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, \( G_d = V_o/(V_B - V_A) \)?

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

\[
V_o = \left( \frac{29 + 1.801}{29 + 1.8} \right) \left( \frac{29}{1.801} \right) V_B - \left( \frac{29}{1.801} \right) V_B = 16.1116V_B - 16.1022V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = (16.1116(1) - 16.1022(-1))/2 = 16.1069
\]

- 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.

\[
G_{cm} = \frac{V_o}{V_d} = |16.1116(1) - 16.1022(1)|/1 = 0.0094
\]

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

\[
CMRR = 20 \log_{10} \frac{16.1069}{0.0094} = 64.68
\]
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.

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

$$V_o = \left(1 + \frac{2 \times 58}{2.6}\right)\left(\frac{49}{3.3}\right) (V_B - V_A) = 677.3 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = $677.3(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.2</td>
<td>1.355</td>
</tr>
<tr>
<td>15</td>
<td>2.9</td>
<td>4.2</td>
<td>0.880</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.2</td>
<td>1.355</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.5</td>
<td>2.912</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.2</td>
<td>1.355</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 45.62 (V_B - V_A) = 45.62 (4.2\text{ mV} - 2.2\text{ mV}) = 0.091\text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 57/2.8 = 21.36$

Ideally, output would swing from $-42.72$ V (at $t = 0$ ms) to $42.72$ V (at $t = 20$ ms).
However, output is limited to $\pm10$ V.
Slope is $2 \times 42.72/20 = 4.272$ V/ms.
So starting at $V=0$, the limit of $10$ V is reached in
$\Delta t = 10\, V / 4.272\, V / ms = 2.341$ ms

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>7.66</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.341</td>
<td>12.34</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.341</td>
<td>27.66</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.341</td>
<td>32.34</td>
<td>-10</td>
</tr>
</tbody>
</table>