Group No:

Experiment-06

Study of Operational Amplifier (Op-Amp)

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To investigate the use of Operational Amplifier (Op-Amp) as Comparator, Inverting Amplifier, Inverting Summing Amplifier in Hardware
2. To investigate the use of Operational Amplifier (Op-Amp) as Non-Inverting Amplifier, Inverting Summing Amplifier in LTspice Simulation

Equipments

1. Op-Amp (uA741)
2. Resistance ($1k\Omega, 2.2k\Omega, 2.7k\Omega$)
3. DC power supply
4. Trainer Board
5. Digital Multimeter
6. Breadboard
7. Chords and Wire

Background Theory

Introduction

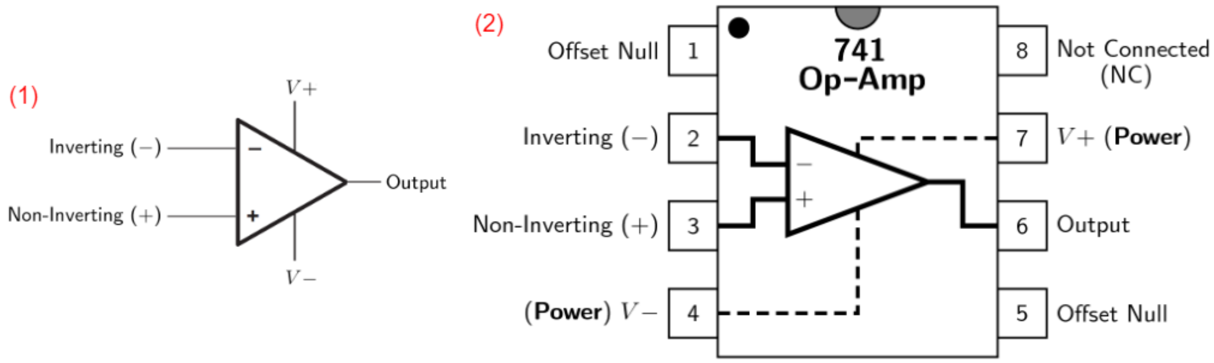
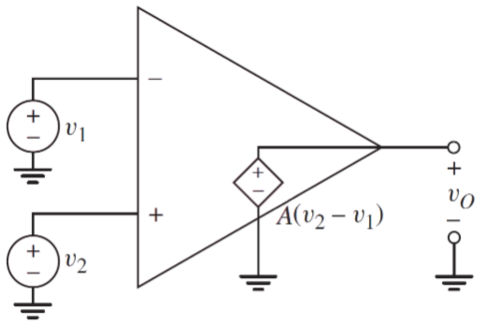


Figure 1: (1) Op-Amp Simplified Circuit Symbol (2) Op-Amp IC Pin Diagram

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. Figure 1 shows the simplified circuit symbol of an 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 $V+$, $V-$ are the terminals used for powering up the Op-Amp. $V+$ is referred to as 'Positive Supply Voltage' and $V-$ is referred to as 'Negative Supply Voltage'. Figure 1 also shows the IC pin diagram of an Op-Amp where all of the terminals are labeled. The Op-Amp is biased with dc supply voltages, although those connections are seldom explicitly shown.

Ideal Op-Amp



Ideal op-amp equivalent circuit

The ideal Op-Amp senses the difference between two input voltages and amplifies this difference to produce an output voltage. The figure shown above represents the equivalent circuit of an ideal Op-Amp and the circuit configuration is known as Op-Amp open loop configuration. The parameter 'A' shown in the equivalent circuit is the open-loop differential voltage gain of the Op-Amp. In the ideal Op-Amp, the open-loop gain 'A' is very large and approaches infinity and there is no current the the input terminals. But in real Op-Amp, there is a small amount of current that flows into the inverting and non-inverting 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.

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 problem is, the output voltage is limited since the Op-Amp is composed of transistors biased in the active region by the dc supply voltages $V+$ and $V-$. When v_O approaches $V+$, it will saturate, or be limited to a value nearly equal to $V+$, since it cannot go above the positive bias voltage. Similarly, when the output voltage approaches $V-$, it will saturate at a value nearly equal to $V-$.

Op-Amp Comparator

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

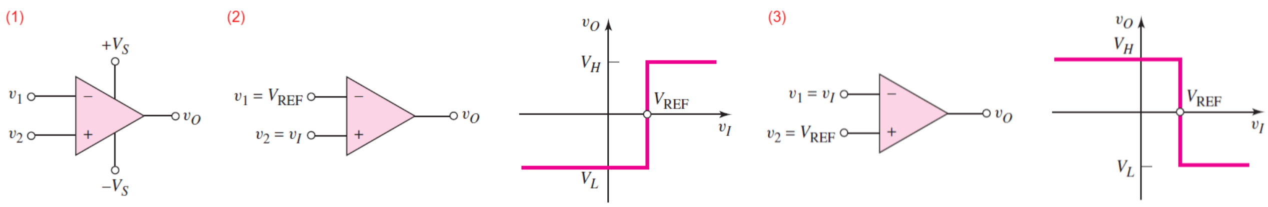
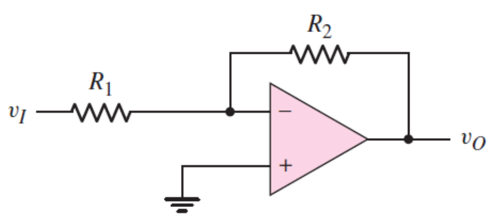


Figure 2: (1) Op-Amp Comparator (2) Noninverting Circuit (3) Inverting Circuit

A comparator compares two voltages to determine which is larger. The comparator is usually biased at voltages $+V_S$ and $-V_S$, although other biases are possible. If non-inverting input > inverting input then $v_O = +V_S$. If inverting input > non-inverting input then $v_O = -V_S$. The figure above shows two comparator configurations along with their voltage transfer characteristics which illustrates the behaviour of a comparator with V_{REF} as reference voltage which can be controlled to get the desired output.

Inverting Amplifier

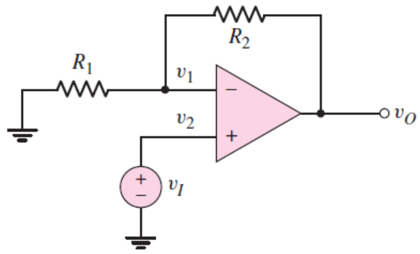


It is one of the most widely used op-amp circuits. The figure above shows the closed-loop configuration of this circuit. This circuit amplifies the v_I according to the gain which can be controlled by the two resistances R_1

and R_2. It is called inverting amplifier because the output voltage gets inverted here. The following equation shows the relationship of the input and output of the inverting amplifier.

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

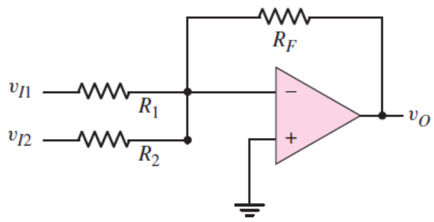
Non-Inverting Amplifier



There is an amplifier circuit that does not invert the input voltage at the output. It is called the non-inverting amplifier which is shown in the figure above. This circuit also amplifies the v_I according to the gain which can be controlled by the two resistances R_1 and R_2. The following equation shows the relationship of the input and output of the inverting amplifier.

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

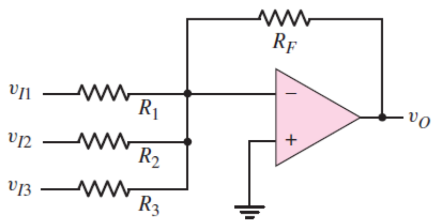
Inverting Summing Amplifier



The figure above shows the summing amplifier which is actually an inverting summing amplifier (because the output voltage will get inverted compared to the input). This Op-Amp circuit can add multiple voltages. The weight of each input voltage during the summing operation can be controlled by the resistances. The following equation shows the relationship of the input and output of the inverting summing amplifier.

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

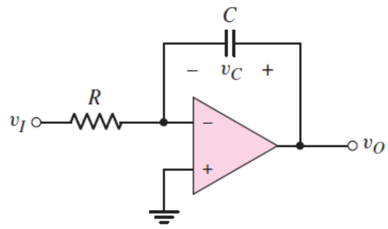
Although this circuit has 2 inputs, it can be extended as many as we want and the equation will change accordingly. Let's say, we need to add another input v_{I3}. Then the circuit and equation will look like the following ones:



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

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

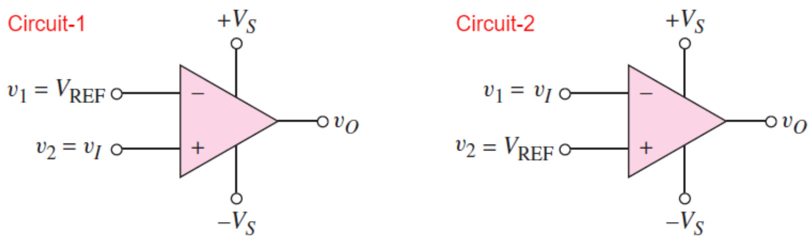
Op-Amp Integrator



The figure above shows an Op-Amp circuit that can do integration operation on the given input voltage. The figure above shows an Op-Amp circuit that can do integration operation on the given input voltage. The following equation shows the relationship between the input and the output.

$$v_O(t) = -\frac{1}{CR}\int_0^t v_I(t)dt - v_C$$

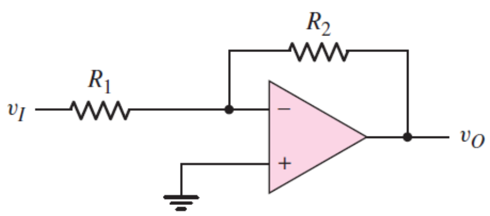
Task-01: Op-Amp Comparator



Procedure

1. Construct Circuit-1 with $v_I = 2$ V (p-p), 1 kHz sine wave and $V_{REF} = 0.5$ V. The supply voltage $+V_S$ and $-V_S$ should be +15 V and -15 V respectively which can be taken from the trainer board. **Use this supply voltage throughout the experiment**. The input voltage v_I can be taken from the oscilloscope.
2. Connect the 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.
3. Now, construct Circuit-2 and repeat the experiment with same values given above. Observe the input and output waveform and capture them using a camera.

Task-02: Inverting Amplifier



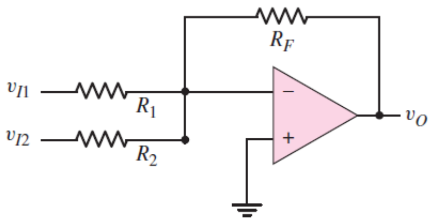
Procedure

1. Construct the circuit with $v_I = 2$ V (p-p), 1 kHz sine wave. Use $R_1 = 1$ kΩ, $R_2 = 2.2$ kΩ.
2. Connect the 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.

Observation and Calculation

The output waveform should be amplified and inverted compared to the input waveform.
Input Amplitude from oscilloscope, $v_I =$
Output Amplitude from equation, $v_O = -(\frac{R_2}{R_1}) \times v_I =$
Output Amplitude from oscilloscope, $v_O =$

Task-03: Inverting Summing Amplifier



Procedure

Part-01

1. Construct the circuit with $v_{I1} = v_{I2} = 2$ V. Use $R_1 = 1$ kΩ, $R_2 = 2.2$ kΩ, $R_F = 2.7$ kΩ.
2. Use the digital multimeter to measure the output voltage.

Part-02

1. Construct the circuit with $v_{I1} = 2$ V (p-p), 1 kHz sine wave and $v_{I2} = 2$ V (from the DC Supply). Use $R_1 = 1$ kΩ, $R_2 = 1$ kΩ, $R_F = 1$ kΩ.
2. Connect the Ch1 and Ch2 of the oscilloscope to v_I and v_O respectively.

Observation and Calculation

For Part-01,
from multimeter, $v_{I1} =$
from multimeter, $v_{I2} =$
Output Amplitude from equation, $v_O = -(\frac{R_F}{R_1} \times v_{I1} + \frac{R_F}{R_2} \times v_{I2}) =$
Output Amplitude from multimeter, $v_O =$

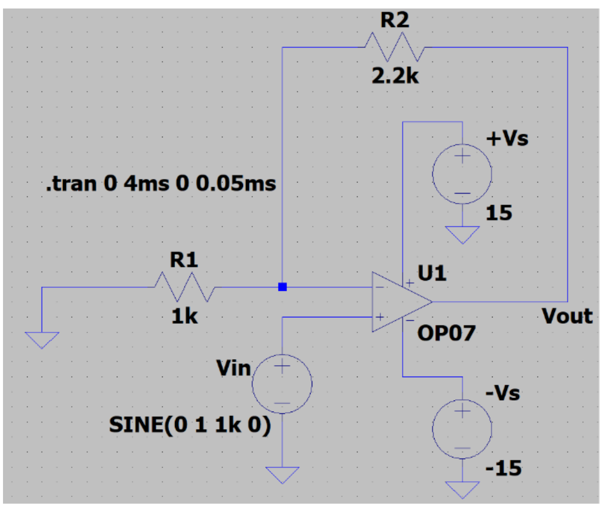
For Part-02,
The output waveform should be amplified and inverted compared to the input waveform. Observe the input and output waveform and capture them using a camera.

Task-04: Simulation (Home Task)

In this part, we will simulate a Non-inverting Amplifier and a 3 input Inverting Summing Amplifier in LTspice.

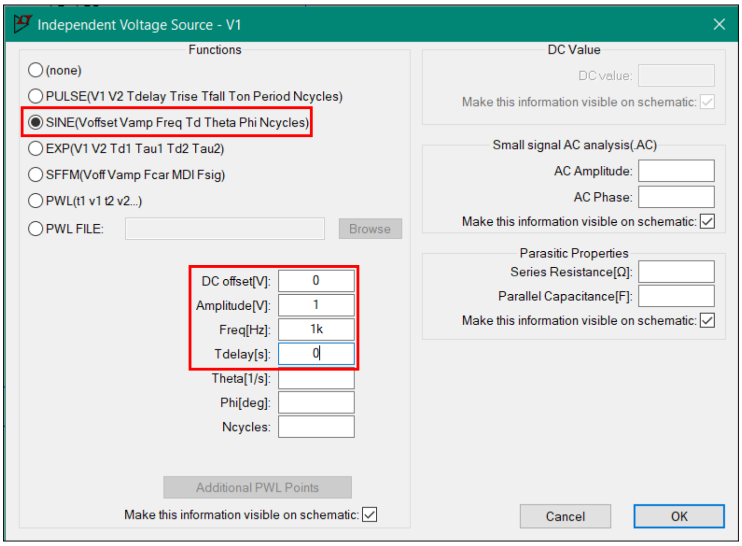
Non-inverting Amplifier

1. Open a new schematic and build the following circuit. To insert an Op-Amp in LTspice, type 'op07' in the Select Component Symbol window and select the Op-Amp from there.

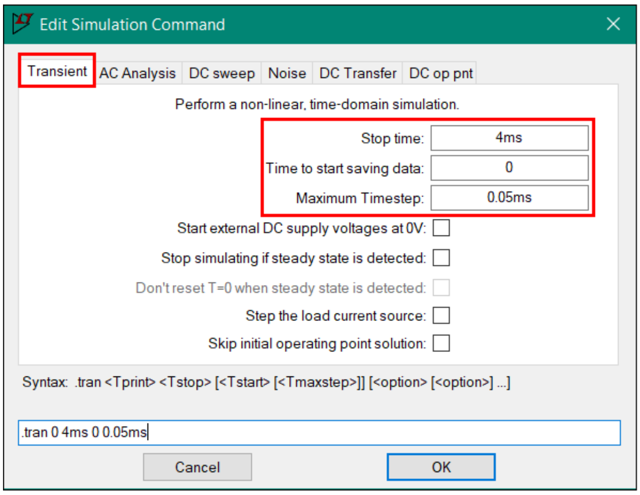


2. Rename the components and set their values as shown in the previous figure. Label the output node of the Op-Amp as 'Vout' using Label Net window. (refer to the previous lab sheets if needed)

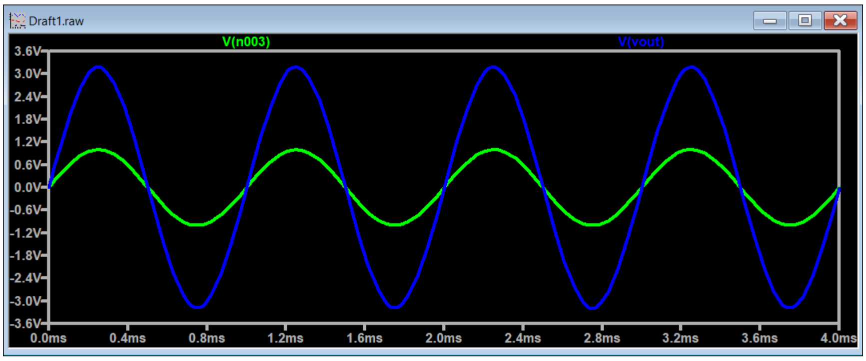
3. To configure 'Vin' as shown in the previous figure, right click on it and configure it as shown below:



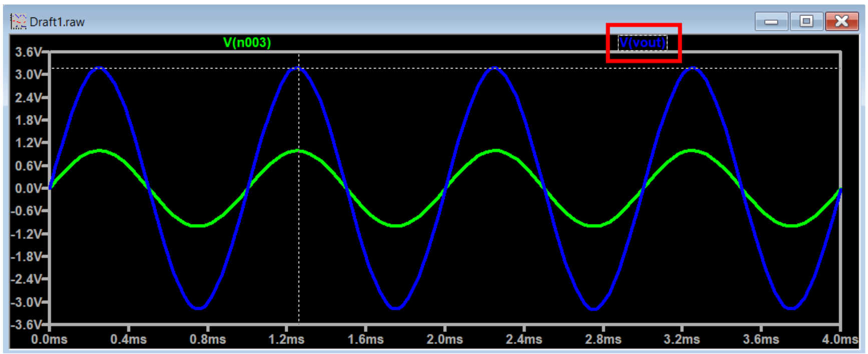
4. Go to the Edit Simulation Command window. In the 'Transient' tab, set the properties as shown below:

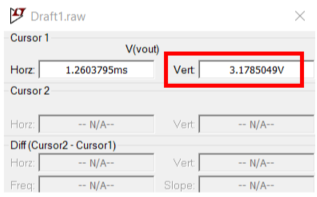


5. Run the simulation. Plot 'Vin' and 'Vout' in the same window. You should get a figure like the following one. Notice that, the output is not inverted as it is a Non-Inverting Amplifier circuit.



6. Measure the peak value of the output from the plot as shown below. Right click on 'Vout' to enable the cursor → move the cursor to the peak → check the peak value from the cursor window at the bottom right corner of your screen.

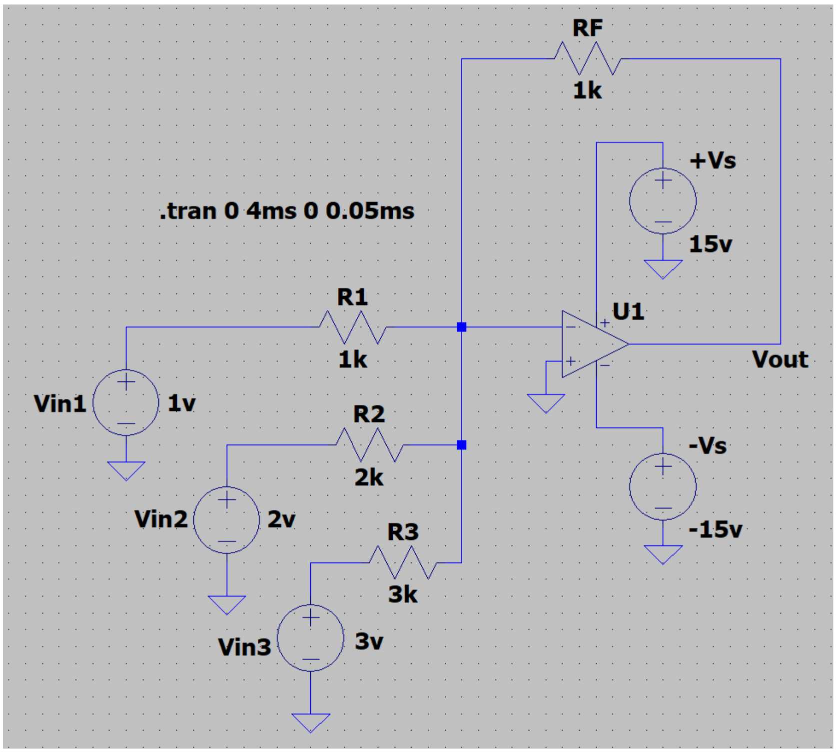




7. Use the peak output voltage and peak input voltage to calculate the gain using $gain = V_{out}/V_{in}$ formula. Now calculate the theoretical value of gain from the equation you learnt in theory and compare it with the simulation value.

Inverting Summing Amplifier

1. Open a new schematic and build the following circuit. Rename the components and set their values according to the figure. Label the output node of the Op-Amp as 'Vout' using Label Net window.



2. Run the simulation using the same properties of 'Transient' tab of the Edit Simulation Command window from the previous circuit.

3. Plot the output voltage 'Vout'.

4. Compare the value of the output voltage with the one you get from the theoretical equation you have learnt earlier.

5. Now, open a new schematic. Build the same circuit. But this time, 'Vin3' will not be a dc value of 3 V like the previous circuit.
For this part of the simulation, it will be a sine wave of 1 V Amplitude and 1 kHz frequency.

6. Plot the output voltage 'Vout'. Observe it and comment on it.

Task-05: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Draw the Circuit Diagrams.
3. Attach the Signed data sheet.
4. Attach the captured photos of all the waveforms you have observed in the oscilloscope.
5. Attach the screenshot of the circuits built in the simulation part.
6. Attach all the graph generated in the simulation part.
7. Don't forget to do the calculations from the simulation part.
8. Discussion