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.

• What is the Differential Gain, \( G_d = \frac{V_o}{(V_B - V_A)} \)?

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

\[
V_o = \left(\frac{22 + 1.1}{22 + 1.101}\right) \left(\frac{22}{1.101}\right) V_B - \left(\frac{22}{1.101}\right) V_B = 19.999 V_B - 19.9818 V_A
\]

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

\[
G_d = \frac{V_o}{V_d} = \frac{(19.9991(1) - 19.9818(-1))}{2} = 19.9904
\]

• 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.

\[
G_{cm} = \frac{V_o}{V_d} = \frac{|19.9991(1) - 19.9818(1)|}{1} = 0.0173
\]

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

\[
CMRR = 20 \log_{10} \frac{19.9904}{0.0173} = 61.26
\]
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.

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

Thus:

\[
V_o = \left(1 + \frac{2 \times 41}{3.4}\right) \left(\frac{41}{3.3}\right) (V_B - V_A) = 312.1 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( V_A ) (mV)</th>
<th>( V_B ) (mV)</th>
<th>( V_o ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.0</td>
<td>0.624</td>
</tr>
<tr>
<td>15</td>
<td>2.2</td>
<td>4.0</td>
<td>0.562</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.0</td>
<td>0.624</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>1.404</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.0</td>
<td>0.624</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 25.12 (V_B - V_A) = 25.12 (4.0 \text{ mV} - 2.0 \text{ mV}) = 0.050 \text{ V}
\]
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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{43}{2.1} = 21.48$

Ideally, output would swing from $-42.96$ V (at $t = 0$ ms) to $42.96$ V (at $t = 20$ ms).

However, output is limited to $\pm 10$ V.
Slope is $2 \times 42.96/20 = 2.148$ V/ms.
So starting at V=0, the limit of 10 V is reached in
$\Delta t = 10 \, V / 2.148 \, V / \text{ms} = 4.655 \, \text{ms}$