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 \( V_{CC} = 15 \text{ V} \) and \( V_{CC} = -15 \text{ V} \).

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

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

\[
V_o = \left( \frac{28 + 1.0}{28 + 1.001} \right) \left( \frac{28}{1.001} \right) V_B - \left( \frac{28}{1.001} \right) V_B = 27.9990 V_B - 27.9720 V_A
\]

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

\[
G_d = V_o/V_d = (27.9990(1) - 27.9720(-1))/2 = 27.9855
\]

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

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

\[
G_{cm} = V_o/V_d = |27.9990(1) - 27.9720(1)|/1 = 0.0270
\]

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

\[
CMRR = 20 \log_{10} \frac{27.9855}{0.0270} = 60.31
\]
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.

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

\[
V_o = \left(1 + \frac{2 \times 44}{2.2}\right) \left(\frac{52}{3.5}\right) (V_B - V_A) = 609.1 \ (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 609.1(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.0</td>
<td>1.096</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.0</td>
<td>0.975</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.0</td>
<td>1.096</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.6</td>
<td>2.680</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.0</td>
<td>1.096</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 41.00 \ (V_B - V_A) = 41.00 \ (4.0 \text{ mV} - 2.2 \text{ mV}) = 0.074 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 56/2.0 = 29.00$

Ideally, output would swing from $-58.00 \text{ V}$ (at $t = 0 \text{ ms}$) to $58.00 \text{ V}$ (at $t = 20 \text{ ms}$).
However, output is limited to $\pm 10 \text{ V}$.
Slope is $2 \times 58.00/20 = 2.900 \text{ V/ms}$.
So starting at $V=0$, the limit of $10 \text{ V}$ is reached in
$\Delta t = 10 \text{ V}/2.900 \text{ V/ms} = 3.448 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.448</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 3.448</td>
<td>13.45</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 3.448</td>
<td>26.55</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 3.448</td>
<td>33.45</td>
<td>-10</td>
</tr>
</tbody>
</table>