



BLACK LAB SYSTEM  
 TECHNICAL NOTE #114

**SUBJECT:** Thermocouple Equations

**DATE OF LAST REVISION:** 10/18/2005

**REV # 1**

The software that accompanies the Black Lab lets the user define a polynomial equation to convert the raw millivolt readings to Engineering Units. A separate equation can be defined for any input channel or multiple channels can use the same equation. The equations can be simple linear ( $mx + b$ ) or can be elaborate polynomial equations up to 5<sup>th</sup> order. See Section F of the Black Lab Operating Manual for a description of how coefficients for polynomial equations can be entered.

Coefficients for 5<sup>th</sup> order polynomial equations have been determined for each of the standard industrial thermocouple types and are shown in the tables below. Table 1 shows the useable range for each TC when the 10 millivolt range is selected. The column headed “Conformity Error” shows how closely the 5<sup>th</sup> order equation matches the temperature/millivolt function defined by NIST. Using the 10 millivolt range gives greater conformity in the lower part of a thermocouple’s range.

The coefficients for the polynomial equations should be based on °C tables. The Black Lab software does the conversion from millivolts to temperature in °C even though the “UNITS” defined in the configuration is °F. Then the conversion is made to °F.

Table 1: 5<sup>th</sup> Order Coefficients when using the 10 millivolt range:

TC Type	Low	High	Coefficients					Conformity Error - °C	
			A0	A1	A2	A3	A4		A5
B	N/A	N/A							
E	-270	150	0.000	17.063	-0.2553	0.0162	-0.00148	0.000065	0.05
J	-210	185	0.000	19.825	-0.2379	0.0219	-0.00164	0.000060	0.06
K	-270	245	0.000	24.857	-0.3295	0.1023	-0.0133	0.00063	2.3
R	-50	950	0.000	167.99	-27.211	4.979	-0.4545	0.0157	8.4
S	-50	1000	0.000	166.73	-24.383	4.5424	-0.4186	0.0145	7.0
T	-270	200	0.000	25.207	-0.590	0.1072	-0.0188	0.001015	2.6

Table 2 shows the useable range when the 100 millivolt range is selected. This range needs to be used when the millivolt equivalent of the temperature to be measured exceeds 10 millivolts.

Table 2: 5<sup>th</sup> Order Coefficients when using the 100 millivolt range:

TC Type	Low	High	Coefficients					Conformity Error - °C	
			A0	A1	A2	A3	A4		A5
B	630	1820	257.61	227.81	-23.654	2.2097	-0.1133	0.002445	0.65
E	0	1000	0.000	16.760	-0.1792	0.00354	-0.000034	1.325E-07	0.72
J	0	1200	0.000	19.850	-0.217	0.0116	-0.0002663	2.02E-06	0.61
K	0	1372	0.000	24.551	0.03845	-0.00485	0.000128	-9.1E-07	1.25
R	0	1768	4.90	141.4109	-9.482	0.7565	-0.0323	0.000549	7.5
S	0	1768	3.4713	145.5143	-9.5064	0.8781	-0.0438	0.000868	6.0
T	0	400	0.000	25.968	-0.7743	0.046385	-0.001816	3.01E-05	0.41

Table 3. Maximum defined limits for each thermocouple type.

TC Type	Min	Max	TC Type	Min	Max
E	-270	150	R	-50	1768
J	-210	1200	S	-50	1768
K	-270	1372	B	630	1820
T	-270	400	C		

Calculate your own coefficients for special ranges

If greater conformity is required over smaller spans, it is possible to determine coefficients for a limited range of the thermocouple that covers the range of use. This can be done easily using functions built into Microsoft Excel.

Establish an Excel spreadsheet that has columns for millivolts and temperature. You should have about 20 values of millivolts over the desired temperature range. For each millivolt value, calculate the exact temperature using the polynomial equations for each thermocouple type as defined by [NIST](http://www.nist.gov). A listing of these equations and coefficients can be found at <http://srdata.nist.gov/its90/main/> where you can choose to either view or download the temperature/millivolt tables or the coefficients for the equations. Type C (tungsten) thermocouples are not defined by NIST but by [ASTM](http://www.astm.org) in their document [E230-03 Standard Specification and Temperature-Electromotive Force \(EMF\) Tables for Standardized Thermocouples](http://www.astm.org/E230-03).

This data is then graphed using an XY(scatter) type of graph. Click on the graph line, then right click and choose “add trendline”. Under the TYPE tab, choose polynomial and under the OPTIONS tab, choose to display the coefficients on the graph. Click OK and the polynomial coefficients will be calculated and displayed on the graph.

To check how well the coefficients work, add another column in the spreadsheet to calculate the temperature using these coefficients and an additional column to compute the difference between the calculated temperature and the exact temperature. It is sometimes possible to “tweak” the coefficients slightly and achieve a better conformance.