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 $V_{CC} = 15$ V and $V_{CC} = -15$ V.

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

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

\[
V_o = \left( \frac{29 + 1.601}{29 + 1.6} \right) \left( \frac{29}{1.601} \right) V_B - \left( \frac{29}{1.601} \right) V_B = 18.1256 V_B - 18.1137 V_A
\]

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

$G_d = V_o/V_d = (18.1256(1) - 18.1137(-1))/2 = 18.1197$

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

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

$G_{cm} = V_o/V_d = |18.1256(1) - 18.1137(1)|/1 = 0.0119$

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

$CMRR = 20 \log_{10} \frac{18.1197}{0.0119} = 63.65$
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.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 522.2($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.2</td>
<td>1.044</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.2</td>
<td>0.731</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.2</td>
<td>1.044</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.7</td>
<td>2.350</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.2</td>
<td>1.044</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 47.36 (V_B - V_A) = 47.36 (4.2 \text{ mV} - 2.2 \text{ mV}) = 0.095 \text{ V}
\]
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: \( G = 1 + R_1 / R_2 = 1 + 59 / 2.6 = 23.69 \)

Ideally, output would swing from \(-47.38 \text{ V} \) (at \( t = 0 \text{ ms} \)) to \(47.38 \text{ V} \) (at \( t = 20 \text{ ms} \)).

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

Slope is \( 2 \times 47.38 / 20 = 4.738 \text{ V/ms} \).

So starting at \( V=0 \), the limit of 10 V is reached in \( \Delta t = 10 \text{ V} / 4.738 \text{ V/ms} = 2.111 \text{ ms} \)

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( t ) (ms)</th>
<th>( V_o ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 2.111</td>
<td>7.89</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.111</td>
<td>12.11</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.111</td>
<td>27.89</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.111</td>
<td>32.11</td>
<td>-10</td>
</tr>
</tbody>
</table>