ECE 320: Electronics

Analog Electronics

ECE 111: Week #19

Please visit Bison Academy for corresponding
lecture notes, homework sets, and solutions

Electronics: Analog Electronics

Topics in Electronics

- Power Amplifiers: Drive 8 Ohm speakers at 100 Watts
- Filters: Pass frequencies below 250Hz, reject frequencies above 400Hz
- Mixers: Combine analog signals
- Sensors: Measure sound, light, temperature, pressure, flow, etc.

This Lecture

- Finding components on Digikey
- Determining parameters for a sensor from the data sheets
- Predicting the voltage vs. temperature relationship for a thermistor
- Determining a calibration function to determine the temperature based upon voltage.

What can we measure?

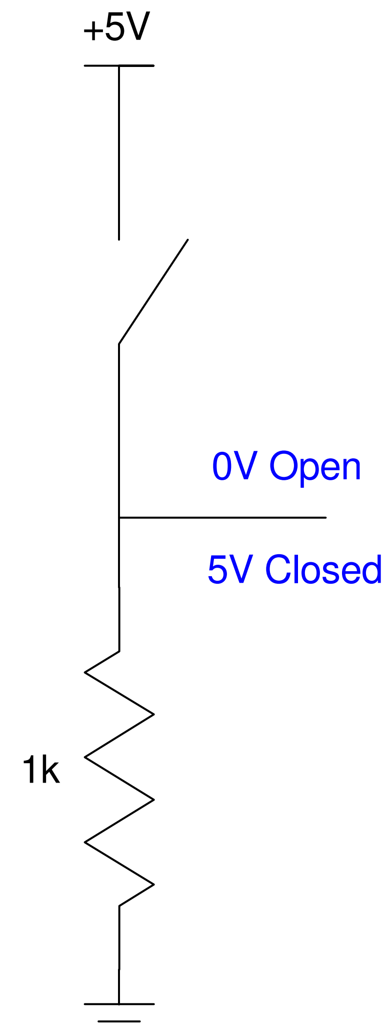
- Time & Voltage

Microprocessors can measure 0V & 5V

- 0V is logic 0
- 5V is logic 1
- (Sometimes 3V is used for logic 1)

Hardware converts a signal to logic levels

- Open switch = 0V
- Closed-switch = 5V



Measuring Time

- You can measure time with insane precision
- PIC18F4620: Measures time to 100ns

Microcontrollers are clocked

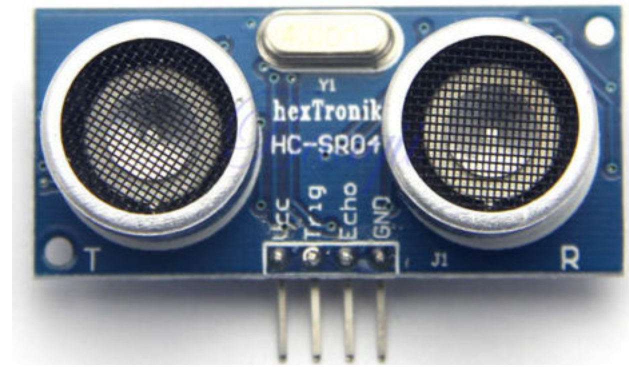
- 10MHz for a PIC18F4620

By counting clocks, you know time to 100ns

- Usain Bolt travels only 1um in 100ns
- Light travels only 100 ft in 100ns
- Due to relativity, time slows down by 15ns when you fly to London

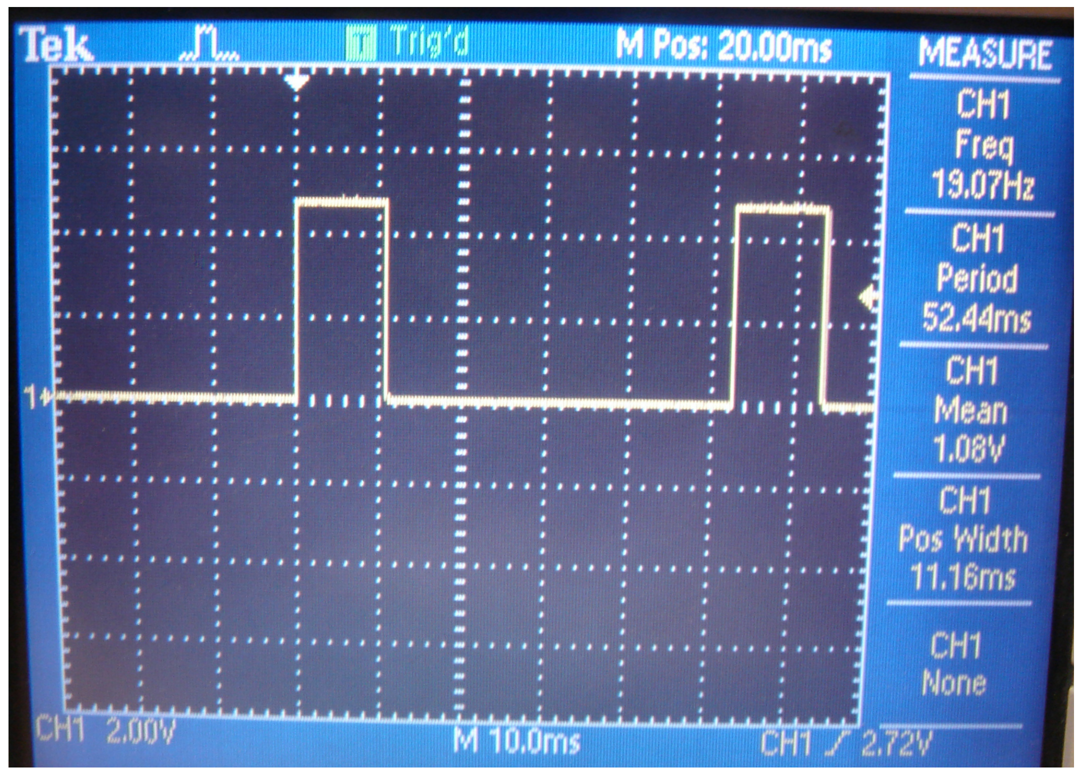
Measuring Distance

- Measuring distance is hard
- Convert distance to time and you can measure distance indirectly



Example 1: Ultrasonic Range Sensor

- Pulse width = time it takes sound to travel to an object and back
- 340mph (speed of sound) @ 100ns = 17um



By measuring time to 100ns, you can measure distance to 17um

Measuring Resistance: 555 Timer

- Resistance cannot be measured directly
- Convert it to a time to measure it indirectly

Example: 555 timers

- Output is a square wave

$$period = (R_1 + 2R_2) \cdot C \cdot \ln(2)$$

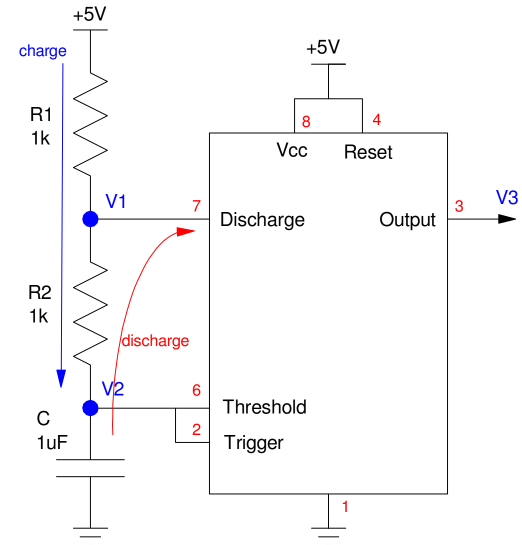
$$period = 2.0794ms$$

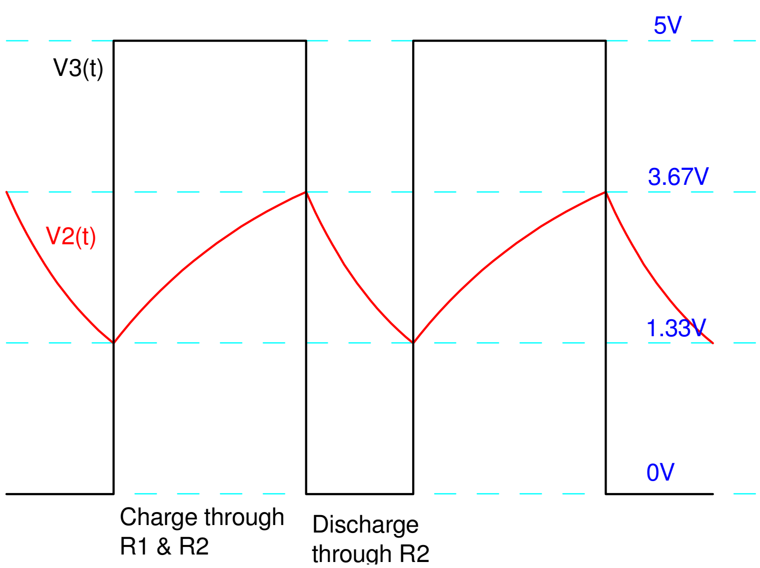
With some algebra

$$R_2 = \left(\frac{period}{2 \cdot C \cdot \ln(2)}\right) - \left(\frac{R_1}{2}\right)$$

If you can measure the period to 100ns

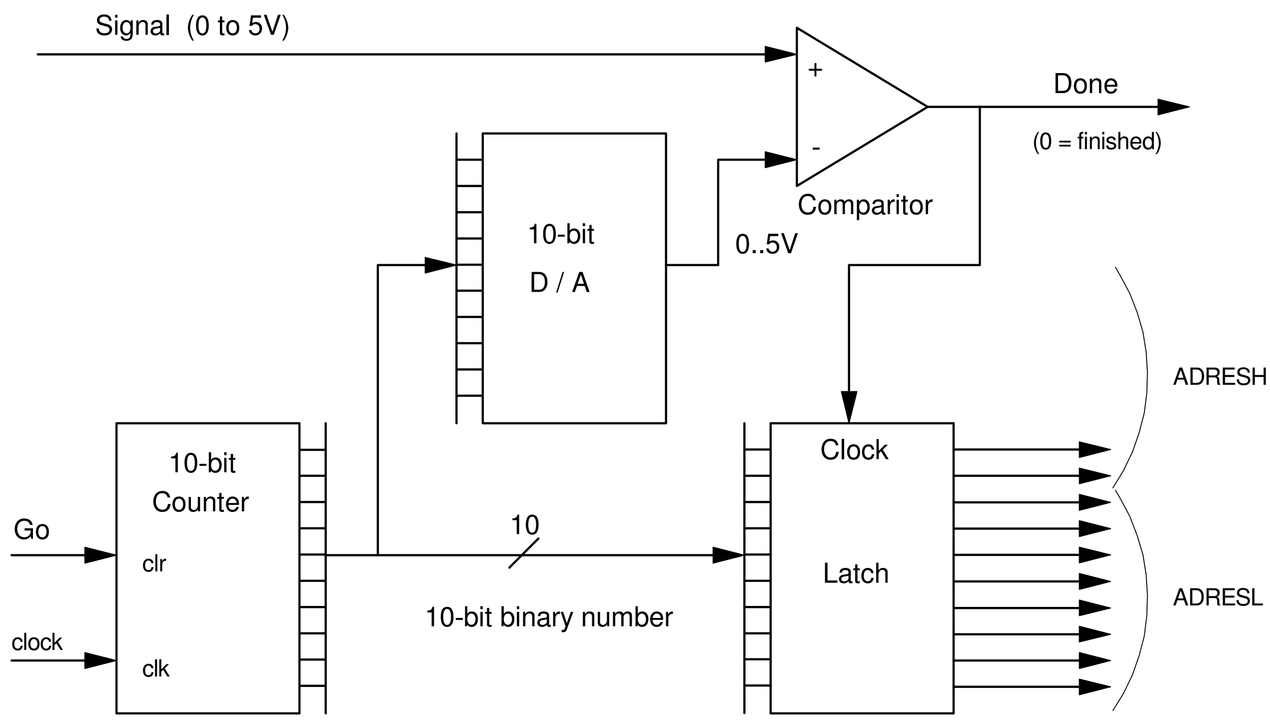
- You can measure resistance to 0.07 Ohms
- R2 has to change by 0.07 Ohms for the period to change by 100ns





Measuring Voltage

- Another thing you can measure directly
- Most microcontrollers have an A/D converter
- 0V - 5V results in A/D going from 0 to 1023 (10-bit A/D)
- Resolution = 4.88mV (one A/D count = 4.88mV)



Measuring Resistance: Voltage Divider

- Resistance cannot be measured directly
- Convert it to a voltage to measure it indirectly

Example: Voltage Divider

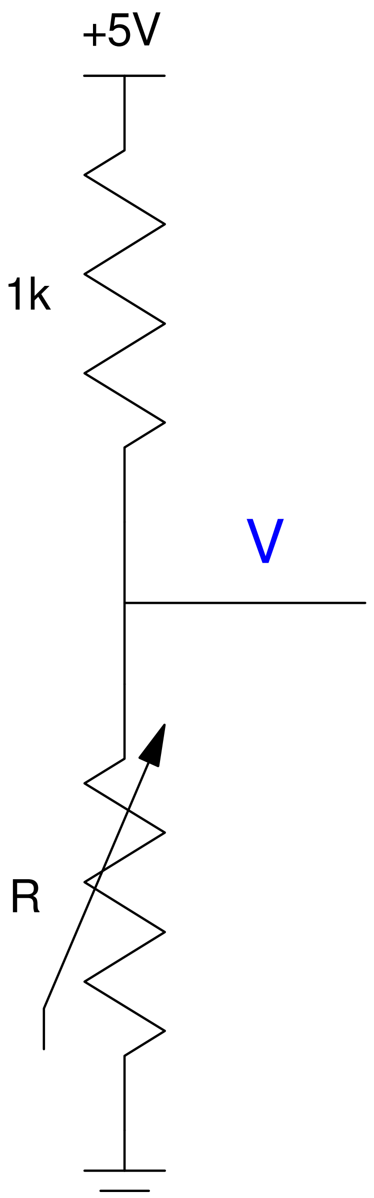
$$V = \left(\frac{R}{R+1000}\right) \cdot 5V$$

With some algebra

$$R = \left(\frac{V}{5-V}\right) \cdot 1000\Omega$$

If R = 1000 Ohms

- V = 2.500V
- The resolution is 3.91 Ohms
- The resistance has to change by 3.91 Ohms for the voltage to change by 4.88mV



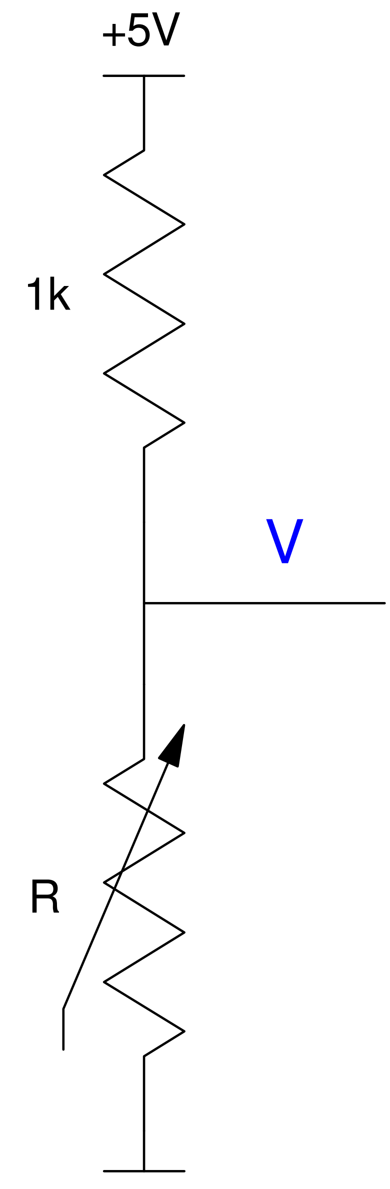
Sensors

Replace R with a sensor

- Temperature-Dependent Resistor (Thermistor)
- Light-Dependent Resistor (CdS cell)
- Strain-Dependent Resistor (strain gage)
- Magnetic-Field-Strength Dependent Resistor (Magneto-resistor)
- etc.

and you can measure

- Temperature
- Light
- Strain
- Magnetic fields,
- etc



Measuring Temperature (take 1)

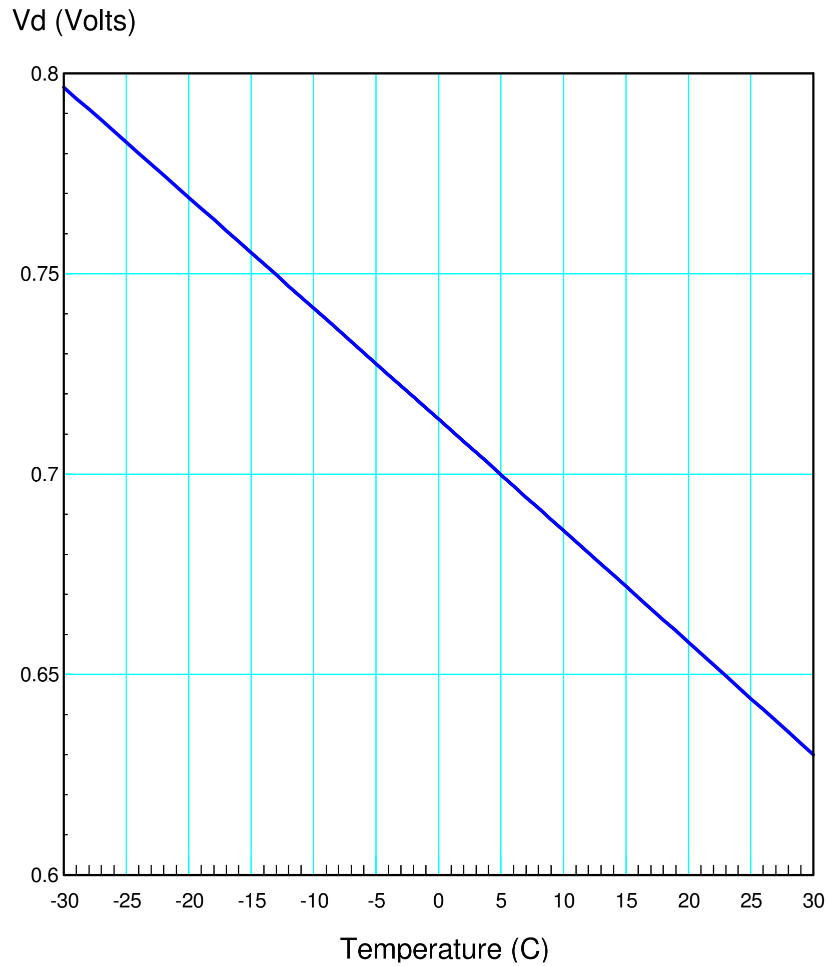
- Thermal Diodes

The voltage drop across a diode varies with temperature

$$V_d = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$n_i = A_0 T^3 \exp\left(\frac{-E_G}{kT}\right)$$

By measuring this voltage, you can measure temperature



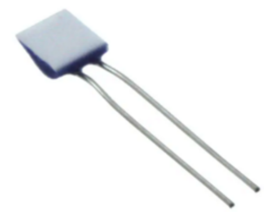
Measuring Temperature (take 2)

- RTD's (resistive thermal devices)

With metals, as the temperature goes up, the resistance goes up

$$R \approx (1 + \alpha T) R_0$$

By measuring the resistance, you can determine the temperature



700-102AAB-B00

Digi-Key Part Number	480-6662-ND
Manufacturer	Honeywell Sensing and Productivity Solutions
Manufacturer Product Number	700-102AAB-B00
Description	SENSOR RTD 1KOHM 0.12% RADIAL
Manufacturer Standard Lead Time	6 Weeks

Example: Copper RTD

- At 0C, R = 1000 Ohms
- At 50C, R = 1215 Ohms

Be	a = 2.5%/C	most sensitive
Ni	a = 0.681%/C	
Fe	a = 0.651%/C	
Cu	a = 0.43%/C	
Al	a = 0.429%/C	
Pt	a = 0.385%/C	
Nd	a = 0.16%/C	least sensitive

Example: Copper RTD

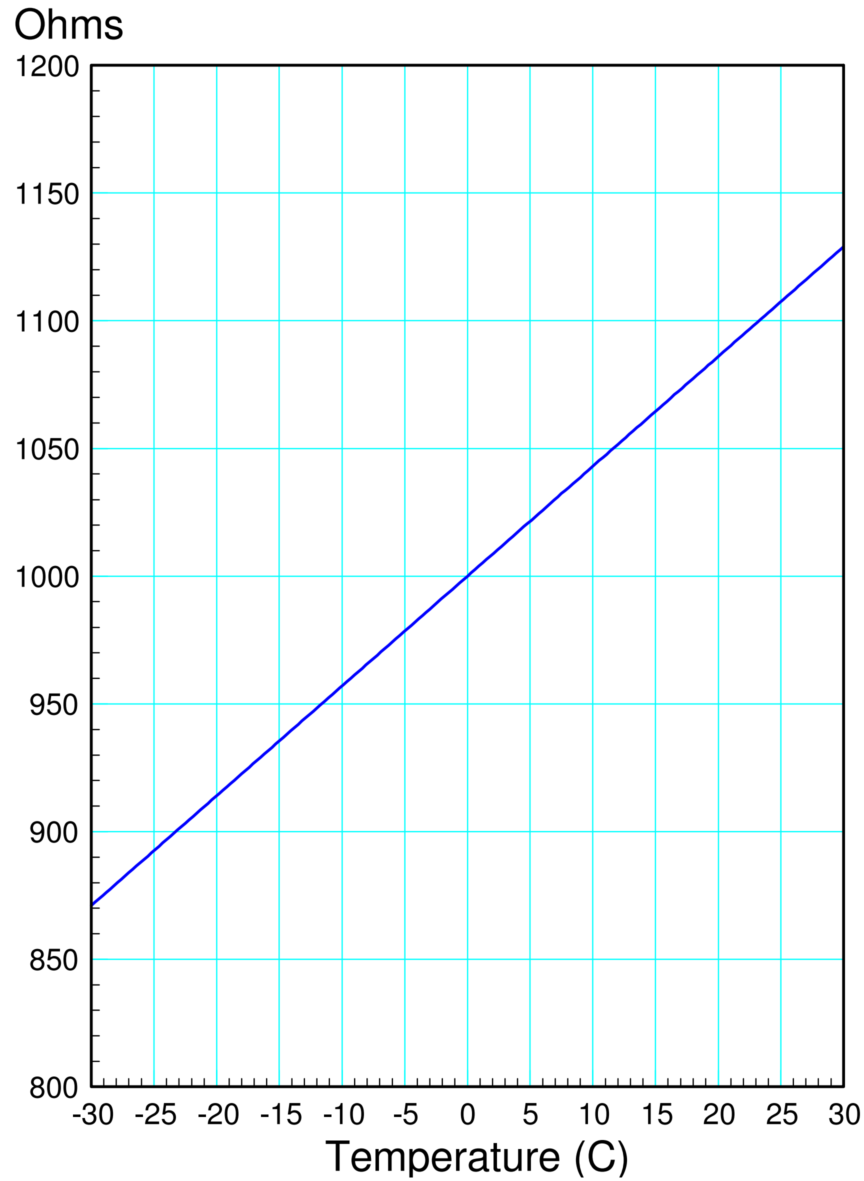
- $R = 1000 \cdot (1 + 0.0043T)\Omega$
- 1000 Ohms @ 0C

If you measure time to 100ns

- R is measured to 0.07 Ohms
- T is measured to 0.016 degrees C

If you measure voltage to 4.88mV

- R is measured to 3.91 Ohms
- T is measured to 0.909 degrees C



Measuring Temperature (take 3)

- Thermistor

With silicon, as the temperature goes up, the resistance goes down

$$R = R_0 \cdot \exp\left(\frac{B}{T+273} - \frac{B}{298}\right)\Omega$$

By measuring the resistance, you can determine the temperature

Example: Thermistor

Assume

- R(25C) = 1000 Ohms
- B = 3905K

$$R = 1000 \cdot \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\Omega$$

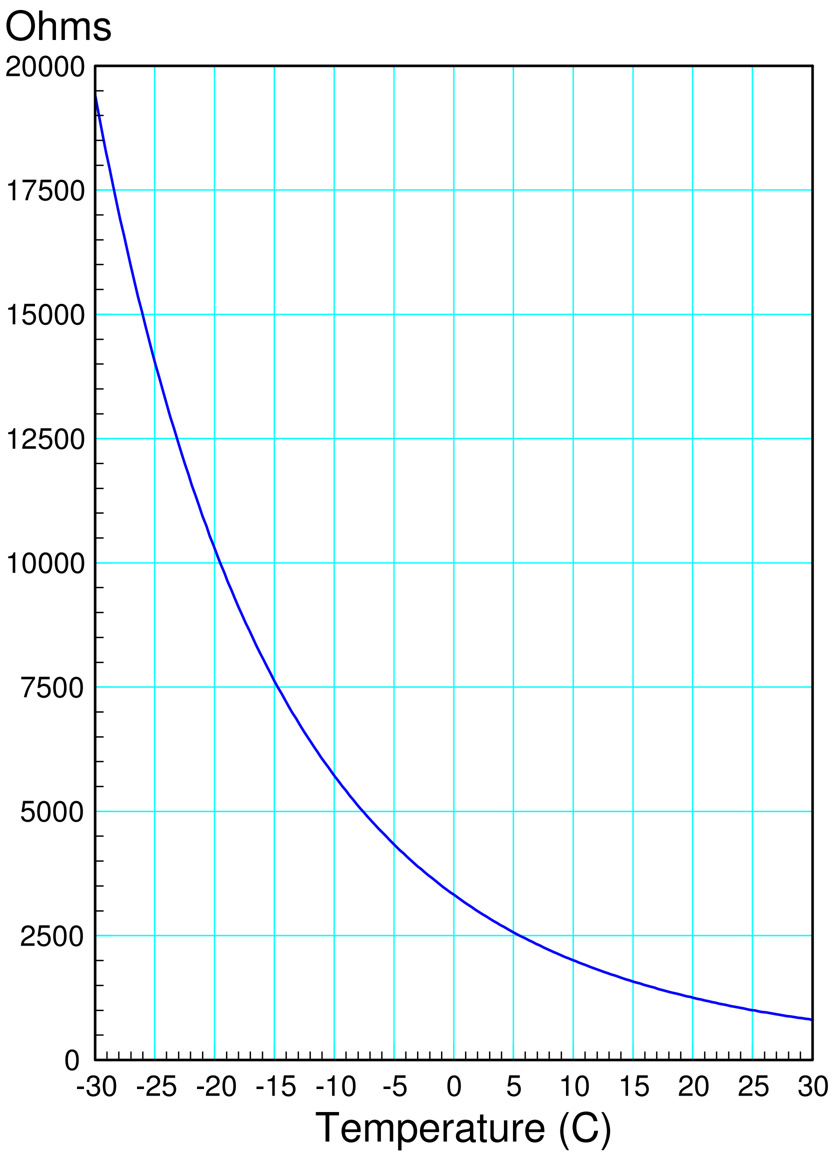
At 25C, R = 1000 Ohms

If you measure time to 100ns

- You measure resistance to 0.07 Ohms
- You can measure temperature to 0.0016 degees C

If you measure voltage to 4.88mV

- You measure resistance to 3.91 Ohms
- You measure temperature to 0.089 degrees C



Problem (Homework)

Find a temperature sensor from Digikey

- Assume a thermistor

Determine the parameters for this sensor

- R(25C) and $B_{0/50}$

Determine Resistance vs. Temperature

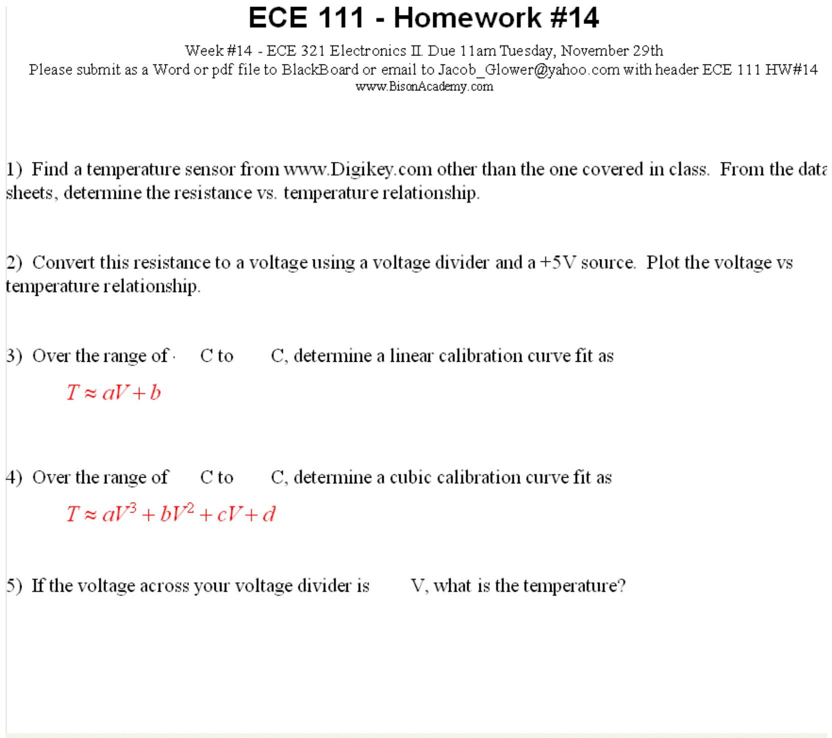
- Assume 0C to 50C range

Determine Voltage vs. Temperature

- Assume a voltage divider

Determine a Calibration Function

- T = f(V)



ECE 111 - Homework #14

Week #14 - ECE 321 Electronics II. Due 11am Tuesday, November 29th
Please submit as a Word or pdf file to BlackBoard or email to Jacob_Glower@yahoo.com with header ECE 111 HW#14
www.BisonAcademy.com

1) Find a temperature sensor from www.Digikey.com other than the one covered in class. From the data sheets, determine the resistance vs. temperature relationship.

2) Convert this resistance to a voltage using a voltage divider and a +5V source. Plot the voltage vs temperature relationship.

3) Over the range of C to C, determine a linear calibration curve fit as

$$T \approx aV + b$$

4) Over the range of C to C, determine a cubic calibration curve fit as

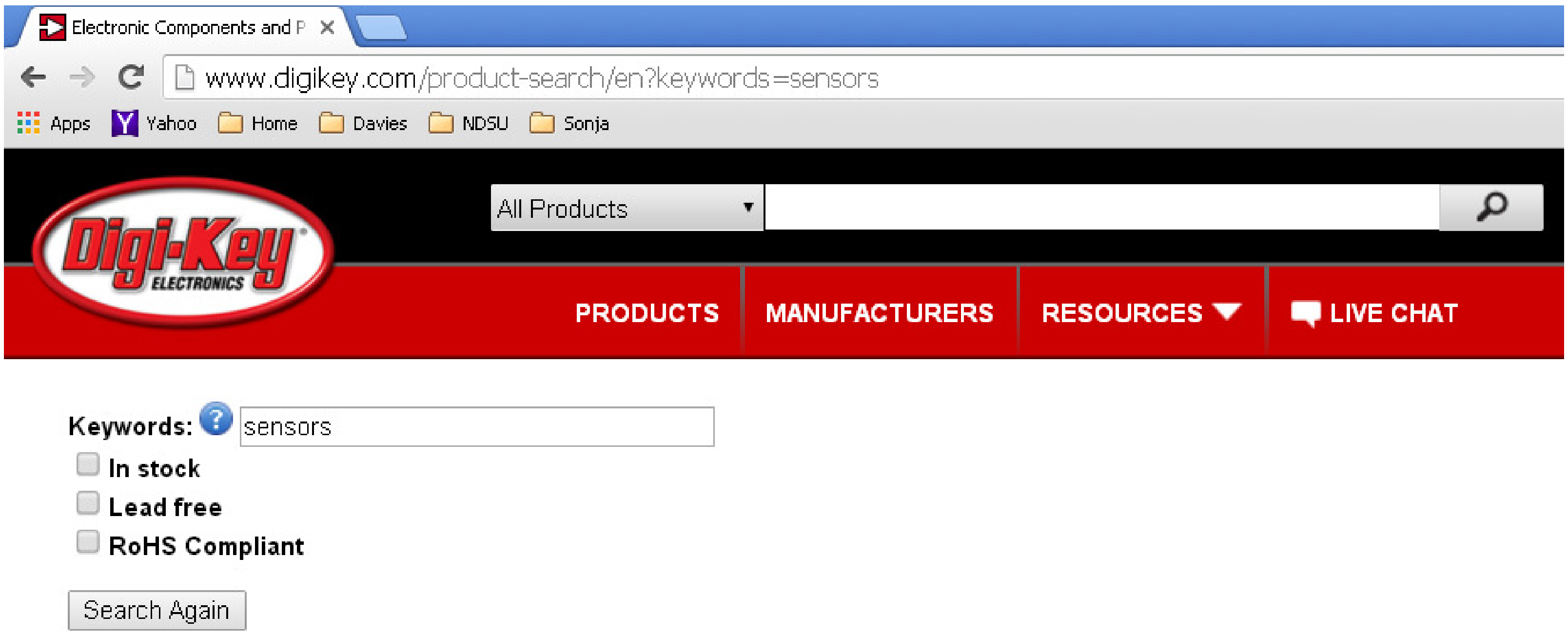
$$T \approx aV^3 + bV^2 + cV + d$$

5) If the voltage across your voltage divider is V, what is the temperature?

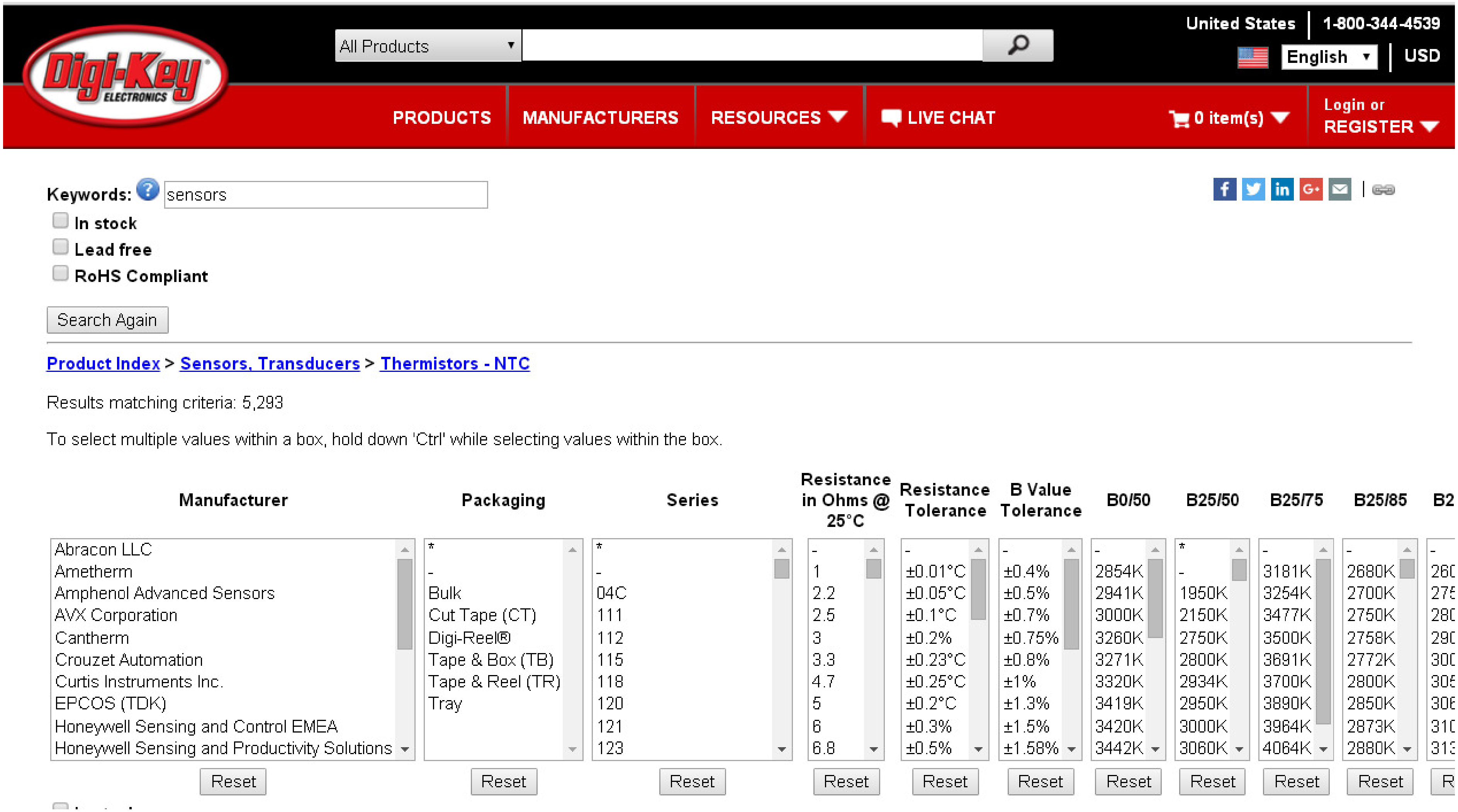
Finding Sensors: Digikey

- www.Digikey.com
- Search "Sensors"

Returns over 19,000 sensors



NTC Thermistor: 5,293 options



- **Resistance @ 25C:** Pretty much what is says. Low values are good for measuring wind speed (low R produces more self heating. The wind provides cooling. Temperature is thus a measurement of the cooling or wind speed). High values are good for low self-heating and low-power consumption.
- **Resistance Tolerance:** Smaller is better. The variation in the resistance at 25C (manufacturing tolerance.) Sort of a measure of the standard deviation - only most people don't know what standard deviation is.
- **B Value Tolerance:** Smaller is better. How accurate you know the temperature / resistance relationship, The lower the number, the more precise the measurement (and the more it costs.)
- **B0/50, B25/50**, etc. The temperature-resistance relationship parameter (more on this later)
- **Operating Temperature** (off the page to the right): The range the sensor can operate
- **Mounting Type** (off the page to the right): Through hole (good for us) or surface mount (good for industry).

Narrow the search to

- 1000 Ohms at 25C
- Through Hole
- In Stock

Compare Parts		Image	Digi-Key Part Number	Manufacturer Part Number	Manufacturer	Description	Quantity Available	Unit Price USD	Minimum Quantity	Packaging	Series	Resistance in Ohms @ 25°C	Resistance Tolerance
			BC2519-ND	NTCLE100E3102JB0	Vishay BC Components	THERMISTOR NTC 1.0K 5% RADIAL	8,535 - Immediate	0.39000	1	Bulk	2381	1k	±5%
			BC2394-ND	NTCLE100E3102HB0	Vishay BC Components	THERMISTOR NTC 1.0K 3% RADIAL	2,954 - Immediate	0.45000	1	Bulk	-	1k	±3%
			BC2393-ND	NTCLE100E3102GB0	Vishay BC Components	THERMISTOR NTC 1.0K 2% RADIAL	1,428 - Immediate	0.67000	1	Bulk	-	1k	±2%
			KC016N-ND	RL2004-582-97-D1	Amphenol Advanced Sensors	THERMISTOR NTC 1K OHM @ 25C	1,233 - Immediate	2.07000	1	Bulk	RL2004	1k	±10%
			480-3157-ND	192-102DEW-A01	Honeywell Sensing and Productivity Solutions	THERMISTOR NTC 1KOHM RADIAL	483 - Immediate	7.29000	1	Bulk	192	1k	±1%
			495-2156-ND	B57891M102J	EPCOS (TDK)	THERMISTOR NTC 1.0K OHM 5% RAD	2,067 - Immediate	0.95000	1	Bulk	-	1k	±5%

Selecting one

[Product Index](#) > [Sensors, Transducers](#) > [Thermistors - NTC](#) > EPCOS (TDK) B57891M102J

All prices are in US dollars.

Digi-Key Part Number	495-2156-ND
Quantity Available	Digi-Key Stock: 2,067 Can ship immediately
Manufacturer	EPCOS (TDK)
Manufacturer Part Number	B57891M102J
Description	THERMISTOR NTC 1.0K OHM 5% RAD
Lead Free Status / RoHS Status	Lead free / RoHS Compliant
Moisture Sensitivity Level (MSL)	1 (Unlimited)

Price Break	Unit Price	Extended Price
1	0.95000	0.95
10	0.72200	7.22
100	0.51680	51.68
500	0.40014	200.07
1,000	0.34457	344.57
5,000	0.30566	1,528.31
10,000	0.29455	2,945.48

Quantity	Item Number	Customer Reference	
1	495-2156-ND		Add to Cart

Image shown is a representation only. Exact specifications should be obtained from the product data sheet.

Open data sheets

General technical data

Climatic category	(IEC 60068-1)		40/125/56	
Max. power	(at 25 °C)	P_{25}	200	mW
Resistance tolerance		$\Delta R_R/R_R$	±5, ±10	%
Rated temperature		T_R	25	°C
Dissipation factor	(in air)	δ_{th}	approx. 3.5	mW/K
Thermal cooling time constant	(in air)	τ_c	approx. 12	s
Heat capacity		C_{th}	approx. 40	mJ/K

Electrical specification and ordering codes

R_{25} Ω	No. of R/T characteristic	$B_{25/100}$ K	Ordering code
1 k	1009	3930 ±3%	B57891M0102+000
1.5 k	1008	3560 ±3%	B57891M0152+000
2.2 k	1013	3900 ±3%	B57891M0222+000
3.3 k	2003	3980 ±3%	B57891M0332+000
4.7 k	2003	3980 ±3%	B57891M0472+000
6.8 k	2003	3980 ±3%	B57891M0682+000
10 k	4901	3950 ±3%	B57891M0103+000
15 k	2004	4100 ±3%	B57891M0153+000
22 k	2904	4300 ±3%	B57891M0223+000

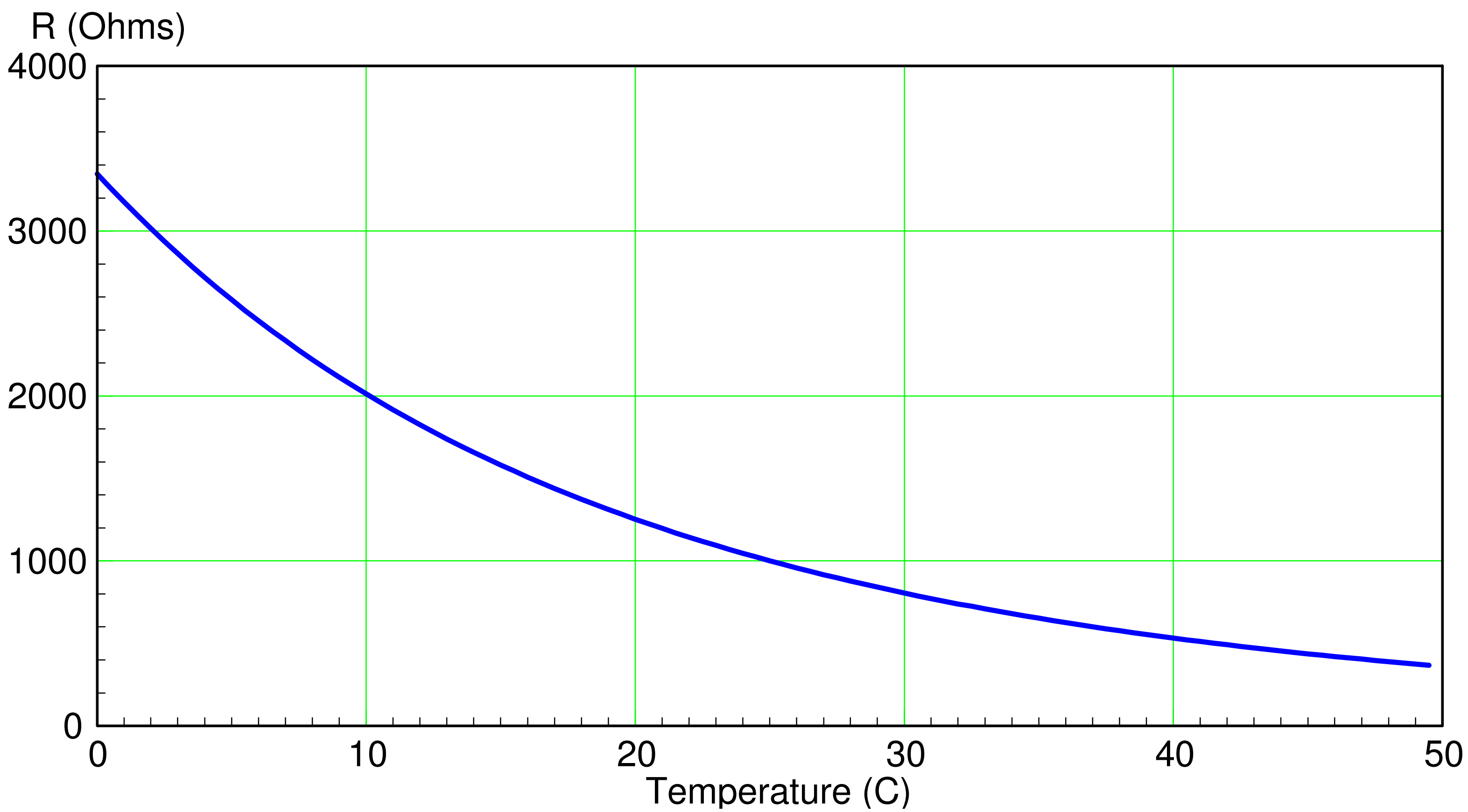
Translation:

- Limit the self-heating to 200mW $(I^2R < 200mW)$. For a 1k thermistor, limit the voltage to less than 14.14V across the thermistor at 25C
- Dissipation factor (in air): 3.5mW/K. At equilibrium, power out = power in. Power in is self heating (I^2R). Power out is from cooling (3.5mW/K).
- Thermal cooling time constant (in air): 12 seconds. It takes some time for the thermistor to warm up to air temperature. The thermistor will be within 5% of equilibrium in 3 time constants, or 36 seconds.
- B25/100: 3930K. This is the temperature - resistance relationship over the range of 25C to 100C (not quite what we want but close). T is the temperature in degrees Celsius (Kelvin + 273)

$$R \approx 1000 \cdot \exp\left(\frac{3930}{T+273} - \frac{3930}{298K}\right)$$

Temperature vs. Resistance

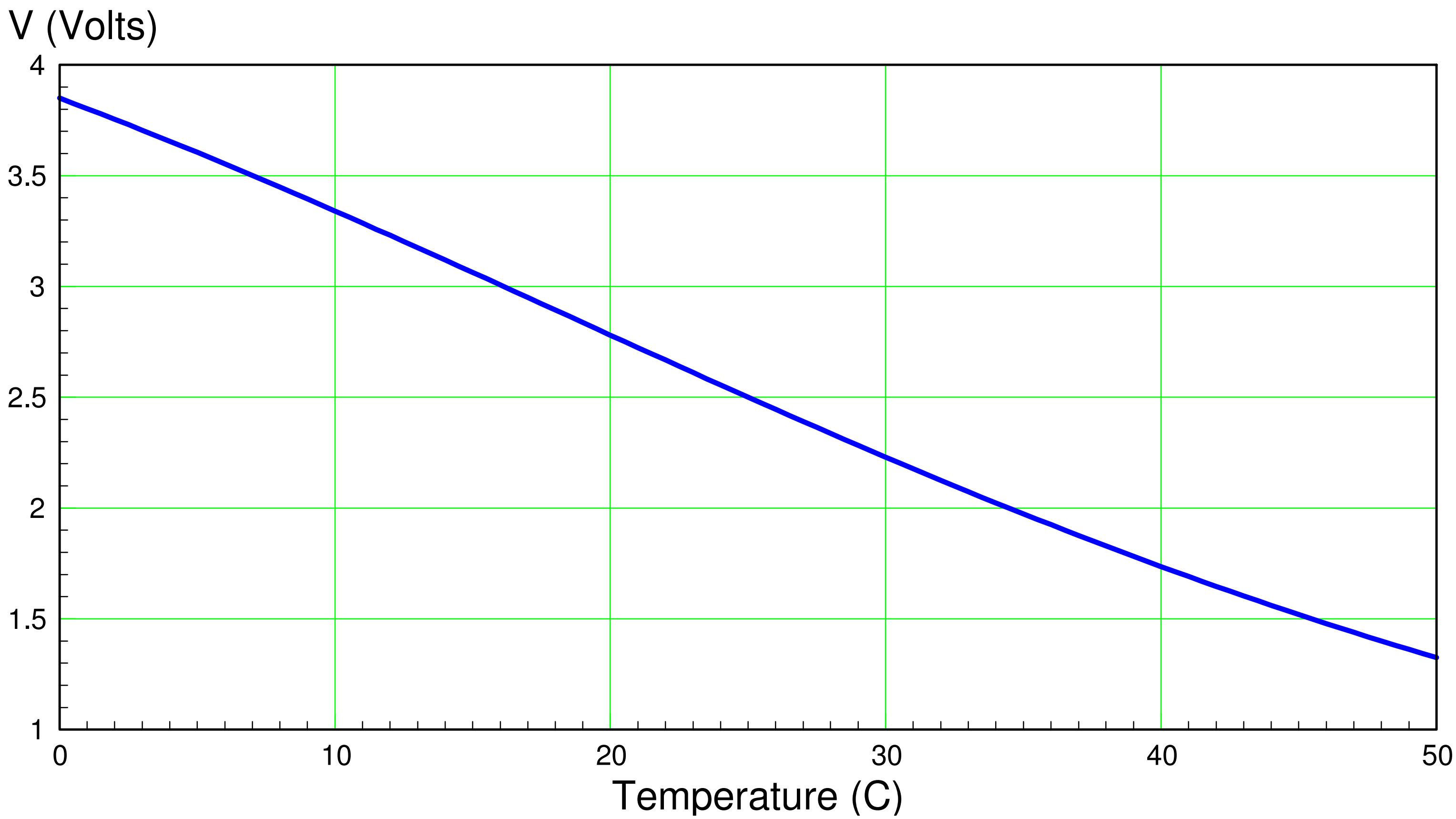
```
T = [0:0.1:50]';
R = 1000 * exp((3930 ./ (T + 273))  -  (3930 / 298) );
plot(T,R)
```



Temperature vs. Voltage

- Assume a voltage divider with a 1k resistor & 5V source

```
V = R ./ (1000 + R) * 5;
plot(T,V)
```



Calibration Functions

- Linear Curve Fit

Assume you measure voltage. What is the temperature?

$$T = f(V)$$

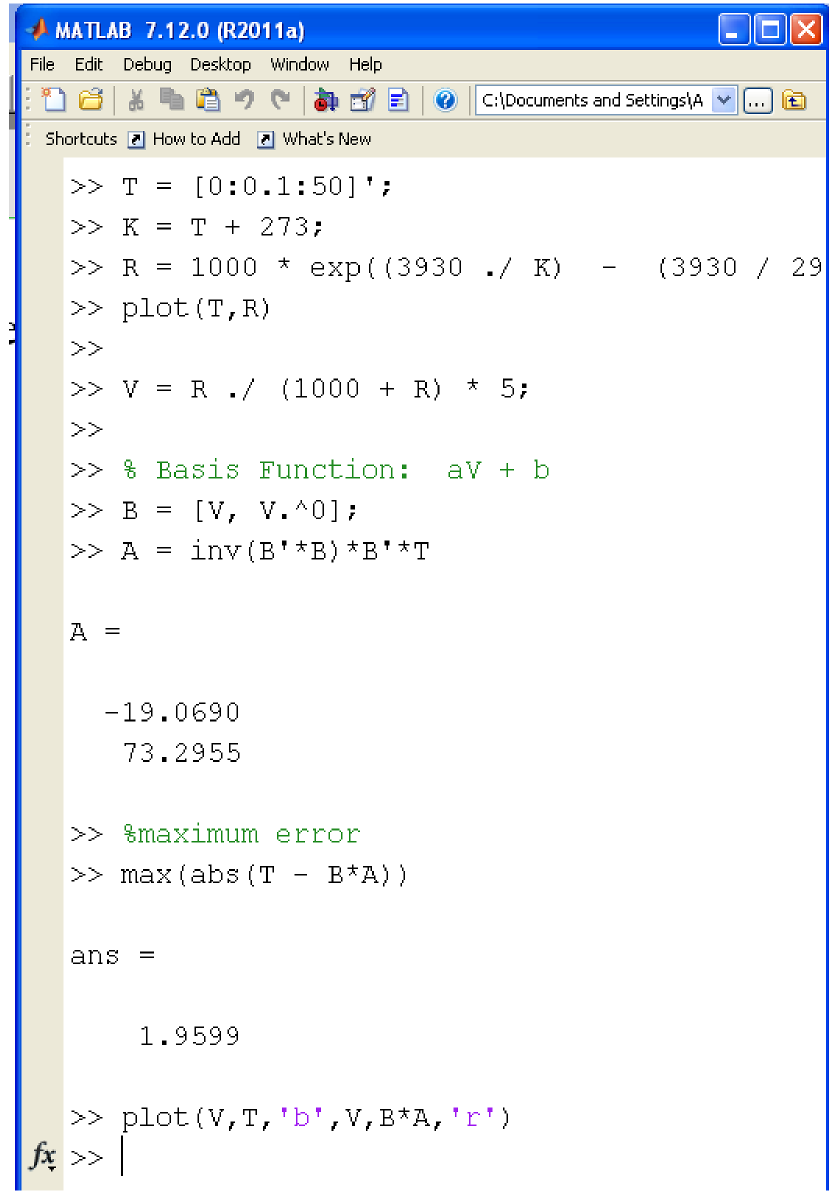
Linear Calibration Function:

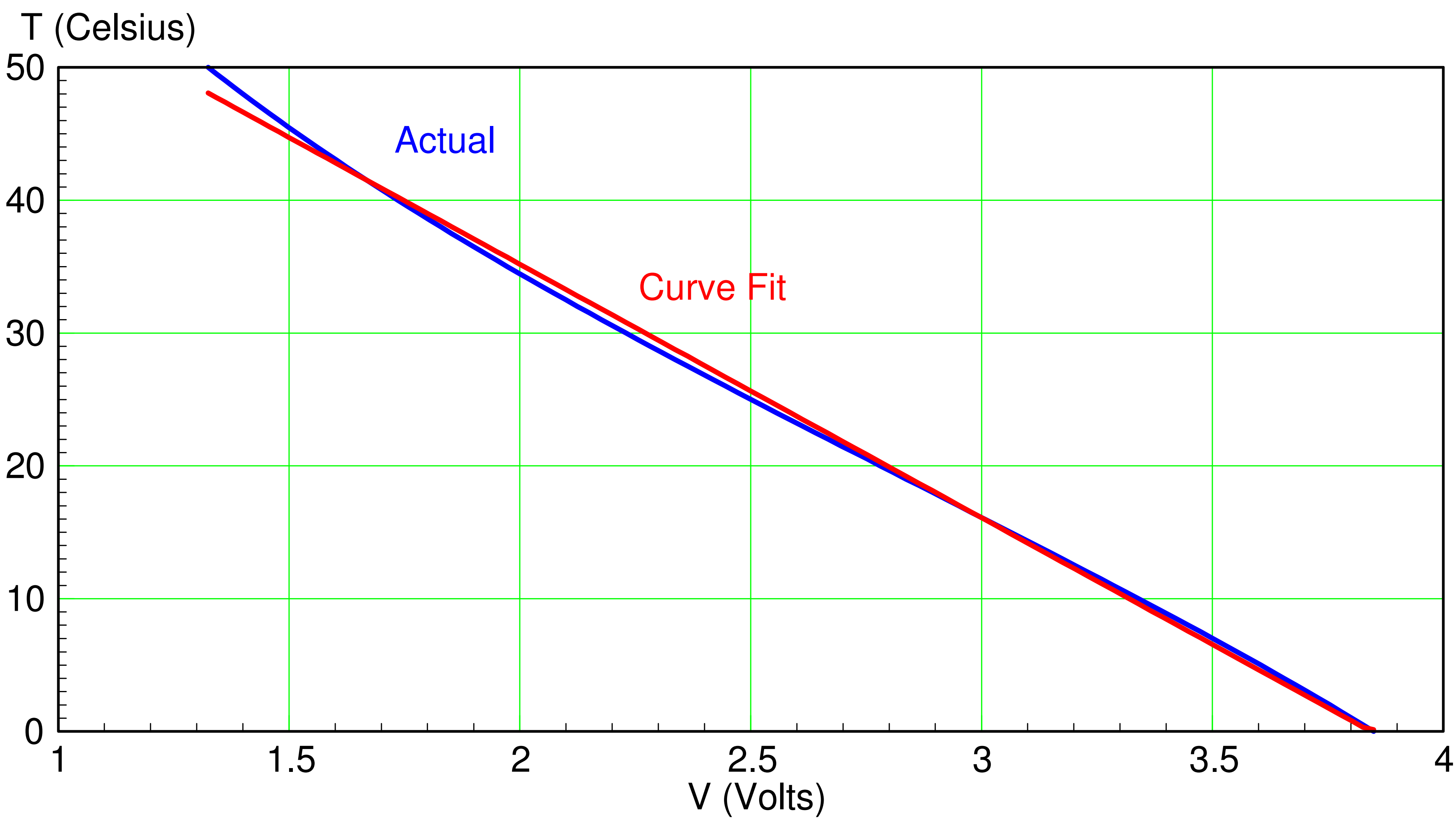
$$T \approx a \cdot V + b$$

The least-squares solution is

$$\boxed{T \approx -19.069 \cdot V + 73.2955}$$

Maximum error: 1.96 degrees




T (Celsius)
50
40
30
20
10
0
1
1.5
2
2.5
3
3.5
4
V (Volts)
Actual
Curve Fit

Calibration Functions

- Cubic Curve Fit

Assume

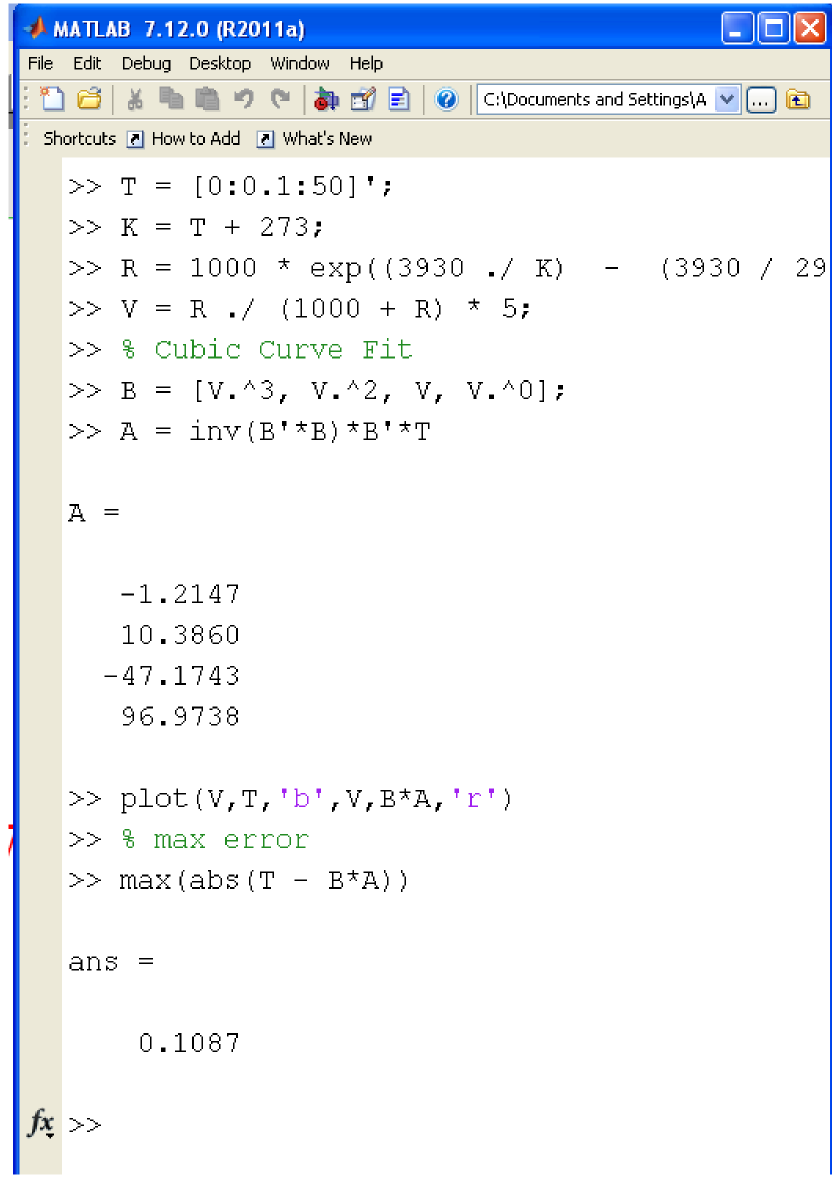
$$T \approx a \cdot V^3 + b \cdot V^2 + c \cdot V + d$$

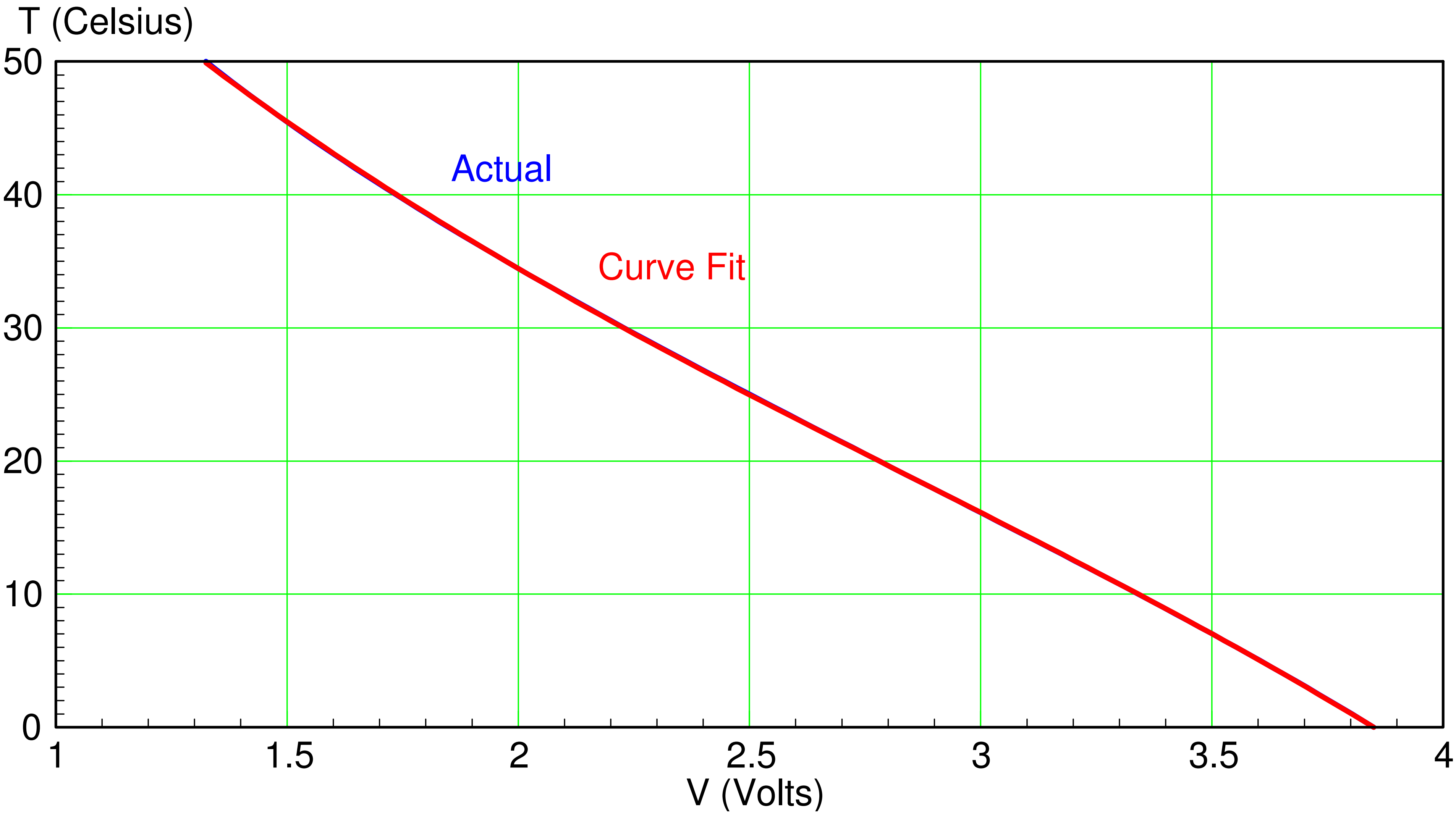
```
B = [V.^3, V.^2, V, V.^0];
A = inv(B'*B)*B'*Y

  - 1.2146531
    10.385968
  - 47.174316
    96.973783
```

meaning...

$$T \approx -1.214 \cdot V^3 + 10.385 \cdot V^2 - 47.174V + 96.97$$

Maximum error = 0.1087 degrees





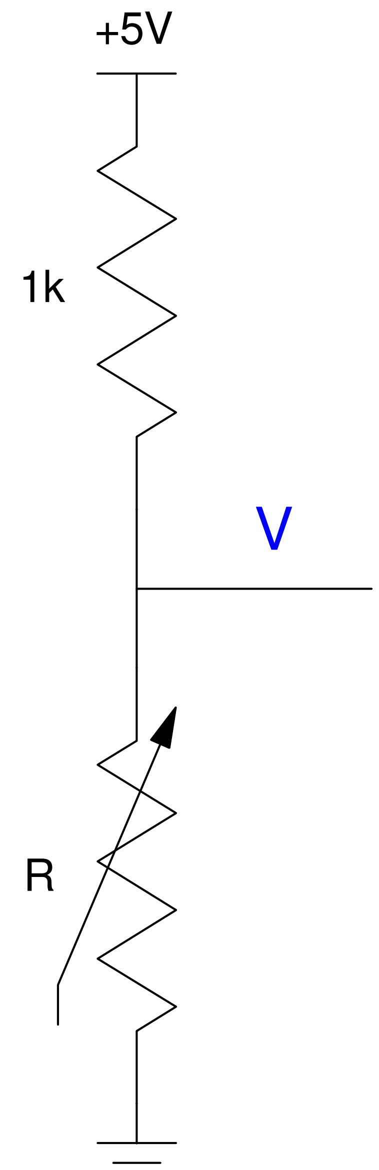
T (Celsius)
50
40
30
20
10
0
Actual
Curve Fit
1
1.5
2
2.5
3
3.5
4
V (Volts)

Converting to Temperature

- If V = 3.23 Volts, what is the temperature?

Solution: Use the calibration function you just computed

```
>> V = 3.23;

>> T = [V^3, V^2, V, 1] * A

T =    12.0248
```



Summary

If you can measure voltage, you can measure resistance

If you can measure resistance, you can measure temperature

- or light, strain, gas, etc.

From the data sheets, find $\{R_{25C}, B_{25/50}\}$

$$R = R_{25C} \cdot \exp\left(\frac{B_{25/50}}{T+273} - \frac{B_{25/50}}{298}\right)\Omega$$

From Matlab, you can then find the temperature - voltage relationship

$$V = \left(\frac{R}{R+1k}\right)5V$$

Calibration is determining a function that relates the two

$$T \approx aV + b$$

Least-squares curve fitting allows you to find {a, b}