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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 12, 1991 12:30 - 3:30 PM

You have three hours to work on the exam, which is to be taken closed book. ***You may omit problem 5a or 5b, depending on your preference.*** Calculators are OK, but not needed. Total points = 200 out of 1000 for the course.

1 _____________ (30 max) 2 _____________ (20 max) 3 ______________ (35 max)

4 _____________ (35 max) 5a _____________ (35 max) 5b ______________ (35 max)

6 ______________ (45 max) TOTAL _____________ (200 max)

COURSE GRADE SUMMARY

LAB REPORTS:

4 __________ 5 __________ 6 __________ 7 __________ 11 __________

12 __________ 13 __________ 14 __________ 15 __________ 16 __________

17 __________ 18 __________ 19 __________ 24 __________

LAB TOTAL =_______ (1000 max) (top 10 lab report grades included- others in parentheses)

LAB TOTAL X 7/10 ______________ (700 max)

MID-TERM ______________ (100 max)

FINAL EXAM ______________ (200 max)

TOTAL COURSE GRADE ______________ (1000 max)

COURSE LETTER GRADE

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Problem 1 (30 points)

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

1.1 Sensor

1.2 Response curve of a sensor

1.3 Sensitivity of a sensor

1.4 Thermocouple sensor

1.5 Thermoelectric heat pump

1.6 Digital angle encoder

Problem 2 (20 points)

Consider a optical digital position encoder capable of measuring linear displacement over a range of 100 mm with an accuracy of 25 μm.

2.1 (5 points) How many bits are needed to achieve the stated accuracy?

2.2 (12 points) Sketch the active components of the device in sufficient detail to show how it works.

2.3 (3 points) What code would be suitable for the optical pattern? (give name or example)

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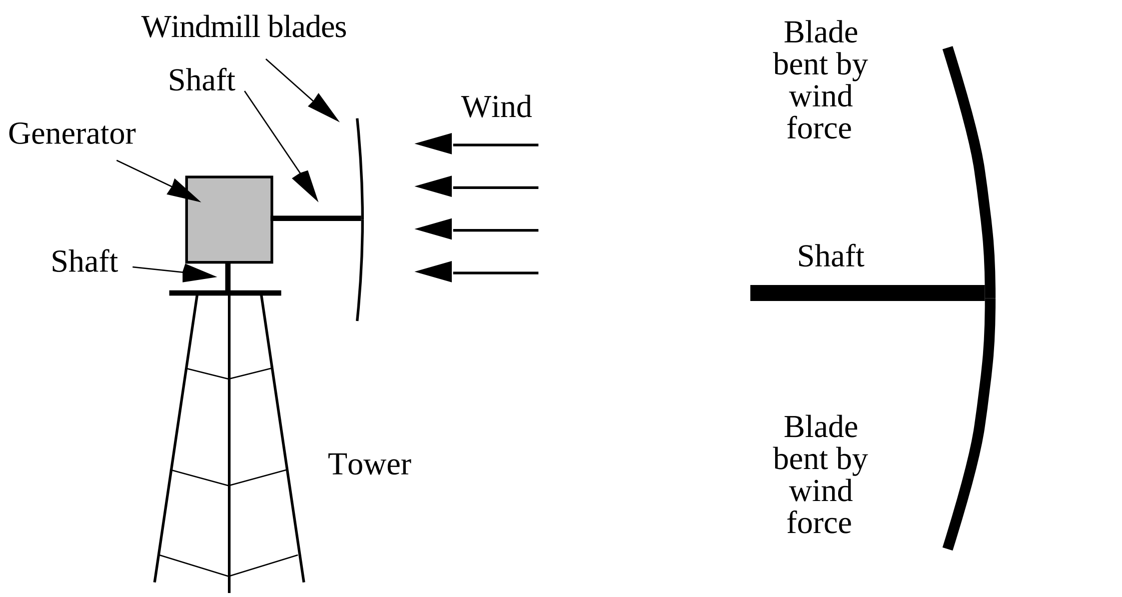
Problem 3 (35 points)

You have just been hired to help test a new type of large windmill. Large windmills generate considerable power at high wind velocity, but their blades can be destroyed if the wind velocity becomes too great. Your job is to instrument a test windmill so that you can measure the backward bending of the moving blades and determine the maximum safe wind velocity. At dangerous wind speeds, the windmill can be "shut down" by rotating the generator housing 90° on a vertical axis so that the wind strikes the blades from the side.

Assume the following:

- You have decided to use metal foil strain gauges with gauge factor G = 2 (similar to those used in the 145L lab)
- You have decided to mount the strain gauges, necessary electronics, and a small, rugged radio transmitter on the moving blade and to transmit the information to a radio receiver on the ground.
- The radio transmitter can accept signals in the –10 to + 10 volt range and the radio receiver reproduces the transmitted signal with the same amplitude.
- The radio system has a frequency response 0 Hz to 10 kHz, and adds 10 mV of white noise in this frequency band.

Design a system that senses the backward bending of the wind on the moving blade, transmits the signal to a radio receiver on the ground, and interfaces the signal to a microcomputer.
- Your design should reject noise outside of the 0-100 Hz frequency band of interest
- Your design should compensate for temperature variations



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3.1 (10 points) On the diagram on the previous page, show where you would attach the strain gauges and other components to the blade.

3.2 (15 points) Draw a block diagram of your system, showing and labeling all essential components and connecting wires both on the blade and on the ground.

3.3 (10 points) Show on your block diagram above the voltages that would occur for typical strains $|\Delta L/L| = 0.1\%$.

Problem 4 (35 points)

You are designing a thermocouple-based temperature system for measuring the temperature of a furnace over the 25 °C to 500 °C range with an absolute accuracy of 2 °C but do not want the bother of providing ice to stabilize the temperature of the reference junction. Instead, you decide to leave the reference junction in the air of the room and measure the temperature of the room (maximum range 10 to 45 °C) with a thermistor, which would provide sufficient accuracy. The correction of the thermocouple output for room temperature will be done by a microcomputer program.

4.1 (7 points) Design a circuit that converts the thermocouple output into a suitable voltage V_{tc} (–5 to +5 volts) for input to a microcomputer. Draw a block diagram and label all necessary analog circuit elements and signal lines. (It is not necessary to include analog filtering)

4.2 (7 points) Design a circuit that converts the thermistor output into a suitable voltage V_{tm} (–5 to +5 volts) for input to a microcomputer. Draw a block diagram and label all necessary analog circuit elements and signal lines. Show where the thermistor is placed in the diagram 4.1 above. (It is not necessary to include analog filtering)

4.3 (7 points) Sketch below the voltages V_{tc} and V_{tm} as a function of temperature T.

4.4 (7 points) Show graphically on your sketch how the temperature of the sensing junction (in °C) would be determined, given a value of V_{tc} and a value of V_{tm}.

4.5 (7 points) Describe in a flow chart, a list of steps, or a sentence or two what the microcomputer program would have to do to convert V_{tc} and V_{tm} into the temperature of the sensing junction in °C.

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Problem 5a (35 points)

Design a temperature control system using a thermoelectric heat pump, a thermistor, and a micro-computer with –10 V to +10 V A/D and D/A converters. The heat pump and thermistor are in a steel box insulated with glass fibers. (It is not necessary to include analog filtering)

5a.1 (8 points) Sketch below a block diagram for the sensor side of the system, from the thermistor to the A/D converter.

- Include and label all essential components.
- Show typical voltage levels at all important points.

5a.2 (7 points) Sketch on the next page a block diagram for the actuator side of the system, from the D/A converter to the thermoelectric heat pump.

- Include and label all essential components.
- Show typical voltage and current levels at all important points.

5a.3 (15 points) Describe the function of each of the main components of your system.

5a.4 (5 points) What minimum and maximum temperatures do you think that this control system could achieve? Give reasons for your limits.

Problem 5b (35 points)

Your first assignment as an engineer with the Super Prosthetics Corp. is to design a battery-powered EMG-type control system for an motor-operated prosthetic arm. The system is to do the following:

- sense the EMG signal from three electrodes (+, –, ground) on some available muscle
- process the raw EMG signal to produce a control signal with a frequency content 0- 2 Hz and a voltage level between 0 and 10 volts.
- interface the processed signal to an A/D converter connected to a microcomputer-on-a-chip that is built into the prosthetic arm and has a suitable control program.
- interface the microcomputer D/A converter to the prosthetic motor.

Your design must work in spite of electrode and amplifier drift, and large amounts of 60-Hz interference. [Note: Low-voltage battery-powered bioinstrumentation that is clearly isolated from all other power sources does not require an isolation amplifier]

5b.1 (15 points) Sketch block diagram of your system. Include and label all essential components and signals.

5b.2 (5 points) Describe or sketch the raw EMG signal. Include time and voltage scales.

5b.3 (15 points) Describe the function of each of the main components of your system and describe or sketch the waveform that it produces.

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Problem 6 (45 points)

A test kit is available for measuring the levels of lead in eating utensils (cups, bowls, plates, etc.). The utensil is first soaked in hot acetic acid (vinegar) and the acid is mixed with a reagent. If no lead is present, the mixture is clear. If a small amount of lead is present, the mixture is yellow. If a dangerous amount of lead is present, the mixture is dark orange.

Design a system for determining the concentration of lead in ppm, using a green LED, a photodiode, and a microcomputer with A/D converter (input range –10 V to +10 V). (It is not necessary to include analog filtering)

Assume the following:

- The light intensity A passing through the solution is given by $A = A_0 e^{-kLC}$, where C is the lead concentration in ppm, L is the thickness of the solution in cm, and the extinction coefficient for green light is $k = 1\ \text{ppm}^{-1}\ \text{cm}^{-1}$.
- The thickness of the solution L = 1 cm.
- The brightness of the LED is such that a clear solution produces a current of 100 µA in the photodiode and your design should convert this into a signal of 5 volts at the A/D converter of the microcomputer .
- The photodiode has a noise current of 1 µA rms. Ignore all other noise sources.

6.1 (15 points) Sketch a block diagram including and labeling all essential components. (You can show the A/D and microcomputer as a single block).

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6.2 (5 points) Derive an expression for the A/D input voltage as a function of lead concentration C, dark current I_D, and amplifier offset I_B.

6.3 (5 points) Describe how a user would calibrate the system.

6.4 (10 points) Neglecting dark current and amplifier offset, derive an expression for the uncertainty ΔC as a function of concentration C.

Hint: $\Delta C = \dfrac{\Delta I}{dI / dC}$

6.5 (5 points) What is the uncertainty ΔC at C = 0.1 ppm, 1 ppm, and 3 ppm?
[Hint: $e^{0.1} = 1.105$, $e^{1} = 2.718$, $e^{3} = 20.086$, $e^{4.605} = 100$.]

6.6 (5 points) What is the highest concentration of lead that you can reliably measure? (Hint: find the concentration at which $\Delta C = C$)

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Equations, some of which you may need:

$$\frac{V_{\mathbf{1}}}{V_{\mathbf{1}}+V_{\mathbf{2}}}=\frac{R_{\mathbf{1}}}{R_{\mathbf{1}}+R_{\mathbf{2}}} \qquad R(T)=R(T_0)\exp\left[\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)\right]$$

$$V(t)=V_0\sin(\omega t) \qquad \omega=2\pi f \qquad V_{\mathbf{0}}=A(V_{+}-V_{\mathbf{1}})$$

$$T=T_2-(T_2-T_1)e^{-t/\tau} \qquad I=I_0e^{-kLC}$$

$$I_{rms}=\sqrt{2qI(F_2-F_1)} \qquad V_{rms}=\sqrt{4kTR\,(F_2-F_1)}$$

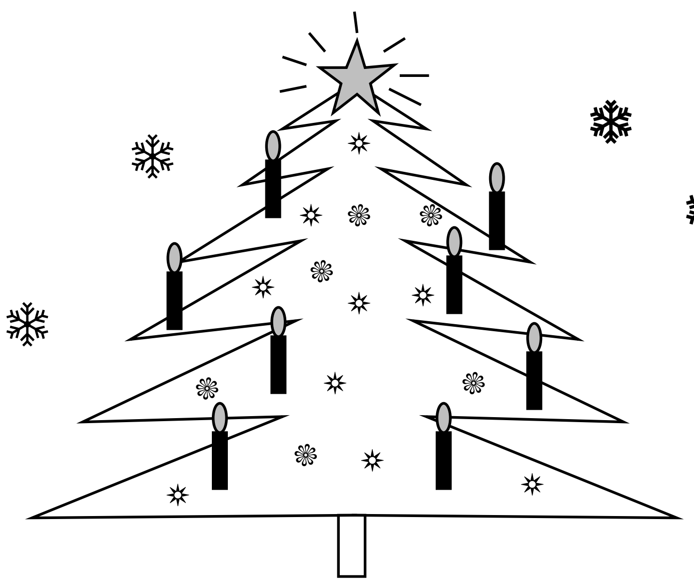
$q = 1.60 \times 10^{-19}$ Coulombs $\qquad$ $k = 1.38 \times 10^{-23}$ Volt^2 sec ohm^{-1} °K^{-1}

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

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

$$\frac{\Delta R}{R}=G\frac{\Delta L}{L} \qquad V_0=V_b\,G\left(\frac{\Delta L}{L}\right)$$

$$Q=\frac{T_{n+\mathbf{2}}-T_{n+\mathbf{1}}}{T_{n+\mathbf{1}}-T_n} \qquad T_{equ}=T_{n+\mathbf{1}}+\frac{T_{n+\mathbf{2}}-T_{n+\mathbf{1}}}{\mathbf{1}-Q}$$



HAPPY
HOLIDAYS!!