ECE 321 - Homework #3

Audio Sensors, Calibration, and Noise. Due Monday, November 19th, 2018

Audio Sensors

Problem 1) Assume a microphone has a resistance which varies with the audio signal

$$R = 1000 \cdot (1 + 0.01\varepsilon)\ \Omega$$

where ε varies from -1 to +1 (the audio input). Design a circuit which amplifiers this signal to a 4Vpp AC signal.

Solution: The resitance goes from

R = 990 Ohms (Vout = -4V)

R = 1010 Ohms (Vout = +4V)

Use a voltge divider with a 1.3k Ohm resistor and a Whetstone bridge:

R = 990 Ohms

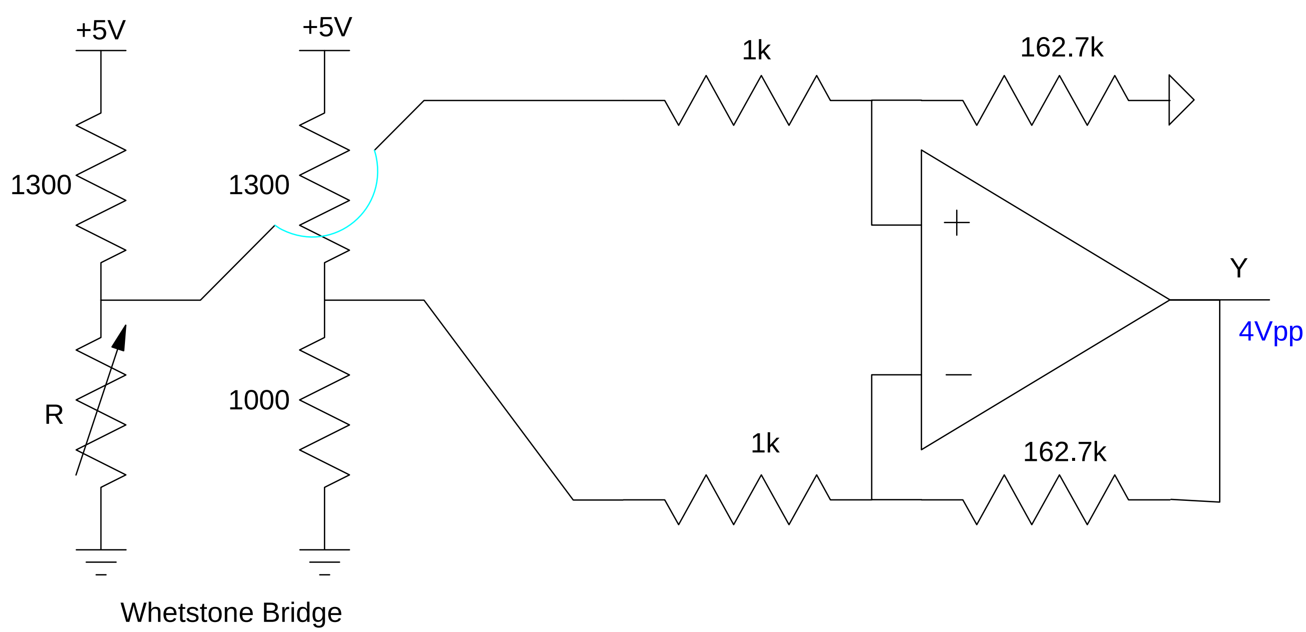
$$V_a = \left(\frac{990}{990+1300}\right)5V = 2.1616V$$

R = 1010 Ohms

$$V_a = \left(\frac{1010}{1010+1300}\right)5V = 2.1861V$$

The gain you need is

$$gain = \left(\frac{4V_{pp}}{2.1861V - 2.1616V}\right) = 162.7$$



Problem 2) Design an envelope detector to convert the output of the circuit from part 1) to a 0V to 2V DC signal. Use an envelope detector. Set the RC time constant so that in 1ms (1kHz) the signal decays 10%

$$\left(e^{-t/RC}\right)_{t=1ms} = 0.9$$

$$\frac{-1ms}{RC} = -0.1054$$

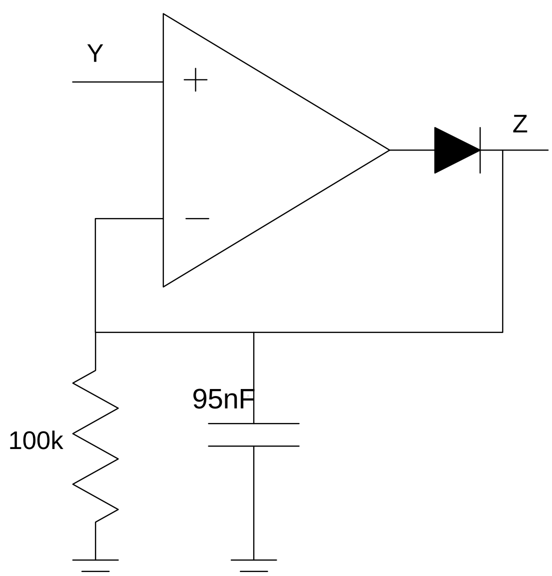
$$\frac{1}{RC} = 105$$

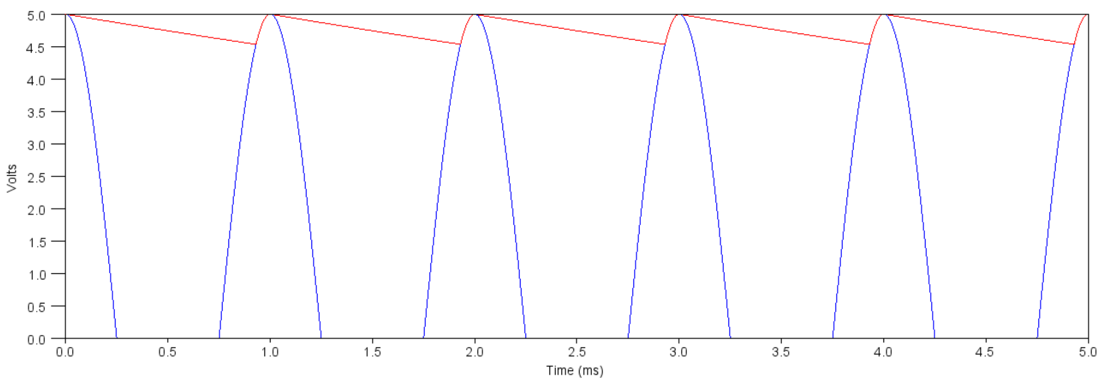
Let R = 100k

$$C = 95nF$$

This results in the signal at Z decaying as

$$z(t) = z_0 \cdot \exp\left(\frac{-t}{RC}\right) = z_0 \cdot e^{-105t}$$





1kHz Sine Wave (blue) and Output of Envelope Detector (red)

Problem 3) Check your design for problem 1 and problem 2 in PartSim. To do this,

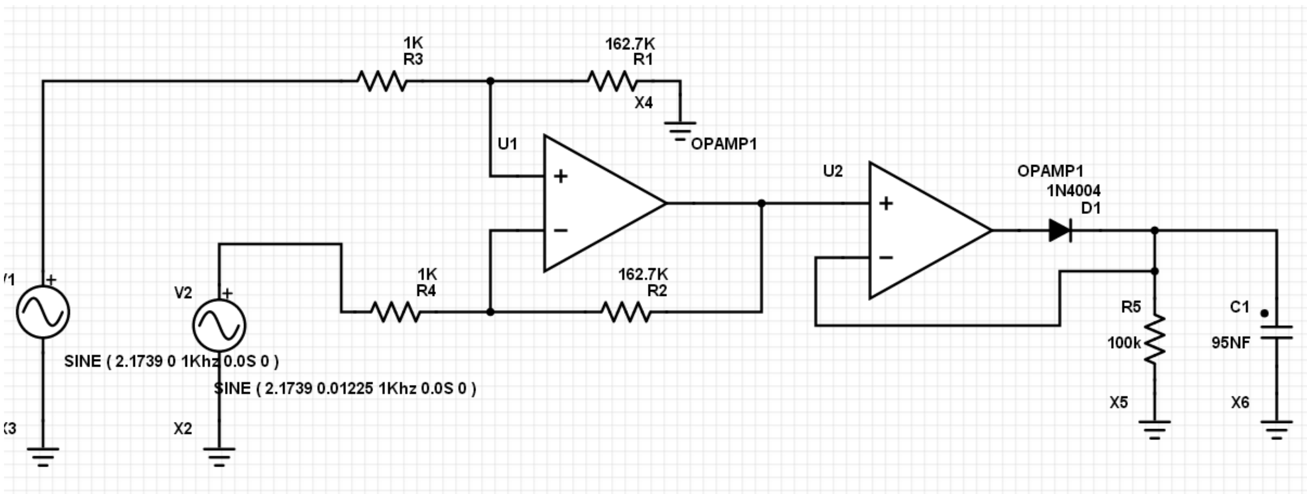
- Use an AC source to model the audio signal (the output of the votlage divider)
- Pick a 'normal' frequency, such as 500Hz

Note: PartSim really hates the rectifier circuit. PartSim assumes Vp = Vm for op-amps. This is only true when the diode is turned on.

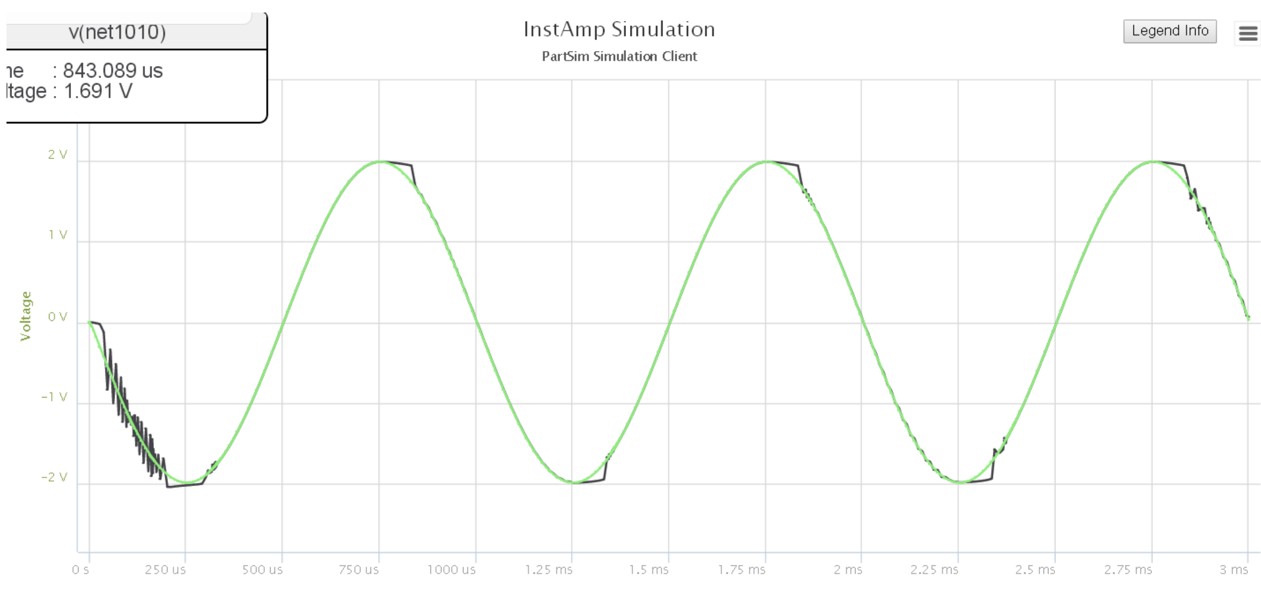
The "correct" circuit with the input voltges including

- A DC offset of 2.1739V
- An AC signal of 0.0123Vp @ 1kHz

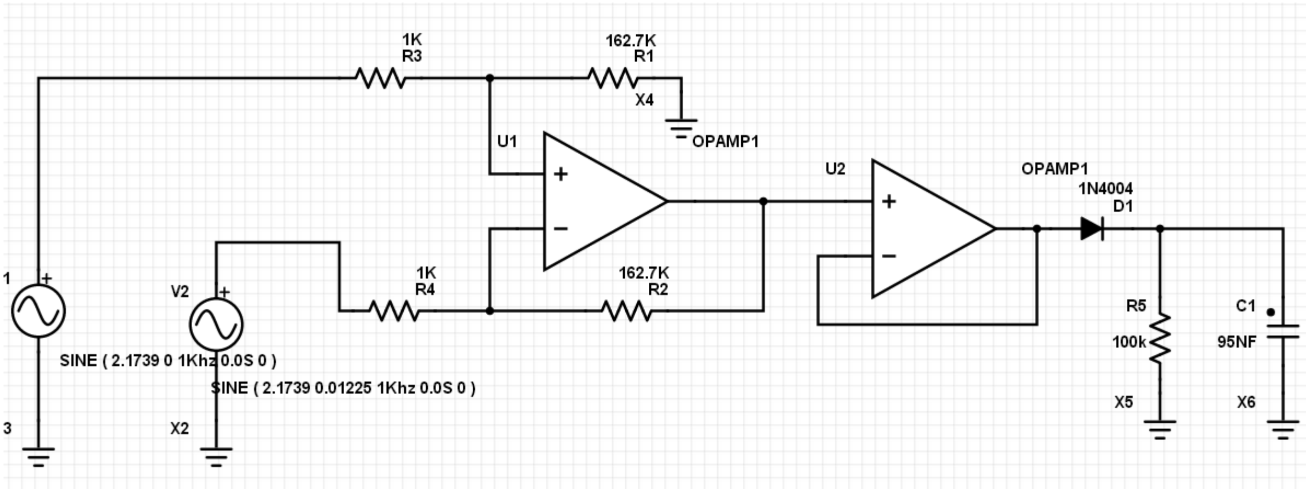
looks like this.



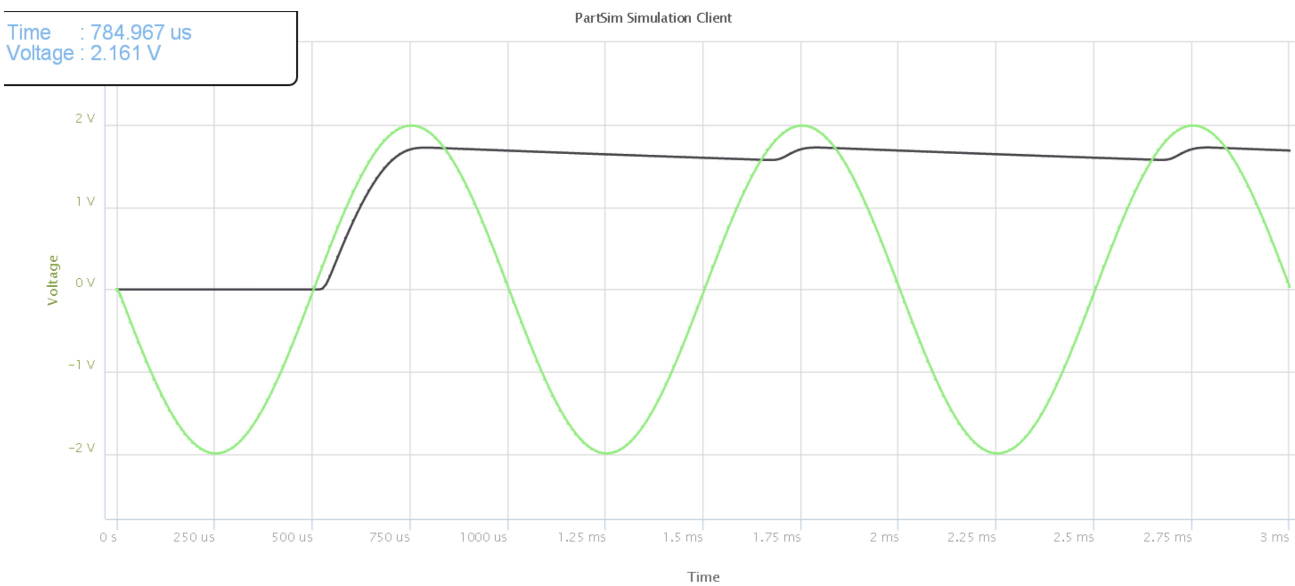
PartSim doesn't simulate this well: it really doesn't like it when Vp ≠ Vm



An almost-correct circuit moves the output of the second op-amp:



This results in a 0.7V drop across diode D1 (bad), but the simulation runs (good)



Voltage at the Input to the last op-amp (green) and its rectified output (black)

Calibration

Determine a calibration function to approximate the relationship between voltage and temperature for the following circuit:

$$R_1 = 1000 \cdot \exp\left(\frac{3905}{T} - \frac{3905}{298}\right)\ \Omega \qquad \text{thermistor}$$

$$R_2 = 700 || R_1 + 500 \qquad \text{linearizing circuit}$$

$$V = \left(\frac{R_2}{R_2+1000}\right) \cdot 10V \qquad \text{voltage divider}$$

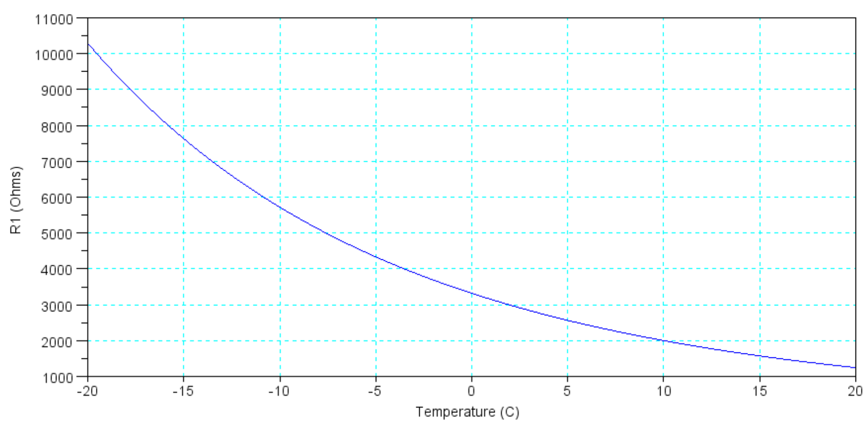
Problem 4) Determine a linear approximation for this relationship over the range of -20C to + 20V

$$T \approx aV + b$$

In Matlab:

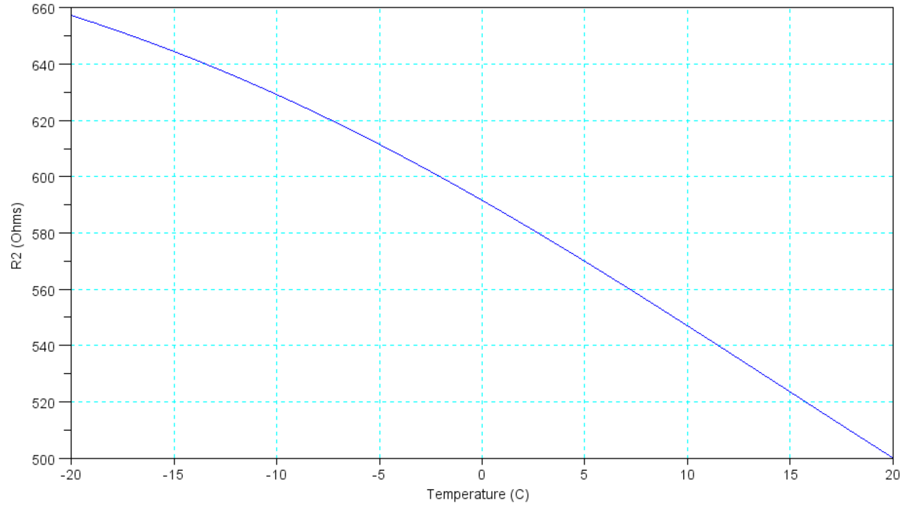
```
T = [-20:0.1:20]';
K = T + 273;
R = 1000 * exp( 3905 ./ K  -  3905/298);
R1 = 1000 * exp( 3905 ./ K  -  3905/298);

plot(T,R1)
xlabel('Temperature (C)');
ylabel('R1 (Ohms)');
```

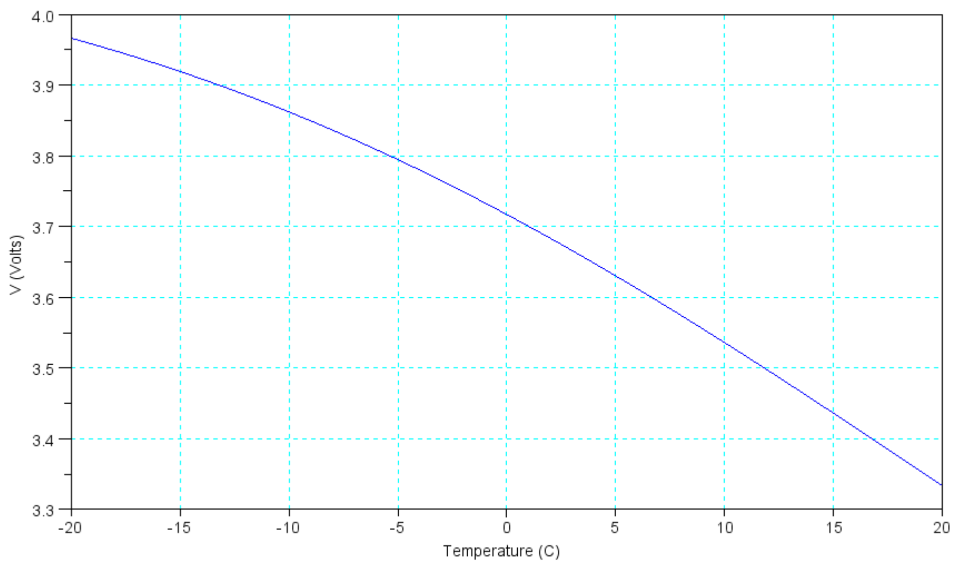


R1 vs. Temperature
Note that the resistance vs. temperature is highly nonlinear

```
R2 = 1 ./ ( 1 ./ (R1 + 500) + 1/700);
plot(T,R2)
xlabel('Temperature (C)');
ylabel('R2 (Ohms)');
```



R2 vs. Temperature
The linearizing circuit helped. It's not optimal - the resistor values could be improved



Voltage vs. Temperature

Now to a linear curve fit:

$$T \approx aV + b$$

In matrix form

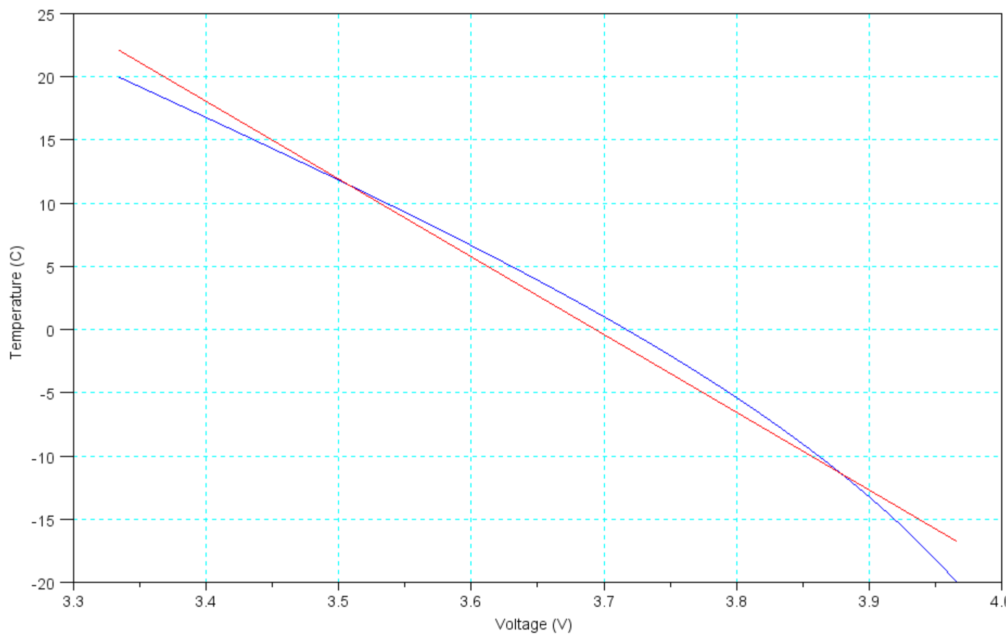
$$Y = \begin{bmatrix} V & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = XA$$

where X is the basis vector:

```
X = [V, V.^0];
A = inv(X'*X)*X'*T

a  -61.474225
b  227.06259


plot(V,T,'b',V,X*A,'r')
xlabel('Voltage (V)');
ylabel('Temperature (C)')
xgrid(4)
```



The accuracy and precision of this calibration scheme is:

```
x = mean(T - X*A)

   x = 0                                the sensor is accurate


s = std(T - X*A)

   s = 1.2679084                       the senor reading is good to about 2.5C (2s)
```

Problem 5) Determine a cubic approximation for this relationship over the range of -20C to + 20V

$T \sim aV3 + bV2 + cV + d$

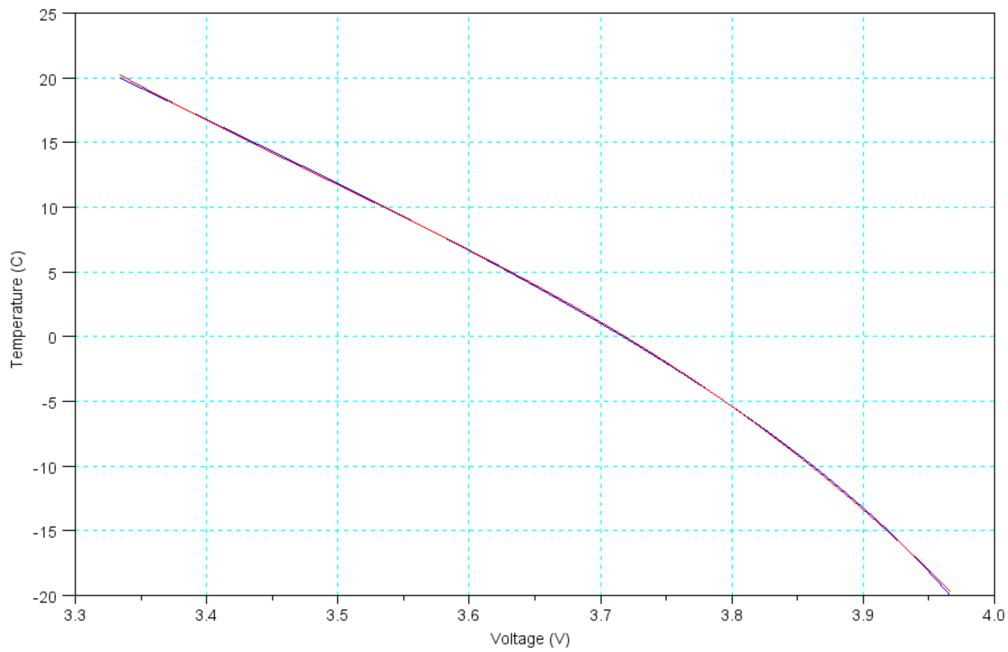
Plot the resulting curve fit and actual teperature vs. voltage.

```
X = [V.^3, V.^2, V, V.^0];

A = inv(X'*X)*X'*T

a  -77.355859
b   809.88096
c  -2875.7458
d   3472.4299

plot(V,T,'b',V,X*A,'r')
xlabel('Voltage (V)');
ylabel('Temperature (C)')
xgrid(4)
```



The accuracy and precision of this calibration scheme are:

```
x = mean(T - X*A)

    x  = - 0.0000002              the sensor is accurate

s = stdev(T - X*A)

    s  =   0.1050780              precision: the sensor is good to about 0.2C
```