NAME (please print) ____

UNIVERSITY OF CALIFORNIA

College of Engineering
Department of Electrical Engineering and Computer Sciences

EECS 145L: Electronic Transducer Laboratory

FINAL EXAMINATION December 18, 1996 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 = 200 out of 1000 for the course.

1 ______________ (40 max) 2 ______________ (35 max)

3 ______________ (60 max) 4 ______________ (65 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)

In 20-50 words, describe the electrical operation of the following circuits:

1a. (10 points) Isolation amplifier (electromagnetic or optical- you choose)

1b. (10 points) Ground Fault Interrupter

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1c. (10 points) Thermistor

1d. (10 points) Bimetallic temperature switch

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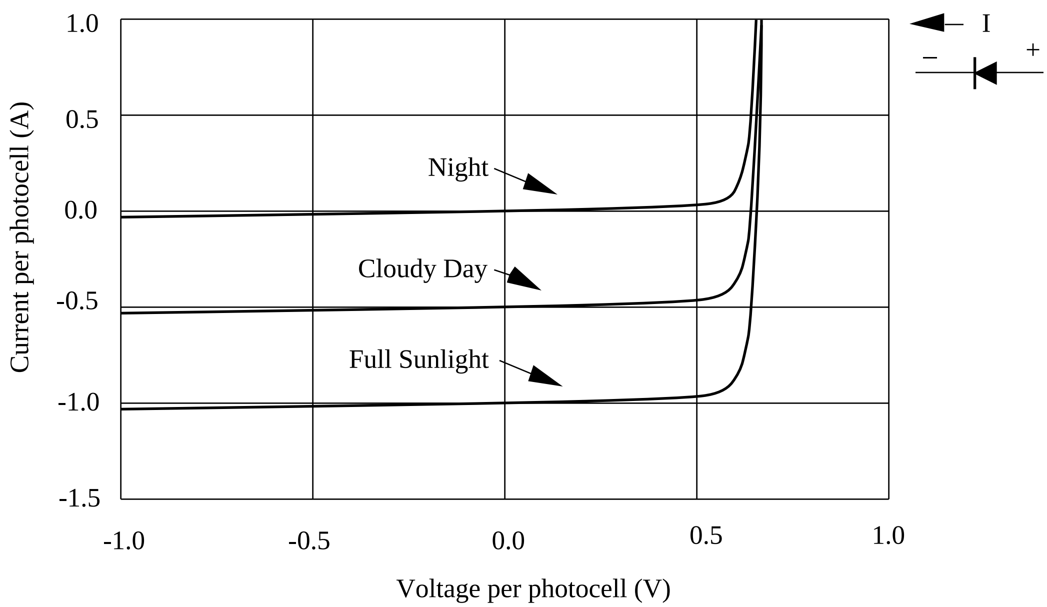
PROBLEM 2 (35 points)

Design a system for converting sunlight into electrical energy stored in a battery.

Assume the following:

- You have 100 large-area photodiodes, to be connected in series.
- You have a clever battery charger circuit (which you do not have to design) whose effective input resistance automatically adjusts to different light levels to extract the largest electrical power from the photodiodes. The batteries are part of this circuit.
- The I-V characteristic of each solar cell is shown in the figure below:



2a. (10 points) Sketch a block diagram of your design. Include and label all essential components and signals.

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2b. (5 points) Describe briefly how the photodiode converts the energy of a photon into electrical energy.

2c. (10 points) On a cloudy day, what is the approximate input to the battery charger circuit in terms of voltage, current, and power? (show your work) (*Hint:* $I = P/V$ is a curve of constant power)

2d. (10 points) Under full sunlight, what is the approximate input to the battery charger circuit in terms of voltage, current, and power? (show your work)

PROBLEM 3 (60 points)

You have designed an electronic circuit that works fine on the bench, but fails miserably in an aircraft during test flights. Thinking that the temperature variations between 0°C and 40°C during the flights might be responsible for the failure, you go back to the lab and test your circuit at different temperatures. To your surprise, you find that your circuit can only operate between 15°C and 25°C.

Your next task is to ***design a temperature control system*** for your circuit, which can be operated on an aircraft in flight.

Assume the following:

- You have decided to mount the circuit in a small, thermally insulated box
- Since your circuit is small, you have decided to use a solid-state thermoelectric (Peltier) heat pump, rather than a larger, heavier mechanical heat pump (motor plus compressor).
- There is ample electrical power on the aircraft to operate your temperature control system

Design requirements:

- The temperature in the insulated box is to be kept within 15°C to 25°C, despite external temperature variations from 10°C to 40°C.
- The above temperature must be maintained during flights lasting 18 hours.

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You should only need components and concepts covered in EECS145L. Your designs will be graded on the basis of

- Meeting the design requirements
- Sufficient detail so that a skilled technician could build your design.
- Avoidance of unnecessary complexity (keep it simple)

3a. (40 points) Sketch a block diagram of your design. Include and label all essential components and signals.

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3b. (10 points) Describe the operation of your system when the temperature outside the box is 0°C. Provide enough detail to convince the other members of your design team that your design will work at 0°C.

3c. (10 points) Describe the operation of your system when the temperature outside the box is 40°C. Provide enough detail to convince the other members of your design team that your design will work at 40°C.

PROBLEM 4 (65 points)

Design a system for recording the electrocardiogram of a human subject in a doctor's office. Assume the following:

- You will use two Ag(AgCl) skin electrodes placed on the arms for the electrocardiogram signal and a third placed on a leg to serve as a "ground" electrode.
- The desired differential electrocardiogram signal has an amplitude of 1 mV (peak-to-peak) and is in the frequency range from 100 Hz to 5,000 Hz.
- The wires from the skin electrodes to your circuit are 1 meter long. The 60 Hz interference on the two arm electrodes are 100 mV (peak-to-peak) common mode and 10 mV (peak-to-peak) differential.
- Electrode drift is approximately 1mV (peak-to-peak) below 1 Hz and can be ignored at higher frequencies.
- For safety, you will use an electromagnetic isolation amplifier, which has a single (not differential) analog input and a fixed gain of 100.

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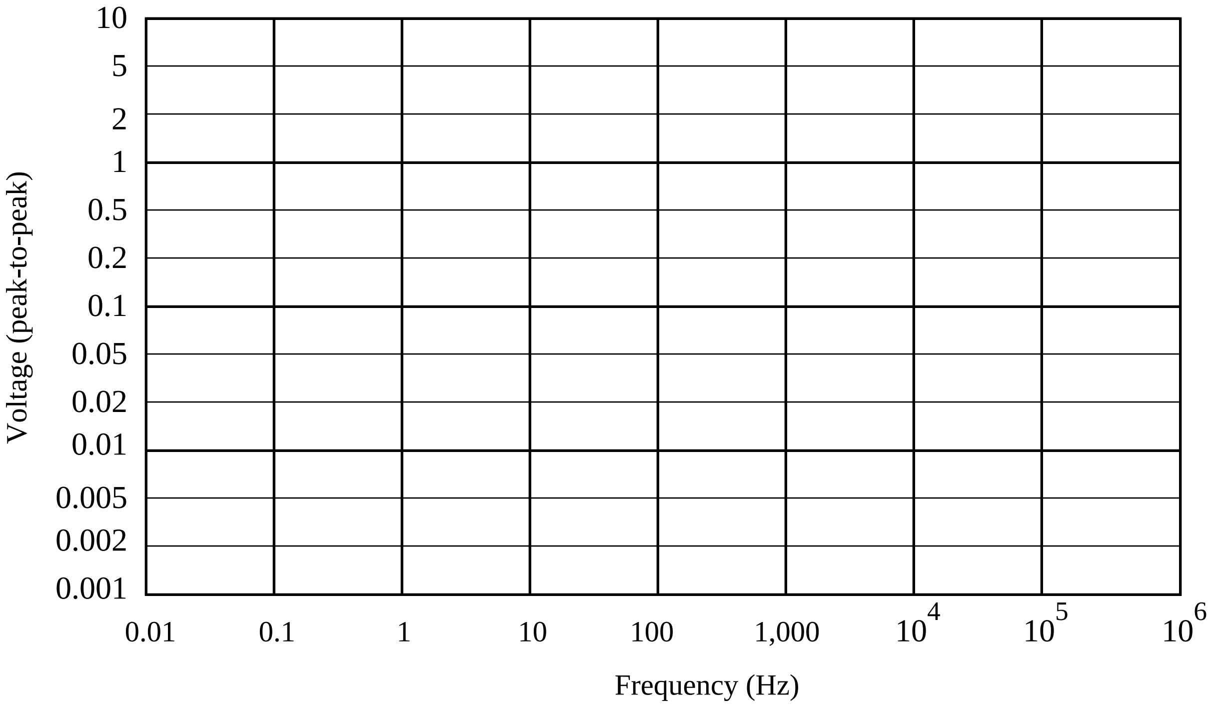
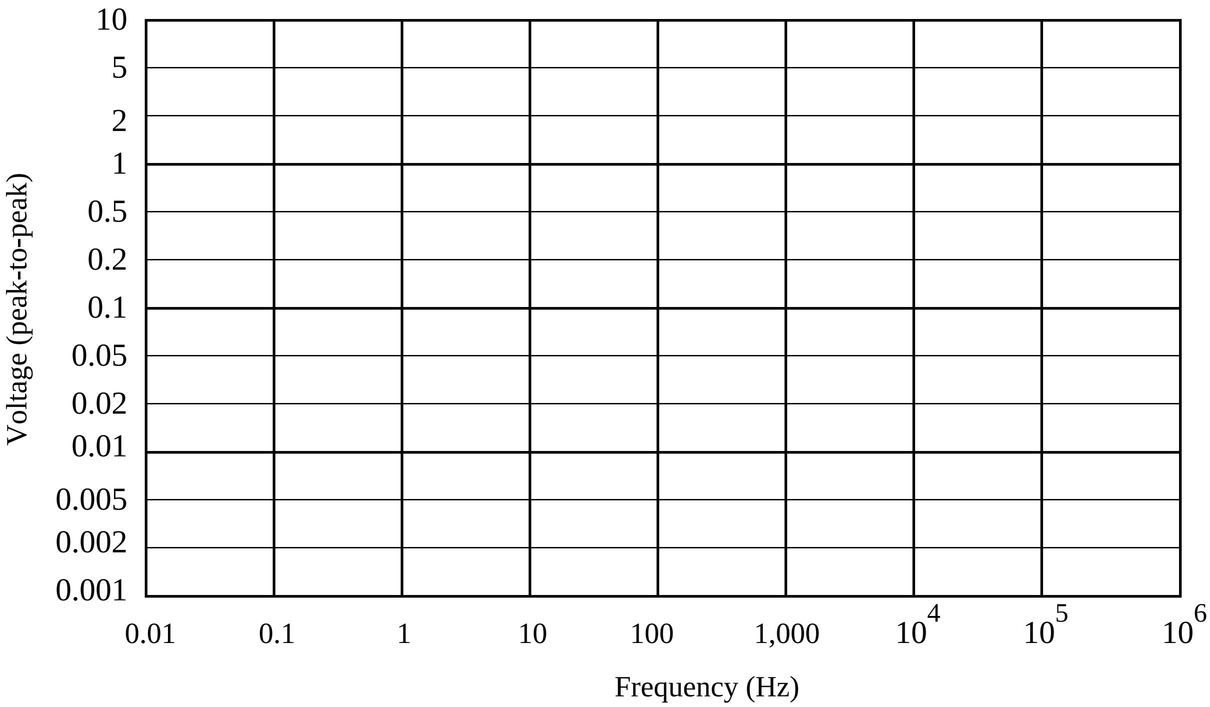
- The output of the isolation amplifier contains 100 mV (peak-to-peak) of 300 kHz carrier wave
- The output of your circuit will be connected to the analog input of a microcomputer with a 12-bit A/D converter sampling at 20 kHz and a –5V to +5V analog input range. At this point, a 1 mV peak-to-peak electrocardiogram signal should be 5 V peak-to-peak and the sum of all other backgrounds should be <1% of the signal.
- You can use any other components and concepts covered in EECS145L

4a. (45 points) Sketch a block diagram of your design. Include and label all essential components and signals. In your diagram, indicate typical voltage levels of signals and backgrounds.

4b. (10 points) Plot the output of your circuit as a function of frequency assuming that no analog filtering is used.



4c. (10 points) Plot the output of your circuit as a function of frequency after the analog filtering that you have designed to meet the design requirements..



Equations, some of which you may need:

$R(T) = R(T_0)\exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$ $\quad I = I_0 e^{-kLC}$ $\quad V_{\rm rms} = \sqrt{B\left[(D_1 G)^2 + (D_0)^2\right]}$

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

$|G| = \frac{1}{\sqrt{1 + (f/f_c)^{2n}}}$ $\quad \tan\left(\frac{\varphi}{n}\right) = \frac{f}{f_c}$ $\quad f_c = \frac{1}{2\pi RC}$

$|G| = \frac{(f/f_c)^n}{\sqrt{1 + (f/f_c)^{2n}}}$ $\quad E = \frac{F/A}{\Delta L/L}$ $\quad I_D = I_S\left(e^{V_D/V_T} - 1\right) + I_P$

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

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

$I_{\rm rms} = \sqrt{2qI(F_2 - F_1)}$ $\quad q$ = 1.60 x 10^{-19} Coulombs

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

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

$N(x) = N(0)e^{-x\mu}$ $\quad$ "CMRR" $= \frac{G_\pm}{G_c}$ $\quad$ "CMR" $= 20\log_{10}\left(\frac{G_\pm}{G_c}\right)$

$R = \rho A/L$ $\quad \frac{\Delta R}{R} = G_s \frac{\Delta L}{L}$ $\quad V_0 = V_b\, G_s\left(\frac{\Delta L}{L}\right)$ $\quad \Delta x = \frac{\Delta V}{dV/dx}$

$V_T = V_{\rm BE2} - V_{\rm BE1} = \frac{kT}{q}\ln\left(\frac{I_1}{I_2}\right)$ $\quad k/q = 86.17\,\mu{\rm V/K}$

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

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

$\eta = \frac{T_{n+2} - T_{n+1}}{T_{n+1} - T_n}$ $\quad T_{\rm equ} = T_{n+1} + \frac{T_{n+2} - T_{n+1}}{1 - \eta}$ $\quad T = T_2 - (T_2 - T_1)\,e^{-t/\tau}$

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

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

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

Johnson noise = 129 μV for 1 MHz and 1 MΩ

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