EECS 145L Final Examination   NAME (please print) ______________________

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UNIVERSITY OF CALIFORNIA

College of Engineering

Department of Electrical Engineering and Computer Sciences

EECS 145L: Electronic Transducer Laboratory

FINAL EXAMINATION   December 13, 1994 5:00 - 8:00 PM

You have three hours to work on the exam, which is to be taken closed book. Calculators are OK, but not needed. Total points = 200 out of 1000 for the course.

1 ______________ (30 max) 2 ______________ (32 max) 3 ______________ (30 max)

4 ______________ (50 max) 5 ______________ (34 max) 6 ______________ (24 max)

TOTAL _____________ (200 max)

COURSE GRADE SUMMARY

LAB REPORTS:

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

LAB TOTAL =_______ (500 max)

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 (30 points)

Give definitions (20 words or less) for the following terms:

1.1 (5 points) Accuracy of a sensor

1.2 (5 points) Precision of a sensor

1.3 (5 points) Seebeck emf

1.4 (5 points) Angle sensor (resistor)

1.5 (5 points) PIN photodiode

1.6 (5 points) Photovoltaic mode of a photodiode

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Problem 2 (32 points)

2.1 (4 points) Name two different sensors for measuring temperature

2.2 (4 points) Name two different actuators for changing temperature

2.3 (4 points) Name two different sensors for measuring position

2.4 (4 points) Name two different actuators for changing position

2.5 (4 points) Name two different sensors for measuring light

2.6 (4 points) Name two different actuators for producing light

2.7 (4 points) Name two different sensors for measuring force

2.8 (4 points) Name two different actuators for producing force

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Problem 3 (30 points)

3.1 (10 points) Describe how you would measure temperature over the range from 0°C to 600 °C with a precision of 0.2 °C and an accuracy of 0.5 °C

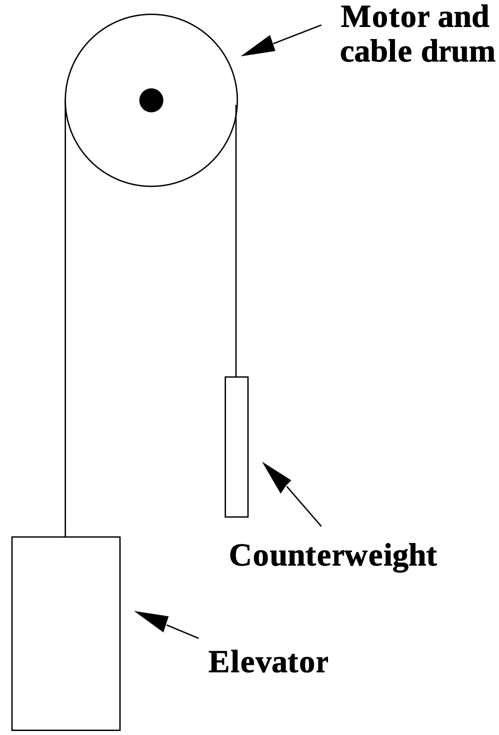
3.2 (10 points) Describe how you would measure temperature over the range from 0°C to 100 °C with a precision of 0.05 °C and an accuracy of 0.1 °C

3.3 (10 points) Describe how you would measure a voltage in the range of 0 to 1 mV across a 1 MΩ resistor in the frequency range from 100 Hz to 10 kHz, where neither end of the resistor is grounded.

Problem 4 (50 points)

Design an <u>analog</u> control system using <u>negative feedback</u> for an elevator in a building.

- **The elevator (1) hangs from a cable in the elevator shaft, (2) can move up and down on a set of vertical rails from the basement to the fifth floor, and (3) carries a maximum of 10 passengers.**
- **The cable is wound around a large drum of radius R, and a large electric motor is provided to turn the drum. The distance between floors is $D = 4\pi R = 4$ m (to an accuracy of 1 mm).**
- **The other end of the cable comes off the drum and is connected to a counterweight which can also move up and down on a set of rails. The counterweight has mass W equal to the mass of the elevator M plus the mass of 5 passengers (assume all passengers have the same mass p).**
- **In the elevator car and on each floor are a set of buttons for the six possible floors: 0 (the basement), 1, 2, 3, 4, and 5.**



- **There is a floor selector circuit that produces an output that corresponds to the last button pushed: –10 V for floor 0 (the basement), –6 V for floor 1, etc., up to +10 V for floor 5. When a new floor is selected, the elevator door closes, the elevator moves to the desired floor, and the door opens.**
- **The elevator lifting motor has a power converter circuit that converts a –10 volt to +10 volt input signal V_{in} (input impedance 10 kΩ) to a high current –600 volt to +600 volt potential V_m that powers the motor. $V_m = 60\ V_{in}$.**
- **The motor provides the force needed to hold the elevator at a selected floor by counteracting the imbalance between the mass of the elevator plus n passengers (M + n p) and the mass of the counterweight (W = M + 5 p).**
- **To hold the elevator when empty V_m = –300 V; with 5 passengers V_m = 0 V; with 10 passengers V_m = +300 V.**
- **The motor also provides the force needed to accelerate the elevator (plus counterweight) from one floor to another.**
- **You have a 10 kΩ helical resistor (10 turns)**
- **You also have a difference amplifier with a 1 MΩ input impedance on both the + and – inputs, an output impedance of 100 Ω, and a gain G that can be set by you.**

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4.1 (20 points) Sketch your circuit design, including the floor selector circuit, the motor power converter, the elevator motor, the difference amplifier, and any other components that may be necessary.

4.2 (5 points) For G = 100 and 1000, tabulate the voltages at important points in your circuit when the elevator has 5 passengers, the 2nd floor has been selected, and the elevator has come to rest.

4.3 (5 points) For G = 100 and 1000, tabulate the voltages at important points in your circuit when <u>5 more passengers enter the elevator</u> (total = 10) while the floor selector circuit is still set to the 2nd floor. Describe any motion of the elevator relative to 4.2 above.

4.4 (5 points) For G = 100 and 1000, tabulate the voltages at important points in your circuit when <u>all passengers get off the elevator</u> while the floor selector circuit is still set to the 2nd floor. Describe any motion of the elevator relative to 4.3 above.

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4.5 (15 points) For G = 1000, plot the voltages at important points in your circuit from time t = 0 to 100 s during the following events:

t = 0 s **the elevator is at rest with 5 passengers at floor 2**

t = 10 s **5 more passengers instantaneously jump on**

t = 20 s **the 4th floor is selected**

t = 30 s **the elevator comes to rest**

t = 40 s **all passengers instantaneously jump off**

t = 50 s **the basement is selected**

t = 70 s **the elevator comes to rest**

Assume that from rest, the elevator takes 1 s to accelerate to its limiting speed, and 1 s to decelerate to rest.

Problem 5 (34 points)

Design a circuit for controlling a street light. The street light is to be turned on at night and turned off during the day. Components available are:

- **PIN photodiode**
- **Street light (200 V, 10 A)**
- **Electromechanical relay switch (input 10 V at 1 A, output 200 V at 10 A)**
- **Additional components as needed, but keep it simple**

5.1 (18 points) Sketch your design, showing and labeling all essential components and interconnections.

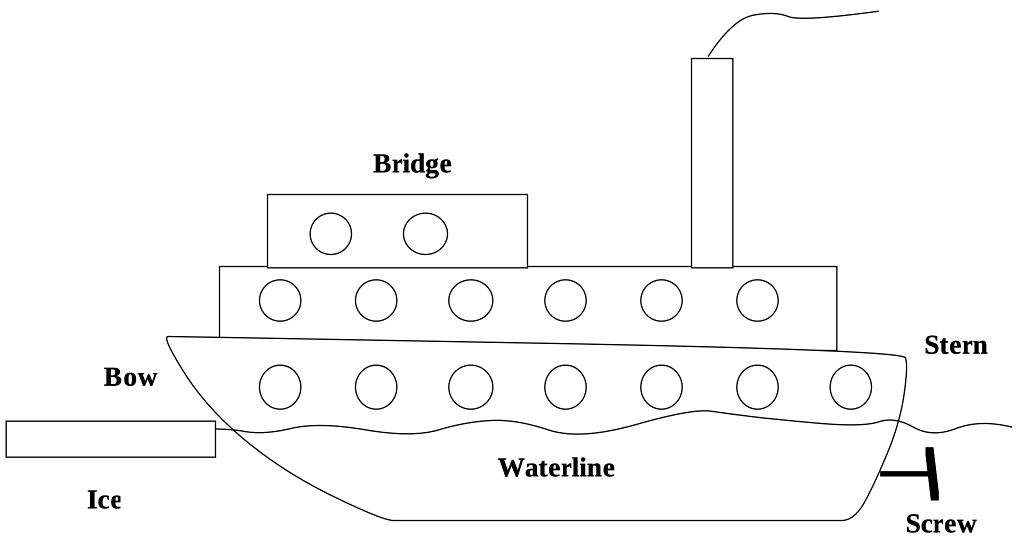
5.2 (5 points) List voltages at key points in the circuit at night.

5.3 (5 points) List voltages at key points in the circuit during the day.

5.4 (6 points) Describe three important common-sense considerations for mounting the PIN photodiode.

Problem 6 (24 points)

You have just been hired to design a sensor for a new class of icebreaker ship. These ships are used to smash their way through sheets of floating ice, either to get to a destination, or to clear a passage for other ships. The hull (outer structural surface) is very thick and strong, but the ship's engines are powerful and it is possible to damage or destroy the hull by driving it against large floating slabs of thick ice. The plan is to provide the captain of the ship with a continuous monitor of the *shear* on the hull at the water line. The *shear* is the difference between the strain a few feet below the water line (where the ice is pushing against the moving ship) and the strain a few feet above the water line (where there is no ice). When the ice becomes thicker or the slabs become larger, the engine speed can be reduced to avoid damage to the hull.



Design a system that

- **Senses the difference in strain $S_+ - S_-$ on the hull between a few feet above the water line S_+ and a few feet below the water line S_-**
- **Provides an analog signal proportional to $S_+ - S_-$ such that an output of 5 V corresponds to $S_+ - S_- = 0.1\%$.**
- **Provides filtering suitable for the signal and noise frequencies that you would anticipate.**
- **Displays the value of the shear on the ship's bridge (control room)**

Assume that the temperature of ice-laden sea water is constant (28°C) so you do not have to compensate for changes in temperature.

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6.1 (16 points) Sketch and label all essential components and connecting wires.

6.2 (4 points) Describe or sketch the location of the strain gauges in your design.

6.3 (4 points) Show on your block diagram the typical voltages that would occur for a compressive strain $S_{-} = \Delta L/L = 0.1\%$ below the water line and $S_{+} = 0$ above the water line.

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Equations, some of which you may need:

$$\frac{V_1}{V_1+V_2}=\frac{R_1}{R_1+R_2} \qquad R(T)=R(T_0)\exp\left[\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)\right] \qquad V_{\text{rms}}=\sqrt{B\left[(D_1G)^2+(D_0)^2\right]}$$

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

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

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

$$v=v_0+at \quad x=x_0+v_0t+0.5at^2 \quad \text{(constant } a\text{)} \qquad g=10\ \text{m s}^{-2}$$

$$T=T_2-(T_2-T_1)e^{-t/\tau} \qquad I=I_0e^{-kLC} \qquad \Delta x=\frac{\Delta V}{dV/dx}$$

$$I_{\text{rms}}=\sqrt{2qI(F_2-F_1)} \qquad q=1.60\times10^{-19}\ \text{Coulombs}$$

$$V_{\text{rms}}=\sqrt{4kTR(F_2-F_1)} \qquad k=1.38\times10^{-23}\ \text{Volt}^2\ \text{sec ohm}^{-1}\ {}^\circ\text{K}^{-1}$$

$$R_T=R_3\frac{V_bR_1-V_0(R_1+R_2)}{V_bR_2+V_0(R_1+R_2)} \qquad V_0=G_\pm(V_+-V_-)+G_c(V_++V_-)2$$

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

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

$$V_T=V_{\text{BE}2}-V_{\text{BE}1}=\frac{kT}{q}\ln\left(\frac{I_1}{I_2}\right) \qquad k/q=86.17\ \mu\text{V/K}$$

$$P_R=\sigma AT^4 \quad \sigma=5.6696\times10^{-8}\ \text{W m}^{-2}\text{K}^4$$

$$E=hc/\lambda \quad hc=1240\ \text{eV nm} \qquad \lambda_{\max}=(2.8978\times10^6\ \text{nm K})/T$$

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

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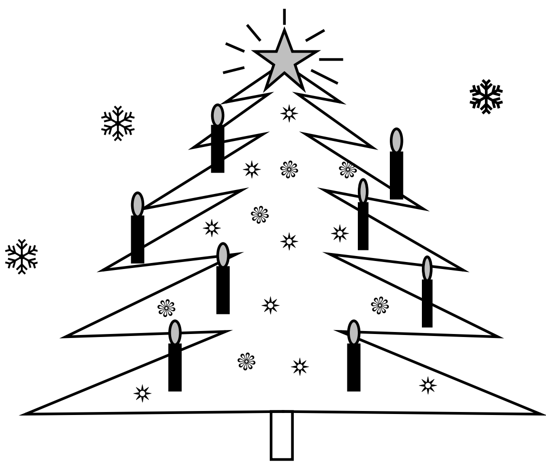
$$Q = \pi I + I^2 R/2 + K_p(T_s - T_0) + K_a(T_a - T_0) \qquad T_{equ} = \frac{\pi I + I^2 R/2 + K_p T_s + K_a T_a}{K_p + K_a}$$

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

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

Johnson noise = 129 μV for 1 MHz and 1 MΩ

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



HAPPY
HOLIDAYS!!