For the circuit above:

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

\[
V_o = \left( \frac{R_3 + R_4}{R_1 + R_2} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B \\
V_o = \left( \frac{23 + 1.1}{23 + 1.101} \right) \left( \frac{23}{1.101} \right) V_B - \left( \frac{23}{1.101} \right) V_B = 20.9082 V_B - 20.8901 V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = (20.9082(1) - 20.8901(-1))/2 = 20.8991
\]

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

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

\[
G_{cm} = \frac{V_o}{V_d} = \frac{|20.9082(1) - 20.8901(1)|}{1} = 0.0181
\]

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

\[
CMRR = 20 \log_{10} \frac{20.8991}{0.0181} = 61.25
\]
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:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = $415.0(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>0.872</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.2</td>
<td>0.747</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>0.872</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.3</td>
<td>1.743</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>0.872</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 27.67 (V_B - V_A) = 27.67 (4.2 \text{ mV} - 2.1 \text{ mV}) = 0.058 \text{ V}$$
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 idea with the indicated $V_{CC}$ and $V_{EE}$ values).

Non-inverting amplifier:
Gain: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{45}{2.1} = 22.43$

Ideally, output would swing from $-44.86\, \text{V}$ (at $t = 0\, \text{ms}$) to $44.86\, \text{V}$ (at $t = 20\, \text{ms}$).

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

Slope is $2 \times 44.86/20 = 2.243\, \text{V/ms}$.

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

$$\Delta t = 10\, \text{V}/2.243\, \text{V/ms} = 4.458\, \text{ms}$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.54</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 4.458</td>
<td>14.46</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 4.458</td>
<td>25.54</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 4.458</td>
<td>34.46</td>
<td>-10</td>
</tr>
</tbody>
</table>