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, \( G_d = V_o/(V_B - V_A) \)?

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

\[
V_o = \left( \frac{22 + 1.3}{22 + 1.301} \right) \left( \frac{22}{1.301} \right) V_B - \left( \frac{22}{1.301} \right) V_B = 16.9224 V_B - 16.9101 V_A
\]

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

\( G_d = V_o/V_d = (16.9224(1) - 16.9101(-1))/2 = 16.9163 \)

- 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.

\( G_{cm} = V_o/V_d = |16.9224(1) - 16.9101(1)|/1 = 0.0123 \)

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

\[
CMRR = 20 \log_{10} \frac{16.9163}{0.0123} = 62.77
\]
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.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 351.4($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.2</td>
<td>0.773</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.2</td>
<td>0.633</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>0.773</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>1.581</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>0.773</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 26.00 (V_B - V_A) = 26.00 (4.2\text{ mV} - 2.0\text{ mV}) = 0.057\text{ V}
\]
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: \( G = 1 + R_1/R_2 = 1 + 44/2.3 = 20.13 \)
Ideally, output would swing from \(-40.26 \text{ V} \) (at \( t = 0 \text{ ms} \)) to \(40.26 \text{ V} \) (at \( t = 20 \text{ ms} \)).
However, output is limited to \( \pm 10 \text{ V} \).
Slope is \( 2 \times 40.26/20 = 2.013 \text{ V/ms} \).
So starting at \( V = 0 \), the limit of 10 V is reached in \( \Delta t = 10 \text{ V}/2.013 \text{ V/ms} = 4.968 \text{ ms} \)

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( t ) (ms)</th>
<th>( V_o ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.03</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 4.968</td>
<td>14.97</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 4.968</td>
<td>25.03</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 4.968</td>
<td>34.97</td>
<td>-10</td>
</tr>
</tbody>
</table>