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Junction Temperature Accuracy Analysis

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Abstract
This document analyzes junction temperature accuracy for the electrical method of junction temperature measurement. It covers two very important topics:

a) the distinction between accuracy and precision for measured data
b) expected accuracy for junction temperature measurements

Accuracy Versus Precision
The "precision" of a numerical quantity is the detail to which it is expressed. For decimal quantities, this essentially means the number of decimal points used in the presentation. For example: 3.14, 3.142, 3.1416, 3.14159 represent varying levels of precision of the number "pi". Most importantly "precision" is a *display* parameter. Precision can be entirely independent of the fidelity or accuracy of the numerical information presented.

The "accuracy" of a numerical quantity depends on the uncertainty associated with the origination of the data and reflects the extent to which the data correctly represents the actual real-world quantity. Accuracy is often expressed in a "+/-" tolerance, either in percentage or absolute terms. For example, a physical length with accuracy tolerance might be expressed at 51.3 +/- 0.5 mm. This accuracy tolerance includes an accumulation of factors that cause the measured data to be different than a hypothetically perfect measurement. In this example, a statement of the length, 51.3 mm +/-0.5 mm, may include the uncertainty associated with factors such as visual interpolation between the 1 mm gradations, the manufactured accuracy of the scale used as well thermal expansion of measurement scale. This example data can be expressed in a variety of precisions: 51.3, 51.32, 51.317, 51.3172 but they ***all*** represent the same data since the underlying accuracy of this measurement +/-0.5 mm.

In summary, precision is a *display* parameter, whereas accuracy represents the fundamental fidelity of a measurement. Ideally, the level of precision is chosen to match that of the measurement accuracy. In our example, the best choice for precision would be, one decimal place: 51.3 +/- 0.5 mm. Using more precision than needed, such as, 51.317+/-0.5 mm, results in a meaningless distortion of the data. Likewise using less precision than needed, such as, 51 +/-0.5 mm results in information loss.

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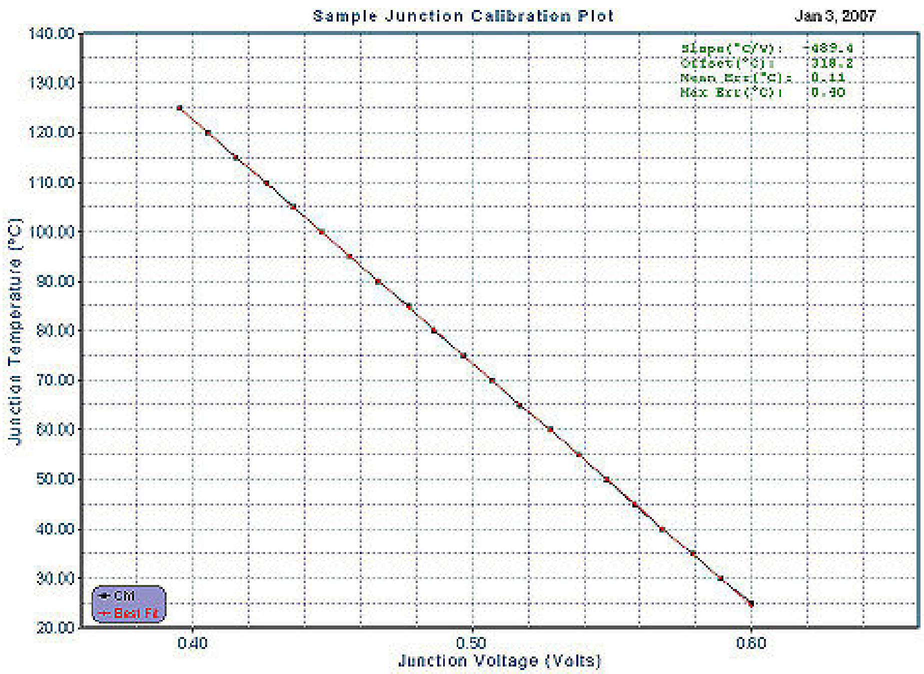
Fundamentals of Junction Temperature Measurement

The key to junction temperature measurement with the electrical method is the relationship between junction temperature and the junction voltage. This relationship is determined for each device to be tested in a procedure called “junction calibration” using measured junction voltages versus measured thermocouple temperatures. (Note: although other means of temperature measurement could be used, thermocouples are almost universally used for this purpose) This procedure yields data typified in this plot:



Once this junction calibration data is collected, the junction temperature of the device under test is computed as

$$Tj = Slope * Vj + Offset$$

where Slope and Offset are the linear regression values that best characterize the measured junction calibration data for the device under test. This equation embodies the measurement of Tj and can be used to effectively analyze the accuracy of the resulting Tj data by examining the accuracy of its components:

a) the accuracy of thermocouple temperature measurement
b) the accuracy of junction voltage measurement
c) the accuracy of the linearity assumption of Vj versus Tj

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Thermocouple Temperature Measurement Accuracy

Thermocouple accuracy is dependent on the type of thermocouple used and the range of temperatures measured. Recognized accuracies of thermocouples are listed at www.en.wikipedia.org/wiki/Thermocouple These accuracies result from metallurgical phenomena of the Seebeck effect as well as issues associated with the accuracy of the cold junction compensation and linearization of the thermocouple voltage curves. From this reference, the following accuracies for class 1 thermocouples are reproduced for some popular thermocouple types:

Class 1 Thermocouple Accuracy and Range

Thermocouple Type	Accuracy	Temp. Range
K	+/- 1.5 ˚C	- 40 to 375 ˚C
J	+/- 1.5 ˚C	- 40 to 375 ˚C
T	+/- 0.5 ˚C	- 40 to 125 ˚C

While some improvement in accuracy can be achieved by calibrating thermocouple measurement systems over a smaller temperature range, commercial calibration of thermocouples to accuracies better than *half* of these accuracies, is quite difficult for the range appropriate to semiconductor thermal testing. *The critical link that associates junction voltage with junction temperature is the thermocouple*: *Junction temperature measurement cannot be more accurate than the thermocouple measurement accuracy.*

Junction Voltage Measurement Accuracy

Is the simplest, most easily quantified accuracy component in the determination of junction temperature. The calibration accuracy of this voltage measurement equipment and the full scale bit count for A/D converts provides all that is required to determine the Vj measurement accuracy. For example, a 12 bit A/D converter with a 1 volt full scale will provide accuracies of +/-0.000122 volts and can easily be calibrated to this level. Assuming a nominal slope of -500˚C/V, this voltage tolerance yields a Tj tolerance of +/-0.06˚C essentially dwarfed by the accuracy tolerance of the thermocouple measurement. Although the use of 16 bit A/D improves this voltage accuracy, it does not affect the dominant accuracy, that of the thermocouple.

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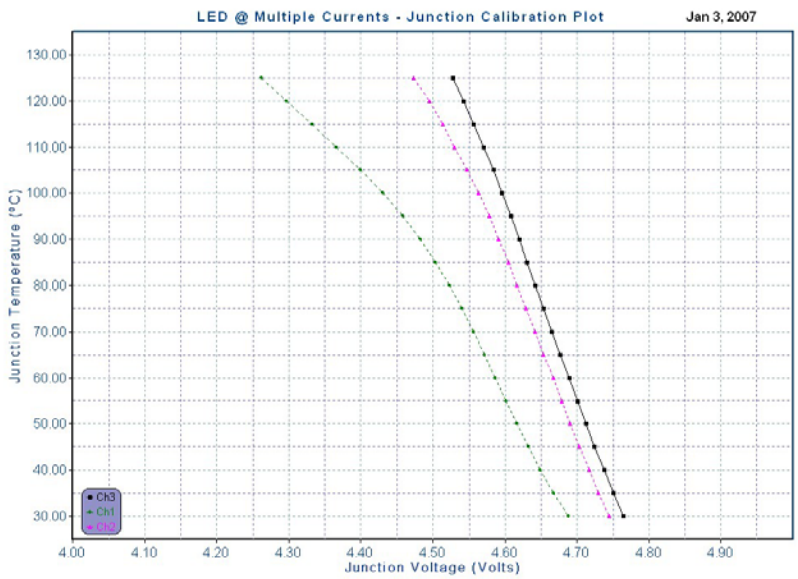
Linearity Accuracy of Tj Versus Vj

The degree of linearity depends on the selected junction and the sense current. The following plot shows calibration curves for one junction at different sense currents.



So, linearity cannot be assumed for any device junction. There also potential accuracy issues with achieving the required condition that the thermocouple junction be isothermal with the device junction since they are not in exactly the same location. Also thermocouple measurement accuracies influence the linearity consideration. This combination of effects is roughly expressed in the parameter called “Mean Error”, the average of unsigned deviations between the measured temperature and the linearized temperature at each Vj data point. For example, the data plotted in the previous plot would be associated with a linearity tolerance of +/-0.1˚C.

Summary: Overall Tj Measurement Accuracy

The combined overall accuracy of Tj measurement associated with the above factors will be approximately the sum of the three accuracy components detailed above. The thermocouple measurement accuracy can determined from equipment calibration trace-documents and the manufacturer’s product specifications. This should be accuracy tolerance can be added to the Mean Error of the Tj versus Vj best fit line.

The absolute best accuracy that can realistically be expected is +/-0.1˚C, more typically, +/-0.2˚C to +/-0.5˚C would be expected. Thus the best practice precision for the reporting of Tj should be one decimal place. For example, 87.5˚C would be correct precision. Reporting 87.53˚C is a misuse of precision since the fundamental accuracy for Tj is +/-0.1˚C or higher.