For the circuit above:

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

\[
V_o = \left(\frac{R_3 + R_4}{R_1 + R_2}\right) \left(\frac{R_3}{R_2}\right) V_B - \left(\frac{R_1}{R_2}\right) V_B
\]
\[
V_o = \left(\frac{28 + 1.7}{28 + 1.701}\right) \left(-\frac{28}{1.701}\right) V_B - \left(-\frac{28}{1.701}\right) V_B = 16.4700 V_B - 16.4609 V_A
\]

Set $V_B = -V_A = 1 \text{ V}$, $V_d = V_B - V_A = 2 \text{ V}$.  
$G_d = V_o/V_d = (16.4700(1) - 16.4609(-1))/2 = 16.4655$

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

Set $V_B = V_A = 1 \text{ V}$, $V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \text{ V}$.  
$G_{cm} = V_o/V_d = |16.4700(1) - 16.4609(1)|/1 = 0.0091$

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

$\text{CMRR} = 20 \log_{10} \frac{16.4655}{0.0091} = 65.15$
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:

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

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 $t = 45$ 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 ideal with the indicated \( V_{CC} \) and \( V_{EE} \) values).

**Non-inverting amplifier:**

**Gain:** \( G = 1 + \frac{R_1}{R_2} = 1 + \frac{56}{2.7} = 21.74 \)

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 \( 2 \times 43.48/20 = 2.174 \) V/ms.

So starting at \( V=0 \), the limit of 10 V is reached in

\[ \Delta t = 10 \text{ V} / 2.174 \text{ V/ms} = 4.600 \text{ ms} \]

Thus:

<table>
<thead>
<tr>
<th>( t ) (ms)</th>
<th>( V_o ) (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – 4.600</td>
<td>–10</td>
</tr>
<tr>
<td>10 + 4.600</td>
<td>+10</td>
</tr>
<tr>
<td>30 – 4.600</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 4.600</td>
<td>–10</td>
</tr>
</tbody>
</table>