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

$$V_o = \frac{R_1 + R_2}{R_3 + R_4} \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B$$
$$V_o = \left( \frac{23 + 1.101}{23 + 1.1} \right) V_B - \left( \frac{23}{1.101} \right) V_B = 20.9100 V_B - 20.8901 V_A$$

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

$G_d = V_o/V_d = (20.9100(1) - 20.8901(-1))/2 = 20.9001$

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

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

$G_{cm} = V_o/V_d = |20.9100(1) - 20.8901(1)|/1 = 0.0199$

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

$CMRR = 20 \log_{10} \frac{20.9001}{0.0199} = 60.43$
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) $= 415.0(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>0.872</td>
</tr>
<tr>
<td>15</td>
<td>2.4</td>
<td>4.2</td>
<td>0.747</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>0.872</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.3</td>
<td>1.743</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>0.872</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 27.67(V_B - V_A) = 27.67(4.2 \text{ mV} - 2.1 \text{ mV}) = 0.058 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 45/2.1 = 22.43$

Ideally, output would swing from $-44.86$ V (at $t = 0$ ms) to $44.86$ V (at $t = 20$ ms).

However, output is limited to $\pm 10$ V.

Slope is $2 \times 44.86/20 = 4.486$ V/ms.

So starting at $V=0$, the limit of $10$ V is reached in

$\Delta t = 10 \text{ V}/4.486 \text{ V/ms} = 2.229 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 2.229</td>
<td>7.77</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 2.229</td>
<td>12.23</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 2.229</td>
<td>27.77</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.229</td>
<td>32.23</td>
<td>-10</td>
</tr>
</tbody>
</table>