For the circuit above:

- What is the Differential Gain, $G_d = V_o/(V_B - V_A)$?
- What is the Common-mode Gain, $G_{cm} = V_o/(\frac{1}{2}(V_B + V_A))$?
- What is the Common-mode Rejection Ratio (CMRR)?

All op amps are ideal with $V_{CC} = 15\, V$ and $V_{CC} = -15\, V$.

- What is the Differential Gain, $G_d = V_o/(V_B - V_A)$?

\[
V_o = \frac{R_3 + R_4}{R_1 + R_2} \frac{R_3}{R_2} V_B - \frac{R_1}{R_2} V_B
\]
\[
V_o = \frac{23 + 1.8}{23 + 1.801} \left( \frac{23}{1.801} \right) V_B - \left( \frac{23}{1.801} \right) V_B = 12.7773 V_B - 12.7707 V_A
\]

Set $V_B = -V_A = 1\, V$, $V_d = V_B - V_A = 2\, V$.

$G_d = V_o/V_d = (12.7773(1) - 12.7707(-1))/2 = 12.7740$

- What is the Common-mode Gain, $G_{cm} = V_o/(\frac{1}{2}(V_B + V_A))$?

Set $V_B = V_A = 1\, V$, $V_{cm} = \frac{1}{2}(V_B + V_A) = 1\, V$.

$G_{cm} = V_o/V_d = |12.7773(1) - 12.7707(1)|/1 = 0.0066$

- What is the Common-mode Rejection Ratio (CMRR)?

\[
CMRR = 20\log_{10} \frac{12.7740}{0.0066} = 65.74
\]
For the circuit above:

- Sketch $V_o$ as a function of time.
- What is $V_x - V_y$ at $t = 45$ ms?

All op amps are ideal with $V_{CC} = 15$ V and $V_{CC} = -15$ V.

Thus:

\[
V_o = \left(1 + \frac{2R_A}{R_G}\right) \left(\frac{R_1}{R_2}\right)(V_B - V_A)
\]

\[
V_o = \left(1 + \frac{2 \times 41}{2.5}\right) \left(\frac{48}{2.4}\right)(V_B - V_A) = 676.0 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V)$ = 676.0($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>1.420</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.2</td>
<td>0.946</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>1.420</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.7</td>
<td>3.110</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>1.420</td>
</tr>
</tbody>
</table>

- What is $V_x - V_y$ at $t = 45$ ms?

\[
V_x - V_y = \left(1 + \frac{2R_A}{R_G}\right)(V_B - V_A)
\]

\[
V_x - V_y = 33.80 (V_B - V_A) = 33.80 (4.2 \text{ mV} - 2.1 \text{ mV}) = 0.071 \text{ V}
\]
For the input, $V_i$, below, sketch the output, $V_o$, on the same graph. Indicate voltage levels and the times of any transitions. (The op amp is idea with the indicated $V_{CC}$ and $V_{EE}$ values).

Non-inverting amplifier:
Gain: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{47}{2.8} = 17.79$

Ideally, output would swing from $-35.58$ V (at $t = 0$ ms) to $35.58$ V (at $t = 20$ ms).

However, output is limited to $\pm 10$ V.
Slope is $2 \times 35.58/20 = 1.779$ V/ms.
So starting at $V=0$, the limit of $10$ V is reached in $\Delta t = 10 \text{ V}/1.779 \text{ V/ms} = 5.621$ ms

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 5.621$</td>
<td>$4.38$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 5.621$</td>
<td>$15.62$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 5.621$</td>
<td>$24.38$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 5.621$</td>
<td>$35.62$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>