Homework #5 Due 5/21/08

1. A circular ceramic pressure sensor has a 1 cm diameter diaphragm with thickness of 200 microns. The Elastic Modulus for ceramic is 8×10^{10} N/m^2. Assume poisson's ratio is 0.2.
   a) How much does the center of the diaphragm deflect for a pressure of 100 kPa?
   b) If the initial capacitance of the sensor is 100 pF, how much does it change for a pressure of 1 kPa?

2. Suppose a supermarket door-opening sensor is made from a large sheet of PVDF (d_{33} = 30 pC/N) piezoelectric film (thickness 28 microns, area 1 meter x 1 meter).
   a) How much voltage is measured when a 75 kg person stands on the mat?
   b) Does it make any difference how big this person's feet are?
   c) Suppose a 30 kg child jumps up and down on the mat at a steady frequency near 1 Hz for more than a minute. Make reasonable assumptions about this situation and quantitatively describe the voltage that appears as a function of time on the electrodes. Draw a graph of the voltage you'd expect to see.

3. A relative pressure sensor for automotive applications consists of a silicon diaphragm with diameter of 2 mm, and will be used to measure pressure differences from 0 to 10 kPa. A capacitive sensing technique is to be used, and the separation between the diaphragm and the fixed electrode is 10 microns.
   a. How thick should the diaphragm be if the capacitance change is to be limited to less than 1%?
   b. How thick should the diaphragm be if the diaphragm deflection is to be less than 1% of the diaphragm thickness?
   c. If we want both nonlinearity and capacitance change to be less than 1%, which thickness should we choose?
   d. Suppose the device is accelerated in a direction perpendicular to the surface of the diaphragm. This acceleration exerts a force on the diaphragm, which causes a deflection, just as if a pressure was applied. Using the thickness chosen in part c, what change of capacitance results from an acceleration of 10g?

4. For this problem, make up your own midterm problem that explores some design, sensor performance, and some interesting issue. Also, write up a solution to this problem. None of these will be used in this year's exam, but they might appear in an exam somewhere in the future.

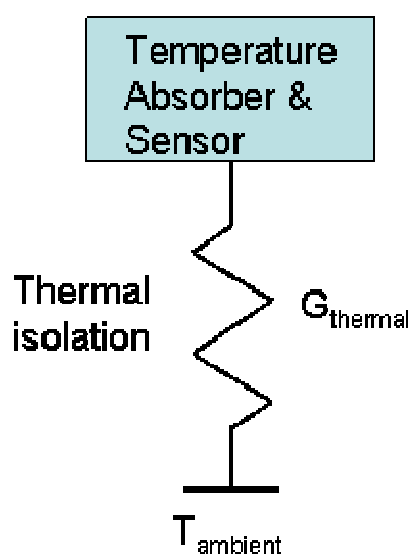
The problem below is NOT REQUIRED. In fact, I don't want you to turn anything in for it. It is one of the two problems from the midterm last year. In fact, I only include it in case you were interested. I will not be providing solutions for this problem.

(1) Caterpillar madness

You're at your wits end with these hairy caterpillars dangling from the trees around campus and frightening you, and you've decided to build a sensor to detect them. You want to build an IR detector that you can wear to sense the radiation coming from them. To do this, you use a heat absorber, temperature sensor, and thermal isolator as shown in the figure below. You're hopeful that the body temperature of a caterpillar will cause a measurable increase in the temperature of your sensor.

Assumptions/facts for your problem:

- All objects have an emissivity and absorptivity of unity (1)
- The nominal temperature of the sensor and the temperature of all other non-caterpillar, non-you objects is an ambient temperature of 20ºC
- The caterpillar is at 30ºC
- You are at 37ºC, but the sensor is perfectly shielded from your IR radiation and heat via conduction
- The area of your body exposed to the caterpillar is 1 m^2
- The outward facing area of your sensor is 2 cm^2
- All sources of heat (once the amount of emitted power is known) can be treated as point sources
- The thermal conductance, G, of your sensor is 10^{-3} W/K
- The heat capacity, C, of your sensor is 10^{-3} J/K
- The caterpillar is 2 cm x 0.5 cm x 0.5 cm
- The surface of the caterpillar facing you is 2 cm x 0.5 cm
- You are a distance R {m} away from the caterpillar
- Assume things are changing slowly (*i.e.,* you're a slow walker), so you can assume the situation is quasistatic, meaning that you do not have to worry about any AC effects, only DC.



a) What is the net amount of radiation power from the caterpillar absorbed by the sensor? (leave R in variable form)

b) What is the sensor's temperature if one caterpillar is a distance R away?

c) Assume you have a magical temperature sensor that gives a perfectly linear response of $V_{out} = \beta T$, where $\beta = 50$ mV/K. What sort of change in output voltage do you expect for the presence vs. absence of a caterpillar? Give the answer in terms of R. Also plug in 5m for R and give the change in output voltage..

d) Your noise is $V_n = 375$ nV/rt(Hz). What is your rms noise voltage for a 16 Hz bandwidth measurement?

e) Considering the physical situation. Is this a reasonable measurement bandwidth? Why or why not?

f) Assuming you need a signal to noise ratio of 5, how far away can you be and still detect the presence of a caterpillar?

g) If there are two caterpillars together, how far away can you be and still detect their presence, still with a signal to noise ratio of 5?

h) If the caterpillar is the same temperature as the ambient, how far away can you be and still detect the presence of a caterpillar?

i) Let's see if the caterpillar can detect you. If you are the distance away found in part (h), what is the change in temperature of the caterpillar? Go ahead and assume your heat radiates as a point source for ease of calculation, even though the assumption may not be perfectly accurate. The thermal conductance of the caterpillar is $G_{caterpillar} = 10^{-2}$W/K, due to the surrounding air.