For the circuit above:

- What is the Differential Gain, $G_d = V_o/(V_B - V_A)$?
- What is the Common-mode Gain, $G_{cm} = V_o/(1/2(V_B + V_A))$?
- What is the Common-mode Rejection Ratio (CMRR)?

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

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

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

\[
V_o = \left( \frac{29 + 1.2}{29 + 1.201} \right) \left( \frac{29}{1.201} \right) V_B - \left( \frac{29}{1.201} \right) V_B = 24.1659 V_B - 24.1465 V_A
\]

Set $V_B = -V_A = 1$ V, $V_d = V_B - V_A = 2$ V.

$G_d = V_o/V_d = (24.1659(1) - 24.1465(-1))/2 = 24.1562$

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

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

$G_{cm} = V_o/V_d = |24.1659(1) - 24.1465(1)|/1 = 0.0194$

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

$\text{CMRR} = 20 \log_{10} \frac{24.1562}{0.0194} = 61.90$
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.

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

$$V_o = \left(1 + \frac{2 \times 55}{2.6}\right) \left(\frac{55}{3.9}\right) (V_B - V_A) = 610.7 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V)$ = $610.7(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.1</td>
<td>1.160</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>4.1</td>
<td>0.977</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.1</td>
<td>1.160</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.3</td>
<td>2.504</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.1</td>
<td>1.160</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 43.31 (V_B - V_A) = 43.31 (4.1 \text{ mV} - 2.2 \text{ mV}) = 0.082 \text{ V}$$
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: \( G = 1 + R_1/R_2 = 1 + 57/2.2 = 26.91 \)

Ideally, output would swing from \(-53.82 \text{ V} \) (at \( t = 0 \text{ ms} \)) to \(53.82 \text{ V} \) (at \( t = 20 \text{ ms} \)).

However, output is limited to \( \pm 10 \text{ V} \).

Slope is \( 2 \times 53.82/20 = 2.691 \text{ V/ms} \).

So starting at \( V=0 \), the limit of \( 10 \text{ V} \) is reached in \( \Delta t = 10 \text{ V}/2.691 \text{ V/ms} = 3.716 \text{ ms} \)

Thus:

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( t ) (ms)</th>
<th>( V_o ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 3.716</td>
<td>6.28</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 3.716</td>
<td>13.72</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 3.716</td>
<td>26.28</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 3.716</td>
<td>33.72</td>
<td>-10</td>
</tr>
</tbody>
</table>