UNIVERSITY OF CALIFORNIA  
College of Engineering  
Department of Electrical Engineering and Computer Sciences  

EECS 145L: Electronic Transducer Laboratory  

FINAL EXAMINATION Fall 2002  

You have three hours to work on the exam, which is to be taken closed book. Calculators are OK, equation sheet provided. You will not receive full credit if you do not show your work. Use back side of sheet if necessary. Total points = 200 out of 1000 for the course.  

1 ______________ (60 max) 2 ______________ (40 max) 3 ______________ (60 max)  
4 ______________ (40 max) TOTAL _____________ (200 max)  

COURSE GRADE SUMMARY  

LAB REPORTS (500 points max):  
[5 short reports (lowest grade dropped)- 100 points max]  
[5 full reports (lowest grade dropped)-400 points max]  

4 __________   5 __________   6 __________   7 __________   11 __________  
12 __________   13 __________   14 __________   15 __________   16 __________  
17 __________   18 __________   19 __________   25 __________  

LAB TOTAL __________ (500 max)  
LAB PARTICIPATION __________ (100 max)  
MID-TERM #1 __________ (100 max)  
MID-TERM #2 __________ (100 max)  
FINAL EXAM __________ (200 max)  
TOTAL COURSE GRADE __________ (1000 max)  

COURSE LETTER GRADE
PROBLEM 1 (60 points)

In 50 words or less, describe the essential differences between the following pairs:

1a (10 points) Johnson noise vs. shot noise

1b (10 points) sensor vs. actuator

1c (10 points) Thompson emf vs. Peltier emf
1d  (10 points) thermocouple vs. Peltier thermoelectric heat pump

1e  (10 points) electromyogram (EMG) vs. electrocardiogram (ECG)

1f  (10 points) beta ray vs. x-ray
PROBLEM 2 (40 points)

2a  (15 points) Derive the voltage gain vs. frequency formula for the following circuit. Hint: the impedance of a capacitor is given by $1/(j\omega C)$.

2b  (5 points) For voltage gains of 10.00 at 0 Hz and 7.07 at 1 kHz, specify suitable values for $R_1$, $R_2$, $R_3$, and $C$. (Hint: For $RC = 0.159$ ms, $1/(2\pi RC) = 1$ kHz)
2c  (15 points) Derive the voltage gain vs. frequency formula for the following circuit.

![Circuit Diagram](image)

2d  (5 points) For voltage gains of 10.00 at 0 Hz and 7.07 at 1 kHz, specify suitable values for $R_1$, $R_2$, and $C$. 

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December 19, 2002  
S. Derenzo
PROBLEM 3 (60 points)

Design a thermocouple-based system for measuring the temperature inside a furnace with an absolute accuracy of 2 °C over the range from 25 °C to 500 °C, without the need to provide a constant supply of ice to keep the reference junction at 0 °C. Instead, you decide to leave the reference junction in the room air outside the furnace, measure its temperature with a platinum resistance thermometer, and correct the thermocouple signal using analog circuits of your design.

To simplify the calculations, assume the following:

- The sensitivity of the thermocouple is 50.00 μV/C°.
- The platinum resistance thermometer has a resistance given by the equation
  \[ R(T) = 100.0 \, \Omega \left(1 + 0.004 \, T\right), \text{ where } T \text{ is the temperature in °C.} \]

3a (15 points) Design a circuit that converts the thermocouple output into a voltage \( V_{tc} \) so that \( V_{tc} = \Delta T \times (10 \, \text{mV/C°}) \), where \( \Delta T = T_{\text{sens}} - T_{\text{ref}} \). Draw a block diagram and label all necessary analog circuit elements and signal lines. Include the thermocouple wires. (It is not necessary to include analog filtering)

3b (15 points) Design a circuit that converts the platinum resistance into a suitable voltage \( V_{pt} \) so that \( V_{pt} = T_{\text{rm}} \times (10 \, \text{mV/C°}) \), where \( T_{\text{rm}} \) is the room temperature in C°. Draw a block diagram and label all necessary analog circuit elements and signal lines. Show where the platinum resistance thermometer is placed in the diagram of part 3a above. (It is not necessary to include analog filtering)
3c (10 points) Sketch the thermocouple voltage $V_{tc}$ as a function of the temperature difference $\Delta T = T_{sens} - T_{ref}$. Label the axes with numbers and units.

3d (10 points) Sketch the platinum resistance circuit voltage $V_{pt}$ as a function of the temperature $T_{rm}$. Label the axes with numbers and units.

3e (10 points) Sketch your design for converting $V_{tc}$ and $V_{rm}$ into a voltage $V_{out}$, where $V_{out} = T_{sens} (10 \text{ mV/C}^\circ)$, independent of room temperature.
PROBLEM 4 (40 points)

After considering how sensitive strain gauges are to the thermal expansion of the element to which they are bonded, you invent a new temperature sensor that consists of two resistive strain gauges cemented to a small aluminum plate.

Assume the following:

• You use the two strain gauges in a bridge circuit
• The two strain gauges have unstrained resistance 100 Ω, gauge factor = 2
• The thermal expansion coefficient of aluminum is 23 ppm/°C (ppm = parts per million)
• The maximum power that the strain gauges can dissipate is 250 mW
• You use an instrumentation amplifier with a noise level of 10 nV/Hz1/2 (relative to the input)

4a (8 points) Sketch your circuit design, including all components and wires.

4b (8 points) Derive the equation that relates bridge output voltage to the resistance of the two strain gauges.
4c  (8 points) What bridge bias voltage gives the maximum bridge sensitivity?

4d  (8 points) At the bias voltage from part 4c, what is the bridge output sensitivity in mV/°C?

4e  (8 points) Assuming the sensitivity from part 4d, what is the noise level in terms of °C at 1M Hz and 1 Hz bandwidths?