ECE 321 - Homework #2

Sensors. Due Wednesday, November 14th, 2018

Temperature Sensors

Problem 1-2) Design a circuit to measure temperature from -20C to +20C.

- Input: Temperature from -20C to +20C
- Output: -10V to +10V, capable of driving a 1k resistor (10mA)
- Relationship:
  - At -20C, the output is -10V
  - At +20C, the output is +10V
  - Proportioanl inbetween

Assume a thermistor with a resistance - temperature relationship of

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

Problem 1) Design a linearizing circuit so that the resistance is approximately linear from -20C to +20C

- Plot the resulting resistance vs. temperature relationship using Matlab (or similar program)

First, assume Rb = 1234 Ohms. Set up a cost funciton in Matlab

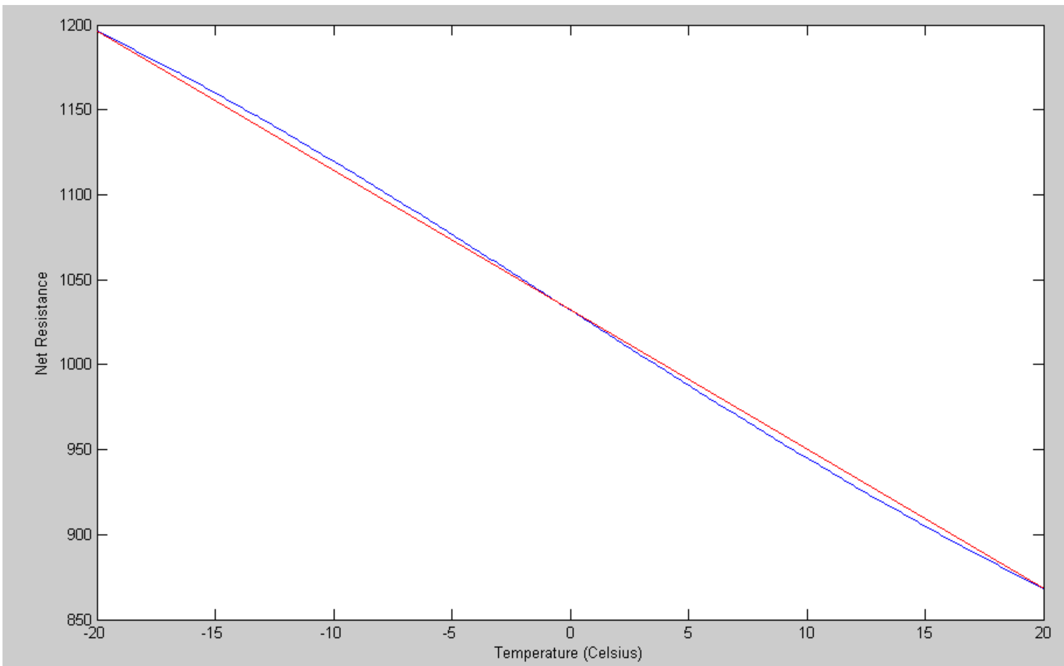
```
function [ J ] = Thermistor( Z )
  Ra = Z;
  Rb = 1234;

  Rm20  = 1000*exp(3905/253 - 3905/298);
  R0 = 1000*exp(3905/273 - 3905/298);
  R20 = 1000*exp(3905/293 - 3905/298);

% Z = R1 R2 / (R1 + R2)

  Zm20  = (Rm20  + Rb)*(Ra) / (Rm20 + Ra + Rb);
  Z0 = (R0 + Rb)*(Ra) / (R0 + Ra + Rb);
  Z20 = (R20 + Rb)*(Ra) / (R20 + Ra + Rb);

  E = Z0 - (Zm20 + Z20)/2;

  J = E*E;

  end
```

Solve using fminsearch.

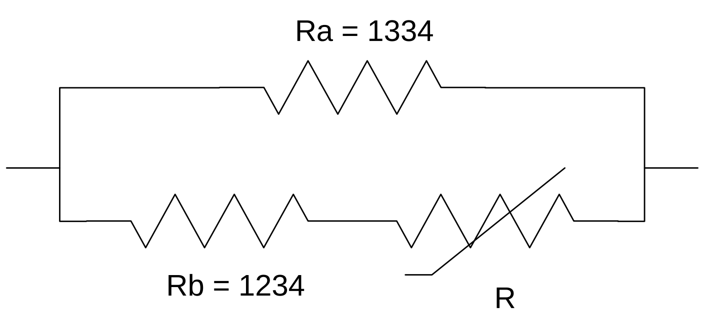
```
>> [Ra, e] = fminsearch('Thermistor',1000)

Ra =  1.3345e+003

e =  2.0953e-013
```

Plot the net resistance vs. temperature from -20C to +20C

```
T = [-20:0.1:20]';
K = T + 273;
R = 1000*exp(3905./K - 3905/298);
Rb = 1234;

Z = (R + Rb)*Ra ./ (R + Ra + Rb);

size(T)

   401     1

N = [1,401];
plot(T,Z,'b',T(N),Z(N),'r')
xlabel('Temperature (Celsius)');
ylabel('Net Resistance');
```



Actual Resistance(blue) & Linear Resistance (red) from -20C to +20C



Problem 2) Using this linearizing circuit, design a circuit which ouputs -10V to +10V as temperature goes from -20C to + 20C.

Assume a 937Ohm resistor for a voltage divider. The voltage will be

-20C:

Z = 1195.9 Ohms

$$V_{in} = \left(\frac{Z}{Z+937}\right) 10V = 5.607V$$

Vout = -10V

+20C:

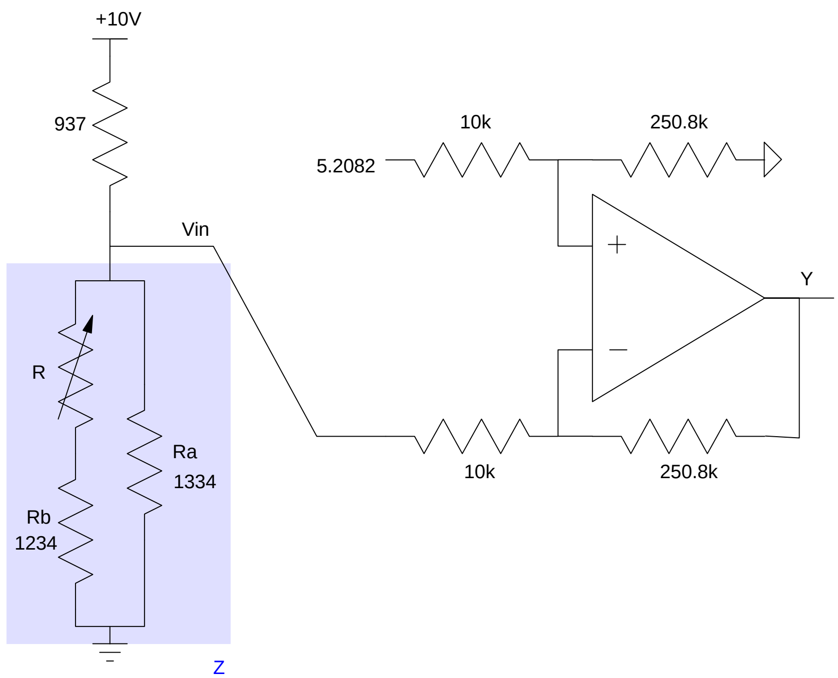
Z = 868.2 Ohms

$$V_{in} = \left(\frac{Z}{Z+937}\right) 10V = 4.9809V$$

Vout = +10V

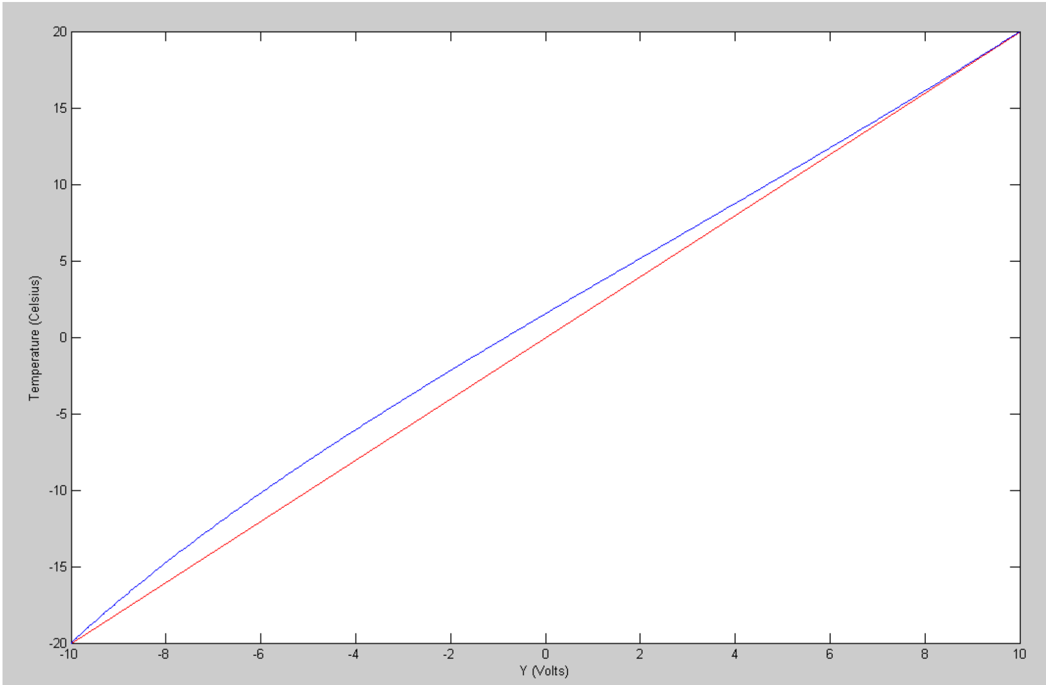
The gain you need is

```
gain = (10 - (-10)) / ( max(Vin) - min(Vin) )

   gain =   25.0744

offset = 10/gain + Vin(401)

   offset =    5.2082

y = gain*(offset - Vin);
plot(y,T)
```



Plot the resulting voltage vs. temperature relationship using Matlab (or similar program)

>>

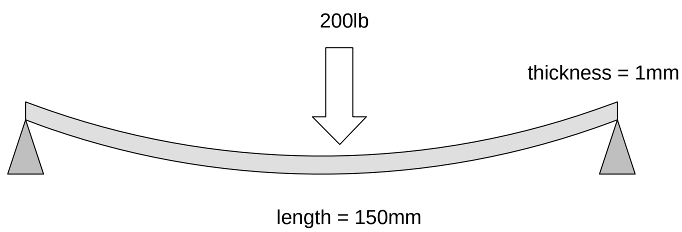


Note: The voltage divider is also non-linear, which causes the actual voltage (blue) to bend away from a linear relationship (red).

You could repeat with the cost being the output (Y) should be linear rather than Z being linear.

Strain Sensors

Problem 3) Assume a bathroom scale uses a steel beam to measure weight, and the beam deflects 10mm with a weight of 200 lb (889N)



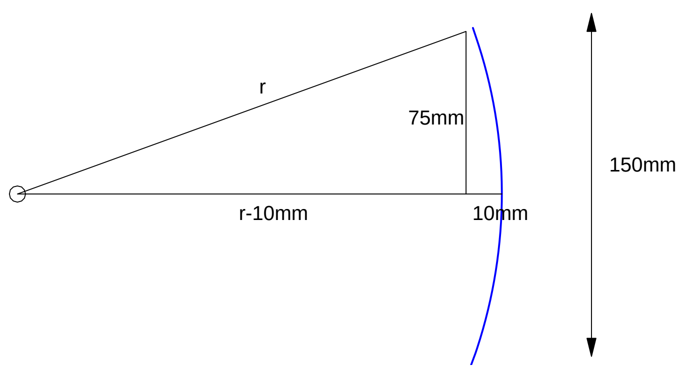
Design a circuit which output

- 0V at 0lb (0N), and
- +10V at 200lb (889N)

Assume a strain sensor:

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

First, compute the strain. A 10mm deflection with a 150mm long beam corresponds to a radius of



$$r^2 = 75^2 + (r - 10)^2$$

$$r = 286.25mm$$

The angle is then

$$\theta = 2 \cdot \arctan\left(\frac{75mm}{276.25mm}\right) = 30.3786^0 = 0.5302 \text{ radians}$$

The arc-length of the inner surface (r = 286.25mm - 0.5mm) is

$$L_{inside} = (0.5302rad) \cdot (286.25mm - 0.5mm) = 151.5064mm$$

$$L_{outside} = (0.5302rad) \cdot (286.25mm + 0.5mm) = 152.0366mm$$

$$L_{avg} = 151.7715mm$$

(the beam will pull inward slightly so that the average length remains 150mm)

The strain is then

$$\varepsilon_{inside} = \left(\frac{151.5064 - 151.7715}{151.7715} \right) = -0.001747 \qquad \textit{compression}$$

$$\varepsilon_{outside} = \left(\frac{152.0366 - 151.7715}{151.7715} \right) = +0.001747 \qquad \textit{tension}$$

The resistance of the strain gage is then

$$R_{inside} = 120 \cdot (1 + 2.14\varepsilon) = 119.551\Omega$$

$$R_{outside} = 120 \cdot (1 + 2.14\varepsilon) = 120.448\Omega$$

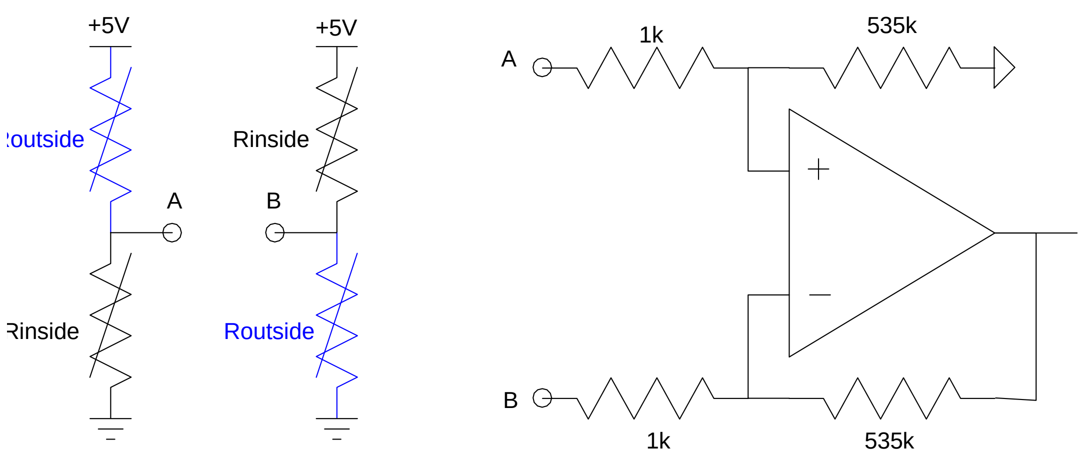
Assume a voltage divider with the strain gages on the inside and outside. The votlages will be

$$V_a = \left(\frac{120.448}{120.446 + 119.551} \right) 5V = 2.50934V$$

$$V_b = \left(\frac{119.551}{120.446 + 119.551} \right) 5V = 2.490655V$$

The gain you need to make this

$$gain = \left(\frac{10V - 0V}{2.50934V - 2.490655V} \right) = 535.04$$



note: When you have this much gain, an instrumentation amplifier designed for strain gages works better. You should use something like an AMP04 for this circuit instead.

ECE 321 Project: Section (A)

Problem 4) Specify the requirements for your power amplifier (section A): (inputs, outputs, how they relate)

Input:

- -5V .. +5V analog signal,
- 0-1kHz,
- capable of driving 10mA

Output:

- 8-Ohm speaker

Relationship:

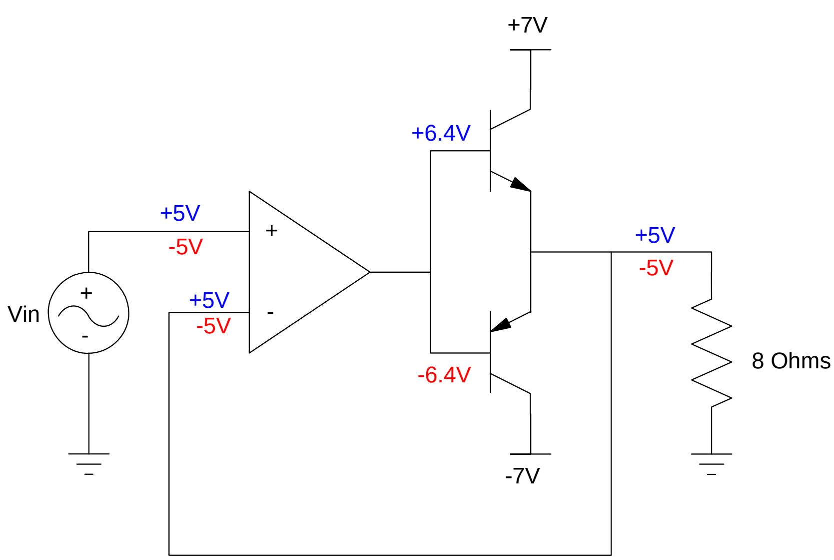
- Y = X
- 200mV tolerance *meaning you need to compensate for crossover distortion*

Problem 5) Design a circuit to meet these requirements. Use a TIP 112 and/or TIP117 transistors

- $\beta = 1000$
- $|V_{be}| = 1.4V$
- $\min(|V_{ce}|) = 0.9V$

The voltages you should get are:

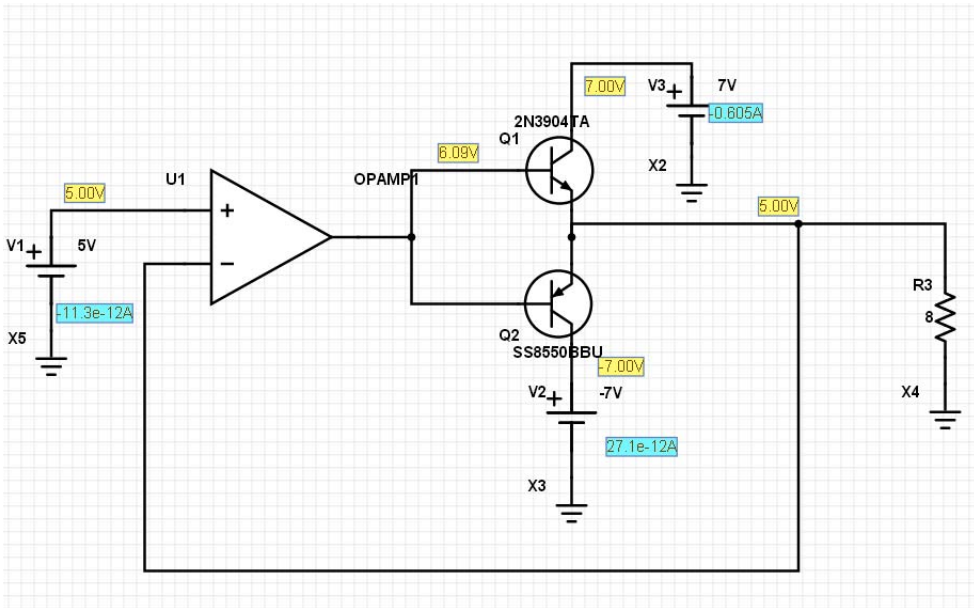
Vin	Vb	Ve
+5V	+6.4V	+5V
+1V	+2.4V	+1V
-1V	-2.4V	-1V
-5V	-6.4V	-5V



Problem 6) Simulate your circuit to verify it operates correctly. Check the voltages and currents at

- Vin = -5V, +5V (endpoints),
- Vin = -1V, +1V (points inbetween)

to see if they match your computations.



	Vb		Ve	
Vin	**Calculated**	**Simulated**	**Calculated**	**Simulated**
+5V	+6.4V	+6.09V	+5V	+5.00V
+1V	+2.4V	+1.83V	+1V	+1.00V
-1V	-2.4V	-1.75V	-1V	-1.00V
-5V	-6.4V	-5.92V	-5V	-5.00V

Note: Vb is off with the simulation since we're using an different transistor in simulation vs. calculation (and lab).

- The calculations assumed a TIP112/TIP117 transistor, which are Darlington pairs (Vbe = 1.4V)
- The simulation used a 3904 transistor, which has Vbe = 0.7V

What we *really* care about is the output (Ve). This matches our calculations.

Problem 7) Build your circuit in lab and verify it operates correctly. Check the voltages and currents at

- Vin = -5V, +5V (endpoints),
- Vin = -1V, +1V (points inbetween)

to see if they match your computations and simulation results.

Problem 8) Demo. Demonstrate your amplfier with an audio signal (video or in person).

Note: Save your circuit. You'll use it again in the following homework sets