AN144

16-131095rev00

Thermistor Steinhart-Hart Coefficients for Calculating Motor Temperature

Introduction

Copley drives use I2T to protect the motor given the motor peak and rms current values, so motor temp sensors are not required. Most motors have switches that can be used with a digital input configured as a motor over-temperature fault. However, on some drives, an analog motor temperature input can be used for motor over-temperature threshold detection. Place a resistor with the desired value for shutdown and measure the analog voltage to set trip point.

Alternatively, with the analog input we can use the resistance to measure motor temperature in degrees C by applying the Steinhart-Hart Coefficients calibrated and measured empirically.

The Steinhart–Hart equation is a model of the resistance at different temperatures given by:

$$\frac{1}{T} = A + Bln(R) + C(\ln(R))^3$$

Where:
T is the temperature in kelvins (Deg C = K -273.15)
R is the resistance at T in ohms
A, B, and C coefficients which vary depending on the model of thermistor and the temperature range of interest.

Calculating Steinhart-Hart Coefficients

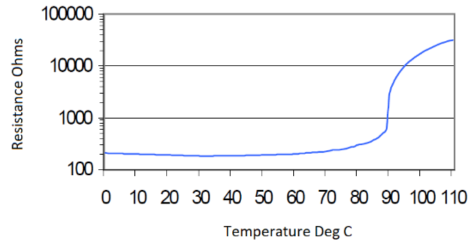
Given 3 points of resistance and temperature we can solve the determinant.

$$\begin{bmatrix} 1 & \ln R_1 & \ln^3 R_1 \\ 1 & \ln R_2 & \ln^3 R_2 \\ 1 & \ln R_3 & \ln^3 R_3 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} \frac{1}{T_1} \\ \frac{1}{T_2} \\ \frac{1}{T_3} \end{bmatrix}$$

$$L_1 = \ln R_1, \quad L_2 = \ln R_2, \quad L_3 = \ln R_3$$
$$Y_1 = \frac{1}{T_1}, \quad Y_2 = \frac{1}{T_2}, \quad Y_3 = \frac{1}{T_3}$$
$$\gamma_2 = \frac{Y_2 - Y_1}{L_2 - L_1}, \quad \gamma_3 = \frac{Y_3 - Y_1}{L_3 - L_1}$$

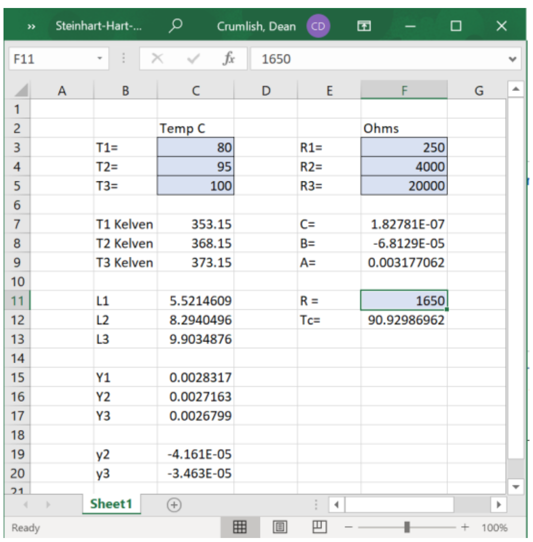
$$C = \left(\frac{\gamma_3 - \gamma_2}{L_3 - L_2}\right)(L_1 + L_2 + L_3)^{-1}$$
$$B = \gamma_2 - C\left(L_1^2 + L_1 L_2 + L_2^2\right)$$
$$A = Y_1 - \left(B + L_1^2 C\right) L_1$$

Example: Below is a typical resistance curve for a PTC (Positive Temperature Coefficient) thermistor that has a 90 Deg C trip point when used with a Copley digital input having a 4.99K Ohms internal pull-up conforming to an old classical standard BS 4999:Part 111:1987.

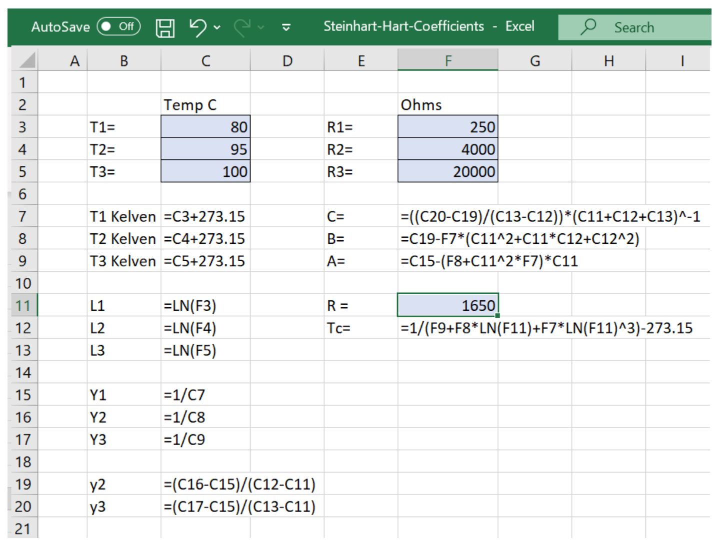


Property	value	units
Resistance in the temperature range 0°C to +70°C	60 to 750	Ohms
Resistance at 85°C	≤1650	Ohms
Resistance at 95°C	≥3990	Ohms
Resistance at 105°C	≥12000	Ohms
Response time for a 20°C to 100°C	≤3	seconds
Maximum continuous voltage	30	Volts
Insulation withstand voltage	2500	Volts
Operating temperature range	0°C to +180	°C

We enter three critical points:
- Too hot to touch 80 Deg C = 250 Ohms,
- Motor about to burn up 95 Deg C = 4k ohms, and
- Motor getting damaged 100 Deg C = 20K Ohms.



	A	B	C	D	E	F	G
1							
2			Temp C			Ohms	
3		T1=	80		R1=	250	
4		T2=	95		R2=	4000	
5		T3=	100		R3=	20000	
6							
7		T1 Kelven	353.15		C=	1.82781E-07	
8		T2 Kelven	368.15		B=	-6.8129E-05	
9		T3 Kelven	373.15		A=	0.003177062	
10							
11		L1	5.5214609		R =	1650	
12		L2	8.2940496		Tc=	90.92986962	
13		L3	9.9034876				
14							
15		Y1	0.0028317				
16		Y2	0.0027163				
17		Y3	0.0026799				
18							
19		y2	-4.161E-05				
20		y3	-3.463E-05				

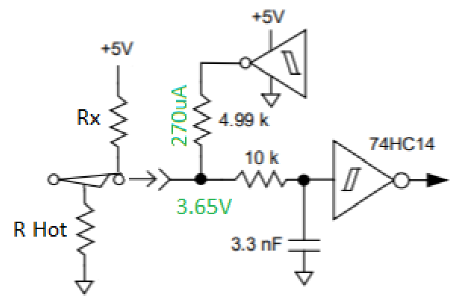


	A	B	C	D	E	F
1						
2			Temp C			Ohms
3		T1=	80		R1=	250
4		T2=	95		R2=	4000
5		T3=	100		R3=	20000
6						
7		T1 Kelven	=C3+273.15		C=	=((C20-C19)/(C13-C12))*(C11+C12+C13)^-1
8		T2 Kelven	=C4+273.15		B=	=C19-F7*(C11^2+C11*C12+C12^2)
9		T3 Kelven	=C5+273.15		A=	=C15-(F8+C11^2*F7)*C11
10						
11		L1	=LN(F3)		R =	1650
12		L2	=LN(F4)		Tc=	=1/(F9+F8*LN(F11)+F7*LN(F11)^3)-273.15
13		L3	=LN(F5)			
14						
15		Y1	=1/C7			
16		Y2	=1/C8			
17		Y3	=1/C9			
18						
19		y2	=(C16-C15)/(C12-C11)			
20		y3	=(C17-C15)/(C13-C11)			
21						

We can enter a value of 1650 Ohms to see what temperature "90.9" deg C the Steinhart-Hart Coefficients produce given the three set points. To calibrate a system to a specific thermistor we can take three measurements at three critical temperatures. Just remember the Copley circuit that measures the resistance has its own pull-up and pull-down resistors so the three points will be calculated using three voltage measurements, and the equivalent circuit analysis. Ask a Copley Applications Engineer for help if the calculation seems too complicated.

Simple Digital Input Protection

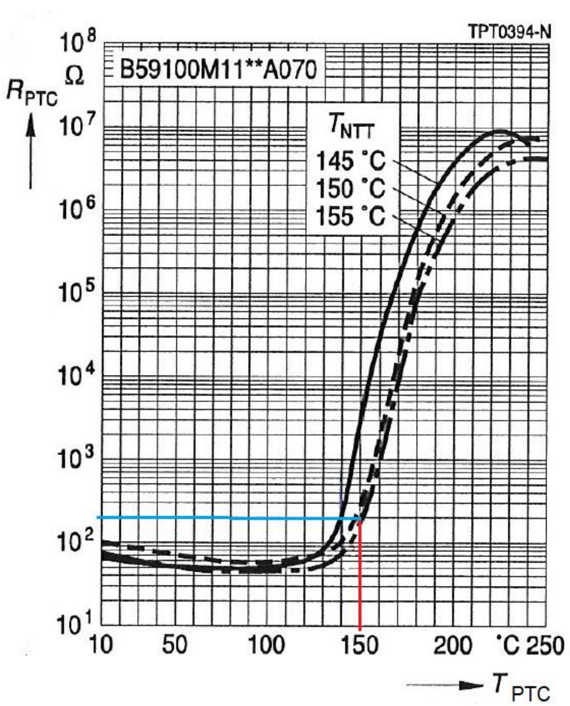
Traditionally a motor temp sensor is embedded in the motor coil and is a closed thermal switch that would open when the motor gets too hot. Some thermal switches are actually PTC (Positive Temperature Coefficient) sensor resistors with low resistance; like 100 Ohms when cold and a sharp knee to 100k Ohms when hot. The sensor is connected to a digital input designed specifically for use with a motor over-temperature switch with respect to ground. The input should be programmed as a pull-up to +5 Vdc assuming the motor switch is grounded when cold, and open or high impedance when over-heating. The classical Copley temp circuit uses a 74HC14 Schmitt trigger with 33 μs RC filter, Vin-LO < 1.35 Vdc, Vin-HI >3.65 Vdc, +30 Vdc max. If the PTC does not have a sharp knee, or a low resistance such as 10k Ohms when hot then we can calculate an external resistor to add as additional pull-up. Rx = (5V-3.65V/Ix) given Ix = 270uA-3.65V/R Hot.

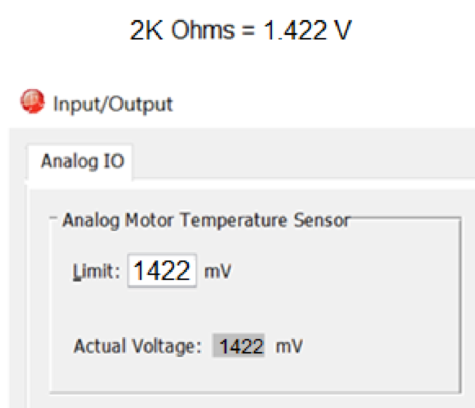


Simple Analog Input Protection

If the Copley drive provides an analog input for motor temperature protection, then the voltage trip point can be set to trip motor over-temperature fault protection. Place a resistor of the desired value for trip point and read the actual voltage to determine the trip value.

Example: At 150 Deg C the motor's PTC is 2K, so by connecting a 2k Ohms resistor we measure 1.422V at the sense resistor. Derivation of V for a given R through circuit analysis can be seen at the end of this note in the calculation section.

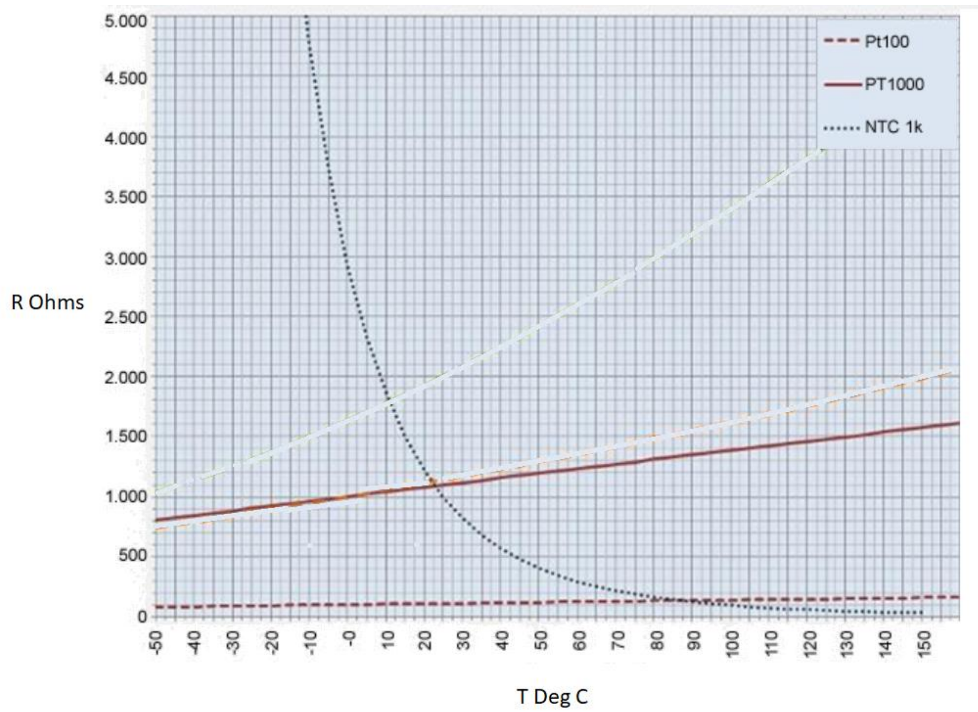




Parameter 0x13B Limit for Analog Motor Temperature Sensor. Units: mV.
If this parameter is set to zero, then analog motor temperature sensor is disabled.
If this parameter is set to a positive value, then a motor temperature error will occur any time voltage on motor temperature input exceeds this value.

If this parameter is set to negative value, then motor temperature error will occur any time voltage on the motor temperature input is lower than absolute value of this limit.

NTC, PT100, PT1000 Sensors



NTC (Negative Temperature Coefficient) thermistor is considered a low-cost sensor that may not have a sufficient curvature and accuracy through the entire temperature range. Typically, 0 Deg C to 150 Deg C. However, they are common so we should understand that the trip point is negative, and it may be best to consider accuracy in the critical motor range of say 25 Deg C to 100 Deg C.

PT1000 (Element Pt) and (1000 Ohms at 0°C) is an industrial platinum resistance temperature sensor having a linear PTC (Positive Temperature Coefficient) defined buy the IEC 60751 that specifies the requirements and temperature/resistance relationship. One advantage of a more expensive is the ability to calculate the values with simple straight-line algebra. However, for the Copley drive to provide temperature measurements we will need to perform the circuit analysis to get the correct Steinhart-Hart coefficient values.

	Temp C		Ohms
T1=	0	R1=	1000
T2=	100	R2=	1385.1
T3=	150	R3=	1573.3
T1 Kelven	273.15	C=	5.39941E-05
T2 Kelven	373.15	B=	-0.0111112
T3 Kelven	423.15	A=	0.062617012
		R =	1272
		Tc=	70.15457315

Calculating Sensor Resistance from Measured Voltage

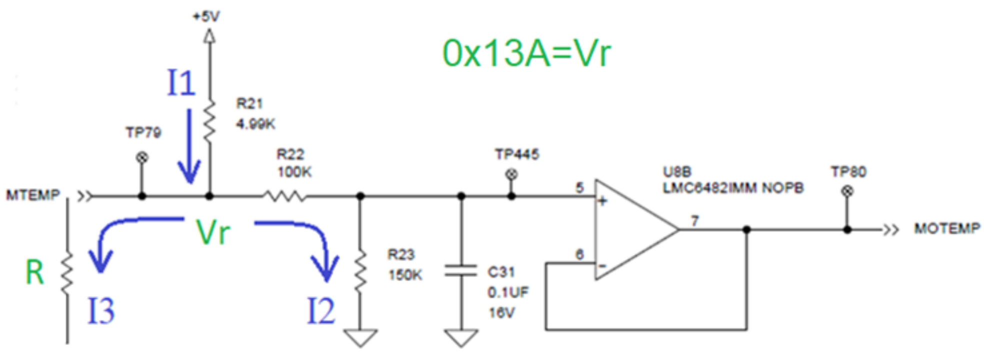
Parameter 0x13A Present voltage at analog motor temperature sensor input in millivolt units.

We can use the measured voltage at the thermistor 0x13A to simply calculate the resistance of the motor temperature sensor so we can then use it with the Steinhart-Hart Coefficients to calculate the motor temperature.

$$R = \frac{V_r}{\left(\frac{5V - V_r}{4.99K}\right) - \left(\frac{V_r}{250K}\right)}$$

Derivation: Ohms Law $R = \frac{V_r}{I3}$, Kirchhoff $I1 = I2 + I3$ or $I3 = I1 - I2$

Note: $I1 = \frac{(5V - V_r)}{4.99k}$, $I2 = \frac{V_r}{250k}$, so $I3 = \left(\frac{5V - V_r}{4.99K}\right) - \left(\frac{V_r}{250K}\right)$



//   The ADC has a 2.5V reference, so given the ADC reading (0 to 32k) we
//   can calculate the voltage at the pin as:
//
// $V_r = ADC * \frac{2.5}{32k} * \frac{250}{150}$
//
//   Note that the max voltage we can sense is 4.166V. Xenus+ XEL/XPL/XML

Calculating Measured Voltage from a given Sense Resistance

Parallel resistance product over the sum: $R_t = R * \frac{250K}{(R + 250K)}$

Voltage divider: $V_r = 5V * \frac{R_t}{(R_t + 4.99K)}$

$$V_r = 5V * \frac{\frac{R * 250K}{R + 250K}}{\left(\frac{R * 250K}{R + 250K}\right) + 4.99K}$$

Revision History

Date	Version	Revision
2/19/2021	Rev 00	Initial release