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

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

\[
V_o = \left(\frac{R_1 + R_2}{R_3 + R_4}\right) \left(\frac{R_3}{R_2}\right) V_B - \left(\frac{R_1}{R_2}\right) V_B \\
V_o = \left(\frac{22 + 1.101}{22 + 1.1}\right) \left(\frac{22}{1.101}\right) V_B - \left(\frac{22}{1.101}\right) V_B = 20.0009 V_B - 19.9818 V_A
\]

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

$G_d = V_o/V_d = (20.0009(1) - 19.9818(-1))/2 = 19.9914$

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

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

$G_{cm} = V_o/V_d = |20.0009(1) - 19.9818(1)|/1 = 0.0191$

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

$\text{CMRR} = 20 \log_{10} \frac{19.9914}{0.0191} = 60.40$
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:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V)$ = 312.1($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.0</td>
<td>0.624</td>
</tr>
<tr>
<td>15</td>
<td>2.2</td>
<td>4.0</td>
<td>0.562</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.0</td>
<td>0.624</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>1.404</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.0</td>
<td>0.624</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 25.12 (V_B - V_A) = 25.12 (4.0 \text{ mV} - 2.0 \text{ mV}) = 0.050 \text{ V}
\]
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: $G = 1 + R_1/R_2 = 1 + 43/2.1 = 21.48$

Ideally, output would swing from $-42.96 \, V$ (at $t = 0 \, ms$) to $42.96 \, V$ (at $t = 20 \, ms$).
However, output is limited to $\pm 10 \, V$.
Slope is $2 \times 42.96/20 = 4.296 \, V/ms$.
So starting at $V=0$, the limit of $10 \, V$ is reached in
$\Delta t = 10 \, V/4.296 \, V/ms = 2.328 \, ms$

Thus:

<table>
<thead>
<tr>
<th>$t (ms)$</th>
<th>$t (ms)$</th>
<th>$V_o (V)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 2.328</td>
<td>7.67</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.328</td>
<td>12.33</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.328</td>
<td>27.67</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.328</td>
<td>32.33</td>
<td>-10</td>
</tr>
</tbody>
</table>