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

$$
V_o = \left( \frac{R_1 + R_2}{R_3 + R_4} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B \\
V_o = \left( \frac{23 + 1.701}{23 + 1.7} \right) \left( \frac{23}{1.701} \right) V_B - \left( \frac{23}{1.701} \right) V_B = 13.5300 V_B - 13.5215 V_A
$$

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

$G_d = V_o/V_d = (13.5300(1) - 13.5215(-1))/2 = 13.5258$

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

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

$G_{cm} = V_o/V_d = |13.5300(1) - 13.5215(1)|/1 = 0.0085$

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

$\text{CMRR} = 20 \log_{10} \frac{13.5258}{0.0085} = 64.03$
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 $V_{CC} = 15 \text{ V}$ and $V_{CC} = -15 \text{ V}$.

- 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:

\[
V_o = \left(1 + \frac{2 \times 50}{2.7}\right) \left(\frac{59}{3.6}\right) (V_B - V_A) = 623.4 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V) = 623.4($V_B - V_A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.1</td>
<td>1.247</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.1</td>
<td>0.873</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.1</td>
<td>1.247</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.6</td>
<td>2.805</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.1</td>
<td>1.247</td>
</tr>
</tbody>
</table>

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

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

\[
V_x - V_y = 38.04 (V_B - V_A) = 38.04 (4.1 \text{ mV} - 2.1 \text{ mV}) = 0.076 \text{ V}
\]
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:
Gain: $G = 1 + R_1/R_2 = 1 + 46/2.7 = 18.04$

Ideally, output would swing from $-36.08\,\text{V}$ (at $t = 0\,\text{ms}$) to $36.08\,\text{V}$ (at $t = 20\,\text{ms}$).

However, output is limited to ±10 V.
Slope is $2 \times 36.08/20 = 3.608\,\text{V/\text{ms}}$.
So starting at $V=0$, the limit of 10 V is reached in
$\Delta t = 10\,\text{V}/3.608\,\text{V/\text{ms}} = 2.772\,\text{ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 2.772$</td>
<td>$7.23$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 2.772$</td>
<td>$12.77$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 2.772$</td>
<td>$27.23$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 2.772$</td>
<td>$32.77$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>