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 \( V_{CC} = 15 \text{ V} \) and \( V_{CC} = -15 \text{ V} \).

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

\[ V_o = \left( \frac{20 + 1.601}{20 + 1.6} \right) \left( \frac{20}{1.601} \right) V_B - \left( \frac{20}{1.601} \right) V_B = 12.5006 V_B - 12.4922 V_A \]

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

\[ G_d = \frac{V_o}{V_d} = \frac{(12.5006(1) - 12.4922(-1))}{2} = 12.4964 \]

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

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

\[ G_{cm} = \frac{V_o}{V_d} = \frac{|12.5006(1) - 12.4922(1)|}{1} = 0.0084 \]

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

\[ \text{CMRR} = 20 \log_{10} \frac{12.4964}{0.0084} = 63.45 \]
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.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 523.7(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.2</td>
<td>1.152</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>4.2</td>
<td>0.890</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>1.152</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>2.357</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>1.152</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 28.37 (V_B - V_A) = 28.37 (4.2\text{ mV} - 2.0\text{ mV}) = 0.062\text{ V}
\]
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 diagram]

Non-inverting amplifier:
Gain: $G = 1 + R_1/R_2 = 1 + 41/2.6 = 16.77$

Ideally, output would swing from $-33.54 \text{ V}$ (at $t = 0 \text{ ms}$) to $33.54 \text{ V}$ (at $t = 20 \text{ ms}$).

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

Slope is $2 \times 33.54/20 = 3.354 \text{ V/ms}$.

So starting at $V=0$, the limit of $10 \text{ V}$ is reached in $\Delta t = 10 \text{ V}/3.354 \text{ V/ms} = 2.982 \text{ ms}$

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 2.982</td>
<td>7.02</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.982</td>
<td>12.98</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.982</td>
<td>27.02</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.982</td>
<td>32.98</td>
<td>-10</td>
</tr>
</tbody>
</table>