Midterm #1 Solutions – EECS 145L Fall 2008

1.1 Electronic Sensor: Device that converts a physical signal into an electrical signal

[3 points off for electronic input only]

[2 points off for electronic or physical input]

1.2 Sensitivity of an electronic sensor: Change in output per unit change in physical quantity being sensed

[2 points off for ability to detect small signals or small changes]

Note: For a physical signal f and an electrical output V the sensitivity is dV/df, a property of the sensor. The smallest detectable signal change is $\Delta f = \Delta V/(dV/df)$ and depends on both the sensitivity and the electronic noise ΔV.

1.3 Instrumentation Amplifier: Amplifier circuit that has (1) output voltage proportional to the voltage difference between the two inputs , (2) very high input impedance, (3) low output impedance, and (4) constant gain over a large bandwidth

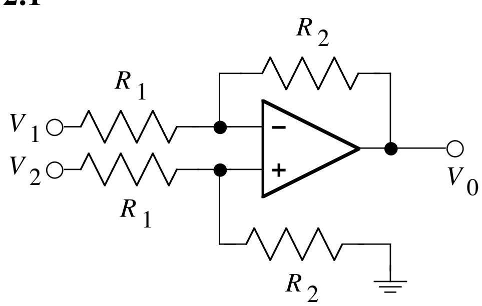
[2 points off for omitting constant gain over a frequency range; high input impedance, low output impedance, and differential gain do not distinguish it from the op-amp]

1.4 Differential gain (of an amplifier with two inputs): Change in output voltage divided by the change in the difference in input voltages

1.5 Common mode gain (of an amplifier with two inputs): The gain for signals present at both inputs

1.6 Johnson noise (of a resistor): Random voltage generated in a resistor due to the thermal agitation of electrons within it.

2.1



Infinite open-loop op-amp gain: virtual short rule: $V_+ = V_-$

$$\frac{V_1 - V_-}{R_1} = \frac{V_- - V_0}{R_2} \qquad \frac{V_2 - V_+}{R_1} = \frac{V_+}{R_2}$$

$V_1R_2 - V_-R_2 = V_-R_1 - V_0R_1 \quad V_2R_2 - V_+R_2 = V_+R_1$

Subtracting, $(V_2 - V_1)\, R_2 = V_0R_1$

$V_0 = (V_2 - V_1)(R_2/R_1)$

2.2 Differential gain $V_0 = G_\pm(V_2 - V_1) + G_C(V_2 + V_1)/2$

$G_\pm = R_2/R_1$ Since V_0 does not depend on $(V_1 + V_2)$, $G_C = 0$

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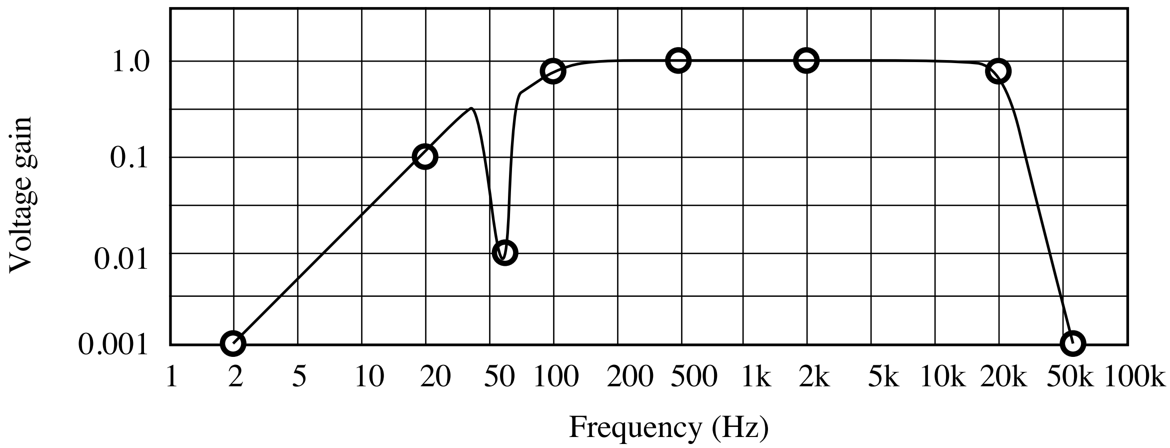
3.1



3.2

The LPF needs to have a gain $G_1 = 0.9$ at $f_1 = 20$ kHz and drop to a gain $G_2 = 0.001$ at $f_2 = 52$ kHz. So we need a filter that has $f_2/f_1 < 2.6$.

n	f_1/f_c	f_2/f_c	ratio	
4	0.834	5.623	6.74	n too low
6	0.886	3.162	3.57	n too low
8	0.913	2.371	2.55	n = 8 OK
10	0.930	1.995	2.15	n high, but OK

$(20 \text{ kHz}/0.913) < f_c < (60 \text{ kHz}/2.371)$
$21.91 \text{ kHz} < f_c < 21.93 \text{ kHz}$

LPF n = 8, $f_c = 21.92$ kHz

[3 points off for $f_c = 20$ kHz, which would make the gain 0.707 (too low) at 20 kHz]
[3 points off for n = 12 or 14]

The HPF needs to have a gain $G_1 = 0.9$ at 100 Hz and drop to a gain $G_2 = 0.001$ at 2 Hz. So we need a filter that has $f_1/f_2 < 50$

n	f_1/f_c	f_2/f_c	ratio	
2	1.437	0.032	44.9	n = 2 OK
4	1.199	0.178	6.74	n = 4 high, but OK

$(2 \text{ Hz}/0.032) < f_c < (100 \text{ Hz}/1.437)$
$62.5 \text{ Hz} < f_c < 69.6 \text{ Hz}$

HPF n = 2, $f_c = 65$ Hz

[3 points off for $f_c = 100$ Hz, which would make the gain 0.707 (too low) at 100 Hz]

This HPF has a gain just a bit below 0.7 at 60 Hz and does not meet the gain requirement of 0.01. A notch filter with accurate components should provide the necessary low gain.

Note: an alternative solution to the notch filter was to use a 10th or 12th order HPF to reduce the gain from 0.9 at 100 Hz to 0.01 at 60 Hz- although this solution uses 2 or 3 more op-amps, costs more, and has more components that can fail, it was accepted.

145L midterm #1 grade distribution:

Problem	
1	33.1 (2.9 rms) (36 max)
2	27.4 (5.4 rms) (30 max)
3	32.2 (3.5 rms) (34 max)

maximum score = 100
average score = 92.7 (8.8 rms)

70-74	2	C-
75-79	2	C
80-84	1	C+
85-89	3	B-
90-94	4	B
95-99	8	B+
100	10	A

Note: The average score among the 14 EECS undergraduates was 95.0. The average score for the 11 BioEng undergraduates was 91.3.