Midterm #1 Solutions – EECS 145L Fall 2004

1a

Johnson Noise	Shot noise
Increases with temperature	Does not depend on temperature
Occurs in resistors	Occurs in resistors and conductors
Random voltage fluctuations caused by thermal agitation of electrons in a resistor	Current fluctuations caused by random fluctuations in the number of electrons per unit time

[-2 points for each missing answer out of 4 statements]

[Several students wrote that one was white noise and the other was not. The noise power for both is proportional to V_{rms}^2 or I_{rms}^2 which is proportional to Δf. So both are white noise.]

1b

Johnson Noise	Electromagnetic Interference Noise
White (random) noise	Structured noise
Due to thermal motion of electrons in a resistor	From other circuits (or lightning)
Increases with temperature	Does not depend on temperature
Cannot be cancelled by differential amplification	Can be cancelled by differential amplification
Cannot be reduced by conductive shielding	Can be reduced by conductive shielding

[-2 points for each missing answer out of 4 statements]

[Many students gave two statements that described one difference. Four statements are needed to describe two differences between two items.]

2a Virtual short rule $V_5 = V_6$

$$\frac{V_3 - V_5}{R_3} = \frac{V_5 - V_0}{R_4} \qquad \frac{V_4 - V_5}{R_3} = \frac{V_5}{R_4}$$

$$V_3 R_4 - V_5 R_4 = V_5 R_3 - V_0 R_3 \qquad V_4 R_4 - V_5 R_4 = V_5 R_3$$

Subtracting, $(V_4 - V_3) R_4 = V_0 R_3$

$$V_0 = (V_4 - V_3)(R_4 / R_3)$$

2b Differential gain $V_0 = G_\pm (V_4 - V_3) + G_C (V_4 + V_3)/2$

$G_\pm = \dfrac{R_4}{R_3}$ Since V_0 does not depend on $(V_3 + V_4)$, $G_C = 0$

[-2 points for $G_C \neq 0$]

3a From textbook, example 2.1, page 91:
common mode $V_- = V_+$

Virtual short rule $V_- = V_2 = V_+ = V_1$

No current through R1 and R2: $V_- = V_2 = V_4 = V_+ = V_1 = V_3$

$$G_c = \frac{V_3 + V_4}{V_- + V_+} = 1$$

3b From textbook, example 2.2, pages 91 and 92:
Virtual short rule $V_- = V_1$ and $V_+ = V_2$

The same current flows through R_1 and R_2: $\dfrac{V_2 - V_1}{R_1} = \dfrac{V_4 - V_3}{R_1 + 2R_2}$

Differential gain of the first stage: $\dfrac{V_4 - V_3}{V_+ - V_-} = \dfrac{R_1 + 2R_2}{R_1}$

3c From textbook, example 2.2, pages 91 and 92:

$$\frac{V_0}{V_+ - V_-} = \left(\frac{V_4 - V_3}{V_+ - V_-}\right)\left(\frac{V_0}{V_4 - V_3}\right) = \left(\frac{R_1 + 2R_2}{R_1}\right)\left(\frac{R_4}{R_3}\right)$$

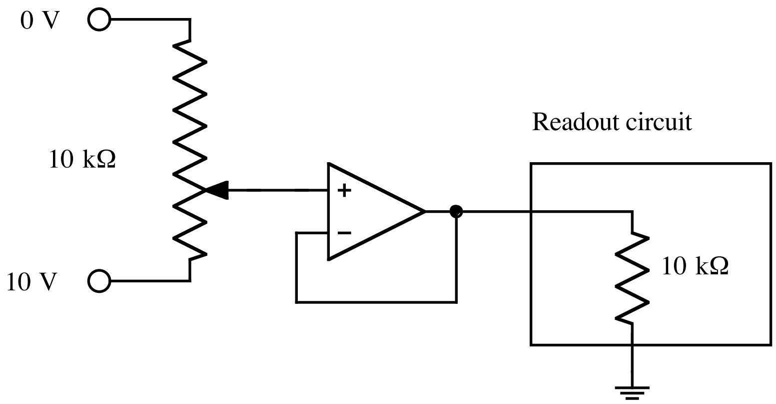
4a $V_3 = V_-(R_1 + R_2)/R_1 \qquad V_4 = V_+(R_1 + R_2)/R_1$

$$\frac{V_4 + V_3}{V_+ + V_-} = \frac{R_1 + R_2}{R_1}$$

4b $\dfrac{V_4 - V_3}{V_+ - V_-} = \dfrac{R_1 + R_2}{R_1}$

4c The new design is inferior because its first stage common mode gain is as high as the differential gain and prone to saturation. The standard design has a first stage common mode gain of only one.

5a



[- 2 points for not producing an output that varied from 0 to 10 V as the liquid level varied from 0 m to 10 m]

[- 4 points off for not providing a buffer amplifier between the 10 kΩ sensor resistor and the readout circuit]

5b Determining the change in the liquid level per minute requires making two measurements one minute apart and taking the difference. The standard deviation of each measurement is 1 mV, which corresponds to 1 mm in liquid level.

$f = (a - b) / \Delta T \qquad \sigma_a = \sigma_b = 1 \text{ mm} \qquad \sigma_f^2 = (\sigma_a^2 + \sigma_b^2) / (\Delta T)^2 = 2 \text{ (mm / min)}^2$

$\sigma_f = 1.414$ mm / min (1.4 mm was accepted for full credit)

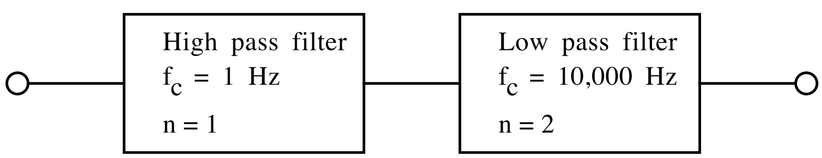
[-3 points for 1 mV] [-1 point for 1.4 mV] [-3 points for 2 mV]

[-2 points for 1 mm] [-2 points for 2 mm]

Note 1: The equation sheet said that if $f = k(a - b)$ then $\sigma_f^2 = k^2(\sigma_a^2 + \sigma_b^2)$

Note 2: The rate of change in liquid level is measured in mm/min, not mV.

6



[-1 points for HPF with n = 2] [-2 points for HPF with n > 2]

[-1 points for LPF with n = 3] [-2 points for LPF with n > 3]

145L midterm #1 grade distribution:

Problem	
1	11.6 (4.7 rms) (16 max)
2	19.2 (2.0 rms) (20 max)
3	15.8 (5.5 rms) (20 max)
4	15.2 (6.1 rms) (20 max)
5	8.8 (4.8 rms) (16 max)

maximum score = 100

average score = 76.8 (17.1 rms)

30-39	1	F
40-49	2	F
50-59	2	D
60-69	4	C
70-79	5	B-
80-89	6	B
90-97	8	A

6	6.2 (1.5 rms) (16 max)	98 (max)	1	A+

3 graduate students: average = 79.7

8 BioEngineering undergraduates: average = 78.6

13 EECS undergraduates: average = 73.3