# Experiment

## Study of OP-AMP characteristics, mathematical operations and applications

## Objectives

1. Study of basic OP-AMP characteristics, inverting and non-inverting amplifier configurations and finding their gain.
2. Study simple mathematical operations - Addition and Subtraction using OP-AMP
3. Applications of OP-AMP - Comparator
4. Applications of OP-AMP - Integration and differentiation

## Contents

# 1 Study of OP-AMP characteristics, inverting and non-inverting amplifier configurations and finding their gain

## 1.1 Circuit components/equipment

1. OPAMP 741
2. Resistors
3. Oscilloscope
4. DC voltage source
5. Breadboard

## 1.2 Theory

An operational amplifier (OP-AMP) is a high-gain electronic amplifier with two inputs and one output. The two inputs are the non-inverting (+) input and the inverting (−) input. The output voltage is proportional to the difference between these two input voltages. OP-AMPs are widely used for amplification, filtering, mathematical operations, signal conditioning, oscillators, and comparator circuits.

Operational amplifiers can be connected using external resistors or capacitors in a number of different ways to form basic "Building Block" circuits such as, Inverting, Non-Inverting, Voltage Follower, Summing, Differential, Integrator and Differentiator type amplifiers. There are a very large number of operational amplifier IC's available to suit every possible application. The most commonly available and used of all operational amplifiers is the industry standard 741 type IC.

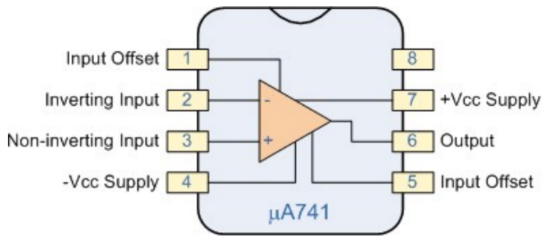


**Figure 1:** Schematic of an OP-AMP.

**Basic Op-Amp Characteristics**

1. **Open-loop gain** ($A_{\mathrm{OL}}$): The amplification provided by the op-amp when no feedback is applied from the output to the input. An ideal op-amp has infinite open-loop gain, while practical op-amps have very high gain.

2. **Input impedance** ($Z_{\mathrm{in}}$): The resistance seen by the signal source looking into the op-amp input terminals. A high input impedance ensures that very little current

is drawn from the source.

3. **Output impedance ($Z_{out}$)**: The resistance seen looking back into the output terminal of the op-amp. Ideally, it is zero so the op-amp can drive loads without voltage loss.

4. **Input offset voltage ($V_{os}$)**: A small unwanted differential voltage that must be applied between the inputs to make the output exactly zero when both inputs should ideally be equal. It arises from internal transistor mismatches.

5. **Common-Mode Rejection Ratio (CMRR)**: A measure of the op-amp's ability to reject signals that are present equally on both inputs. Higher CMRR means better rejection of common noise and interference.

6. **Bandwidth**: The range of frequencies over which the op-amp maintains its specified gain. As frequency increases, the gain eventually begins to decrease.

7. **Slew rate**: The maximum rate at which the output voltage can change, typically expressed in volts per microsecond (V/$\mu$s). It limits the OP-AMP's ability to follow rapidly changing signals.

8. **Voltage follower behavior**: A voltage follower (buffer) is a configuration where the output is directly connected to the inverting input, making the output closely equal to the input voltage. It provides high input impedance and low output impedance.

9. **Output saturation voltage**: The maximum positive and negative output voltage levels that the op-amp can produce. The output cannot exceed the supply voltages and saturates near them.

10. **Closed-loop gain**: The gain of the OP-AMP when feedback is applied through external components such as resistors. This gain is predictable and commonly used in practical amplifier circuits.

11. **Inverting amplifier gain**: In an inverting amplifier, the output is amplified and 180° out of phase with the input.

12. **Non-Inverting amplifier gain**: In a non-inverting amplifier, the output is amplified but remains in phase with the input.

13. **Common-Mode signal**: A signal applied equally to both input terminals. Ideally, it should produce zero output because the op-amp amplifies only the difference between its inputs.

In summary: An OP-AMP is a versatile high-gain differential amplifier, and its key characteristics include gain, input/output impedance, offset voltage, CMRR, bandwidth, slew rate, and saturation limits, all of which determine its practical performance in electronic circuits.

### Inverting amplifier

In inverting amplifier circuit, the operational amplifier is connected with feedback to produce a closed loop operation. There are two very important rules to remember about inverting amplifiers: "no current flows into the input terminal" and that '$V_1 = V_2$'. This is because the junction of the input and feedback signal ($X$) is at the same potential as the positive (+) input which is at zero volts or ground then, the junction is a "Virtual Earth". Because of this virtual earth node, the input resistance of the amplifier is equal to the value of the input resistor, $R$. Then by using these two rules one can find the equation for calculating the gain of an inverting amplifier, using first principles. Current ($I$) flows through the resistor network as shown.

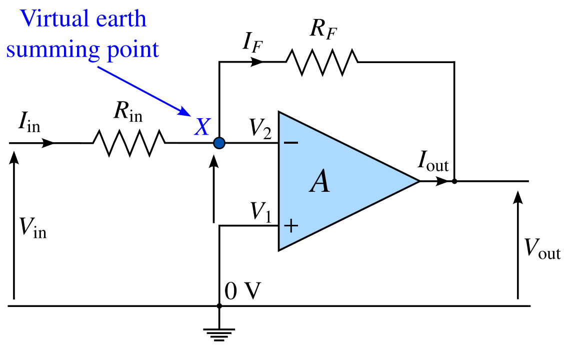


**Figure 2:** Typical circuit diagram of an OP-AMP.

$$I_{in} = \frac{V_{in}}{R_{in}} = -\frac{V_{out}}{R_F}$$

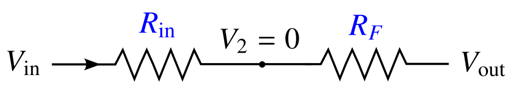


**Figure 3:** Voltage divider circuit.

The negative sign in the equation indicates an inversion of the output signal with respect to the input as it is 180° out of phase. This is due to the feedback being negative in value. Then, the Closed-Loop Voltage Gain of an Inverting Amplifier is given as

$$\text{Gain} = \frac{V_{out}}{V_{in}} = -\frac{R_F}{R_{in}}$$

### Non-inverting amplifier

The second basic configuration of an operational amplifier circuit is that of a non-inverting amplifier. In this configuration, the input voltage signal, ($V$) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes "positive" in value in contrast to the "inverting amplifier" circuit whose output gain is negative in value. Feedback control of the non-inverting amplifier is achieved by applying a small part of the output voltage signal back to the inverting (−) input terminal via a $R_F - R_2$ voltage divider network, again producing negative feedback. This produces a non-inverting amplifier circuit with very good stability, a very high input impedance, $R$ approaching infinity (as no current flows into the positive input terminal) and a low output impedance, $R_{out}$ as shown below.

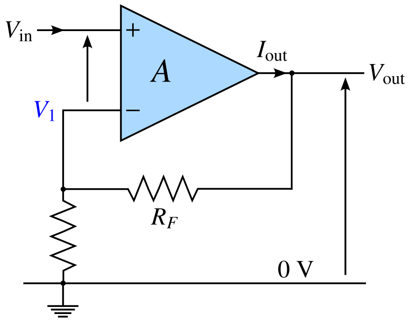


**Figure 4:** A typical non-inverting amplifier circuit.

Since no current flows into the input of the amplifier, $V_1 = V_{in}$. In other words, the junction is a "virtual earth" summing point. Because of this virtual earth node, the resistors $R_F$ and $R_2$ form a simple voltage divider network across the amplifier and the voltage gain of the circuit is determined by the ratios of $R_2$ and $R_F$ as shown below.

### Equivalent voltage divider network

Then using the formula to calculate the output voltage of a potential divider network, we can calculate the output voltage gain of the Non-Inverting Amplifier as:

$$V_{out} = V_{in}\left(1 + \frac{R_F}{R_2}\right)$$
$$\text{Gain} = \frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R_2}.$$

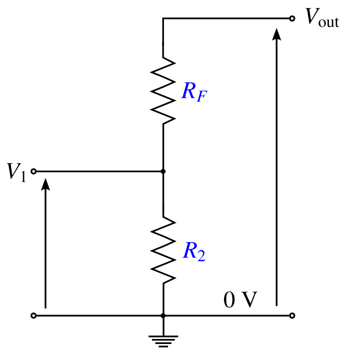


**Figure 5:** Voltage divider circuit (Non-inverting).

## 1.3 Circuit diagram

The circuit diagrams for inverting and non-inverting amplifiers are shown in figure 6 and figure 7 respectively.

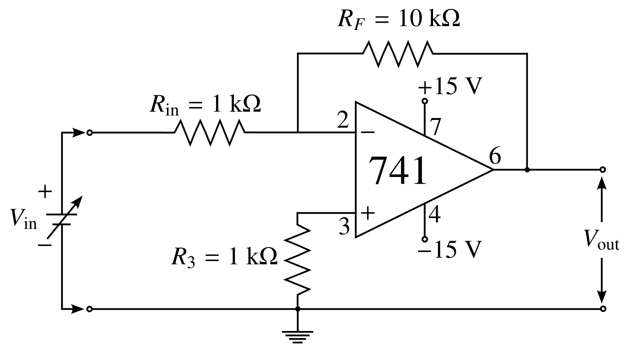


**Figure 6:** Inverting amplifier circuit.

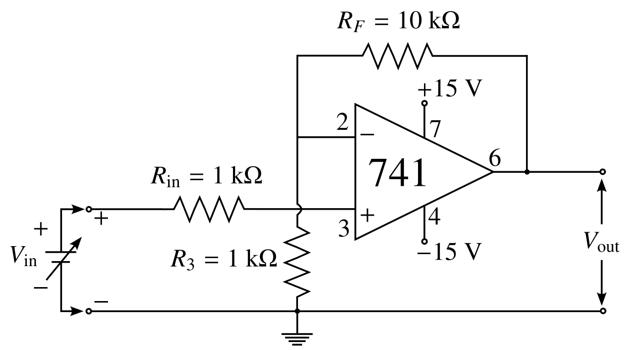


**Figure 7:** Non-inverting amplifier circuit.

## 1.4 Procedure

### 1.4.1 Inverting amplifier

1. Configure the circuit as shown in the circuit diagram. Connect pins 7 and 4 of the IC to the ±15 V output terminals of the DC power supply. Connect the 0 V terminal to the ground. Choose $R_{\text{in}} = 1$ kΩ and $R_F = 10$ kΩ. Measure the resistance values with a multimeter and calculate gain, $-R_F/R_{\text{in}}$. Connect a resistor $R_3(R_{\text{in}} \vee R_F \approx R_{\text{in}})$ as shown in the circuit diagram to minimize offset due to input bias current.

2. Connect one of the output terminals of the DC power supply (0 - 30V) at the inverting input (pin no. 2).

3. Switch on the power supply and apply different voltages in the range 0 - 1.5 V in steps of 0.2 V at the inverting terminal. Measure this input using a digital multi-meter.

4. Measure the corresponding output voltages with the multimeter and calculate gain $V_{\text{out}}/V_{\text{in}}$. Note the sign of the output voltage.

5. Now, replace $R_F$ by 50 kΩ. Measure the resistance value with the multimeter and calculate gain, $-R_F/R_{\text{in}}$.

6. Apply different voltages in the range 0 - 0.5 V in steps of 0.1 V at the inverting terminal. Measure this input using a digital multimeter.

7. Measure the corresponding output voltages with the multimeter and calculate gain $V_{\text{out}}/V_{\text{in}}$.

8. Plot graphs for $V_{\text{in}}$ vs. $V_{\text{in}}$ for both the values of $R_F$.

9. You may also use a function generator to give a sinusoidal input and notice the output waveform using an oscilloscope.

### 1.4.2 Non-inverting amplifier

1. Configure the circuit as shown in the circuit diagram with $R_{\text{in}} = 1$ kΩ and $R_F = 10$ kΩ. Using the measured value of resistance calculate gain, $1 + (R_F/R_{\text{in}})$.

2. Connect one of the output terminals of the DC power supply (0 - 30V) at the non-inverting input (pin no. 3).

3. Repeat steps 3. onwards of procedure of the inverting amplifier with inputs applied at the non-inverting terminal.

## 1.5 Observations

**Table 1:** Inverting amplifier

| Obs. No. | Input (V) | $-R_F/R_{\text{in}} =$ | | | $-R_F/R_{\text{in}} =$ | | |
|---|---|---|---|---|---|---|---|
| | | Output (V) | Gain = $V_{\text{out}}/V$ | Average | Output (V) | Gain = $V_{\text{out}}/V$ | Average |
| 1 | 0.2 | | | | | | |
| 2 | 0.4 | | | | | | |
| ... | ... | | | | | | |

## 1.6 Results

## 1.7 Precautions

1. Verify Op-Amp pin configuration and power supply polarity.

**Table 2:** Non-inverting amplifier

| Obs. No. | Input (V) | $1 + R_F/R_{\text{in}} =$ | | | $1 + R_F/R_{\text{in}} =$ | | |
|---|---|---|---|---|---|---|---|
| | | Output (V) | Gain = $V_{\text{out}}/V$ | Average | Output (V) | Gain = $V_{\text{out}}/V$ | Average |
| 1 | 0.2 | | | | | | |
| 2 | 0.4 | | | | | | |
| ... | ... | | | | | | |

2. Keep power OFF while making connections.
3. Use specified supply voltages only.
4. Avoid output short circuits and excessive input signals.
5. Ensure proper grounding and firm connections.
6. Take readings after the output stabilizes.

# 2 Study simple mathematical operations - Summing and difference amplifiers

## 2.1 Circuit components/equipment

1. OPAMP 741
2. Resistors
3. Oscilloscope
4. DC voltage source
5. Breadboard

## 2.2 Theory

**Summing amplifier**

The summing amplifier is a very flexible circuit based upon the standard inverting operational amplifier configuration. We saw previously that the inverting amplifier has a single input signal applied to the inverting input terminal. If we add another input resistor equal in value to the original input resistor, $R_{\text{in}}$ we end up with another operational amplifier circuit called a "summing amplifier", "summing inverter" or even a "voltage adder" circuit as shown below

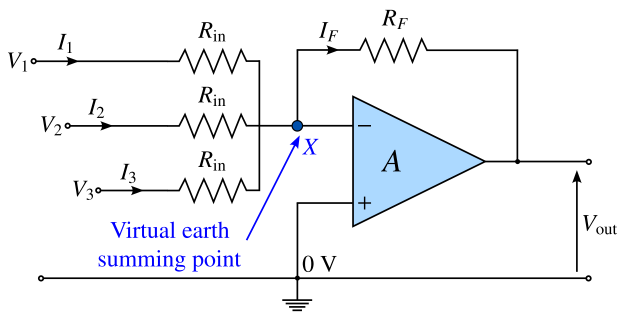


**Figure 8:** Typical summing amplifier circuit.

The output voltage, ($V_{\text{out}}$) now becomes proportional to the sum of the input voltages, $V_1, V_2, V_3$ etc. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

$$I_F = I_1 + I_2 + I_3 = -\left(\frac{V_1 + V_2 + V_3}{R_{\text{in}}}\right) = \frac{V_{\text{out}}}{R_F}$$

$$V_{\text{out}} = -\frac{R_F}{R_{\text{in}}}(V_1 + V_2 + V_3)$$

The summing amplifier is a very flexible circuit indeed, enabling us to effectively "add" or "sum" together several individual input signals. If the input resistors are all equal a unity gain inverting adder can be made. However, if the input resistors are of different values a "scaling summing amplifier" is produced which gives a weighted sum of the input signals.

### Difference amplifier

Up to now we have used only one input to connect to the amplifier, using either the "inverting" or the "non-inverting" input terminal to amplify a single input signal with the other input being connected to ground. But we can also connect signals to both of the inputs at the same time producing another common type of operational amplifier circuit called a differential amplifier. The resultant output voltage will be proportional to the "difference" between the two input signals, $V_1$ and $V_2$. This type of circuit can also be used as a subtractor.

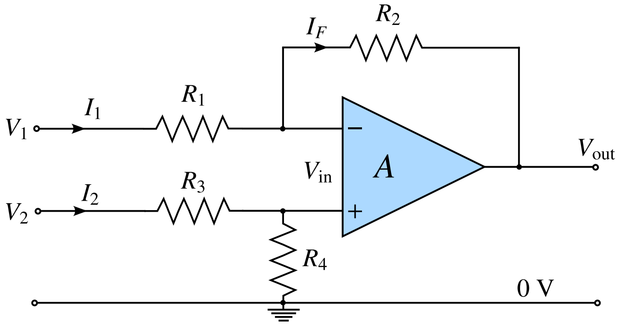


**Figure 9:** Typical difference amplifier circuit.

The transfer function for a differential amplifier circuit is given as:

$$V_{\text{out}} = -\frac{R_2}{R_1}V_1 + \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right)V_2.$$

When $R_1 = R_3$ and $R_2 = R_4$, the transfer function formula can be modified to the following:

$$V_{\text{out}} = -\frac{R_2}{R_1}(V_2 - V_1).$$

If all the resistors are of the same ohmic value, the circuit will become a unity gain differential amplifier and the gain of the amplifier will be 1 or unity.

## 2.3 Circuit diagram

The circuit diagrams for summing and difference amplifiers are shown in figure 10 and figure 11 respectively.

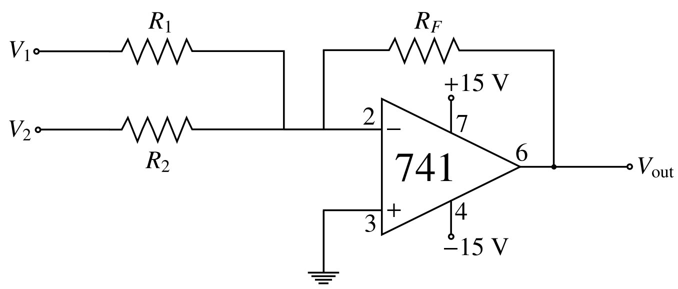


**Figure 10:** Summing amplifier circuit.

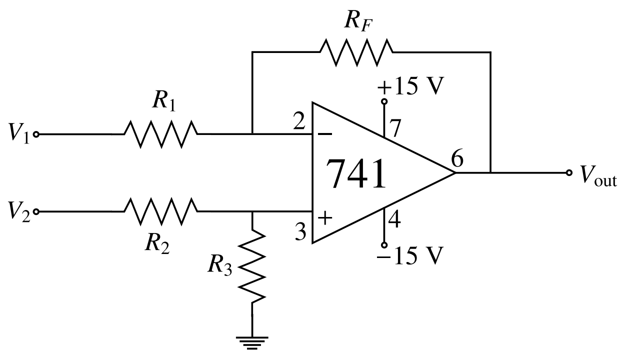


**Figure 11:** Difference amplifier circuit.

## 2.4 Procedure

### 2.4.1 Summing amplifier

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2, R_F = 10$ kΩ each. Use 0 to ±15 V terminal output to provide supply to the IC.

2. Using 0 to 30 V and 5 V terminals of the power supply, apply two inputs at the inverting terminal. Measure each input with multimeter.

3. Measure the output with multimeter for at least five input combinations.

4. Compare the output with the sum of the two inputs.

### 2.4.2 Difference amplifier

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2, R_F = 10$ kΩ each. Use 0 to ±15 V terminal output to provide supply to the IC.

2. Using 0 - 30 V and 5 V terminals of the power supply, apply two inputs at the inverting terminal. Measure each input with multi-meter.

3. Measure the output with multi-meter for at least five input combinations.

4. Compare the output with the sum of the two inputs.

## 2.5 Observations

**Table 3:** Summing amplifier

| Obs. No. | $V_1$ (V) | $V_2$ (V) | $V_{out}$ (V) | $V_1 + V_2$ (V) |
|---|---|---|---|---|
| 1 | | | | |
| . . . | | | | |
| 5 | | | | |

**Table 4:** Difference amplifier

| Obs. No. | $V_1$ (V) | $V_2$ (V) | $V_{out}$ (V) | $V_1 - V_2$ (V) |
|---|---|---|---|---|
| 1 | | | | |
| . . . | | | | |
| 5 | | | | |

## 2.6 Results

## 2.7 Precautions

1. Verify Op-Amp pin configuration and power supply polarity.
2. Keep power OFF while making connections.
3. Use specified supply voltages only.
4. Avoid output short circuits and excessive input signals.
5. Ensure proper grounding and firm connections.
6. Take readings after the output stabilizes.

# 3 Applications of OP-AMP - Comparator

## 3.1 Components/Equipment

1. OPAMP (IC-741) chip,
2. A DC power supply,
3. A digital multimeter (DMM),
4. A digital storage oscilloscope (DSO),
5. Connecting wires,
6. Breadboard

## 3.2 Theory

### 3.2.1 Comparator

When the feedback signal (voltage) is applied to the inverting (−) input of the op- amp then the feedback is negative. Negative feedback tends to reduce the difference between the voltages at the inverting and non-inverting terminals and make linear circuits. Without negative feedback the op-amp output is highly sensitive to the input, which can be used to design switching or nonlinear circuits. The voltage comparator is a device which uses no feedback; then saturation is the desired result.

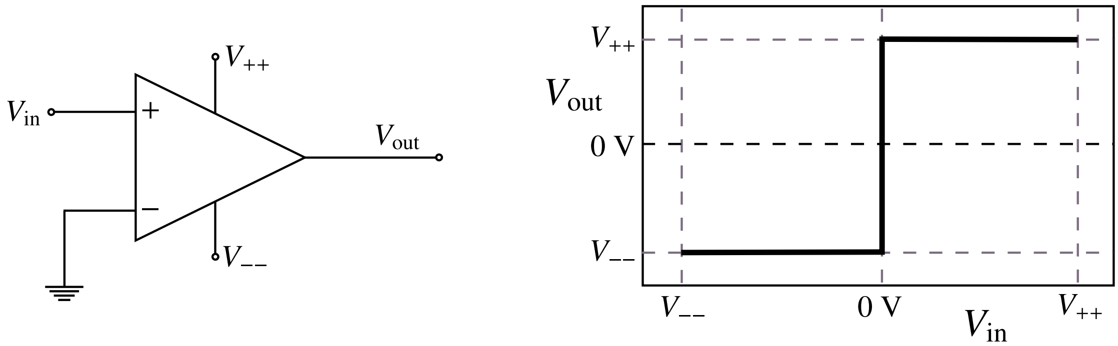


**Figure 12:** OP-AMP as a ground level comparator.

In this circuit, we want a simple yes-no answer to be signified by either positive saturation or negative saturation of the output. In the circuit diagram shown for figure 12,

1. if $V_{in} > 0$, $V_{out} \approx V_{++}$
2. if $V_{in} < 0$, $V_{out} \approx V_{--}$

The output is no longer linearly related to the input. It's more like a digital signal, high or low depending on how $V_{in}$ compares to ground (0 V). Needless to mention that, if $V_{in}$ is applied at the inverting terminal with respect to a grounded non-inverting terminal, the output will switch to low when $V_{in} > 0$.

Figure 13 shows a small modification, allowing the circuit to switch its output when $V_{in}$ crosses a certain preset voltage level, often called the threshold voltage, $V_{th}$.

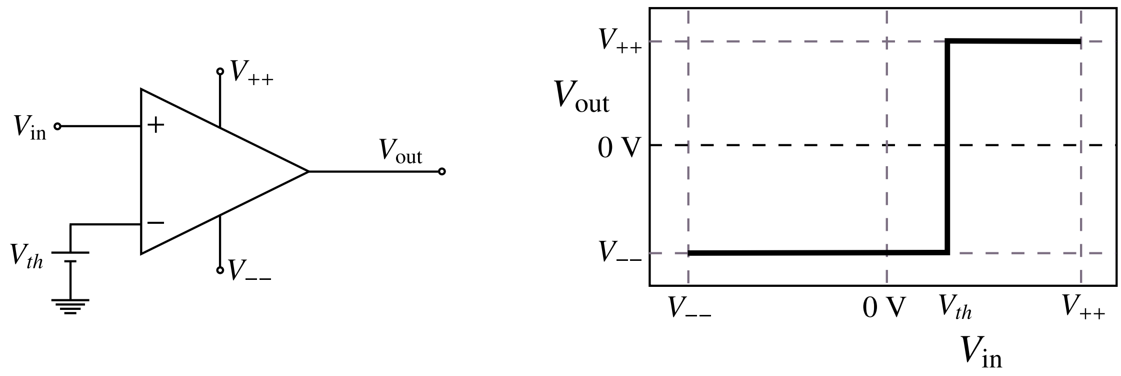


**Figure 13:** OP-AMP as a threshold comparator.

Typical applications of this circuit are crossover detectors, analog to digital converters or counting applications where one wants to count pulses that exceed a certain voltage level.

## 3.3 Procedure

### 3.3.1 Comparator

1. Construct the comparator circuit on the breadboard as shown in the circuit diagram. Take care to give proper connections at the desired pins of the IC.

2. Use terminal C of the DC power supply (denoted by $V_+$ and $V_-$ knobs) to provide power supply to IC. Connect the 0 V terminal to ground.

3. Connect terminal $A$ of the DC power supply (0 - 30 V) at the input. Use terminal $B$ (5 V) to provide threshold voltage $V_{th}$ for circuit shown in figure 13.

4. Vary the input from a negative value to a positive value through 0.

5. Using the DMM, measure and tabulate $V_{\text{in}}$ and $V_{\text{out}}$. You can also look at the output using a DSO by coupling the output to it in DC mode.

6. Make a plot of $V_{\text{out}}$ vs. $V_{\text{in}}$ for each circuit. Estimate $V_{th}$ from graph for figure 13 and compare with the $V_{th}$ value applied. You can repeat the same procedure for different values of threshold.

7. Repeat the entire procedure described above with input at the inverting terminal and the non-inverting terminal being grounded w/o and with the threshold voltage connected to it.

**Table 5:** Ground level comparator

| Obs. No. | $V_{in}$ (V) | $V_{out}$ (V) |
|---|---|---|
| 1 | | |
| ... | | |
| ... | | |

**Table 6:** Threshold comparator

| Obs. No. | $V_{in}$ (V) | $V_{out}$ (V) |
|---|---|---|
| 1 | | |
| ... | | |
| ... | | |

## 3.4 Observations

## 3.5 Results

## 3.6 Precautions

1. Verify Op-Amp pin configuration and power supply polarity.
2. Keep power OFF while making connections.
3. Use specified supply voltages only.
4. Avoid output short circuits and excessive input signals.
5. Ensure proper grounding and firm connections.
6. Take readings after the output stabilizes.

# 4 To study OP-AMP as an integrator

## Components/equipment required

1. OPAMP IC 741
2. D.C. power supply
3. Resistors
4. Digital multi-meter
5. Connecting wires
6. Breadboard
7. Function generator
8. Digital storage oscilloscope

### 4.1 Theory

We have seen how an operational amplifier can be used as part of a positive or negative feedback amplifier or as an adder or subtractor type circuit using pure resistors in both the input and the feedback loop. But what if we were to change the purely Resistive ($R_F$) feedback element of an inverting amplifier to that of a reactive element, such as a Capacitor, . We now have a resistor and capacitor combination forming an Network across the operational amplifier as shown below.

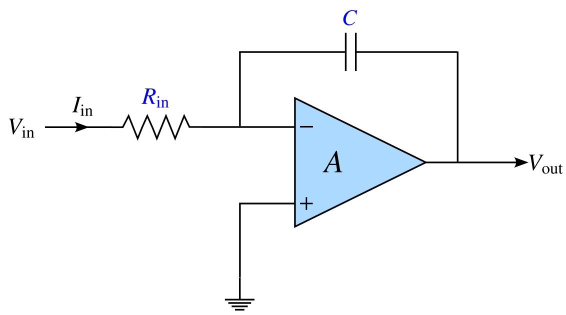


**Figure 14:** OP-AMP as an integrator.

The integrator amplifier performs the mathematical operation of integration, that is, we can cause the output to respond to changes in the input voltage over time and the integrator amplifier produces a voltage output which is proportional to that of its input voltage with respect to time. In other words, the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor.

When a voltage, $V_{\text{in}}$ is firstly applied to the input of an integrating amplifier, the uncharged capacitor $C$ has very little resistance and acts a bit like a short circuit (voltage follower circuit) giving an overall gain of less than 1, thus resulting in zero output. As the feedback capacitor $C$ begins to charge up, the ratio of $Z_F/R_{\text{in}}$ increases producing an output voltage that continues to increase until the capacitor is fully charged. At this point the ratio of feedback capacitor to input resistor ($Z_F/R_{\text{in}}$) is infinite resulting in

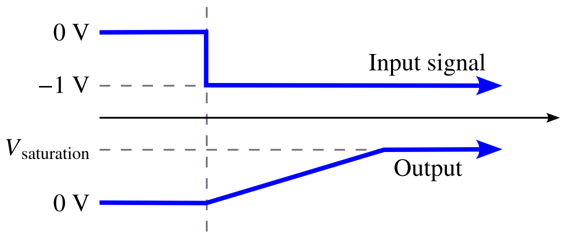


**Figure 15:** Output waveform in an OPAMP integrator.

infinite gain and the output of the amplifier goes into saturation as shown in the diagram. (Saturation is when the output voltage of the amplifier swings heavily to one voltage supply rail or the other with no control in between).

Since the node voltage of the integrating op-amp at its inverting input terminal is zero, the current $I_{\text{in}}$ flowing through the input resistor is given as:

$$I_{\text{in}} = \frac{V_{\text{in}}}{R_{\text{in}}}$$

The current flowing through the feedback capacitor is given as:

$$I_{\text{in}} = C\frac{dV_{\text{out}}}{dt}$$

Assuming that the input impedance of the OP-AMP is infinite (ideal OP-AMP), no current flows into the OP-AMP terminal. Therefore, the nodal equation at the inverting input terminal is given as:

$$\frac{V_{\text{in}}}{R_{\text{in}}} = C\frac{dV_{\text{out}}}{dt} = 0$$

From which we have an ideal voltage output for the Integrator Amplifier as:

$$V_{\text{out}} = -\frac{1}{R_{\text{in}}C} = \int V_{\text{in}}dt = -\frac{V_{in}}{j\omega R_{in}C}$$

where $j\omega = 2\pi f$ and the output voltage is a constant times the integral of the input voltage with respect to time. The minus sign $(-)$ indicates a 180° phase shift because the input signal is connected directly to the inverting input terminal of the OP-AMP.

## 4.2 Circuit diagram

## 4.3 Procedure

In this practical integrator circuit, $R_F$ is connected parallel with $C_F$. $R_F$ discharges left over charges present in the capacitor before the next pulse being applied and limits the

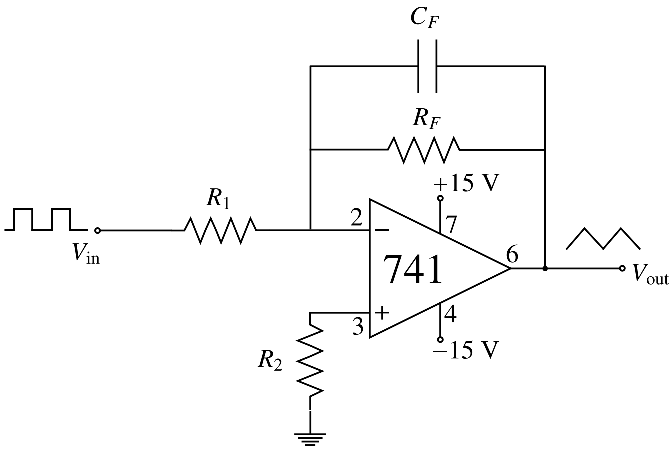


**Figure 16:** Circuit diagram of an integrator.

gain of the circuit at low frequencies, which is infinite at DC. $R_2$ is known as offset minimizing resistor (ROM) which reduces output offset voltage due to input bias current.

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2 = 10$ kΩ each, $R_F = 100$ kΩ, and $C_1 = 0.1$ μF. Use 0 to ±15 V terminal output to provide supply to the IC.
2. Feed a square wave input of required amplitude from the function generator, which is set at 1 kHz frequency.
3. Feed both the input and output signals to an oscilloscope. The output should be a triangular wave

## 4.4 Observations

Paste the various input and corresponding output waveforms here

| Observation | Waveform |
|---|---|
| **Input** | |
| **Output** | |
| | |

## 4.5 Discussion

Discuss your observations

## 4.6 Precautions

1. Verify Op-Amp pin configuration and power supply polarity.

2. Keep power OFF while making connections.
3. Use specified supply voltages only.
4. Avoid output short circuits and excessive input signals.
5. Ensure proper grounding and firm connections.
6. Take readings after the output stabilizes.

# 5 To study OP-AMP as a differentiator

# Components/equipment required

1. OPAMP IC 741
2. D.C. power supply
3. Resistors
4. Digital multi-meter
5. Connecting wires
6. Breadboard
7. Function generator
8. Digital storage oscilloscope

## 5.1 Theory

The basic differentiator amplifier circuit is the exact opposite to that of the Integrator operational amplifier circuit. Here, the position of the capacitor and resistor have been reversed and now the Capacitor, $C$ is connected to the input terminal of the inverting amplifier while the resistor, $R_F$ forms the negative feedback element across the operational amplifier. This circuit performs the mathematical operation of **Differentiation**, i.e. it produces a voltage output which is proportional to rate-of-change of the input voltage and the current flowing through the capacitor. In other words, the faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change in response becoming more of a “spike” in shape.

As with the integrator circuit, we have a resistor and capacitor forming an RC Network across the operational amplifier and the reactance ($X_C$) of the capacitor plays a major role in the performance of a differentiator amplifier.

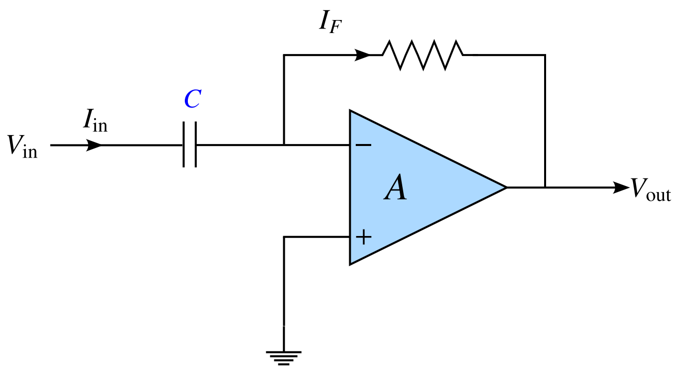


**Figure 17:** OP-AMP as a differentitator.

Since the node voltage of the operational amplifier at its inverting input terminal is zero, the current, flowing through the capacitor will be given as:

$$I_{in} = I_F \text{ and } I_F = -\frac{V_{out}}{R_F}$$

The charge on the capacitor = Capacitance × Voltage across the capacitor

$$Q = C \times V_{\text{in}}$$

The rate of change of this charge is

$$\frac{dQ}{dt} = C\frac{dV_{\text{in}}}{dt}$$

But is the capacitor current

$$I_{\text{in}} = C\frac{dV_{\text{in}}}{dt} = I_F$$

From which we have an ideal voltage output for the Differentiator Amplifier is given as:

$$V_{\text{out}} = -R_F C\frac{dV_{\text{in}}}{dt}$$

Therefore, the output voltage $V_{\text{out}}$ is a constant $-R_F C$ times the derivative of the input voltage $V_{\text{in}}$ with respect to time. The minus sign indicates a 180° phase shift because the input signal is connected to the inverting input terminal of the operational amplifier.

If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependent upon the RC time constant of the Resistor/Capacitor combination.

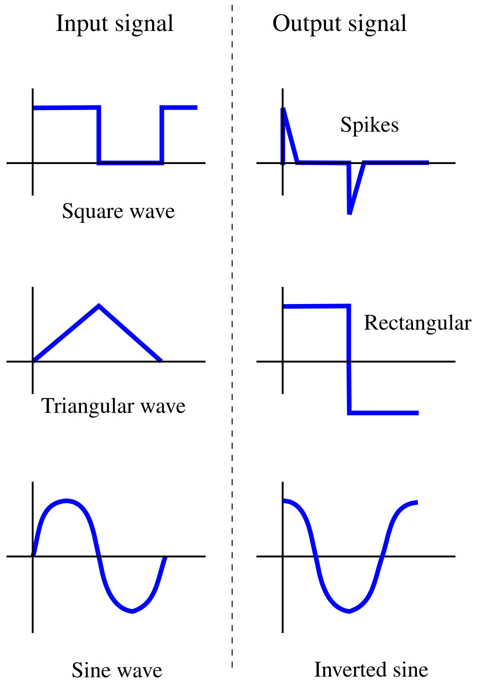


**Figure 18:** Output waveforms in a OP-AMP differentiator.

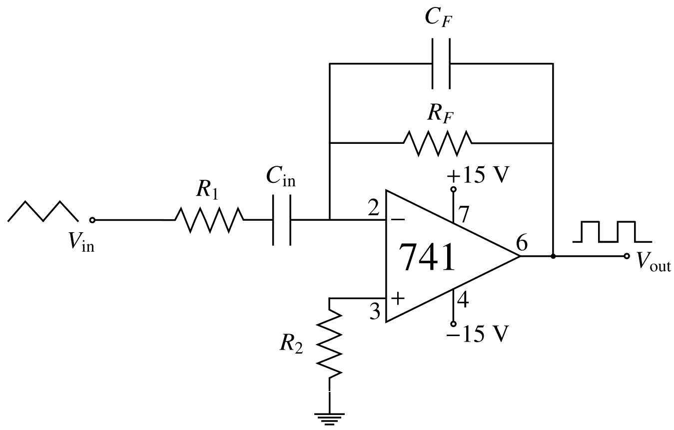


**Figure 19:** Circuit diagram of an integrator.

## 5.2 Circuit diagram

## 5.3 Procedure

For the practical differentiator, is added in parallel to to control the gain and a small resistance at the input in series with Cin drops the noise at the input. is known as offset minimizing resistor (ROM) which reduces output offset voltage due to input bias current.

1. Assemble the circuit as shown in circuit diagram choosing $R_1, R_2$ = 1 kΩ each, $R_F$ = 10 kΩ, $C_{in}$ = 0.1 μF and $C_F$ = 0.01 μF. Use 0 to ±15 V terminal output to provide supply to the IC.

2. Feed a triangular input signal of required amplitude from the function generator, which is set at 1 kHz frequency.

3. Feed both the input and output signals to an oscilloscope and save. The output should be approximately a square wave.

4. Check the output waveform with sine and square waves as inputs and save.

## 5.4 Observations

Paste the various input and corresponding output waveforms here

| Observation | Waveform | | |
|---|---|---|---|
| Input | Triangular | Sine | Square |
| Output | | | |

## 5.5 Discussion

Discuss your observations

## 5.6 Precautions

1. Verify Op-Amp pin configuration and power supply polarity.
2. Keep power OFF while making connections.
3. Use specified supply voltages only.
4. Avoid output short circuits and excessive input signals.
5. Ensure proper grounding and firm connections.
6. Take readings after the output stabilizes.