For the circuit above:

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

\[
V_o = \left( \frac{R_3 + R_4}{R_1 + R_2} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B
\]

\[
V_o = \left( \frac{28 + 1.4}{28 + 1.401} \right) \left( \frac{28}{1.401} \right) V_B - \left( \frac{28}{1.401} \right) V_B = 19.9993V_B - 19.9857V_A
\]

Set \( V_B = -V_A = 1 \) V, \( V_d = V_B - V_A = 2 \) V.
\( G_d = \frac{V_o}{V_d} = \frac{(19.9993(1) - 19.9857(-1))}{2} = 19.9925 \)

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

Set \( V_B = V_A = 1 \) V, \( V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \) V.
\( G_{cm} = \frac{V_o}{V_d} = \frac{|19.9993(1) - 19.9857(1)|}{1} = 0.0136 \)

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

\( \text{CMRR} = 20 \log_{10} \frac{19.9925}{0.0136} = 63.35 \)
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.

---

- Sketch $V_o$ as a function of time.

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

Thus:

\[
V_o = \left(1 + \frac{2 \times 51}{2.1}\right) \left(\frac{55}{3.1}\right) (V_B - V_A) = 879.5 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 879.5($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.1</td>
<td>1.671</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.1</td>
<td>1.231</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.1</td>
<td>1.671</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.7</td>
<td>3.958</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.1</td>
<td>1.671</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 49.57 (V_B - V_A) = 49.57 (4.1 \text{ mV} - 2.2 \text{ mV}) = 0.094 \text{ V}
\]
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 ideal with the indicated $V_{CC}$ and $V_{EE}$ values).

Non-inverting amplifier:
Gain: $G = 1 + R_1/R_2 = 1 + 56/2.4 = 24.33$

Ideally, output would swing from $-48.66 \text{ V}$ (at $t = 0 \text{ ms}$) to $48.66 \text{ V}$ (at $t = 20 \text{ ms}$).
However, output is limited to $\pm 10 \text{ V}$.
Slope is $2 \times 48.66/20 = 2.433 \text{ V/ms}$.
So starting at $V=0$, the limit of $10 \text{ V}$ is reached in
$\Delta t = 10 \text{ V}/2.433 \text{ V/ms} = 4.110 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 4.110</td>
<td>5.89</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 4.110</td>
<td>14.11</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 4.110</td>
<td>25.89</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 4.110</td>
<td>34.11</td>
<td>-10</td>
</tr>
</tbody>
</table>