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, \( G_d = \frac{V_o}{(V_B - V_A)} \)?

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

\[
V_o = \left( \frac{25 + 1.901}{25 + 1.901} \right) \left( \frac{25}{1.901} \right) V_B - \left( \frac{25}{1.901} \right) V_B = 13.1584 V_B - 13.1510 V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = \frac{(13.1584(1) - 13.1510(-1))}{2} = 13.1547
\]

- 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.

\[
G_{cm} = \frac{V_o}{V_d} = \frac{13.1584(1) - 13.1510(1)}{1} = 0.0074
\]

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

\[
CMRR = 20 \log_{10} \frac{13.1547}{0.0074} = 65.00
\]
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:

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

$V_o = \left(1 + \frac{2 \times 46}{3.0}\right)\left(\frac{49}{2.6}\right)(V_B - V_A) = 596.8(V_B - V_A)$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 596.8(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.0</td>
<td>1.134</td>
</tr>
<tr>
<td>15</td>
<td>2.9</td>
<td>4.0</td>
<td>0.656</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.0</td>
<td>1.134</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.5</td>
<td>2.626</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.0</td>
<td>1.134</td>
</tr>
</tbody>
</table>

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

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

$V_x - V_y = 31.67(V_B - V_A) = 31.67(4.0 \text{ mV} - 2.1 \text{ mV}) = 0.060 \text{ V}$
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: $G = 1 + R_1/R_2 = 1 + 50/2.9 = 18.24$

Ideally, output would swing from $-36.48$ V (at $t = 0$ ms) to $36.48$ V (at $t = 20$ ms).
However, output is limited to $\pm10$ V.
Slope is $2 \times 36.48/20 = 3.648$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10 \text{ V}/3.648 \text{ V/ms} = 2.741$ ms

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.741</td>
<td>+10</td>
</tr>
<tr>
<td>30</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.741</td>
<td>-10</td>
</tr>
</tbody>
</table>