EECS 145L Final Examination Solutions (Fall 2006)

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

1.1 A virtual short occurs between the two input terminals of an op-amp in negative feedback. The output feeds back to the negative input and the high open loop gain A makes $V_+ - V_- = V_0/A$ very small.

[5 points off for defining but not saying how it works]

[2 points off for not stating that the output is connected to the negative input]

[2 points off for describing a virtual ground rather than a virtual short]

1.2 The isolation amplifier consists of (1) a modulator that multiplies an input waveform by a carrier frequency, (2) a transformer that couples the carrier but blocks dangerous 60 Hz currents, and (3) a demodulator that recovers the input waveform.

[1 point off for omitting each component]

[2 points off for omitting each function]

1.3 The digital angle encoder consists of (1) a row of light emitters (2) a digital pattern of coded transparent and opaque sectors on a circular plate and (3) a row of light detectors. The angle of the plate is transduced into the digital signals received by the light detectors.

[4 points off if it is not stated how the code is read electronically]

1.4 PID controller uses the error signal of a control system to generate proportional, integral, and differential signals that are summed to produce a control signal

1.5 The smoke detector consists of an alpha source, an air gap, and an alpha detector. When smoke particles enter the air gap, some of the alpha particles are stopped and the alpha detector signal is reduced, triggering an audible alarm.

[7 points off for not stating that the alarm sounds when there is a reduction in the rate of detection of alpha particles]

[3 points off for stating that the alpha's are reflected off the smoke particles]

2.1 The high pass filter gain is given by

$$G = (f / f_c) / \sqrt{1 + (f / f_c)^2}$$

$f_c = 1/(2\pi RC) = 1/[(2\ \pi)\ (1\ \text{k}\Omega)\ (0.16\ \mu\text{F})] = 1$ kHz.

$G = V_0/V_1 = 0.1$ will occur very near 100 Hz, since $(f/f_c)^2 = 0.01 << 1$

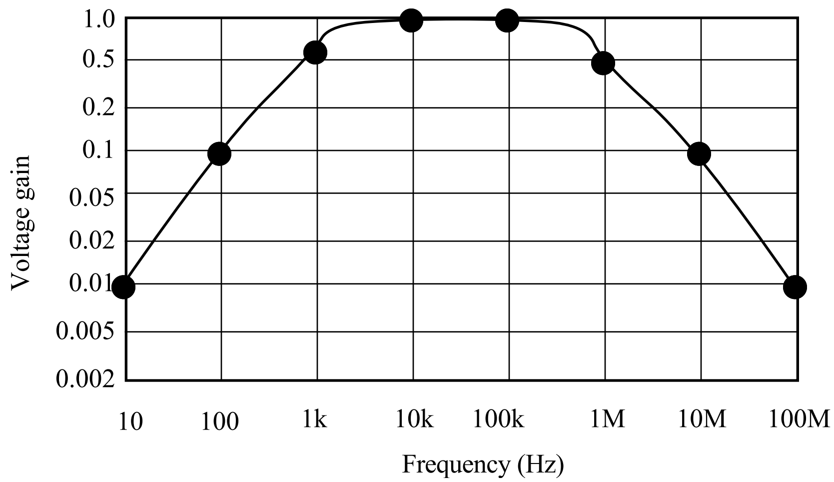
At high frequencies, the amplifier gain falls as the op-amp open loop gain $=10^6$ Hz/f

The gain = 0.1 at 10^7 Hz.

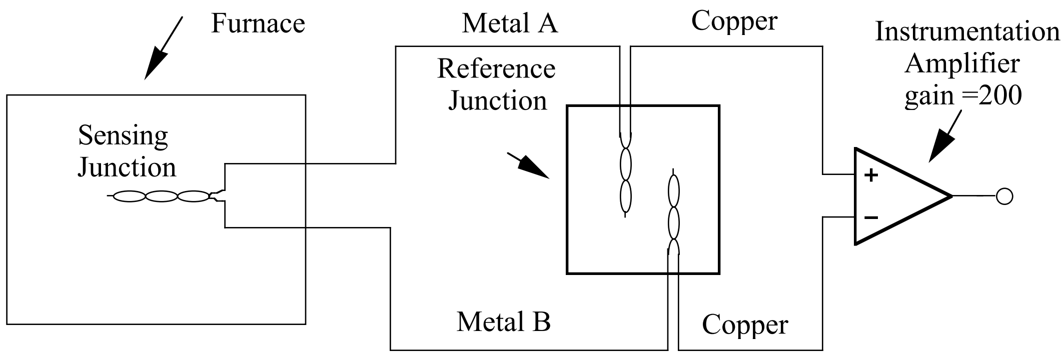
So the circuit gain = 0.1 at 100 Hz and 10^7 Hz.

[7 points off for omitting the low frequency part of the curve]

[7 points off for omitting the high frequency part of the curve]

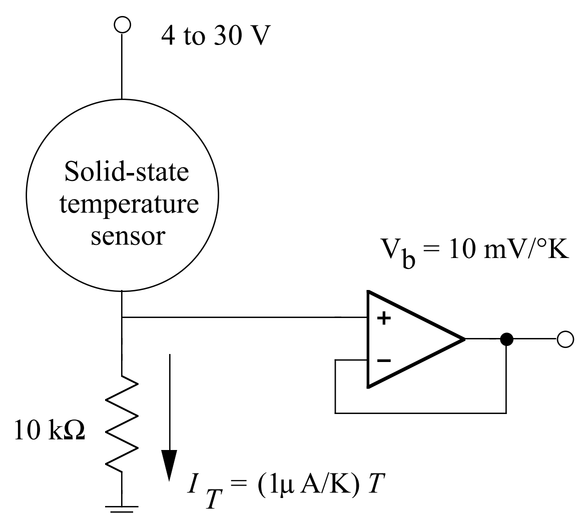


3.1



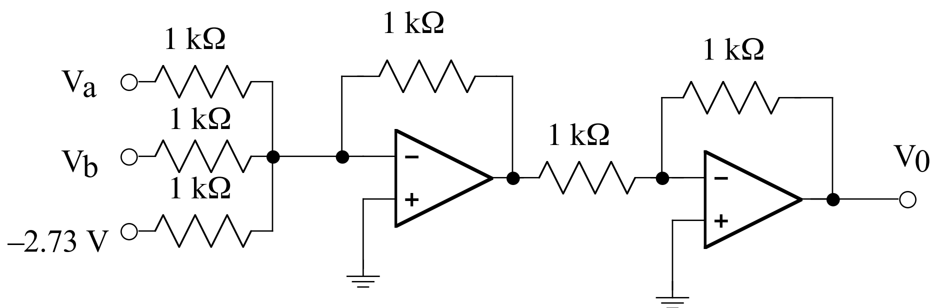
Since the thermocouple has a sensitivity of 50 µV/°C, we need a differential gain of 200 to get the required 10 mV/°C
[3 points off for not producing 10 mV/C°]

3.2



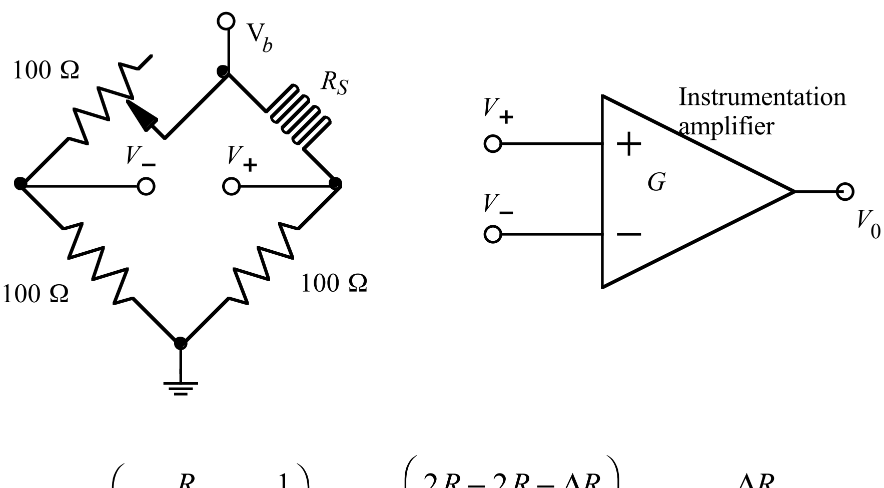
With a sensitivity of 1 µA/K, a series resistor of 10 kΩ will give us the required 10 mV/K. A buffer amplifier prevents loading of the summing amplifier, but was not required for full credit.
[3 points off for not producing 10 mV/C°]

3.3



The output $V_0 = V_a + V_b - 2.73$ V.
As a check, consider the following situation: The sensing and the reference junction are both at 0 °C, so Va = 0.0 V. The solid state temperature sensor is at 273K and V_b = 2.73V. The above circuit produces V_0 = 0.0 V, as desired.
[3 points off for omitting the 2.73 volt bias or not converting solid state sensor K to C°]

4.1

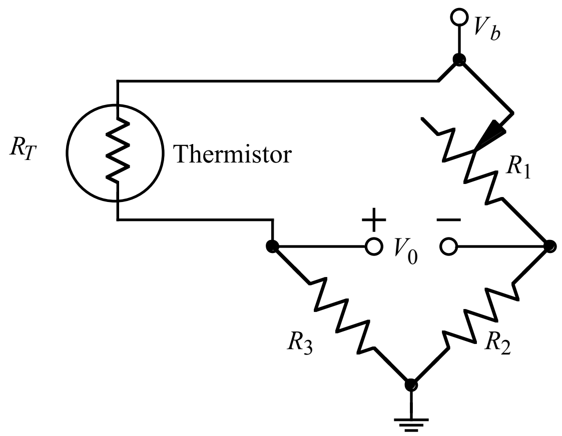


$$V_0 = GV_b\left(\frac{R}{2R+\Delta R} - \frac{1}{2}\right) = GV_b\left(\frac{2R-2R-\Delta R}{2(2R+\Delta R)}\right) = -GV_b\frac{\Delta R}{4R} = -GV_b\frac{\Delta L}{2L}$$

For a strain of ΔL/L = ±10–5 to produce V_0 = ±1 volt, need $GV_b = 2 \times 10^5$ volts.
Typical design would be Vb = –1 volt, $G = 10^5$.
[1 point off for $GV_b = 10^5$ volts]
[2 points off for $GV_b = 5 \times 10^4$ volts]

[3 points off for no bridge equation]
[5 points off for $GV_b = 10^{-5}$ volts]
[5 points off if no GV_b given]

4.2



For maximum sensitivity at 25°C, want $R_2 = R_3 = 5$ kΩ
For zero output at 0°C, want $R_1 = 10$ kΩ
Use a differential amplifier with gain G to produce 5 volts at 50°C

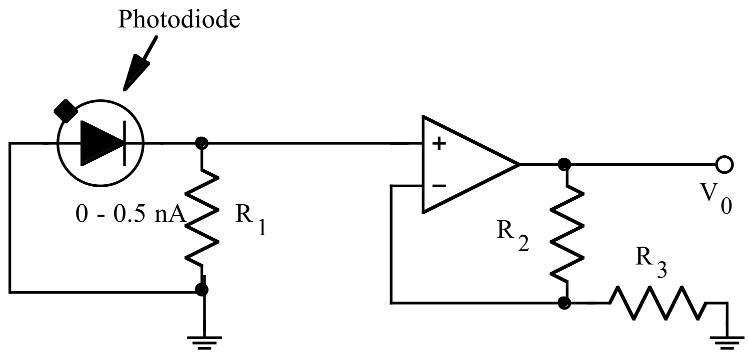
$$V_0 = GV_b\left(\frac{R_3}{R_3 + R_T} - \frac{R_2}{R_1 + R_2}\right) = GV_b\left(\frac{5}{7} - \frac{5}{15}\right) = GV_b\left(\frac{5}{7} - \frac{5}{15}\right) = GV_b\frac{8}{21} = 5 \text{ volts}$$

$GV_b = 105/8$ volts = 13.125 volts
Full credit was given for $V_b = 13.125$ volts, but it would produce a maximum of (13.125)2/2000 = 86 mW, which might cause some self-heating.
A better design is $V_b = 1$ volt, $G = 13.125$.
[3 points off for all three resistors 10 kΩ, because this does not maximize the sensitivity at 25°C.

4.3

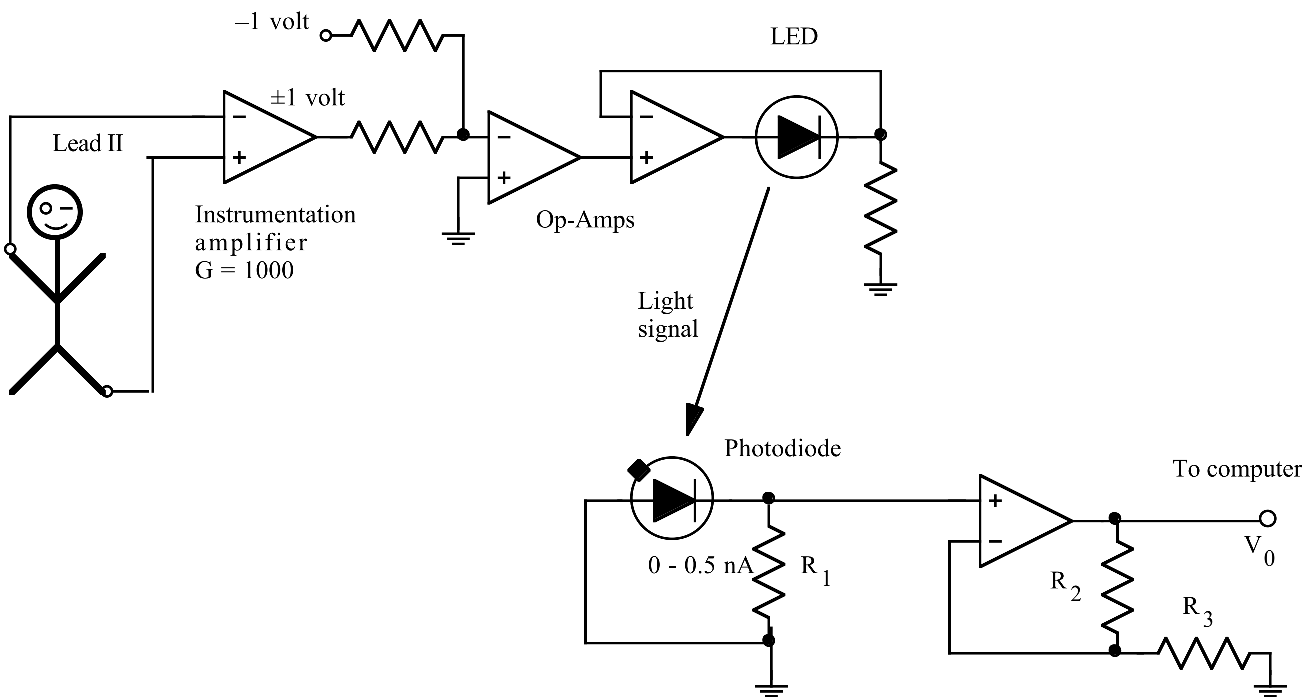
A light beam of 6.241 x 10^{18} photons per second will produce 1 nC/s = 1 nA at QE =1 and 0.5 nA at QE =0.5

$V_0 = (0.5 \text{ nA})R_1G = 1$ volt $G = (R_2 + R_3)/R_3$
Require $R_1G = 2 \times 10^9$ Ω
Typical design would be $R_1 = 2$ MΩ, $G = 1000$
[4 points off if no amplifier]



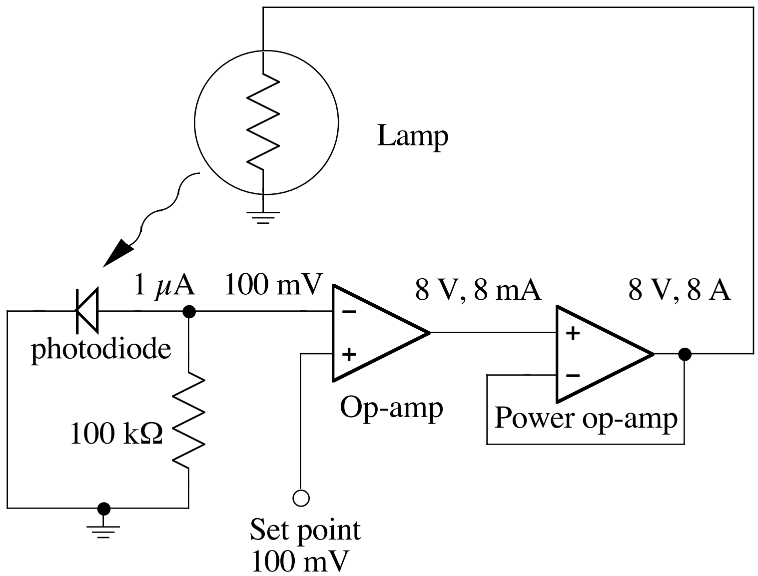
4.4

Lead II of the ECG is amplified to produce a ±1 volt signal. A summing amplifier changes the level and inverts to produce a waveform from 0 to 2 volts, which is used to control a voltage-controlled current driver. The light level produced by the LED follows the ECG waveform. The optical signal is received by a photodiode and converted to a voltage waveform with a current to voltage circuit.



[2 points off if no instrumentation amplifier connected to the electrodes]
[2 points off if no level shift before the LED]
[4 points off if no light source and light sensor]
[2 points off if no voltage to current converter for the LED]
[2 points off if no current to voltage converter at the photodiode]

5.1



The op-amp provides whatever voltage is necessary to make the negative and positive inputs equal (virtual short rule for very high gain). It was also okay to use a high-gain differential amplifier in place of the op-amp. If the gain is 10^4, the difference between the negative and positive amplifier inputs would only be 8 V x 10^{-4} = 0.8 mV.

5.2

- the increasing thickness of metal film causes a decrease in lamp output
- photodiode output decreases below the set point
- the op-amp output voltage increases (negative feedback)
- the power amplifier output voltage increases and the lamp becomes brighter
- the increase in lamp voltage stops when the photodiode signal is once again equal to the set point

145L FINAL EXAM GRADE STATISTICS

Problem	1	2	3	4	5	Total
Average	41.3	22.7	43.0	34.6	29.5	171.1
rms	5.6	7.2	2.2	7.0	0.9	18.1
Maximum	50	30	45	45	30	200

Total score distribution:

100-109	0	110-119	0	120-129	0
130-139	1	140-149	1	150-159	3
160-169	3	170-179	3	180-189	1
190-199	4	200	0		

145L COURSE GRADE STATISTICS

Grade	Undergraduate Scores	Graduate Scores
A+	962.5	964.0
A	953.5, 955.5	
A–		
B+	913.0, 917.0, 927.0	
B	903.5, 904.0, 907.0	
B–	882.5, 885.0, 889.0, 895.5	883.0
C+		
C	845.0	
C–		
D+		
D		
D–		
F		
Maximum	1000	
Average	911.7	
rms	33.7	

Note: the average grade for the lab report 4, 6, 12 series was 94.6 and the average grade for the lab report 5, 11, 13 series was 95.2. This factor did not affect any letter grades.