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

EECS 145L: Electronic Transducer Laboratory

FINAL EXAMINATION Fall 2010

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 _______________(40 max) 2 _______________ (20 max) 3 ________________ (25 max)

4 _______________ (30 max) 5 _______________ (40 max) 6 __________ (45 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

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PROBLEM 1 (40 points)

Briefly describe the construction and function of the following components.

1.1 Digital position (or angle) encoder (8 points)

1.2 Thermocouple (8 points)

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1.3 Thermistor (8 points)

1.4 Isolation amplifier (8 points)

1.5 Silicon photodiode (8 points)

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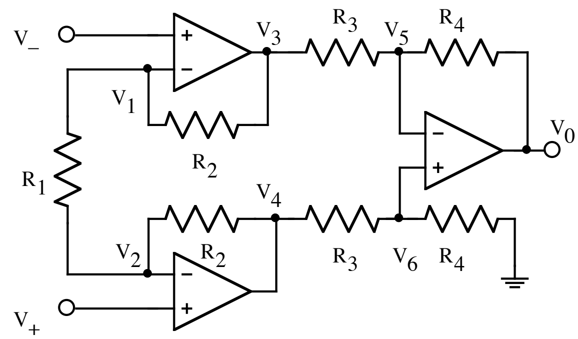
PROBLEM 2 (20 points)

Analyze the **first stage** of the standard instrumentation amplifier, shown here:



2.1 (10 points) Derive an equation for the **common mode** gain $(V_4+V_3)/(V_++V_-)$ of the **first stage** of the above instrumentation amplifier. Assume the virtual short rule for all op-amps.

2.2 (10 points) Derive an equation for the **differential gain** $(V_4-V_3)/(V_+-V_-)$ of the **first stage** of the instrumentation amplifier shown above. Assume the virtual short rule for all op-amps.

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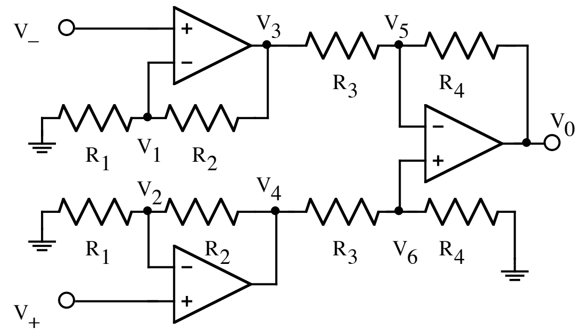
PROBLEM 3 (25 points)

You have been asked to analyze the **first stage** of a new instrumentation amplifier design, shown here:



3.1 (10 points) Derive an equation for the **common mode** gain $(V_4+V_3)/(V_++V_-)$ of the **first stage** of the new instrumentation amplifier design shown above. Assume the virtual short rule for all op-amps.

3.2 (10 points) Derive an equation for the **differential mode** gain $(V_4-V_3)/(V_+-V_-)$ of the **first stage** of the new instrumentation amplifier design shown above. Assume the virtual short rule for all op-amps.

3.3 (5 points) Is the new instrumentation amplifier design better than the standard design (problem 2 above)? If not, why not?

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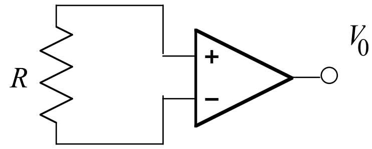
PROBLEM 4 (30 points)
In this problem you will consider an instrumentation amplifier as used to measure the rms Johnson noise in a resistor *R*.



The instrumentation amplifier has the following characteristics:

- Amplifier noise rms (relative to input) = 12.9 nV $Hz^{-1/2}$ sqrt(Δf)
- Gain-bandwidth product = 100 MHz
- Input leakage currents can be neglected
- The gain can be set by external resistors (since these resistors are after the first gain stage, you can neglect their Johnson noise)

4.1 (5 points) With the instrumentation amplifier set for a differential gain of 100, and *R* = 1 MΩ at T = 300 K, what is the total rms noise voltage (amplifier plus resistor) at the amplifier output ? Hint: See the equation sheet for Johnson noise and combining random variables.

4.2 (5 points) With the instrumentation amplifier set for a differential gain of 10,000, and *R* = 1 MΩ at T = 300 K, what is the total rms noise voltage at the amplifier output?

4.3 (5 points) With the instrumentation amplifier set for a differential gain of 10,000, and R = 1 MΩ at T = 75 K, what is the total rms noise voltage at the amplifier output?

4.4 (5 points) With the instrumentation amplifier set for a differential gain of 10,000, and R = 500 kΩ at T = 300 K, what is the total rms noise voltage at the amplifier output ?

4.5 (5 points) With the instrumentation amplifier set for a differential gain of 10,000, R = two 500 kΩ resistors in series, use the result from part **4.4** to compute the total rms noise voltage at the amplifier output. (Hint: use the formula for adding two independent random variables)

4.6 (5 points) With the instrumentation amplifier set for a differential gain of 10,000, and R = 1 MΩ, at what resistor temperature T does its Johnson noise equal the instrumentation amplifier noise?

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PROBLEM 5 (40 points)

Design a system that converts sound into light for transmission down an optical fiber and then converts the optical signal back into sound.

Assume the following

1 You have a microphone that produces a maximum differential signal of 100 mV p-p (peak-to-peak) at the maximum sound intensity that you need to consider.
2. The microphone wires have 60 Hz electromagnetic pickup of pure 10 mV common mode (for simplicity assume zero differential 60 Hz pickup).
3. You have an light emitting diode (on one end of the optical fiber) that should be driven at 100 mA p-p when the microphone signal is at maximum.
4. You have a photodiode (on the other end of the optical fiber) that produces 1 mA p-p when the light emitting diode is producing its maximum signal (100 mA p-p input).
5. The loudspeaker should be driven at 10 V p-p when the microphone signal is at maximum. The speaker has an input impedance of 10 Ω.
6. Each element in the system should be operated in a linear mode (output proportional to input).

In your design you should provide enough detail so that a skilled technician could be able to build it and understand how it works. Include all necessary components and label all signals with their maximum (p-p) amplitude. You may use any circuit components used in the laboratory exercises or discussed in lecture, but keep it simple.

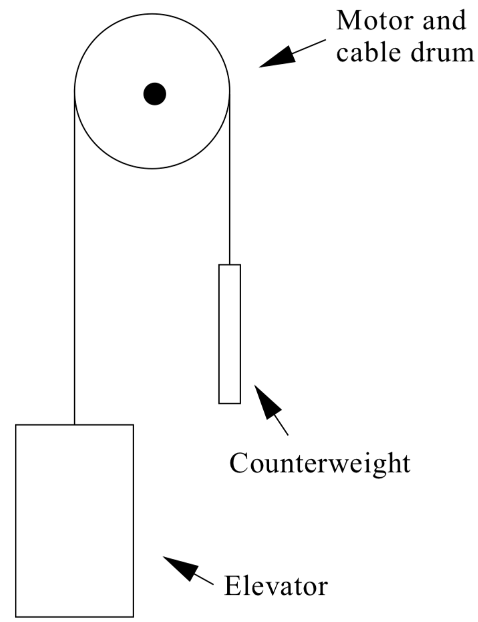
PROBLEM 6 (45 points)

Design a system for the PID control of an elevator. The elevator has a counterweight that is equal to the weight of the elevator plus the weight of the average passenger load (5 persons).

Set point: A knob connected to the shaft of a 10 kΩ rotary resistor is used to specify the desired floor from floor 0 (basement) to floor 10.

Actuator: The elevator is raised and lowered on cables wound on a drum. A motor at the top of the shaft rotates the drum to raise and lower the elevator. A motor actuator circuit converts an input voltage into a motor current that produces a force on the cables. An input of -5V will hold an empty elevator and an input of +5V will hold an elevator with 10 passengers.

Sensor: A 10 kΩ multi-turn helical resistor connected to the shaft of the cable drum. The wiper is at one end at floor 0 and at the other end at floor 10.



6.1 (13 points) Sketch your design, showing all resistors and amplifiers, but leave the controller circuit (that converts an error signal into a motor controller input) as a box.

6.2 (12 points) Sketch the design of a PID controller (as an analog circuit) with separate manual (knob) controls for the proportional, integral, and differential coefficients.

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6.3 (10 points) Describe how your PID design works for the average passenger load (5 persons) when a new floor is selected.

6.4 (10 points) Describe how your PID design works when 10 people enter an empty elevator while it is holding at a floor. (Note: real elevators have additional controls that prevent movement while the doors are open.)