For the circuit above:

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

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

$$V_o = \left( \frac{21 + 1.401}{21 + 1.4} \right) \left( \frac{21}{1.401} \right) V_B - \left( \frac{21}{1.401} \right) V_B = 15.007 V_B - 14.9893 V_A$$

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

$G_d = V_o/V_d = (15.0007(1) - 14.9893(-1))/2 = 14.9950$

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

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

$G_{cm} = V_o/V_d = |15.0007(1) - 14.9893(1)|/1 = 0.0114$

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

CMRR $= 20 \log_{10} \frac{14.9950}{0.0114} = 62.38$
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:

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

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 516.2 ($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.1</td>
<td>1.084</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.1</td>
<td>0.878</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.1</td>
<td>1.084</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.2</td>
<td>2.168</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.1</td>
<td>1.084</td>
</tr>
</tbody>
</table>

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

$$V_x - V_y = 33.67 (V_B - V_A) = 33.67 (4.1 \text{ mV} - 2.0 \text{ mV}) = 0.071 \text{ V}$$
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: \( G = 1 + \frac{R_1}{R_2} = 1 + \frac{43}{2.4} = 18.92 \)

Ideally, output would swing from $-37.84 \text{ V}$ (at $t = 0 \text{ ms}$) to $37.84 \text{ V}$ (at $t = 20 \text{ ms}$).

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

Slope is $2 \times \frac{37.84}{20} = 3.784 \text{ V/ms}$.

So starting at $V=0$, the limit of $10 \text{ V}$ is reached in $\Delta t = 10 \text{ V} / 3.784 \text{ V/ms} = 2.643 \text{ ms}$

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 2.643$</td>
<td>$7.36$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 2.643$</td>
<td>$12.64$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 2.643$</td>
<td>$27.36$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 2.643$</td>
<td>$32.64$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>