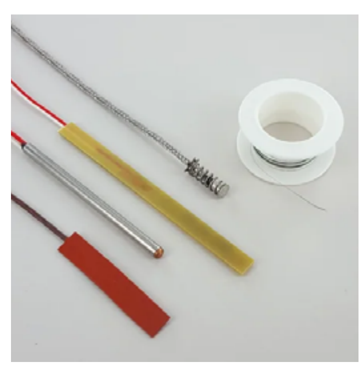
EVERY CONNECTION COUNTS

WHITE PAPER

TEMPERATURE SENSORS-PRODUCT DESIGN SELECTION

Application Note



INTRODUCTION

In a perfect world, product design – from initial concept to production release – would be a straight line, with no wasted engineering capacity, purchasing time, or redesigns. However, the reality is that it rarely follows a linear path. Factors such as integration challenges, quality issues, late-stage testing results, and design reconsiderations can often cause rework and delays.

Temperature sensors are among the most cross-functional components in a system, influencing mechanical packaging, electrical performance, and system control. Involving sensor engineers early in the concept phase can help better identify optimal placement, response, and reliability, helping reduce redesign risk and accelerating time to market.

THE VALUE OF EARLY COLLABORATION

As an example of the value of early engagement, a major computer manufacturer approached TE with a predefined probe design that incorporated two exposed thermistors at the end of a plastic tube. TE produced the probe according to the customer's specifications; however, during product release, the manufacturer encountered frequent thermistor breakage, delaying a multi-billion-dollar launch.

TE's engineering team quickly travelled to the customer site to review the issue. After analyzing the application environment and mechanical stresses, the team recommended a revised probe design with improved protection for the thermistors, an approach that differed from the original specification. The updated design resolved the failure and enabled production to resume.

This experience reinforces the importance of partnering with sensor manufacturers early in the concept phase to help develop robust design specifications, when material selection, packaging design, and mechanical interfaces can still be optimized for performance and durability.

INTERDISCIPLINARY DESIGN

Because temperature sensors sit at the intersection of mechanical, electrical, and systems design, effective integration requires collaboration across disciplines.

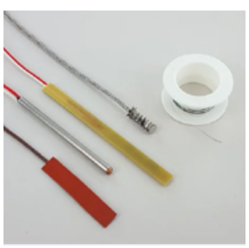
Electrical engineers typically define the sensor's electrical characteristics and interface with the control system, while mechanical engineers focus on thermal modeling and physical integration. TE's design teams encompass both competencies, providing comprehensive support that evaluates trade-offs across system performance, manufacturability, and long-term reliability.

Thermistor typically refers to negative temperature coefficient (NTC) thermistors.

- NTC thermistors exhibit a large, nonlinear decrease in resistance over their usable range.
- Temperature coefficients are typically in the 4 to 5% per degree centigrade range, giving NTC's very high sensitivity.
- They provide high measurement precision, fast thermal response, and compact size but are limited to a narrower operating range (approximately –40 °C to +150 °C).
- There is another class of positive temperature coefficient (PTC) thermistors that is more commonly used as a heater.

RTD stands for resistance temperature detectors.

- While an NTC thermistor is also a resistance device, an RTD is reserved for positive temperature coefficient metal resistance detectors.
- The most common metals used for RTDs are Platinum and Nickel.
- RTDs have a wider usable temperature range than NTC thermistors, but the temperature coefficient is much lower, 0.3 to 0.5%/degree, which requires more sophisticated measuring circuitry.



A Thermocouple is formed by joining wires of dissimilar metals in a thermocouple junction.

- When the thermocouple junction is at a different temperature than the other end of the wires a millivolt signal is generated.
- A thermocouple will only indicate what the temperature difference is between the hot and the cold end, therefore another sensor is required, typically an NTC, to measure the temperature at the metering side. This is called cold junction compensation.
- The strength of thermocouples lies in the very wide temperature range that they are capable of handling.

Digital temperature sensors integrate sensing elements, signal conditioning, and analog-to-digital conversion within a single microcircuit.

- Digital sensors are the evolution of semiconductor sensors, with several key architectural and performance advancements.
- These sensors directly output calibrated digital data, eliminating the need for external compensation or complex signal processing.
- They often deliver excellent accuracy and compact packaging, but typically at a cost of a more limited temperature range.
- Digital sensors typically require attention to bus/interconnect design (addressing, pull-ups, capacitance).
- Operating and sleep currents are extremely low, making these sensors ideal for power conscious applications.

COMPARISON OF COMMON TEMPERATURE SENSING TECHNOLOGIES

	NTC Thermistor	Platinum RTD	Thermocouple	Digital Sensor
Sensor	Ceramic (metal-oxide spinel)	Platinum wire-wound or metal film	Thermoelectric	Semiconductor
Temperature Range (typical)	-100 to +325˚C	-200 to +650˚C	-200 to +1750˚C	-40 to +125°C
Accuracy (typical)	0.05 to 1.5 ˚C	0.1 to 1.0˚C	0.5 to 5.0˚C	0.1 to 1.0°C
Long-term Stability @ 100C	0.2˚C/year (epoxy) 0.02˚C/year (glass)	0.05˚C/year (film) 0.002˚C/year (wire)	very prone to aging	0.02 °C to 0.1 °C per year
Output	NTC Resistance	PTC resistance 0.00385W/W/°C	Thermo-voltage 10mV to 40mV/°C	Digital, various, I2C, SPI
Linearity	Exponential	Fairly linear	Most types non-linear	Digital
Power Required	Constant voltage or current	Constant voltage or current	Self-powered	Very low
Response Time	Fast (0.12 to 10 seconds	Generally slow (1 to 50 seconds)	Fast (0.10 to 10 seconds)	Fast to very fast
Susceptibility to Electrical Noise	Rarely susceptible; High resistance only	Rarely susceptible	Susceptible/ Cold junction compensation	Some susceptibility, depends on design
Lead Resistance Effects	Low resistance parts only	Very susceptible. 3 or 4-wire configurations required.	None over short runs. TC extension cables required.	None
Cost	Low to moderate	Wire-wound: High Film: Low	Low	Low

KEY DESIGN CONSIDERATIONS

Linearity defines how well over a range of temperature a sensor's output consistently changes. NTC Thermistors are exponentially non-linear, exhibiting a much higher sensitivity at low temperatures than at high temperatures. Linearity of a sensor has become less of an issue over time, as microprocessors are more widely used in sensor signal conditioning circuits.

When powering, both thermistors and platinum RTD require careful consideration of the power dissipated in the sensor element to prevent **self-heating**. For platinum RTD sensors the measuring current is specified in the applicable standards (ASTM, DIN). No such standard exists for NTC thermistors, so it is up to the design team to determine a suitable current level to confirm no significant self-heating occurs while providing adequate signal to noise ratio. These currents are typically in the microamp range.

Response time, or how quickly a sensor indicates temperature, is dependent on the size and mass of the sensor element (assuming no predictive method is used). Digital sensors can often be the slowest responding due to their encapsulated IC packaging and internal conversion process. Platinum wire-wound elements are next slowest as their construction adds thermal mass. Platinum film thermistors and thermocouples are available in small packages, and thus have high-speed options. Glass micro-beads are the fastest responding thermistor configuration.

Response time itself is a poorly defined characteristic. A better measure of thermal response is the time constant (TC), which is the time it takes for the sensor to register a 63.2% change in temperature when transferred between two different temperatures. As its name suggests this is a constant value for a given media, regardless of the starting and ending temperatures, which is based on fundamental physics of heat transfer. There are different time constants for different media being measured. For instance, the time constant of a temperature probe measured in still air will be approximately 10 times longer than the same probe measured in stirred oil.

Electrical noise inducing errors in temperature indication is a problem mostly with thermocouples due to their weak millivolt signals. Noise can also be a problem for some NTC thermistors with very high resistances which act somewhat like antennae.

Lead resistance may cause an error offset in resistive devices such as thermistors or RTDs. This effect is more pronounced with low resistance devices such as 100Ω platinum elements or low resistance thermistors. The relatively low temperature coefficient of platinum RTD sensors compounds the problem, therefore 3 or 4-wire lead configurations are used to subtract the lead resistance from the measurement. For thermistors, typically choosing a higher resistance value eliminates the effect. Thermocouples must use extension leads and connectors of the same material as the leads themselves or an error may be introduced.

Cost of the sensor element should not be the primary consideration when choosing the type of sensing technology to use. Each of the types, NTC, RTD, Thermocouple, or Digital, has its strengths and weaknesses. And within each technology there is a wide range in cost related to sensor characteristics like accuracy, stability, temperature range, and environmental resistance. It is important to look at the overall cost of implementation to determine the most effective solution for any application.

CONCLUSION

Temperature sensing may appear straightforward, but selecting the right technology, configuration, and integration approach requires careful consideration of application environment, response time, and system interface. Partnering early with sensor manufacturers helps ensure that design specifications are robust, manufacturable, and optimized for long-term reliability.

Working on a new concept that requires thermal sensing? Connect with TE for design support, expertise and product selection on your next temperature sensing project.

About TE Connectivity

TE Connectivity plc (NYSE: TEL) is a global industrial technology leader creating a safer, sustainable, productive, and connected future. As a trusted innovation partner, our broad range of connectivity and sensor solutions enable the distribution of power, signal and data to advance next-generation transportation, energy networks, automated factories, data centers enabling artificial intelligence, and more.

Our more than 90,000 employees, including 10,000 engineers, work alongside customers in approximately 130 countries. In a world that is racing ahead, TE ensures that EVERY CONNECTION COUNTS. Learn more at www.te.com and on LinkedIn, Facebook, WeChat and Instagram.

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