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 $V_{CC} = 15 \text{ V}$ and $V_{CC} = -15 \text{ V}$.

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

\[ V_o = \left( \frac{21 + 1.3}{21 + 1.301} \right) \left( \frac{21}{1.301} \right) V_B - \left( \frac{21}{1.301} \right) V_B = 16.1531 V_B - 16.1414 V_A \]

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

$G_d = V_o / V_d = (16.1531(1) - 16.1414(-1)) / 2 = 16.1472$

- What is the Common-mode Gain, $G_{cm} = V_o / (\frac{1}{2}(V_B + V_A))$?
  
  Set $V_B = V_A = 1 \text{ V}$, $V_{cm} = \frac{1}{2}(V_B + V_A) = 1 \text{ V}$.

  $G_{cm} = V_o / V_d = |16.1531(1) - 16.1414(1)| / 1 = 0.0117$

- What is the Common-mode Rejection Ratio (CMRR)?
  
  $CMRR = 20 log_{10} \frac{16.1472}{0.0117} = 62.80$
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:

$$V_o = \left(1 + \frac{2R_A}{R_G}\right) \left(\frac{R_1}{R_2}\right) (V_B - V_A)$$
$$V_o = \left(1 + \frac{2 \times 46}{2.7}\right) \left(\frac{47}{3.4}\right) (V_B - V_A) = 484.8 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 484.8($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.2</td>
<td>1.067</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.2</td>
<td>0.873</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>1.067</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>2.182</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>1.067</td>
</tr>
</tbody>
</table>

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

$$V_x - V_y = \left(1 + \frac{2R_A}{R_G}\right) (V_B - V_A)$$
$$V_x - V_y = 35.07 (V_B - V_A) = 35.07 (4.2 \text{mV} - 2.0 \text{mV}) = 0.077 \text{V}$$
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: $G = 1 + R_1/R_2 = 1 + 42/2.3 = 19.26$

Ideally, output would swing from $-38.52$ V (at $t = 0$ ms) to $38.52$ V (at $t = 20$ ms).
However, output is limited to $\pm 10$ V.
Slope is $2 \times 38.52/20 = 1.926$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10 \text{ V}/1.926 \text{ V/ms} = 5.192 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 5.192</td>
<td>4.81</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 5.192</td>
<td>15.19</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 5.192</td>
<td>24.81</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 5.192</td>
<td>35.19</td>
<td>-10</td>
</tr>
</tbody>
</table>