Thermistor software design

TI Precision Labs – Thermistors

Presented and prepared by Bryan Padilla

Lookup table (LUT)

1 °C Steps

Temperature (°C)	Typical Resistance (Ω)
-40	6656
-39	6699
-38	6741
-37	6784
-36	6827
-35	6871
-34	6915
-33	6959
-32	7004
-31	7049
-30	7094
-29	7139
-28	7185
-27	7231
-26	7278
-25	7324

⋮

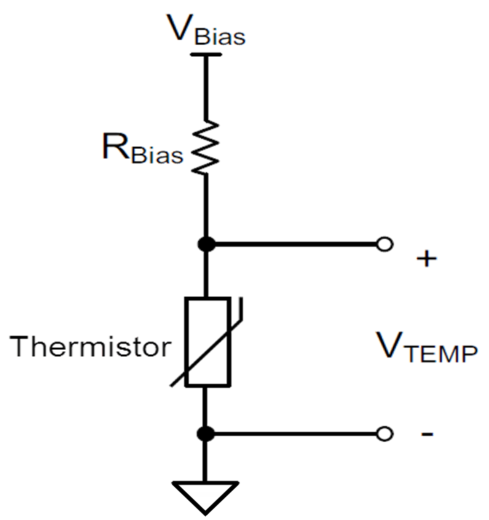
5 °C Steps

Temperature (°C)	Typical Resistance (Ω)
-40	6656
-35	6871
-30	7094
-25	7324
-20	7563
-15	7809
-10	8063
-5	8325
0	8594
5	8871
10	9155
15	9447
20	9747

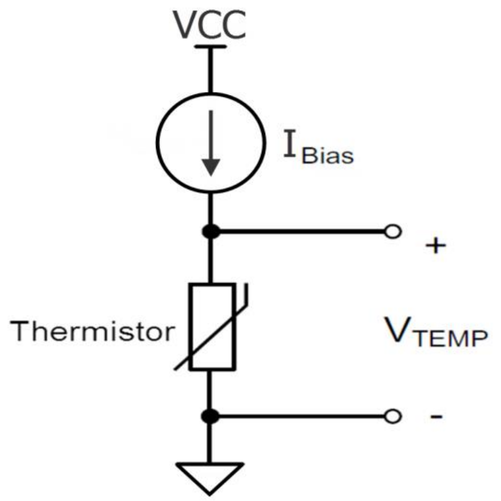
⋮

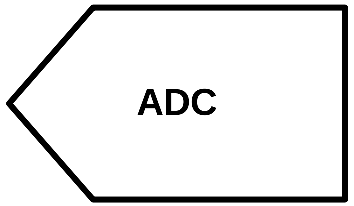
Lookup table (LUT)

1. Store known values in memory:
   - $V_{bias}, R_{bias}, \#\ of\ ADC\ bits\ (ex: 14\ bit)$




```
LookupTable =
{
{ -40,  6656},
{ -39,  6699},
{ -38,  6741},
{ -37,  6784},
{ -36,  6827},
{ -35,  6871},
{ -34,  6915},
{ -33,  6959},
{ -32,  7004},
{ -31,  7049},
{ -30,  7094}}
```

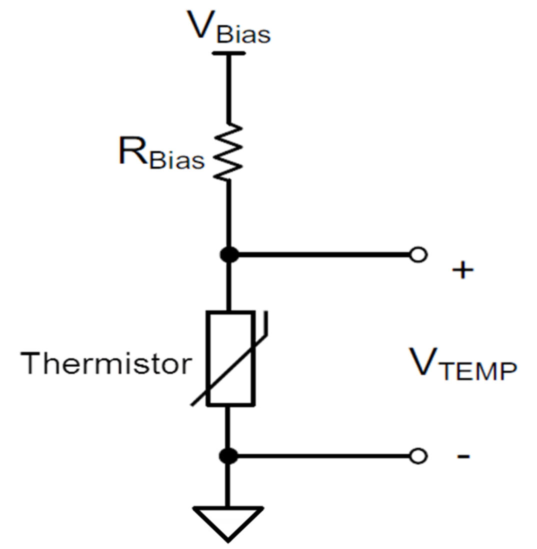




Lookup table (LUT)

1. Store known values in memory:
   - $V_{bias}, R_{bias}, \# \ of \ ADC \ bits \ (ex: 14 \ bit)$

2. Calculate V_{temp}



$$V_{temp} = \frac{V_{bias}}{2^{(\# \ of \ ADC \ bits)}}(\boldsymbol{ADC \ Count})$$

$$V_{temp} = \frac{5}{2^{(14)}}(\boldsymbol{ADC \ Count})$$

$$V_{temp} = (3.0517 \cdot 10^{-4})(\mathbf{6685})$$

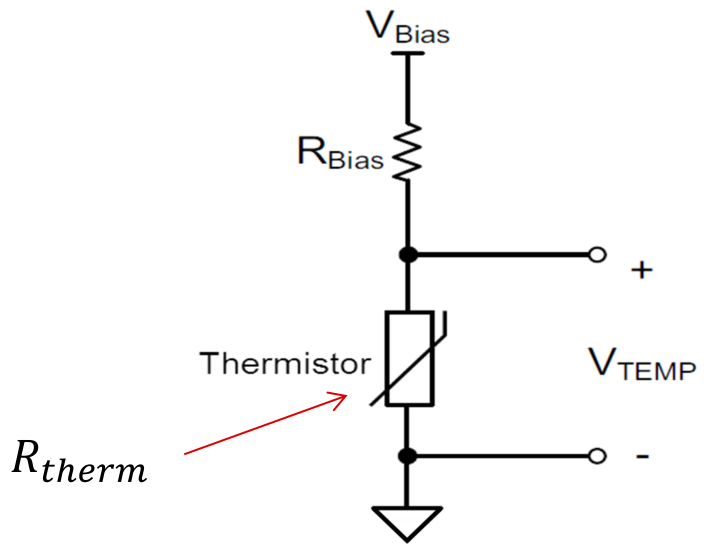
$$V_{temp} = 2.0401 \text{ V}$$

Lookup table (LUT)

1. Store known values in memory:
   - $V_{bias}, R_{bias}, \#\ of\ ADC\ bits\ (ex: 14\ bit)$

2. Calculate V_{temp}

3. Calculate R_{therm}



$$R_{therm} = \frac{V_{temp}}{(V_{bias} - V_{temp})/R_{bias}}$$

$$R_{therm} = \frac{2.0401}{(5 - 2.0401)/10{,}000}$$

$$R_{therm} = 6893\ \Omega$$

Lookup table (LUT)

1. Store known values in memory:
   - $V_{bias}, R_{bias}, \#\ of\ ADC\ bits\ (ex: 14\ bit)$

2. Calculate V_{temp}

3. Calculate R_{therm}

4. Loop through LUT, return temp

LookupTable =

```
{
{-40, 6656},
{-39, 6699},
{-38, 6741},
{-37, 6784},
{-36, 6827},
{-35, 6871},
{-34, 6915},
{-33, 6959},
{-32, 7004},
{-31, 7049},
{-30, 7094}}
```

→ $R_{therm} \leq table[i][1]$

→ $6{,}893 \leq 6{,}915$ True

→ $temp = \mathbf{-35}$

Lookup table (LUT)

1. Store known values in memory:
   - $V_{bias}, R_{bias}, \#\ of\ ADC\ bits\ (ex{:}\,14\ bit)$

2. Calculate V_{temp}

3. Calculate R_{therm}

4. Loop through LUT, return temp

5. Linear interpolation

LookupTable =

```
{
{ -40,  6656} ,
{ -39,  6699} ,
{ -38,  6741} ,
{ -37,  6784} ,
{ -36,  6827} ,
{ -35,  6871} ,
{ -34,  6915} }
```

Y_1 → { -35, 6871} ← X_1

Y_2 → { -34, 6915} ← X_2

$Y = -34.5$

$$Y = Y_1 + \left(\frac{X - X_1}{X_2 - X_1}\right)(Y_2 - Y_1)$$

X is the known value of resistance

Y is the unknown value of temperature

X_1, X_2 = lower, upper resistance limits in table

Y_1, Y_2 = lower, upper temperature limits in table

Linear PTC Steinhart-Hart equation

$T\ in\ °K$

1. Pre-calculate variables, store in memory

$$\boldsymbol{L_1} = ln(R_1) \qquad \boldsymbol{L_2} = ln(R_2) \qquad \boldsymbol{L_3} = ln(R_3)$$

$$\boldsymbol{Y_1} = \frac{1}{T_1} \qquad \boldsymbol{Y_2} = \frac{1}{T_2} \qquad \boldsymbol{Y_3} = \frac{1}{T_3}$$

$R_1, T_1 = Resistance, Temperature\ @\ low\ temp\ (ex{:}\ -40°C\ \rightarrow 233.15°K)$

$R_2, T_2 = Resistance, Temperature\ @\ mid\ temp\ (ex{:}\ 25°C\ \rightarrow 298.15°K)$

$R_3, T_2 = Resistance, Temperature\ @\ high\ temp\ (ex{:}\ 150°C\ \rightarrow 423.15°K)$

$$\boldsymbol{\gamma_2} = \frac{Y_2 - Y_1}{L_2 - L_1} \qquad \boldsymbol{\gamma_3} = \frac{Y_3 - Y_1}{L_3 - L_1}$$

$$\boldsymbol{A} = Y_1 - (B + (L_1)^2 C)L_1$$

$$\boldsymbol{B} = \gamma_2 - C\left({L_1}^2 + L_1 L_2 + {L_2}^2\right)$$

$$\boldsymbol{C} = \frac{\gamma_3 - \gamma_2}{L_3 - L_2}(L_1 + L_2 + L_3)^{-1}$$

2. Convert resistance to temperature in real time

$$\frac{\boldsymbol{1}}{\boldsymbol{T}} = A + B[\ln(R_{therm})] + C[\ln(R_{therm})]^3$$

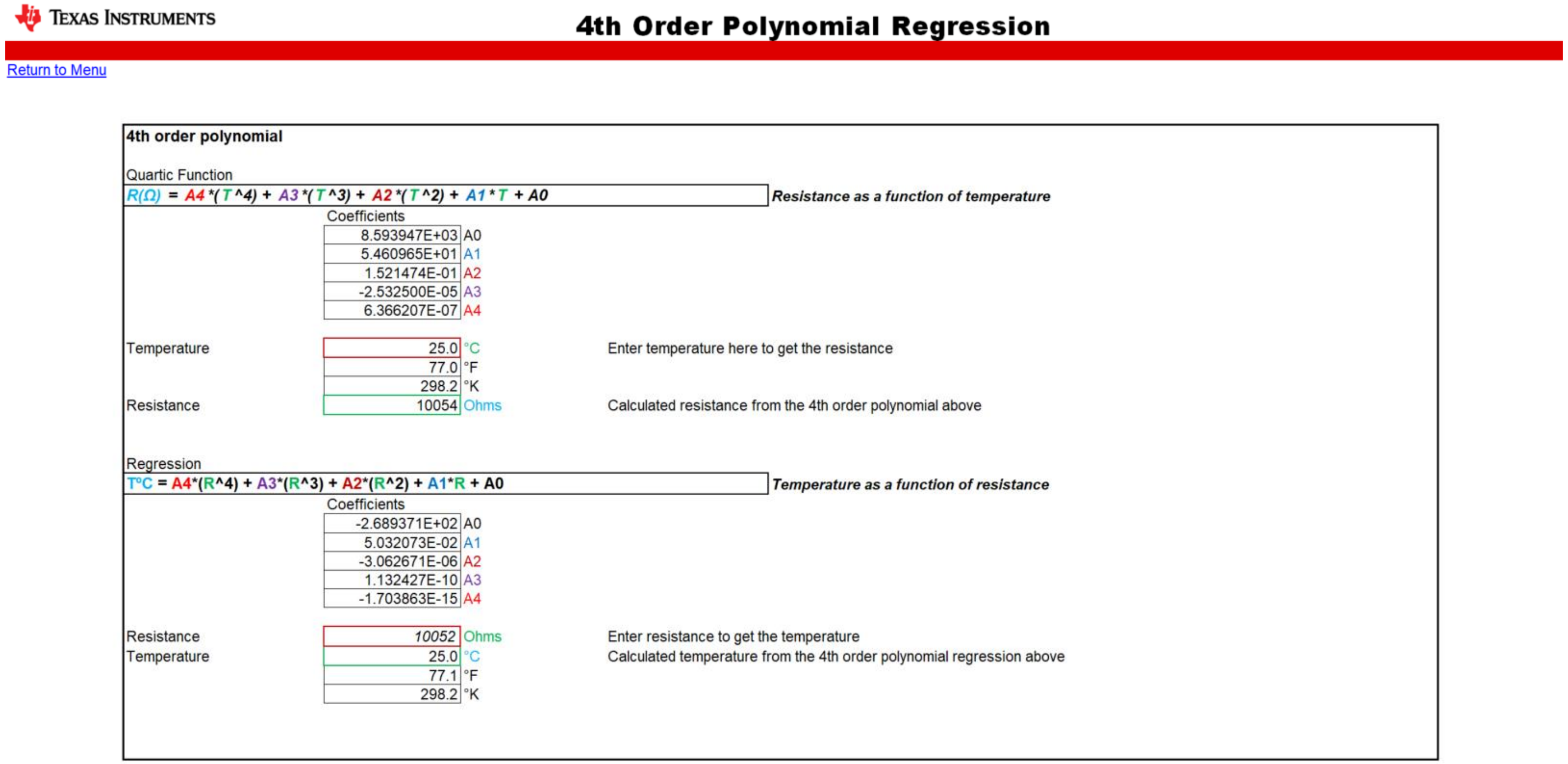
```
int R        10000 ;                                         // set the value of the Rbias (top resistor)
float            5 ;                                         // set the VBias voltage
float     0.000305 ;                                         // set the voltage per bit based on the ADC bits / VREF
float t_volt = 0;                                            // set up the variable for the divider voltage
float t_res = 0;                                             // setup the variable for the calculated resistance
float NLog = 0;                                              // setup the variable for the natural log of the resistance
float Temp = 0;                                              // setup the variable for the calculated temperature

int Thermistor(int raw_ADC)
{
    float A =           0.064865802 ;                        //temperature Coefficients for the thermistor
    float B =          -0.009034398 ;                        //temperature Coefficients for the thermistor
    float C =           0.000027785 ;                        //temperature Coefficients for the thermistor

    t_volt = raw_ADC * bit_volt;                             // convert the raw ADC value to a measured voltage
    t_res = t_volt/((VBias - t_volt)/RBias);                 // convert the measured voltage to a resistance
    NLog = log(t_res);                                       // calculate the natural log of the resistance
    Temp = 1 / (A + B * NLog) + (C * NLog * NLog * NLog);    // run the Steinhart/Hart equation

    return Temp - 273.15;                                    // Convert Kelvin to Celsius and return the temperature
}
```

Linear PTC polynomial regression

$T \ in \ °C$

$$T = A_4R^4 + A_3R^3 + A_2R^2 + A_1R + A_0$$

- No additional libraries
- No natural log function
- Up to 10x faster than Steinhart-Hart Equation



TEXAS INSTRUMENTS

4th Order Polynomial Regression

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4th order polynomial

Quartic Function

$R(\Omega) = A4*(T^4) + A3*(T^3) + A2*(T^2) + A1*T + A0$ — *Resistance as a function of temperature*

Coefficients

8.593947E+03	A0
5.460965E+01	A1
1.521474E-01	A2
-2.532500E-05	A3
6.366207E-07	A4

Temperature	25.0	°C	Enter temperature here to get the resistance
	77.0	°F	
	298.2	°K	
Resistance	10054	Ohms	Calculated resistance from the 4th order polynomial above

Regression

$T°C = A4*(R^4) + A3*(R^3) + A2*(R^2) + A1*R + A0$ — *Temperature as a function of resistance*

Coefficients

-2.689371E+02	A0
5.032073E-02	A1
-3.062671E-06	A2
1.132427E-10	A3
-1.703863E-15	A4

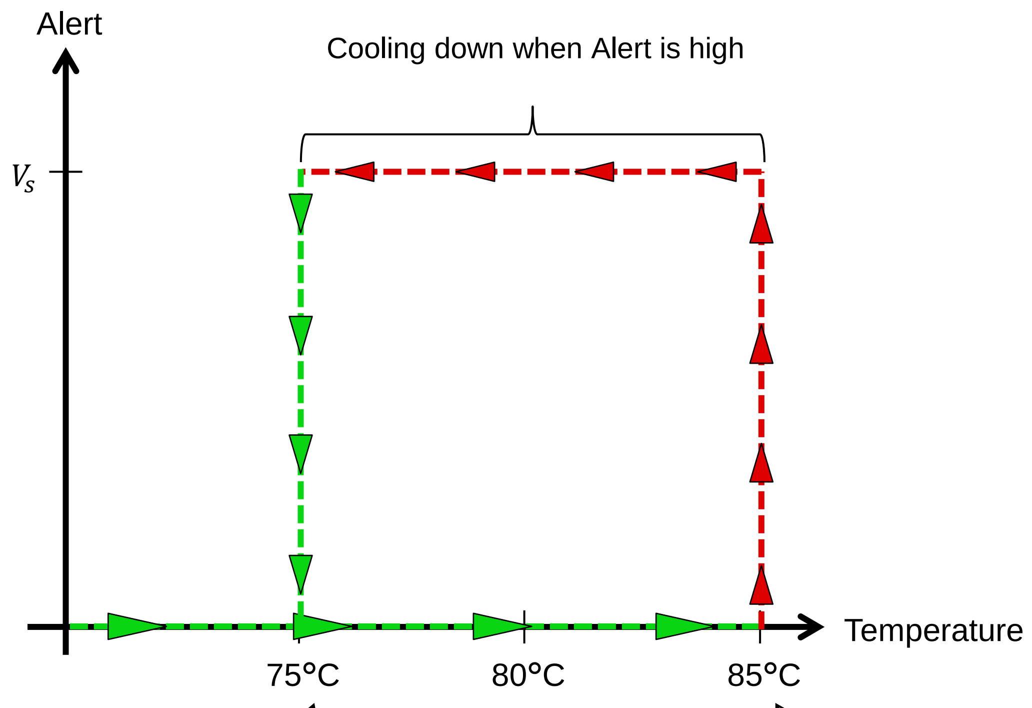
Resistance	10052	Ohms	Enter resistance to get the temperature
Temperature	25.0	°C	Calculated temperature from the 4th order polynomial regression above
	77.1	°F	
	298.2	°K	

Order of values

1. ADC Count
2. V_{temp}
3. R_{therm}
4. Temperature

Shortest to longest time to obtain

Threshold detection & hysteresis



Alert = 0
ADC Count = 9428 steps
$V_{Temp} = 2.8773\ V$
$R_{Therm} = 13555\ \Omega$
$T_{low} = 75°C$

Alert = 1
ADC Count = 9656 steps
$V_{Temp} = 2.9648\ V$
$R_{Therm} = 14353\ \Omega$
$T_{low} = 85°C$

Shortest to longest time to obtain

Texas Instruments

Threshold Detection

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Set High Temperature

T_high	85.0	°C	Enter the high temperature limit required in degrees C	ADC_V	2.946840515	Vdc	Resistor divider voltage at temperature
	185.0	°F		ADC	9656	bits	ADC bits at temperature
	358.2	°K					
Resistance	14353	Ohms	Calculated resistance from the 4th order polynomials				
VBias	5.00	V	Input bias voltage for the resistor divider				
RBias	10000	Ohms	Top resistor				
ADC (bits)	14	bits	Bits of resolution				

Threshold values (ADC_V, ADC)

Set low temperature

T_low	75.0	°C	Enter the low temperature limit required in degrees C	ADC_V	2.877304699	Vdc	Resistor divider voltage at temperature
	167.0	°F		ADC	9428	bits	ADC bits at temperature
	348.2	°CK					
Resistance	13555	Ohms	Calculated resistance from the 4th order polynomials above				
VBias	5.00	V	Input bias voltage for the resistor divider				
RBias	10000	Ohms	Top resistor				
ADC (bits)	14	bits	Bits of resolution				

Threshold values (ADC_V, ADC)

$$\#\ of\ ADC\ bits = 14$$

$$Total\ ADC\ Count = 2^{(14)} = 16384\ steps$$

$$Voltage\ per\ step = \frac{V_{bias}}{Total\ ADC\ Count} = \frac{5}{16384} = 3.0517 \cdot 10^{-4}\ V$$

Summary

Converting to °C

Add interpolation

Very accurate

	Lookup Table	Steinhart-Hart	Polynomial Regression
NTC	✓	✓	X
Linear PTC	✓	✓	✓

Fastest

Only care about certain temperatures?

- Save conversion time with threshold detections using values known prior to temperature.

Quickest

1. ADC Count
2. V_{temp}
3. R_{therm} effective resistance
4. Temperature

Slowest

Thank you!

To find more thermistor resources and products visit ti.com/thermistors