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.

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

\[ V_o = \left( \frac{24 + 1.601}{24 + 1.6} \right) \left( \frac{24}{1.601} \right) V_B - \left( \frac{24}{1.601} \right) V_B = 15.0006 V_B - 14.9906 V_A \]

Set \( V_B = -V_A = 1 \) V, \( V_d = V_B - V_A = 2 \) V.
\[
G_d = V_o / V_d = (15.0006(1) - 14.9906(-1))/2 = 14.9956
\]

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

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

Set \( V_B = V_A = 1 \) V, \( V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \) V.
\[
G_{cm} = V_o / V_d = \frac{|15.0006(1) - 14.9906(1)|}{1} = 0.0100
\]

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

\[ \text{CMRR} = 20 \log_{10} \frac{14.9956}{0.0100} = 63.52 \]
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 $V_{CC} = 15 \text{ V}$ and $V_{CC} = -15 \text{ V}$.

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

\[ V_o = \left(1 + \frac{2 \times 50}{3.0}\right) \left(\frac{47}{2.9}\right) (V_B - V_A) = 556.4 (V_B - V_A) \]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>1.168</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.2</td>
<td>0.835</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>1.168</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.6</td>
<td>2.504</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>1.168</td>
</tr>
</tbody>
</table>

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

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

\[ V_x - V_y = 34.33 \,(V_B - V_A) = 34.33 \,(4.2 \text{ mV} - 2.1 \text{ mV}) = 0.072 \text{ V} \]
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: $G = 1 + R_1/R_2 = 1 + 49/2.6 = 19.85$

Ideally, output would swing from $-39.70 \text{ V}$ (at $t = 0 \text{ ms}$) to $39.70 \text{ V}$ (at $t = 20 \text{ ms}$).
However, output is limited to $\pm 10 \text{ V}$.
Slope is $2 \times 39.70/20 = 3.970 \text{ V/ms}$.
So starting at $V=0$, the limit of $10 \text{ V}$ is reached in
$\Delta t = 10 \text{ V}/3.970 \text{ V/ms} = 2.519 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>7.48</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.519</td>
<td>12.52</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.519</td>
<td>27.48</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.519</td>
<td>32.52</td>
<td>-10</td>
</tr>
</tbody>
</table>