TEMPERATURE SENSORS— PRODUCT DESIGN SELECTION

APPLICATION NOTE

In a perfect world, product design from initial concept to production release is a straight line, with no wasted engineering capacity, purchasing time, or redesigns required by design changes. In the real world, the path to product release is much more circuitous, where the path to product release almost serpentine at times.

At TE Connectivity (TE), we believe the preferred timing for temperature sensor design involvement is during product concept. This allows our temperature sensor design engineers to take an active role in product design, offering our years of thermal design experience. Our experiences in the process have lead us to believe this is the preferred timing. For example, years back when working with major computer manufacturer our probes were built into the manufacturers design. The probe design was provided by the manufacturer and the application required two thermistors that were exposed at the end of a plastic tube. We provided the thermistors to the manufacturers specifications and, unfortunately during the process of product release, it was discovered that the probes had design problems. The exposed thermistors were being broken. This thermistor design problem was holding up multi-billion dollars of product. Our design engineers traveled to the customer to discuss the problems. During our lengthy meeting with a large team of employees responsible for the product release, the well-respected senior design engineer asked our team, "Why didn't you place the probes in a sheath?". Our response was, "If you had asked us, we would have; we built to your design specifications." Once our team was aware of the product design and application limitations we could design a temperature sensor suited for the product.

With over 60 years of thermal sensor design and manufacturing expertise, and experiences like the example above at other major companies, our team believes that temperature sensor selection should be encouraged during the product concept phase.

FIGURE 1
Typical Path to Product Release

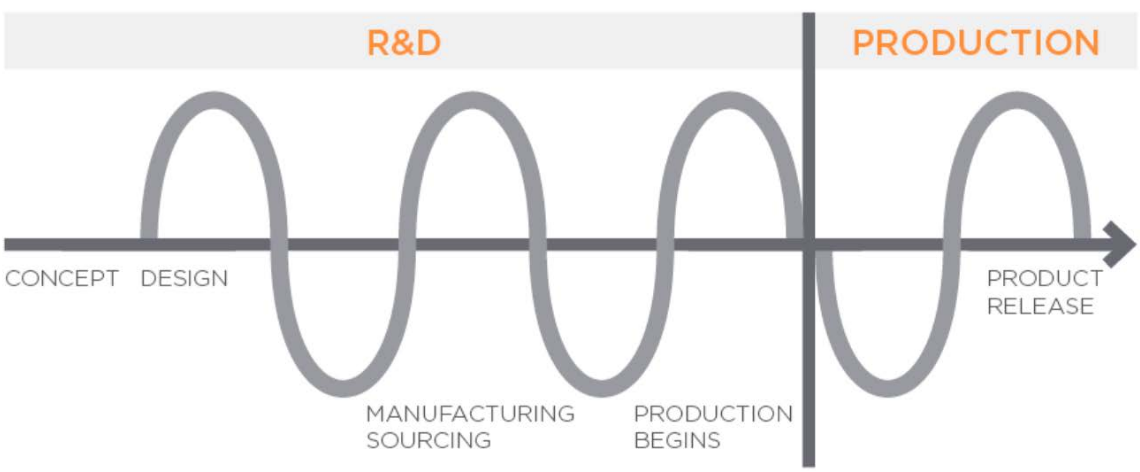
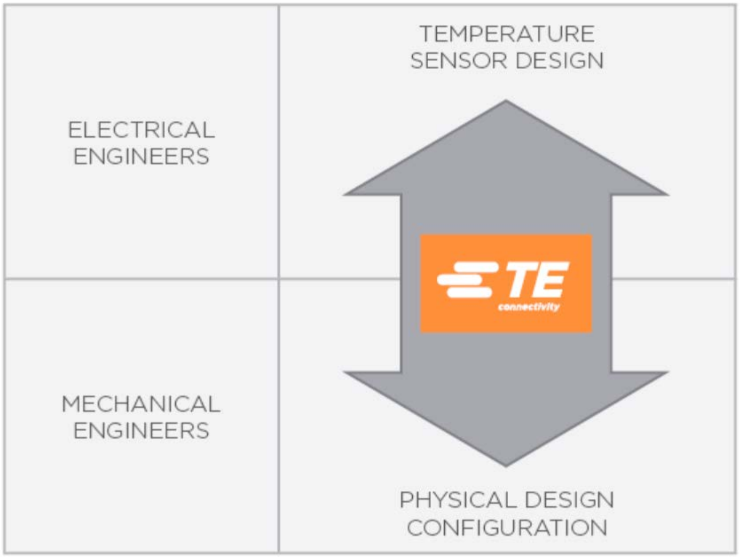


FIGURE 2.
Relationship between Electrical and Mechanical Engineering

DISCIPLINES NEED TO CONSIDER EACH OTHER IN PRODUCT DESIGN



An interesting feature of temperature sensor design is that it crosses engineering disciplines. Electrical engineers are typically involved in specifying the electrical characteristics of the sensor and interface with the electrical system. Mechanical engineers are usually responsible for the thermal modeling and physical integration of the sensor into the equipment design.

It varies from company to company as to whether a Mechanical or Electrical engineer is involved. Rarely are there engineers from both disciplines involved unless the company is relatively large. Our design engineering teams encompass both disciplines, providing the customer with comprehensive support across the entire system design.

TEMPERATURE SENSOR CHARACTERISTICS

Most temperature sensors fall into one of four categories: Thermistors, RTDs, Themocouples or Semiconductors

- **Thermistor** typically refers to negative temperature coefficient (NTC) thermistors. NTC thermistors exhibit a large 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. There is another class of positive temperature coefficent (PTC) thermistor that is more commonly used as a heater and will not be discussed here.
- **RTD** stands for resistance temperature detector. 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 thermcouple 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.
- **Semiconductor** sensors are quite varied in their technology and their output signals. The basic temperature sensitive feature is a diode junction, however onboard processing can provide outputs such as 0-5V, 4-20mA, mA/degree, or digital. The main limitations for semiconductor sensors are their maximum temperature limit and high cost.

	NTC Thermistor	Platinum RTD	Thermocouple	Semiconductor
Sensor	Ceramic (metal-oxide spinel)	Platinum wire-wound or metal film	Thermoelectric	Semiconductor junction
Temperature Range (typical)	-100 to +325˚C	-200 to +650˚C	-200 to +1750˚C	-70 to 150˚C
Accuracy (typical)	0.05 to 1.5 ˚C	0.1 to 1.0˚C	0.5 to 5.0˚C	0.5 to 5.0˚C
Long-term Stability @ 100˚C	0.2˚C/year (epoxy) 0.02˚C/year (glass)	0.05˚C/year (film) 0.002˚C/year (wire)	Variable, some types very prone to aging	>1˚C/year
Output	NTC Resistance	PTC resistance 0.00385W/W/°C	Thermo-voltage 10mV to 40mV/°C	Digital, various outputs
Linearity	Exponential	Fairly linear	Most types non- linear	Linear
Power Required	Constant voltage or current	Constant voltage or current	Self-powered	4 to 30 VDC
Response Time	Fast 0.12 to 10 seconds	Generally slow 1 to 50 seconds	Fast 0.10 to 10 seconds	Slow 5 to 50 seconds
Susceptibility to Electrical Noise	Rarely susceptible High resistance only	Rarely susceptible	Susceptible/Cold junction compensation	Board layout dependent
Lead Resistance Effects	Low resistance parts only	Very susceptible. 3 or 4-wire configurations required	None over short runs. TC extension cables required.	N/A
Cost	Low to moderate	Wire-wound: High Film: Low	Low	Moderate

SELF-HEATING, TIME RESPONSE AND OTHER TEMPERATURE SENSOR 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 Pt 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). Semiconductors are the slowest responding. Platinum wire-wound elements are next slowest. 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 Semiconductor, has it 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.

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.

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