Data Collection & Calibration

ECE 376 Embedded Systems

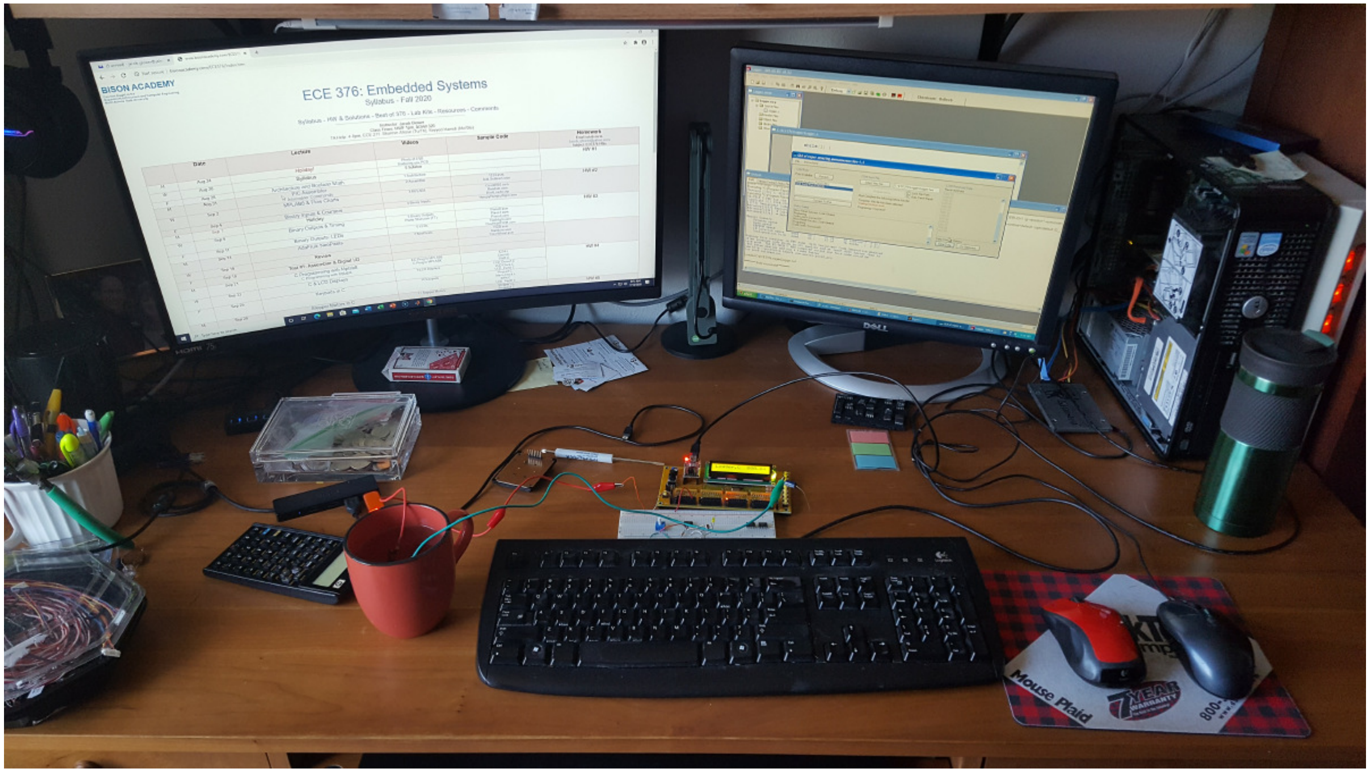
Jake Glower - Lecture #14

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

Data Collection & Calibration

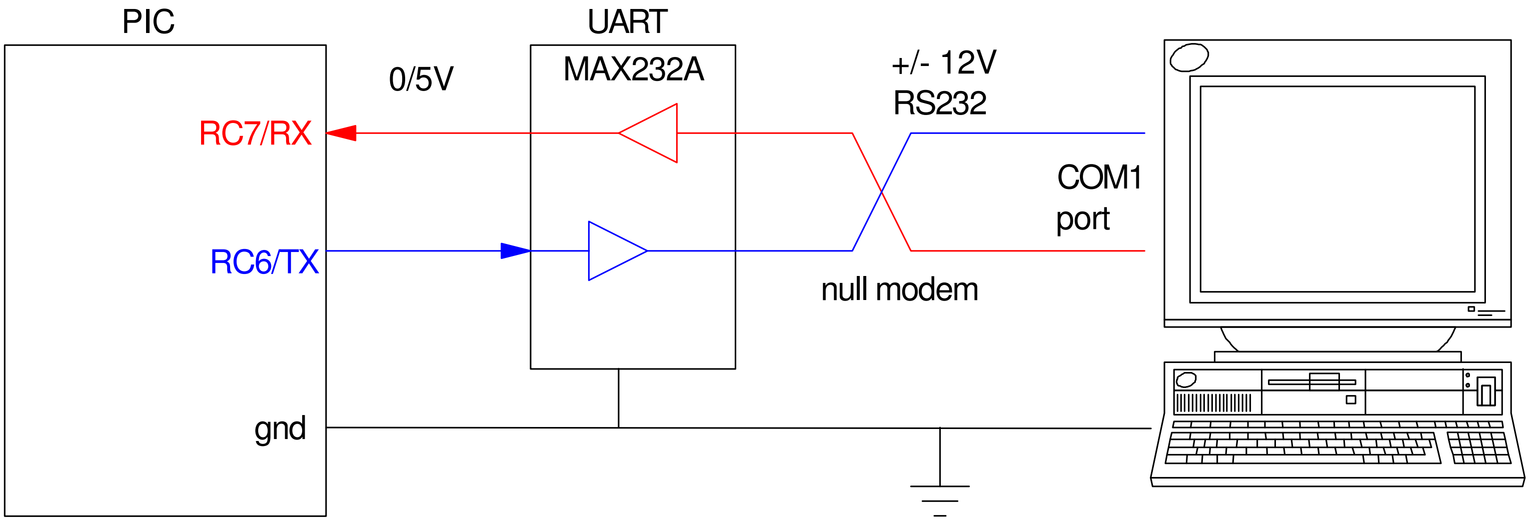
Objective

- Record lots and lots of data over time (data collection)Data Collection & Calibration
- Design a circuit which outputs 0 .. 5V for a sensor (instrumentation amplifier)
- Convert the data to temperature (calibration)



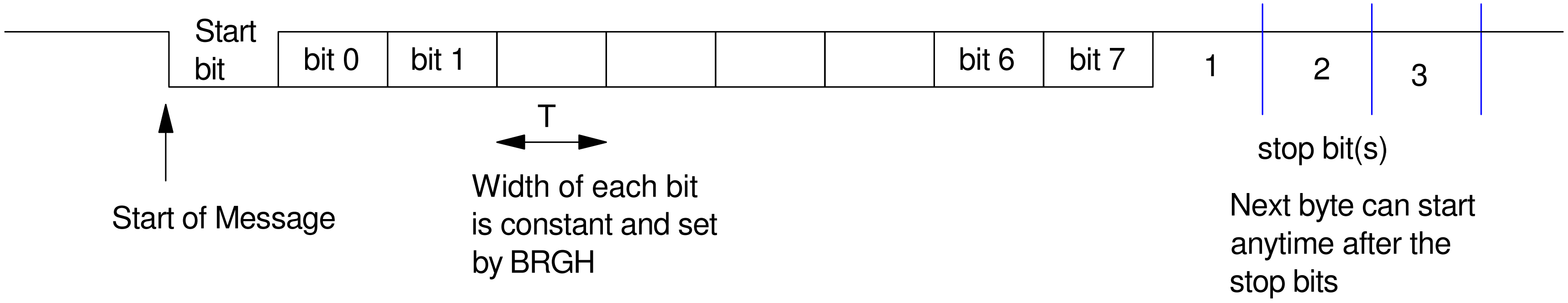
SCI Communications

- Communications between your PIC board and a computer
- TX: Transmit data
- RX: Receive data
- Null Modem: Swaps TX/ RX
- USB Port on PIC chip



SCI Data

- The data line idles high.
- When you want to send a byte, the data line goes low for one count.
- Eight data bits are then sent, least significant bit first.
- The data line then goes back to 5V until the next byte is to be sent.



Initializing the SCI Port:

- Baud rate = bits per second
- Bit length = 1 / Baud
- 9600 baud means you send 9600 bits per second (or one bit is 1/9600 seconds long)

Other baud rates are supported as well:

Baud Rate	SPBRG	BRGH	BRG16	SYNC	Error (%)
2,400	255	0	1	0	-1.70%
4,800	129	0	1	0	-0.16%
9,600	255	1	1	0	-1.70%
19,200	129	1	1	0	-0.16%
38,400	64	1	1	0	-0.16%
57,600	42	1	1	0	-0.95%
115,200	21	1	1	0	+1.44%

SCI Software:

```
// Turn on the serial port for 9600 baud

   TRISC = TRISC | 0xC0;
   TXIE = 0;
   RCIE = 0;
   BRGH = 1;
   BRG16 = 1;
   SYNC = 0;
   SPBRG = 255;
   TXSTA = 0x22;
   RCSTA = 0x90;


void SCI_CRLF(void)
{
   while(!TRMT);      // wait until the serial port is free
   TXREG = 13;        // send a carriage return (ascii 13)
   while(!TRMT);      // wait until the serial port is free
   TXREG = 10;        // send a line feed (ascii 10)
   }
```

Included in LCD_PortD.c

- Similar to LCD_Out.c

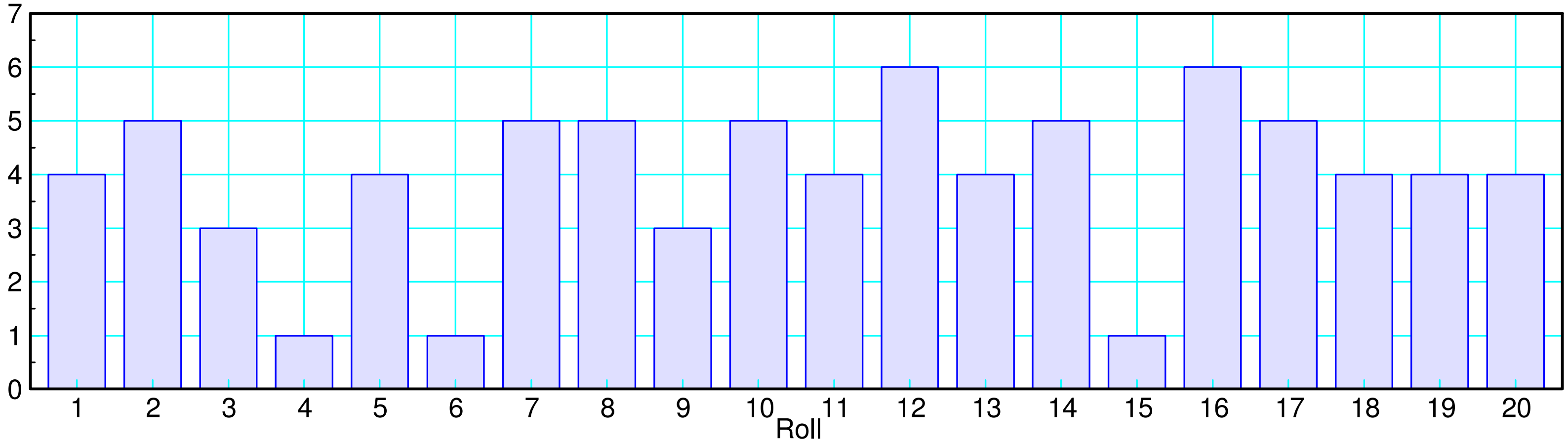
```
void SCI_Out(long int DATA, unsigned char D, unsigned char N)
{
   unsigned char A[10], i;

   while(!TRMT);
   if(DATA < 0) {
      TXREG = '-';
      DATA = -DATA;
      }
   else TXREG = ' ';
   for (i=0; i<10; i++) {
      A[i] = DATA % 10;
      DATA = DATA / 10;
      }
   for (i=D; i>0; i--) {
      if (i == N) { while(!TRMT); TXREG = '.'; }
      while(!TRMT);  TXREG = A[i-1] + 48;
      }
   }
```

Roll a Six-Sided Die

- Record the data via the serial port @ 9600 baud

Code:

```
while(1) {
   while(!RB0);
   while(RB0) DIE = (DIE + 1) % 6;
   DIE += 1;
   LCD_Move(1,0);  LCD_Out(DIE, 1, 0);
   SCI_Out(DIE, 1, 0);
   SCI_CRLF();
   }
```



Read voltage on RA1 every 100ms

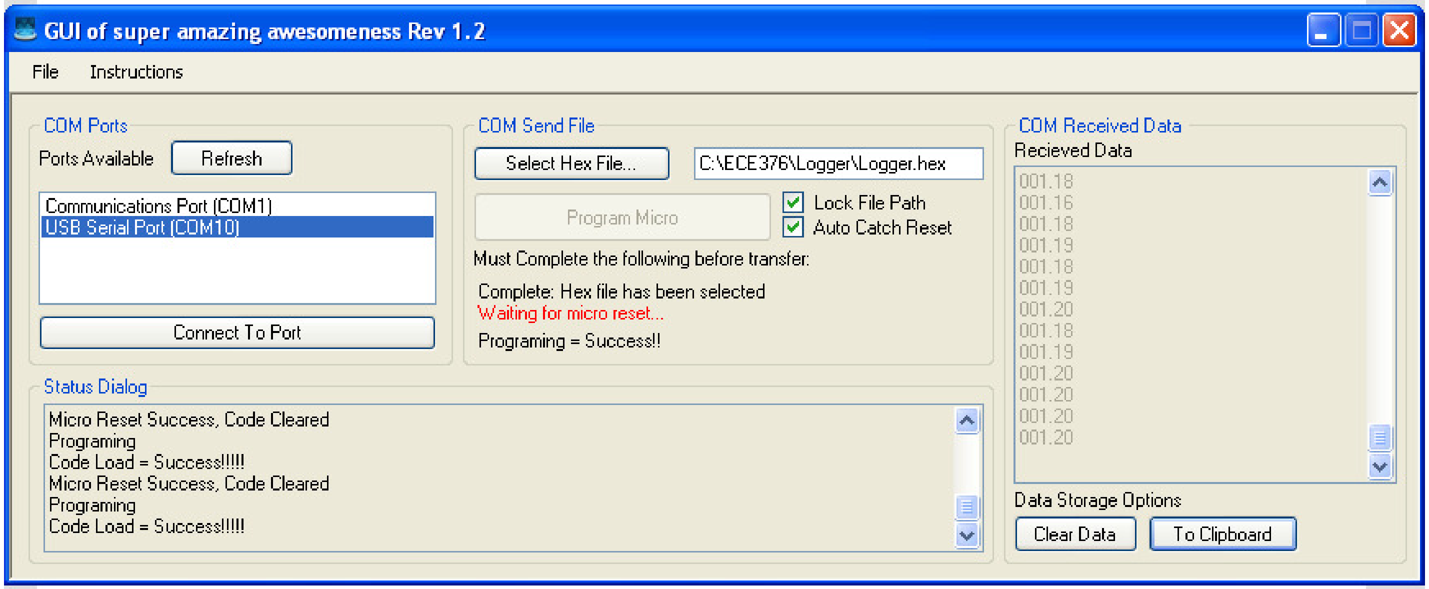
- Data appears on serial port at 9600 baud

```
// Turn on the serial port for 9600 baud
   TRISC = TRISC | 0xC0;
   TXIE = 0;
   RCIE = 0;
   BRGH = 1;
   BRG16 = 1;
   SYNC = 0;
   SPBRG = 255;
   TXSTA = 0x22;
   RCSTA = 0x90;

   while(1) {
      A2D = A2D_Read(0);
      VOLT = 0.488*A2D ;
      SCI_Out(VOLT, 4, 3);
      SCI_CRLF();             // send carriage return line feed
      Wait_ms(100);
      }
   }
```

Recording Serial Data

- Clear clipboard to start
- Copy clipboad to record data
- In Matlab, paste in the data

```
DATA = [
    < paste data here (control V) >
   ]
```



Communications Port (COM1)
USB Serial Port (COM10)

C:\ECE376\Logger\Logger.hex

☑ Lock File Path
☑ Auto Catch Reset

Must Complete the following before transfer:

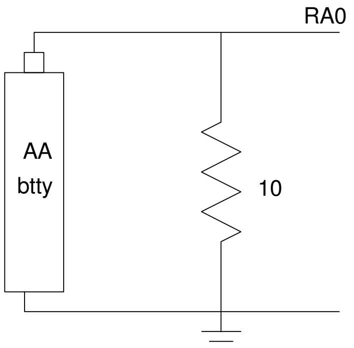
Complete: Hex file has been selected
Waiting for micro reset...
Programing = Success!!

```
001.18
001.16
001.18
001.19
001.18
001.19
001.20
001.18
001.19
001.20
001.20
001.20
001.20
```

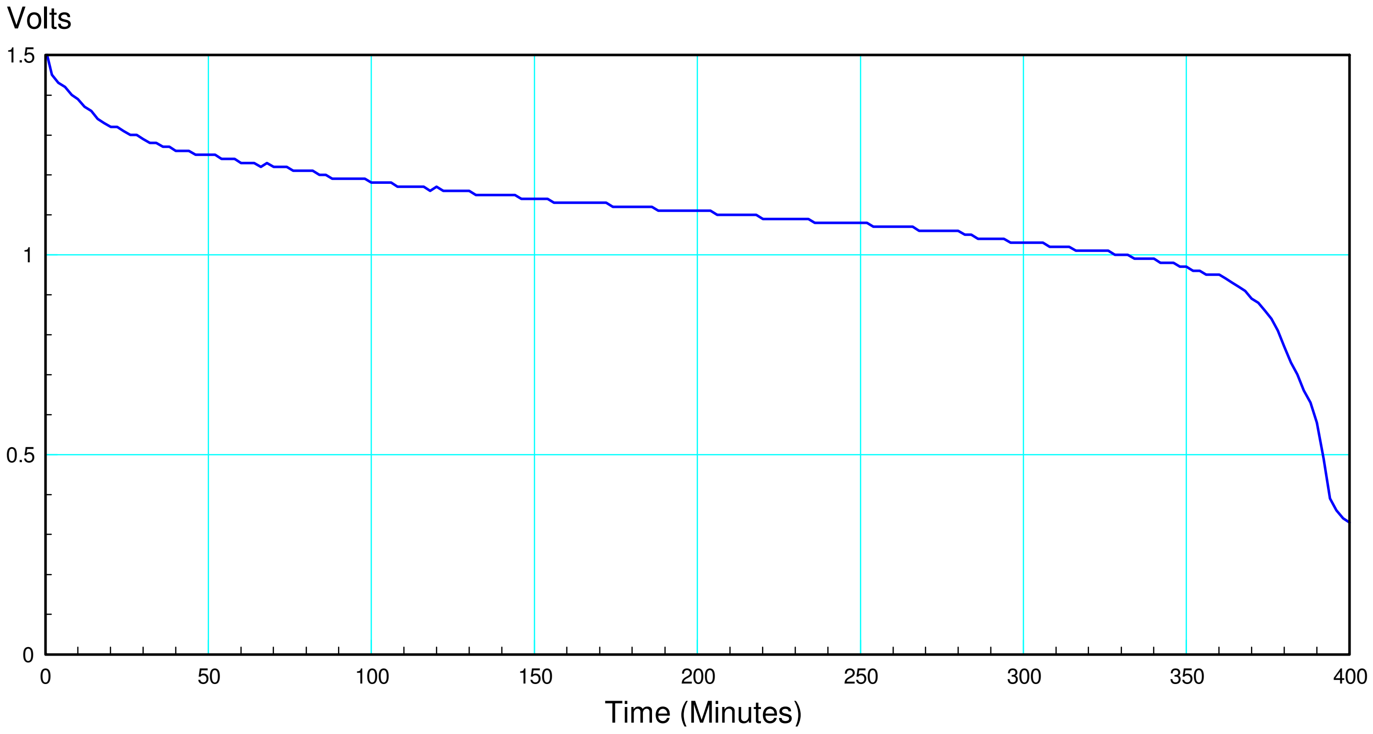
```
Micro Reset Success, Code Cleared
Programing
Code Load = Success!!!!!
Micro Reset Success, Code Cleared
Programing
Code Load = Success!!!!!
```

Example 1: Voltage of a AA Battery

- Watch a AA battery discharge across a 10 Ohm resistor

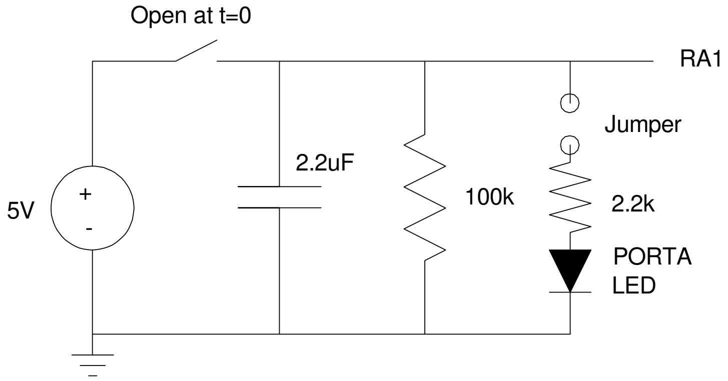


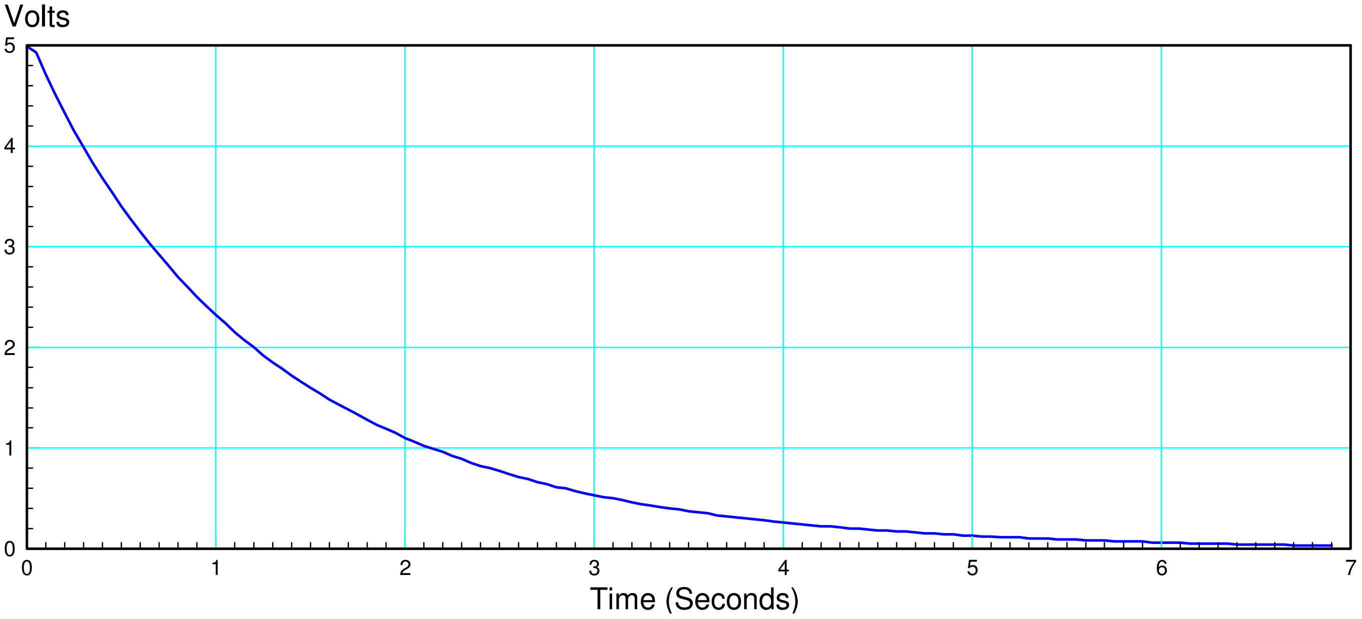
minutes	volts
0	1.520
2	1.450
4	1.430
6	1.420



Voltage Across a Capacitor

- Charge a capacitor up to +5V
- Measure the voltage as it discharges across a 100k resistor

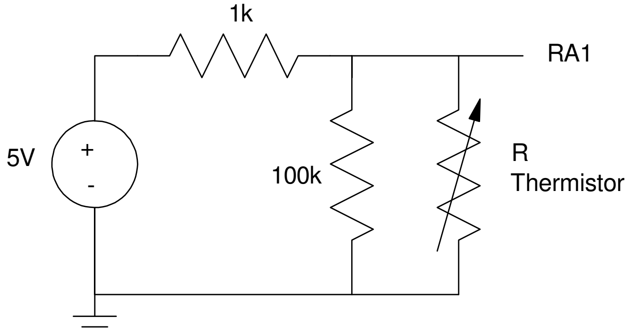


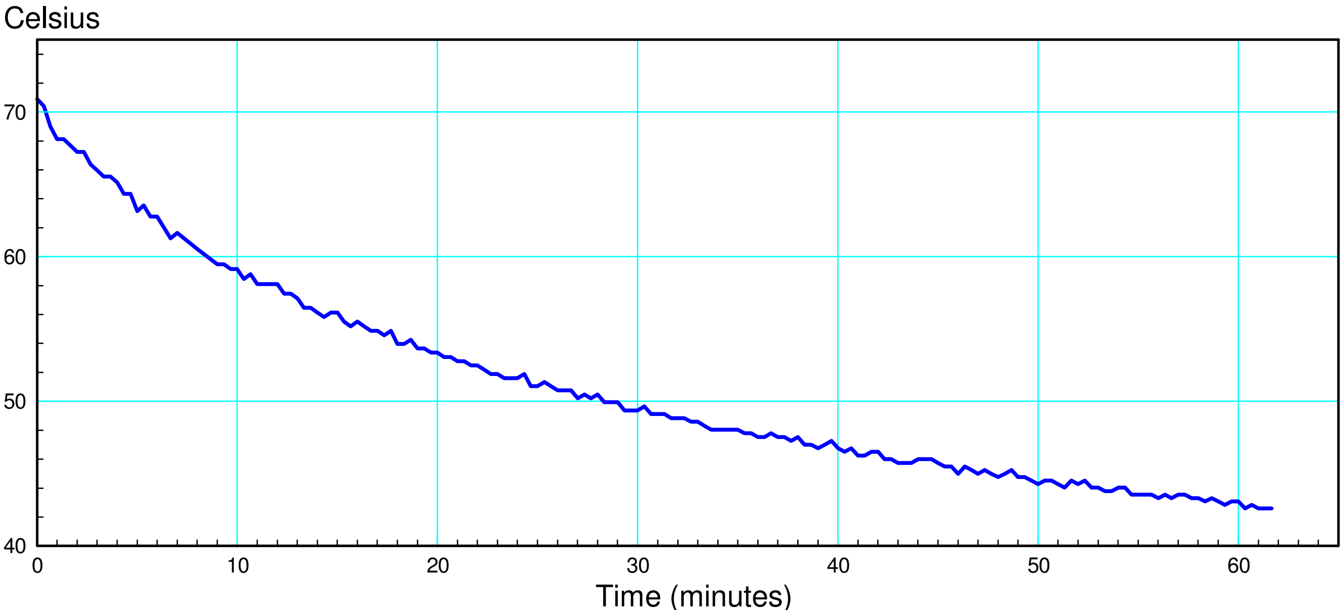


Example 3: Temperature of a Coffee Cup

- Measure voltage
- Calculate resistance
- Calculate temperature

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

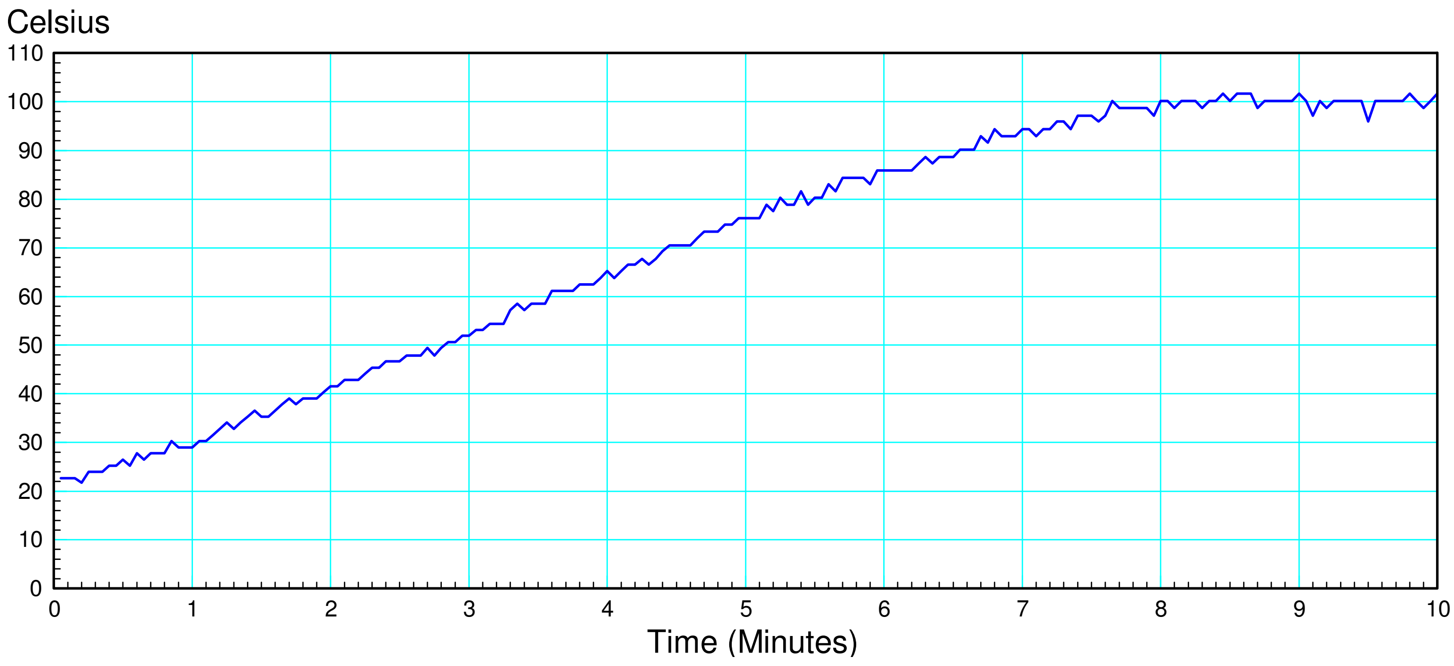




Heating Water on a Stove

Procedure

- Place a quart of cold tap water in a pot of water on the stove, set temperature to high.
- Record the temperature every 6 seconds
  - $P = \left(0.19 \frac{\text{degrees}}{\text{sec}}\right)\left(3957 \frac{\text{Joules}}{\text{degree}}\right) = 751 \text{ Watts}$



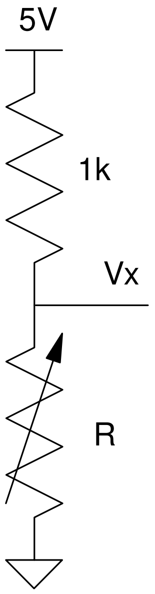
Sensors (Digikey)

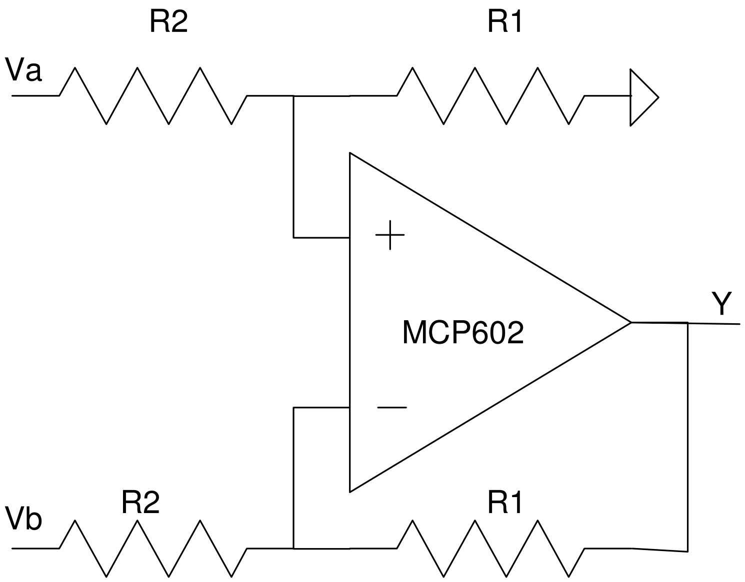
- Replace the thermistor and you can measure flex, flow, magnetic field, moisture...

Sensors, Transducers - 1017 New Products
Accelerometers (1135 items)
Accessories (3898 items)
Amplifiers (313 items)
Capacitive Touch Sensors, Proximity Sensor ICs (606 items)
Color Sensors (135 items)
Current Transducers (1503 items)
Dust Sensors (16 items)
Encoders (4364 items)
Flex Sensors (1 items)
Float, Level Sensors (622 items)
Flow Sensors (191 items)
Force Sensors (104 items)
Gas Sensors (78 items)
Gyroscopes (248 items)
Image Sensors, Camera (555 items)
Inclinometers (55 items)
IrDA Transceiver Modules (295 items)
LVDT Transducers (Linear Variable Differential Transformer) (8 items)
Magnetic Sensors - Compass, Magnetic Field (Modules) (24 items)
Magnetic Sensors - Hall Effect, Digital Switch, Linear, Compass (ICs) (3747 items)
Magnetic Sensors - Position, Proximity, Speed (Modules) (3288 items)
Magnets (145 items)
Moisture Sensors, Humidity (376 items)
Motion Sensors, Detectors (290 items)
Multifunction (147 items)
Optical Sensors - Ambient Light, IR, UV Sensors (736 items)
Optical Sensors - Distance Measuring (41 items)
Optical Sensors - Mouse (118 items)
Optical Sensors - Photo Detectors - CdS Cells (59 items)
Optical Sensors - Photo Detectors - Logic Output (134 items)
Optical Sensors - Photo Detectors - Remote Receiver (1188 items)
Optical Sensors - Reflective - Analog Output (332 items)
Optical Sensors - Reflective - Logic Output (134 items)
Position Sensors - Angle, Linear Position Measuring (1290 items)
Pressure Sensors, Transducers (26790 items)
Proximity Sensors (3762 items)
Proximity/Occupancy Sensors - Finished Units (240 items)
RTD (Resistance Temperature Detector) (87 items)
Shock Sensors (15 items)
Solar Cells (103 items)
Strain Gauges (22 items)
Temperature Regulators (Mechanical) (3947 items)
Temperature Sensors, Transducers (3457 items)
Temperature Switches (917 items)
Thermistors - NTC (5293 items)
Thermistors - PTC (1251 items)
Thermocouple, Temperature Probe (431 items)
Tilt Sensors (55 items)
Ultrasonic Receivers, Transmitters (96 items)
Vibration Sensors (58 items)

Instrumentation Amplifiers:

- A/D reads 0V .. 5V
- Best resolution if you amplify signal so that it's output is (0V, 5V)





Instrumentation Amplifier: $Y = \left(\frac{R_1}{R_2}\right)(V_a - V_b)$

RTD Example (resistive temperature device)

- $R = 1000(1 + 0.004T)\,\Omega$
- 0V at 0C, 5V at +50C

Convert R to Voltage

- Use a voltage divider with a 1k

@0C:

- R = 1000
- $V_x = \left(\frac{R}{R+1000}\right) 5V = 2.5V$

@50C

- R = 1200
- $V_x = \left(\frac{R}{R+1000}\right) 5V = 2.7273V$

Connect to the + input

- Output goes up as Vx goes up

Set the gain

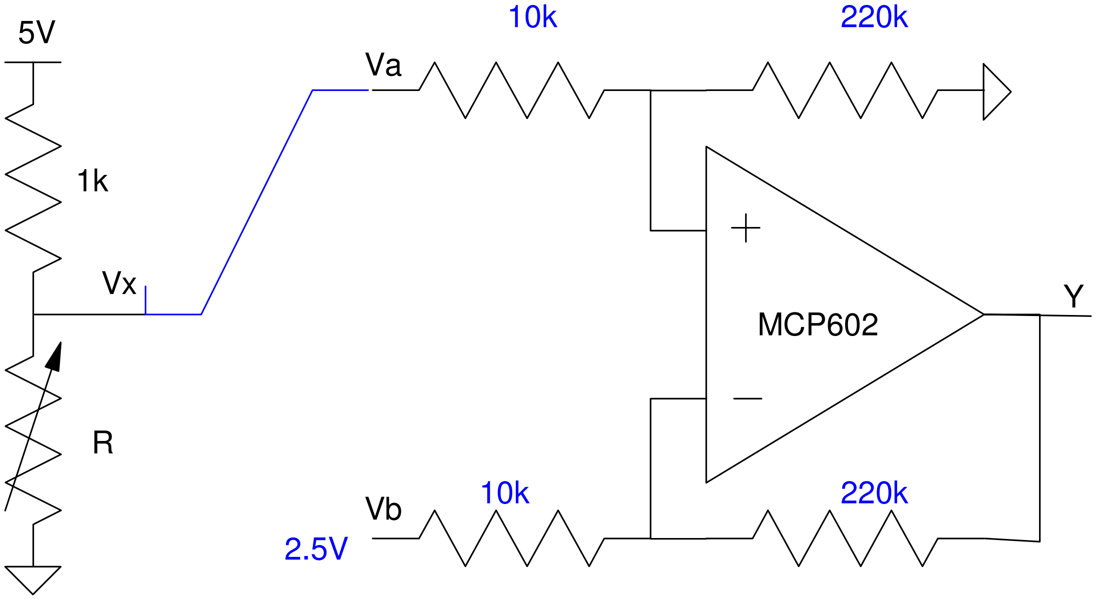
$$Gain = \frac{\text{change in output}}{\text{change in input}}$$

$$Gain = \left(\frac{5V - 0V}{2.7273V - 2.5V}\right) = 22$$

Step 5: Determine the offset.

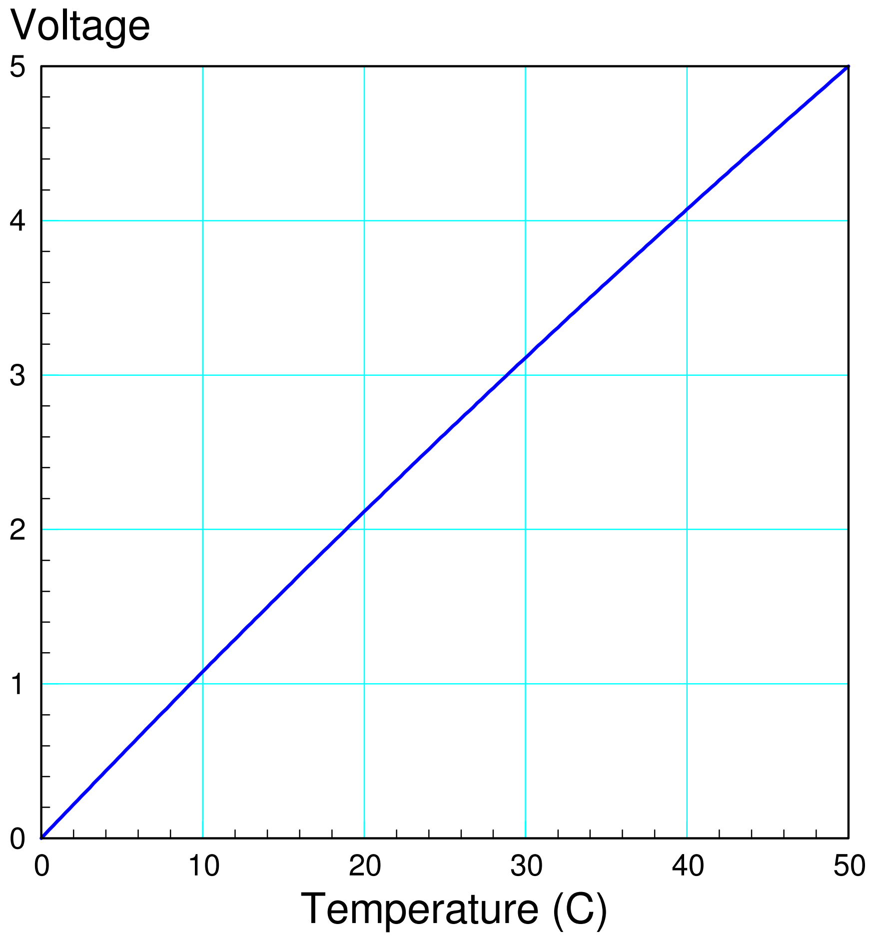
- Y = 0V when Vx = 2.5V

$$V_b = 2.5V$$



V vs. T Graph

```
T = [0:0.25:50]';
R = 1000 * (1 + 0.004*T);

Vx = R ./ (1000+R) * 5;

gain = (5 - 0) / (max(Vx) - min(Vx))

    22.

Vb = min(Vx)

    2.5

Vy = gain*(Vx - 2.5);
plot(T,Vy)
xlabel('Temperature (C)');
ylabel('Voltage (Vy)');
```



Calibration (Least Squares)

Find a function

$$T = f(V)$$

Linear Curve Fit

$$T \approx a \cdot A/D + b$$

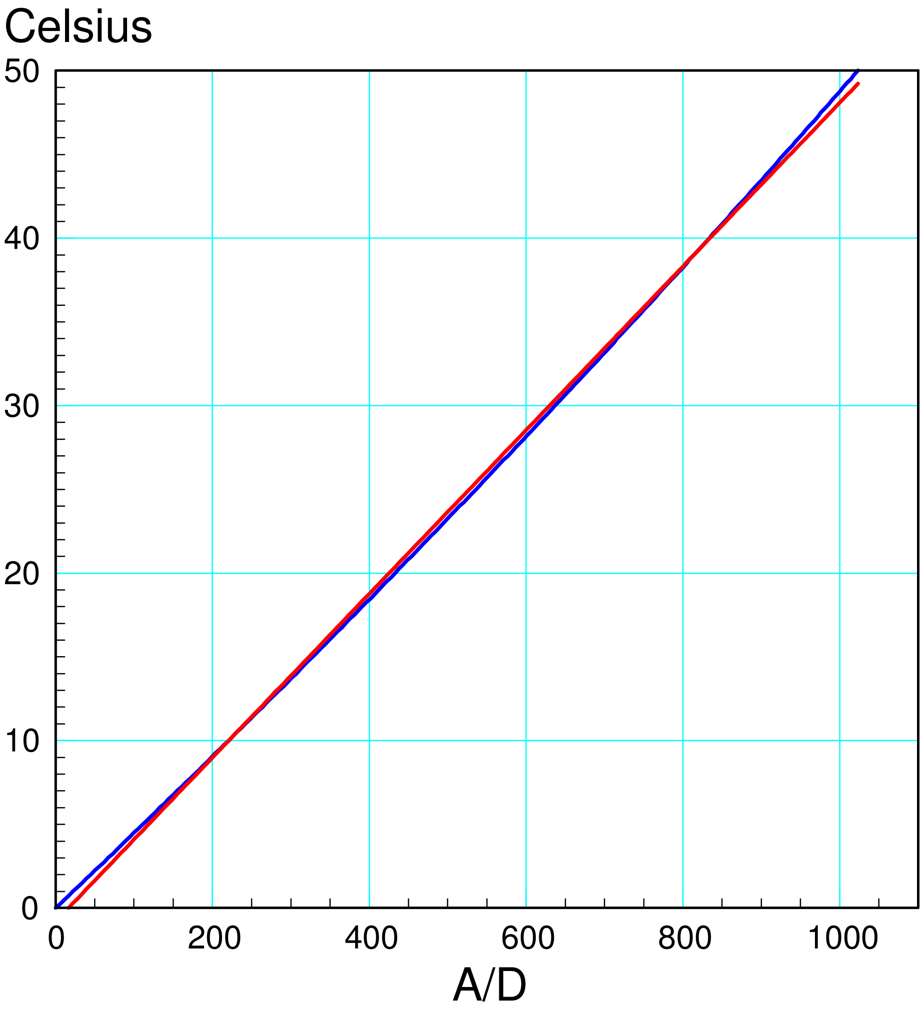
$$Y_{501x1} = B_{501x2} A_{2x1}$$

$$B^T Y = B^T B A$$

$$A = (B^T B)^{-1} B^T Y$$

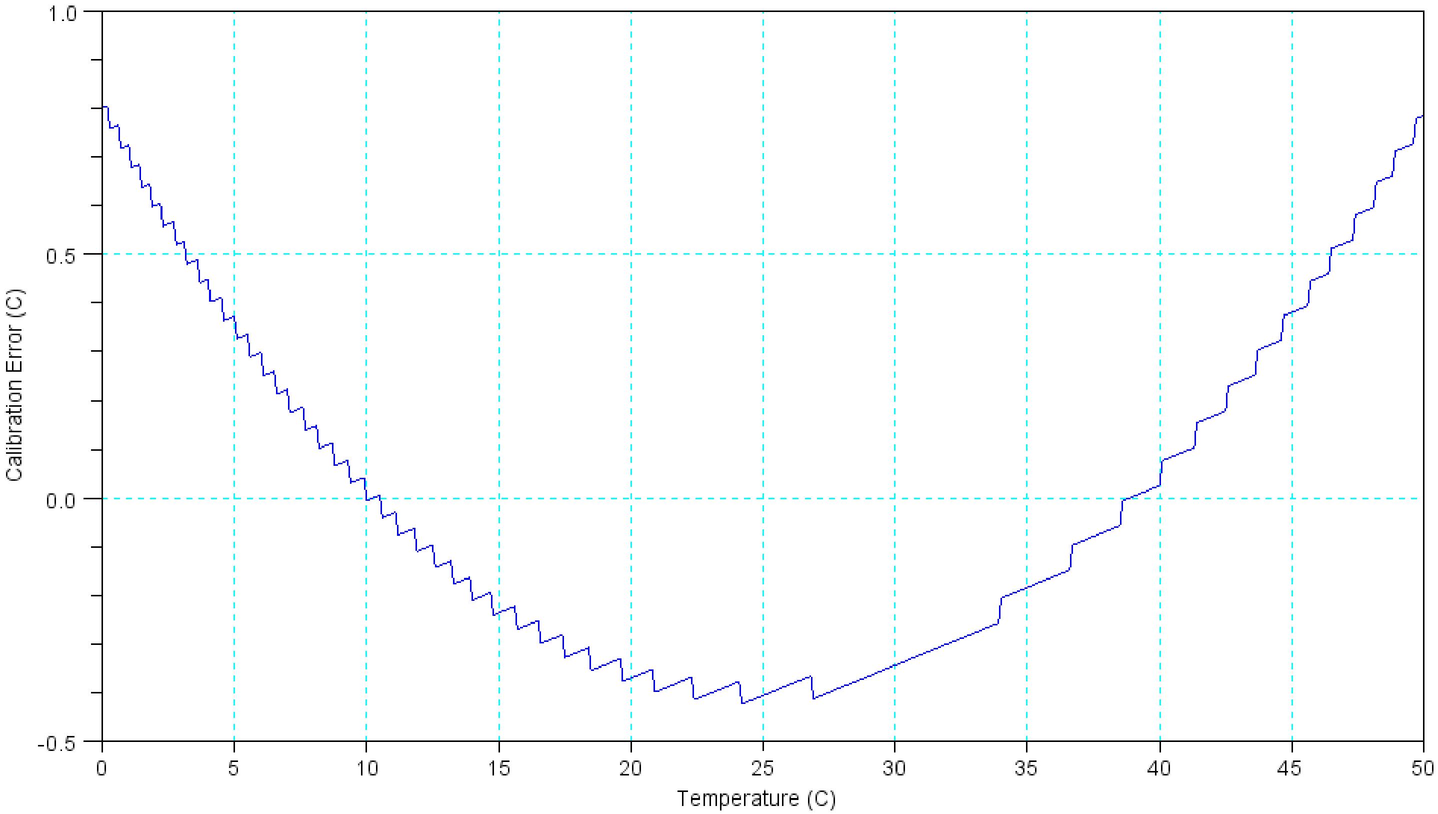
```
A2D = Vy*1023/5;
A2D = round(A2D);
Y = T;
B = [A2D, A2D.^0];
A = inv(B'*B)*B'*Y
    0.0488903
  - 0.8000303
```

$$T \approx 0.0488903 \cdot A/D - 0.80003$$



Residual:

```
plot(T, T-B*A)
xlabel('Temperature (C)');
ylabel('Calibration Error (C)');
```



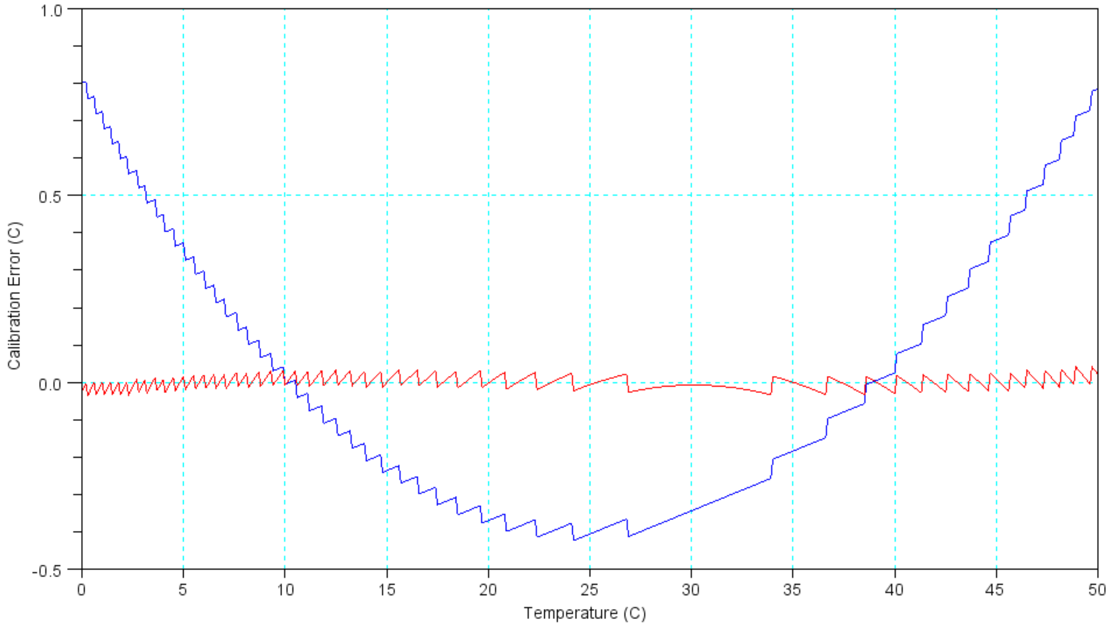
Calibration Error for a Linear Curve Fit for Temperature

Calibration: Polynomial Curve Fit

- Change the basis

$$T \approx a \cdot A/D^2 + b \cdot A/D + c$$

```
B = [A2D.^2, A2D, A2D.^0];

A = inv(B'*B)*B'*Y

a =      0.0000046
b =      0.0441556
c =      0.0258837
```



Residual:

```
max(T - B*A)
 ans  =    0.0424377

min(T - B*A)
 ans  =  -0.0351971
```

Summary

Couple the analog input with the serial port, and you can record data

- The discharge of a capacitor vs. time
- The discharge of a battery over time
- The temperature of a coffee cup over time.

Calibration allows you to convert the raw A/D reading to whatever you're measuring

- Ohms
- Degrees C
- Lux
- etc.