

# How to Select the Right Digital Temperature Sensor for Your Application

## Introduction

Temperature measurement and control is one of the most critical processes used in electronics. Found in virtually every piece of electronic equipment and in every industrial process, temperature sensor technologies are as diverse as the applications that utilize them. With such a wide spectrum of devices available, selecting the right temperature sensor is not always straightforward. In this design solution, we will explore the broad categories of local and remote digital temperature sensors, examine specific technologies used within these applications, and provide guidance on the appropriate temperature sensing solution for each case.



Figure 1. High Temperature Measurement Display

## Temperature Sensor Applications

Sensors have become ubiquitous in the industrial environment. As they increase in sophistication and shrink in size, sensors enable Industry 4.0, adding more intelligence across the factory floor. Industrial end equipment often operates in harsh electronic environments and must be durable and reliable. They are used in many industrial applications such as electronics equipment, automotive, food and beverage, chemical processing, oil and gas, pharmaceutical, manufacturing, water and wastewater management and refrigeration systems.

## Local Temperature Sensors

Local temperature sensors are typically silicon-based. The sensing element resides in the same IC that performs the process of measurement, digitization, and communication. Because of the tight connection to the silicon and packaging technology, the temperature range is limited to  $-55^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ , the typical operating range of silicon semiconductor devices. The common use of temperature sensors in electronic equipment is to stop equipment from overheating and prevent eventual degradation and failure. They also allow for temperature-related system calibration to compensate for common temperature-related errors or drifts in the system.

### Silicon Temperature Sensors

With silicon temperature sensors, the sensing mechanism is based on the temperature dependence of a transistor junction voltage (the negative temperature coefficient, TC, of the base-emitter voltage,  $V_{BE}$ ) or the voltage difference of two transistor junctions (positive TC of the  $\Delta V_{BE}$ ). The digital temperature sensor has a minimum of five I/Os: data, clock, power, ground, and overtemperature output. Accordingly, the entire function fits in a very small package such as a SOT23-5, having just 5 pins.

### When Should You Use a Silicon Temperature Sensor?

Use a silicon temperature sensor in local electronic equipment applications that operate across a moderate temperature range.

In datacom applications, a small, local temperature sensor IC is typically used to regulate the temperature of a network equipment box. A small device with good accuracy such as the [DS1775](#) is a perfect option for this application. It is available in a 5-pin SOT23 package and provides accuracy of  $\pm 2^{\circ}\text{C}$  over a temperature range of  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

Expensive base-station equipment like oven-controlled crystal oscillators (OCXO) require a more sophisticated and accurate solution. For this application, higher accuracy temperature sensors, such as the [MAX31725/MAX31726](#) in an 8-pin TDFN package, offer an accuracy of  $\pm 0.5^{\circ}\text{C}$  (max) and  $0.1^{\circ}\text{C}$  (typ) in a smaller package.

Table 1 gives an overview of all the local temperature sensing technologies discussed.

**Table 1. Local Temperature Sensing Technologies**

Type	Local Temperature Sensing	
Sensor Technology	Silicon	Silicon
Sensor Temperature Range	-55°C to +125°C	-55°C to +150°C
Accuracy (Max)	±2°C (-10°C to +85°C)	±0.5°C (-40°C to +105°C)
Applications	Network Equipment, 'PizzaBox'	Basestations, Oven Controlled Crystal Oscillators (OCXO)
Control IC	DS1775	MAX31725
IC Temperature Range	-55°C to +125°C	-55°C to +150°C
IC Package	SOT23-5	SO-8
Communication Bus	I <sup>2</sup> C	I <sup>2</sup> C

**Remote Temperature Sensors**

In remote temperature sensors, the sensing element is detached from the processing chip and is often located far from it. Because of the physical separation, and depending on the sensing element material, the temperature range can be as wide as -270°C to +1820°C (as in a thermocouple, for example). Remote temperature sensors are used to monitor and control industrial processes with extreme temperatures like fractioned distillation in the oil industry or food processing in ovens or freezers. Figure 2 illustrates the crude oil fractional distillation process, based on

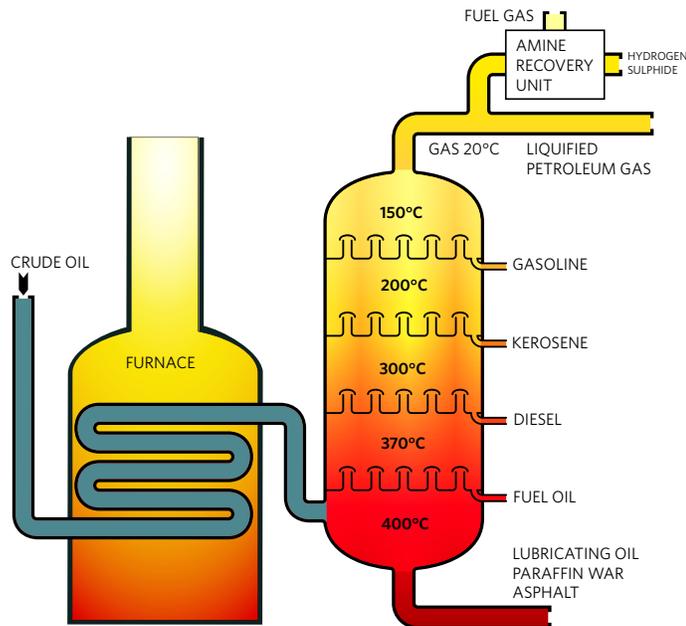


Figure 2. Crude Oil Distillation Column and Temperatures

the difference in boiling point temperature of various substances (i.e., diesel kerosene, gasoline, etc.). This is one example of many processes in which heat management and temperature monitoring is critical.

Figure 3 illustrates a typical temperature sensor system in a factory environment.

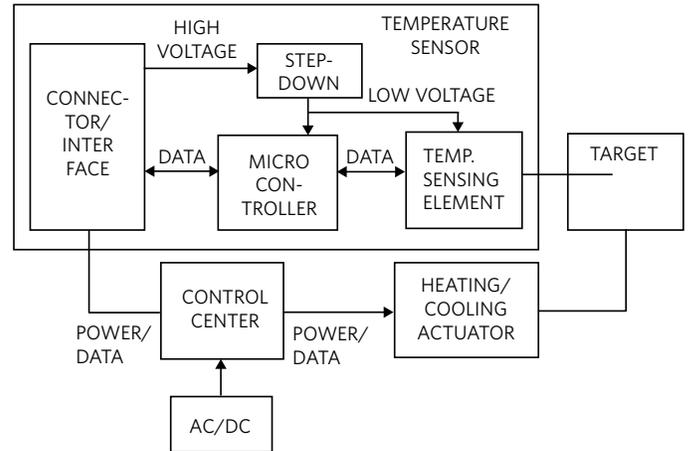


Figure 3. Typical Temperature Sensor System

Temperature sensors may be located anywhere on the factory floor. The control center receives information from the sensor and sends the appropriate action to the actuator via a field bus. The sensor “box” includes a front-end connector/interface that handles data and routes power to a step-down voltage regulator delivering the appropriate voltage to the ASIC/microcontroller/field-programmable gate array (FPGA) and the sensing element. This type of communication and control intensive environment dictates that temperature sensors must be digital, with on-board communications.

**Remote Temperature Sensors Types**

Diodes, resistance temperature detectors (RTDs), and thermocouples are all examples of remote temperature sensors.

*Remote Diode Temperature Sensors*

For remote diode temperature sensors, the sensing element is a silicon diode that may be discrete or may be part of a highly complex application-specific standard product (ASSP), an FPGA, or a microprocessor. If the remote diode is discrete it works in conjunction with a processing IC located in the control center.

*When Should You Use a Remote Diode Temperature Sensor?*

For applications that require a moderate temperature range such as water/wastewater management and refrigeration systems, the use of a remote diode temperature sensor is a great option. For multi-point remote temperature sensing of discrete diodes, a processing IC like the [MAX31730](#), receives the infor-

mation from the diodes, digitizes the temperature of up to 3 remote diodes and guarantees  $\pm 1^{\circ}\text{C}$  accuracy over the  $0^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$  temperature range.

#### Resistance Temperature Detectors

RTDs are resistors (often made from platinum wire) with resistance that varies with temperature. Their characteristics include a wide temperature range (up to  $+750^{\circ}\text{C}$ ), excellent accuracy and repeatability, and reasonable linearity. Signal conditioning for an RTD usually consists of a precision current source and a high-resolution ADC. While the RTD can be remotely exposed to temperatures from  $-200^{\circ}\text{C}$  to  $+600^{\circ}\text{C}$ , the controlling IC temperature range is typically  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ . Figure 4 shows a typical RTD module.



Figure 4. RTD Module

#### When Should You Use an RTD Sensor?

Using an RTD sensor in automotive, industrial, oven, food processing, and drug manufacturing plants is an excellent option especially since it can operate within a wide temperature range and works in conjunction with a processing IC located in the control center.

The [MAX31865](#) processing IC, optimized for RTDs, reports temperature with an accuracy of  $\pm 0.5^{\circ}\text{C}$ . For example, high temperature accuracy in food processing is the difference between a perfectly baked loaf of bread and a poorly baked one. An external resistor sets the sensitivity for the RTD and an on-chip precision delta-sigma ADC converts the ratio of the RTD resistance to the reference resistance into digital form.

#### Thermocouples

Thermocouples are made by joining two wires of dissimilar metals. The point of contact between the wires generates a voltage that is approximately proportional to temperature. Thermocouples have the highest temperature range, from  $-270^{\circ}\text{C}$  to  $+1820^{\circ}\text{C}$  depending on their type. Thermocouples work in conjunction with a processing/converter IC located in the control center. Figure 5 shows two thermocouple sensor probes.



Figure 5. Thermocouple Sensor Probes

#### When Should You Use a Thermocouple?

Use a thermocouple sensor in industrial, automotive exhaust systems, diesel engines, and fractional distillation applications that require the widest temperature range. For maximum flexibility choose a temperature sensing converter IC like the [MAX31856](#), which has a lookup table that stores linearity correction data for several types of thermocouples (K, J, N, R, S, T, E, and B) and guarantees an accuracy of  $\pm 0.15\%FS$ .

#### Remote Temperature Sensing Table

Table 2 gives an overview of all the reviewed remote temperature sensing technologies.

Table 2. Remote Temperature Sensing Technologies

Type	Remote Temperature Sensing		
Sensor Technology	Diode	Resistive Temperature Detector (RTD)	Thermocouple
Sensor Temperature Range	$-64^{\circ}\text{C}$ to $+150^{\circ}\text{C}$	$-200^{\circ}\text{C}$ to $+600^{\circ}\text{C}$	$-270^{\circ}\text{C}$ to $+1820^{\circ}\text{C}$
Accuracy (Max)	$\pm 1^{\circ}\text{C}$ (0 to $+70^{\circ}\text{C}$ )	$\pm 0.5^{\circ}\text{C}$ ( $-20$ to $+125^{\circ}\text{C}$ )	$\pm 0.15\%FS$ ( $-20$ to $+85^{\circ}\text{C}$ )
Applications	Water/Waste-water Management and Refrigeration System	Automotive, Industrial, Ovens, Food Processing, Drug Manufacturing	Industrial, Automotive, Car Exhaust Systems, Diesel Engines, Fractioned Distillation
Control IC	MAX31730	MAX31865	MAX31856
IC Temperature Range	$-40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$	$-40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$	$-55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$
IC Package	$\mu\text{MAX}^{\text{®}}$ -10	SSOP-20	TSSOP-14
Communication Bus	I <sup>2</sup> C	I <sup>2</sup> C	I <sup>2</sup> C

## Conclusion

Temperature sensors are diverse and their technology implementation fits a variety of the specific applications. Silicon temperature sensors have a moderate temperature range suitable to local applications and are widely used inside electronic equipment. Remote diode temperature sensors have a moderate temperature range and are used in water/wastewater management and refrigeration systems. RTD sensors span a wide temperature range essential for applications in automotive, industrial, oven, food processing and drug manufacturing plants. And finally thermocouples, which have the widest temperature range, are utilized in industrial, automotive exhaust systems, diesel engines and fractional distillation. Maxim provides a broad selection of complete temperature sensing solutions for local applications. For remote applications Maxim's rich portfolio of processing ICs works in conjunction with diodes, RTDs and thermocouples.

**FS:** Full scale

**RTD:** Resistance temperature detector

**TC:** Temperature coefficient

**V<sub>BE</sub>:** Base-to-emitter voltage of a bipolar transistor

Learn more:

[DS1775 Digital Thermometer and Thermostat in SOT23](#)

[MAX31725 ±0.5°C Local Temperature Sensor](#)

[MAX31726 ±0.5°C Local Temperature Sensor](#)

[MAX31730 3-Channel Remote Temperature Sensor](#)

[MAX31856 Precision Thermocouple-to-Digital Converter with Linearization](#)

[MAX31865 RTD-to-Digital Converter](#)

[Application Note : Selecting Temperature Sensors for System Measurement and Protection](#)

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