For the circuit above:

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

\[
V_o = \left( \frac{R_3 + R_4}{R_1 + R_2} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B \\
V_o = \left( \frac{28 + 1.6}{28 + 1.601} \right) \left( \frac{28}{1.601} \right) V_B - \left( \frac{28}{1.601} \right) V_B = 17.4994 V_B - 17.4891 V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = \frac{17.4994(1) - 17.4891(-1)}{2} = 17.4943
\]

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

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

\[
G_{cm} = \frac{V_o}{V_d} = \frac{|17.4994(1) - 17.4891(1)|}{1} = 0.0103
\]

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

\[
\text{CMRR} = 20 \log_{10} \frac{17.4943}{0.0103} = 64.60
\]
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.

---

- Sketch $V_o$ as a function of time.

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

\[
V_o = \left( 1 + 2 \times \frac{40}{3.6} \right) \left( \frac{59}{2.4} \right) (V_B - V_A) = 570.9 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 570.9($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.1</td>
<td>1.085</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.1</td>
<td>0.799</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.1</td>
<td>1.085</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.6</td>
<td>2.512</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.1</td>
<td>1.085</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 23.22 (V_B - V_A) = 23.22 (4.1 \text{ mV} - 2.2 \text{ mV}) = 0.044 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 56/2.6 = 22.54$

Ideally, output would swing from $-45.08$ V (at $t = 0$ ms) to 45.08 V (at $t = 20$ ms).
However, output is limited to $\pm 10$ V.
Slope is $2 \times 45.08/20 = 2.254$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10 V/2.254 V/ms = 4.437$ ms

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 4.437$</td>
<td>$5.56$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 4.437$</td>
<td>$14.44$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 4.437$</td>
<td>$25.56$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 4.437$</td>
<td>$34.44$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>