EECS 145L Final Examination Solutions (Fall 2007)

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1.1 Ideal op-amp: Device with differential inputs V_- and V_+, and an output V_0. The output is given by $V_0 = A(V_+ - V_-)$, where A is infinite at all frequencies. No current flows into either input (infinite input impedance) and the output impedance is zero.

[2 points off for missing each of the four critical properties: infinite differential gain, zero common mode gain, infinite input impedance, zero output impdance]

[$V_0 = A(V_+ - V_-)$ with infinite A was accepted for zero common mode gain]

1.2 Johnson noise: Random voltage generated by the thermal agitation of electrons in a resistor or semiconductor.

1.3 Sensitivity (of a sensor): Change in electrical output per unit change in the physical quantity being sensed

1.4 Actuator: Device that converts electrical energy into physical energy

1.5 Strain (mechanical): Fractional change in length $\Delta L/L$

[3 points off for defining a strain gauge]

2.1 Differential gain 1000, bandwidth 10 kHz

[3 points off for Gain = 10,000, bandwidth 1 kHz]

[3 points off for Gain = 100, bandwidth 100 kHz]

2.2 Output $V_{rms} = (4 \text{ nV Hz}^{-1/2})\ (100 \text{ Hz}^{1/2})\ (1000) = 0.4$ mV in 10 kHz

[2 points off for input noise rather than output noise]

[3 points off for not taking the square root of the bandwidth]

2.3 We want a Butterworth low-pass filter with a gain of $G_1 = 0.99$ at $f_P = 1$ kHz and $G_2 = 0.01$ at $f_S = 2$ kHz. $f_S/f_P = 2$.

n	f_1/f_c	f_2/f_c	f_2/f_1	
6	0.723	2.154	2.98	n too low
8	0.784	1.778	2.27	n too low
10	0.823	1.585	1.93	n =10 OK

Using $f_l/f_c = 0.823$, $f_c = 1 \text{ kHz}/0.823 = 1.215$ kHz

Using $f_l/f_c = 1.585$, $f_c = 2 \text{ kHz}/1.585 = 1.262$ kHz

The order is 10 and a corner frequency between 1.215 kHz and 1.262 kHz is OK. (order 12 also accepted)

[2 points off for order 8]

[2 points off for giving input noise before filtering]

[2 points off for giving input noise of 0.141 μV]

After amplification and filtering, the output noise is $V_{rms} = (4 \text{ nV Hz}^{-1/2})$ sqrt(1.24 kHz) (1000) = $(4 \text{ nV Hz}^{-1/2})\ (35.3 \text{ Hz}^{1/2})\ (1000) = 0.141$ mV.

So the filtering reduced the output noise from ±0.4 mV to ±0.14 mV

[3 points off if output noise not given or determined by multiplying the answer from 2.2 by 0.01 or 0.99]

2.4 The best way to reduce the 60 Hz interference from the middle of a band of frequencies of interest is to use a notch filter. The common mode rejection ratio of 60 dB means that the common mode gain is 1000/1000 = 1. So the instrumentation amplifier 60 Hz output will be ±10 mV from a common mode input of ±10 mV. The output due to a differential 60 Hz interference is (±0.01 mV) (1000) = ±10 mV. In the worst case, these are in phase, producing a total of ±20 mV. A notch filter can reduce this total by a factor of typically 30, to ±0.7 mV.

[Any value between 0.1 and 2 mV was accepted for full credit]

[2 points off for including one 10 mV and not the other]

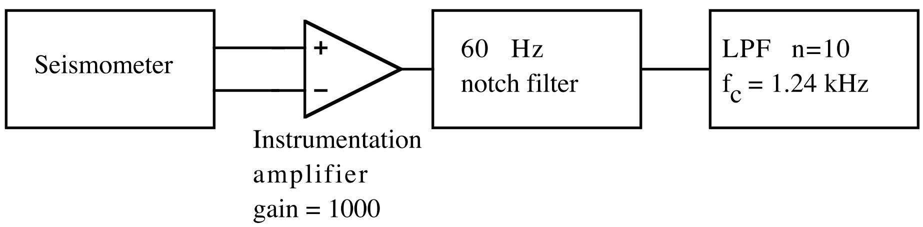
[3 points off for giving output noise as ~ zero]

[4 points off if input noise not given or not based on 60 Hz interference]

[4 points off if output noise not given]

[8 points off for using a HPF, which removes the important earthquake frequencies below 60 Hz]

2.5 [OK to reverse order of low pass and notch filters]



[4 points off if amplifier not in circuit]

3.1 Since $R_2/(R_1 + R_2) = R_3/(R_T + R_3)$, $R_2 = R_3$, and R_T = 10 kΩ at 20°C the solution is R_1 = 10 kΩ.

3.2 $P = V_T^2/R$ = (0.5 volts)^2/(10 kΩ) = 25 μW

[3 points off for assuming V_T = 1 volt]

3.3 Amplifier output of 0.05 volts means a bridge output $V_+ – V_–$ = 0.01 volts. Using the bridge equation (supplied on the equation sheets), we have RT = (10000 Ω)*(10000 Ω – 0.01*20,000 Ω)/(10000 Ω + 0.01*20,000 Ω) = 10,000 Ω (9,800/10,200) = 9608 Ω

[2 points off for not dividing by the amplifier gain]

[3 points off for assuming a linear response from 0 °C and 0 Ω to 20 °C and 10 kΩ]

3.4 T = 20°C + (9608 Ω – 10000 Ω)/(–300 Ω/C°) = 21.3°C

3.5 V_T = 1 – 10000 Ω /(10000 Ω + 9608 Ω) = 0.490 volts

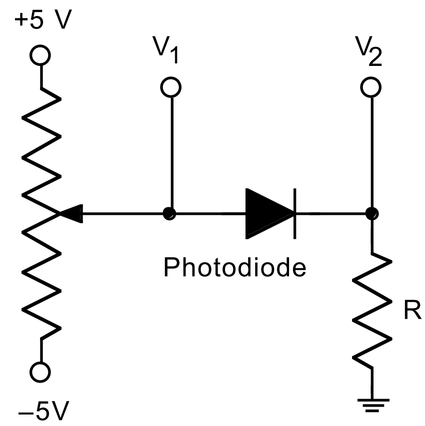
P = (0.490 volts)^2/(9608 Ω) = 24.99 μW (25 μW was accepted for full credit)

3.6 Dissipation coefficient = 25 μW/(21.3°C – 20°C) = 19 μW/°C

[2 points off for using difference between 3.5 and 3.2 in numerator]

[2 points off for using 20C in denominator]

4.1



[6 points of if circuit does not allow control of V_{diode} or I_{diode}]

[8 points of if no external bias]

[8 points off for a voltage controlled current driver]

[4 points off if only forward or only reverse bias]

4.2 Adjust potentiometer, measure V_1

Measure V_2

Voltage across diode $V_{diode} = V_1 – V_2$

Current through diode $I_{diode} = V_2/R$

Change V_1 and repeat to measure entire curve

[2 points off for measuring a single V_{diode}, I_{diode} point- the problem asked for a measurement of I_{diode} as a function of V_{diode}.]

[4 points off for failing to determine I_{diode} or V_{diode}]

Its is also possible to use a voltage-controlled current driver. A series of currents is set and the voltage across the diode measured for each current.

4.3 See textbook, figure 4.36 for I_{diode} vs. V_{diode} curves

5.1

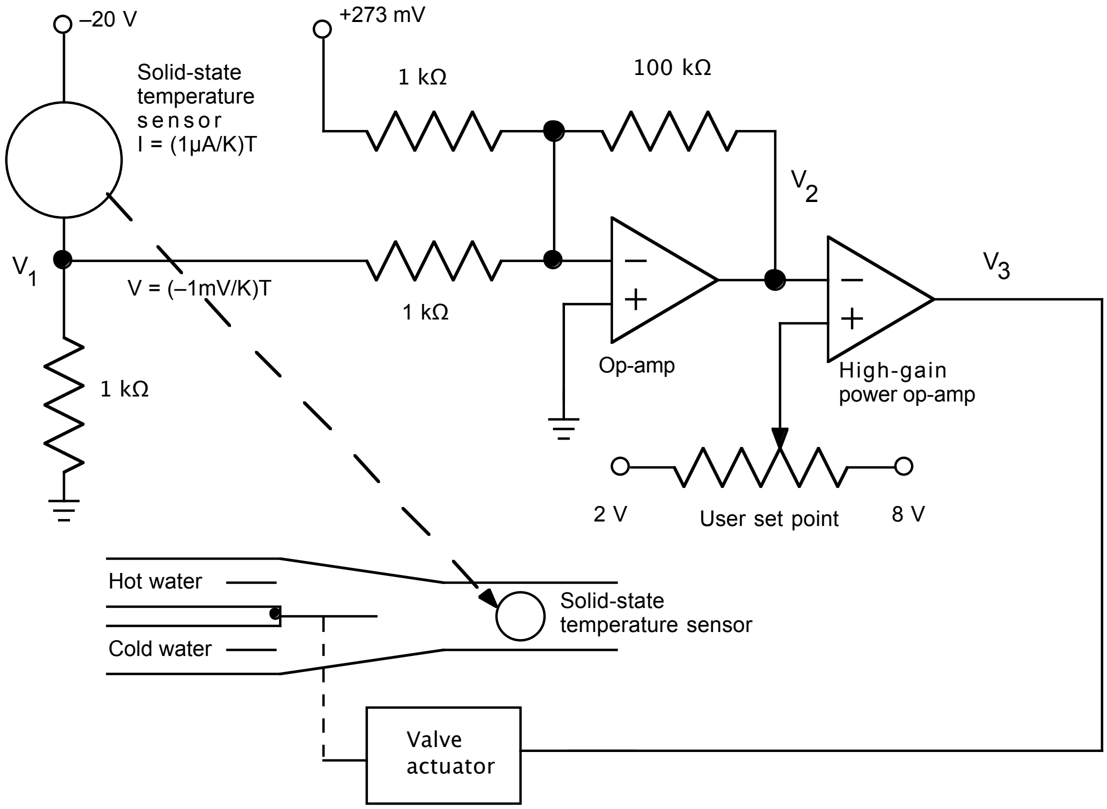
If the temperature at the output of the mixing valve is T (in °C), the output of the solid state temperature sensor is $V_1 = –(T+273)$ mV which is summed with +273 mV to produce V_2 = (100 mV)T at the output of the summing op-amp.

[A thermocouple could also be used, but this would require keeping the reference junction at a known temperature]

[a thermistor was allowed, in spite of its nonlinear response. As may be seen in Figure 4.23 of the textbook, the thermistor bridge output is reasonably linear over a ± 30°C temperature range.]

[3 points off for using a thermistor without specifying resistance at 50C because this is needed to put the maximum sensitivity at midrange between 20C and 80C.]

[3 points off for not designing 10C/V sense value at set point comparison point]



5.2 The user set point is at 2.0V, and by the virtual short rule, V2 = 2.0 volts, which corresponds to a temperature of 20 °C, as desired. The power op-amp output V3 = –5V, as needed to pass only 20°C water through the mixing valve.

[Note that V2 is actually a bit higher than 2.0 V so that the power op-amp gain can produce –5V. Remember the basis for the virtual short rule: The op-amp produces whatever output is necessary to make both of its inputs nearly equal. The difference in inputs is 5 V divided by the open-loop gain which in this case is the gain of the final amplifier]

5.3 When the set point temperature is changed to 6.0 V, the output of the power op-amp will be driven strongly positive to mix in hot water. The system will come into equilibrium when V2 is approximately 6.0 V, which occurs when the solid state temperature sensor is at 60 °C, as desired.

5.4 If the hot water temperature is reduced from 80°C to 70°C, the output of the mixing valve will become cooler, and V2 will drop below the user set point of 6.0V. This will increase the voltage to the valve controller, and increase the faction of hot water in the mix. The system will again come into equilibrium when V2 is approximately 6.0 V, which occurs when the solid state temperature sensor is at 60 °C, as desired.

145L FINAL EXAM GRADE STATISTICS

Problem	1	2	3	4	5	Total
Average	36.6	32.1	35.9	27.8	43.0	175.4
rms	2.6	4.7	3.6	5.6	5.4	13.3
Maximum	40	40	40	34	46	200

Total score distribution:

100-109	0	110-119	0	120-129	0
130-139	1	140-149	1	150-159	1
160-169	3	170-179	8	180-189	8
190-199	3	200	0		

145L COURSE GRADE STATISTICS

Grade	Undergraduate Scores	Graduate Scores
A+	945	none
A	922, 926, 930, 937, 943	
A–		
B+	888, 888, 893, 896, 903	
B	854, 860, 865, 868, 871, 877, 877, 878	
B–	825	
C+	794, 802, 805, 806	
C		
C–	730	
D+		
D		
D–		
F		
Maximum	1000	
Average	871.3	
rms	53.5	

Note: the average grade for the lab report 4, 6, 12, 14 series was 89.7 and the average grade for the lab report 5, 11, 13, 15 series was 91.3. To compensate, one bonus point was awarded to lab reports 4, 6, 12 , and 14. This did not affect any letter grades.