AN16.4

Using Anti-Parallel Diodes (APD) with Microchip's Remote Temperature Sensing Devices

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INTRODUCTION

This application note provides information on maintaining temperature measurement accuracy and noise immunity when using anti-parallel diodes (APD) with Microchip's APD temperature sensing devices.

USING ANTI-PARALLEL THERMAL DIODES FOR TEMPERATURE MEASUREMENT

Anti-Parallel Diodes (APD)

Unlike other traditional temperature monitoring devices which require two pins for each thermal zone, Microchip's APD temperature sensors can monitor two separate temperature zones using only two pins. This is accomplished using two anti-parallel connected transistors, as shown on the DP1/DN2 and DN1/DP2 pins in Figure 1. This technique maintains high accuracy while minimizing pin count and reducing board routing complexity. It is not compatible with substrate transistors because the architecture of substrate transistors does not support reverse biasing.

> **Note:** In the semiconductor industry, substrate transistors are sometimes called thermal diodes or on-chip sense junctions.

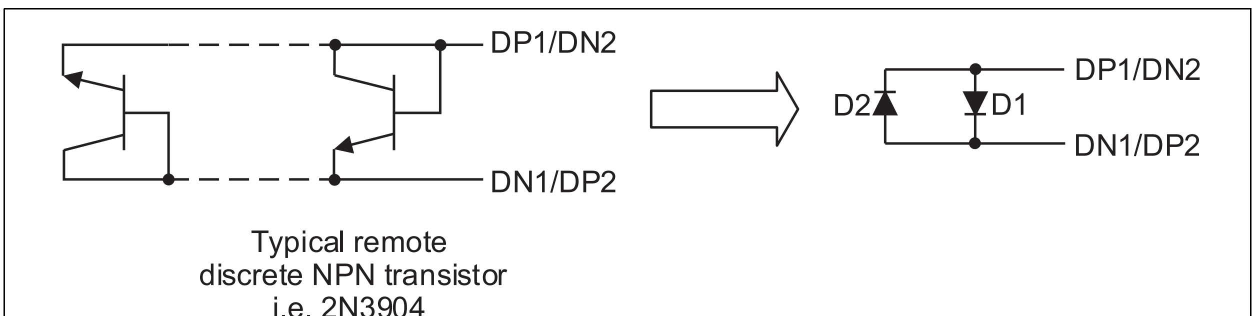

FIGURE 1: *APD Example.*

To measure two temperatures using an APD pair, the circuit first sources currents through the DP1 pin and measures the voltage across D1. This is the same as normal non-APD measurement, except that the parallel connected D2 is reverse-biased (Figure 2). After calculating D1's temperature, the D1/D2 Selection signal will switch the direction of the currents and force them through the DP2 pin, measuring D2's temperature with D1 reverse-biased.

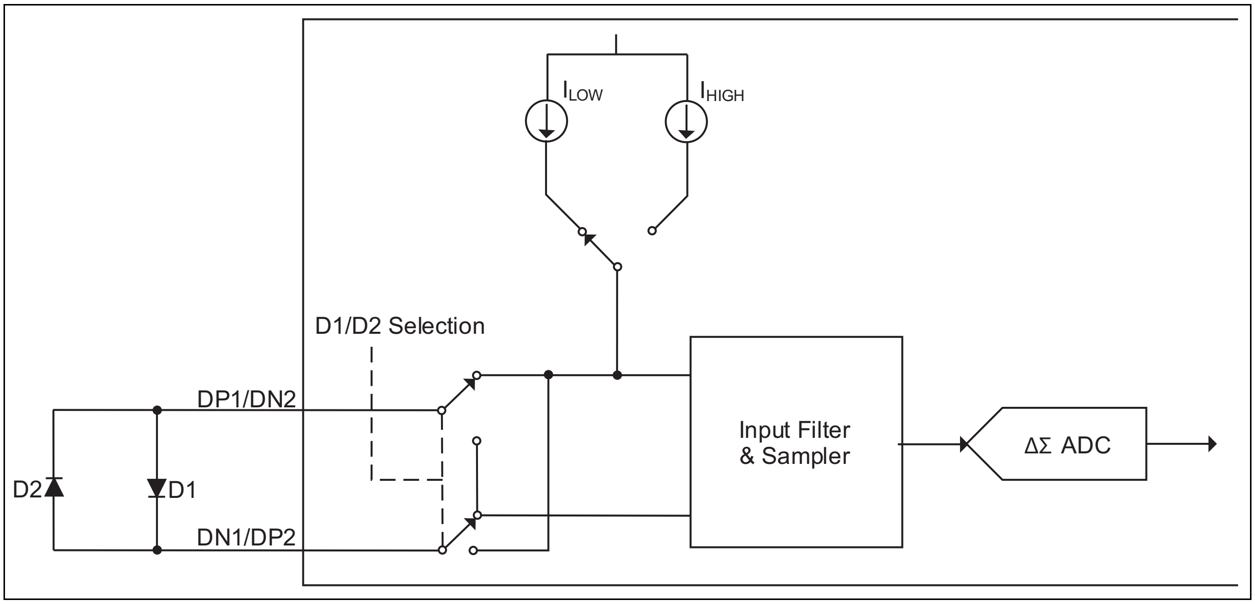

FIGURE 2: APD Temperature Measurement.

Diode Reverse Saturation Current and Measurement Accuracy

Since the ΔV_{BE} is a function of the temperature (T) and bias currents (I_{HIGH} and I_{LOW}), as shown in Equation 1 in **Appendix A: "Thermal Diode Temperature Measurement"**, different bias currents will generate different ΔV_{BE} voltages at the same temperature. Therefore, when using an APD pair for temperature measurement, it is necessary to ensure that the measured temperature accuracy is not affected by the reverse saturation current of the reverse-biased diode.

Note:	In the semiconductor industry, a diode's reverse saturation current is sometimes called the diode's leakage current.

MAXIMUM ALLOWED BIAS CURRENT ERROR

Microchip's temperature sensing devices are designed to monitor the remote temperature zones with a ±1°C accuracy. To maintain this accuracy when using the anti-parallel diodes, the reverse saturation current of the reversed diode must be much smaller than 75 nA, based on the calculations in **Appendix B: "Calculations for Maximum Allowed Reverse Saturation Current when Implementing APD"**.

THE TEMPERATURE DEPENDENCE OF REVERSE SATURATION CURRENT

A diode's reverse saturation current is a function of the diode's temperature. Driven by the same bias voltage, the reverse saturation current will be greater at a higher temperature, as shown in Figure 3. Therefore, all data in this application note will be shown at 125°C.

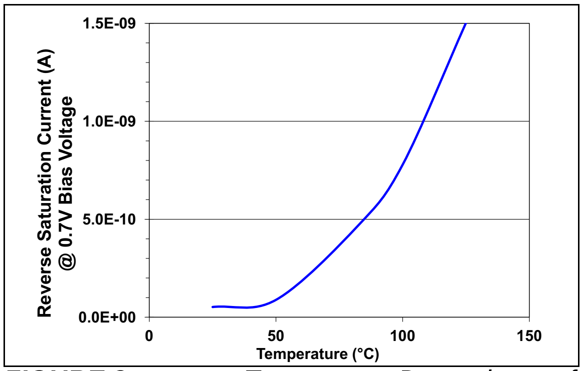

FIGURE 3: *Temperature Dependence of Reverse Saturation Current.*

REVERSE SATURATION CURRENT TEST FOR POPULAR COMMERCIAL THERMAL DIODES

Reverse saturation currents of 96 discrete NPN transistors (2N3904) from different vendors (Fairchild Semiconductor®, ON Semiconductor®, Phillips and ROHM Semiconductor) have been tested. The transistors were connected as a diode and tested using an Agilent 4156C semiconductor parameter analyzer.

Figures 4 to 7 show the measured results at 125°C, when V_{BE} is between 0.6V and 0.8V. Depending on the vendor, the maximum reverse saturation current values range from 1.5 nA to 5.8 nA, which are much smaller than the 1°C error allowance of 75 nA. In fact, the temperature errors caused by reverse saturation current are all smaller than 0.1° C for the tested diodes, as shown in these figures. It is clear that the general transistor used for normal temperature measurement can also be used for APD temperature measurement while maintaining the same accuracy.

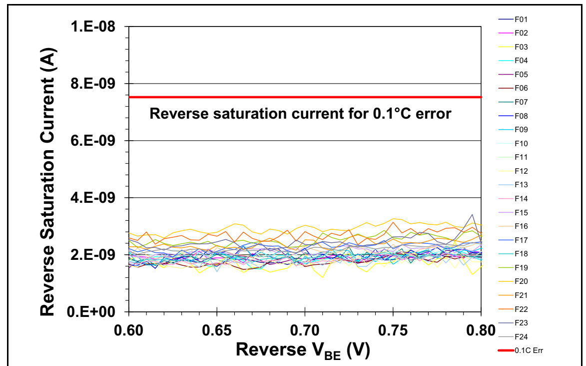

FIGURE 4: *Fairchild Semiconductor® Diode Reverse Saturation Currents at 125°C.*

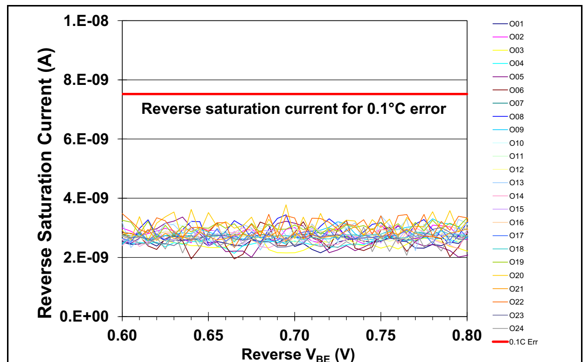

FIGURE 5: *ON Semiconductor® Diode Reverse Saturation Currents at 125°C.*

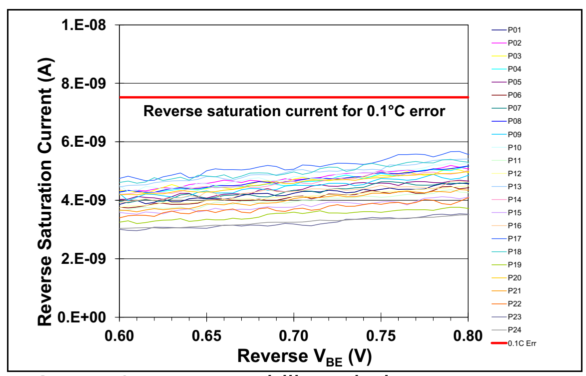

FIGURE 6: *Philips Diode Reverse Saturation Currents at 125°C.*

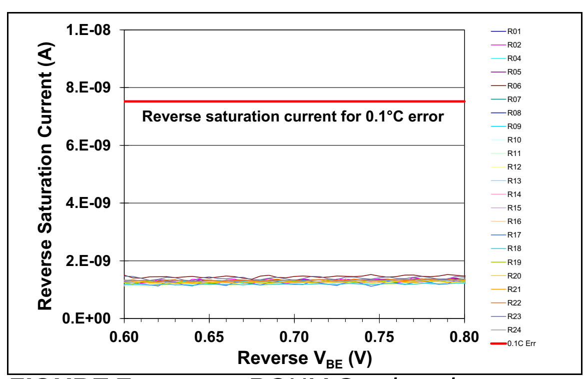

FIGURE 7: *ROHM Semiconductor Diode Reverse Saturation Currents at 125°C.*

Layout Considerations

CONNECTING APD TO MICROCHIP'S REMOTE TEMPERATURE SENSING DEVICES

There are three recommended ways to connect the two anti-parallel diodes to a temperature sensing device, as shown in Figures 8 to 10.

Connection Type (A)

This connection is recommended when the two anti-parallel diodes are placed close to each other, up to 12 inches away from the temperature sensing device.

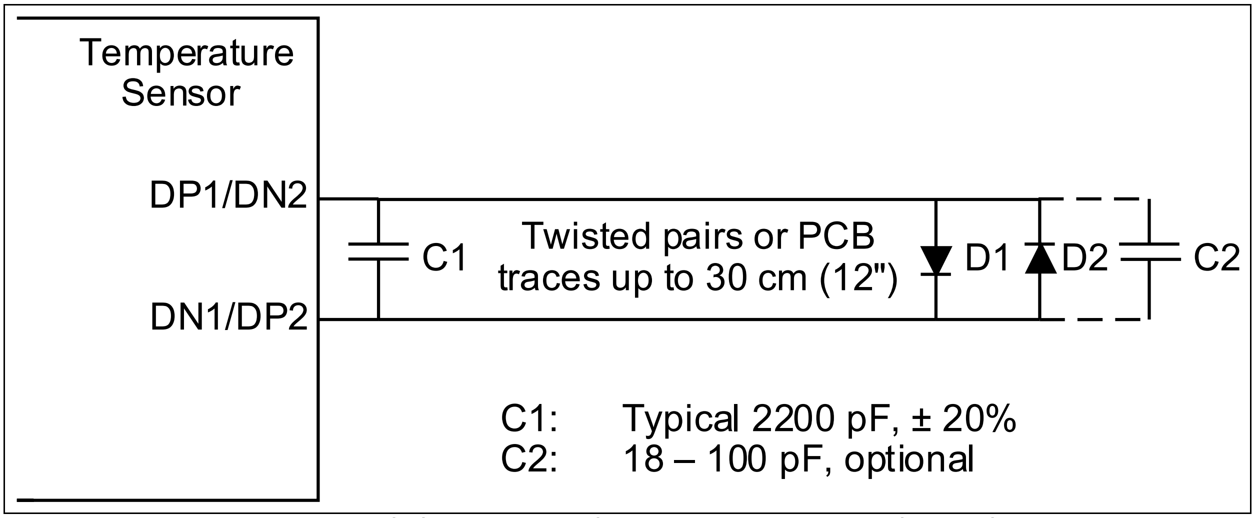

FIGURE 8: *Recommended APD Connections to Temperature Sensing Devices – Type A.*

Connection Type (B)

This connection is recommended when the two anti-parallel diodes are not located closely and both are away from the temperature sensing device. Split the traces as close to the temperature sensing device as possible.

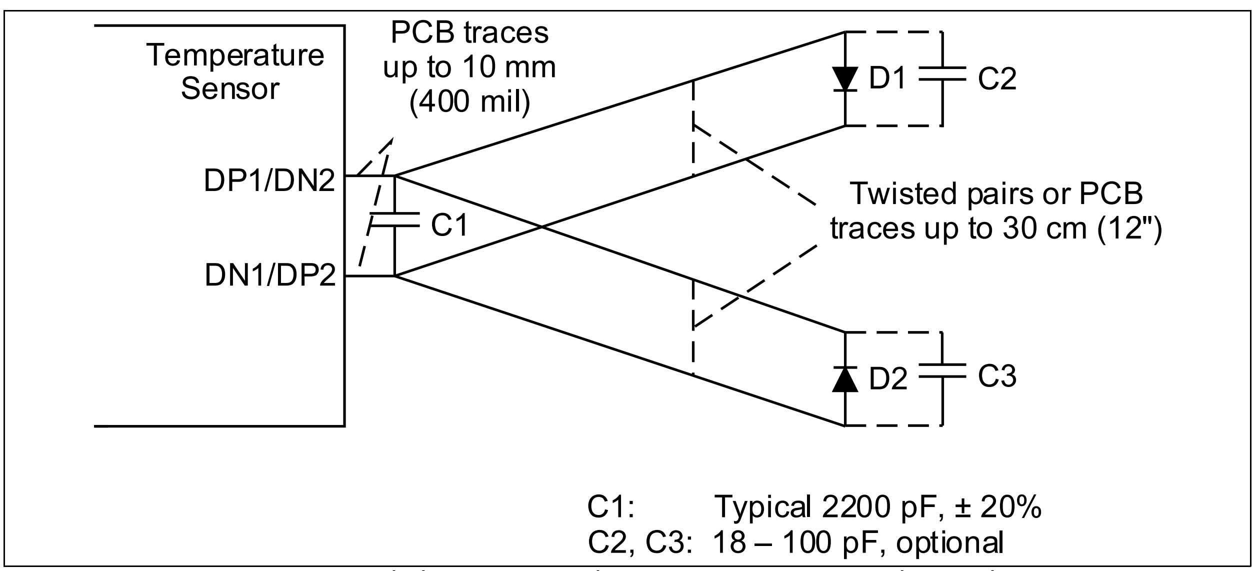

FIGURE 9: *Recommended APD Connections to Temperature Sensing Devices – Type B.*

Connection Type (C)

This connection can reduce the board routing complexity by using a single pair of traces or twisted cable.

It is not recommended to split the traces or cables more than 0.4 inch away from the temperature sensing device. The noise pickup characteristics of this configuration are too complex to give predictable results.

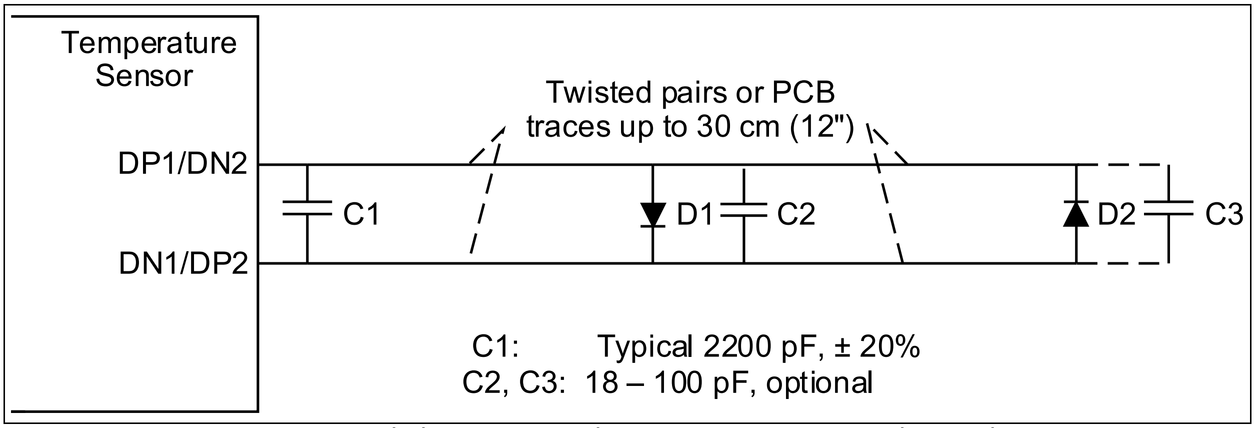

FIGURE 10: *Recommended APD Connections to Temperature Sensing Devices – Type C.*

EXTERNAL DIODE PCB LAYOUT CONSIDERATIONS

Apply the guidelines from the “Maintaining Accuracy” section of Microchip’s AN10.14. These include layout, device power supply decoupling, capacitor, cabling, manufacturing and thermal recommendations for remote diodes, which all apply to APD.

APPENDIX A: THERMAL DIODE TEMPERATURE MEASUREMENT

Thermal diode temperature measurements are based on the change in forward bias voltage (ΔV_{BE}) of a diode when operated at two different currents:

EQUATION 1:

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

Where:

k = Boltzmann's constant

T = Absolute temperature in Kelvin

q = Electron charge

η = Diode ideality factor

APPENDIX B: CALCULATIONS FOR MAXIMUM ALLOWED REVERSE SATURATION CURRENT WHEN IMPLEMENTING APD

If ΔV_{BE} is the measured ADC result at temperature T using a single diode and $\Delta V'_{BE}$ is the result at the same temperature using APDs, then Equation 1 results in Equations 2 and 3 or 4.

EQUATION 2:

$$\Delta V_{BE} = \frac{\eta kT}{q} \times ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)$$

Where:

k = Boltzmann's constant

T = Absolute temperature in Kelvin

q = Electron charge

η = Diode ideality factor

EQUATION 3:

$$\Delta V'_{BE} = \frac{\eta kT}{q} \times ln\left(\frac{I_{HIGH} + I_R}{I_{LOW} + I_R}\right)$$

Where:

I_R = Reverse saturation current of reversed diode

EQUATION 4:

$$\Delta V'_{BE} - \Delta V_{BE} = \frac{\eta kT}{q} \times \left[ln\left(\frac{I_{HIGH} + I_R}{I_{LOW} + I_R}\right) - ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)\right]$$

Equation 1 also results in Equations 5 or 6.

EQUATION 5:

$$\Delta V'_{BE} - \Delta V_{BE} = \frac{\eta kT'}{q} \times ln\left(\frac{I_{HIGH}}{I_{LOW}}\right) - \frac{\eta kT}{q} \times ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)$$

EQUATION 6:

$$\Delta V'_{BE} - \Delta V_{BE} = \frac{\eta k\Delta T}{q} \times ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)$$

Where:

ΔT = T' – T

Using Equations 3 and 5 results in Equation 7.

EQUATION 7:

$$\frac{\eta k\Delta T}{q} \times ln\left(\frac{I_{HIGH}}{I_{LOW}}\right) = \frac{\eta kT}{q} \times \left[ln\left(\frac{I_{HIGH} + I_R}{I_{LOW} + I_R}\right) - ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)\right]$$

Let ΔT = 1 and solve Equations 8 – 11 for I_R.

EQUATION 8:

$$ln\left(\frac{I_{HIGH}}{I_{LOW}}\right) = T \times \left[ln\left(\frac{I_{HIGH} + I_R}{I_{LOW} + I_R}\right) - ln\left(\frac{I_{HIGH}}{I_{LOW}}\right)\right]$$

EQUATION 9:

$$ln\left(\frac{I_{HIGH}}{I_{LOW}}\right) + T \times ln\left(\frac{I_{HIGH}}{I_{LOW}}\right) = T \times ln\left(\frac{I_{HIGH} + I_R}{I_{LOW} + I_R}\right)$$

EQUATION 10:

$$\left(\frac{I_{HIGH}}{I_{LOW}}\right)^{\left(\frac{T+1}{T}\right)} = \frac{I_{HIGH} + I_R}{I_{LOW} + I_R}$$

EQUATION 11:

$$I_R = \frac{\left(\frac{I_{HIGH}}{I_{LOW}}\right)^{\left(\frac{T+1}{T}\right)} \times I_{LOW} - I_{HIGH}}{\left(1 - \left(\frac{I_{HIGH}}{I_{LOW}}\right)^{\left(\frac{T+1}{T}\right)}\right)}$$

For I_{HIGH} = 170 µA, I_{LOW} = 10 µA and T = 400ºK, I_R = -75 nA.

CONCLUSION

This application note has covered the anti-parallel diode feature of Microchip's remote temperature sensor products. It summarizes the benefits of APDs, illustrates proper layout techniques and discusses error sources and how to mitigate them in an application.

REFERENCES

- Microchip Application Note 10.14 – *"Using Temperature Sensing Diodes with EMC Devices – Remote Sensors"* (DS00001839A)
- Microchip Application Note 12.14 – *"Remote Thermal Sensing Diode Selection Guide"* (DS00001838A)

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