Learn How to Measure Body Temperature Accurately and Cost Effectively

Emmy Denton
Temperature Sensor Applications
Texas Instruments
March 17, 2015
Overview and challenges of thermometry solutions

Principles behind IC temperature sensors

Comparison of different types of sensors

System implementation using IC temperature sensor
There are several technical challenges for measuring body temperature.

Accuracy:

- **RTD**
- **THERMISTOR**
- **THERMOCOUPLE**

![Graph showing temperature reading error](image)

37.00°C
There are a variety of body locations that have been used

<table>
<thead>
<tr>
<th>Locations</th>
<th>Target Accuracy</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary artery catheter</td>
<td>“Golden Standard”</td>
<td>Critically ill – blood flow</td>
</tr>
<tr>
<td>Sublingual</td>
<td>0.1C</td>
<td>Home/hospital</td>
</tr>
<tr>
<td>Rectal</td>
<td>0.1C</td>
<td>Home/hospital</td>
</tr>
<tr>
<td>Superficial temporal artery</td>
<td>0.1C</td>
<td>Home/hospital</td>
</tr>
<tr>
<td>Ear (ympanic)</td>
<td>0.2C</td>
<td>Home/hospital</td>
</tr>
<tr>
<td>Telemetry pill (Intestinal)</td>
<td>0.1C</td>
<td>Athletics (heat stress)</td>
</tr>
<tr>
<td>Wrist</td>
<td>0.5C</td>
<td>Fitness</td>
</tr>
<tr>
<td>Axillary (armpit)</td>
<td>0.5C</td>
<td>Home</td>
</tr>
<tr>
<td>Forehead (NFC or LCD sticker)</td>
<td>1C</td>
<td>Child/infant dispensable home</td>
</tr>
</tbody>
</table>
Most accurate sensing methods are internal to the body or in a body cavity
Skin temperature - How many sensors do you actually need to measure core temperature?

You regulate your core temperature by modulating your skin temperature through sweat and blood perfusion.
Complicating the matter further, there are a variety of temperature sensor types:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Temp Sense IC</th>
<th>Thermistor</th>
<th>RTD</th>
<th>Thermocouple</th>
<th>IR Temp Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temp Range</strong></td>
<td>-55°C to +150°C</td>
<td>-100°C to +500°C</td>
<td>-240°C to 700°C</td>
<td>-267°C to +2316°C</td>
<td>-100°C to +500°C</td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>Meets requirements</td>
<td>Depends on calibration</td>
<td>Meets requirements</td>
<td>Depends on cold junction compensation</td>
<td>Depends on calibration</td>
</tr>
<tr>
<td><strong>Linearity</strong></td>
<td>Best</td>
<td>Least</td>
<td>Better</td>
<td>Better</td>
<td>Better</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>Better</td>
<td>Best</td>
<td>Less</td>
<td>Least</td>
<td>Less</td>
</tr>
<tr>
<td><strong>Circuit Simplicity</strong></td>
<td>Simplest</td>
<td>Simpler</td>
<td>Complex</td>
<td>Complex</td>
<td>Simple to Complex</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Lowest</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$</td>
<td>$-$-$-$-$-$</td>
<td>$$</td>
<td>$$</td>
<td>$$</td>
</tr>
</tbody>
</table>

*(Images of sensors shown as placeholders for actual representations)*
The principles behind IC temperature sensors are simply based on the temperature coefficient of a base emitter junction forward voltage drop

\[
V_F = \frac{kT}{q} \ln \left( \frac{I_F}{I_S} \right)
\]

Slope \( \approx -2 \text{mV/°C} \)

\[
V_{F1} - V_{F2} = \frac{kT}{q} \ln \frac{J_1}{J_2}
\]

Slope \( \approx 240 \text{μV/°C} \)

Compensates for \( I_S \)
Types of IC temperature sensors include simple analog to more complex digital that simplify system design.

### Analog Output

- **SERIES**
  - Sensor
  - $V_{OUT}$
  - $+V_{SUPPLY}$

- **SHUNT**
  - Sensor
  - $V_{OUT}$
  - $+V_{SUPPLY}$
  - $R_{BIAS}$

- **CURRENT**
  - Sensor
  - $V_{OUT}$
  - $+V_{Supply}$
  - $1\mu A/K$
  - $R_{SET}$

### Digital Output

**TMP112**

- Temp Sensor
- $\Sigma A$ ADC
- Control Logic and Registers
- I2C/SMBus Interface Logic
- $V_{ref}$
Challenges of output impedance

Thevenin Equivalent Resistance?

Error Sources

SAR Analog-to-Digital Converter

LMT70

Error Sources
Response time of an IC temperature sensor is slightly better than a thermistor.

Stainless Steel Probe Assembly

LMT70 DSBGA 4-bump (0.8mm x 0.8mm)
PCB material and layout can affect thermal response time
LMT70 requires less processor resources or analog signal processing than RTDs or thermistors

LMT70 is a single ended measurement

RTD requires differential measurement with 3 or 4 wire kelvin connections

![Diagram of LMT70 and RTD connections]
LMT70 has excellent accuracy over a wide range of -55°C to +150°C

LMT70 accuracy using LUT linear interpolation

RTD accuracy curves

Meets 0.36°C over wide range!
LMT70 beats IEC Class AA RTDs from 10°C to 150°C
What is the system implementation using a semiconductor temperature sensor?
Use a digital sensor if your MCU excludes an ADC that provides the necessary performance.
ADC error sources include INL, DNL, offset and gain error
ADC error sources can be calibrated using calibration methods.

![Diagram](image)

Calibrated vs Uncalibrated ADC Temperature Readings

- **Temp Probe**
- **Uncalibrated ADC Temperature**
- **Calibrated ADC Temperature**

![Graph](image)
Over a narrow temperature range you can improve the LMT70’s accuracy using a single point calibration.
Analog or digital temperature sensors provide an answer for varying system resources and accuracy requirements.

±0.1°C accuracy over an ultra-wide temperature range using analog sensor and integrated 12-bit ADC

High-accuracy, low-power, digital temperature sensor with SMBus™ and two-wire serial interface in SOT563
Technical challenges and IC solutions for measuring body temperature accurately and cost effectively
Order a new LMT70 evaluation board and check out its ±0.1°C accuracy

www.ti.com/sensing

ti.com/tool/lmt70evm
IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designated for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Automotive and Transportation</td>
</tr>
<tr>
<td>Amplifiers</td>
<td>Communications and Telecom</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Computers and Peripherals</td>
</tr>
<tr>
<td>DLP® Products</td>
<td>Consumer Electronics</td>
</tr>
<tr>
<td>DSP</td>
<td>Energy and Lighting</td>
</tr>
<tr>
<td>Clocks and Timers</td>
<td>Industrial</td>
</tr>
<tr>
<td>Interface</td>
<td>Medical</td>
</tr>
<tr>
<td>Logic</td>
<td>Security</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Space, Avionics and Defense</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Video and Imaging</td>
</tr>
<tr>
<td>RFID</td>
<td></td>
</tr>
<tr>
<td>OMAP Applications Processors</td>
<td></td>
</tr>
<tr>
<td>Wireless Connectivity</td>
<td></td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2015, Texas Instruments Incorporated

www.ti.com/dataconverstion
www.ti.com/energy
www.ti.com/industrial
www.ti.com/medical
www.ti.com/security
www.ti.com/space-avionics-defense
www.ti.com/video
www.e2e.ti.com