ECE 321 - Homework #2

Temperature and Calibration. Due Monday, November 15th

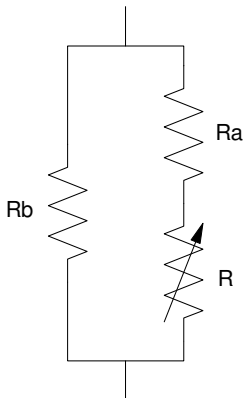
Please make the subject "ECE 321 HW#2" if submitting homework electronically to Jacob_Glower@yahoo.com (or on blackboard)

Temperature Sensors: Voltage Output

1) A B57891M0103J000 (Digikey 495-2157-ND) thermistor has a temperature - resistance relationship of

$$R = 10,000 \ \exp\left(\frac{3950}{T+273} - \frac{3950}{298}\right) \ \Omega$$

where T is the temperature in degrees Celsius.



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

$$Z = R_b \ || \ (R_a + R)$$

This took some trial and error to get an answer other than

- Ra = infinity
- Rb = 0

Eventually, this worked:

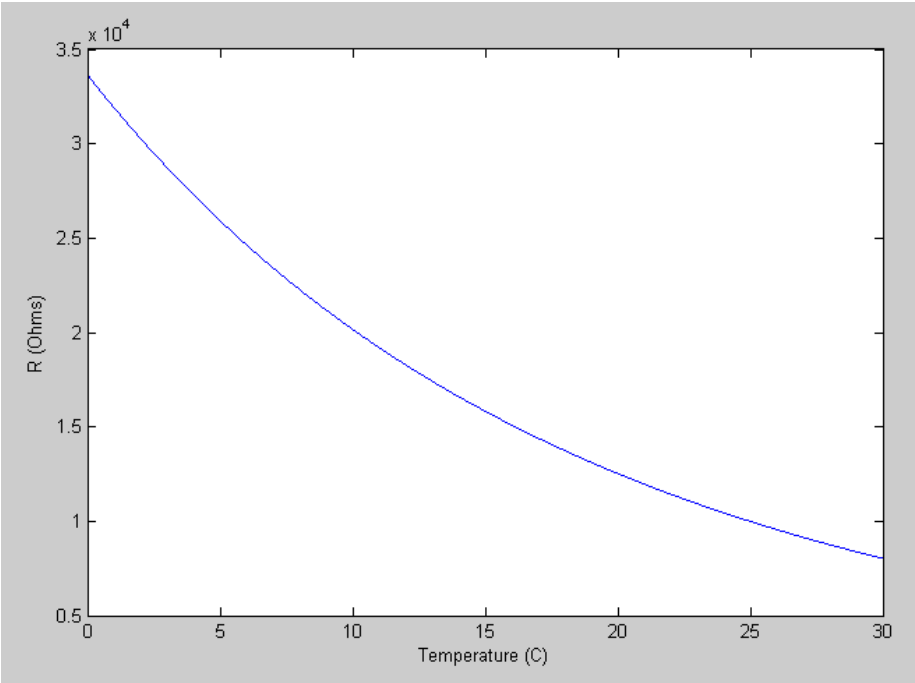
```
function [ J ] = Thermistor( Z )
 Ra = Z(1);
 Rb = 10000;
 R0  = 10000*exp(3950/273 - 3950/298);
 R15 = 10000*exp(3950/288 - 3950/298);
 R30 = 10000*exp(3950/303 - 3950/298);
% Z = R1 R2 / (R1 + R2)
 Z0  = (R0 + Rb)*(Ra) / (R0 + Ra + Rb);
 Z15 = (R15 + Rb)*(Ra) / (R15 + Ra + Rb);
 Z30 = (R30 + Rb)*(Ra) / (R30 + Ra + Rb);
 E = Z15 - (Z0 + Z30)/2;
 J = E*E;
 end
```

resulting in

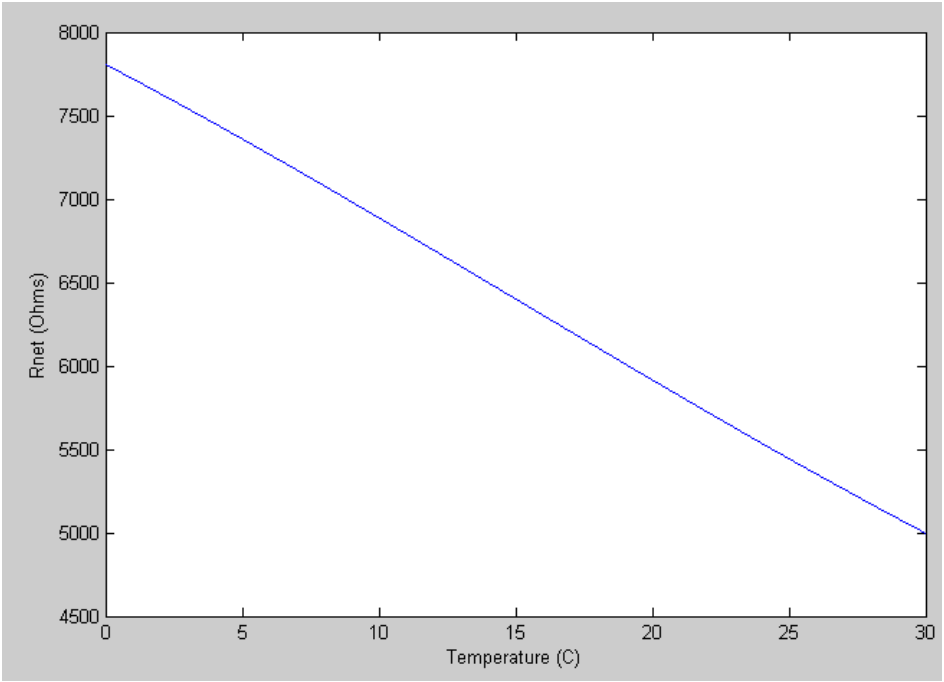
```
>> [Ra,e] = fminsearch('Thermistor',[3000])

Ra =  1.9588e+003

e =  5.0397e-016
```

(Rb = 10k)

```
>> Rb = 10000;
>> R = 10000 * exp( 3950 ./ (T+273) - 3950/298 );
>> plot(T,R)
>> xlabel('Temperature (C)');
>> ylabel('R (Ohms)');
```




```
>> Rnet = 1 ./ ( 1/Rb + 1./(Ra + R));
>> plot(T,Rnet)
>> xlabel('Temperature (C)');
>> ylabel('Rnet (Ohms)');
```



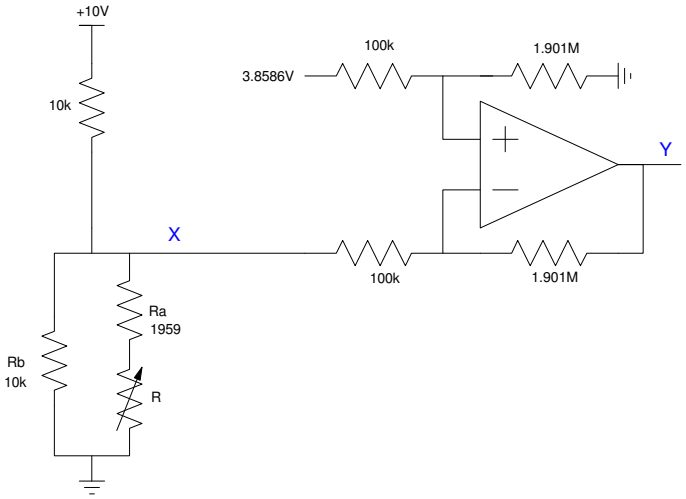
2) Using the linearizing circuit from part 1, design a circuit which outputs

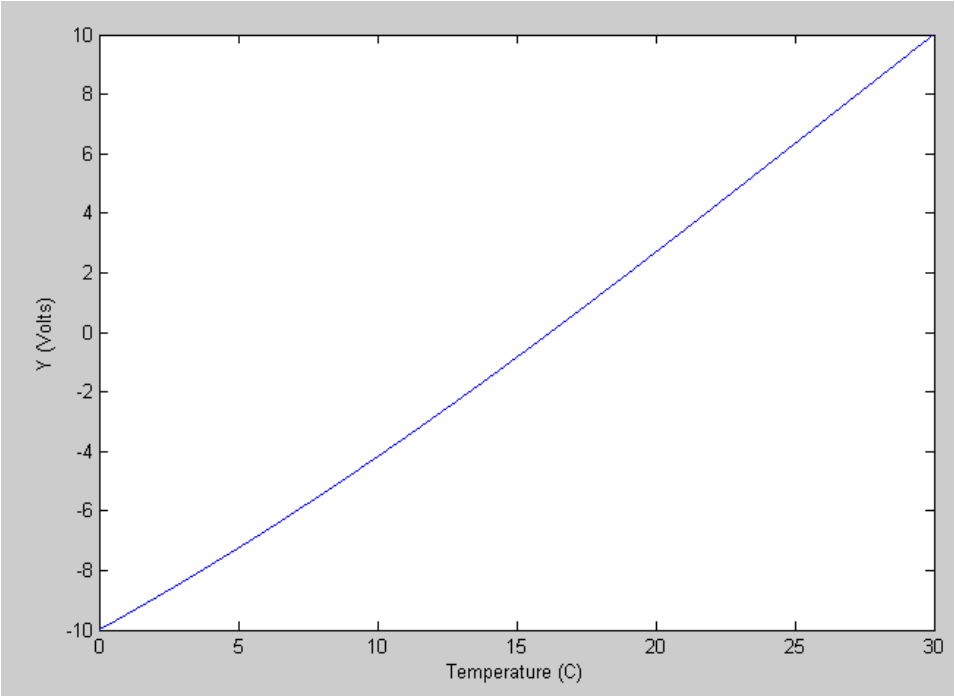
- -10V at 0C
- +10V at +30C
- Proportional in between.

Plot the resulting output voltage vs. temperature.

Assume a voltage divider with a 10k resistor

```
>> X0 = Rnet0 / (Rnet0 + 10e3) * 10

X0 =    4.3846

>> X30 = Rnet30 / (Rnet30 + 10e3) * 10

X30 =    3.3327

>> gain = 20 / (X0 - X30)

gain =   19.0134

>> offset = (X0 + X30)/2

offset =    3.8586

>> X = Rnet ./ (Rnet + 10000) * 10;
>> Y = gain*(offset - X);
>> plot(T,Y)
>> xlabel('Temperature (C)');
>> ylabel('Y (Volts)');
```





3) Determine a caliration funciton of the form

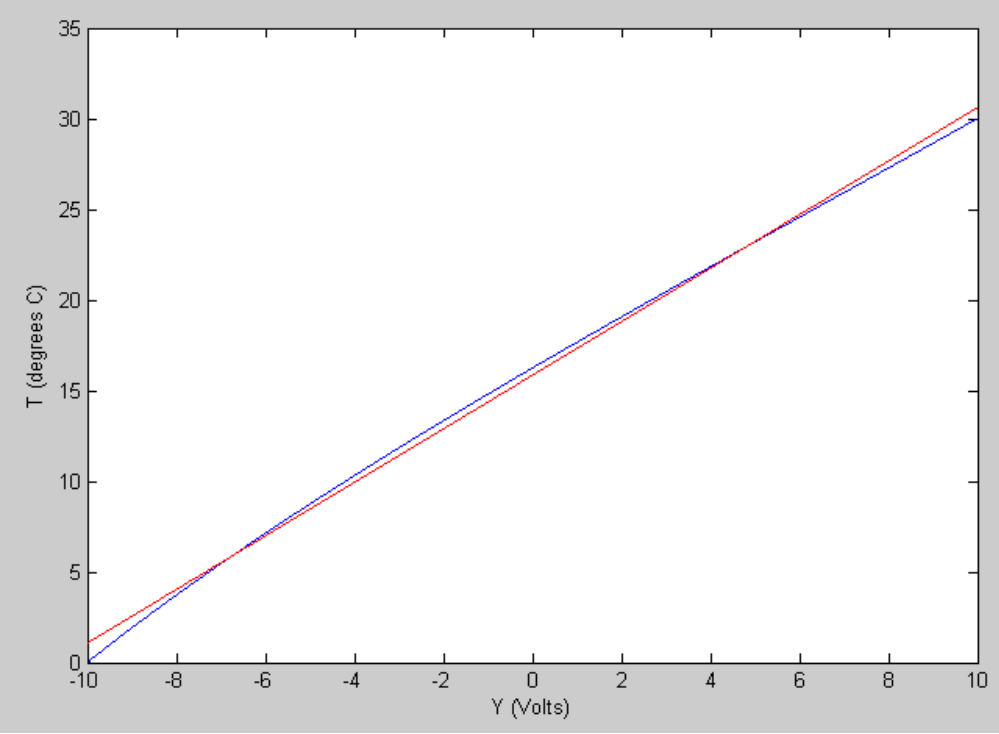
$$T = aV + b$$

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    1.4769
b   15.8343

>> plot(Y,T,'b',Y,B*A,'r');
>> xlim([-10,10])
>> xlabel('Y (Volts)');
>> ylabel('T (degrees C)');
>> max(abs(T - B*A))

ans =    1.0651
```

This calibration scheme is off by 1.0651 degrees (worst case)



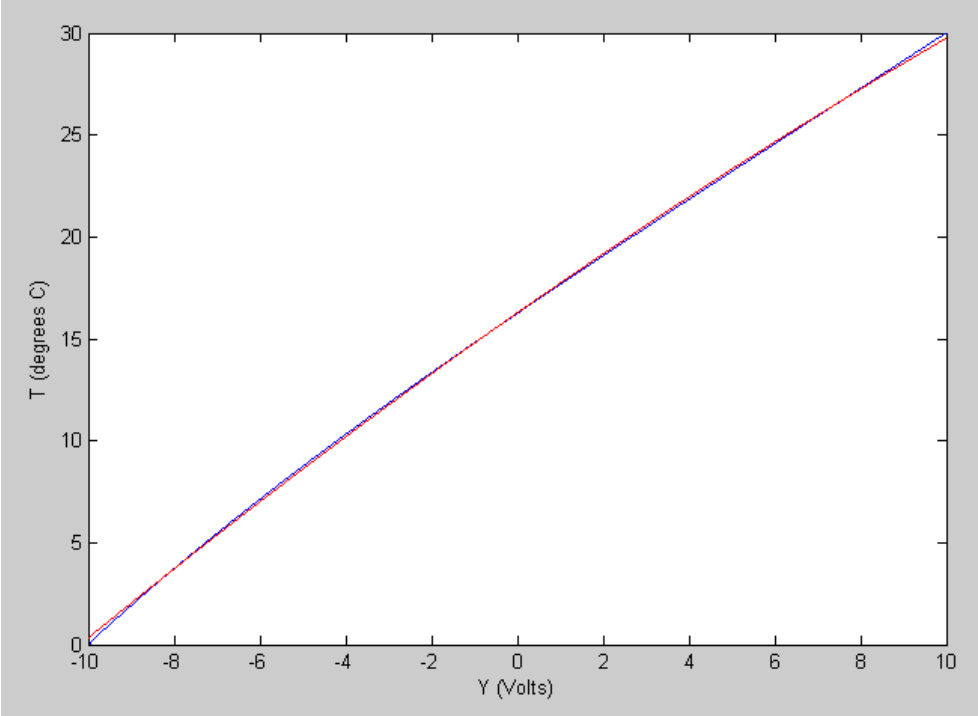
4) Determine a calibration function of the form

$$T = aV^2 + bV + c$$

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

- What is the maximum calibration error?

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

A =

a   -0.0124
b    1.4713
c   16.2594

>> plot(Y,T,'b',Y,B*A,'r');
>> xlim([-10,10])
>> xlabel('Y (Volts)');
>> ylabel('T (degrees C)');
>> max(abs(T - B*A))

ans =

    0.3104
```



Temperature Sensors: Frequency Output

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

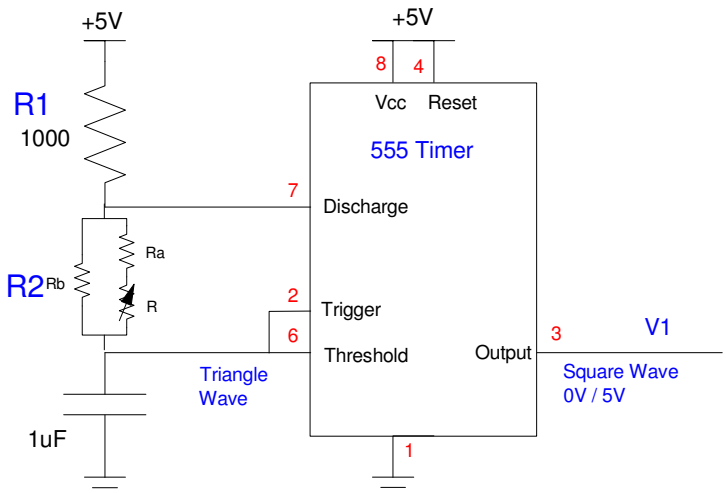
Note: For this 555 timer circuit

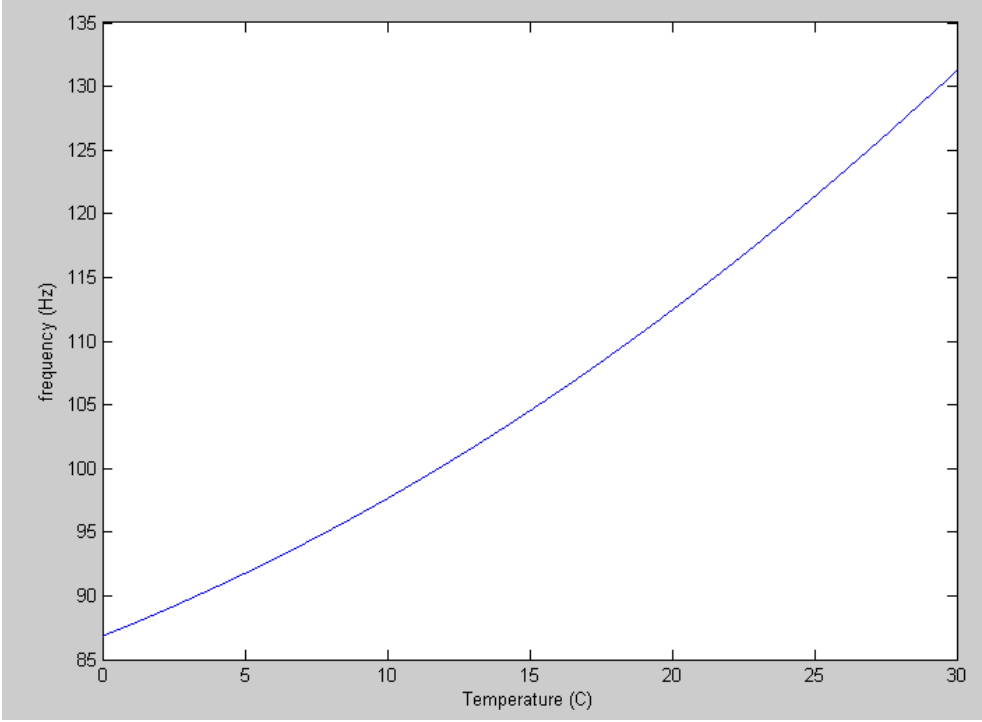
$$t_{on} = (R_1 + R_2) \cdot C \cdot \ln(2)$$

$$t_{off} = R_2 \cdot C \cdot \ln(2)$$

$$f = \left(\frac{1}{t_{on} + t_{off}} \right) \text{ Hz}$$

```
>> R1 = 1000;
>> R2 = Rnet;
>> C = 1e-6;
>> period = (R1 + 2*R2)*C*log(2);
>> f = 1 ./ period;
>> plot(T,f);
>> xlabel('Temperature (C)');
>> ylabel('frequency (Hz)');
```





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

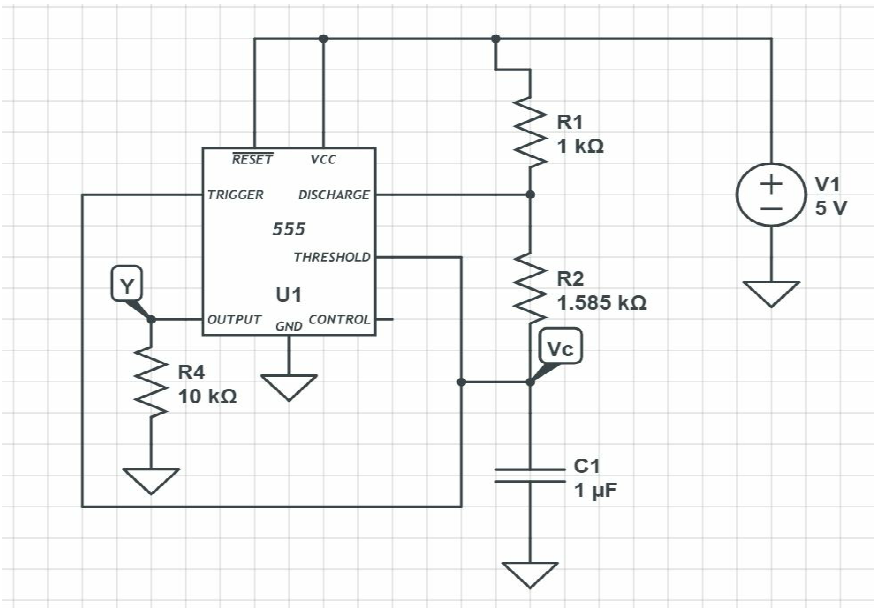
- Does the simulated frequency match your computed frequency?

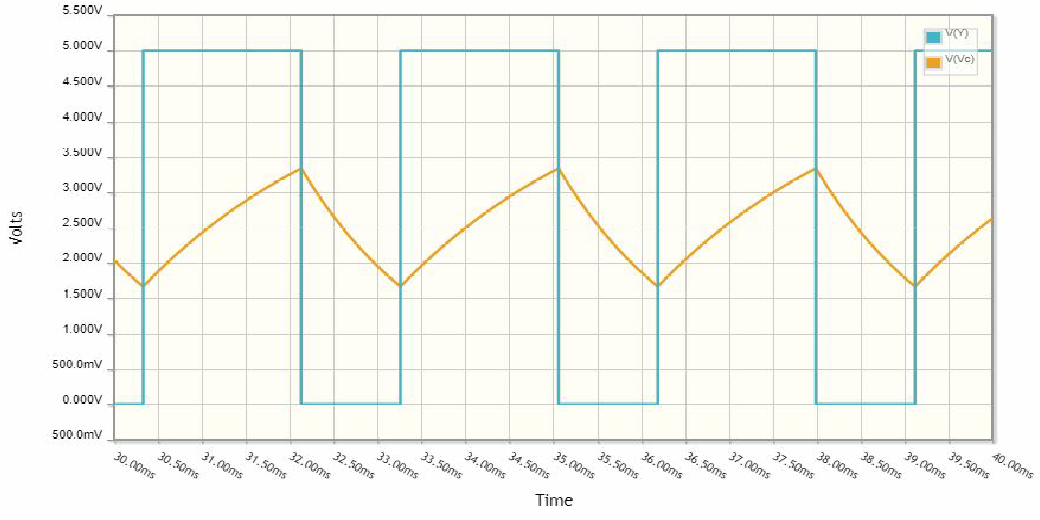
Expected Period when R2 = 1585 Ohms

$$t = (R_1 + 2R_2) \cdot C \cdot \ln(2) = 2.890ms$$

CircuitLab:

period = 2.94ms





7) Determine a calibration function of the form

$$T = a \cdot Hz + b$$

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

- What is the maximum calibration error for your temperature sensor?

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

    0.6689
  -55.9174

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

ans =    2.1619
```

The maximum calibration error for this sensor is 2.1619 degrees C