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, \( G_d = V_o/(V_B - V_A) \)?

\[
V_o = \frac{R_1 + R_2}{R_3 + R_4} \frac{R_3}{R_2} V_B - \frac{R_1}{R_2} V_B
\]

\[
V_o = \left( \frac{27 + 1.201}{27 + 1.2} \right) \left( \frac{27}{1.201} \right) V_B - \left( \frac{27}{1.201} \right) V_B = 22.5008 V_B - 22.4813 V_A
\]

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

\[
G_d = V_o/V_d = (22.5008(1) - 22.4813(-1))/2 = 22.4911
\]

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

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

\[
G_{cm} = V_o/V_d = |22.5008(1) - 22.4813(1)|/1 = 0.0195
\]

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

\[
\text{CMRR} = 20 \log_{10} \frac{22.4911}{0.0195} = 61.24
\]
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:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = $515.0 (V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>1.081</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.2</td>
<td>0.927</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>1.081</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.5</td>
<td>2.266</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>1.081</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 34.33 (V_B - V_A) = 34.33 (4.2 \text{ mV} - 2.1 \text{ mV}) = 0.072 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 54/2.2 = 25.55$

Ideally, output would swing from $-51.10$ V (at $t = 0$ ms) to $51.10$ V (at $t = 20$ ms).
However, output is limited to ±10 V.
Slope is $2 \times 51.10/20 = 5.110$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10 \text{ V}/5.110 \text{ V/ms} = 1.957 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 1.957</td>
<td>8.04</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 1.957</td>
<td>11.96</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 1.957</td>
<td>28.04</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 1.957</td>
<td>31.96</td>
<td>-10</td>
</tr>
</tbody>
</table>