# AN10.14

# Using Temperature-Sensing Diodes with Remote Thermal Sensors

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## OVERVIEW

Microchip offers a family of remote diode temperature sensors that accurately measure CPU and GPU temperatures, as well as the temperatures of discrete diodes, e.g., 2N3904, 2N3906. Most of these devices include an internal sensor and can measure one or more external sensors.

This application note describes how to maintain accuracy when diodes are used as remote sensors with the remote temperature sensing devices from Microchip. It lists the characteristics of a diode that is appropriate for use as an external sensor. It also provides recommendations for the layout of a printed circuit board that could reduce the errors that may be caused by electrical noise or trace resistance.

Throughout this document, the term “remote sensor” refers to a remotely placed thermal diode.

## THERMAL DIODE TEMPERATURE MEASUREMENT

Thermal diode temperature measurements are based on changes in the forward bias voltage ($\Delta V_{BE}$) of a diode when it is operated at two different currents.

**EQUATION 1:**

$$\Delta V_{BE} = V_{BE\_HIGH} - V_{BE\_LOW} = \frac{\eta k T}{q} ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)$$

Where:

k = Boltzmann’s constant
T = Absolute temperature in Kelvin
q = Electron charge
η = Diode ideality factor

Figure 1 presents a functional block diagram of a temperature measurement circuit. The sensor incorporates switched capacitor technology that samples the temperature diode voltage at two bias currents and holds the voltage difference.

Output of the switched-capacitor, sample-and-hold circuit interfaces to a single-bit, delta-sigma, analog-to-digital (ADC) converter. The ADC runs at 100 kHz sample frequency. ADC output is digitally filtered, averaged over 2048 samples, and generates an 11-bit output.

The advantages of this architecture are superb linearity and inherent noise immunity. The linearity is directly attributable to the comparator in the ADC, the noise immunity is due to the digital averaging filter.

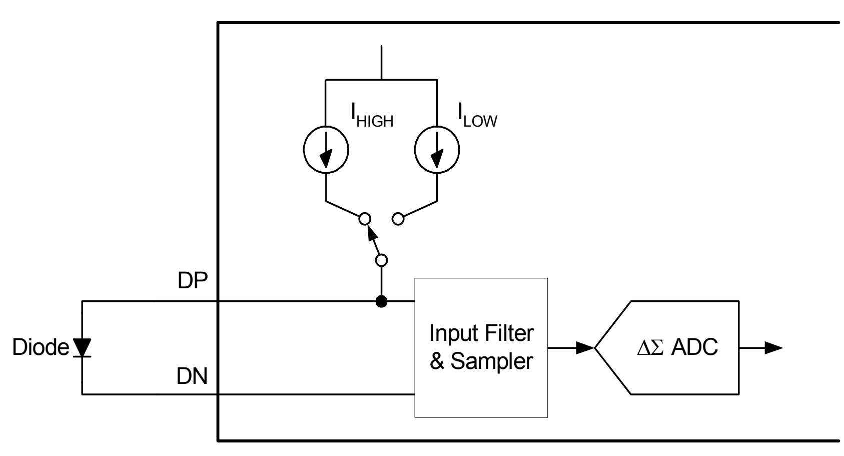



***FIGURE 1:*** *Thermal Diode Temperature Measurement Circuit.*

## MAINTAINING ACCURACY

### Physical Factors

Temperature measurement is performed by measuring the change in forward bias voltage of a diode when two different currents are forced through the junction. The circuit board itself can impact the ability to accurately measure these small changes in voltage. For example, an excessive amount of series resistance can introduce error in the measurement.

#### LAYOUT

Apply the following guidelines when designing the printed circuit board:

- Route both remote diode traces on the same layer. Minimize use of via and layer change.
- For single diode traces that do not utilize anti-parallel diodes, the DP line is more sensitive to noise than the DN line. For long runs, routing the DP line on the outside of the PCB is advised.
- Place a ground plane on the layer immediately below the diode traces.
- Keep the diode traces short. It is possible with careful layout to route the diode traces 20-30 cm (8-12 inches); however, longer traces pick up more noise.
- Keep the diode traces parallel, and the length of the two traces identical within 7.6 mm (300 mil).
- Use a diode trace width of 0.127-0.254 mm (5-10 mil), with another 0.127-0.254 mm between traces.
- For non-PC environments, where the ground is noise free, place a 0.127-0.254 mm-wide ground guard trace on both sides of the differential pair of diode traces at 0.127-0.254 mm (5-10 mil) spacing. The guard traces should be connected to the ground plane at least every 6.35 mm (250 mil).

| | |
|---|---|
| **Note:** | Do not connect the guard traces to the CPU ground pins. These pins may inject noise due to locally high currents. |

- If the guard traces are not applicable for the PCB (which is generally the case in a PC environment), separate the diode traces from any other signal traces by at least 0.5 mm (20 mil).
- Keep the diode traces away from sources of high frequency noise such as power supply filtering or high-speed digital signals.
- When the diode traces must cross high-speed digital signals, make them cross at a 90 degree angle.
- Avoid joints of copper to solder that might introduce thermocouple effects.

These recommendations are illustrated in Figure 2 (with guard traces) and Figure 3 (without guard traces).

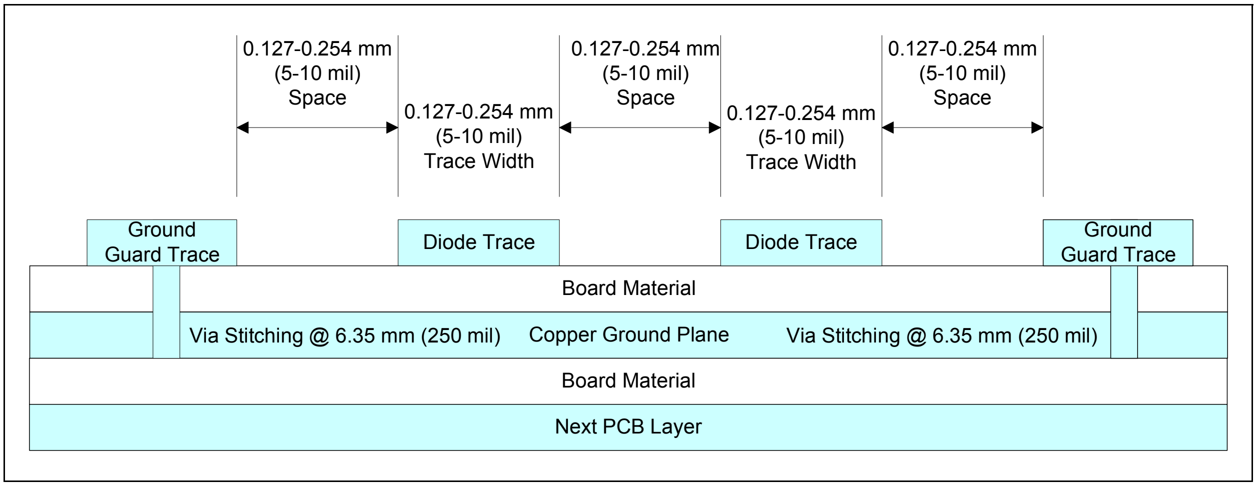
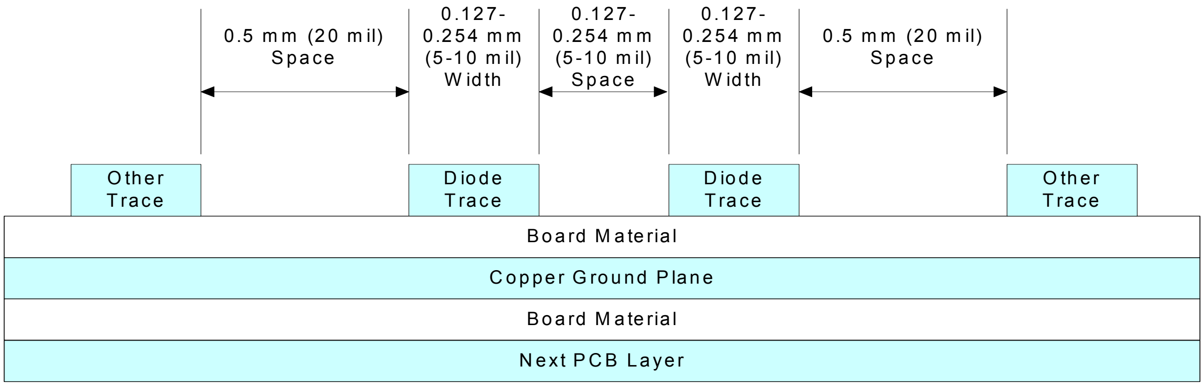



***FIGURE 2:*** *Routing the Diode Traces (With Ground Guard Traces).*




If guard traces are not applicable for the PCB (which is generally the case in a PC environment), separate the diode traces from any other signal traces by at least 0.5 mm (20 mil).

***FIGURE 3:*** *Routing the Diode Traces (Ground Guard Traces Not Applicable).*

## DEVICE POWER SUPPLY DECOUPLING

Accurate temperature measurements require a clean, stable power supply to the remote temperature sensing device. Locate a 0.1 µF capacitor as close as possible to the power pin of the sensor with a good ground. A low ESR capacitor (such as a 1 µF ceramic) should be placed across the power source (see Figure 4). Add additional power supply filtering in systems that have a noisy power supply.

A capacitor may be placed across the DP/DN pair at the remote diode in noisy environments.

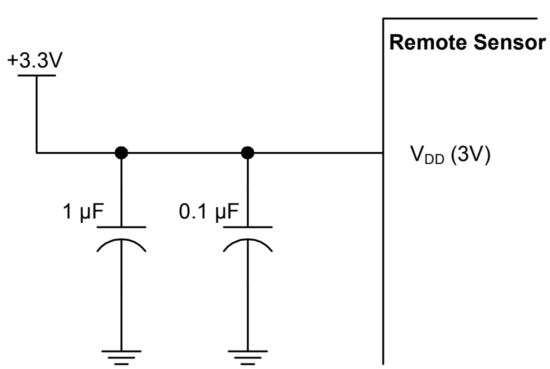



***FIGURE 4:*** *Device Power Supply Decoupling.*

## CAPACITORS ON DIODE TRACES

In the board layout, provide pads to install a capacitor across the DP and DN traces as close to the package pins as possible. The value of the capacitor should not exceed 2200 pF for the 2N3904-type diode-connected transistors, and must not exceed 470 pF for CPU and GPU thermal diode applications.

It is recommended that pads for a capacitor also be placed at the diode and that this capacitor is generally not populated. In certain noisy environments, it may be necessary to install a small capacitor (18 - 100 pF) at the diode.

## REMOTE SENSORS CONNECTED BY CABLES

When connecting remote diodes with a cable (instead of traces on the PCB), use shielded twisted-pair cable. The shield should be attached to ground near the remote sensor and should be left unconnected at the sensor end. Belden 8451 or 88641 cable can be a good choice for this application.

## MANUFACTURING

Circuit board assembly processes may leave a residue on the board. This residue can result in unexpected current leakage that may introduce errors if the circuit board is not clean. For example, processes that use water soluble soldering fluxes have been known to cause problems if the board is not kept clean.

## THERMAL CONSIDERATIONS

Keep the diode in good thermal contact with the component to be measured. The temperature of the leads of a discrete diode will greatly affect the temperature of the diode junction. Make use of the printed circuit board to disperse any self heating that may occur.

## Sensor Characteristics

The characteristics of the diode junction that is used for temperature sensing affects the accuracy of the measurements. The remote sensor is typically a small signal bipolar transistor connected as a diode. It may be either a discrete transistor or a substrate diode built into the die of a high power component such as a CPU or graphics controller.

### SELECTING A SENSOR

Small signal transistors like the 2N3904 or the 2N3906 are recommended. Silicon diodes are not good choices for remote sensors. Desirable characteristics for the sensor would include the following:

- Constant value of $h_{FE}$ in the range of 7.5-170 μA. Variation in $h_{FE}$ from one device to another, or from one manufacturer to another, cancels out of the temperature equations.
- Low values of emitter and base resistance minimize the effect of series input resistance.

For more information regarding the selection of remote thermal sensing diodes, see the Microchip Application Note AN12.14.

### COMPENSATING FOR NON-UNITY IDEALITY FACTOR

The on-die thermal diode incorporated into a CPU is often used as the remote sensor diode. The characteristics of this diode may be different than a small signal transistor because of the manufacturing process. The manufacturer of the CPU will specify the ideality factor parameter in the CPU data sheet. When the ideality factor is known, the temperature measurement can be compensated mathematically. Refer to the Microchip remote temperature sensor data sheet for register information on a specific component. Contact a Microchip Field Applications Engineer (FAE) for updated information on specific processors. A list of Microchip offices is available on the final page of this document.

### CIRCUIT CONNECTIONS

The more negative terminal for the remote sensor (DN) is internally biased above ground with a forward diode voltage. This means that the DN pin is not referenced to ground, but to this internal bias voltage. The remote temperature diodes can be constructed as shown below in Figure 5.

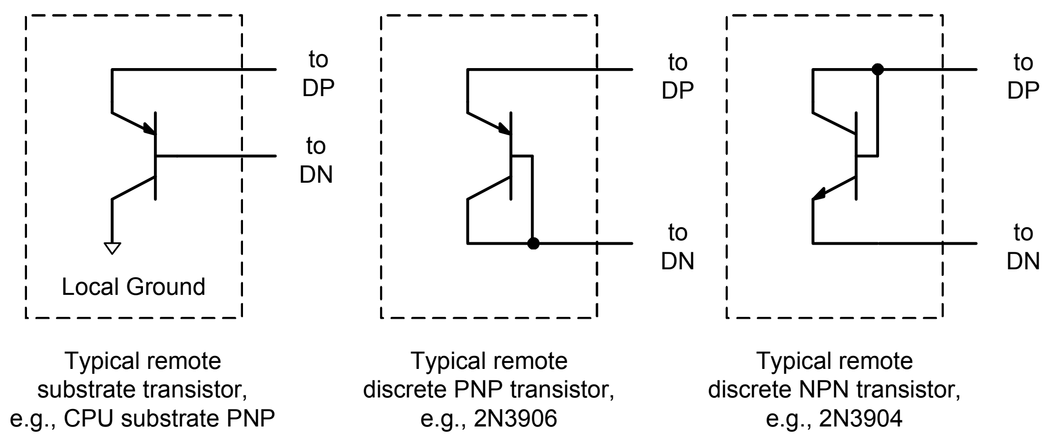



***FIGURE 5:*** *Remote Temperature Diode Examples.*

## CONCLUSION

Temperature-sensing diodes from Microchip are designed to make accurate temperature measurements. Careful design of the printed circuit board and equally careful selection of the remote sensing diodes leads to greater accuracy.

## REFERENCES


- Microchip Device Data sheets
- Microchip Application Note 12.14, “*Remote Thermal Sensing Diode Selection Guide*” (DS0001838)
- Microchip Application Note 16.4, “*Using Anti-Parallel Diodes (APD) with Microchip Temperature Sensing Devices*” (DS0001828)

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