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

\[
V_o = \frac{R_3 + R_4}{R_1 + R_2} \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B
\]
\[
V_o = \frac{26 + 1.6}{26 + 1.601} \left( \frac{26}{1.601} \right) V_B - \left( \frac{26}{1.601} \right) V_B = 16.2494 V_B - 16.2399 V_A
\]

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

$G_d = V_o / V_d = (16.2494(1) - 16.2399(-1))/2 = 16.2447$

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

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

$G_{cm} = V_o / V_d = |16.2494(1) - 16.2399(1)|/1 = 0.0095$

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

$\text{CMRR} = 20 \log_{10} \frac{16.2447}{0.0095} = 64.66$
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.

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

$$V_o = \left(1 + \frac{2 \times 57}{3.5}\right) \left(\frac{44}{3.7}\right) (V_B - V_A) = 399.2 (V_B - V_A)$$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1</td>
<td>4.2</td>
<td>0.838</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>4.2</td>
<td>0.599</td>
</tr>
<tr>
<td>25</td>
<td>2.1</td>
<td>4.2</td>
<td>0.838</td>
</tr>
<tr>
<td>35</td>
<td>2.1</td>
<td>6.5</td>
<td>1.756</td>
</tr>
<tr>
<td>45</td>
<td>2.1</td>
<td>4.2</td>
<td>0.838</td>
</tr>
</tbody>
</table>

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

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

$$V_x - V_y = 33.57 (V_B - V_A) = 33.57 (4.2 \text{ mV} - 2.1 \text{ mV}) = 0.070 \text{ V}$$
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: $G = 1 + R_1/R_2 = 1 + 51/2.6 = 20.62$

Ideally, output would swing from $-41.24\text{ V}$ (at $t = 0\text{ ms}$) to $41.24\text{ V}$ (at $t = 20\text{ ms}$).
However, output is limited to $\pm 10\text{ V}$.
Slope is $2 \times 41.24/20 = 2.062\text{ V/ms}$.
So starting at $V=0$, the limit of $10\text{ V}$ is reached in
$\Delta t = 10\text{ V}/2.062\text{ V/ms} = 4.850\text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 4.850</td>
<td>5.15</td>
<td>-10</td>
</tr>
<tr>
<td>10 + 4.850</td>
<td>14.85</td>
<td>+10</td>
</tr>
<tr>
<td>30 - 4.850</td>
<td>25.15</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 4.850</td>
<td>34.85</td>
<td>-10</td>
</tr>
</tbody>
</table>