DALLAS SEMICONDUCTOR /\/\/\XI/\/\

INTRODUCTION

Dallas Semiconductor uses its unique manufacturing capabilities to provide factory calibrated digital temperature sensors with accuracy as high as ±0.5°C. This level of accuracy is sufficient for many applications; however, some scientific and industrial applications require even greater precision.

This application note presents a technique that can allow the user to improve the accuracy of bandgap-based digital temperature sensors by as much as a factor of 10 by compensating for the offset and curvature of the device error characteristic. This method is successful due the simple second order error curve and the repeatable nature of the output over temperature for bandgap-based sensors.

Note that the technique presented in this article can be applied to any IC temperature sensor with a bandgap-based thermal circuit. This technique will not work for Dallas Semiconductor's older thermal ICs, which have a dual-oscillator-based thermal measurement circuit.

ERROR COMPENSATION

To illustrate the second order error curve inherent to band-gap based sensors, a DS1631 IC was characterized over a -35°C to +85°C temperature range in a thermally conductive liquid bath, and its thermal error relative to a NIST traceable platinum RTD was recorded at 5°C intervals. The results from this sweep are shown in Figure 1 (♦ = DS1631 bath measurements).

The error characteristic shown in Figure 1 makes a second order curve that can be represented by the following equation:

Eq. 1) $\quad$ $\text{Error} = \text{OFFSET} + \alpha \cdot (T_{TS} - T_{ZERO\_SLOPE})^2$

where T_{TS} is the temperature measured by the temperature sensor (the DS1631 in this case), α is a curvature correction coefficient, T_{ZERO_SLOPE} is the temperature at which the error curve has zero slope, and OFFSET is the error at T_{ZERO_SLOPE}.

After determining values for α, OFFSET and T_{ZERO_SLOPE} such that Equation 1 provides a close fit to the temperature sensor's output error curve, the user can calculate the approximate measurement error at any temperature and then compensate for the error by subtracting the calculated value from the measured temperature. Thus, the compensated temperature is:

Eq. 2) $\quad$ $T_{COMP} = T_{TS} - \text{Error} = T_{TS} - [\text{OFFSET} + \alpha \cdot (T_{TS} - T_{ZERO\_SLOPE})^2]$

For the best results with this technique, each temperature sensor should be characterized over the desired temperature range in order to determine the best fit calculated error curve for the specific device.
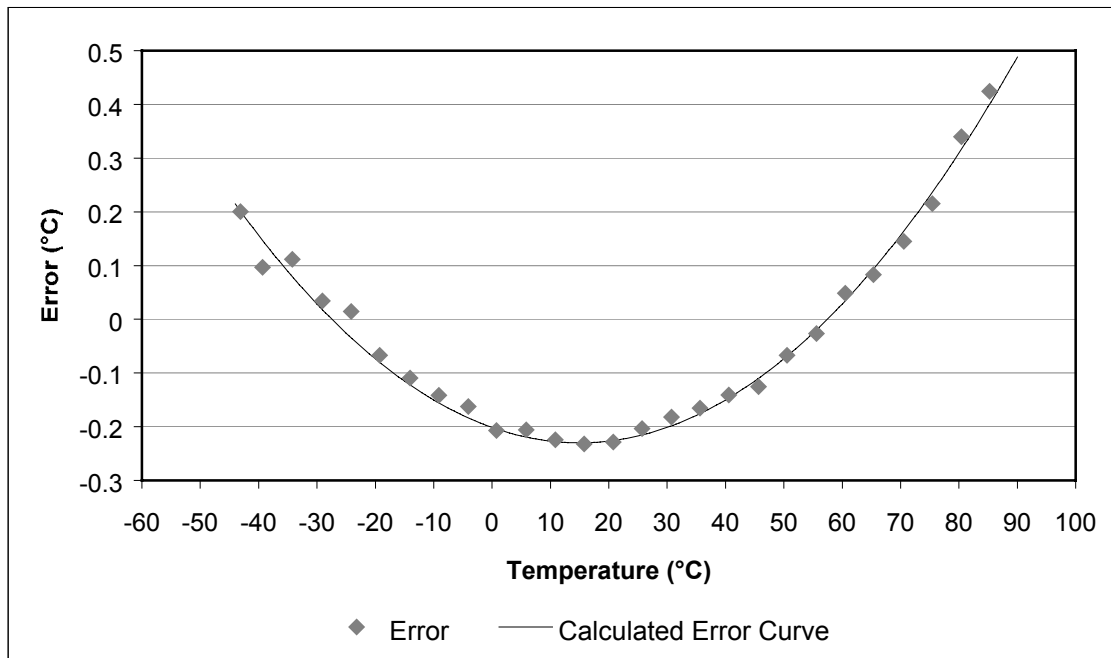
EXAMPLE

This example uses the characterized DS1631 to illustrate the compensation technique described above. Table 1 lists the values measured by the DS1631 and the error of the measurements relative to the actual ambient temperature. From examining Figure 1, T_{ZERO_SLOPE} can be estimated to be 15°C and OFFSET to be approximately -0.23°C, for which $\alpha = 1.28 \times 10^{-4}$ provides a very close fit to the measured error curve (see Figure 1). Plugging the measured temperatures into Equation 2 results in the compensated

temperatures shown in Table 1. The error of the compensated temperature relative to the ambient temperature, as shown in Table 1 and Figure 2, is up to 10 times lower than the error of the original measurements.

Note that it may take several iterations to arrive at values for T_{ZERO_SLOPE}, OFFSET, and α that provide the best fit curve. Once initial estimations for T_{ZERO_SLOPE} and OFFSET have been made, α can be calculated with readily available math or spreadsheet software.

DS1631 MEASURED ERROR AND CALCULATED ERROR Figure 1

EXAMPLE COMPENSATED ERROR Figure 2
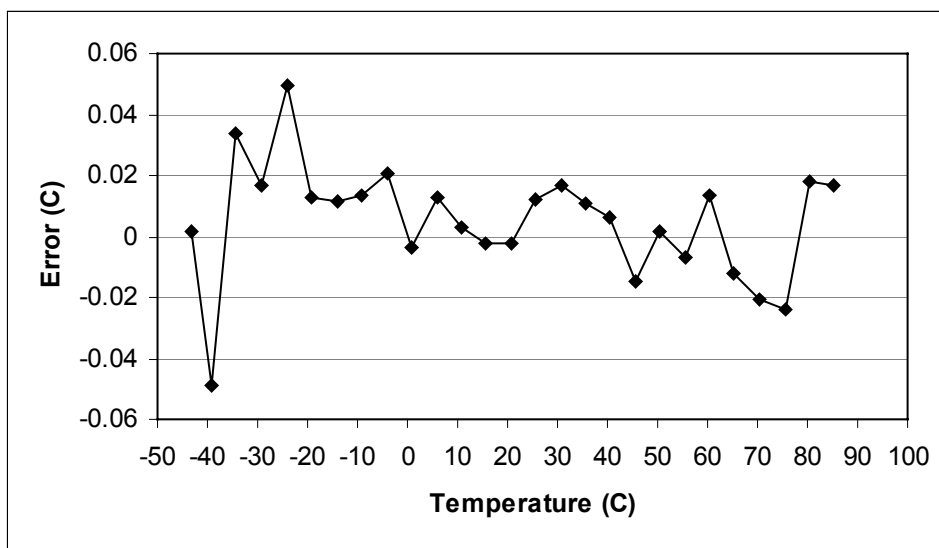
COMPENSATION EXAMPLE DATA Table 1

Ambient Temperature*	Measured Temperature	Measured Error	Compensated Temperature	Compensated Error
-43.1377	-42.9375	0.20015	-43.13603	0.001619
-39.3466	-39.25	0.0966	-39.39572	-0.04912
-34.2368	-34.125	0.11182	-34.20308	0.033737
-29.0969	-29.0625	0.03443	-29.08036	0.016573
-24.1398	-24.125	0.01481	-24.09042	0.049389
-19.2454	-19.3125	-0.06715	-19.23280	0.012547
-14.0779	-14.1875	-0.10964	-14.06626	0.011603
-9.10834	-9.25	-0.14166	-9.09507	0.013266
-4.08784	-4.25	-0.162158	-4.06731	0.020535
0.769446	0.5625	-0.2069459	0.76589	-0.00356
5.831063	5.625	-0.206063	5.84378	0.012717
10.84934	10.625	-0.22434	10.85256	0.003216
15.79473	15.5625	-0.23223	15.79246	-0.00227
20.79082	20.5625	-0.22832	20.78855	-0.00227
25.70361	25.5	-0.20361	25.71593	0.012315
30.74484	30.5625	-0.18234	30.76158	0.016741
35.60317	35.4375	-0.16567	35.61418	0.011006
40.57861	40.4375	-0.14111	40.58489	0.006284
45.68797	45.5625	-0.12547	45.67325	-0.01472
50.56738	50.5	-0.06738	50.56911	0.001733
55.58933	55.5625	-0.02683	55.58245	-0.00688
60.51409	60.5625	0.04841	60.52748	0.01339
65.35461	65.4375	0.08289	65.34273	-0.01188
70.54241	70.6875	0.14509	70.52161	-0.0208
75.40949	75.625	0.21551	75.38579	-0.0237
80.41012	80.75	0.33988	80.42811	0.017987
85.26303	85.6875	0.42447	85.27961	0.016576

*As measured by a NIST traceable platinum RTD