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.

\[
V_o = \left( \frac{R_1 + R_2}{R_3 + R_4} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B \\
V_o = \left( \frac{20 + 1.201}{20 + 1.2} \right) \left( \frac{20}{1.201} \right) V_B - \left( \frac{20}{1.201} \right) V_B = 16.6675 V_B - 16.6528 V_A
\]

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

\[
G_d = V_o/V_d = \frac{16.6675(1) - 16.6528(-1)}{2} = 16.6602
\]

- What is the Differential Gain, \( G_d = V_o/(V_B - V_A) \)?

\[
G_{cm} = V_o/\left(\frac{1}{2}(V_B + V_A)\right)
\]

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

\[
G_{cm} = V_o/V_d = \frac{|16.6675(1) - 16.6528(1)|}{1} = 0.0147
\]

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

\[
CMRR = 20 \log_{10} \frac{16.6602}{0.0147} = 61.09
\]
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.

- Sketch $V_o$ as a function of time.

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

\[
V_o = \left(1 + \frac{2 \times 41}{2.6}\right) \left(\frac{56}{2.4}\right) (V_B - V_A) = 759.2 (V_B - V_A)
\]

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>4.2</td>
<td>1.670</td>
</tr>
<tr>
<td>15</td>
<td>2.3</td>
<td>4.2</td>
<td>1.442</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>1.670</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>3.416</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>1.670</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 32.54 (V_B - V_A) = 32.54 (4.2 \text{ mV} - 2.0 \text{ mV}) = 0.072 \text{ V}
\]
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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{41}{2.2} = 19.64$

Ideally, output would swing from $-39.28$ V (at $t = 0$ ms) to $39.28$ V (at $t = 20$ ms).

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

Slope is $2 \times 39.28/20 = 3.928$ V/ms.

So starting at $V=0$, the limit of $10$ V is reached in $\Delta t = 10$ V/$3.928$ V/ms = 2.546 ms

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.546</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.546</td>
<td>12.55</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.546</td>
<td>27.45</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.546</td>
<td>32.55</td>
<td>-10</td>
</tr>
</tbody>
</table>