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.

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

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

\[
V_o = \left( \frac{29 + 1.501}{29 + 1.5} \right) \left( \frac{29}{1.501} \right) V_B - \left( \frac{29}{1.501} \right) V_B = 19.3340V_B - 19.3205V_A
\]

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

\( G_d = \frac{V_o}{V_d} = (19.3340(1) - 19.3205(-1))/2 = 19.3272 \)

- 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.

\( G_{cm} = \frac{V_o}{V_d} = \frac{|19.3340(1) - 19.3205(1)|}{1} = 0.0135 \)

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

\[
CMRR = 20 \log_{10} \frac{19.3272}{0.0135} = 63.12
\]
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) = 504.2 ($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.1</td>
<td>0.958</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.1</td>
<td>0.706</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.1</td>
<td>0.958</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.1</td>
<td>1.966</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.1</td>
<td>0.958</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 35.07 (V_B - V_A) = 35.07 (4.1 \text{ mV} - 2.2 \text{ mV}) = 0.067 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 57/2.5 = 23.80$

Ideally, output would swing from $-47.60$ V (at $t = 0$ ms) to $47.60$ V (at $t = 20$ ms).
However, output is limited to $\pm 10$ V.
Slope is $2 \times 47.60/20 = 4.760$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10 \text{V}/4.760 \text{V/ms} = 2.101 \text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-2</td>
</tr>
<tr>
<td>10 + 2.101</td>
<td>-2.90</td>
</tr>
<tr>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>30 + 2.101</td>
<td>27.90</td>
</tr>
<tr>
<td>32.10</td>
<td>-2</td>
</tr>
</tbody>
</table>