For the circuit above:

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

All op amps are ideal with \( V_{CC} = 15 \) V and \( V_{CC} = -15 \) V.

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

\[
V_o = \left(\frac{24 + 1.701}{24 + 1.7}\right)\left(\frac{24}{1.701}\right)V_B - \left(\frac{24}{1.701}\right)V_B = 14.1182V_B - 14.1093V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = (14.1182(1) - 14.1093(-1))/2 = 14.1137
\]

- What is the Common-mode Gain, \( G_{cm} = \frac{V_o}{\left(\frac{1}{2}(V_B + V_A)\right)} \)?
  
  Set \( V_B = V_A = 1 \) V, \( V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \) V.
  
  \[
  G_{cm} = \frac{V_o}{V_d} = \left|14.1182(1) - 14.1093(1)\right|/1 = 0.0089
  \]

- What is the Common-mode Rejection Ratio (CMRR)?
  
  \[
  \text{CMRR} = 20\log_{10}\frac{14.1137}{0.0089} = 64.01
  \]
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.

Thus:

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

$$V_o = \left(1 + \frac{2 \times 47}{3.1}\right) \left(\frac{54}{3.8}\right) (V_B - V_A) = 445.1 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 445.1(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>0.890</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.1</td>
<td>0.623</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>0.890</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.2</td>
<td>1.825</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>0.890</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 31.32 (V_B - V_A) = 31.32 (4.1 \text{ mV} - 2.1 \text{ mV}) = 0.063 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 48/2.7 = 18.78$

Ideally, output would swing from $-37.56$ V (at $t = 0$ ms) to $37.56$ V (at $t = 20$ ms).

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

Slope is $2 \times 37.56/20 = 3.756$ V/ms.

So starting at $V=0$, the limit of 10 V is reached in $\Delta t = 10 \text{ V} / 3.756 \text{ V/ms} = 2.662 \text{ ms}$

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.662</td>
<td>-10</td>
</tr>
<tr>
<td>10</td>
<td>12.66</td>
<td>+10</td>
</tr>
<tr>
<td>30</td>
<td>12.66</td>
<td>+10</td>
</tr>
<tr>
<td>30</td>
<td>32.66</td>
<td>-10</td>
</tr>
</tbody>
</table>