Student ID:	
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Experiment-02

Study of Op-Amp: Introduction to Op-Amp, Comparator Circuits, Non-Inverting Amplifier, Inverting Amplifier, Inverting Summing Amplifier & their VTCs

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CSE251 - Electronic Devices and Circuits Lab

Objective

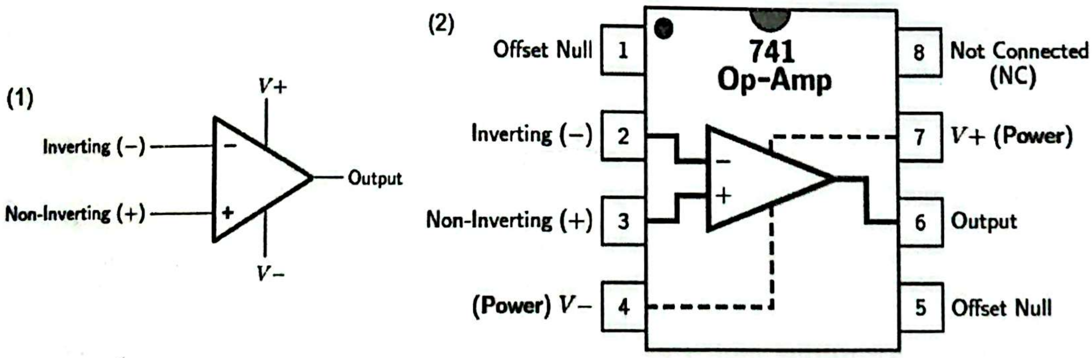
1. To understand the basic principles and characteristics of an Operational Amplifier (Op-Amp)
2. To understand Operational Amplifier (Op-Amp) as a Comparator and investigate its use
3. To investigate the use of Operational Amplifier (Op-Amp) as Non-Inverting Amplifier, Inverting Amplifier and Inverting Summing Amplifier

Equipment

1. Op-Amp (uA741)
2. Resistance ($1k\Omega$, $2.7k\Omega$, $10k\Omega$)
3. DC Power Supply
4. Function Generator
5. Digital Multimeter
6. Trainer Board, Breadboard, Chords and Wires

Background Theory

Introduction

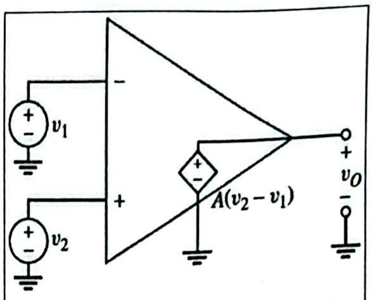


(1) Op-Amp Simplified Circuit Symbol (2) Op-Amp IC Pin Diagram

One of the most widely used electronic devices in linear applications is the Operational Amplifier, commonly known as the Op-Amp. An Op-Amp is an integrated circuit that amplifies the difference between two input voltages and produces a single output. We can also do various mathematical operations like addition, subtraction, multiplication, integration, differentiation etc. with the help of Op-Amp. With the addition of suitable external components, Op-Amp can be used for a variety of applications. The figure above shows the simplified circuit symbol of an Op-Amp. There are 2 terminals for input, 1 terminal for output and 2 terminals for powering up the Op-Amp. Inverting, Non-Inverting are the input terminals and V_S^+, V_S^- are the terminals used for powering up the Op-Amp. V_S^+ is referred to as 'Positive Supply Voltage' and V_S^- is referred to as 'Negative Supply Voltage'. The IC pin diagram of an Op-Amp is also shown where all of the terminals are labeled. Op-Amp is biased with dc supply voltages, although those connections are seldom explicitly shown.

Ideal Op-Amp

The ideal Op-Amp senses the difference between two input voltages and amplifies the difference to produce an output voltage. The figure shown on the right side represents the equivalent circuit of an ideal Op-Amp and the circuit configuration is known as the open-loop configuration of Op-Amp. The parameter 'A' shown in the equivalent circuit is the open-loop differential voltage gain of the Op-Amp. In an ideal Op-Amp, the open-loop gain 'A' is very large value approaching infinity and there is no current flowing into the the input terminals. But in a real Op-Amp, a small amount of current flows into the input terminals and the open-loop gain ranges from 10^4 to 10^5 or higher. We will analyze the circuits using the ideal Op-Amp throughout this experiment.



Ideal op-amp equivalent circuit

Practical Considerations

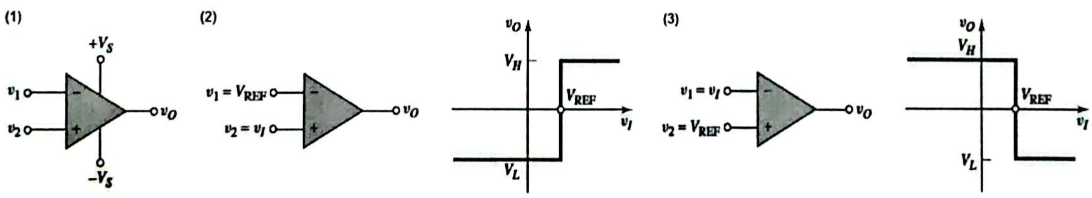
Looking into the equation of the output, $v_O = A(v_2 - v_1)$, one may think that, we can get any voltage at the output of the Op-Amp. But the output voltage is limited since the Op-Amp is composed of transistors biased in the active region by the dc supply voltages V_S^+ and V_S^-. When v_O approaches V_S^+, it will saturate, or be limited to a value almost equal to V_S^+, since it cannot go beyond the positive bias voltage. Similarly, when the output voltage approaches V_S^-, it will saturate at a value almost equal to V_S^-.

Voltage Transfer Characteristics (VTC)

Voltage Transfer Characteristics (VTC) refers to the relationship between the output voltage and the input voltage of a circuit. It is a crucial concept in circuit design. The VTC curve plots the output voltage against the input voltage, revealing how a circuit responds to varying input signals.

Op-Amp Comparator and it's VTC

The comparator is essentially an op-amp operated in an open-loop configuration, as shown below:



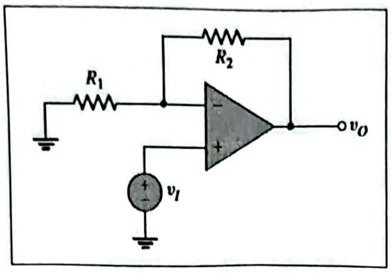
(1) Op-Amp Comparator (2) Non-inverting Circuit (3) Inverting Circuit

A comparator compares two voltages to determine which one is larger. Comparator is usually biased at voltages V_S^+ and V_S^- , although other biases are also possible. When, non-inverting input > inverting input then, $v_O = V_S^+$. When, inverting input > non-inverting input, i.e. $v_1 > v_2$ then, $v_O = V_S^-$. The figures above show two comparator configurations along with their voltage transfer characteristics to illustrate the behaviour of a comparator with V_{REF} as reference voltage which can be controlled to get the desired output.

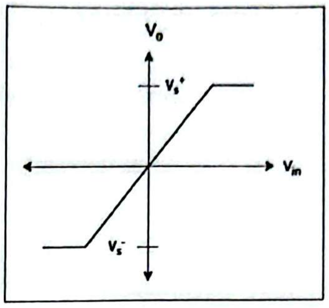
Non-Inverting Amplifier and it's VTC

The amplifier circuit of an op-amp that does not invert the input voltage at the output is called the non-inverting amplifier. This circuit amplifies the input voltage, v_I according to the gain which can be controlled by the resistances R_1 and R_2. The following equation shows the relationship between the input and output of a non-inverting amplifier, and the following diagrams show a non-inverting amplifier and its VTC:

$$v_O = (1 + \frac{R_2}{R_1}) \times v_I; \ \texttt{where, gain = } (1 + \frac{R_2}{R_1})$$



Non-inverting Amplifier

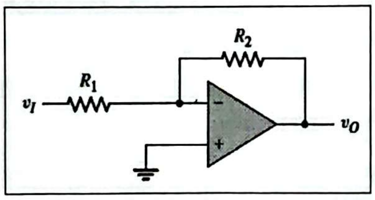


VTC of Non-inverting Amplifier

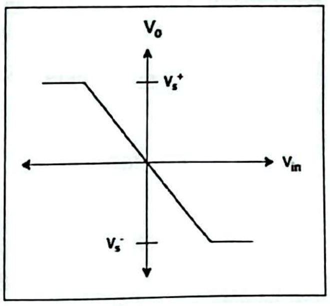
Inverting Amplifier and it's VTC

Inverting amplifier configuration of an op-amp is one of the most widely used op-amp circuits. It amplifies the input voltage, v_I according to the gain which can be controlled by the resistances R_1 and R_2. The input voltage gets inverted at the output, hence the name inverting amplifier. The following equation shows the relationship between the input and output of an inverting amplifier, and the following diagrams show an inverting amplifier and its VTC:

$$v_O = -(\frac{R_2}{R_1}) \times v_I; \ \texttt{where, gain} = -\frac{R_2}{R_1}$$



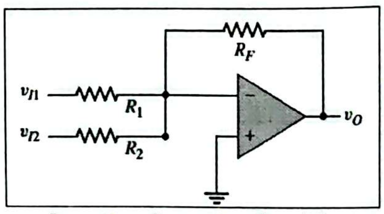
Non-inverting Amplifier



VTC of Non-inverting Amplifier

Inverting Summing Amplifier

The figure shows the circuit configuration of an op-amp known as inverting summing amplifier that does the job of weighted summation. The input voltages are added according to their weight and gets inverted at the output. The weight of each input voltage during the summing operation can be controlled by the resistances R_1, R_2 and R_F. The following equation shows the relation between input and output of the circuit:



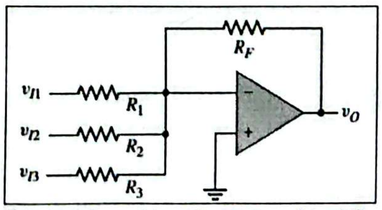
Inverting Summing Amplifier

$$v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2}); \quad \texttt{where, gain for } v_{I1} = -\frac{R_F}{R_1}, \ \texttt{gain for } v_{I2} = -\frac{R_F}{R_2}$$

The inverting summing amplifier circuit has 2 inputs which can be extended to as many inputs as we want and the equation will change accordingly. Let's say, we need to add another input, v_{I3}. The equation will become:

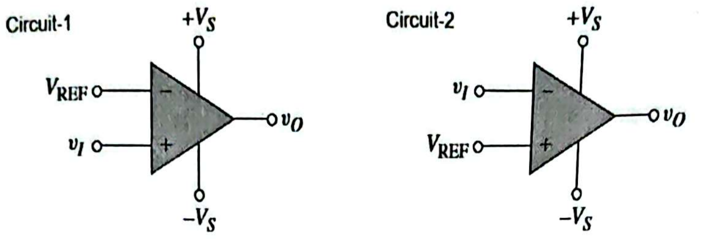
$$v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2} + \frac{R_F}{R_3} \times v_{I3})$$

$$\texttt{where, gain for } v_{I1} = -\frac{R_F}{R_1}, \ \texttt{gain for } v_{I2} = -\frac{R_F}{R_2}$$
$$\texttt{gain for } v_{I3} = -\frac{R_F}{R_3}$$



3-input Inverting Summing Amplifier

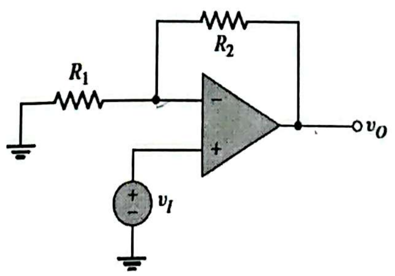
Task-01: Input, Output Waveform and VTC of Op-Amp Comparator



Procedure

1. Construct ***Circuit-1*** with $v_I = 10$ V (p-p), 1 kHz sine wave and $V_{REF} = 2$ V. Use the trainer board for the supply voltages, $V_S^+ = +8V$ and $V_S^- = -8V$
2. **The ground of the oscilloscope, trainer board and function generator should be connected.**
3. Connect CH1 and CH2 of the oscilloscope to v_I and v_O respectively. Observe the input and output waveform and capture them using a camera.
4. For Observing VTC we need to go to the XY mode:
   (a) Press the **Autoset** button → Push the **Position** knobs of both channels (i.e. push to zero).
   (b) Press the **Acquire** button → Press the **XY** button which can be found below the display → Press the **Triggered XY** button which can be found on the right side of the display.
   (c) Change the scaling and position of the plot using the **Scale** knob and **Position** knob of both channels respectively if you need.
   (d) Observe the VTC graph and capture it along with the measurements using a camera.
   (e) Increase the V_{REF} and set it to 4 V, then observe the VTC graph and capture it with a camera.
   (f) Next, decrease the V_{REF} and set it to 0 V, observe the VTC graph and capture it using a camera.
5. Now, construct ***Circuit-2*** and repeat the experiment with same values given above. Observe the input, output waveform and VTC and capture them using a camera.

Task-02: Input, Output Waveform and VTC of Non-Inverting Amplifier



Procedure

1. Construct the circuit with $v_I = 2$ V (p-p), 1 kHz sine wave. Use $R_1 = 1$ kΩ, $R_2 = 2.7$ kΩ. Use the supply voltages, $V_S^+ = +8V$ and $V_S^- = -8V$
2. Connect the CH1 and CH2 of the Oscilloscope to v_I and v_O respectively. Use the ***Scale*** knob to make sure that the scales of CH1 and CH2 are the same. Observe the input and output waveform and capture them using a camera.
3. Use the ***Measure*** button to get necessary data for the 'Data Sheet' attached at the end of the lab sheet. Capture the measurements of CH1 and CH2 using a camera.
4. Now, for Observing VTC we need to go to the XY mode:
   (a) Set $v_I = 10$ V (p-p), 1 kHz sine wave and keep rest of the parameters as they are.

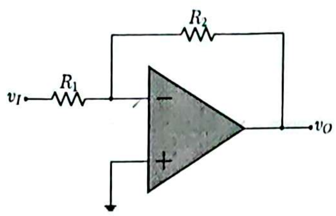
(b) Press the **Autoset** button → Push the **Position** knobs of both channels (i.e. push to zero).

(c) Press the **Acquire** button → Press the **XY** button which can be found below the display → Press the **Triggered XY** button which can be found on the right side of the display.

(d) Change the scaling and position of the plot using the **Scale** knob and **Position** knob of both channels, respectively if you need.

(e) Observe the VTC graph and capture it with a camera.

Task-03: Input, Output Waveform and VTC of Inverting Amplifier



Procedure

1. Construct the circuit with $v_I = 2$ V (p-p), 1 kHz sine wave. Use $R_1 = 1$ kΩ, $R_2 = 2.7$ kΩ.

2. Connect the CH1 and CH2 of the Oscilloscope to v_I and v_O respectively. Use the ***Scale*** knob to make sure that the scales of CH1 and CH2 are the same. Observe the input and output waveform and capture them using a camera.

3. Use the ***Measure*** button to get necessary data for the 'Data Sheet'. Capture the measurements of CH1 and CH2 using a camera.

4. Now, for Observing VTC we need to go to the XY mode:

   (a) Set $v_I = 10$ V (p-p), 1 kHz sine wave and keep rest of the parameters as they are.

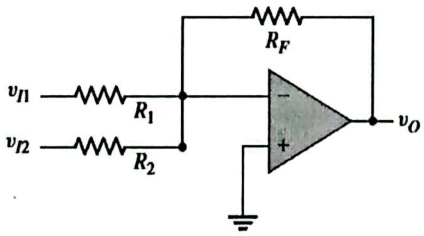
   (b) Press the **Autoset** button → Push the **Position** knobs of both channels (i.e. push to zero).

   (c) Press the **Acquire** button → Press the **XY** button which can be found below the display → Press the **Triggered XY** button which can be found on the right side of the display.

   (d) Change the scaling and position of the plot using the **Scale** knob and **Position** knob of both channels, respectively if you need.

   (e) Observe the VTC graph and capture it with a camera.

Task-04: Inverting Summing Amplifier



Procedure

1. Construct the circuit using the CH1 and CH2 of the DC Power Supply for $v_{I1} = 1$ V and $v_{I2} = 2$ V respectively.

2. Use $R_1 = 10$ kΩ, $R_2 = 10$ kΩ and $R_F = 10$ kΩ.

3. Use the digital multimeter to measure the output voltage v_O to get necessary data for the 'Data Sheet'.

Task-05: Report

1. Attach the signed Data Sheet (if any)
2. Attach the captured images (if any)
3. Answer the questions in the "Test Your Understanding" section
4. Add a brief Discussion regarding the experiment. For the Discussion part of the lab report, you should include the answers of the following questions in your own words:
   - What did you learn from this experiment?
   - What challenges did you face and how did you overcome the challenges? (if any)
   - What mistakes did you make and how did you correct the mistakes? (if any)
   - How will this experiment help you in future experiments of this course?

Data Sheet

For Task-02:

Quantity	Value
Value of R_1 using multimeter	0.985
Value of R_2 using multimeter	2.169
Input Amplitude from Oscilloscope, $v_I = \frac{Pk-Pk}{2}$ (use the Measure button of the Oscilloscope)	5V
Output Amplitude, $v_O = \frac{Pk-Pk}{2}$ (use the Measure button of the Oscilloscope)	7
Output Amplitude, $v_O = (1 + \frac{R_2}{R_1}) \times v_I$ (theoretical calculation)	16.01

For Task-03:

Quantity	Value
Value of R_1 using multimeter	0.985
Value of R_2 using multimeter	2.169
Input Amplitude from Oscilloscope, $v_I = \frac{Pk-Pk}{2}$ (use the Measure button of the Oscilloscope)	4.9
Output Amplitude, $v_O = \frac{Pk-Pk}{2}$ (use the Measure button of the Oscilloscope)	6.8
Output Amplitude, $v_O = -(\frac{R_2}{R_1}) \times v_I$ (theoretical calculation)	10.78

For Task-04:

Quantity	Value
Value of R_1 using multimeter	9.96
Value of R_2 using multimeter	9.5
Value of R_F using multimeter	9.7
from multimeter, v_{I1}	0.999
from multimeter, v_{I2}	2.133
Output Amplitude from multimeter, v_O	-3.467
Output Amplitude from equation, $v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2})$	-3.15

08.07.25

Signature of the lab faculty

Test Your Understanding

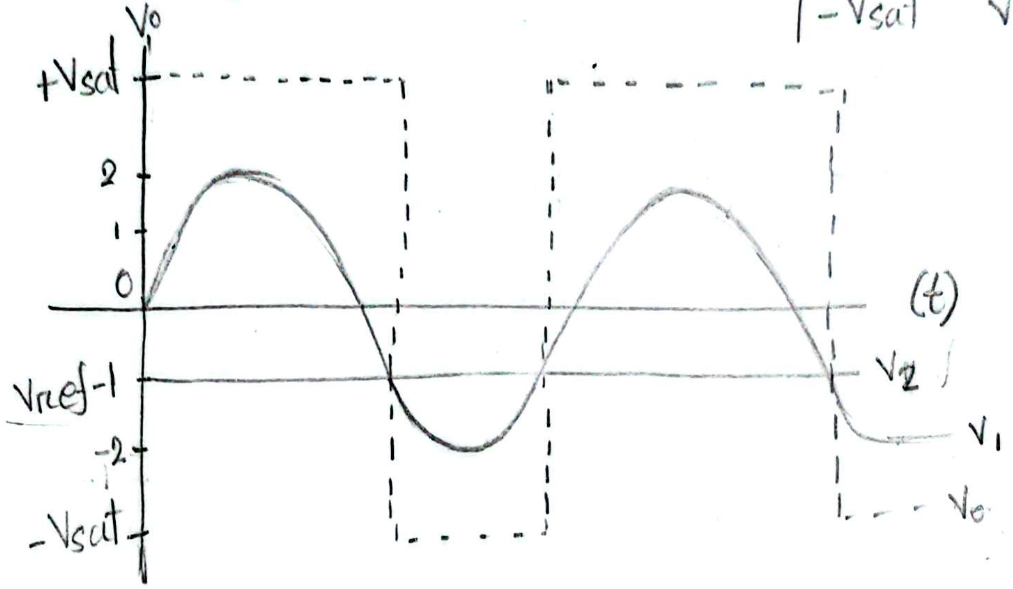
Answer the following questions:

1. You are given an Op-Amp comparator with $v_1 = 4$ V (p-p) sine wave and $v_2 = V_{REF} = -1$ V. Draw the waveform of v_1, v_2 and v_O in the same graph with proper labels.
Answer:

here, $V_1 = 4V$ p-p or $V_1(t) = 2\sin t$

$V_2 = V_{ref} = -1$

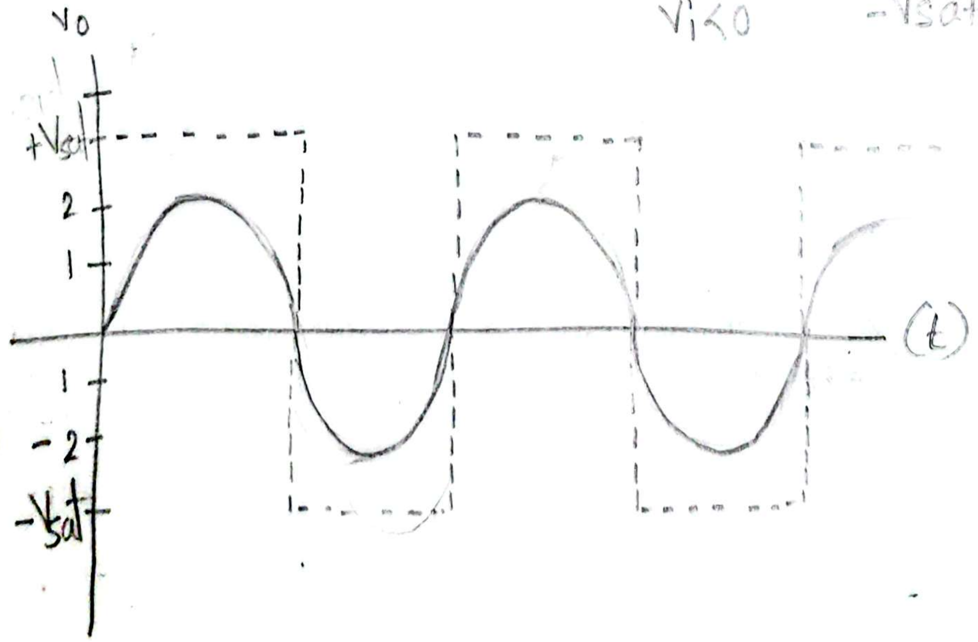
$$V_{out} = \begin{cases} +V_{sat} & V_1 > V_2 \\ -V_{sat} & V_1 < V_2 \end{cases}$$



2. You are given an Op-Amp comparator with $v_i = 2\sin(t)$, where the two ends of the input voltage, v_i (sinusoidal source) is connected to v_1 and v_2 of Op-Amp. Draw the waveform of v_{AC} and v_O in the same graph with proper labels.
Answer:

$V_i = 2\sin t$, $V_1 - V_2 = V_i$ if $V_i > 0$ $+V_{sat}$

$V_i < 0$ $-V_{sat}$

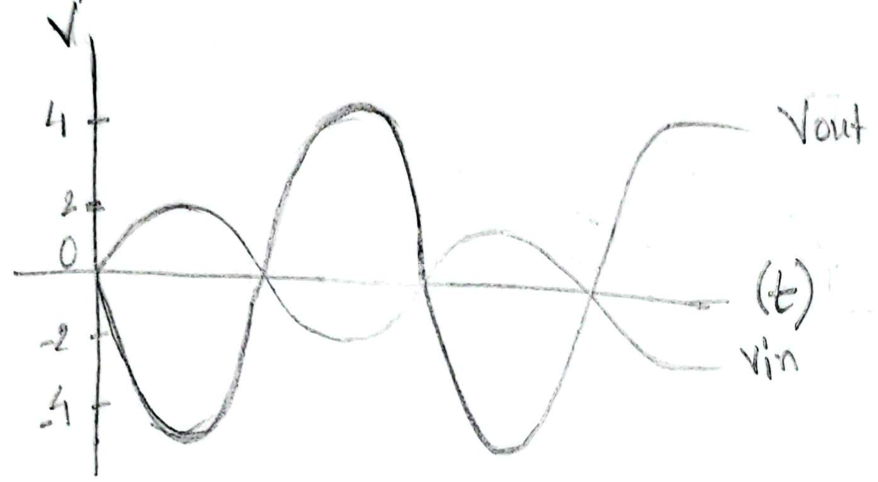


3. You are given an inverting amplifier with $v_I = 4$ V (p-p) sine wave, $R_1 = 1\ k\Omega$, $R_2 = 2.2\ k\Omega$. Draw the waveform of v_I and v_O in the same graph with proper labels.

Answer:

$V_i = 4\ V_{p\text{-}p} = 2\sin t$ Gain $A = -\frac{R_2}{R_1} = \frac{-2.2}{1} = -2.2$

Inverted and amplified sine wave with peak amplitude $2 \times 2.2 = 4.4V$



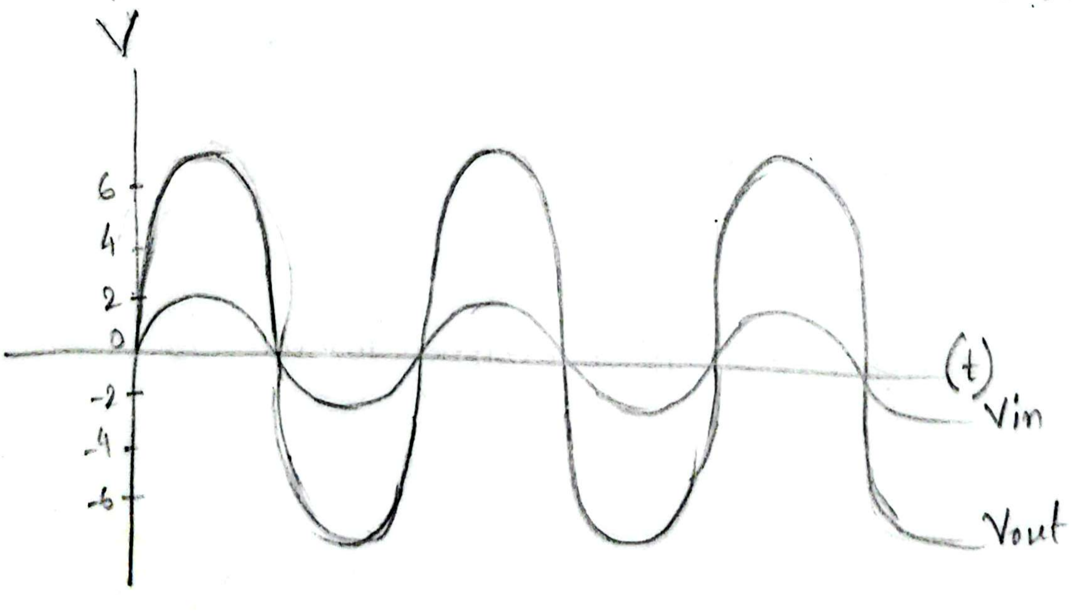
4. You are given a non-inverting amplifier with $v_I = 4$ V (p-p) sine wave, $R_1 = 1\ k\Omega$, $R_2 = 2.2\ k\Omega$. Draw the waveform of v_I and v_O in the same graph with proper labels.

Answer:

$V_i = 4V\ p\text{-}p = 2\sin t$

Gain $A = 1 + \frac{R_2}{R_1} = 1 + \frac{2.2}{1} = 3.2$

Amplified sine wave with peak amplitude $2 \times 3.2 = 6.4$

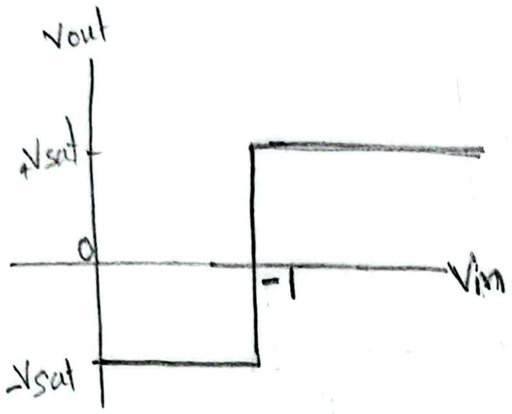


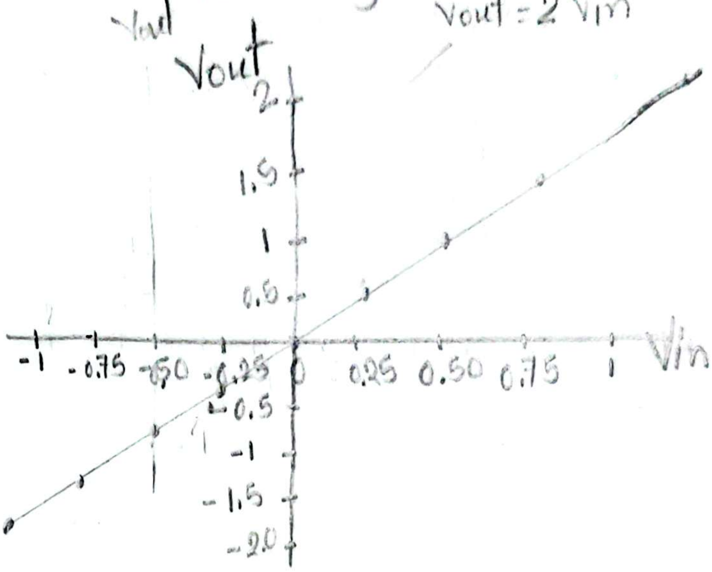
CamScanner

5. Discuss the differences in behavior between the comparator's switching operation and the amplifier's linear scaling. For the comparator, use a 4 V (peak-to-peak) sine wave to the inverting terminal with a fixed reference of −1 V to the non inverting terminal. For the non-inverting amplifier, set the gain to 2 with a 1 V (peak-to-peak) sine wave input. For each circuit, draw the VTC (i.e., v_{out} vs. v_{in}) on separate graphs with proper labels and discuss accordingly.

Answer:

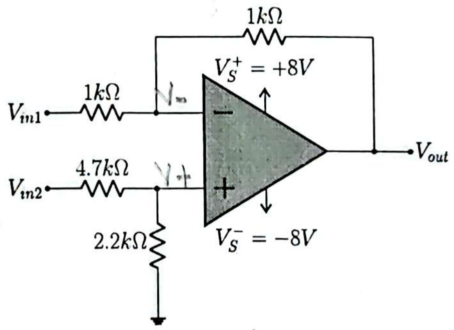
here gain = 2
Vout = 2 Vin





6. Deduce the value of V_{out} from the circuit below.

*[**Hints:** Consider the current towards the inverting and non-inverting terminals of Op-Amp is zero, and the voltage of the inverting terminal equals the voltage of the non-inverting terminal]*



Answer: Voltage at non-inverting terminal

$$V_+ = V_{in2} = \frac{2.2}{4.7+2.2} = 0.3188 \cdot V_{in2}$$

So, $V_- = V_+ = 0.3188 \cdot V_{in2}$

Applying KCL at inverting terminal,

$$\frac{V_{in1} - V_-}{1} + \frac{V_{out} - V_-}{4.7} = 0$$

$$\Rightarrow V_{out} = -4.7\, V_{in1} + 1.817 \cdot V_{in2}$$

Discussion:

During the lab, we for the first time used op-amp and we had to bring the VTC graph on the osilloscope. We were trying our best to bring the graph but sometimes we messed up. Once we forgot to put the saturation voltage. We put V+ wire in V- . There were some silly mistakes we had done during the lab. But at last we were able to do the 4 tasks gracefully. We also took picture of those VTC. Overall, we learned a lot during this lab.