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

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

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

$$V_o = \left(\frac{24 + 2.0}{24 + 2.001}\right) \left(\frac{24}{2.001}\right) V_B - \left(\frac{24}{2.001}\right) V_B = 11.9995 V_B - 11.9940 V_A$$

Set $V_B = -V_A = 1$ V, $V_d = V_B - V_A = 2$ V.

$G_d = V_o/V_d = (11.9995(1) - 11.9940(-1))/2 = 11.9968$

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

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

$G_{cm} = V_o/V_d = |11.9995(1) - 11.9940(1)|/1 = 0.0055$

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

$CMRR = 20 \log_{10} \frac{11.9968}{0.0055} = 66.77$
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:

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

\[
V_o = \left(1 + \frac{2 \times 50}{2.3}\right) \left(\frac{57}{3.5}\right) (V_B - V_A) = 724.4 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( V_A ) (mV)</th>
<th>( V_B ) (mV)</th>
<th>( V_o) (V) = 724.4((V_B - V_A))</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>1.521</td>
</tr>
<tr>
<td>15</td>
<td>2.9</td>
<td>4.2</td>
<td>0.942</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>1.521</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.4</td>
<td>3.115</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>1.521</td>
</tr>
</tbody>
</table>

- What is \( V_x - V_y \) at \( t = 45 \) ms?

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

\[
V_x - V_y = 44.48 (V_B - V_A) = 44.48 (4.2 \text{ mV} - 2.1 \text{ mV}) = 0.093 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 49/3.0 = 17.33$

Ideally, output would swing from $-34.66$ V (at $t = 0$ ms) to $34.66$ V (at $t = 20$ ms).
However, output is limited to $\pm 10$ V.
Slope is $2 \times 34.66/20 = 1.733$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10 V/1.733 V/ms = 5.770$ 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>$5.770$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10$</td>
<td>$15.77$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30$</td>
<td>$24.23$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30$</td>
<td>$35.77$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>