For the circuit above:

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

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

\[
V_o = \left( \frac{29 + 1.001}{29 + 1.0} \right) \left( \frac{29}{1.001} \right) V_B - \left( \frac{29}{1.001} \right) V_B = 29.0010 V_B - 28.9710 V_A
\]

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

\( G_d = \frac{V_o}{V_d} = \frac{(29.0010(1) - 28.9710(-1))}{2} = 28.9860 \)

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

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

\( G_{cm} = \frac{V_o}{V_d} = \frac{|29.0010(1) - 28.9710(1)|}{1} = 0.0300 \)

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

\[
\text{CMRR} = 20 \log_{10} \frac{28.9860}{0.0300} = 59.70
\]
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.

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

\[
V_o = \left(1 + \frac{2 \times 46}{2.7}\right) \left(\frac{54}{3.8}\right) (V_B - V_A) = 498.4 (V_B - V_A)
\]

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>2.2</td>
<td>4.0</td>
<td>0.897</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.0</td>
<td>0.797</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.0</td>
<td>0.897</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.0</td>
<td>1.894</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.0</td>
<td>0.897</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 35.07 (V_B - V_A) = 35.07 (4.0 \text{ mV} - 2.2 \text{ mV}) = 0.063 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 59/2.0 = 30.50$

Ideally, output would swing from $-61.00$ V (at $t = 0$ ms) to $61.00$ V (at $t = 20$ ms).

However, output is limited to $\pm 10$ V.

Slope is $2 \times 61.00/20 = 6.100$ V/ms.

So starting at $V=0$, the limit of 10 V is reached in

$\Delta t = 10 \text{ V} / 6.100 \text{ V/ms} = 1.639 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.639</td>
<td>-10</td>
</tr>
<tr>
<td>8.36</td>
<td>10.00</td>
<td>+10</td>
</tr>
<tr>
<td>11.64</td>
<td>30.00</td>
<td>+10</td>
</tr>
<tr>
<td>28.36</td>
<td>30.00</td>
<td>+10</td>
</tr>
<tr>
<td>31.64</td>
<td>30.00</td>
<td>-10</td>
</tr>
</tbody>
</table>