For the circuit above:

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

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

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

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

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

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

\[
V_o = \left( \frac{27 + 1.6}{27 + 1.601} \right) \left( \frac{27}{1.601} \right) V_B - \left( \frac{27}{1.601} \right) V_B = 16.8744 V_B - 16.8645 V_A
\]

Set $V_B = -V_A = 1$ V, $V_d = V_B - V_A = 2$ V.

$G_d = V_o/V_d = (16.8744(1) - 16.8645(-1))/2 = 16.8695$

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

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

$G_{cm} = V_o/V_d = |16.8744(1) - 16.8645(1)|/1 = 0.0099$

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

$CMRR = 20 \log_{10} \left( \frac{16.8695}{0.0099} \right) = 64.63$
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.

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

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 1394.5(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>2.789</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.1</td>
<td>1.952</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>2.789</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.6</td>
<td>6.275</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>2.789</td>
</tr>
</tbody>
</table>

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

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

\[ V_x - V_y = 59.00 (V_B - V_A) = 59.00 (4.1 \text{mV} - 2.1 \text{mV}) = 0.118 \text{ V} \]
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: $G = 1 + R_1/R_2 = 1 + 54/2.6 = 21.77$

Ideally, output would swing from $-43.54$ V (at $t = 0$ ms) to $43.54$ V (at $t = 20$ ms).

However, output is limited to $\pm 10$ V.
Slope is $2 \times 43.54/20 = 2.177$ V/ms.
So starting at $V=0$, the limit of $10$ V is reached in $\Delta t = 10 \text{ V}/2.177 \text{ V/ms} = 4.593 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10.593</td>
<td>-10</td>
</tr>
<tr>
<td>10.593</td>
<td>14.593</td>
<td>+10</td>
</tr>
<tr>
<td>20.593</td>
<td>25.41</td>
<td>+10</td>
</tr>
<tr>
<td>30.593</td>
<td>34.593</td>
<td>-10</td>
</tr>
</tbody>
</table>