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

- 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 $V_B = -V_A = 1 \text{ V}$, $V_d = V_B - V_A = 2 \text{ V}$.

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

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

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

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

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

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.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 848.7(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.2</td>
<td>1.697</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>4.2</td>
<td>1.443</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.2</td>
<td>1.697</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.3</td>
<td>3.480</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.2</td>
<td>1.697</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 37.13 (V_B - V_A) = 37.13 (4.2 \text{mV} - 2.2 \text{mV}) = 0.074 \text{ V}$$
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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{58}{2.2} = 27.36$

Ideally, output would swing from $-54.72\,\text{V}$ (at $t = 0\,\text{ms}$) to $54.72\,\text{V}$ (at $t = 20\,\text{ms}$).

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

Slope is $2 \times \frac{54.72}{20} = 2.736\,\text{V/ms}$.

So starting at $V=0$, the limit of $10\,\text{V}$ is reached in $\Delta t = 10\,\text{V}/2.736\,\text{V/ms} = 3.655\,\text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 3.655$</td>
<td>$6.34$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 3.655$</td>
<td>$13.65$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 3.655$</td>
<td>$26.34$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 3.655$</td>
<td>$33.66$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>