Application Report
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Accessing the Onboard Temperature Diode in the ADS1240 and ADS1241

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ABSTRACT

The ADS1240 and ADS1241 are precision, wide dynamic range, delta-sigma Analog-to-Digital Converters (ADCs) with 24-bit resolution. These products offer a wide variety of features, including accurate sensing of the ambient temperature without additional components. This is done by connecting the input multiplexer to onboard diodes which are specifically matched for temperature measurement. This application report describes the theory and operation of this circuitry and calibration methods for accurate temperature measurement.

Contents

Figures

Tables

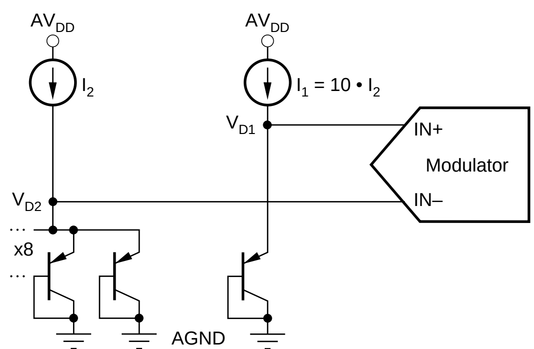
Introduction

In order to take temperature measurements with the ADS1240 and ADS1241, the input multiplexer is configured to connect the diodes to the modulator inputs. In order to understand the calibration techniques used to obtain accurate measurements, we review the equivalent circuit and derive the temperature-voltage equation.

Equivalent Circuit

Figure 1 shows the equivalent circuit when the onboard temperature diodes are activated.

Figure 1. Schematic of the Onboard Temperature Sensor



Theory

In an ideal diode, voltage-to-temperature dependence can be defined as shown in Equation 1:

$$V_{DIODE} = \frac{nkT}{q} \bullet \ln\left(\frac{I_{DIODE}}{I_{SAT}}\right) \quad (1)$$

The variables in Equation 1 are defined in Table 1.

Table 1. Variable Definitions

Variable	Description
V_{DIODE}	Voltage Drop Across Diode
N	Diode Emission Coefficient (typically n = 1)
K	Boltzman's Constant = $1.3806503 \times 10^{-23}$ Joules/Kelvin
T	Absolute Temperature in Kelvin (K)
Q	Charge of an Electron = $1.602176462 \times 10^{-19}$ Coulombs
I_{DIODE}	Current Through the Diode
I_{SAT}	Diode Saturation Current

From the schematic shown in Figure 1, Equations 2 and 3 can be derived.

$$V_{D1} = \frac{nkT}{q} \bullet \ln\left(\frac{I_1}{I_{SAT}}\right) \quad (2)$$

$$V_{D2} = \frac{nkT}{q} \bullet \ln\left(\frac{I_2}{8 \bullet I_{SAT}}\right) \quad (3)$$

By taking the difference of Equations 2 and 3, we get an expression for voltage in terms of diode current, as shown in Equation 4:

$$V_{TEMP} = V_{D1} - V_{D2} = \frac{nkT}{q} \bullet \ln\left(\frac{I_1}{I_{SAT}}\right) - \frac{nkT}{q} \bullet \ln\left(\frac{I_2}{8 \bullet I_{SAT}}\right) \quad (4)$$

Since $I_1 = 10 \bullet I_2$, the diode current terms cancel out and Equation 4 becomes Equation 5:

$$V_{TEMP} = \frac{nkT}{q} \bullet \ln\left(\frac{8 \bullet 10 \bullet I_1}{I_1}\right) = \frac{nkT}{q} \bullet \ln(80) \quad (5)$$

However, there is some variation in the constant multiplier evaluated by the natural logarithm. 80 is a close value, but each part is unique; this number must be found through individual calibration and measurement.

Calibration

There are many options available to calibrate this device for temperature conversion; this application report uses the single-point line-fit method.

Curve-fitting and multiple-point calibration can often improve measurement results. To see a more extensive evaluation of a similar circuit and curve-fits, refer to application report SBAA100 (*Using the MSC121x as a High-Precision Intelligent Temperature Sensor*), available for download at the TI web site, www.ti.com.

Set up the device to read the voltage drop across the temperature diodes, as outlined in this application report. Measure the temperature, and then read the voltage from the device.

Example values:

V = 113.1mV
T = 26.95°C (300.1°K)

Using Equation 5, we can find a more suitable value (approximately 80) for the constant in the natural logarithm. We will call this variable β, and substitute it into the temperature equation, as shown in Equation 6:

$$V_{TEMP(T)} = \frac{n \bullet k}{q} \bullet \ln(\beta) \bullet (T) \quad (6)$$

Now, we simply substitute the real values of the constants into the equation to reveal the value of β for the device. Equation 7 shows β for our example of temperature and voltage listed above.

$$\frac{1 \bullet 1.381 \bullet 10^{-23}}{1.602 \bullet 10^{-19}} \bullet \ln(\beta) \bullet 300.1 = 0.1131 \tag{7}$$

where $\beta = 79.3160837128$

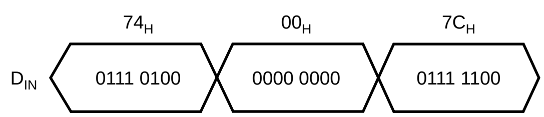
Given this value for β, we can now accurately measure the temperature with the ADS1240 or ADS1241 by using Equation 7 to achieve a linear fit.

Accessing the Onboard Temperature Diodes

To connect the temperature measurement diodes, pin 8 is tied HIGH, rather than to ground, which allows access to a set of special configuration registers in addition to the standard control and configuration registers. For normal operation, and to avoid the activation of undesired modes, pin 8 should normally remain LOW. If data is inadvertently written to these registers, a reset will return the device to the default state without incurring damage. After utilizing the special configuration registers, bringing pin 8 LOW resets the registers and returns the ADS1240 and ADS1241 to the original default settings.

With pin 8 HIGH, a special command word (74_H, 00_H, $7C_H$) is programmed to activate the temperature sensing diode circuit and switch the input multiplexer to connect the diodes to the modulator inputs. Output data is then read from the converter as in normal operation. The external multiplexer inputs are ignored in this state. Figure 2 shows the input bit pattern required to activate the temperature measurement circuit.

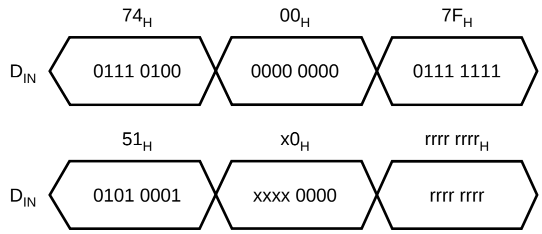
Figure 2. Bit Pattern to Activate the Temperature Sensor



Measuring V_{TEMP} Directly

The ADS1240 and ADS1241 also provide external access to the analog voltage, V_{TEMP}, at the input pins. Activate the measurement mode by bringing pin 8 HIGH and load the command word (74_H, 00_H, $7F_H$) to connect the diode circuit. Configure the input multiplexer to connect the internal V_{TEMP} to the desired output pin pair. See the ADS1240, ADS1241 data sheet (SBAS173) for more information. Just as when selecting an input pin pair to perform a measurement, the WREG command (51_H) is used to connect the input multiplexer pins indicated by the register operand *rrrr*, where *rrrr* indicates input pins consisting of AIN0 (rrrr = 0000) through AIN7 (rrrr = 0111) and AINCOM (rrrr = 1xxx but not 1111), where AIN0/AIN1 is the default connection. The second byte, $x0_H$, indicates that only one register is being written (xxxx nnnn - 1). See Figure 3 for the bit pattern required to access V_{TEMP} at the multiplexer input pins.

Figure 3. Bit Pattern for Access to V_{TEMP}



Measured Data

Figure 4 shows a plot of voltage measured at the input multiplexer pins over temperature as discussed above. Table 2 compares the measured V_{TEMP} voltage to the measurement obtained from the ADC.

Figure 4. Temperature versus ADC Output Plot (sample data)

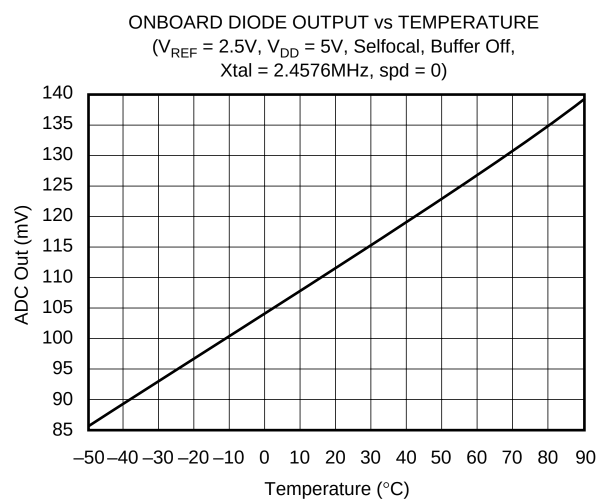


Table 2. Temperature versus DVM and ADC Output (sample data)

TEMP (°C)	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90
DVM (mV)	85.32	89.14	93.08	96.85	100.6	104.35	108.07	111.85	115.56	119.24	123.2	126.5	130.97	134.28	139.34
ADC (mV)	85.48	89.33	93.2	96.91	100.5	104.38	108.08	111.84	115.55	119.23	123.16	127	130.9	135	139.4

References

1. *ADS1240, ADS1241* Data Sheet (SBAS173)
2. *ADS1241-EVM* User's Guide (SBAU070)
3. *Using the MSC121x as a High-Precision Intelligent Temperature* Sensor Application Report (SBAA100)

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