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.

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

\[
V_o = \left( \frac{25 + 1.9}{25 + 1.901} \right) \left( \frac{25}{1.901} \right) V_B - \left( \frac{25}{1.901} \right) V_B = 13.1574 V_B - 13.1510 V_A
\]

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

\( G_d = V_o/V_d = (13.1574(1) - 13.1510(-1))/2 = 13.1542 \)

- 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.

\( G_{cm} = V_o/V_d = |13.1574(1) - 13.1510(1)|/1 = 0.0064 \)

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

\[
CMRR = 20 \log_{10} \left( \frac{13.1542}{0.0064} \right) = 66.26
\]
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.**

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

$$V_o = \left(1 + \frac{2 \times 42}{2.9}\right) \left(\frac{56}{2.1}\right) (V_B - V_A) = 799.1 (V_B - V_A)$$

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>2.1</td>
<td>4.0</td>
<td>1.518</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.0</td>
<td>0.959</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.0</td>
<td>1.518</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.3</td>
<td>3.356</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.0</td>
<td>1.518</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 29.97 (V_B - V_A) = 29.97 (4.0 \text{ mV} - 2.1 \text{ mV}) = 0.057 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 50/2.9 = 18.24$

Ideally, output would swing from $-36.48$ V (at $t = 0$ ms) to $36.48$ V (at $t = 20$ ms).
However, output is limited to $\pm 10$ V.
Slope is $2 \times 36.48/20 = 1.824$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in $\Delta t = 10 \text{ V} / 1.824 \text{ V/ms} = 5.482$ 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>5.482</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 5.482</td>
<td>15.48</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 5.482</td>
<td>24.52</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 5.482</td>
<td>35.48</td>
<td>-10</td>
</tr>
</tbody>
</table>