ECE 321 - Homework #2

Temperature Sensors, Audio & Strain Sensors, Calibration & Noise. Due Monday, April 11th

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

Temperature Sensors

Assume you are using a thermistor where the temperature - resistance relationship is

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

where T is the temperature in degrees C.

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

Set up a file in Matlab to compute the impedance at 15C vs. the average of 0C and 30C

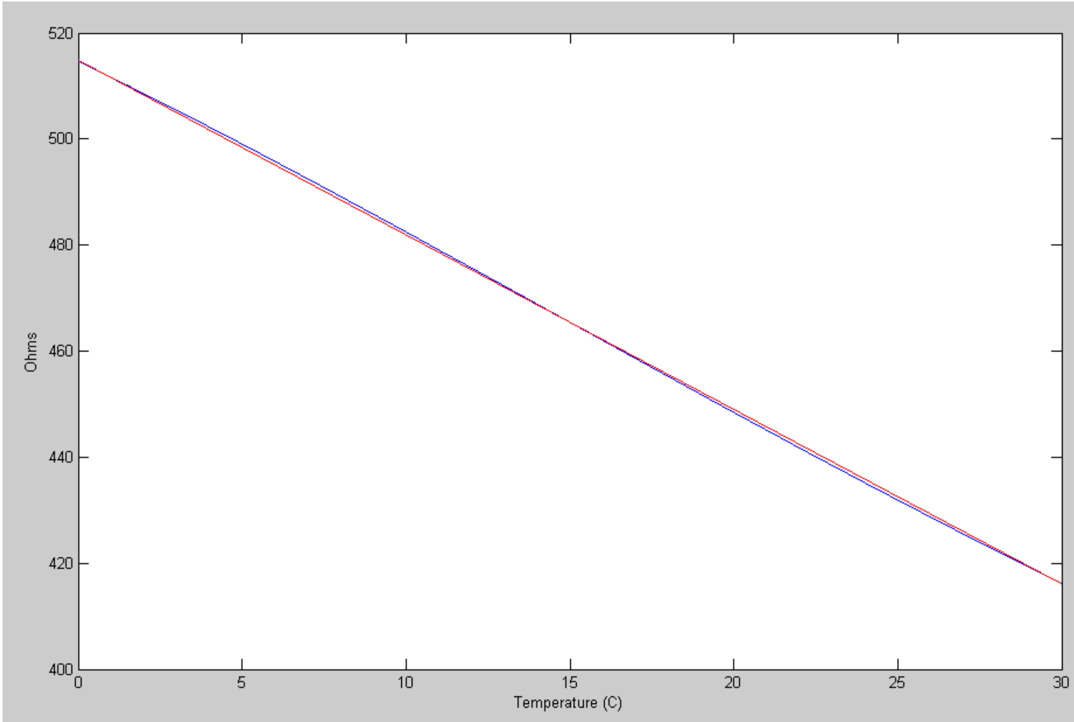
```
function [ J ] = Thermistor( Z )
 Ra = Z(1);
 Rb = Ra;

 T = [0,15,30];
 R = 1000 * exp(3905 ./ (T+273) - 3905/298);
 Z = (R + Ra)*Rb ./ (R + Ra + Rb);

 E = Z(2) - (Z(1) + Z(3))/2;
 J = E*E;
 end
```

Solve using fmsearch

```
>> [Ra,e] = fminsearch('Thermistor',1000)

Ra =   592.6961

e =   2.7813e-013
```

Ra = Rb = 592.6961 Ohms

```
>> Rb = Ra;
>> T = [0:0.01:30]';
>> R = 1000*exp(3905 ./ (T+273) - 3905/298);
>> Z = (R+Ra)*Rb ./ (Ra + Rb + R);
>> plot(T,Z,'b',T([1,3000]),Z([1,3000]),'r');
>> xlabel('Temperature (C)');
>> ylabel('Ohms');
```

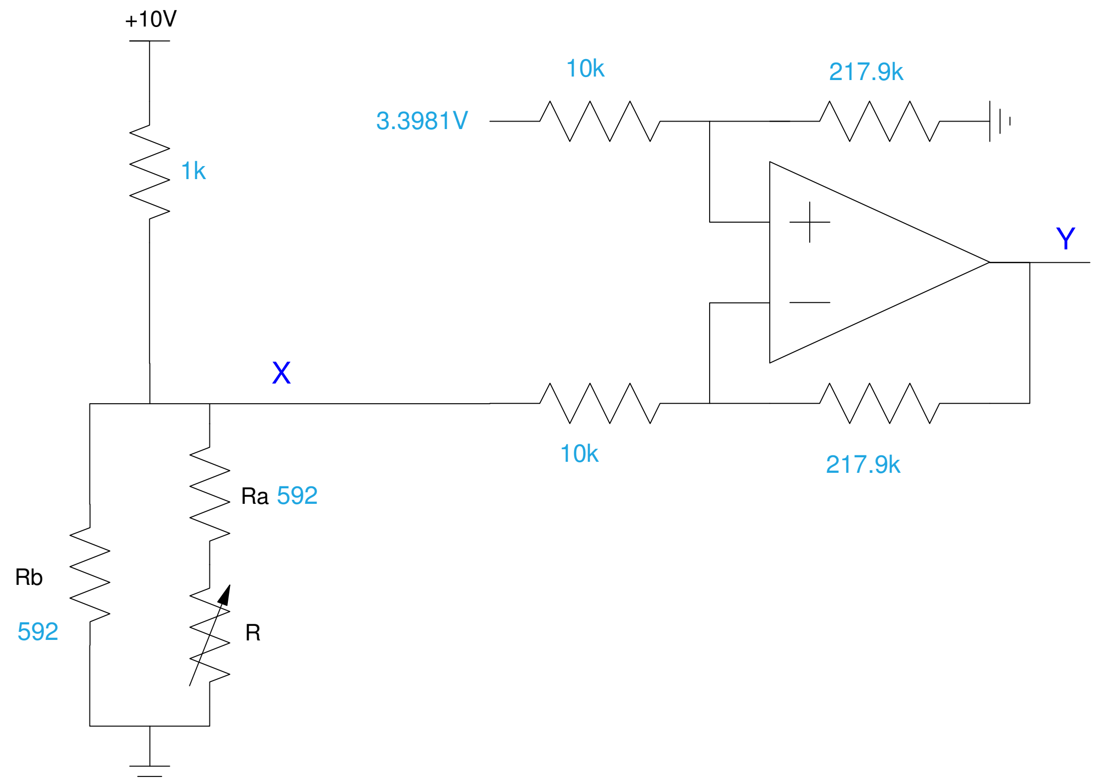


Linearizing Circuit Impedance for Ra = Rb = 592.6961 Ohms

2) Using the linearizing circuit from problem 4, design a circuit which outputs

- 0V at 0C
- +5V at +30C
- Proportional in between.

Plot the resulting output voltage vs. temperature.



Assume a 1k resistor for the voltage divider

0C:

- Z = 514.722 Ohms
- X = 3.3981V
- Y = 0V

30C

- Z = 416.2825 Ohms
- X = 2.9393V
- Y = 10V

As X goes down, Y goes up. Connect to the minus input

Y = 0V when X = 3.3981V. Make the offset 3.3981V

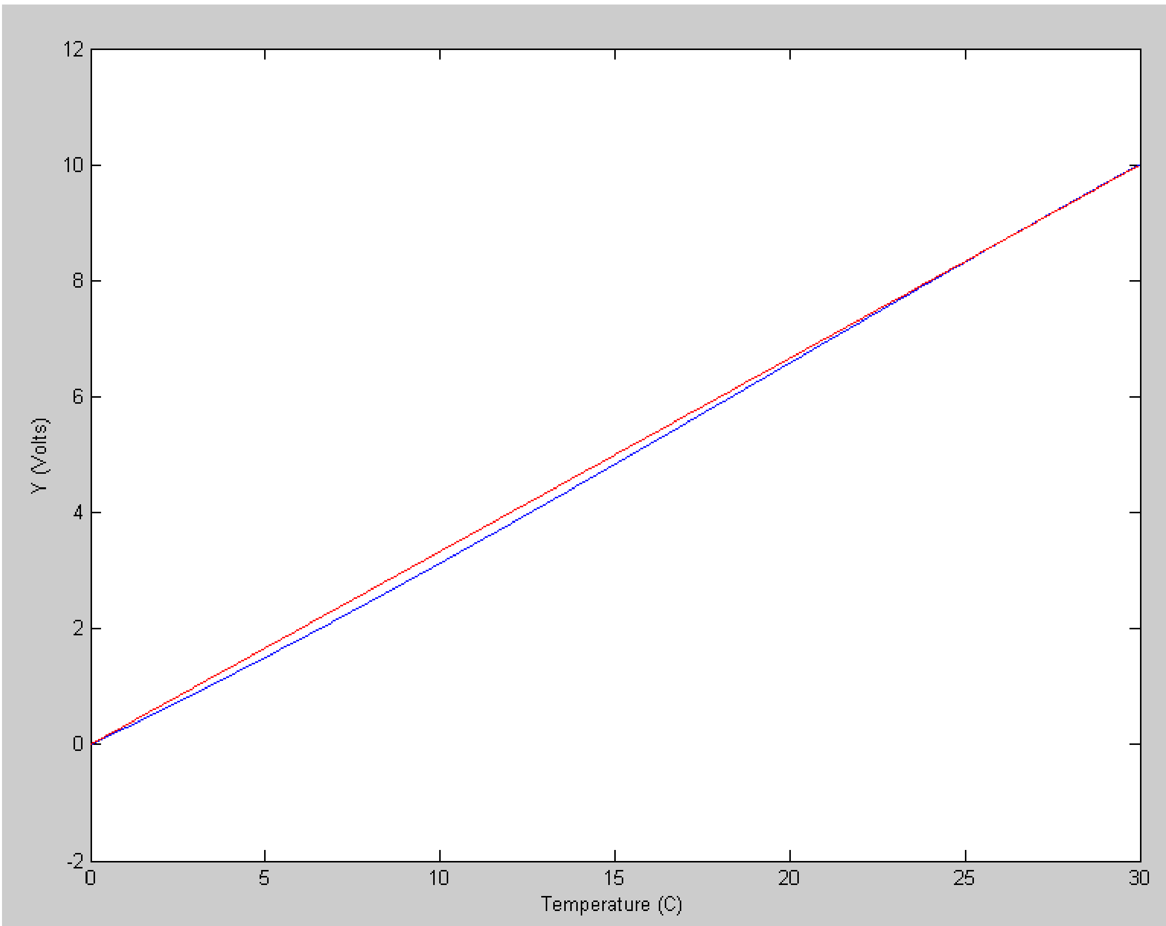
The gain needed is

$$gain = \left(\frac{10V - 0V}{3.3981V - 2.9393V} \right) = 21.79$$

Make the gain of the instrumentation amplifier 21.79

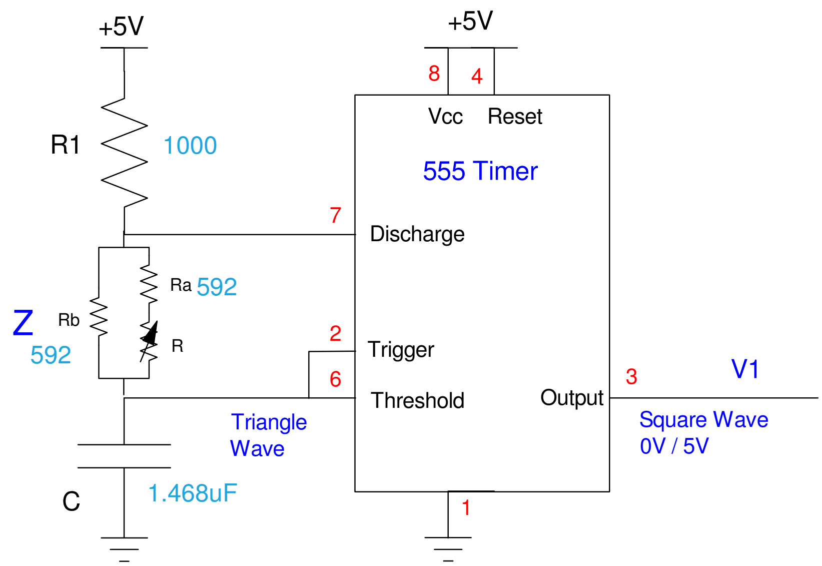
The resulting voltage vs. temperature is

```
>> X = Z ./ (Z + 1000) * 10;
>> Y = 21.7928 * (3.3981 - X);
>> plot(T,Y);
>> plot(T,Y,'b',T([1,3000]),Y([1,3000]),'r');
>> xlabel('Temperature (C)');
>> ylabel('Y (Volts)');
```



3) Using the linearizing circuit from problem 4, design a 555 timer which outputs 500Hz at +10C

- Determine the frequency it outputs from 0C to +30C



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

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

The period is then

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

frequency is 1/period

At 10C,

Z = 482.54 Ohms.

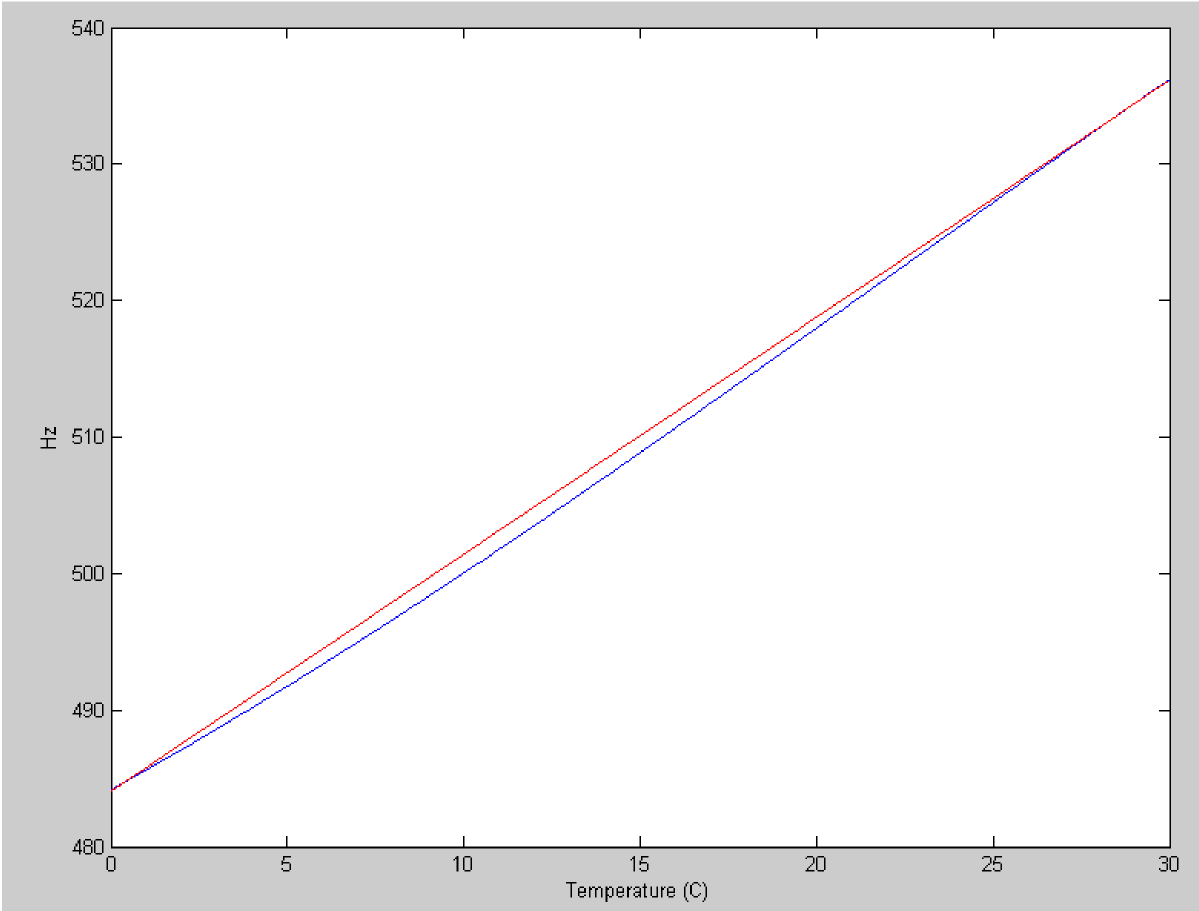
Let R1 = 1000 Ohms

$$period = 2ms = (1000\Omega + 2 \cdot 482.54\Omega) \cdot C \cdot \ln(2)$$

$$C = 1.468\mu F$$

Plotting the frequency vs. temperature

```
>> C = 1.4683e-6;
>> period = (1000 + 2*Z) * C * log(2);
>> Hz = 1 ./ period;
>> plot(T,Hz)
>> plot(T,Hz,'b',T([1,3000]),Hz([1,3000]),'r')
>> xlabel('Temperature (C)');
>> ylabel('Hz');
```



Output frequency of a 555 timer with a linearizing circuit

Calibration

4) Assume a thermistor is used with a 1k resistor to convert resistance to voltage:

$$V = \left(\frac{R}{R+1000}\right) 10V$$

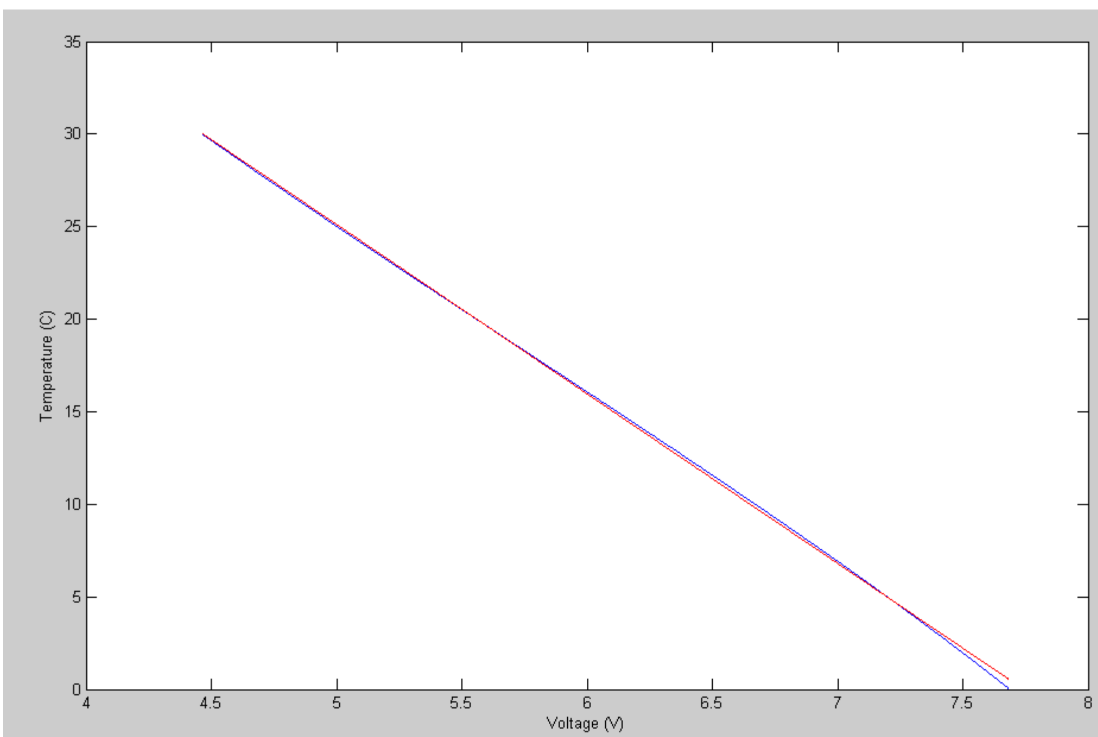
Determine a calibration function to determine temperature given the voltage as

$$T \approx aV + b$$

over the range of (0C, +30C). What is the maximum error in your curve fit?

```
>> T = [0:0.01:30]';
>> R = 1000*exp(3905 ./ (T+273) - 3905/298);
>> V = R ./ (R + 1000) * 10;
>> B = [V, V.^0];
>> A = inv(B'*B)*B'*T

a   -9.1578
b   70.8925

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

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

ans =    0.5125
```

The maximum error is 0.5125 degrees C



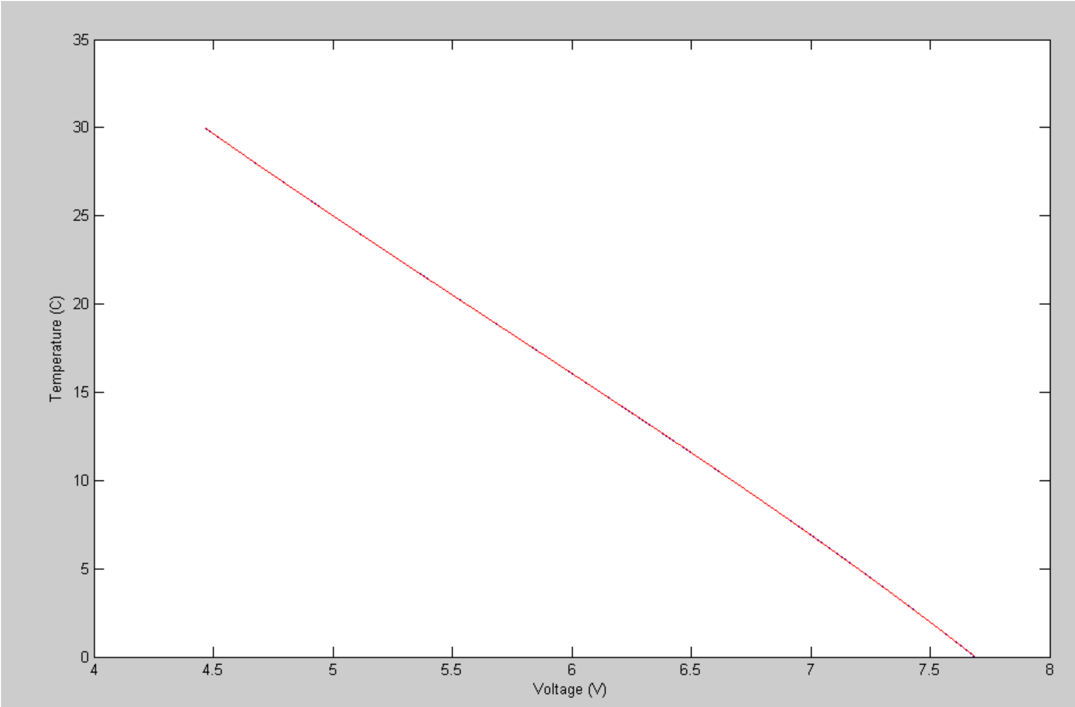
Voltage vs. Temperature & Linear Curve Fit

5) Repeat problem #4 with a cubic curve fit.

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

```
>> T = [0:0.01:30]';
>> R = 1000*exp(3905 ./ (T+273) - 3905/298);
>> V = R ./ (R + 1000) * 10;
>> B = [V.^3, V.^2, V, V.^0];
>> A = inv(B'*B)*B'*T

a   -0.1457
b    2.5048
c  -23.2255
d   96.7149

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

ans =    0.0247
```

The maximum error is 0.0247 degrees C



Voltage vs. Temperature and Cubic Curve Fit

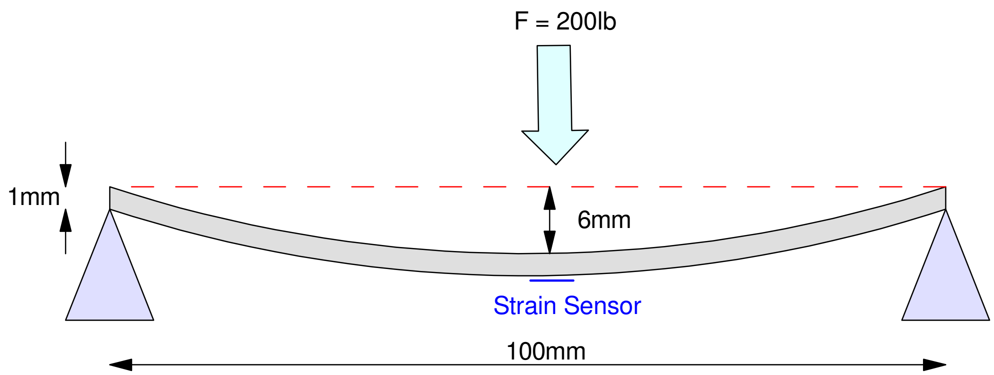
Audio / Strain Sensors

6) A strain sensor is connected to a metal rod to measure the force applied to the center of the beam. Assume

- The beam's thickness is 1mm,
- The beam's lenfgth is 100mm,
- The beam deflects 6mm when a force of 200lb is applied to it, and
- The strain - resistance relationship of the strain sensor is

$$R = 120(1 + 2.14\varepsilon)\Omega$$

a) Determine the strain and the resistance when the beam deflects by 6mm



First, find the radius of the arc

$$R^2 = 50^2 + (R - 6)^2$$

$$R = 211.33mm$$

The strain is then

$$\varepsilon = \left(\frac{0.5\text{mm center line to outside}}{211.33mm}\right) = 0.002366$$

b) Design a circuit which outputs

- 0V at 0lb force and
- 10V at 200lb force

At 0lb force

R = 120

At 200lb force

$$R = 120 \cdot (1 + 2.14\varepsilon)\Omega = 120.6075\Omega$$

Use a voltage divider with a 120 ohm resistor

At 0lb

$$X = 5.000V$$

At 200lb

$$X = \left(\frac{120.6075}{120.6075-120}\right)10V = 5.012626V$$

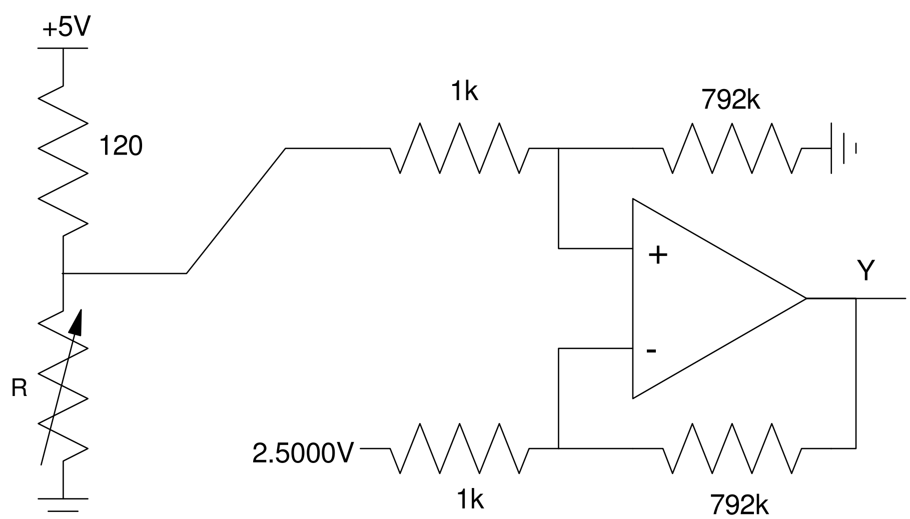
The offset should be 2.5000V so that Y = 0V at 0lb input

As X increases, Y increases. Connecct to the the plus input

The gain needed is

$$gain = \left(\frac{10V-0V}{5.012626V-5.000V}\right) = 792.03$$

(note: if you use two strain gages, the gain is 1/2 of 792. If you use four strain gages, the gain is 1/4th of 792)

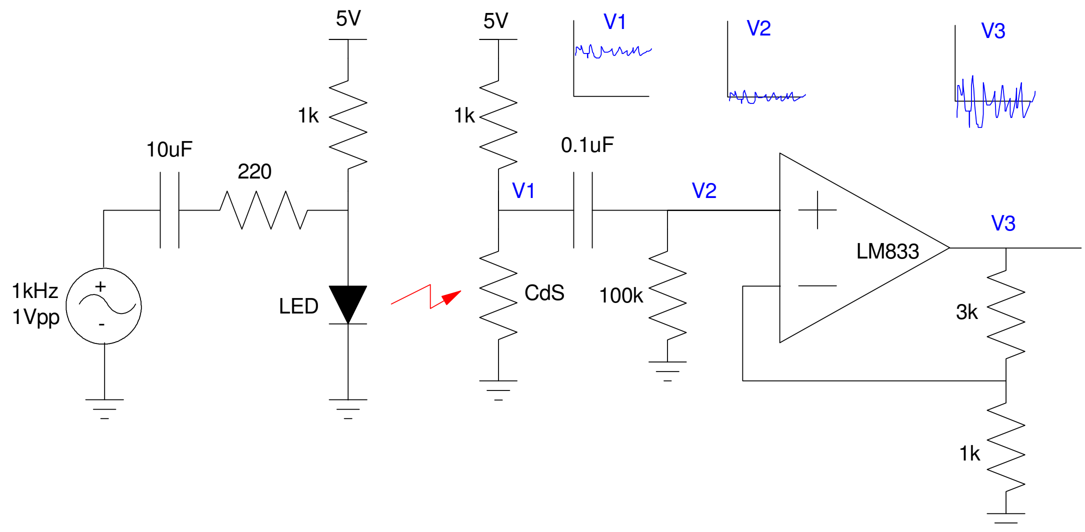


Sound to Light

7) Assume the CdS light sensor has a resitance of

$$R = 1000 + 50\sin(\omega t) \text{ Ohms}$$

determine the voltages at V1, V2, and V3 (both DC and AC. Peak-to-peak votlages are OK (and easier) for the AC voltages).



$$V_1(1000\Omega) = 2.500V$$

$$V_1(1050\Omega) = \left(\frac{1050}{1050+1000}\right)5V = 2.56098V$$

$$V_1(DC) = 2.50V$$

$$V_1(AC) = 60.98mV_p$$

V2 passes the AC and blocks the DC term (2.5V)

$$V_2(DC) = 0V$$

At 1kHz, 0.1uF has an impedance of -j1592 Ohms

$$V_2(AC) = \left(\frac{100k}{100k - j1592}\right)60.98V_p$$

$$V_2(AC) = 60.97mV_p$$

V3 = 4*V2

$$V_3(DC) = 0V$$

$$V_3(AC) = 243.88mV_p$$

Hardware (option #1)

8) Design a circuit to amplify a condenser micropohone to 0..5V

Note: You can also use a speaker as a microphone. From duality

- If you apply a voltage to a speaker, it produces sound
- If you apply sound to a speaker, it produces voltage

9) Test your audio amplifier with your amplifier with the push-pull amplifier from homework set #1 and your amplifier in problem #8.

Hardware (option #2)

8) Build the light-to-sound circuit for problem #7. Measure the voltages for a 1kHz sine wave input.

9) Test your light-to-sound circuit with the push-pull amplifier from homework set #1 and an audio signal from your cell phone (or similar device).