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.

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

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

$$V_o = \left( \frac{28 + 1.701}{28 + 1.7} \right) \left( \frac{28}{1.701} \right) V_B - \left( \frac{28}{1.701} \right) V_B = 16.4711 V_B - 16.4609 V_A$$

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

$G_d = V_o / V_d = (16.4711(1) - 16.4609(-1))/2 = 16.4660$

- 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.

$G_{cm} = V_o / V_d = |16.4711(1) - 16.4609(1)| / 1 = 0.0102$

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

$CMRR = 20 \log_{10} \frac{16.4660}{0.0102} = 64.16$
For the circuit above:

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

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

- 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>$V_o(V) = 622.5(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.0</td>
<td>1.121</td>
</tr>
<tr>
<td>15</td>
<td>2.8</td>
<td>4.0</td>
<td>0.747</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
<td>4.0</td>
<td>1.121</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.5</td>
<td>2.677</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.0</td>
<td>1.121</td>
</tr>
</tbody>
</table>

- What is $V_x - V_y$ at $t = 45 \text{ ms}$?

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

$$V_x - V_y = 43.86 (V_B - V_A) = 43.86 (4.0 \text{ mV} - 2.2 \text{ mV}) = 0.079 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 56/2.7 = 21.74$

Ideally, output would swing from $-43.48$ V (at $t = 0$ ms) to $43.48$ V (at $t = 20$ ms).
However, output is limited to $\pm 10$ V.
Slope is $2 \times 43.48/20 = 4.348$ V/ms.
So starting at $V=0$, the limit of $10$ V is reached in

$$\Delta t = 10 \text{ V} / 4.348 \text{ V/ms} = 2.300 \text{ ms}$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 − 2.300</td>
<td>7.70</td>
<td>−10</td>
</tr>
<tr>
<td>10 + 2.300</td>
<td>12.30</td>
<td>+10</td>
</tr>
<tr>
<td>30 − 2.300</td>
<td>27.70</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.300</td>
<td>32.30</td>
<td>−10</td>
</tr>
</tbody>
</table>