Application Report

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Measuring Temperature with the ADS1216, ADS1217, or ADS1218

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OVERVIEW

The ADS1216, ADS1217, and the ADS1218 are integrated systems for single-chip high-resolution measurements. Included among the analog features is a diode inside the input MUX. Coupled with the high-resolution Analog-to-Digital Converter (ADC), the diode provides a convenient means of measuring temperature. This application discusses some of the considerations and techniques in using this diode. The last section presents some measurement data to help illustrate the performance that can be expected.

MEASURING TEMPERATURE WITH A DIODE

To understand how to use the diode to measure temperature, it helps to briefly review some of the key equations. For a good, detailed description of the diode's operation, see *The PN Junction Diode* by Gerold W. Neudeck. The current through a diode (I_{DIODE}) can be approximated by:

$$I_{DIODE} = I_S e^{\frac{V_{DIODE}}{nV_T}} \quad (1)$$

where I_S is a constant that depends on the area of the diode and its temperature among other things; V_{DIODE} is the forward voltage across the diode, n is a constant usually close to 1, and V_T is the thermal voltage given by:

$$V_T = \frac{KT}{q} \quad (2)$$

where K is Boltzman's constant, T is the absolute temperature (°K) and q is the charge of an electron. Figure 1 shows the typical plot of I_{DIODE} versus V_{DIODE} (the ADS1216's diode was used in this and all other plots).

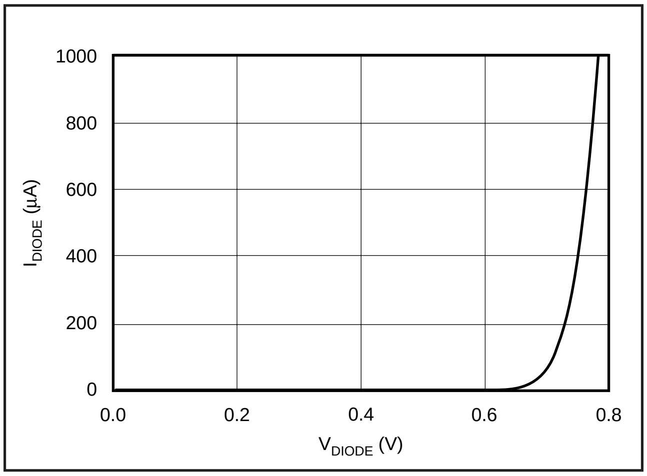

FIGURE 1. I_{DIODE} vs V_{DIODE}.

Now consider Equation 1's temperature-dependent terms. Equation 2 gives V_T's dependence; it's proportional to the absolute temperature. The other temperature-dependent term, I_S, roughly doubles every 5°C. Together, these two terms produce a net change in the voltage across the diode of approximately –2mV/°C for a diode biased with a constant current. This relationship can be used to measure temperature by simply measuring the voltage across the diode; just bias the diode with a constant current and measure the diode's voltage. Figure 2 shows the diode voltage versus temperature for 2µA and 10µA bias currents.

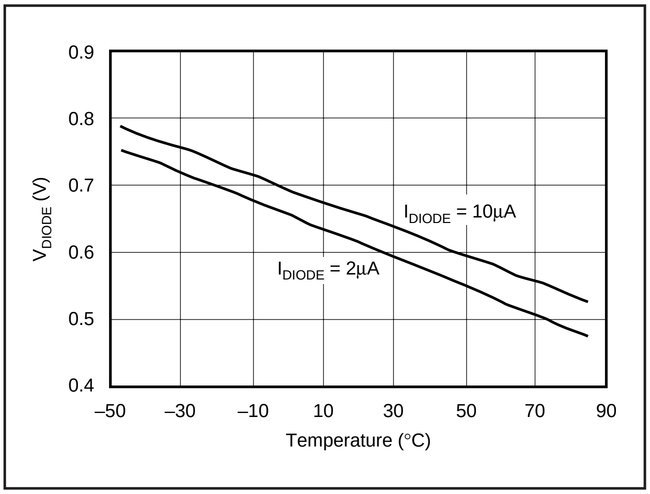

FIGURE 2. V_{DIODE} vs Temperature.

In practice, there are a few issues to consider when using this technique. First, manufacturing process variations between diodes create subsequent variations in the diode voltages. The ADS1216 has a 6σ statistical variation in diode voltage that exceeds 5mV. In other words, if you took a large sample of ADS1216 diodes, biased each of them with the same current at the same temperature, and measured the voltage across the diodes, the minimum and maximum readings would differ by more than 5mV. To remove this uncertainty and the errors in the derived temperature measurement that would result, each diode must be calibrated to determine its voltage at a known temperature.

In addition to variations in diode voltage, there are variations in the slope of this voltage, that is, the change in voltage with respect to temperature. When measuring temperature, you can think of the room temperature variations as an "offset" error and the slope variations as a "gain" error. To correct for the slope error, a second calibration point is needed at a different temperature.

Finally, the slope of the diode voltage versus temperature is not perfectly linear. Figure 3 shows the derivative of V_{DIODE} for the 2μA biased diode from Figure 2. Notice that the slope increases as the temperature increases. This nonlinearity will cause errors even when the diode's voltage versus temperature is calibrated at two points.

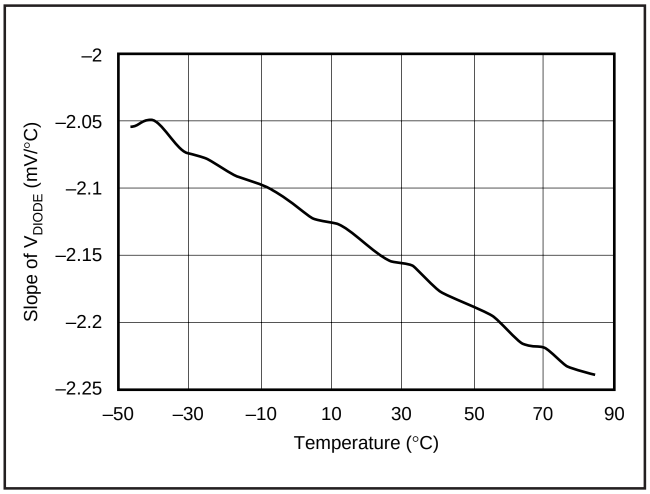

FIGURE 3. Slope of V_{DIODE} vs Temperature.

To devise an improved scheme for measuring temperature, consider what happens when we rearrange Equation 1 to give the diode's voltage as a function of bias current:

$$V_{DIODE} = nV_T \ln\left(\frac{I_{DIODE}}{I_S}\right) \qquad (3)$$

Assuming we bias the diode at two different currents, I_1 and I_2, and measure the resulting *differential* voltage. The resulting voltage, derived using Equation 3, is:

$$\Delta V_{DIODE} = V_2 - V_1 = nV_T \ln\left(\frac{I_2}{I_S}\right) - nV_T \ln\left(\frac{I_1}{I_S}\right) \qquad (4)$$

Now combine the natural log functions and cancel the common terms so that:

$$\Delta V_{DIODE} = nV_T \ln\left(\frac{I_2}{I_1}\right) \qquad (5)$$

or

$$\Delta V_{DIODE} = \alpha T \qquad (6)$$

where,

$$\alpha = n\frac{K}{q}\ln\left(\frac{I_2}{I_1}\right) \qquad (7)$$

Notice that ΔV_{DIODE} is proportional to absolute temperature. Measuring ΔV_{DIODE} allows the temperature to be directly determined. I_S drops out of α in Equation 7 so the variations in this parameter are of no concern. If calibration is required, now only one reading is needed to find the slope of Equation 6 (α). Finally, the absolute bias currents drop out of Equation 5, leaving only the ratio of currents. This reduces the requirements on the biasing circuitry. The next section describes how to use the ADS1216's onboard current Digital-to-Analog Converters (IDACs) to bias the diode. Removing the sensitivity to absolute bias currents allows a low tolerance R_{DAC} resistor to be used to set the current. See the ADS1216 data sheet (SBAS171B) at www.ti.com for more information on the current DACs.

HOW TO USE THE ADS1216'S DIODE

Figure 4 shows a block diagram of the relevant circuitry inside of the ADS1216 when using the onboard diode. The switches that connect the diode are controlled by the MUX register. See the data sheet (SBAS171B) for more details on the registers. Writing FF_H to this register closes switches SDP, SDN, and SDI and opens all the switches to the input pins AIN0-AINCOM (S0P, S0N . . . S7P, S7N, SCP, SCN). With the closing of SDI, IDAC1's output connects to the diode allowing IDAC1 to bias the diode during the temperature measurements. Notice that IDAC1's output always remains connected to the output pin. Remember to account for the effects of any circuitry on this pin when measuring temperature. If possible, leave IDAC1's output pin disconnected when using the diode.

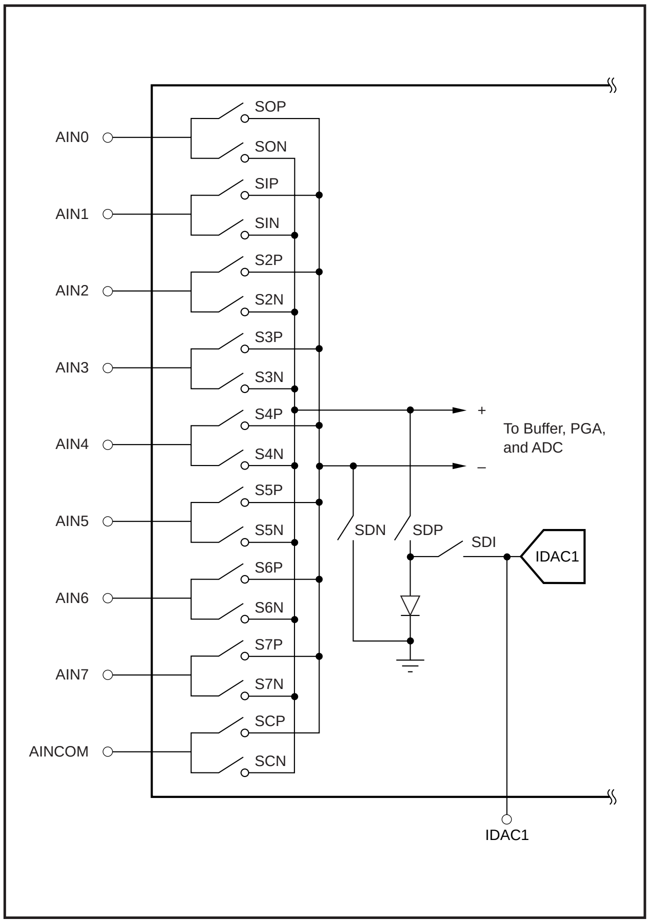

FIGURE 4. Block Diagram of ADS1216 Input Circuitry.

To measure temperature using Equation 6 from the last section, first prepare the ADC. For the best results, set the Programmable Gain Amplifier (PGA) to 1, enable the buffer, and perform a self-calibration. Once the ADC is ready, configure the diode by writing FF_H to the MUX register. If possible, use a 3V digital supply to reduce the ADS1216's digital power dissipation which causes self-heating. Now apply the first current bias by setting IDAC1's value; 2µA works well. You can use other values, just make sure to keep the currents low (< 30µA) to minimize errors from IR drops. After setting IDAC1, allow the ADC's digital filter to settle, then read the first data. Additional readings can be averaged to reduce the noise, though if the decimation ratio is above 300, this probably won't be necessary. Repeat this process for the second current bias: set IDAC1 to the new current level (10µA works well); wait for the filter to settle, then read the second data. The measurement is now complete. Use the two data readings in Equation 6 to calculate temperature. For the ADS1216, α is typically 7000°K/V. Calibration can be used to find a more accurate value. To do this, measure a known temperature and use Equation 6 to find α. Remember, Equation 6 uses *absolute temperature* in °K. Subtract 273 to convert to °C.

Steps:

1) set PGA = 1 and enable the buffer,
2) self-calibrate,
3) connect the diode: write FF_H to the MUX register,
4) set IDAC1 to 2µA,
5) after the digital filter has settled, read data (V_{D1}),
6) set IDAC1 to 10µA,
7) after the digital filter has settled, read data (V_{D2}),
8) calculate temperature: $T(^\circ K) = \frac{1}{\alpha}^{(1)}(V_{D2} - V_{D1})$.

NOTE: (1) For the best results, determine α for each ADS1216.

RESULTS

An ADS1216 was placed in an oven with a calibrated thermometer mounted nearby as the temperature was swept from –40°C to +85°C. Two different techniques were used to measure temperature. Afterwards, the error of each technique was measured.

For the first technique ("Single Measurement Technique"), the diode was biased at 2µA and the voltage across it was measured. The data was calibrated at two temperatures, –10°C and 50°C. Figure 5 shows the absolute error.

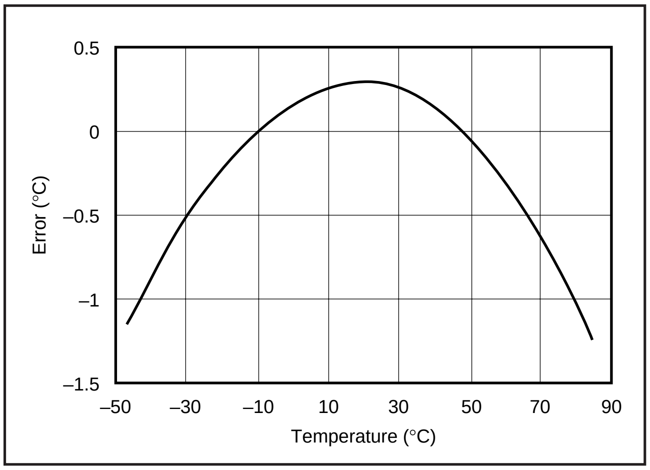

FIGURE 5. Error vs Temperature, Single Measurement Technique.

For the second technique ("Differential Measurement Technique"), the differential voltage measurement in Equation 6 was used as described in the previous section. The data was calibrated at 25°C to give α = 6971°C/V. Figure 6 shows the absolute error.

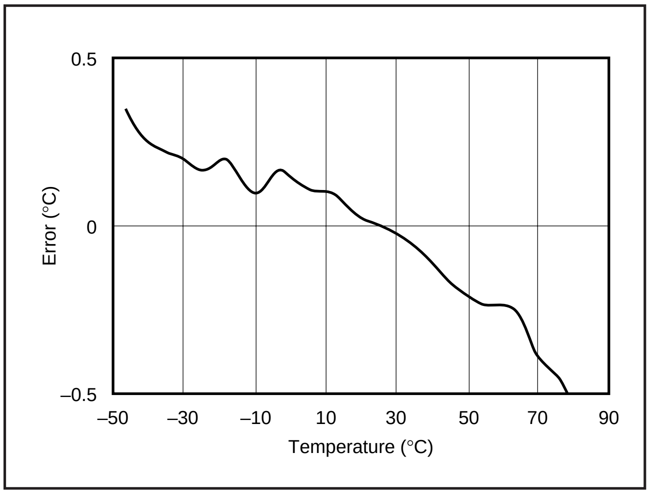

FIGURE 6. Error vs Temperature, Differential Measurement Technique.

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