UNIVERSITY OF CALIFORNIA

College of Engineering
Department of Electrical Engineering and Computer Sciences

EECS 145L: Electronic Transducer Laboratory

FINAL EXAMINATION **December 11, 1993 12:30 - 3:30 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 _____________ (45 max) 3 ______________ (50 max)

4 _____________ (30 max) 5 _____________ (45 max)

TOTAL _____________ (200 max)

COURSE GRADE SUMMARY

LAB REPORTS:

4 __________	5 __________	6 __________	11 __________
12 __________	13 __________	14 __________	15 __________
17 __________	18 __________	19 __________	24 __________

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

LAB TOTAL X 5/10	____________	**(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

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

Problem 1 (30 points)

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

1.1 Young's modulus

1.2 Precision of a sensor

1.3 Bimetal switch

1.4 Common Mode Rejection Ratio (of an instrumentation amplifier)

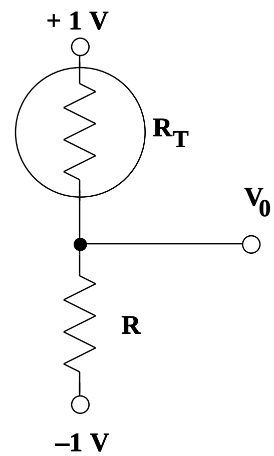
1.5 T-wave (in the ECG)

1.6 Corner frequency (of a Butterworth filter)

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

Problem 2 (45 points)

You are designing a system for measuring temperature using a thermistor in a voltage divider. The voltage is to be read by the analog interface of a computer. The A/D input range is –10.24 V to +10.24 V and the output range is 0 to 2047 (11 bits).



2.1 (10 points) Sketch a block diagram of your design, showing the resistor divider, the microcomputer with analog input port, and anything else needed. (The best value of the resistor R will be explored below.)

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

2.2 (5 points) Write an expression for the output V_0 as a function of thermistor resistance R_T.

2.3 (15 points) Determine the resistor value R that provides the maximum sensitivity dV_0/dT at a temperature of 40°C. At 40°C the thermistor resistance is R_T = 2.5 kΩ and dR_T/dT = 100 Ω/°C.
Hint 1: Maximize $dV_0/dT = (dV_0/dR_T)\ (dR_T/dT)$
Hint 2: The maximum value of $x/(1 + x^2)$ occurs at x = 1.

2.4 (5 points) What is the change in A/D input voltage ΔV that corresponds to a change of one unit in the A/D output?

2.5 (10 points) At 40°C, what is the temperature change ΔT that corresponds to ΔV?

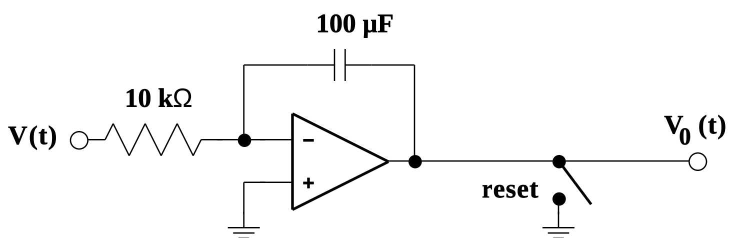
Problem 3 (50 points)

Your job is to design an analog altitude control system for an airplane, using negative feedback. This system is supposed to keep the airplane at a nearly constant altitude (height above sea level), despite updrafts, downdrafts, and changes in engine speed.

The vertical acceleration is measured using a piezoelectric transducer connected to a mass. When the unit it accelerated, the force causes charges to separate. The sensitivity is 10 pC/g (g = 10 m s^{-2}, the acceleration of gravity), and the capacitance is 1 nF.

Integrating this signal gives the vertical velocity. Integrating again gives the altitude.

The circuit below performs the first integral of V(t). A input voltage of 1 V will produce an output V_0 that increases at 1 V/s. A switch can set V_0 to zero at any time t_0.



$$V_0(t) = \int_{t_0}^{t} V(t')dt'$$

Set your circuit gains so that if the system is reset and subjected to a 0.1g acceleration for 1 s, the output is 50 mV.

The altitude of the airplane is changed by a stepping motor that adjusts the angle of the trailing horizontal tail surfaces (the elevators). If the elevators are angled down, the tail of the airplane is forced up, and the airplane dives. If the elevators are angled up, the tail of the airplane is forced down, and the airplane climbs.

3.1 (20 points) Sketch below your system design. Include the sensors, actuators, and any other necessary electronics (but keep it simple). Include and label all essential components and interconnections.

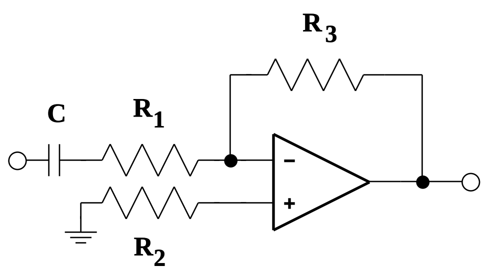
3.2 (15 points) Plot voltage vs. time for the (i) accelerometer output, (ii) the first derivative output, and (iii) the second derivative output for the situation where the system has been reset at t = 0 s, and then subjected to a 0.1 g acceleration for 1 s. Show the time period from t = 0 s to t = 2 s.

3.2 (15 points) Describe how the various components of the system function when the airplane encounters a downdraft.

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

Problem 4 (30 points)

Design a single-stage, inverting, high-pass filter using the op-amp circuit below:



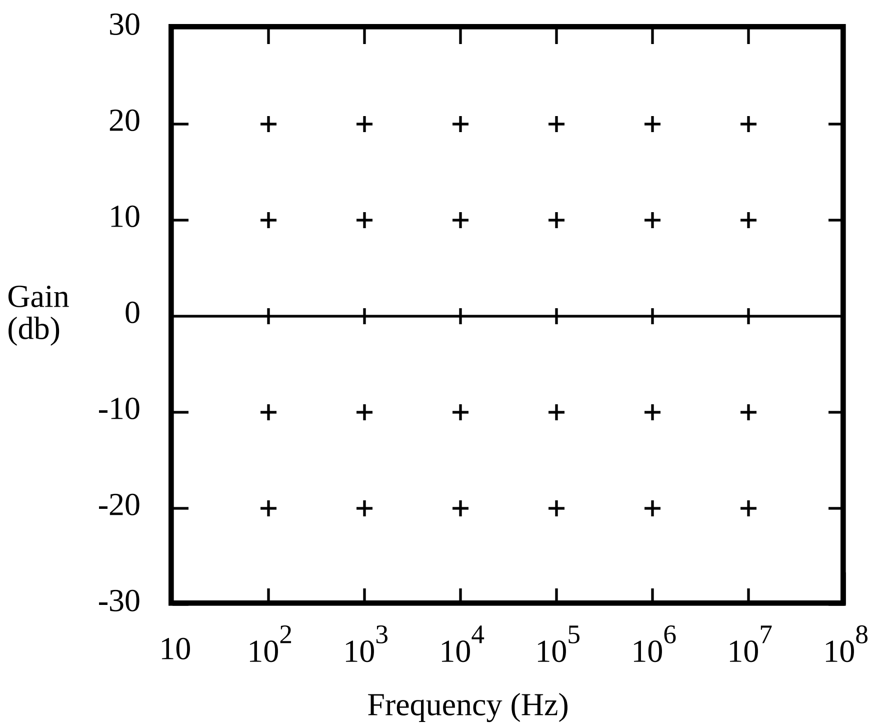
The op-amp specifications are:
• infinite input impedance, no input leakage currents
• above 10 Hz, the open loop gain varies as (frequency)$^{-1}$ and reaches unity gain at 10^7 Hz.

The high pass filter circuit specifications are:
• Low frequency 3 dB point at 100 Hz.
• Gain = 10 in the passband.

4.1 (10 points) For C = 1.59 µF, what values of R_1, R_2, and R_3 would you use?

4.2 (10 points) Give typical values for the input and output impedance of the filter circuit at 10 kHz.

4.3 (10 points) For your design, sketch the Bode plot below:



Problem 5 (45 points)

For the following physical quantities, describe (1) typically what causes them, (2) their nature (the qualities that define them, typical magnitude, etc.), (3) and a means for sensing them and producing a useful ≈5 V electrical signal.

5.1 (15 points) The electrocardiogram (ECG)

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

5.2 (15 points) Visible light

5.3 (15 points) Strain

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

Equations, some of which you may need:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

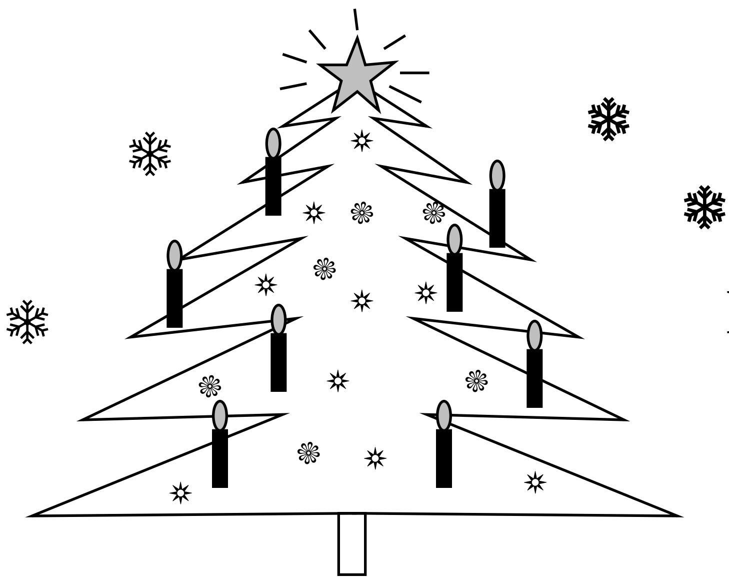
$$\eta=\frac{T_{n+2}-T_{n+1}}{T_{n+1}-T_n} \qquad T_{\mathrm{equ}}=T_{n+1}+\frac{T_{n+2}-T_{n+1}}{1-\eta}$$

SHOW ALL WORK ON THESE PAGES- If necessary, write on reverse side

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

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

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



HAPPY
HOLIDAYS!!