12-bit ADC, a voltage reference, an EEPROM to store the lookup tables, and a self-calibration circuit.

[Insert Fig. 3: Slope of Andigilog aTS10 temperature sensor. Linearity: Each step up in voltage produces an identical increase in the temperature.]

Recent advances in temperature sensor product design have produced offerings with standard accuracy on most parts of +/- 1°C, linear output, and factory calibrated parts. In Fig. 3, the linear output of the temperature sensor maintains a constant slope of 10mV/C°. In Fig. 4, using the same sensor designed into a typical analog temperature management circuit, the 12-bit ADC provides 4,096 bits (measurement steps) for the 4.096 V reference chip producing a 0.1°C/LSB, or 0.18°F/LSB, closer to the objective of a resolution of 0.1°F.

$$\text{Resolution} = \frac{\text{V REF}}{\text{\# of bits}} = \frac{4.096\ \text{V}}{4096\ \text{bits}} = 1\ \text{mV per bit}$$

$$= 0.1^{\circ}\text{C / bit (or LSB), when output slope is } 10\text{mV/}^{\circ}\text{C}$$

Linear output of a factory calibrated analog temp sensor allows the design team to eliminate the EEPROM (no lookup tables are required) and the self-calibration circuit. Depending on system requirements, high accuracy and linear output may also allow the designer to use a lower-bit, lower-cost ADC.

[Insert Fig. 4: Typical analog temp sensor thermal management System.]

Digital Temperature Sensors

A digital temperature sensor is, in effect, an integrated thermal management system device. The digital device includes the analog temp sensor, voltage reference, the ADC, user-programmable alarms, and a serial port. Most digital temperature sensors include a 9-bit ADC. Newly marketed digital temp sensors achieve +/-1°C accuracy and offer programmable 9- to 12-bit resolution.

If the design team selects 12-bit operation, they can achieve an LSB of 0.0625°C/bit based on a 2.56 V reference approaching further the desired 0.1°F. The temp sensor attains this performance because of the simplicity inherent in the linear output of the device's internal analog temp sensor. By using a digital temp sensor solution, the system design team may realize substantial net cost savings in terms of reduced thermal circuit design, smaller real estate requirements, and reduced component counts.

$$\text{Resolution} = \frac{\text{V REF}}{\text{\# of bits}} = \frac{2.56\ \text{V}}{4096\ \text{bits}} = 0.625\ \text{mV per bit}$$

$$= 0.0625\ °\text{C / LSB, when output slope is 10mV/°C}$$

$$= 0.1125\ °\text{F / LSB}$$

Summary

Accuracy and linearity are inherently linked and critical performance criteria of any temperature sensor. New advancements in factory-calibrated, high-accuracy temperature sensors allow design teams to consider using analog or digital temperature sensors as net low cost solutions to replace thermistors.

[Word count: 994]