1

<table>
<thead>
<tr>
<th></th>
<th>Op Amp</th>
<th>Inverting op-amp circuit amplifier</th>
<th>Non-inverting op-amp circuit amplifier</th>
<th>Differential op-amp circuit amplifier</th>
<th>Instrumentation amplifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Z_in</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Differential input</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Defined gain over a frequency band</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

[1 point off for each wrong answer]

2a

Op-amp equation \( V_0 = -AV_3 \)

Kirchhoff’s current law at node \( V_2 \):

\[
\frac{V_1 - V_2}{100 \Omega} + \frac{V_3 - V_2}{1 \Omega} + \frac{0 - V_2}{1 \Omega} = 0
\]

\( V_1 = V_2 + 100V_2 - 100V_3 + 100V_2 = 20V_2 - 100V_3 \)

Kirchhoff’s current law at node \( V_3 \):

\[
\frac{V_2 - V_3}{1 \ k\Omega} + \frac{V_0 - V_3}{100 \ k\Omega} = 0
\]

\[
100V_2 = 100V_3 + V_3 - V_0 = (0.01+ A)V_3
\]

\[
V_3 = \left[ \frac{1030+201A}{100} \right] V_3
\]

\[
V_1 = \left[ \frac{201-100A}{101+ A} \right] V_2 = \left[ \frac{1030+201A}{101+ A} \right] V_2
\]

\[
V_2 = \frac{0.01+ A)V_1}{1030+201A} \approx \frac{1+ A/100}{100+2A} V_1
\]

\[
V_3 = \frac{100V_1}{1030+210A} = \frac{V_1}{100+2A}
\]

\[
V_0 = -100(V_1/101) = -AV_1
\]

[7 points off for setting up the first three equations but not solving them]

[10 points off for following through with the erroneous starting equation \( V_2 = V_1/101 \)]

2b

\( f = 10 \text{ Hz}, A = 10^5 \)

\( V_2 = V_1/201 = 5 \times 10^{-3} V_1 \)

\( V_3 = 100V_1/(201 \times 10^5) = 5 \times 10^{-6} V_1 \)

\( V_0 = -0.5 V_1 \)

\( f = 1 \text{ MHz}, A = 1 \)

\( V_2 = 100V_1/10000 = 10^{-2} V_1 \)

\( V_3 = 100V_1/10000 = 10^{-2} V_1 \)

\( V_0 = -10^{-2} V_1 \)

[15 points off for determining \( A \) only]

[2 points off if some answers off by 2x]
3a  The lower corner frequency is given by the RC time constant of the high-pass filter
\[ f_c = \frac{1}{(2\pi RC)} = \frac{1}{(2\pi \times 0.16 \times 10^{-3})} = 1 \text{ kHz} \]
[1 point off for 6.25 kHz]

3b  The frequency where the gain of the buffer amplifier falls to 0.5 is the frequency where A falls to 1
which is 1 MHz. [2 MHz was also allowed].
[4 points off if LPF formula used to get 500 to 2000 Hz]

3c  

![Graph showing voltage gain vs. frequency]

[5 points off if gain does not decrease as \(1/f\) above 1 MHz]
[5 points off if gain does not increase as \(f\) below the \(f_c\) value answer in 3a]

4  

![Circuit diagram]

[2 points off for overall sign error, e.g. \(V_0 = -V_1 - V_2 + V_3 + V_4\)]
[2 points off for a working circuit that uses three op amps]
[5 points off for using two differential amps to take \(V_1 - V_3\) and \(V_2 - V_4\) and then connecting the output
directly together]
[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]
[2 points off for the following circuit with resistor values shown because of the overall sign error, e.g. \(V_0 =
-V_1 - V_2 + V_3 + V_4\)]
[4 points off for the following circuit with no resistor values shown]
### 145L midterm #1 grade distribution:

<table>
<thead>
<tr>
<th>Problem</th>
<th>Percentage</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.4 (15 max)</td>
<td>F</td>
</tr>
<tr>
<td>2</td>
<td>22.5 (40 max)</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>17.7 (25 max)</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>17.3 (20 max)</td>
<td>B</td>
</tr>
</tbody>
</table>

- **Maximum score:** 100
- **Average score:** 70.9