For the circuit above:

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

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

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

All op amps are ideal with \( V_{CC} = 15 \text{ V} \) and \( V_{CC} = -15 \text{ V} \).

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

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

\[
V_o = \left(\frac{25 + 1.201}{25 + 1.2}\right) \left(\frac{25}{1.201}\right) V_B - \left(\frac{25}{1.201}\right) V_B = 20.8341V_B - 20.8160V_A
\]

Set \( V_B = -V_A = 1 \text{ V} \), \( V_d = V_B - V_A = 2 \text{ V} \).

\( G_d = \frac{V_o}{V_d} = \frac{(20.8341(1) - 20.8160(-1))}{2} = 20.8251 \)

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

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

\( G_{cm} = \frac{V_o}{V_d} = \frac{|20.8341(1) - 20.8160(1)|}{1} = 0.0181 \)

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

\[ \text{CMRR} = 20 \log_{10} \frac{20.8251}{0.0181} = 61.22 \]
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:

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

$$V_o = \left(1 + \frac{2 \times 60}{3.8}\right) \left(\frac{47}{2.4}\right) (V_B - V_A) = 638.0 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 638.0(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>1.276</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.1</td>
<td>1.085</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>1.276</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.3</td>
<td>2.680</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>1.276</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 32.58 (V_B - V_A) = 32.58 (4.1 \text{ mV} - 2.1 \text{ mV}) = 0.065 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 49/2.2 = 23.27$

Ideally, output would swing from $-46.54 \text{ V}$ (at $t = 0 \text{ ms}$) to $46.54 \text{ V}$ (at $t = 20 \text{ ms}$).

However, output is limited to $\pm10 \text{ V}$.

Slope is $2 \times 46.54/20 = 4.654 \text{ V/ms}$.

So starting at $V=0$, the limit of $10 \text{ V}$ is reached in $\Delta t = 10 \text{ V}/4.654 \text{ V/ms} = 2.149 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t_1$ (ms)</th>
<th>$t_2$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 2.149$</td>
<td>$7.85$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 2.149$</td>
<td>$12.15$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 2.149$</td>
<td>$27.85$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 2.149$</td>
<td>$32.15$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>