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, \( G_d = \frac{V_o}{(V_B - V_A)} \)?

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

\[
V_o = \left( \frac{22 + 1.5}{22 + 1.501} \right) \left( \frac{22}{1.501} \right) V_B - \left( \frac{22}{1.501} \right) V_B = 14.6660 V_B - 14.6569 V_A
\]

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

\( G_d = \frac{V_o}{V_d} = (14.6660(1) - 14.6569(-1))/2 = 14.6615 \)

- 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.

\( G_{cm} = \frac{V_o}{V_d} = |14.6660(1) - 14.6569(1)|/1 = 0.0091 \)

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

\[
CMRR = 20 \log_{10} \frac{14.6615}{0.0091} = 64.14
\]
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)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.2</td>
<td>0.891</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>4.2</td>
<td>0.689</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>0.891</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.4</td>
<td>1.782</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>0.891</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 28.69 (V_B - V_A) = 28.69 (4.2 \text{ mV} - 2.0 \text{ mV}) = 0.063 \text{ V}$$
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 idea with the indicated $V_{CC}$ and $V_{EE}$ values).

---

**Non-inverting amplifier:**

**Gain:** $G = 1 + R_1/R_2 = 1 + 44/2.5 = 18.60$

Ideally, output would swing from $-37.20\,\text{V}$ (at $t = 0\,\text{ms}$) to $37.20\,\text{V}$ (at $t = 20\,\text{ms}$).

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

Slope is $2 \times 37.20/20 = 1.860\,\text{V/ms}$.

So starting at $V=0$, the limit of $10\,\text{V}$ is reached in $\Delta t = 10\,\text{V}/1.860\,\text{V/ms} = 5.376\,\text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t_1$ (ms)</th>
<th>$t_2$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 5.376</td>
<td>4.62</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 5.376</td>
<td>15.38</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 5.376</td>
<td>24.62</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 5.376</td>
<td>35.38</td>
<td>-10</td>
</tr>
</tbody>
</table>