For the circuit above:

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

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

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

All op amps are ideal with \( V_{CC} = 15 \) V and \( V_{CC} = -15 \) V.

\[
V_o = \left( \frac{R_1 + R_2}{R_3 + R_4} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B = 19.1675 V_B - 19.1507 V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = \frac{(19.1675(1)) - (19.1507(-1))}{2} = 19.1591
\]

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

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

\[
G_{cm} = \frac{V_o}{V_d} = \frac{|19.1675(1) - 19.1507(1)|}{1} = 0.0168
\]

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

\[
CMRR = 20 \log_{10} \frac{19.1591}{0.0168} = 61.14
\]
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:

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

$$V_o = \left(1 + \frac{2 \times 54}{3.3}\right) \left(\frac{47}{3.9}\right) (V_B - V_A) = 406.5 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$(V) = 406.5($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>0.813</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.1</td>
<td>0.691</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>0.813</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.6</td>
<td>1.829</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>0.813</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 33.73 (V_B - V_A) = 33.73 (4.1 \text{ mV} - 2.1 \text{ mV}) = 0.067 \text{ V}$$
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: \( G = 1 + \frac{R_1}{R_2} = 1 + \frac{46}{2.2} = 21.91 \)

Ideally, output would swing from \(-43.82 \text{ V} \) (at \( t = 0 \text{ ms} \)) to \(43.82 \text{ V} \) (at \( t = 20 \text{ ms} \)).
However, output is limited to \(\pm 10 \text{ V} \).
Slope is \(2 \times 43.82/20 = 4.382 \text{ V/ms} \).

So starting at \( V = 0 \), the limit of 10 V is reached in
\[ \Delta t = 10 \text{ V}/4.382 \text{ V/ms} = 2.282 \text{ ms} \]

Thus:

<table>
<thead>
<tr>
<th>( t \text{ (ms)} )</th>
<th>( t \text{ (ms)} )</th>
<th>( V_o \text{ (V)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 2.282</td>
<td>7.72</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.282</td>
<td>12.28</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.282</td>
<td>27.72</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.282</td>
<td>32.28</td>
<td>-10</td>
</tr>
</tbody>
</table>