For the circuit above:

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

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

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

\[
V_o = \left(\frac{R_1 + R_2}{R_3 + R_4}\right) \left(\frac{R_3}{R_2}\right) V_B - \left(\frac{R_1}{R_2}\right) V_B
\]
\[
V_o = \left(\frac{22 + 1.901}{22 + 1.9}\right) \left(\frac{22}{1.901}\right) V_B - \left(\frac{22}{1.901}\right) V_B = 11.5794 V_B - 11.5729 V_A
\]

Set \( V_B = -V_A = 1 \) V, \( V_d = V_B - V_A = 2 \) V.
\( G_d = V_o/V_d = (11.5794(1) - 11.5729(-1))/2 = 11.5762 \)

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

Set \( V_B = V_A = 1 \) V, \( V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \) V.
\( G_{cm} = V_o/V_d = |11.5794(1) - 11.5729(1)|/1 = 0.0065 \)

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

\( \text{CMRR} = 20 \log_{10} \frac{11.5762}{0.0065} = 65.01 \)
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.

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

Thus:

\[
V_o = \left(1 + \frac{2 \times 57}{3.8}\right) \left(\frac{55}{2.2}\right) (V_B - V_A) = 775.0 (V_B - V_A)
\]

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>2.0</td>
<td>4.2</td>
<td>1.705</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.2</td>
<td>1.085</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>1.705</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.2</td>
<td>3.255</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>1.705</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 31.00 (V_B - V_A) = 31.00 (4.2 \text{ mV} - 2.0 \text{ mV}) = 0.068 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 44/2.9 = 16.17$

Ideally, output would swing from $-32.34 \text{V}$ (at $t = 0 \text{ms}$) to $32.34 \text{V}$ (at $t = 20 \text{ms}$).

However, output is limited to ±10 V.

Slope is $2 \times 32.34/20 = 3.234 \text{V/ms}$.

So starting at $V=0$, the limit of 10 V is reached in $\Delta t = 10 \text{V}/3.234 \text{V/ms} = 3.092 \text{ms}$.

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 3.092</td>
<td>6.91</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 3.092</td>
<td>13.09</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 3.092</td>
<td>26.91</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 3.092</td>
<td>33.09</td>
<td>-10</td>
</tr>
</tbody>
</table>