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

\[
V_o = \left(\frac{R_3 + R_4}{R_1 + R_2}\right) \left(\frac{R_3}{R_2}\right) V_B - \left(\frac{R_1}{R_2}\right) V_B
\]
\[
V_o = \left(\frac{21 + 1.7}{21 + 1.701}\right) \left(\frac{21}{1.701}\right) V_B - \left(\frac{21}{1.701}\right) V_B = 12.3524 V_B - 12.3457 V_A
\]

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

$G_d = V_o/V_d = (12.3524(1) - 12.3457(-1))/2 = 12.3491$

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

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

$G_{cm} = V_o/V_d = |12.3524(1) - 12.3457(1)|/1 = 0.0067$

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

$\text{CMRR} = 20 \log_{10} \frac{12.3491}{0.0067} = 65.31$
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.

- Sketch $V_o$ as a function of time.

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

$$V_o = \left(1 + \frac{2 \times 56}{2.2}\right) \left(\frac{47}{2.4}\right) (V_B - V_A) = 1016.6 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (mV) = 1016.6$(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.2</td>
<td>2.237</td>
</tr>
<tr>
<td>15</td>
<td>2.6</td>
<td>4.2</td>
<td>1.627</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.2</td>
<td>2.237</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.6</td>
<td>4.676</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.2</td>
<td>2.237</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 51.91 (V_B - V_A) = 51.91 (4.2 \text{ mV} - 2.0 \text{ mV}) = 0.114 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 42/2.7 = 16.56$

Ideally, output would swing from $-33.12$ V (at $t = 0$ ms) to $33.12$ V (at $t = 20$ ms).
However, output is limited to ±10 V.
Slope is $2 \times 33.12/20 = 1.656$ V/ms.
So starting at $V=0$, the limit of 10 V is reached in $\Delta t = 10 \text{ V}/1.656 \text{ V/ms} = 6.039 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10 - 6.039$</td>
<td>$-10$</td>
</tr>
<tr>
<td>$10 + 6.039$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 - 6.039$</td>
<td>$+10$</td>
</tr>
<tr>
<td>$30 + 6.039$</td>
<td>$-10$</td>
</tr>
</tbody>
</table>