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, $G_d = V_o/(V_B - V_A)$?

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

$$V_o = \left( \frac{24 + 1.6}{24 + 1.601} \right) \left( \frac{24}{1.601} \right) V_B - \left( \frac{24}{1.601} \right) V_B = 14.9994V_B - 14.9906V_A$$

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

$G_d = V_o/V_d = (14.9994(1) - 14.9906(-1))/2 = 14.9950$

- 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.

$G_{cm} = V_o/V_d = |14.9994(1) - 14.9906(1)|/1 = 0.0088$

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

$CMRR = 20 \log_{10} \frac{14.9950}{0.0088} = 64.63$
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:

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = $556.4(V_B - V_A)$</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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{49}{2.6} = 19.85$

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 $2 \times 39.70/20 = 1.985 \,\text{V/ms}$.
So starting at $V=0$, the limit of $10\,\text{V}$ is reached in
$\Delta t = 10\,\text{V}/1.985\,\text{V/ms} = 5.038\,\text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 − 5.038</td>
<td>4.96</td>
<td>−10</td>
</tr>
<tr>
<td>10 + 5.038</td>
<td>15.04</td>
<td>+10</td>
</tr>
<tr>
<td>30 − 5.038</td>
<td>24.96</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 5.038</td>
<td>35.04</td>
<td>−10</td>
</tr>
</tbody>
</table>