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, $G_d = V_o/(V_B - V_A)$?**

\[
V_o = \left(\frac{R_1 + R_2}{R_3 + R_4}\right) \left(\frac{R_3}{R_2}\right) V_B - \left(\frac{R_1}{R_2}\right) V_B \\
V_o = \left(\frac{25 + 1.501}{25 + 1.5}\right) \left(\frac{25}{1.501}\right) V_B - \left(\frac{25}{1.501}\right) V_B = 16.6673 V_B - 16.6556 V_A
\]

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

$G_d = \frac{V_o}{V_d} = (16.6673(1) - 16.6556(-1))/2 = 16.6614$

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

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

$G_{cm} = \frac{V_o}{V_d} = |16.6673(1) - 16.6556(1)|/1 = 0.0117$

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

$\text{CMRR} = 20 \log_{10} \frac{16.6614}{0.0117} = 63.07$
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) = $725.3(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>1.523</td>
</tr>
<tr>
<td>15</td>
<td>2.6</td>
<td>4.2</td>
<td>1.160</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>1.523</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.6</td>
<td>3.264</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>1.523</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 38.24 (V_B - V_A) = 38.24 (4.2 \text{ mV} - 2.1 \text{ mV}) = 0.080 \text{ V}$$
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: $G = 1 + \frac{R_1}{R_2} = 1 + \frac{51}{2.5} = 21.40$

Ideally, output would swing from $-42.80 \text{ V}$ (at $t = 0 \text{ ms}$) to $42.80 \text{ V}$ (at $t = 20 \text{ ms}$).
However, output is limited to $\pm 10 \text{ V}$.
Slope is $2 \times 42.80 / 20 = 4.280 \text{ V/ms}$.
So starting at $V=0$, the limit of $10 \text{ V}$ is reached in
$\Delta t = 10 \text{ V} / 4.280 \text{ V/ms} = 2.336 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.336</td>
<td>10</td>
</tr>
<tr>
<td>30 - 2.336</td>
<td>10</td>
</tr>
<tr>
<td>30 + 2.336</td>
<td>-10</td>
</tr>
</tbody>
</table>