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 $V_{CC} = -15 \text{ V}$.

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

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

$$
V_o = \left( \frac{21 + 1.4}{21 + 1.401} \right) \left( \frac{21}{1.401} \right) V_B - \left( \frac{21}{1.401} \right) V_B = 14.9993 V_B - 14.9893 V_A
$$

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

$G_d = V_o/V_d = (14.9993(1) - 14.9893(-1))/2 = 14.9943$

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

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

$G_{cm} = V_o/V_d = |14.9993(1) - 14.9893(1)|/1 = 0.0100$

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

$CMRR = 20 \log_{10} \frac{14.9943}{0.0100} = 63.52$
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.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 648.0($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.1</td>
<td>1.361</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.1</td>
<td>1.102</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.1</td>
<td>1.361</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.3</td>
<td>2.786</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.1</td>
<td>1.361</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 42.74 (V_B - V_A) = 42.74 (4.1 \text{ mV} - 2.0 \text{ mV}) = 0.090 \text{ V}
\]
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).

![Diagram of non-inverting amplifier](image)

### Non-inverting amplifier:

**Gain:** \( G = 1 + \frac{R_1}{R_2} = 1 + \frac{42}{2.4} = 18.50 \)

Ideally, output would swing from \(-37.00\) V (at \( t = 0 \) ms) to \(37.00\) V (at \( t = 20 \) ms).

However, output is limited to \( \pm 10 \) V.

Slope is \( 2 \times \frac{37.00}{20} = 1.850 \) V/ms.

So starting at \( V=0 \), the limit of 10 V is reached in

\[ \Delta t = 10 \text{ V} / 1.850 \text{ V/ms} = 5.405 \text{ ms} \]

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( t ) (ms)</th>
<th>( V_o ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – 5.405</td>
<td>4.59</td>
<td>–10</td>
</tr>
<tr>
<td>10 + 5.405</td>
<td>15.40</td>
<td>+10</td>
</tr>
<tr>
<td>30 – 5.405</td>
<td>24.59</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 5.405</td>
<td>35.41</td>
<td>–10</td>
</tr>
</tbody>
</table>