# Midterm #1 Solutions – EECS 145L Fall 2009

**1** There are at least six differences between the ideal and realistic op-amp

| **Property** | **Ideal op-amp** | **Realistic op-amp** |
|---|---|---|
| Differential gain | Infinite at all frequencies | Finite gain that decreases as 1/f |
| Common mode gain | 0 | Not 0 |
| Input impedance | Infinite | Large but not infinite |
| Output impedance | 0 | Not 0 |
| Output offset | 0 | Not 0 |
| Input leakage current | 0 | Not 0 |

[3 points off for describing the limitations of the realistic op-amp and not mentioning the ideal op-amp or its properties]
[2 points off for describing only three differences]

**2 The electromagnetic isolation amplifier Essential points for full credit:**
1) uses the input signal to modulate a higher-frequency carrier wave in the input stage
2) couples the modulated carrier signal to the output stage by electromagnetic induction through the air (this blocks dangerous low frequency voltages)
3) demodulates and amplifies the modulated carrier signal in the output stage to recover an isolated, amplified version of the input signal
4) the input stage is powered by a high-frequency oscillator in the output stage that is coupled through the air. similar to the modulated signal carrier
[2 points off for not describing how the input stage is powered]
[5 points off for describing how a differential amplifier can reduce electromagnetic interference]
[4 students out of 20 got a perfect score in this problem]

**3.1**

Op-amp equation $V_0 = -AV_3$

Kirchhoff's current law at node $V_2$: $\frac{V_1 - V_2}{100\text{k}\Omega} + \frac{V_3 - V_2}{1\text{ k}\Omega} + \frac{0 - V_2}{1\text{ k}\Omega} = 0$

$V_1 = V_2 + 100V_2 - 100V_3 + 100V_2 = 201V_2 - 100V_3$

Kirchhoff's current law at node $V_3$: $\frac{V_2 - V_3}{1\text{ k}\Omega} + \frac{V_0 - V_3}{100\text{ k}\Omega} = 0$

$100V_2 = 100V_3 + V_3 - V_0 = (101 + A)V_3$

$$V_1 = \left[\frac{201(101 + A)}{100} - 100\right]V_3 = \left[\frac{10301 + 201A}{100}\right]V_3$$

$$V_1 = \left[201 - \frac{100(100)}{101 + A}\right]V_2 = \left[\frac{10301 + 201A}{101 + A}\right]V_2$$

$$\boxed{V_2 = \frac{(101 + A)V_1}{10301 + 201A} \approx \frac{1 + A/100}{100 + 2A}V_1 = \left(\frac{f + 10{,}000}{f + 20{,}000}\right)\left(\frac{V_1}{100}\right)}$$

$$\boxed{V_3 = \frac{100V_1}{10301 + 201A} \approx \frac{V_1}{100 + 2A} = \left(\frac{f}{f + 20{,}000}\right)\left(\frac{V_1}{100}\right)}$$

$$\boxed{V_0 = \frac{-100AV_1}{10301 + 201A} \approx \frac{-AV_1}{100 + 2A} = \frac{-10{,}000V_1}{f + 20{,}000}}$$

[8 points off for setting up the op-amp and two node equations but not solving them correctly]

[8 points off for using the virtual short rules, which made it impossible to calculate V3 at low frequency and all the values at high frequency]

**3.2**

**f = 10 Hz**, A = $10^5$

$V_2 \approx V_1/201 \approx 5 \times 10^{-3}\ V_1$ $V_3 \approx 100V_1/(201 \times 10^5) \approx 5 \times 10^{-6}\ V_1$ $V_0 \approx -0.5\ V_1$

**f = 1 MHz**, A = 1

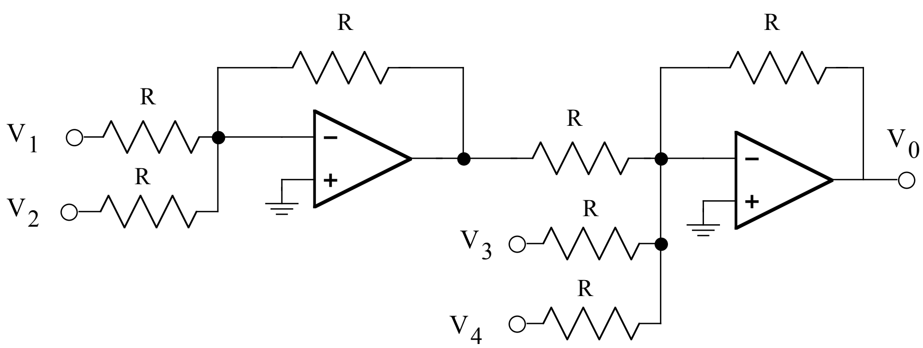
$V_2 \approx 100V_1/10000 \approx 10^{-2}\ V_1$ $V_3 \approx 100V_1/10000 \approx 10^{-2}\ V_1$ $V_0 \approx -10^{-2}\ V_1$

[2 points off if some answers off by 2x]

Note how V2 and V3 increases with increasing frequency. At high frequencies the op-amp gain is low and the feedback current through the 100 kΩ feedback resistor is small. V2 is no longer loaded by the input resistor and is determined by the voltage divider as V1/100.

This point was specifically asked in question 5.2 of Lab 4, and this problem is nearly identical to Problem 2.1 at the end of Chapter 2.

**4**




[2 points off for overall sign error, e.g. $V_0 = -V_1 - V_2 + V_3 + V_4$]

[1 point off for each op-amp used above two in a working circuit]

[3 points off for a missing current summing resistor]

[5 points off for one summing amp plus two resistors connected to the + input of a buffer amp; this input is not a summing point]

**5.1** First, connect both inputs to a wave generator and measure the output/input voltage ratio as a function of frequency. This is the common mode gain. Then, ground one input and repeat. This is a combination of differential and common-mode gains, but the common mode gain was measured above. Solve the formula (one equation, one unknown) for the differential gain as a function of frequency.

$$G_{\pm} = \frac{V_0 - G_C V_C}{V_+ - V_-} \qquad V_C = \frac{V_+ + V_-}{2}$$

[3 points off for not using two values of gain]

**5.2** Set the amplifier in low-gain configuration. Ground both inputs and measure the output offset. Repeat in high gain configuration and solve the formula for the separate input and output offsets.

**5.3** Set the amplifier with high gain G and with both inputs connected directly to ground. Measure the output offset. Then ground one input through a large value resistor R and measure the change in output offset $\Delta V$. The leakage current for that input is given by $IB = \Delta V/(RG)$. Repeat for the other input.

**5.4** Set the amplifier in low-gain configuration. Ground both inputs and measure the rms noise at the output. Repeat in high gain configuration and solve the formula (two equations, two unknowns) for the separate input and output noise factors.

[3 points off for not using two values of gain]

**145L midterm #1 grade distribution:**

| Problem | |
|---|---|
| 1 | 8.8 (1.6 rms) (10 max) |
| 2 | 6.7 (3.2 rms) (10 max) |
| 3 | 29.9 (7.4 rms) (36 max) |
| 4 | 17.0 (4.4 rms) (20 max) |
| 5 | 18.3 (5.7 rms) (24 max) |

maximum score = 100
average score = 80.5 (B-) (13.9 rms)

| | | |
|---|---|---|
| 50-54 | 0 | F |
| 55-59 | 3 | F |
| 60-64 | 0 | D |
| 65-69 | 1 | D |
| 70-74 | 1 | C |
| 75-79 | 4 | C |
| 80-84 | 3 | B |
| 85-89 | 1 | B |
| 90-94 | 3 | A |
| 95-99 | 4 | A |
| 100 | 0 | A |

EECS average 75.1 (11.7 rms)
BioEng average 84.9 (13.2 rms)