For the circuit above:

- What is the Differential Gain, $G_d = \frac{V_o}{(V_B - V_A)}$?

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

- 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, $G_d = \frac{V_o}{(V_B - V_A)}$?

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

\[
V_o = \left(\frac{27 + 1.701}{27 + 1.7}\right) \left(\frac{27}{1.701}\right) V_B - \left(\frac{27}{1.701}\right) V_B = 15.8829 V_B - 15.8730 V_A
\]

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

$G_d = \frac{V_o}{V_d} = (15.8829(1) - 15.8730(-1))/2 = 15.8780$

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

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

$G_{cm} = \frac{V_o}{V_d} = \left|\frac{15.8829(1) - 15.8730(1)}{1}\right|/1 = 0.0099$

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

CMRR = $20 \log_{10} \frac{15.8780}{0.0099} = 64.10$
For the circuit above:

- Sketch $V_o$ as a function of time.
- What is $V_x - V_y$ at $t = 45$ ms?

All op amp are ideal with $V_{CC} = 15$ V and $V_{CC} = -15$ V.

- Sketch $V_o$ as a function of time.

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

$$V_o = \left(1 + \frac{2 \times 49}{2.1}\right) \left(\frac{51}{2.3}\right) (V_B - V_A) = 1057.0 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 1057.0(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.0</td>
<td>2.008</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.0</td>
<td>1.374</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.0</td>
<td>2.008</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.2</td>
<td>4.334</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.0</td>
<td>2.008</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 47.67 (V_B - V_A) = 47.67 (4.0 \text{ mV} - 2.1 \text{ mV}) = 0.091 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 55/2.7 = 21.37$
Ideally, output would swing from $-42.74 \text{ V}$ (at $t = 0 \text{ ms}$) to $42.74 \text{ V}$ (at $t = 20 \text{ ms}$).
However, output is limited to $\pm 10 \text{ V}$.
Slope is $2 \times 42.74/20 = 4.274 \text{ V/ms}$.
So starting at $V=0$, the limit of $10 \text{ V}$ is reached in $\Delta t = 10 \text{ V} / 4.274 \text{ V/ms} = 2.340 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 − 2.340</td>
<td>7.66</td>
<td>−10</td>
</tr>
<tr>
<td>10 + 2.340</td>
<td>12.34</td>
<td>+10</td>
</tr>
<tr>
<td>30 − 2.340</td>
<td>27.66</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.340</td>
<td>32.34</td>
<td>−10</td>
</tr>
</tbody>
</table>