For the circuit above:

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

All op amps are ideal with \( V_{CC} = 15 \text{ V} \) and \( V_{CC} = -15 \text{ V} \).

\[
\begin{align*}
V_o &= \left( \frac{R_3 + R_4}{R_1 + R_2} \right) \frac{R_3}{R_2} V_B - \left( \frac{R_1}{R_2} \right) V_B \\
V_o &= \left( \frac{27 + 1.8}{27 + 1.801} \right) \left( \frac{27}{1.801} \right) V_B - \left( \frac{27}{1.801} \right) V_B = 14.9995V_B - 14.9917V_A
\end{align*}
\]

Set \( V_B = -V_A = 1 \text{ V} \), \( V_d = V_B - V_A = 2 \text{ V} \).
\( G_d = \frac{V_o}{V_d} = (14.9995(1) - 14.9917(-1))/2 = 14.9956 \)

- What is the Common-mode Gain, \( G_{cm} = \frac{V_o}{(\frac{1}{2}(V_B + V_A))} \)?
  Set \( V_B = V_A = 1 \text{ V} \), \( V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \text{ V} \).
  \( G_{cm} = \frac{V_o}{V_d} = |14.9995(1) - 14.9917(1)|/1 = 0.0078 \)

- What is the Common-mode Rejection Ratio (CMRR)?
  \( \text{CMRR} = 20 \log_{10} \frac{14.9995}{0.0078} = 65.68 \)
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.

Thus:

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

$$V_o = \left(1 + \frac{2 \times 47}{3.0}\right) \left(\frac{42}{2.9}\right) (V_B - V_A) = 468.3 \, (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 468.3(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>0.937</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.1</td>
<td>0.609</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>0.937</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.1</td>
<td>1.873</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>0.937</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 32.33 \, (V_B - V_A) = 32.33 \, (4.1 \, \text{mV} - 2.1 \, \text{mV}) = 0.065 \, \text{V}$$
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:
Gain: $G = 1 + R_1/R_2 = 1 + 54/2.8 = 20.29$

Ideally, output would swing from $-40.58\, V$ (at $t = 0\, ms$) to $40.58\, V$ (at $t = 20\, ms$).

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

Slope is $2 \times 40.58/20 = 2.029\, V/ms$.

So starting at $V=0$, the limit of $10\, V$ is reached in $\Delta t = 10\, V/2.029\, V/ms = 4.929\, ms$

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 4.929$</td>
<td>$5.07$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 4.929$</td>
<td>$14.93$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 4.929$</td>
<td>$25.07$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 4.929$</td>
<td>$34.93$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>