For the circuit above:

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

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

$$V_o = \left( \frac{24 + 1.9}{24 + 1.901} \right) \left( \frac{24}{1.901} \right) V_B - \left( \frac{24}{1.901} \right) V_B = 12.6311 V_B - 12.6249 V_A$$

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

$G_d = V_o/V_d = (12.6311(1) - 12.6249(-1))/2 = 12.6280$

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

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

$G_{cm} = V_o/V_d = |12.6311(1) - 12.6249(1)|/1 = 0.0062$

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

$CMRR = 20 \log_{10} \frac{12.6280}{0.0062} = 66.18$
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.

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

\[
V_o = \left(1 + \frac{2 \times 52}{3.3}\right) \left(\frac{50}{2.8}\right)(V_B - V_A) = 580.6(V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>1.219</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.2</td>
<td>0.813</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>1.219</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.5</td>
<td>2.555</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>1.219</td>
</tr>
</tbody>
</table>

• What is $V_x - V_y$ at $t = 45$ ms?

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

\[
V_x - V_y = 32.52(V_B - V_A) = 32.52(4.2 \text{ mV} - 2.1 \text{ mV}) = 0.068 \text{ V}
\]
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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{49}{2.9} = 17.90$

Ideally, output would swing from $-35.80 \text{V}$ (at $t = 0 \text{ms}$) to $35.80 \text{V}$ (at $t = 20 \text{ms}$).

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

Slope is $2 \times 35.80/20 = 1.790 \text{V/ms}$.

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

$\Delta t = 10 \text{V}/1.790 \text{V/ms} = 5.587 \text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 5.587</td>
<td>4.41</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 5.587</td>
<td>15.59</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 5.587</td>
<td>24.41</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 5.587</td>
<td>35.59</td>
<td>-10</td>
</tr>
</tbody>
</table>