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, $G_d = V_o/(V_B - V_A)$?

\[
V_o = \left(\frac{R_1 + R_2}{R_3 + R_4}\right) \frac{R_3}{R_2} V_B - \left(\frac{R_1}{R_2}\right) V_B
\]
\[
V_o = \left(\frac{21 + 1.401}{21 + 1.4}\right) \left(\frac{21}{1.401}\right) V_B - \left(\frac{21}{1.401}\right) V_B = 15.0007 V_B - 14.9893 V_A
\]

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

$G_d = V_o/V_d = (15.0007(1) - 14.9893(-1))/2 = 14.9950$

- 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.

$G_{cm} = V_o/V_d = |15.0007(1) - 14.9893(1)|/1 = 0.0114$

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

$CMRR = 20 \log_{10} \frac{14.9950}{0.0114} = 62.38$
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:

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

$$V_o = \left(1 + \frac{2 \times 55}{4.0}\right) \left(\frac{58}{3.8}\right) (V_B - V_A) = 435.0 \, (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 435.0(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.1</td>
<td>0.913</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.1</td>
<td>0.740</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.1</td>
<td>0.913</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>1.958</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.1</td>
<td>0.913</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 28.50 \, (V_B - V_A) = 28.50 \, (4.1 \, \text{mV} - 2.0 \, \text{mV}) = 0.060 \, \text{V}$$
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 circuit diagram]

Non-inverting amplifier: 
Gain: $G = 1 + R_1/R_2 = 1 + 42/2.4 = 18.50$

Ideally, output would swing from $-37.00\,\text{V}$ (at $t = 0\,\text{ms}$) to $37.00\,\text{V}$ (at $t = 20\,\text{ms}$).

However, output is limited to $\pm 10\,\text{V}$.
Slope is $2 \times 37.00/20 = 3.700\,\text{V/ms}$.
So starting at $V=0$, the limit of $10\,\text{V}$ is reached in $\Delta t = 10\,\text{V}/3.700\,\text{V/ms} = 2.703\,\text{ms}$

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10$</td>
<td>$2.703$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 2.703$</td>
<td>$12.70$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 2.703$</td>
<td>$27.30$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 2.703$</td>
<td>$32.70$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>