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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 18, 1995 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. You will not receive full credit if you do not show your work. Total points = 210 out of 1000 for the course.

1 _______________ (48 max) 2 _______________ (60 max)

3 _______________ (42 max) 4 _______________ (60 max)

TOTAL ______________ (210 max)

COURSE GRADE SUMMARY

LAB REPORTS (5 required, 100 points each):

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 _____________ (90 max)

FINAL EXAM _____________ (210 max)

TOTAL COURSE GRADE _____________ (1000 max)

COURSE LETTER GRADE

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Problem 1 (48 points)

In 50 words or less, describe the following:

1.1 (8 points) The differences between the electrical functions of (a) the ground fault interrupter circuit and (b) the circuit breaker.

1.2 (8 points) The differences between the electronic properties of (a) the operational amplifier and (b) the instrumentation amplifier.

1.3 (8 points) The differences between (a) common mode gain and (b) differential gain.

1.4 (8 points) The difference between (a) stress and (b) strain.

1.5 (8 points) The difference between (a) accuracy and (b) precision

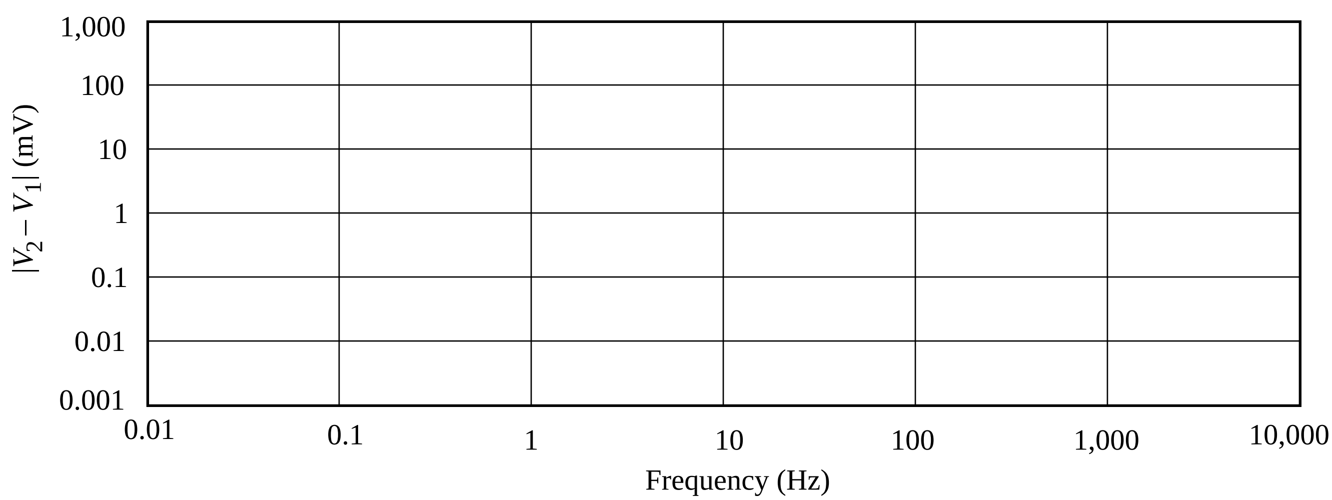
1.6 (8 points) The difference between (a) systolic and (b) diastolic blood pressure

Problem 2 (60 points)

Design a system for the amplification and analog filtering of EEG (brain-wave) data, given that

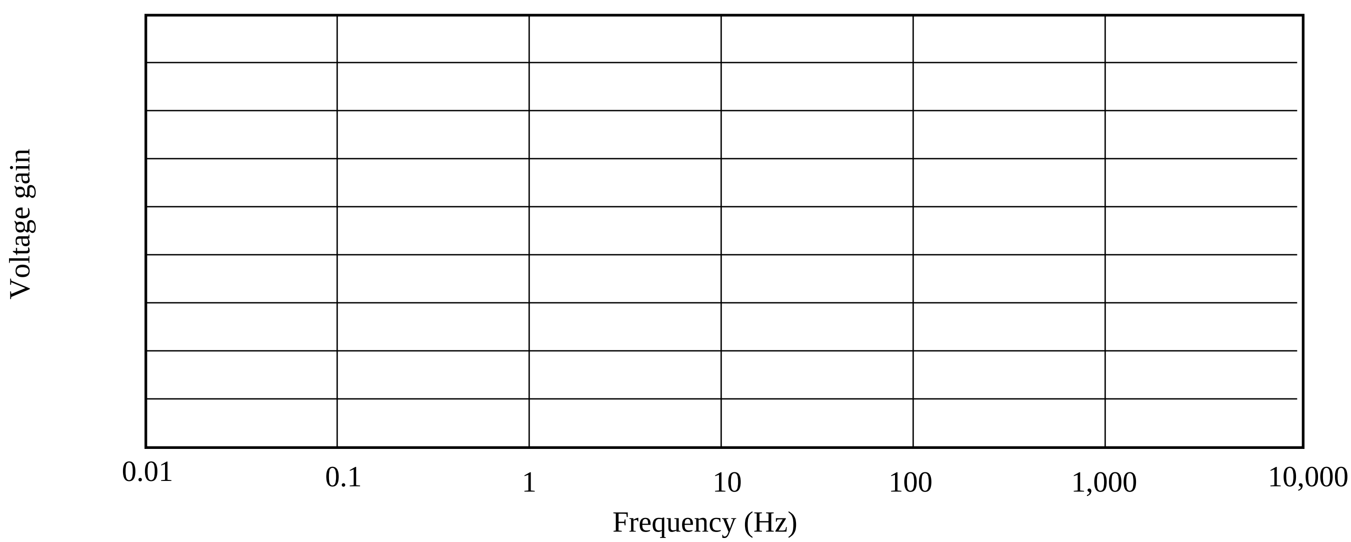
- The electrical signals (V_1 and V_2) are taken from two skin electrodes placed on the head (a third "ground" electrode is placed on the neck).
- The wires from the skin electrodes to your system are approximately 1 m long. The 60 Hz electromagnetic interference received by one wire is 100 mV (peak-to-peak) and by the other wire is 110 mV (peak-to-peak).
- The desired differential EEG signal has an amplitude of 50 µV peak-to-peak and is in the 0.5 to 30-Hz frequency band.
- Electrode drift produces a differential voltage $V_{ED2} - V_{ED1}$ of 1 mV in the 0 Hz to 0.1 Hz frequency range, and can be ignored at frequencies above this range.
- The EMG background amplitude $V_{EMG2} - V_{EMG1}$ from the head muscles is 100 µV and is in the 100-Hz to 3-kHz band.
- To summarize the voltages present on the two wires:
  $V_1 = V_{ED1} + V_{EEG1} + V_{EMG1} + (0.050 \text{ volts}) \sin(2\pi t f_0)$ (f_0 = 60 Hz)
  $V_2 = V_{ED2} + V_{EEG2} + V_{EMG2} + (0.055 \text{ volts}) \sin(2\pi t f_0)$
- You wish to see the differential EEG signal $V_{EEG2} - V_{EEG1}$ undistorted (variations in gain less than 10% from 0.5 to 30 Hz) and reduce all other backgrounds to below 2% of the EEG signal
- You decide to use an instrumentation amplifier followed by analog filtering.
- Your system should amplify the EEG signal to 5 volts peak-to-peak for input to a microcomputer analog input circuit with an input impedance of 10 kΩ.

2.1 (10 points) Using the grid below, show the magnitude of $|V_2 - V_1|$ as a function of frequency before amplification and filtering. Label all signals and backgrounds.



2.2 (15 points) Sketch a block diagram of your system, showing all essential components and signal lines

2.3 (15 points) Plot the differential voltage gain $|V_{out}/(V_2 - V_1)|$ of your system after amplification and filtering, using the grid below. (You may use the voltage ratio or dB for the vertical axis.)



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2.4 (15 points) Describe your analog filtering in terms of filtering elements, number of poles, and approximate location of corner frequencies.

2.5 (5 points) What is the maximum common mode gain that the instrumentation amplifier can have at 60 Hz?

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Problem 3 (42 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 (unstrained resistance 100Ω, gauge factor = 2) in a bridge circuit
- 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/Hz$^{1/2}$ (relative to the input)

3.1 (21 points) Sketch your circuit design, including all components and wires.

3.2 (7 points) What bridge bias voltage gives maximum bridge sensitivity?

3.3 (7 points) What is the bridge output sensitivity in mV/C°?

3.4 (7 points) What is the noise level in terms of C° at 1M Hz and 1 Hz?

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Problem 4 (60 points)

Design a system for automatically measuring the output offset voltage of an instrumentation amplifier from 0°C to 40°C in 5°C steps (0, 5, 10, 15, 20, 25, 30, 35, 40°C).

Design requirements:

- The system uses a computer to change and measure the temperature of the instrumentation amplifier to an accuracy of 0.1 °C.
- The computer also records the output offset voltage at each of the nine temperatures
- The instrumentation amplifier output offset voltage is to be measured to an accuracy of 1 mV over the range from –100 mV to +100 mV.
- The instrumentation amplifier to be tested is set to a gain of 1000 by a single external 10 kΩ resistor.
- The inputs of the instrumentation amplifier are to be connected to ground through 1 kΩ resistors.

Components available:

- Instrumentation amplifier to be tested
- Thermoelectric heat pump
- Power amplifier (input and outputs –10 to +10 volts)
- Computer with two analog input ports (–10 to + 10 volts) and one analog output port (–10 to + 10 volts). All analog ports have 12 bits of resolution (one part in 4095).
- An expert programmer (who has not taken EECS 145L)
- Thermocouple temperature sensor (assume 50 μV/C°)
- Any other circuit elements you may need, but keep it simple

4.1 (35 points) Sketch your design, showing and labeling all essential components and interconnections.

4.2 (25 points) List the steps that the system must perform to measure the output offset voltage at the nine temperatures.

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Equations, some of which you may need:

$R(T) = R(T_0)\exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$ $\qquad V_{\text{rms}} = \sqrt{B\left[(D_1 G)^2 + (D_0)^2\right]}$ $\qquad \Delta x = \dfrac{\Delta V}{dV/dx}$

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

$|G| = \dfrac{1}{\sqrt{1+(f/f_c)^{2n}}} \qquad \tan\left(\dfrac{\phi}{n}\right) = \dfrac{f}{f_c}$ $\qquad |G| = \dfrac{(f/f_c)^n}{\sqrt{1+(f/f_c)^{2n}}} \qquad \tan\left(\dfrac{\phi}{n}\right) = \dfrac{-f}{f_c}$

$N(x) = N(0)e^{-x\mu}$ $\qquad I = I_0 e^{-kLC}$ $\qquad T = T_2 - (T_2 - T_1)e^{-t/\tau}$

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

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

$I_{\text{rms}} = \sqrt{2qI(F_2 - F_1)}$ $\qquad q = 1.60 \times 10^{-19}$ Coulombs

$V_{\text{rms}} = \sqrt{4kTR(F_2 - F_1)}$ $\qquad k = 1.38 \times 10^{-23}$ Volt^2 sec ohm^{-1} °K^{-1}

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

$f_c = \dfrac{1}{2\pi RC}$ $\qquad$ "CMRR" $= \dfrac{G_\pm}{G_c}$ $\qquad$ "CMR" $= 20\log_{10}\left(\dfrac{G_\pm}{G_c}\right)$

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

$V_T = V_{\text{BE2}} - V_{\text{BE1}} = \dfrac{kT}{q}\ln\left(\dfrac{I_1}{I_2}\right)$ $\qquad k/q = 86.17\ \mu\text{V/K}$

$P_R = \sigma A T^4 \qquad \sigma = 5.6696 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^4$

$E = hc/\lambda \quad hc = 1240$ eV nm $\qquad \lambda_{\max} = (2.8978 \times 10^6\ \text{nm K})/T$

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

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

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

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

Johnson noise = 129 μV for 1 MHz and 1 MΩ

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