ECE 321 - Homework #2

Tmperature and Calibration. Due Monday, November 16th

Please make the subject "ECE 321 HW#2" if submitting homework electronically to Jacob_Glower@yahoo.com (or on blackboard)

Temperature Sensors: Voltage Output

1) A MF52A1103F3380 thermistor from Digikey has a temperature - resistance relationship of

$$R = 10,000 \ \exp\left(\frac{3380}{T+273} - \frac{3380}{298}\right) \ \Omega$$

where T is the temperature in degrees Celsius.

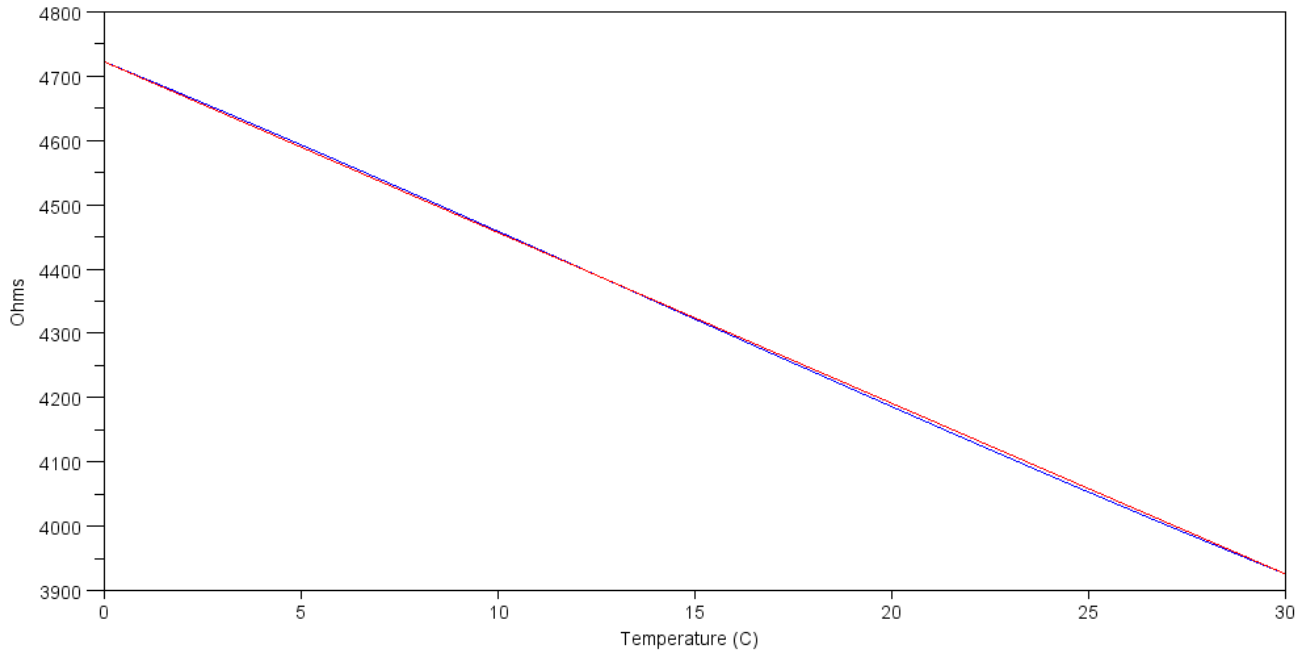
1) Design a linearizing circuit so that the resistance is approximately linear from 0C to +30C. Plot the resulting resitance vs. temperature relationship.

In Matlab, set the cost equal to the square of the error terms minus the resulting spread in Z (in Ohms)

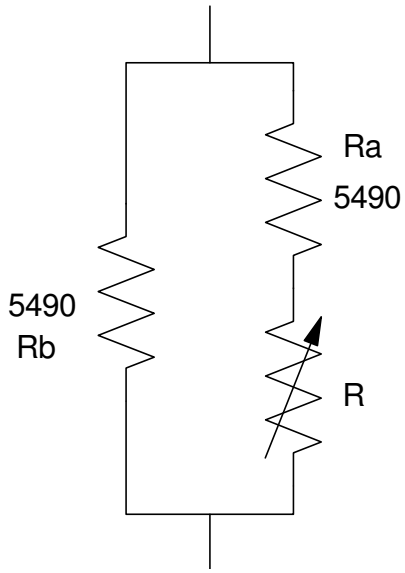
```
function [ J ] = costR( Z )

   a = Z(1);
   b = Z(2);

   R0  = 1e4 * exp(3380/273 - 3380/298);
   R15 = 1e4 * exp(3380/288 - 3380/298);
   R30 = 1e4 * exp(3380/303 - 3380/298);

   Z0  = (R0 + a)*b / (R0 + a + b);
   Z15 = (R15 + a)*b / (R15 + a + b);
   Z30 = (R30 + a)*b / (R30 + a + b);

   e1 = Z0 + Z30 - 2*Z15;
   e2 = a - b;

   J = e1^2 + e2^2 - abs(Z30 - Z0);

   T = [0:0.1:30]';
   R  = 1e4 * exp(3380./(T+273) - 3380/298);

   Z = (R + a)*b ./ (R + a + b);

   plot(T,Z);
   pause(0.01);
   end


>> [Z,e] = fminsearch('costR',[5000,5000])

Z =5490.7    5490.8

e = -781.1555
```

The resulting resistance vs. temperature is then

```
Ra = 5490;
Rb = 5490;
T = [0:0.1:30]';
R = 10000 * exp(3380 ./ (T + 273) - 3380/298);
Z = (R + Ra) * Rb ./ (R + Ra + Rb);
plot(T,Z)
plot(T([1,301]),Z([1,301]),'r')
xlabel('Temperature (C)');
ylabel('Ohms');
```



Resulting resistance vs. temperature with the linearizing circuit



2) Using the linearizing circuit from part 1, design a circuit which outputs

- -10V at 0C
- +10V at +30C
- Proportional in between.

Plot the resulting output voltage vs. temperature.

At 0C: Y =-10V

- Z = 4722.4 Ohms
- X = 2.9223V

At +30C: Y = +10V

- Z = 3926.6 Ohms
- X = 2.5727V

As X goes down, Y goes up

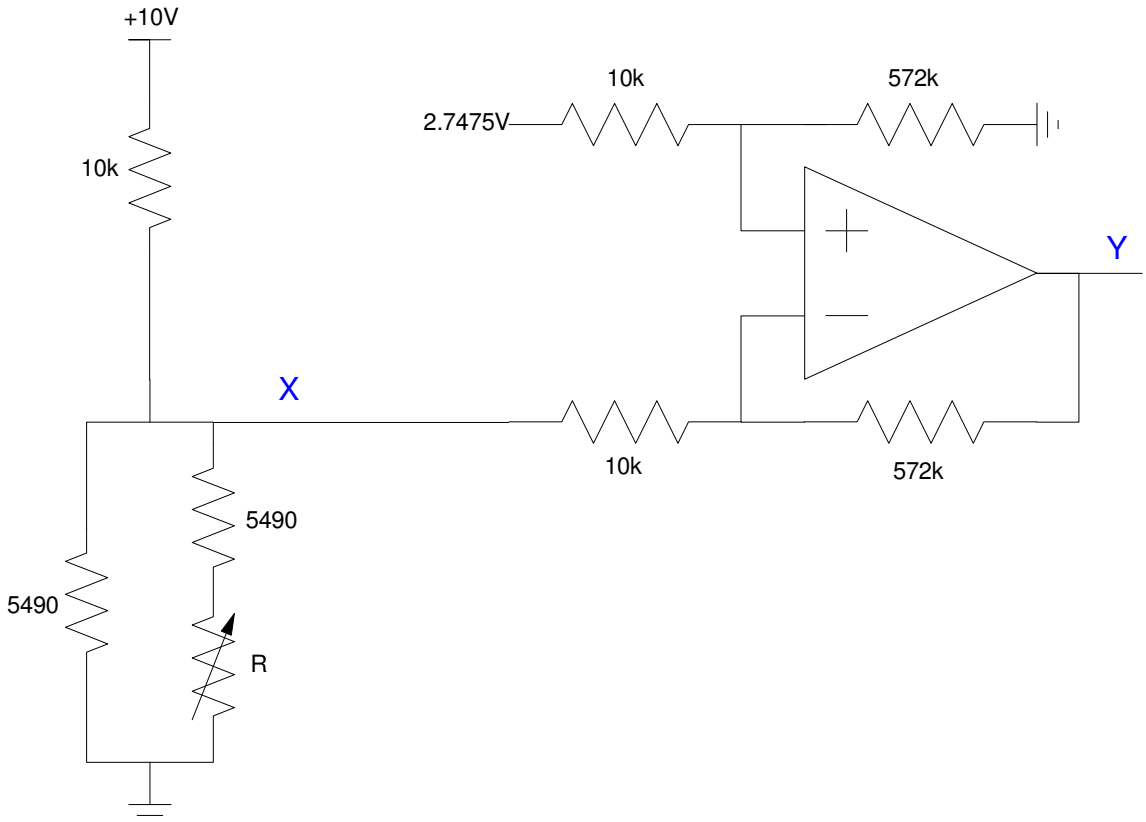
- Connect to the minus input

At midband, the output is 0V

- $offset = \left(\frac{\max(X)+\min(X)}{2}\right) = 2.7475V$

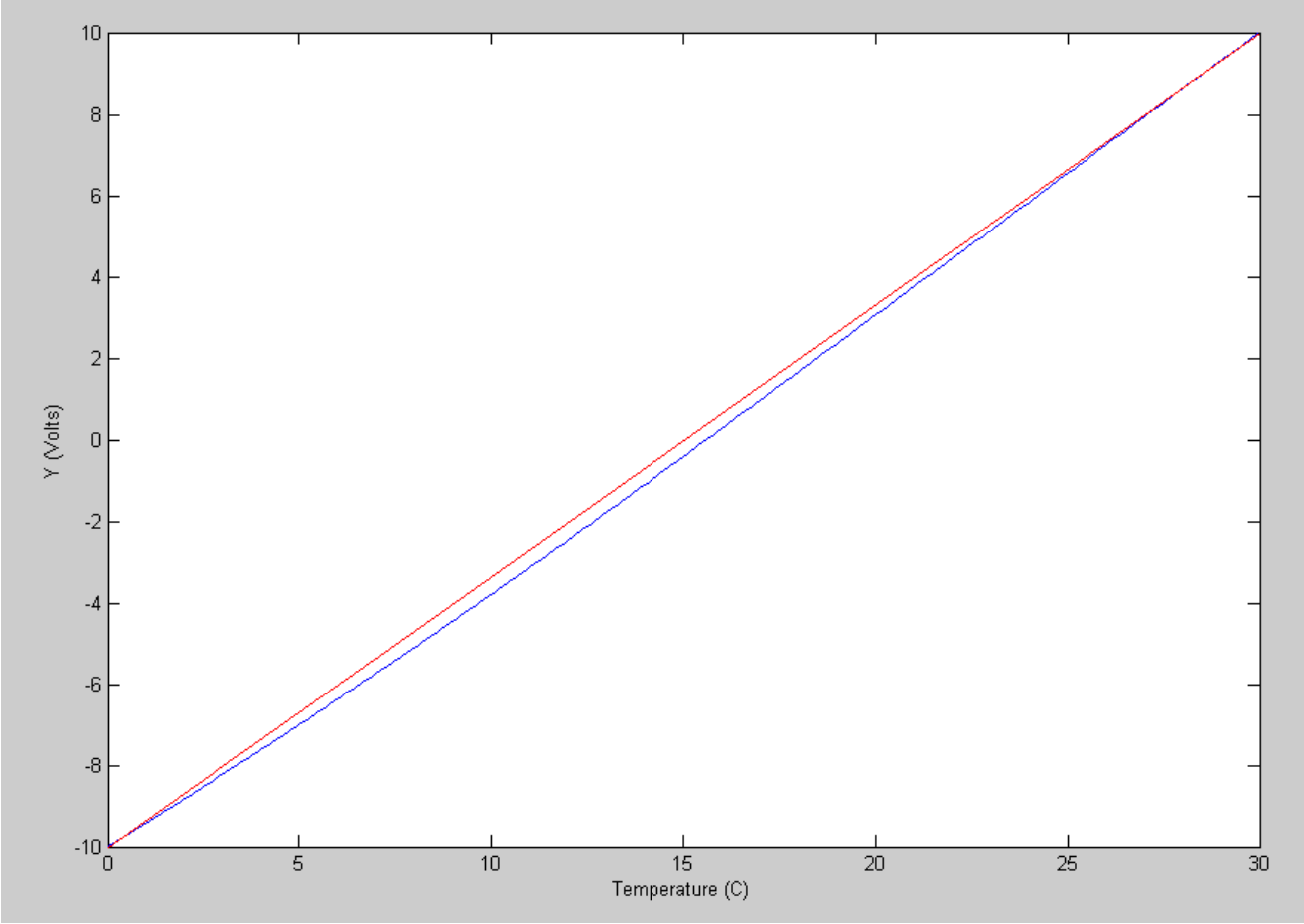
The gain needed is

$$gain = \left(\frac{\text{change in output}}{\text{change in input}}\right) = \left(\frac{10V-(-10V)}{2.9223V-2.5257V}\right) = 57.2$$



The resulting voltage vs. temperature is then

```
a = Z(1);
b = Z(2);
T = [0:0.1:30]';
R  = 1e4 * exp(3380./(T+273) - 3380/298);
Z = (R + a)*b ./ (R + a + b);
X = Z ./ (Z + 10000) * 10;

offset = (max(X) + min(X)) / 2
offset =    2.7475

gain = (10 - (-10)) / (max(X) - min(X))
gain =   57.2000

Y = gain*(offset - X);
plot(T,Y,[0,30],[-10,10],'r');
xlabel('Temperature (C)');
ylabel('Y (Volts)');
```



3) Determine a caliration funciton of the form

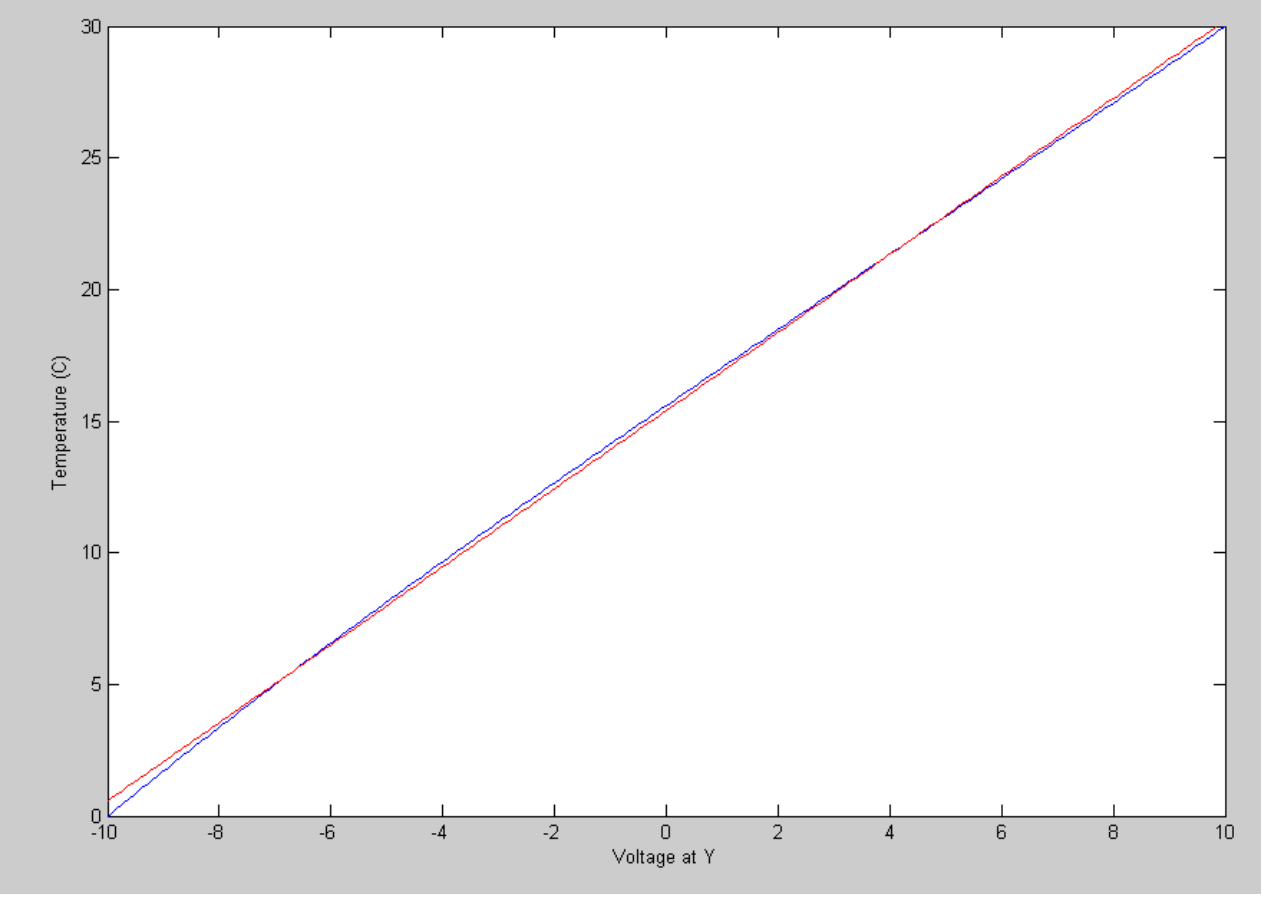
$$T = aV + b$$

to determine the temperature based upon the output voltage from your circuit in problem #2

- What is the maximum calibration error?

```
>> B = [Y, Y.^0];
>> A = inv(B'*B)*B'*T

A =

    1.4823
   15.4010

>> plot(Y,T,'b',Y,B*A,'r');
>> xlabel('Voltage at Y');
>> ylabel('Temperature (C)')

>> max(abs(T - B*A))

ans =    0.5779
```

The maximum error is 0.5779C



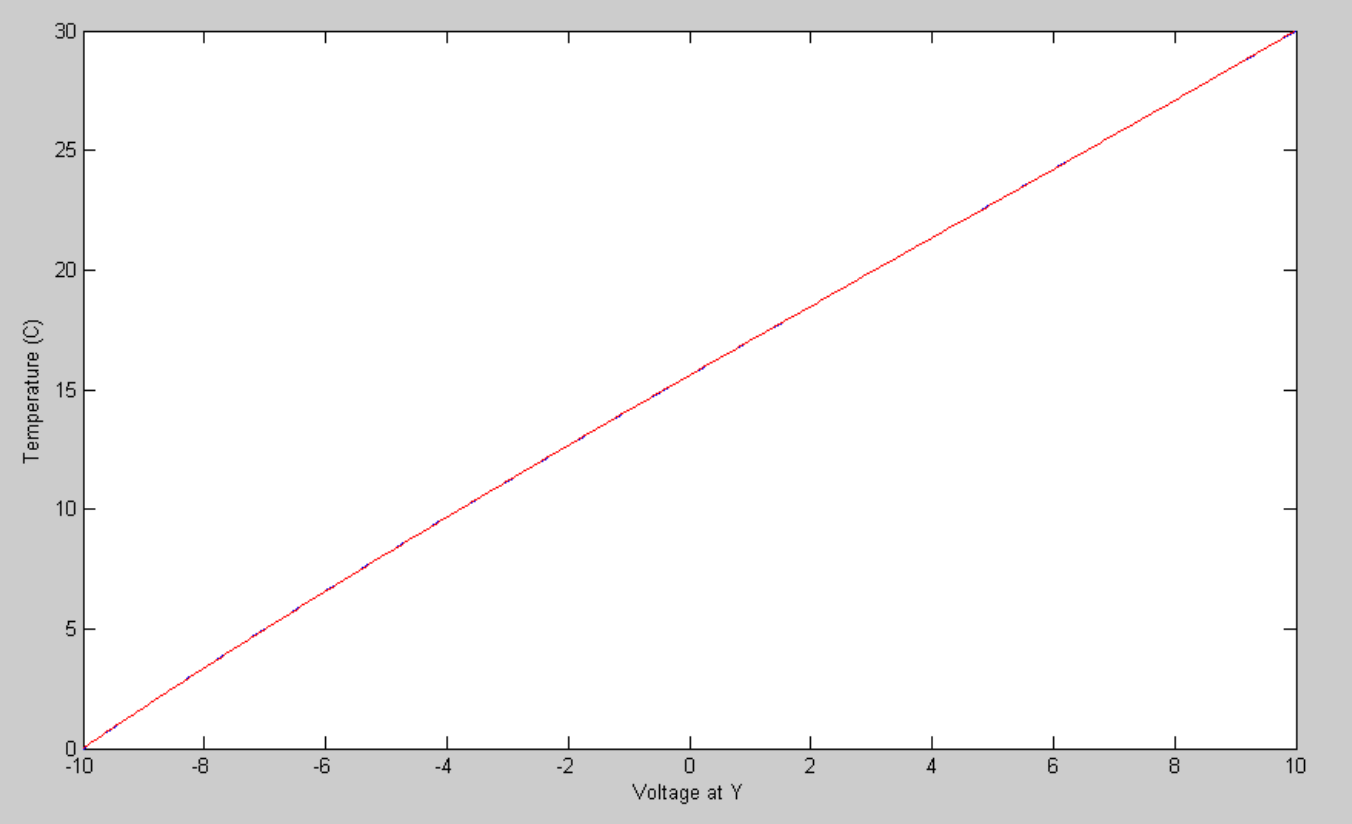
4) Determine a calibration function of the form

$$T = aV^3 + bV^2 + cV + d$$

to determine the temperature based upon the output voltage from your circuit in problem #2

- What is the maximum calibration error?

```
>> B = [Y.^3, Y.^2. Y, Y.^0];
>> A = inv(B'*B)*B'*T

A =

    0.0005
   -0.0058
    1.4519
   15.6017

>> plot(Y,T,'b',Y,B*A,'r');
>> ylabel('Temperature (C)')
>> xlabel('Voltage at Y');
>> max(abs(T - B*A))

ans =

    0.0215
```



Temperature Sensors: Frequency Output

5) Determine the frequency of the following 555 timer with R being the linearizing circuit from problem #2.

Note: For this 555 timer circuit

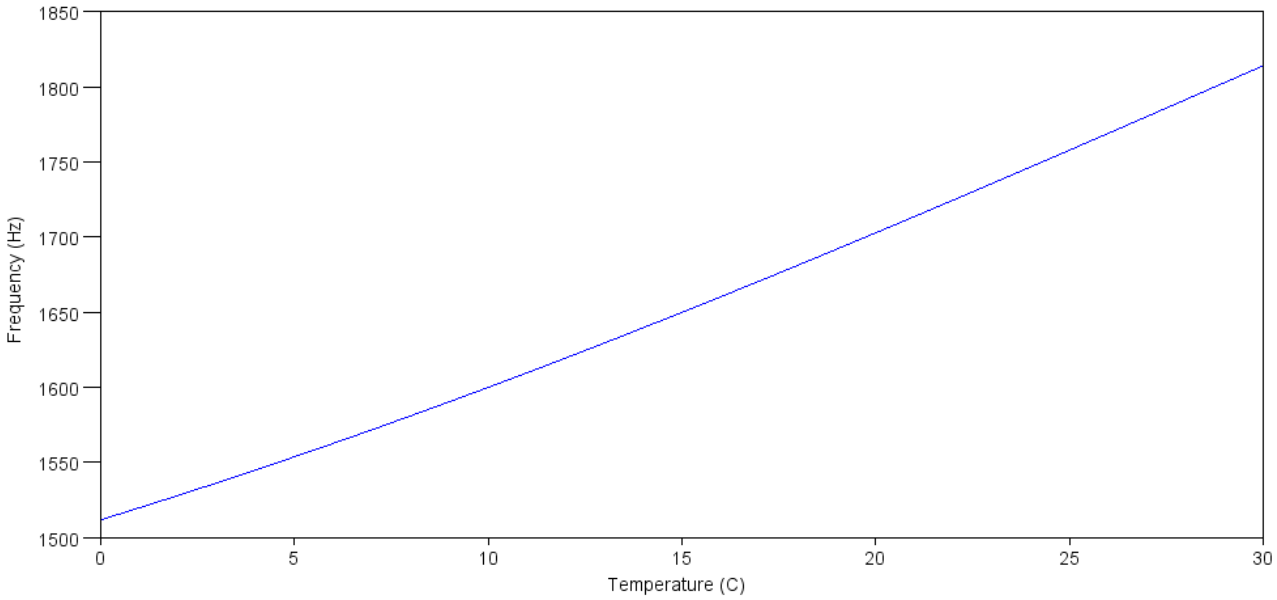
$$t_{on} = (100 + Z) \cdot C \cdot \ln(2) \qquad \textit{C charges through R1 and R2}$$

$$t_{off} = Z \cdot C \cdot \ln(2) \qquad \textit{C discharges through R2}$$

$$f = \frac{1}{T} \text{ Hz}$$

where Z is the impedance of the linearizing circuit from problem #2.

```
C = 0.1e-6;
Ton = (100 + Z)*C*log(2);
Toff = Z*C*log(2);
Hz = 1 ./ (Ton + Toff);

plot(T,Hz)
xlabel('Temperature (C)');
ylabel('Frequency (Hz)')
```



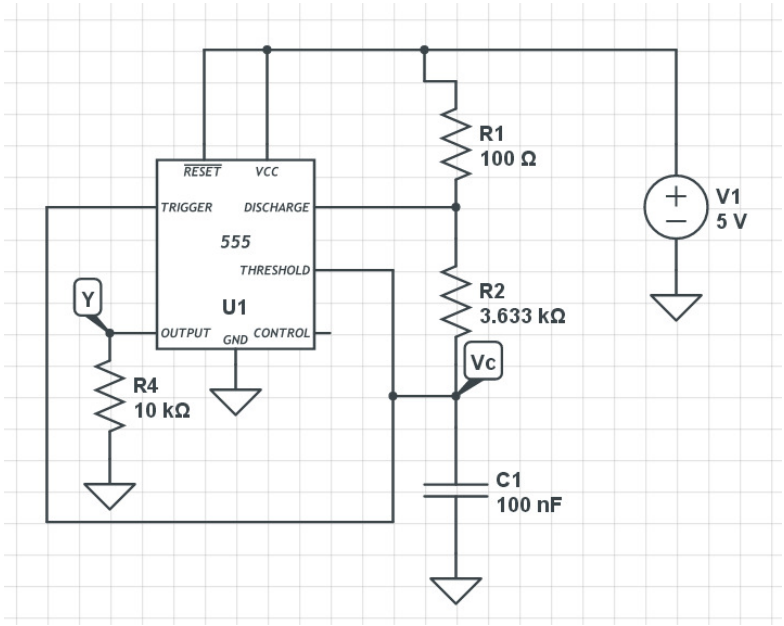
Temperature - Frequency relationship for a 555 timer with a thermistor

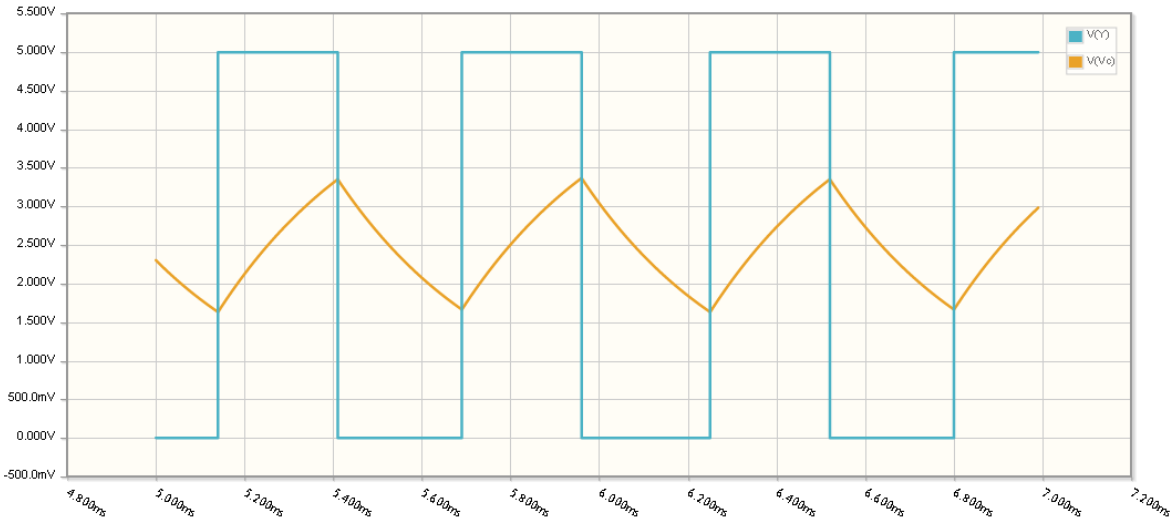
6) In CircuitLab, simulate the 555 timer at T = 15C.

- Does the simulated frequency match your computed frequency?

At 15C,

- R = 5247 Ohms
- Z = 3633 Ohms
- Perion (ton + toff) = 510.5us
- f = 1959Hz





Period = 555us (1800Hz) vs. 1950Hz computed

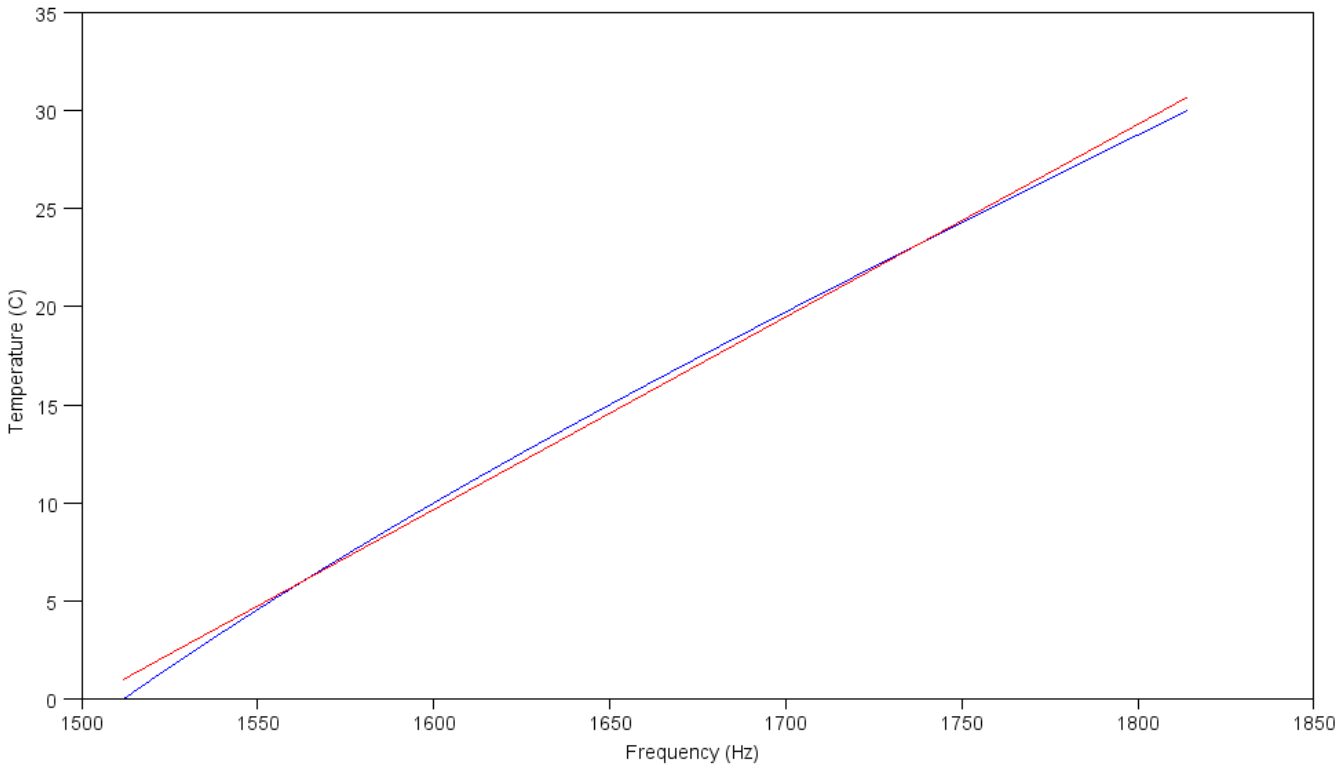
7) Determine a calibration function of the form

$$^{0}C = a \cdot Hz + b$$

where Hz is the frequency of the oscillator over the temperature range of 0C to 30C

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

     0.0980799
  -147.25696

plot(Hz,T,'b',Hz,B*A,'r')
xlabel('Frequency (Hz)');
ylabel('Temperature (C)');
max(abs(T - B*A))

    1.0092957
```

The maximum calibration error is 1.009 degrees C over the range of 0C to +30C



Temperature - Frequency relationship (blue) and linear curve fit (red)