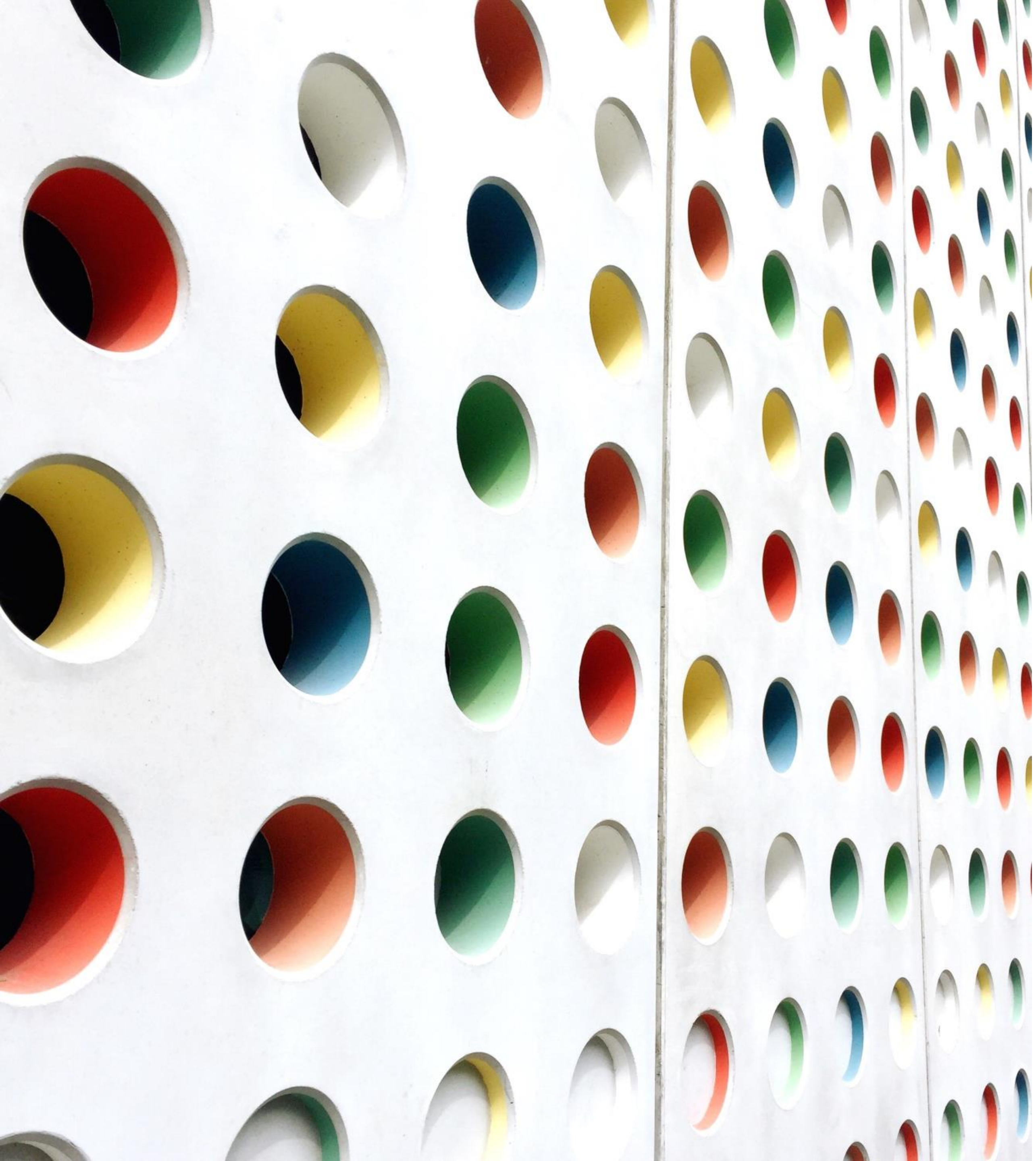

Operational Amplifier

UNIT-III

Introduction

- Operational amplifier (op-amp)
  - Very high gain differential amplifier
  - High input impedance
  - Low output impedance
- Applications
  - Oscillators
  - Filters
  - Instrumentation Amplifier
  - A to D Converters
  - Zero Crossing Detectors
  - Precision Rectifiers

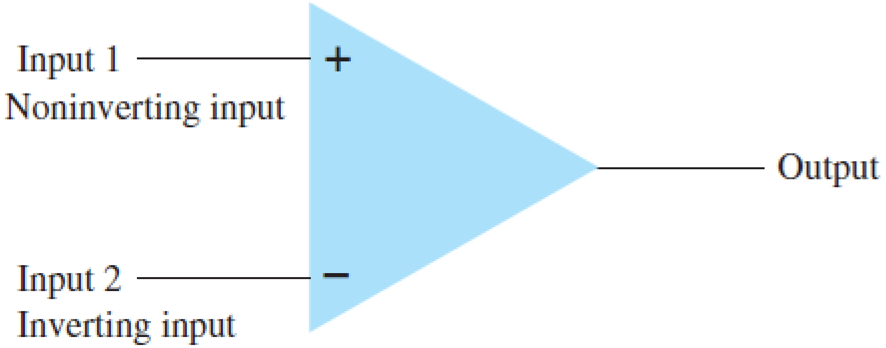

Fig.1: Single- Ended Operation

Single Ended Input

- Single-ended input operation results when the input signal is connected to one input with the other input connected to ground.

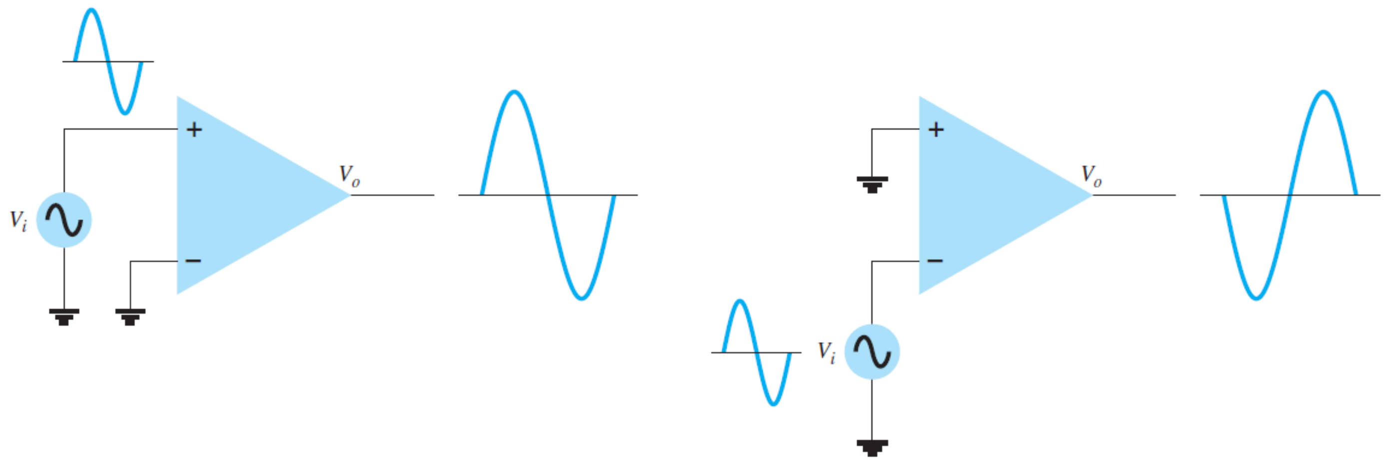

Fig.2: Single- Ended Operation

Double-Ended (Differential) Input

- In addition to using only one input, it is possible to apply signals at each input.
- Resulting configuration is called double-ended operation.

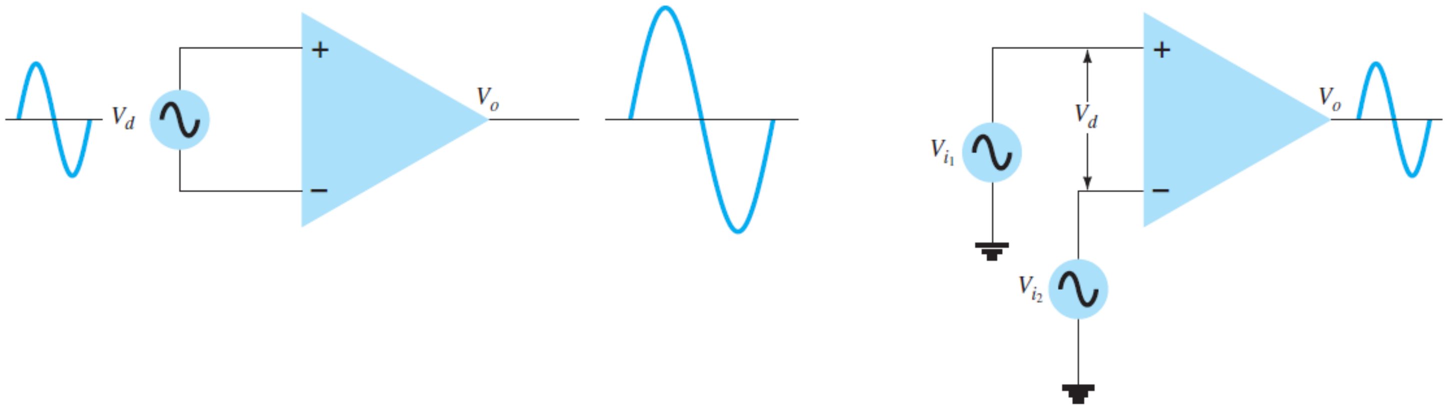

Fig.3: Double- Ended Operation

Op-Amp Basics

- An operational amplifier having
  - Very high gain
  - Very high input impedance (typically a few megohms)
  - Low output impedance (less than 100)
  - High CMRR (Common mode rejection ratio)
- Fig.4 shows a basic op-amp unit.
- Input terminals:
  - Inverting Input (marked with "-")
  - Non-Inverting Input (marked with "+")

$$V_O = A(V^+ - V^-)$$

A : open loop gain of op-amp

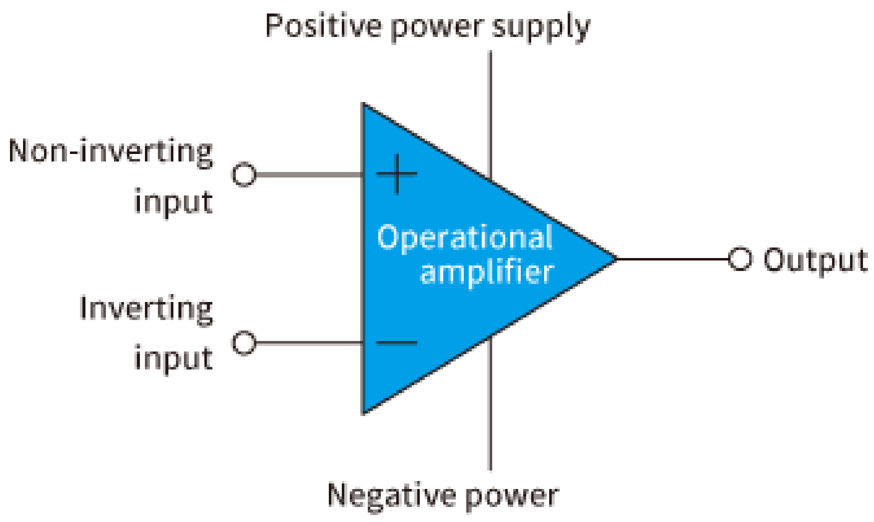

Fig.4: *Basic op- amp*

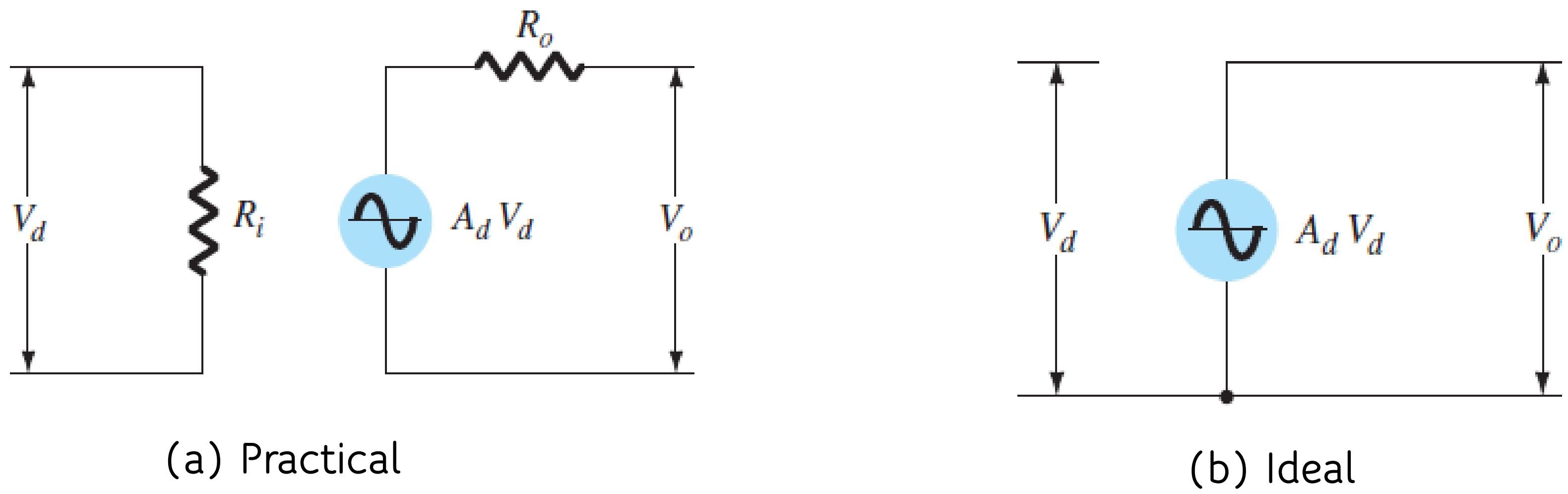

Fig.5: *AC equivalent of op- amp circuit*

Op-Amp Characteristics

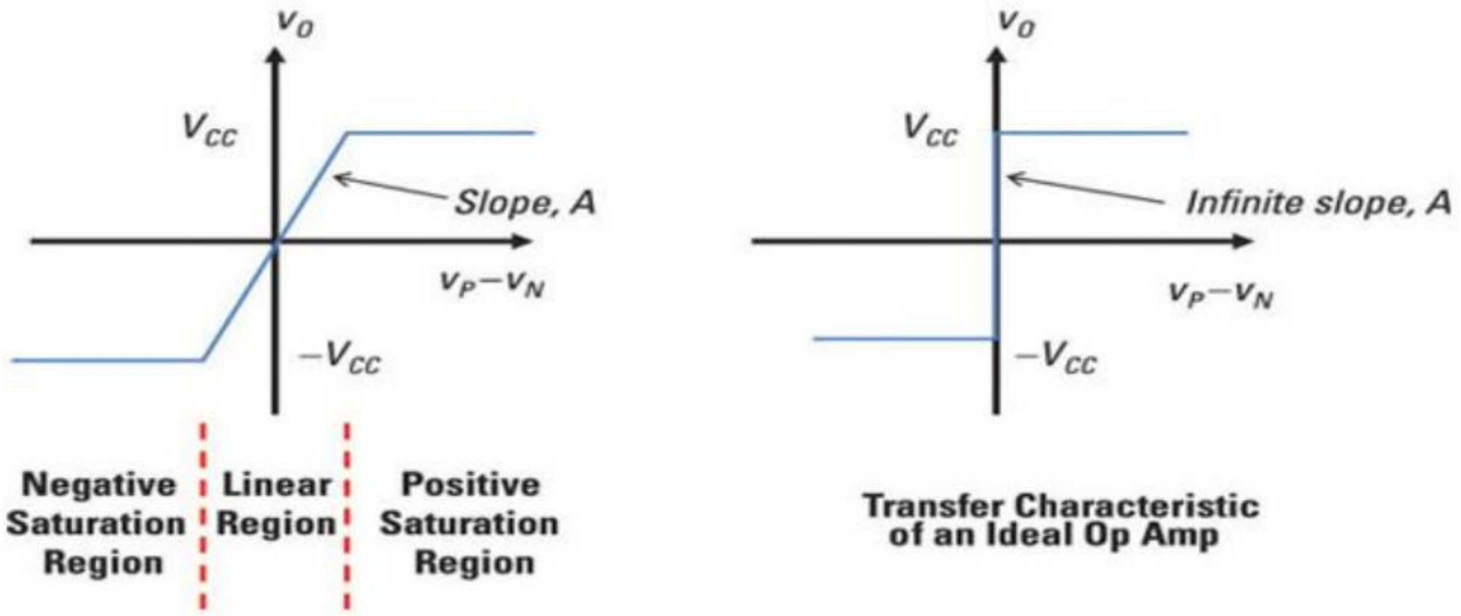

Fig.6: Ideal vs. practical characteristics of Op-amp

Parameter	Ideal	General Purpose 741 Op-Amp
Voltage Gain, G	∞	$1 \times 10^{[illegible]}$
Output Impedance, Ro	0	75 Ω
Input Resistance, Rin	∞	2 MΩ
Offset Current, I_{io}	0	20 nA
Offset Voltage, V_{io}	0	2 mV
Bandwidth, BW	∞	1 MHz
Slew Rate, SR	∞	.7 V/uS

Working Principle

OPEN LOOP OPERATION

- The ideal op-amp amplifies the difference between the two applied input (i.e. at inverting and non inverting) signals.
- This difference between the two input signal is called the differential input voltage.
- The output voltage of open loop op-amp is given as

$$V_{out} = A_{OL}(V^{+} - V^{-})$$

Where, A_{OL} is open loop of op-amp

- In open loop, op-amp works as comparator

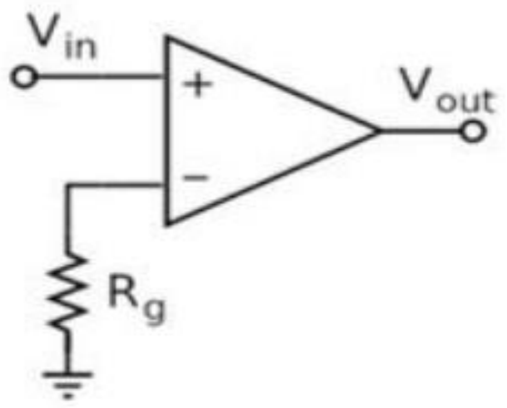

Fig.7: Open-loop operation

CLOSED LOOP OPERATION

- Feedback is introduced in the closed-loop configuration.
- This feedback path feeds the output signal back to input side.
- The output voltage of closed loop op-amp is given as

$$V_{out} = A_{CL}(V^{+} - V^{-})$$

Where, A_{CL} is the closed-loop gain

- Feedback circuit connected to op-amp determines A_{CL}
- Types of feedback
  - Positive (used in Oscillators)
  - Negative (used in Amplifiers)

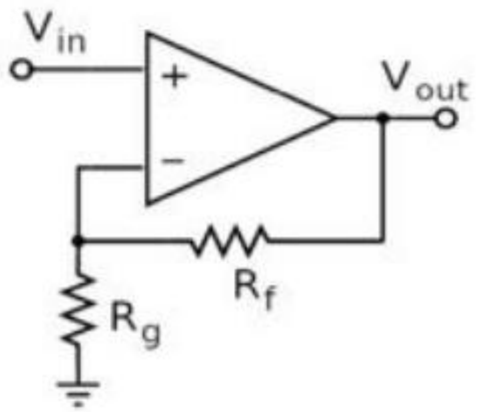

Fig.8: Closed-loop operation

Concept of Virtual Short

- Basically the "short" between two points that are imaginary.
- In context to op-amp, virtual short means, the voltage at inverting terminal tracks the voltage at non-inverting terminal under negative feedback($V_+ = V_-$)
- As we know that, $\text{Gain} = \frac{V_{out}}{V_{in}}$
- As ideal gain is infinite, hence Vin = 0

$$Vin = V_+ - V_-$$

$$\mathbf{V_+ = V_-}$$

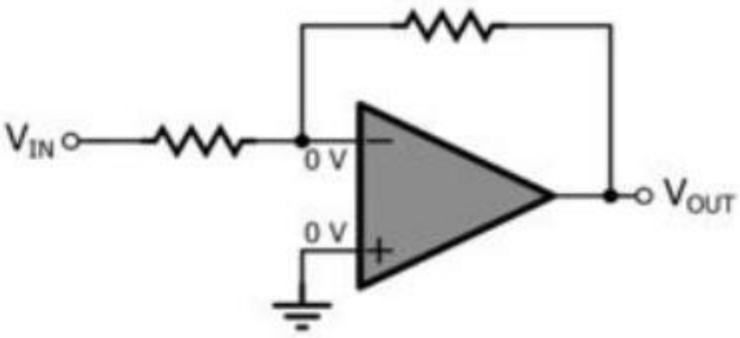

Fig.9: Virtual Ground in negative feedback

Electrical Parameters of Op-amp

Input bias current: Average current flows in inverting & no-inverting terminal.

Input & output impedance: Resistance offered by input and output terminals to varying voltages.

Open loop gain: Overall voltage gain of amplifier.

Input offset voltage: It is the voltage that must be applied between the two terminals of op-amp to make then output zero.

Input offset current: The algebraic difference between the current in to the inverting and non-inverting terminal.

Op-Amp IC

- The most commonly used op-amp is IC741.
- It is a 8-pin dual-in-line package with a pinout shown above.
  - Pin 1: Offset null
  - Pin 2: Inverting input terminal
  - Pin 3: Non-inverting input terminal
  - Pin 4: –VCC (negative voltage supply)
  - Pin 5: Offset null
  - Pin 6: Output voltage
  - Pin 7: +VCC (positive voltage supply)
  - Pin 8: No Connection

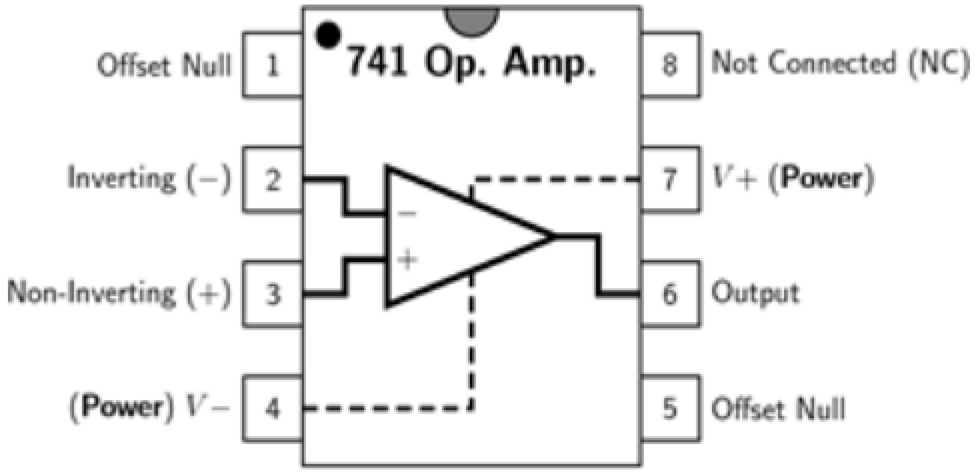

Fig.10: Pin Diagram of LM741

Applications

- Operational amplifiers are popular building block, finds application in most of the consumer and industrial electronic system.
- They can be configured as
  - Inverting Amplifier
  - Non-Inverting Amplifier
  - Buffer (Voltage follower)
  - Summing Amplifier
  - Difference Amplifier
  - Differentiator
  - Integrator
  - Filters
  - Comparator etc.

Inverting Amplifier

$$V_o = -\frac{R_f}{R_1} V_1$$

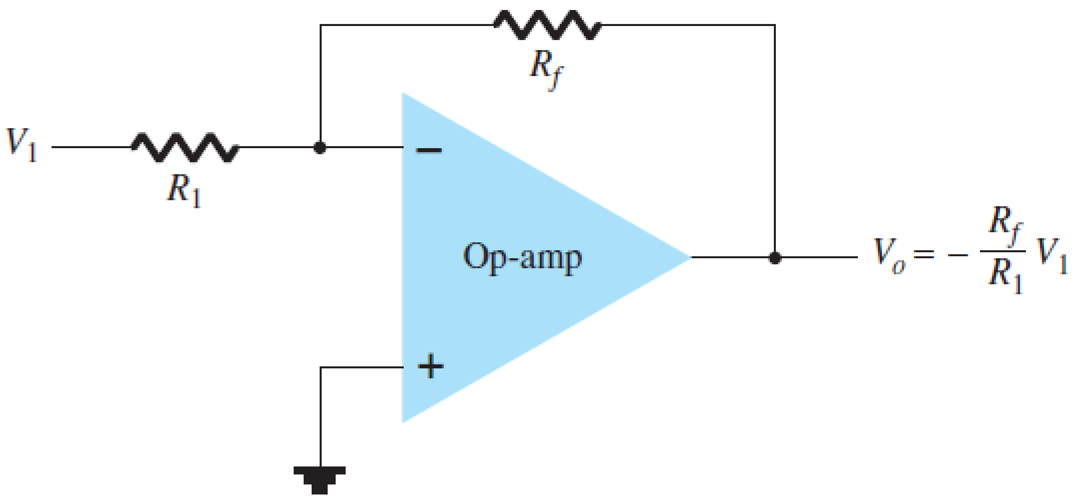

Fig.11: Inverting Amplifier

Non Inverting Amplifier

$$\frac{V_o}{V_1} = \frac{R_1 + R_f}{R_1} = 1 + \frac{R_f}{R_1}$$

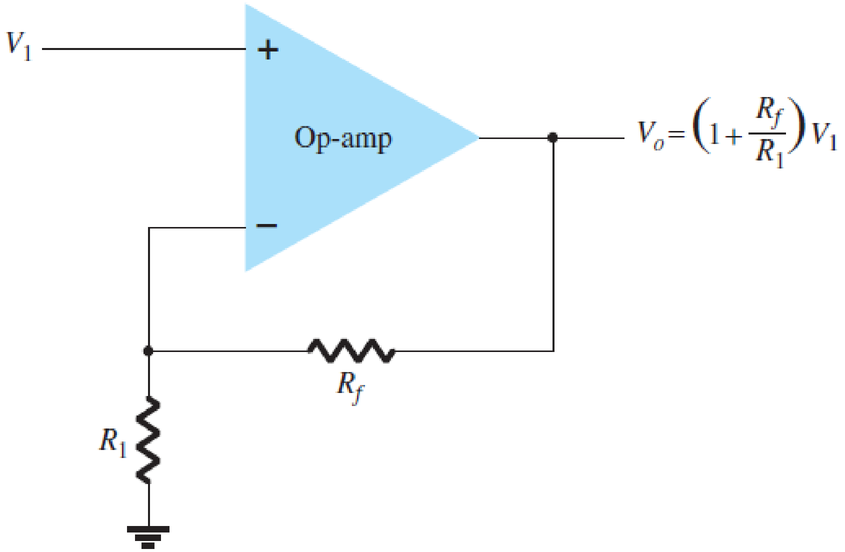

Fig.12: Non-Inverting Amplifier

Unity Follower

It provides a gain of unity (1) with no polarity or phase reversal.

$$V_o = V_1$$

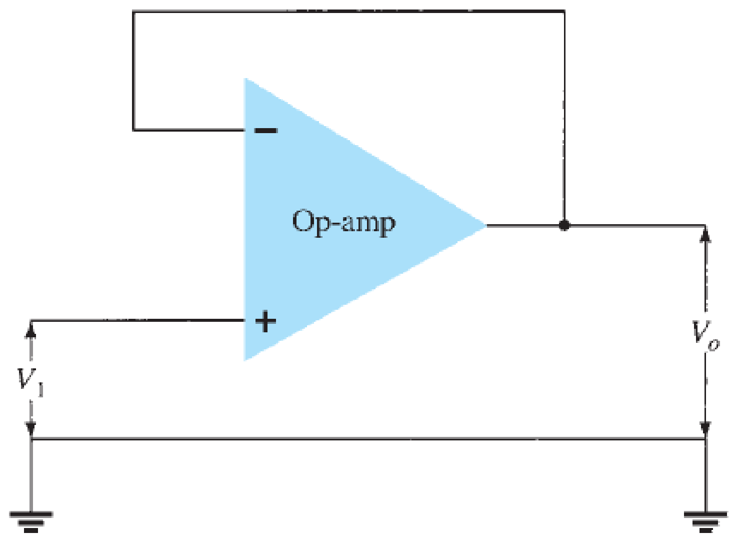

Fig.13: Unity Follower

Summing Amplifier

$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

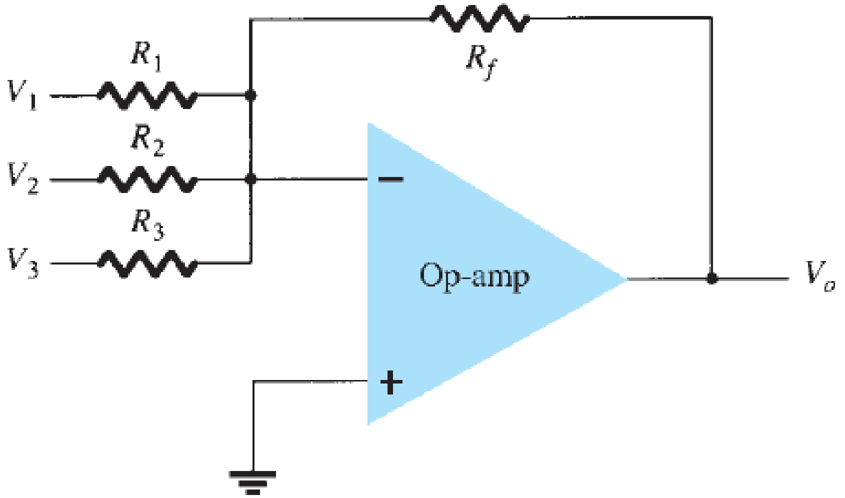

Fig.14: Summing Amplifier

Difference Amplifier

If $R_1 = R_2$ and $R_f = R_g$:

$$V_{out} = \frac{R_f}{R_1}(V_2 - V_1)$$

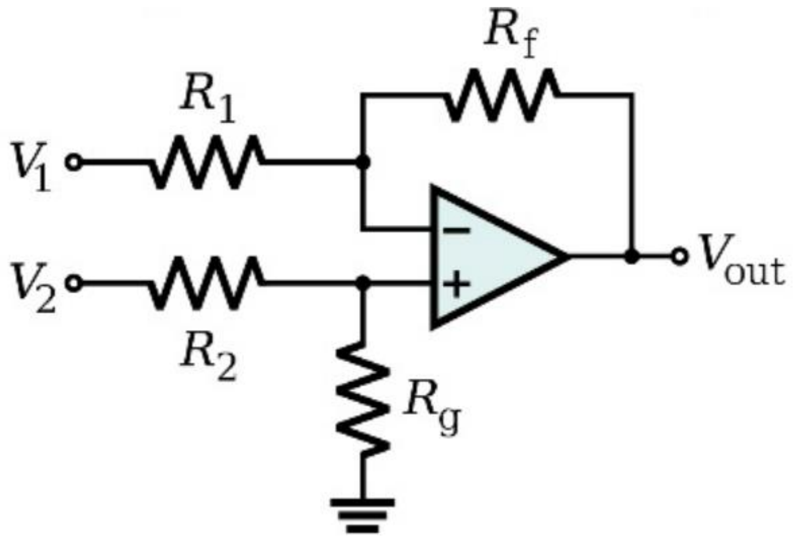

Fig.15: Difference Amplifier

Integrator

$$v_o(t) = -\frac{1}{RC}\int v_1(t)\,dt$$

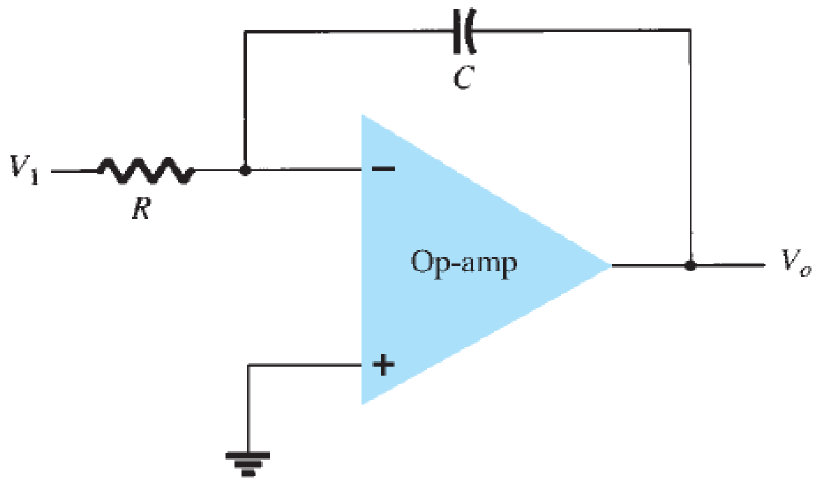

Fig.16: Integrator

Differentiator

$$v_o(t) = -RC\frac{dv_1(t)}{dt}$$

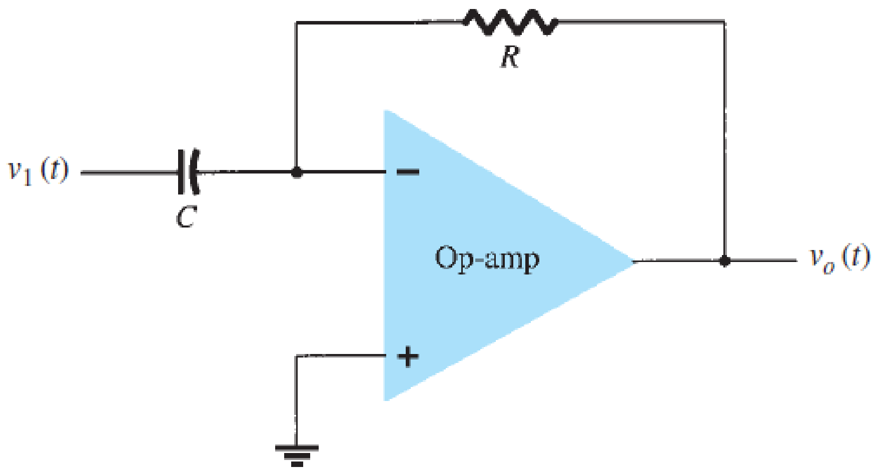

Fig.17: Differentiator