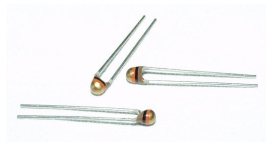
Name: ______________________________ Date: __________

DIY Temperature Probe / Thermistor



Introduction

A thermistor is a special type of resistor whose resistance varies significantly with temperature -- more than standard resistors. In fact, most thermistors have a negative thermal coefficient (NTC) - meaning that the resistance decreases as the temperature increases. If you look closely at a thermistor, there are colored bands on it - similar to a resistor. These are used for “coding” or identifying a thermistor.

The ones we are going to use have the colors, Gold, Red, Black. Looking this up on the datasheet, you’ll find that it is a 10K thermistor -- meaning it has a nominal value of 10K Ohm at 25 degrees C.

ELECTRICAL DATA AND ORDERING INFORMATION

R_{25}	$B_{25/85}$-VALUE		UL APPROVED	SAP MATERIAL NUMBER	OLD 12NC CODE	COLOR CODE [3]		
(Ω)	(K)	(± %)	(Y/N)	NTCLE100E3....B0/T1/T2 [2]	2381 640 3/4/6.... [1]	I	II	III
470	3560	1.5	Y	471*B0	*471	Yellow	Violet	Brown
680	3560	1.5	Y	681*B0	*681	Blue	Grey	Brown
1000	3528	0.5	Y	102*B0	*102	Brown	Black	Red
1500	3528	0.5	Y	152*B0	*152	Brown	Green	Red
2000	3528	0.5	Y	202*B0	*202	Red	Black	Red
2200	3977	0.75	Y	222*B0	*222	Red	Red	Red
2700	3977	0.75	Y	272*B0	*272	Red	violet	Red
3300	3977	0.75	Y	332*B0	*332	Orange	Orange	Red
4700	3977	0.75	Y	472*B0	*472	Yellow	Violet	Red
5000	3977	0.75	Y	502*B0	*502	Green	Black	Red
6800	3977	0.75	Y	682*B0	*682	Blue	Grey	Red
10 000	3977	0.75	Y	103*B0	*103	Brown	Black	Orange
12 000	3740	2	Y	123*B0	*123	Brown	Red	Orange
15 000	3740	2	Y	153*B0	*153	Brown	Green	Orange
22 000	3740	2	Y	223*B0	*223	Red	Red	Orange

Digging deeper into the datasheet, it appears that the resistance values of the thermistor can be calculated using the Steinhart-Hart equation:

$$R_{(T)} = R_{ref} \times e^{(A + B/T + C/T^2 + D/T^3)} \quad (1)$$

$$T_{(R)} = \left(A_1 + B_1 \ln\frac{R}{R_{ref}} + C_1 \ln^2\frac{R}{R_{ref}} + D_1 \ln^3\frac{R}{R_{ref}}\right)^{-1} \quad (2)$$

where:

A, B, C, D, A_1, B_1, C_1 and D_1 are constant values depending on the material concerned; see table below.

$R_{ref.}$ is the resistance value at a reference temperature (in this event 25 °C, $R_{ref.} = R_{25}$).

T is the temperature in K.

Formulae numbered and are interchangeable with an error of max. 0.005 °C in the range 25 °C to 125 °C and max. 0.015 °C in the range - 40 °C to + 25 °C.

Look down in the table for the material that is designated by the same $B_{25/85}$ value as our thermistor:

A_1 = ______________________

B_1 = ______________________

C_1 = ______________________

D_1 = ______________________

Measuring resistance

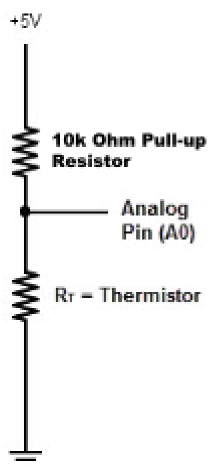
The Steinhart-hart equation is based on the resistance value of the sensor. So, the first task is to build an Ohm-meter (resistance meter) using Arduino. Before we do anything with Arduino, first measure the resistance of the thermistor at room temperature in the lab using a standard multi-meter:

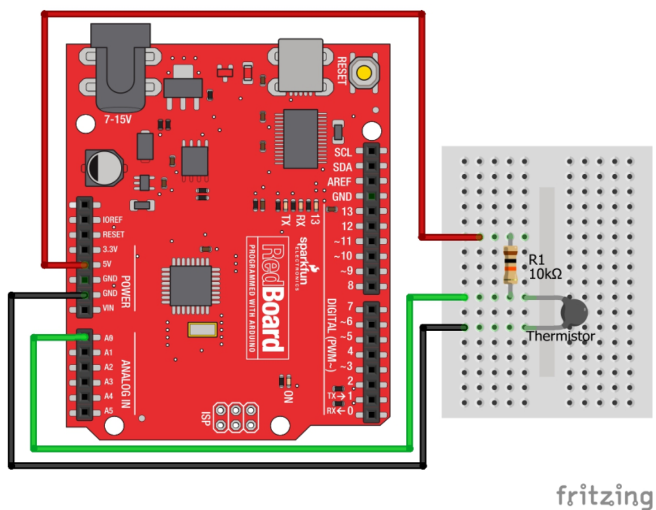
$R_{thermistor}$ = _______________

Okay, now -- just checking the math of the Steinhart-Hart equation, let's calculate what we should get with Arduino using the formula and the constants you found from the datasheet. Be sure to show all of your work neatly on a separate sheet of paper.

Temperature (Kelvin) = _________________

Now, let's setup a simple voltage divider circuit:





Write an equation for the voltage across the Thermistor. Let's call it V_{therm}.

On the Analog Inputs of the Arduino, the microcontroller converts voltages to a numeric value (LSB[1]) from 0 to 1023. 5V = 1023 and 0V = 0. Revise the formula you have above to now be in units of (LSB).

Finally, re-arrange this formula to solve for the resistance of the Thermistor: $\mathbf{R_T}$

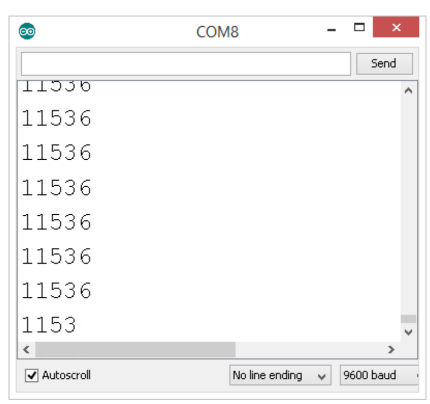
[1] LSB stands for least-significant bit. It's really a unit-less quantity, but we need a name for the units.

Example Code

download code: https://codebender.cc/sketch:62316

```
/*******************************************************************
 * Arduino Thermistor Demo
 * Written by: B. Huang, Nov. 17, 2014
 *
 * Reads the temperature from a 10K NTC Thermistor
 * (https://www.sparkfun.com/products/250)
 *
 * Hardware connections:
 * Connect 10K Pull-up Resistor between A0 and 5V.
 * Connect Thermistor between A0 and GND
 *
 * Upload this example, open up the serial monitor - set to 9600 bps.
 ******************************************************************/

float Temperature;
int rawAnalogReading;

// Variables used in the code for calculations
unsigned long delayTime = 250; // number of milliseconds between measurements
unsigned long R_t;         // calculated resistance of the thermistor

/******************************************************************************/
void setup()
{
  Serial.begin(9600);
  Serial.println("Temperature Readings taken using Ardunio");
}

void loop()
{
  rawAnalogReading = analogRead(A0);  // reads in value from A0 [0-1023]

  R_t = resistance(rawAnalogReading)   ;  // insert your equation here
  Serial.println(R_t);
}

/******************************************************************************/
unsigned long resistance(unsigned long rawAnalogInput)
{
  unsigned int pullupResistor = 10000;
  unsigned long tempVal;  // temporary variable to store calculations in

  tempVal = ( 0 ); // insert your equation here

  return tempVal;  // returns the value calculated to the calling function.
}
```

You must insert the necessary code here to convert between the analog reading and resistance of the thermistor. We started the basic "skeleton" of the code here. You'll need to add your equation in the function called `resistance()`. You measured it with a multi-meter, so you know what you should get.



Once your code compiles, upload it to your Arduino, and open up your Serial Monitor. Make sure the baud rate is set to **9600**. You should see something like this. You might notice that the value is slightly different from your multi-meter reading. We're looking for something close.

Steinhart-Hart Equation:

Okay, this one is a nasty looking equation, so we're going to help you with the code -- you still need to add the equation into this function. We've created a shell of a function called `steinharthart()` below. Start with this as an example.

```
/******************************************************************************/
float steinharthart(unsigned long resistance)
/* function users steinhart-hart equation to return a temperature in degrees celsius.
 * This version utilizes the Steinhart-Hart Thermistor Equation -- from datasheet:
 * Temp in Kelvin = 1 / {A + B[ln(R/Rref)] + C[ln(R/Rref)]^2 + D[ln(R/Rref)]^3}
 */
{
float tempVal; // temporary variable to store calculations in

// calculating logirithms is time consuming for a microcontroller - so we just
// do this once and store it to a variable. Use this in your equation.
float logRes = log((float) resistance / 10000);

// constants for thermistor can be found on the datasheet.
// http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Temp/ntcle100.pdf
// Part Number: NTCLE100E3103JB0
  float a1 = 0; // type in your constants here
  float b1 = 0;
  float c1 = 0;
  float d1 = 0;


  tempVal = 0;  // put your equation for the Steinhart-hart equation here.
  tempVal = tempVal - 273.15;  // convert from Kelvin to Celsius
  return tempVal;
}
```

And, in the loop() part of your code, remove the printing of the resistance and add the following lines:

```
Temperature = steinharthart(R_t);  // Applies the Steinhart-hart equation

Serial.print(millis());  // number of ms since the start of program
Serial.print("\t"); // tab character
Serial.println(Temperature, 1);  // display temperature to one digit
delay(delayTime);
```

Labs / Examples / Investigation Ideas

Temperature is the key to measuring quantities such as energy flow, heat capacity, Q, and general principles of thermodynamics. Put the thermistor into a small sandwich bag and run wires to it for a water-proof temperature probe! Fun experiments to explore:

- Newton's law of cooling
- Mixing of liquids of different temperatures
- Phase changes - liquid chocolate, water-ice, water-vapor…
- Characterizing heating / cooling systems.
- Temperature of combustion

Fully working code example available here: https://codebender.cc/sketch:62399