ELEC ENG 2CJ4 Circuits and Systems Lab 1

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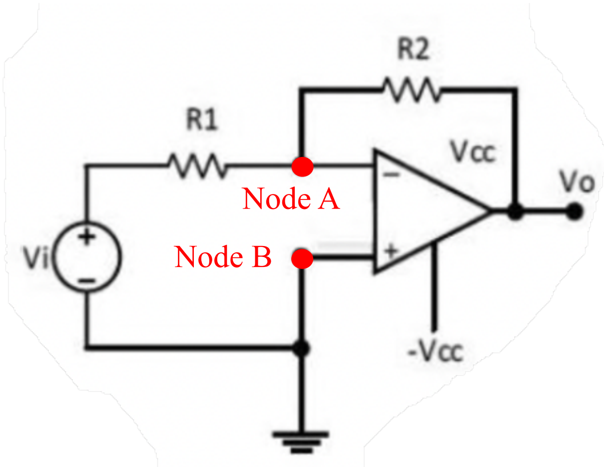
Section L01

Submission Date:

Given the circuit in Figure 8 with R1 = 1OkΩ,, R2 = 47kΩ, +VCC 5 and -Vcc = -5 V, express the gain A = V_o/V_{in} as a function of R1 and R2 and determine the linear active region and saturation region.



R1 = 10kΩ
R2 = 47kΩ

The given circuit is an inverting op-amp.
Nodal Analysis:

Node A: $\frac{Va - Vin}{R1} + \frac{Va - Vout}{R2} = 0$

Node B: Vb = 0

Since we are assuming an ideal op-amp Vb = Va and therefore:

$-\frac{Vin}{R1} = \frac{Vout}{R2} \longrightarrow \frac{Vout}{Vin} = -\frac{R2}{R1}$

Gain (A) = $\frac{Vout}{Vin} = -\frac{R2}{R1} = -\frac{47}{10}$ = -4.7

Vout = Avin = -4.7Vin

Linear active region for supply of ±5V:

$$-Vcc < -4.7(Vout) < +Vcc$$

$$-\frac{5}{-4.7} > Vin > +\frac{5}{-4.7}$$

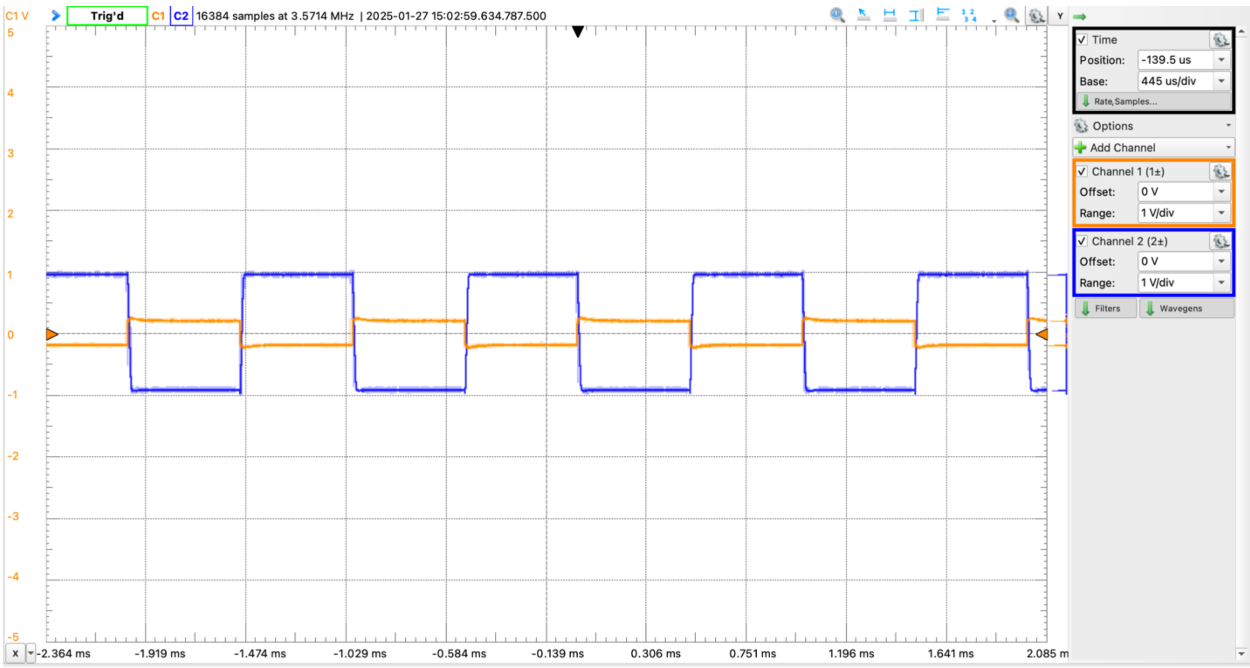
$$-1.064 < Vin < +1.064$$

For an op-amp supply of ±5V, the linear active region is when Vin is between -1.06 and 1.06. If Vin is outside of the linear active region, then it becomes the saturation region. Therefore, the saturation region is when $-1.064 > Vin$ or $Vin > +1.064$ where Vout will have a value of +5V or -5V, respectively.

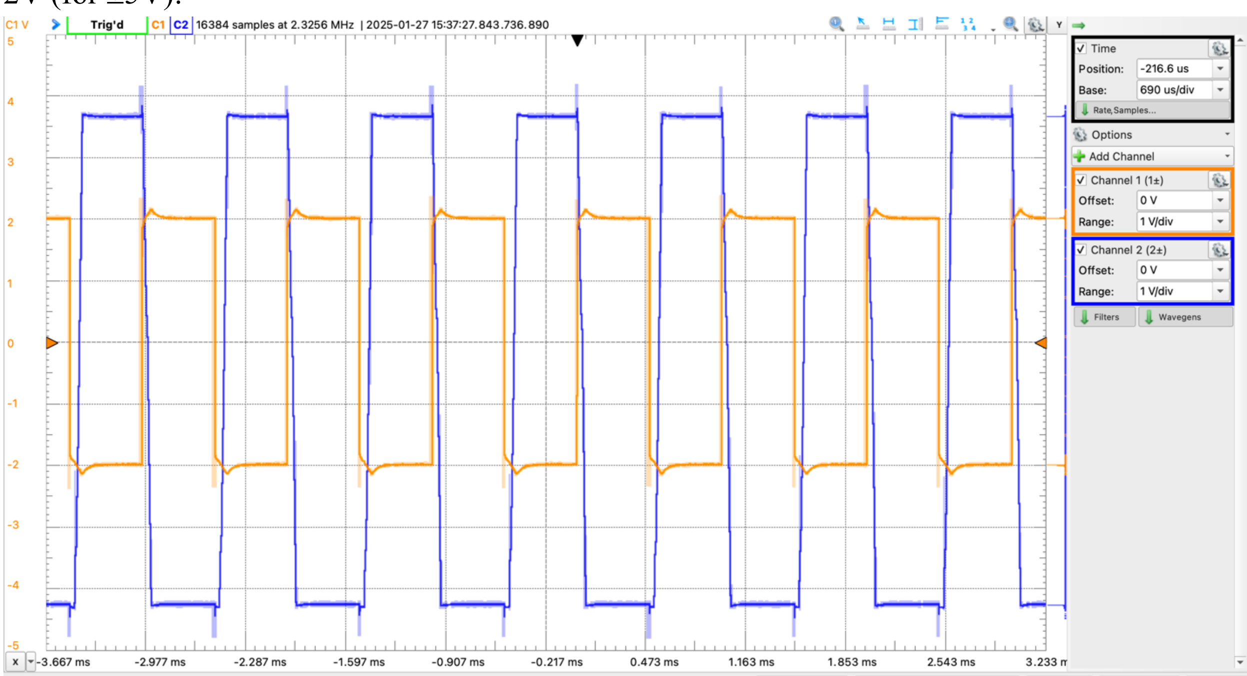
i. Build the circuit with the values given and with % being a 1 kHz square wave with amplitudes of 200 mV, 2 V, and 5 V and an offset of 0 V, where you should only observe the peak-to-peak magnitude. Plot V_i and V_o using the oscilloscope tool on the Analog Discovery 2 in the linear active region and saturation region.

Orange is V_{in} and Blue is V_{out}

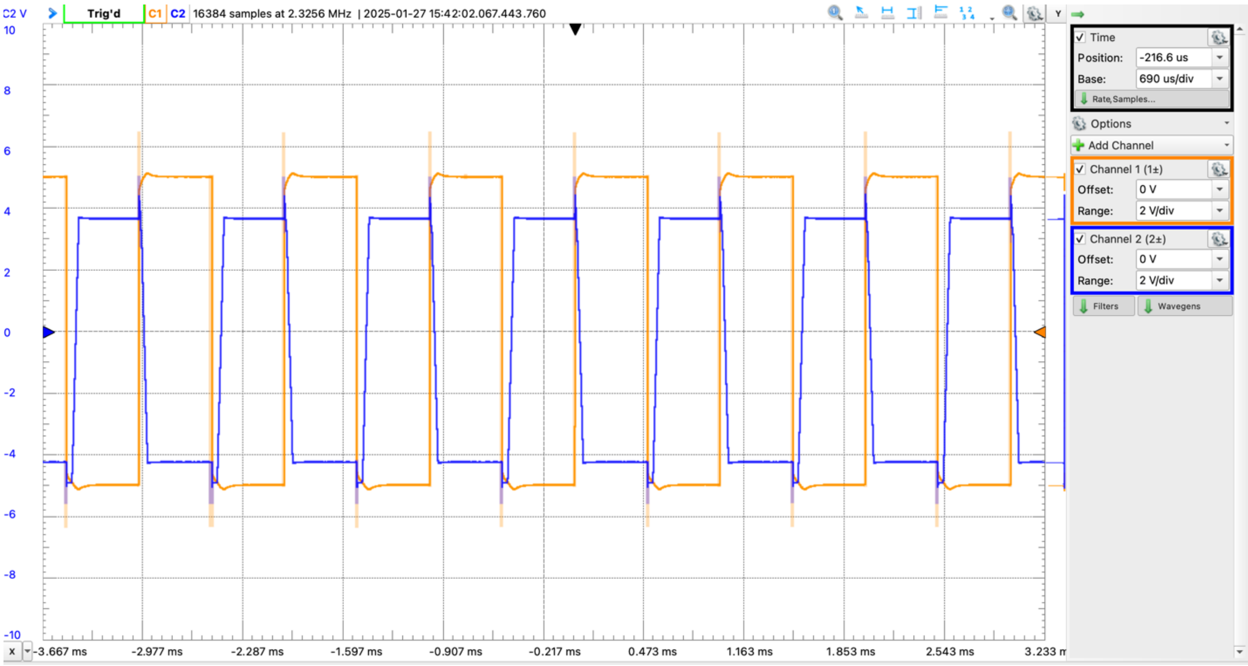
200 mV (for ±5V):



2V (for ±5V):



5V (for ±5V):



ii. Using the circuit from part i, estimate the gain using the Analog Discovery 2. Compare your analytical results with your experimental measures.

V_{in}	V_{out}	$A_{experimental}$ (V_{out}/V_{in})	$A_{theoretical}$	% Error
204.9 mV	-935.42 mV	-4.56	-4.7	0.76%
2.013 V	-4.2808 V	-2.13	-4.7	75.26%
5.014 V	-4.2534 V	-0.83	-4.7	139.96%

<u>iii. Repeat parts i-ii for the following values: +Vcc = 2.5 V, -Vcc = -2.5 V. Does the gain change? Explain.</u>

Linear active region for supply of ±2.5V:

$$-Vcc < -4.7(Vout) < +Vcc$$

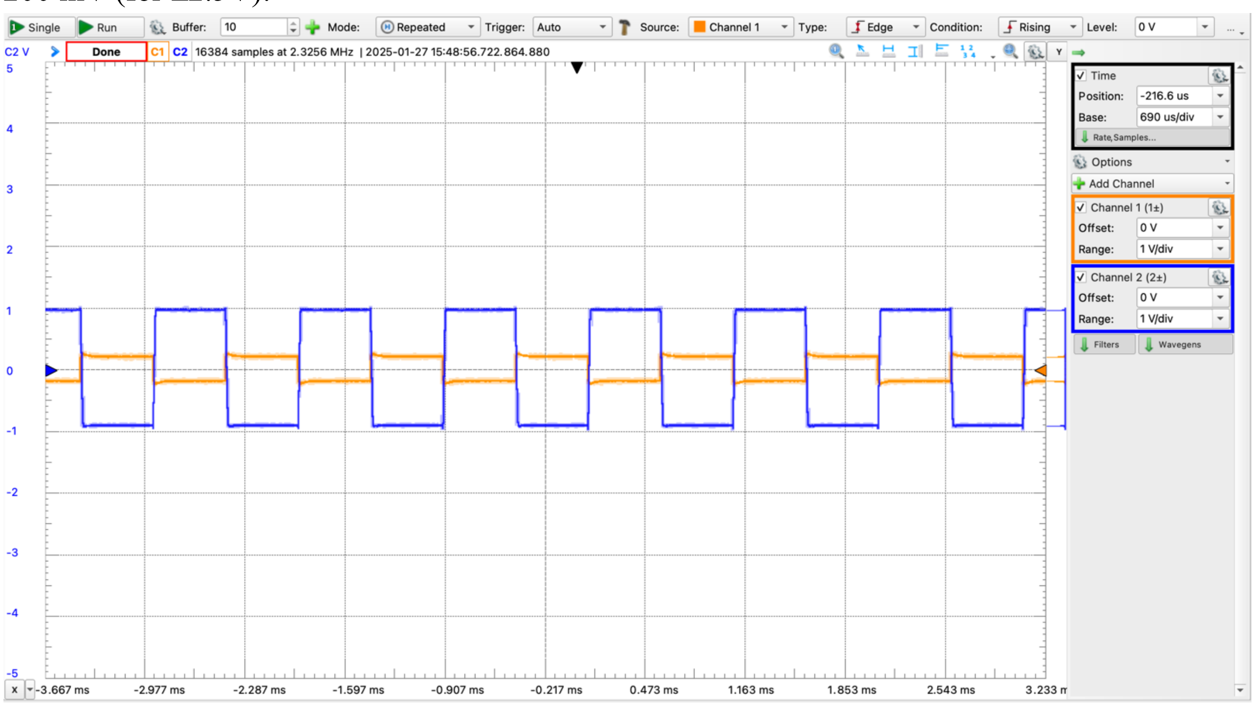
$$-\frac{2.5}{-4.7} > Vin > +\frac{2.5}{-4.7}$$

$$-0.532 < Vin < +0.532$$

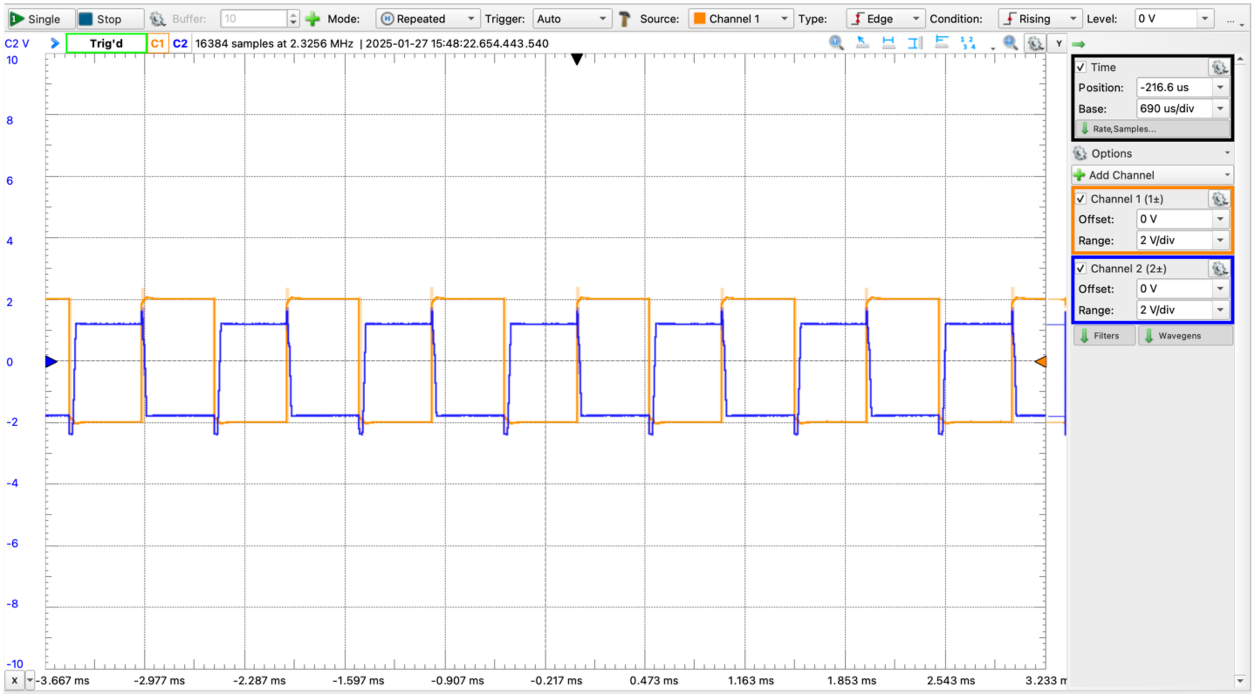
For an op-amp supply of ±2.5V, the linear active region is when Vin is between -0.532 and 0.532. If Vin is outside of the linear active region, then it becomes the saturation region. Therefore, the saturation region is when $-0.532 > Vin$ or $Vin > \pm 0.532$ where Vout will have a value of +2.5V or -2.5V, respectively.

Orange is V_{in} and Blue is V_{out}

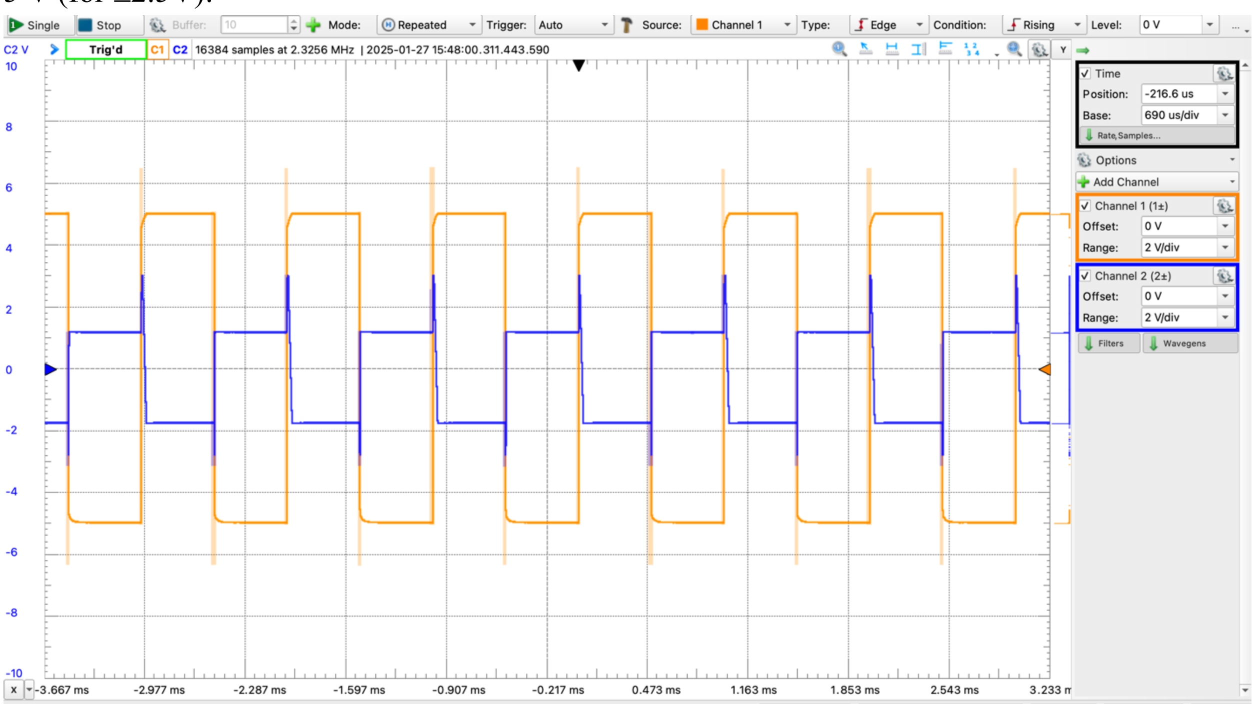
200 mV (for ±2.5V):



2 V (for ±2.5V):

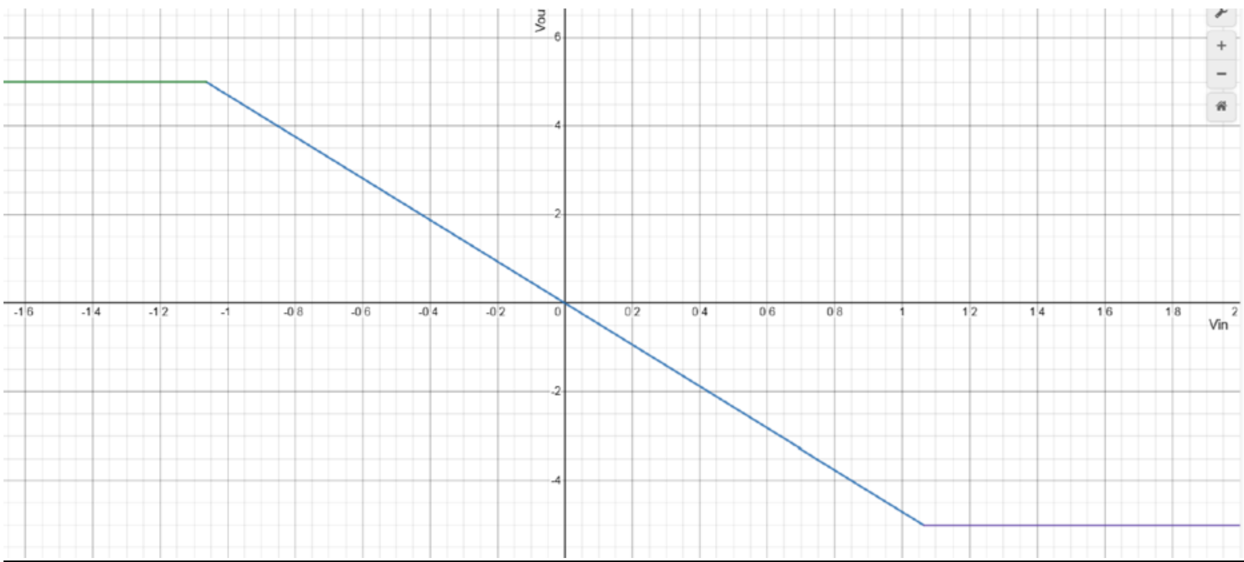


5 V (for ±2.5V):



ii.

V_{in}	V_{out}	$A_{experimental}$ (V_{out}/V_{in})	$A_{theoretical}$	% Error
205 mV	-921.56 mV	-4.495	-4.7	5.32%
1.972 V	-1.8962 V	-0.962	-4.7	79.53%
5.007 V	-1.7824 V	-0.356	-4.7	92.43%



The op-amps expected graph is shown with a supply of ±5V. The linear active region, shown by the negatively sloped line has an equation of $V_{out} = -4.7V_{in}$ and reaches the saturation region, as shown by the two horizontal lines, at a value of the supply voltage of ±5V. Within the linear active region, the slope of the line is -4.7, determined from the V_{out} = Gain*V_{in} formula. This matches an inverting op-amp as when the input voltages magnitude increases, the output voltages magnitude increases in the opposite direction.

For a supply voltage ±2.5V, the graph would look the same but would become horizontal at the saturation regions of values ±2.5V.

<u>Does the gain change for a supply of ±2.5V?</u>

Since the equation of the gain for an inverting op-amp is $A = -\frac{R2}{R1}$, changing the supply voltage would not change the gain. Looking at the equation, the gain only depends on the resistor values and is not affected by the supply voltages. Therefore, as the resistor values remain the same (10kΩ and 47kΩ), the gain would remain the same value of -4.7. Changing the supply voltage to ±2.5V would only affect the maximum and minimum output voltage the op-amp can produce.

Conclusion

In general, the circuit behaves as expected for an inverting op-amp. For example, when using an amplitude of 200 mV with a supply of ±5V, the calculated gain is -4.56 which is like the theoretical gain of -4.7. However, when calculating the gain at saturation regions, the calculated gain does not match theoretical gain. This is because at the saturation regions V_{out} will cap at the value of V_{cc}, meaning that the amplified V_{out} may not represent its actual value, reflecting the error in the calculated gain. This explain why when the amplitude increases and reaches the saturation region, the experimental gain's % error increases. Additionally, when using values at the op-amps saturation range where the expected output voltage should be the supply voltage, the output voltage displays as a value less than the supply voltage (around ±4V for a supply of ±5V and around ±1.9V for a supply of ±2.5V). This is due to internal limitations of the op-amp such as saturation of transistors within the op-amp, leading to the output voltage not reaching the exact supply voltage.