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

\[
V_o = \left(\frac{R_1 + R_2}{R_3 + R_4}\right) \left(\frac{R_3}{R_2}\right) V_B - \left(\frac{R_1}{R_2}\right) V_B \\
V_o = \left(\frac{28 + 1.001}{28 + 1.0}\right) \left(-\frac{28}{1.001}\right) V_B - \left(-\frac{28}{1.001}\right) V_B = 28.0010 V_B - 27.9720 V_A
\]

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

$G_d = \frac{V_o}{V_d} = \frac{28.0010(1) - 27.9720(-1)}{2} = 27.9865$

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

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

$G_{cm} = \frac{V_o}{V_d} = \frac{|28.0010(1) - 27.9720(1)|}{1} = 0.0290$

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

CMRR = $20 \log_{10} \frac{27.9865}{0.0290} = 59.69$
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.

- 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) = 609.1($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.2</td>
<td>4.0</td>
<td>1.096</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.0</td>
<td>0.975</td>
</tr>
<tr>
<td>25</td>
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<td>1.096</td>
</tr>
<tr>
<td>35</td>
<td>2.2</td>
<td>6.6</td>
<td>2.680</td>
</tr>
<tr>
<td>45</td>
<td>2.2</td>
<td>4.0</td>
<td>1.096</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 41.00 (V_B - V_A) = 41.00 (4.0 \text{ mV} - 2.2 \text{ mV}) = 0.074 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 56/2.0 = 29.00$
Ideally, output would swing from $-58.00 \, \text{V}$ (at $t = 0 \, \text{ms}$) to $58.00 \, \text{V}$ (at $t = 20 \, \text{ms}$).
However, output is limited to $\pm 10 \, \text{V}$.
Slope is $2 \times 58.00/20 = 5.800 \, \text{V/ms}$.
So starting at $V=0$, the limit of $10 \, \text{V}$ is reached in $\Delta t = 10 \, \text{V}/5.800 \, \text{V/ms} = 1.724 \, \text{ms}$