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

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

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

\[
V_o = \left( \frac{27 + 1.801}{27 + 1.8} \right) \left( \frac{27}{1.801} \right) V_B - \left( \frac{27}{1.801} \right) V_B = 15.0005V_B - 14.9917V_A
\]

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

\[
G_d = V_o/V_d = (15.0005(1) - 14.9917(-1))/2 = 14.9961
\]

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

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

\[
G_{cm} = V_o/V_d = |15.0005(1) - 14.9917(1)|/1 = 0.0088
\]

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

\[
CMRR = 20 \log_{10} \frac{14.9961}{0.0088} = 64.63
\]
For the circuit above:

- Sketch $V_o$ as a function of time.
- What is $V_x - V_y$ at $t = 45$ ms?

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

- Sketch $V_o$ as a function of time.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (mV) = 468.3($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>0.937</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.1</td>
<td>0.609</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>0.937</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.1</td>
<td>1.873</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>0.937</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 32.33 \ (V_B - V_A) = 32.33 \ (4.1 \text{ mV} - 2.1 \text{ mV}) = 0.065 \text{ V}$$
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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{54}{2.8} = 20.29$

Ideally, output would swing from $-40.58$ V (at $t = 0$ ms) to $40.58$ V (at $t = 20$ ms).

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

Slope is $2 \times 40.58/20 = 4.058$ V/ms.

So starting at $V=0$, the limit of $10$ V is reached in

$\Delta t = 10 \, \text{V} / 40.58 \, \text{V/ms} = 2.464 \, \text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 2.464</td>
<td>7.54</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.464</td>
<td>12.46</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.464</td>
<td>27.54</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.464</td>
<td>32.46</td>
<td>-10</td>
</tr>
</tbody>
</table>