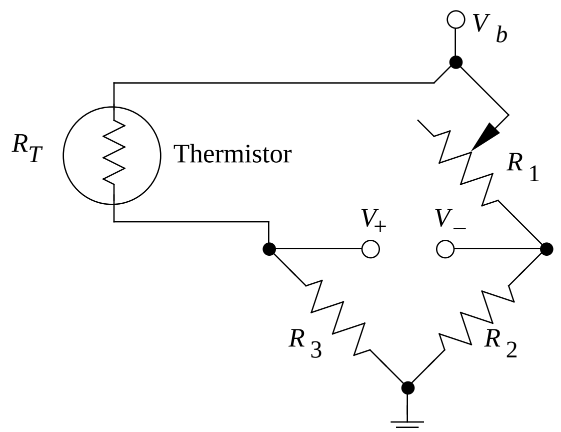
UNIVERSITY OF CALIFORNIA
Electrical Engineering and Computer Sciences

EECS 145L Electronic Transducer Lab
MIDTERM #2 (100 points maximum)

(closed book, calculators OK- note formulas on last page)
(You will not receive full credit if you do not show your work)

PROBLEM 1 (45 points)

You wish to measure air temperatures over the range from 0°C to 50°C using the thermistor bridge shown below.



Assume the following:

- $R_2 = R_3 = 5$ kΩ.
- You use an instrumentation amplifier with a gain of 5: $V_0 = 5\,(V_+ - V_-)$.
- The thermistor resistance R_T vs. temperature T as shown in the table below

0°C	10°C	20°C	30°C	40°C	50°C
10.000 kΩ	6.667 kΩ	5.000 kΩ	3.333 kΩ	2.500 kΩ	1.667 kΩ

- $dR_T/dT = -150$Ω/°C at 20 °C.

You then perform a series of experiments to explore the thermistor self-heating of your system and to determine the best bias voltage V_b.

Experiment 1: With $V_b = 1$ volt and the thermistor in **water** at 20°C, you adjust R_1 to make the amplifier output $V_0 = 0.000$ volts. (Assume that there is no self heating in water with $V_b = 1$ volt)

a. (4 points) What are the values of R_1 and R_T?

b. (4 points) What electrical power is consumed by the thermistor?

Experiment 2: You then move the thermistor to **air** at 20 °C, wait a while, and find that the amplifier output $V_0 =$ 0.0075 volts (V_b = 1 volt).

c. (5 points) What is the thermistor resistance R_T?

d. (4 points) What is the temperature of the thermistor?

e. (4 points) What electrical power is consumed by the thermistor?

Experiment 3: With the thermistor in air at 20 °C, you increase V_b to 10 volts, wait a while, and find that the amplifier output V_0 = 8.333 volts.

f. (5 points) What is the thermistor resistance R_T?

g. (4 points) What is the temperature of the thermistor?

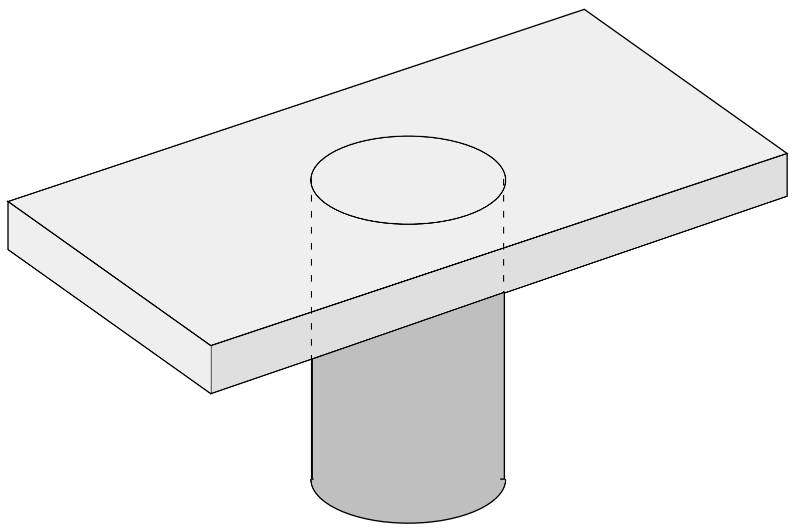
h. (4 points) What electrical power is consumed by the thermistor?

i. (5 points) From your calculations of experiment 3, what is the thermal dissipation coefficient in mW per C°?

j. (6 points) Comment on the design factors that determine the approximate **minimum** and **maximum** bias voltages or this application.

PROBLEM 2 (45 points)

You are assigned the task of designing a truck scale for the North Dakota Department of Transportation. The scale consists of a large steel plate at the road level sitting on top of a large steel cylinder. When a truck drives onto the plate the steel cylinder is slightly compressed along its axis. The ambient temperature is expected to vary from –20°C to +40°C. The thermal expansion coefficient of the steel cylinder is 10 ppm/C°.



Design a system that meets the following requirements:

- The system should produce an output that is proportional to the weight of the truck.
- The maximum truck weight of 10,000 kg should produce an output of 10 volts.
- Trucks are to be weighed to an accuracy of 100 kg over the full temperature range.

Assume the following:

- You have decided to use four metal foil strain gauges with gauge factor G_S = 2.00 and an unstrained resistance of 100 Ω (similar to those used in the 145L lab)
- You may use any electronic components used in the 145L lab, but keep it simple.
- You cement the strain gauges (to wherever you decide to place them) at a temperature of 20°C. At this temperature, the strain is zero.

- The maximum truck weight of 10,000 kg produces a compressive strain $\Delta L/L = -0.2\%$
- The steel cylinder is hollow so the load only compresses the steel cylinder along its length and changes in diameter are negligible.
- All dimensions (e.g. length and diameter) change equally when the temperature changes.
- The steel plate weighs 1,000 kg.
- The resistivity ρ of the strain gauge metal foil does not depend on temperature.

a. (20 points) Sketch your circuit, showing all essential components. **Also**, sketch the placement and orientation of the four strain gauges on the previous drawing.

c. (5 points) With no load on the scale, what are the resistances of the 4 strain gauges and the voltages at 3 key points in your circuit (2 bridge outputs, 1 amplifier output) at +20°C?

d. (10 points) With the maximum 10,000 kg load on the scale, what are the resistances of the 4 strain gauges and the voltages at 3 key points in your circuit at +20°C?

e. (10 points) With no load on the scale, what are the resistances of the 4 strain gauges and the voltages at 3 key points in your circuit at –20°C?

PROBLEM 3 (10 points)

a. (5 points) What function is the Ground Fault Interrupter Circuit designed to do?

b. (5 points) Describe how a Ground Fault Interrupter Circuit works.

Equations, some of which you may need:

$$R(T) = R(T_0)\exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right] \qquad V_{\mathrm{rms}} = \sqrt{B\left[\left(D_1 G\right)^2 + \left(D_0\right)^2\right]}$$

$$V(t) = V_0 \sin(\omega t) \qquad \omega = 2\pi f \qquad V_0 = A(V_+ - V_-)$$

$$|G| = \frac{1}{\sqrt{1 + \left(f / f_c\right)^{2n}}} \qquad \tan\left(\frac{\varphi}{n}\right) = \frac{f}{f_c} \qquad N(x) = N(0)e^{-x\mu}$$

$$x = e^{-\alpha t}\left[A\cos(\omega t) + B\sin(\omega t)\right] = Re^{-\alpha t}\cos(\omega t + \delta) \qquad V = q / C$$

$$v = v_0 + at \quad x = x_0 + v_0 t + 0.5\, at^2 \quad (\text{constant } a) \qquad g = 10 \text{ m s}^{-2}$$

$$T = T_2 - (T_2 - T_1)\, e^{-t/\tau} \qquad I = I_0\, e^{-kLC} \qquad \Delta x = \frac{\Delta V}{dV / dx}$$

$$I_{\mathrm{rms}} = \sqrt{2qI(F_2 - F_1)} \qquad q = 1.60 \text{ x } 10^{-19} \text{ Coulombs}$$

$$V_{\mathrm{rms}} = \sqrt{4kTR(F_2 - F_1)} \qquad k = 1.38 \text{ x } 10^{-23} \text{ Volt}^2 \text{ sec ohm}^{-1}\ {}^\circ\text{K}^{-1}$$

$$R_T = R_3 \frac{V_b R_1 - V_0(R_1 + R_2)}{V_b R_2 + V_0(R_1 + R_2)} \qquad V_0 = G_\pm(V_+ - V_-) + G_c(V_+ + V_-)2$$

$$f_c = \frac{1}{2\pi RC} \qquad \text{“CMRR”} = \frac{G_\pm}{G_c} \qquad \text{“CMR”} = 20\log_{10}\left(\frac{G_\pm}{G_c}\right)$$

$$R = \rho A / L \qquad \frac{\Delta R}{R} = G_s \frac{\Delta L}{L} \qquad V_0 = V_b\, G_s\left(\frac{\Delta L}{L}\right)$$

$$V_T = V_{\mathrm{BE2}} - V_{\mathrm{BE1}} = \frac{kT}{q}\ln\left(\frac{I_1}{I_2}\right) \qquad k / q = 86.17\ \mu\text{V} / \text{K}$$

$$P_R = \sigma A T^4 \quad \sigma = 5.6696 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^4$$

$$E = hc / \lambda \quad hc = 1240 \text{ eV nm} \qquad \lambda_{\max} = (2.8978 \times 10^6 \text{ nm K}) / T$$

$$\eta = \frac{T_{n+2} - T_{n+1}}{T_{n+1} - T_n} \qquad T_{\mathrm{equ}} = T_{n+1} + \frac{T_{n+2} - T_{n+1}}{1 - \eta}$$

$$Q = \pi I + I^2 R/2 + K_p(T_s - T_0) + K_a(T_a - T_0) \qquad T_{\mathrm{equ}} = \frac{\pi I + I^2 R/2 + K_p T_s + K_a T_a}{K_p + K_a}$$

$$\mu \approx \bar{a} = \frac{1}{m}\sum_{i=1}^{m} a_i \qquad \sigma_a^2 = \frac{1}{m-1}\sum_{i=1}^{m}\left(a_i - \bar{a}\right)^2 \qquad \sigma_{\bar{a}} = \frac{\sigma_a}{\sqrt{m}}$$

$$\sigma_f = \sqrt{\left(\frac{\partial f}{\partial a_1}\right)^2 \sigma_{a1}^2 + \left(\frac{\partial f}{\partial a_2}\right)^2 \sigma_{a2}^2 + \cdots + \left(\frac{\partial f}{\partial a_n}\right)^2 \sigma_{an}^2}$$

Johnson noise = 129 μV for 1 MHz and 1 MΩ

Iron+Constantan - 52.6 μV/°C   W+W(Rh) - 16.0 μV/°C