# UNIT-V

# Fundamentals of Filters and Operational Amplifiers

Lecture 33-34

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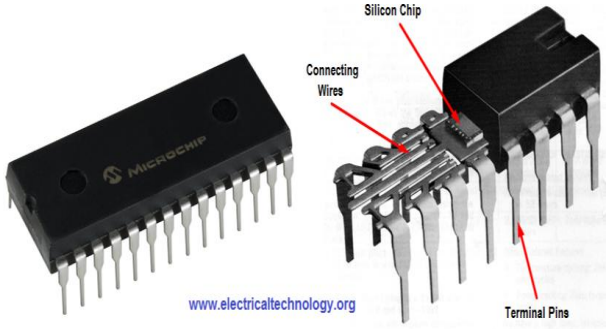
# Content

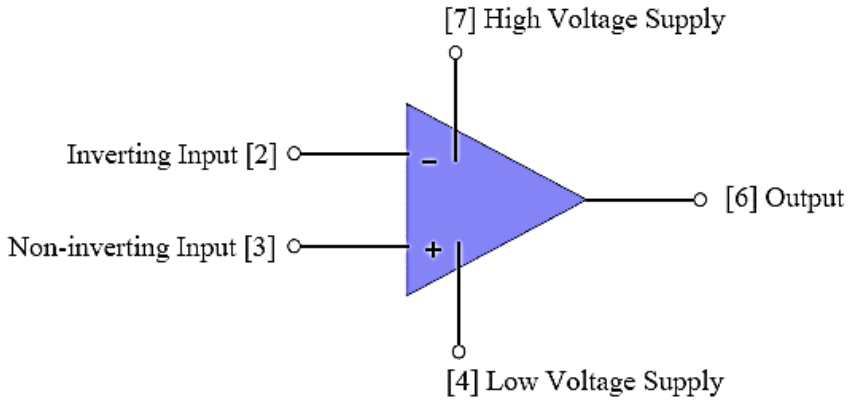
**Fundamentals of filters and operational amplifier** : filter examples- band-pass filter, low-pass filter, high-pass filter, operational amplifier abstraction- device properties of the operational amplifier, simple op amp circuits – virtual ground concept, inverting and non-inverting op-amp, op-amp as an adder and subtractor, op-amp RC circuits – op-amp integrator, op-amp differentiator, op-amp as a comparator and its application in anti-lock braking systems

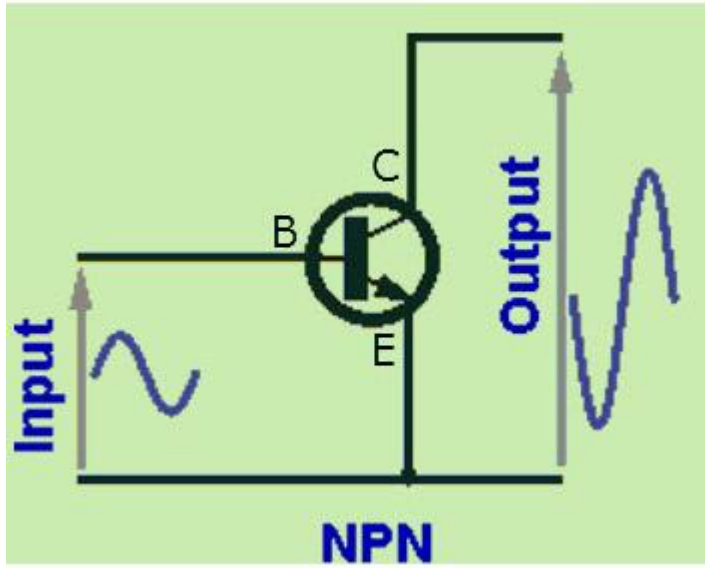
# Introduction

- OP-AMP is basically a multistage amplifier which uses a number of amplifier stages interconnected to each other.
- The integrated op amp offers all the advantage of monolithic integrated circuit such as small size ,high reliability ,reduced cost, less power consumption.
- OP-AMP amplifies the difference between two signal and diminish common signal.

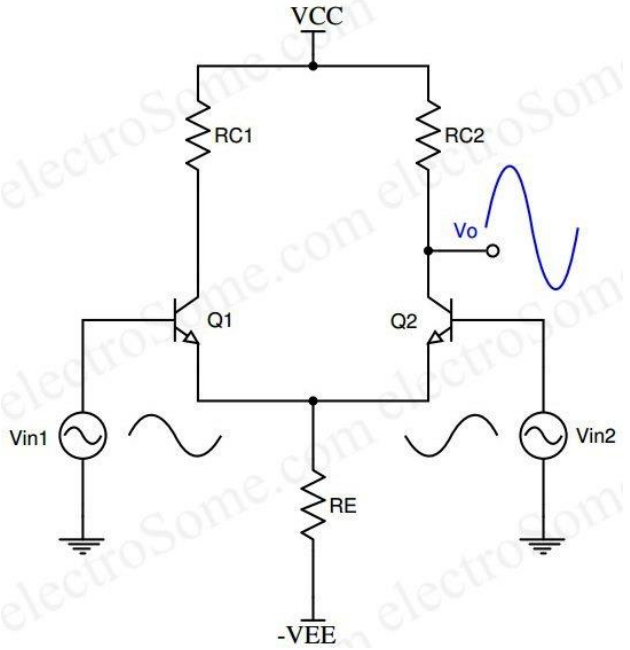


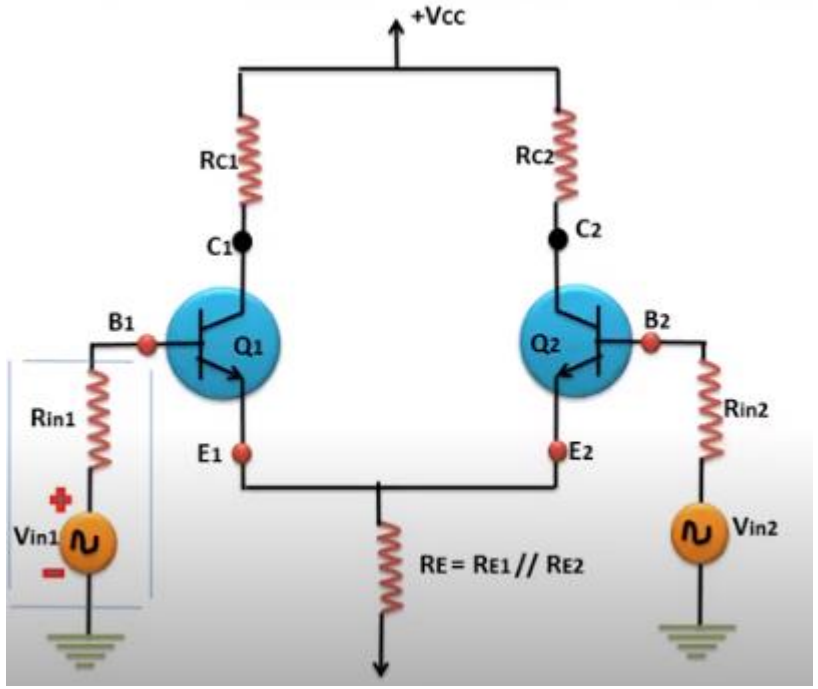
Monolithic IC in Plastic Package (DIP)




# EXPLANATION



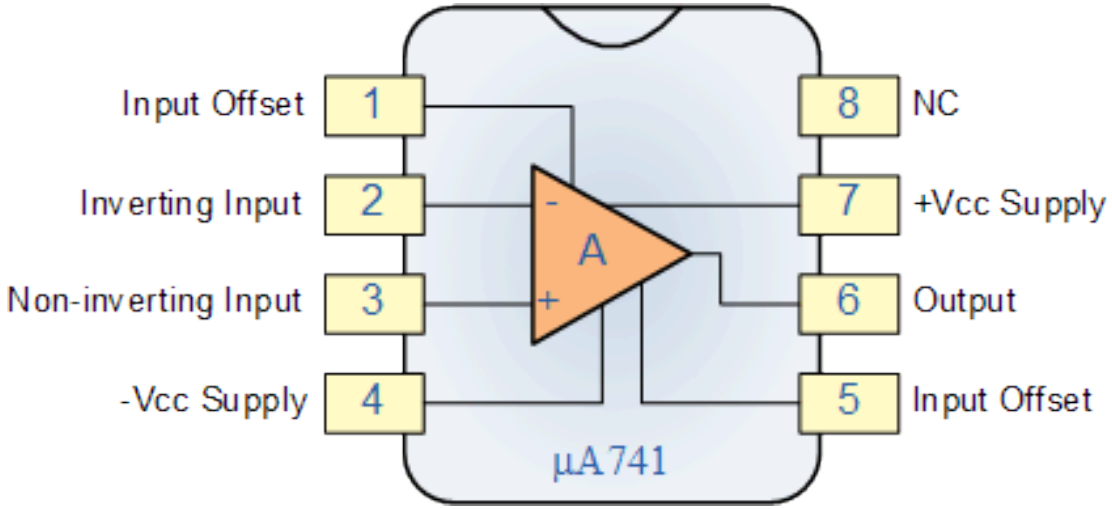



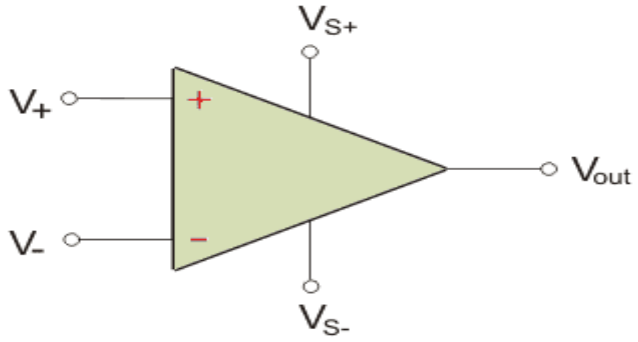

Inverting and Non inverting Inputs

# Symbol and Terminals

- One of the inputs is called the inverting input (-); the other is called the noninverting input. There is a single output.
- The input terminal marked with negative(-) sign is called as an inverting terminal .If we connect the input signal to this terminal then the amplified output signal is 180º out of phase with respect to input.

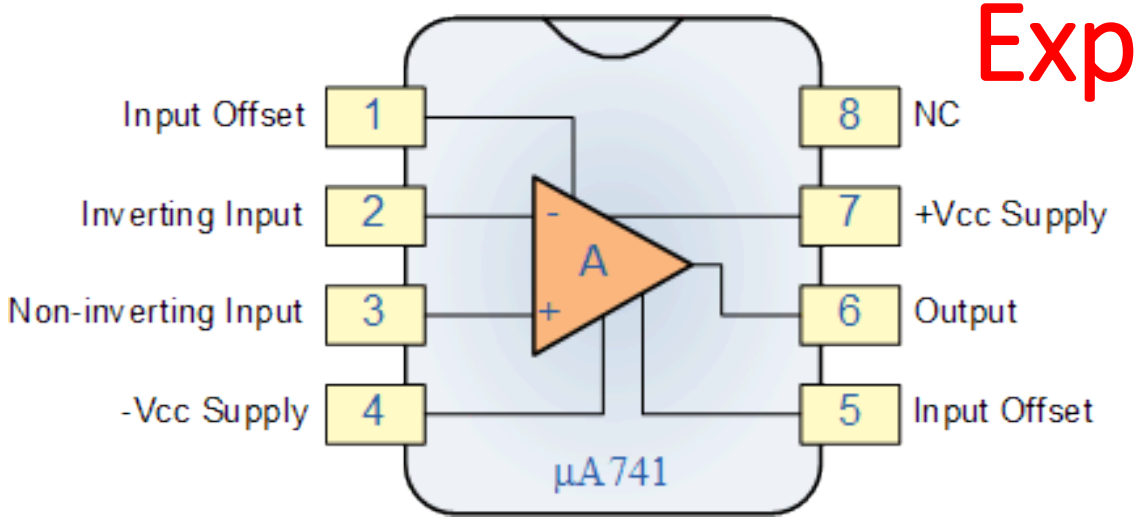
**Why 741 ??**



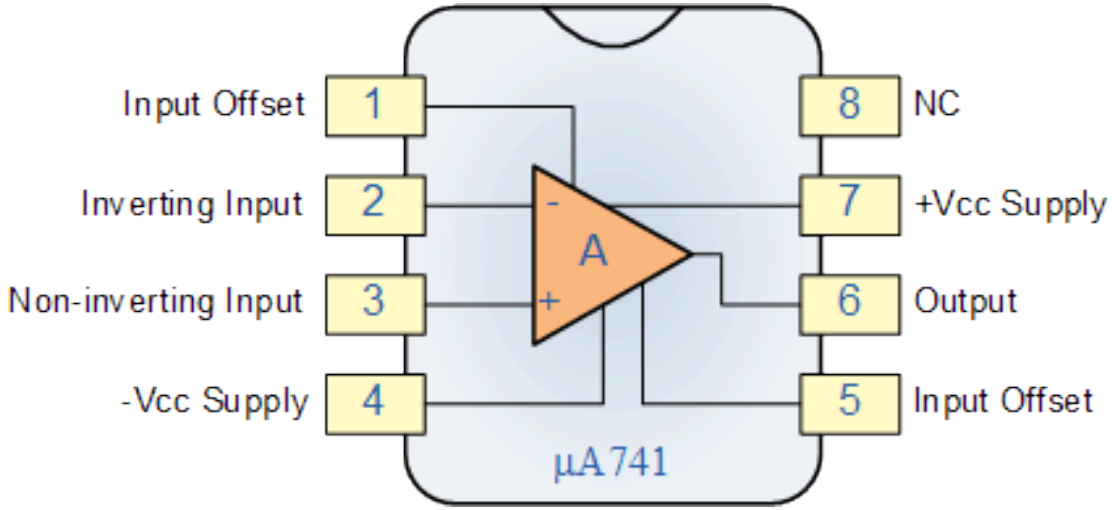

$V_+$ = non-inverting input
$V_-$ = inverting input
$V_{out}$ = output
$V_{S+}$ = positive power supply
$V_{S-}$ = negative power supply

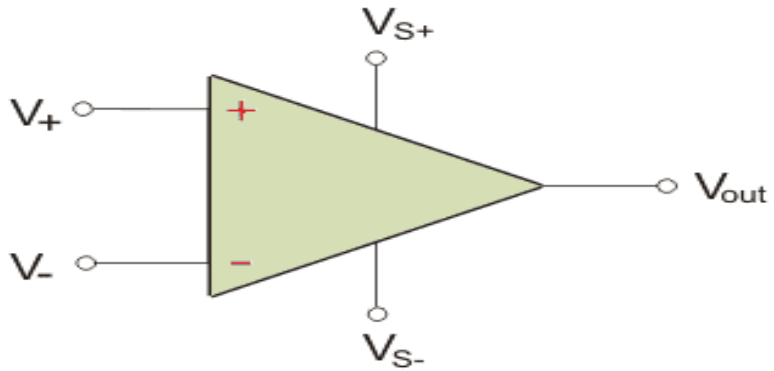
# Explanation



# Symbol and Terminals

- The input terminal marked with positive (+) sign is called as Non-Inverting terminal. If the input is applied to this pin then the amplified output is in phase with the input.
- Offset null is used to nullify the offset voltage and pin no 8 is dummy pin




$V_+$ = non-inverting input
$V_-$ = inverting input
$V_{out}$ = output
$V_{S+}$ = positive power supply
$V_{S-}$ = negative power supply

**A voltage-controlled voltage source.**

# QUICK QUIZ (POLL)

**IC 741**

a) is a 8 pin, NOT gate.

b) is a 14 pin, op amp.

c) Is a 8 pin, op amp

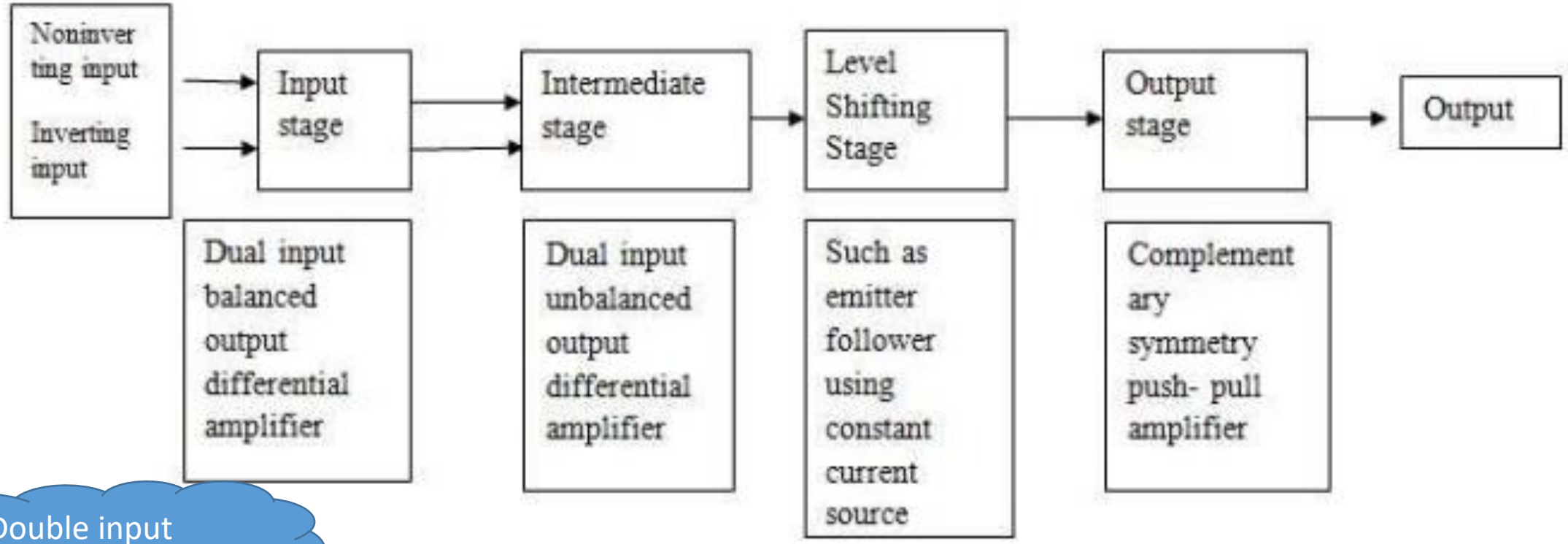
d) is a 14 pin, XOR gate.

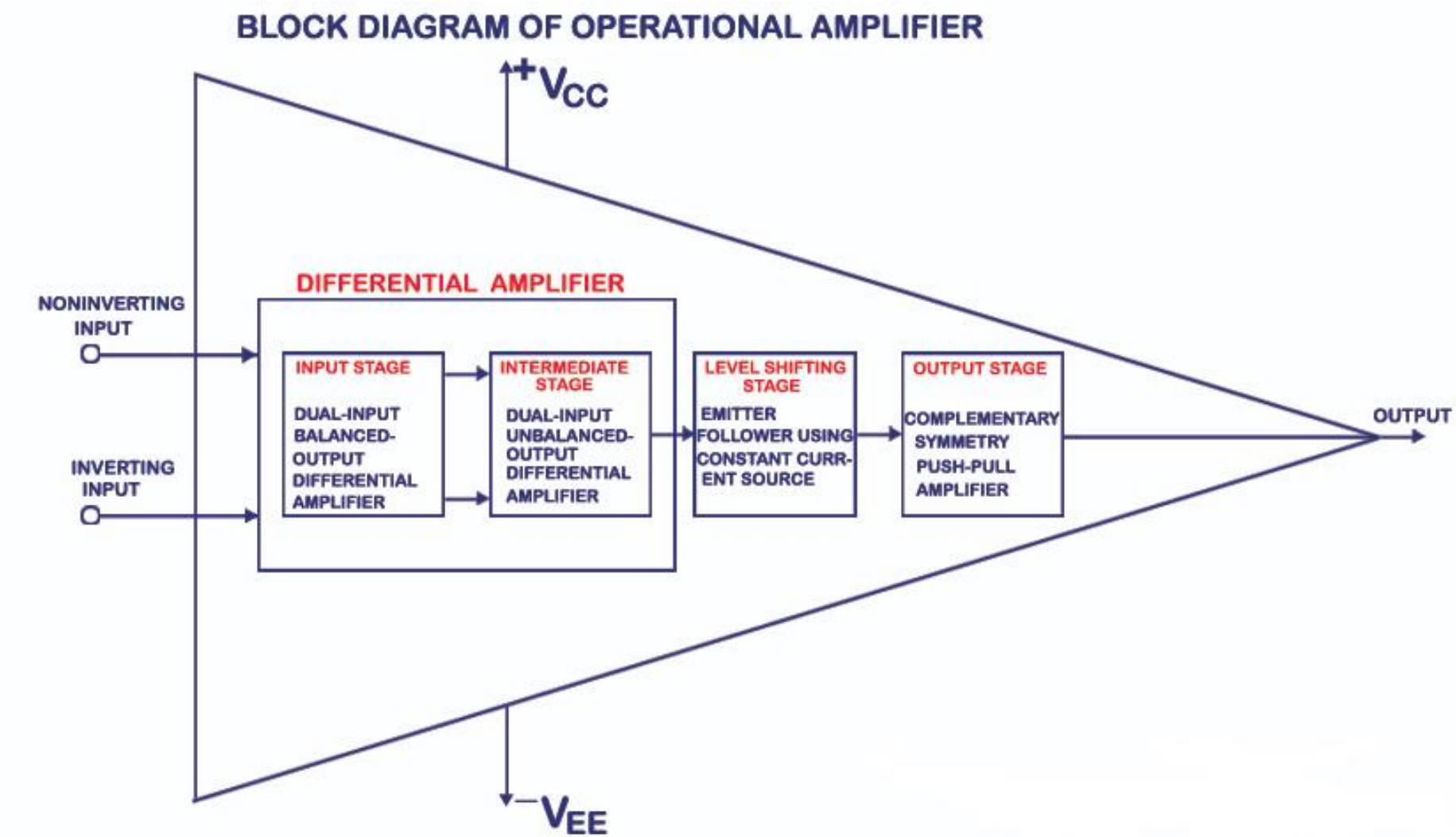
# QUICK QUIZ (POLL)

**The purpose of off set pins is to:**

a) Amplify the voltage.
b) Amplify the current.
c) nullify the offset voltage
d) To ensure that the output signal is in-phase

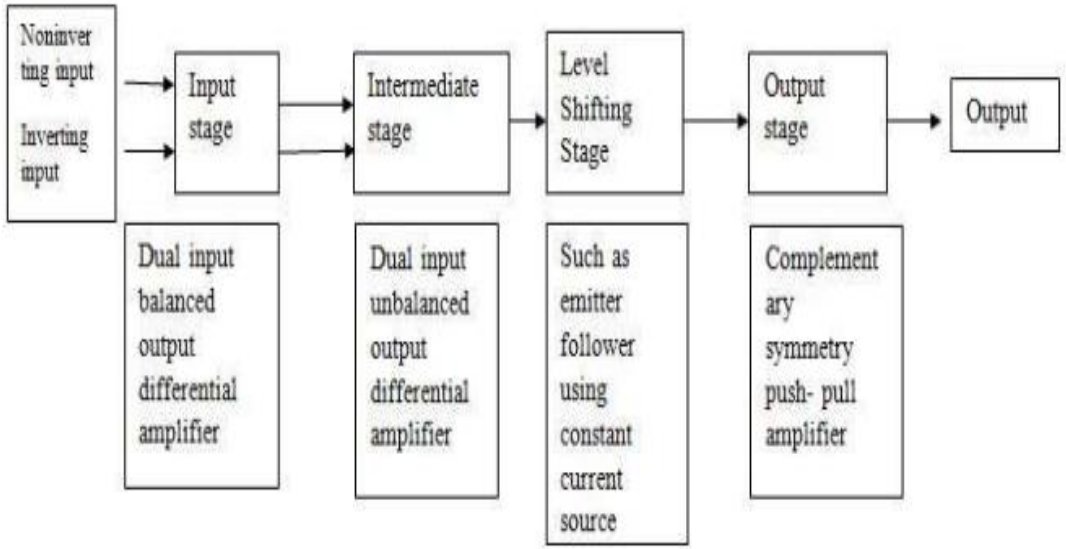
# Block Diagram of an OP Amp




BLOCK DIAGRAM OF OPERATIONAL AMPLIFIER
+VCC
DIFFERENTIAL AMPLIFIER
NONINVERTING INPUT
INVERTING INPUT
INPUT STAGE
DUAL-INPUT BALANCED-OUTPUT DIFFERENTIAL AMPLIFIER
INTERMEDIATE STAGE
DUAL-INPUT UNBALANCED-OUTPUT DIFFERENTIAL AMPLIFIER
LEVEL SHIFTING STAGE
EMITTER FOLLOWER USING CONSTANT CURR-ENT SOURCE
OUTPUT STAGE
COMPLEMENTARY SYMMETRY PUSH-PULL AMPLIFIER
OUTPUT
−VEE

# Block Diagram of an OP Amp

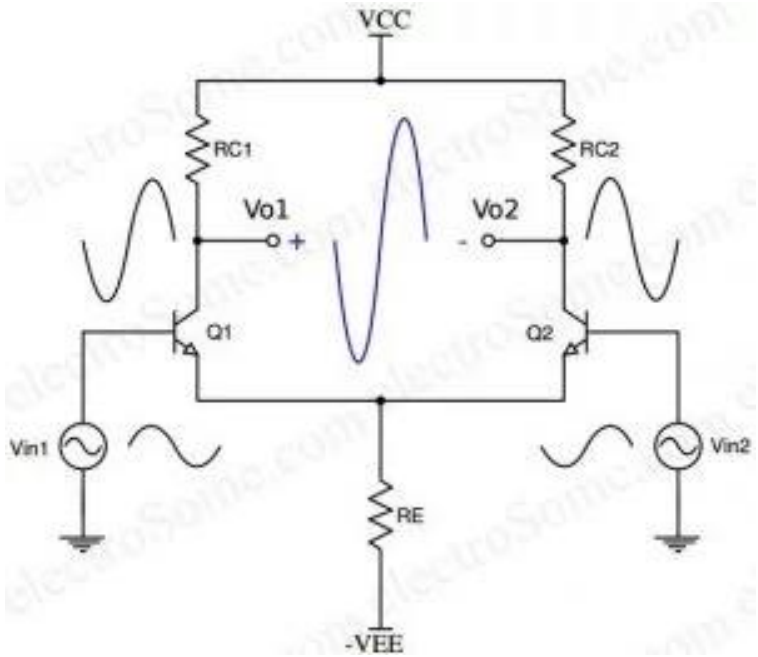
- **Input stage** provides most of the voltage gain of OP-AMP and decides input resistance.
- **Intermediate stage** is another differential amplifier which is driven by the output of input stage.
- Due to direct coupling between the first two stages, the input of level shifting is an amplified signal with some non zero dc level.
- **Level shifting stage** is used to bring this dc level to zero volts with respect to ground.
- **Output stage** increase the current supplying capability of OP-AMP and also provides low output resistance.
- For this Complementary push pull amplifier used.



# Block Diagram of an OP Amp

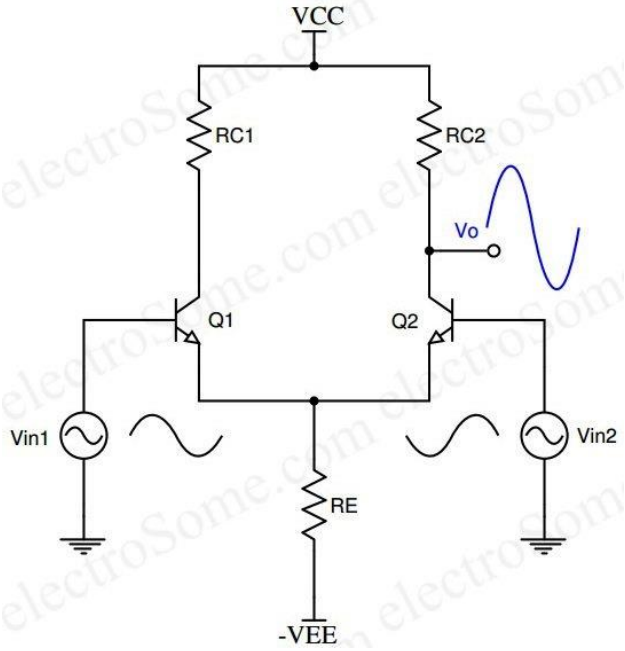
## ❑ Input Stage

Input Stage is a dual input balanced output differential amplifier which provides most of the voltage gain of amplifier and also establishes the input resistance of op-amp. Simple circuit of a dual input balanced output differential amplifier is shown below.




## ❑ Intermediate Stage

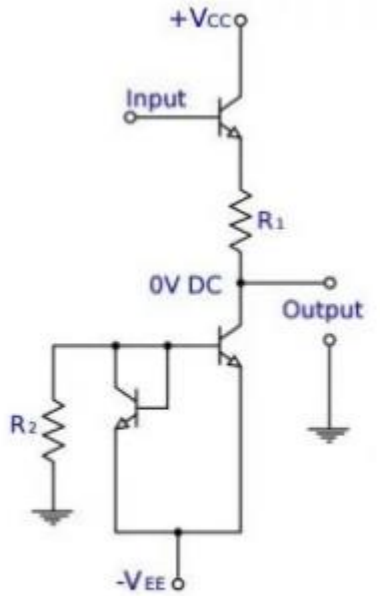
Intermediate Stage is a dual input unbalanced output differential amplifier. A simple circuit of a dual input unbalanced output differential amplifier is shown below.



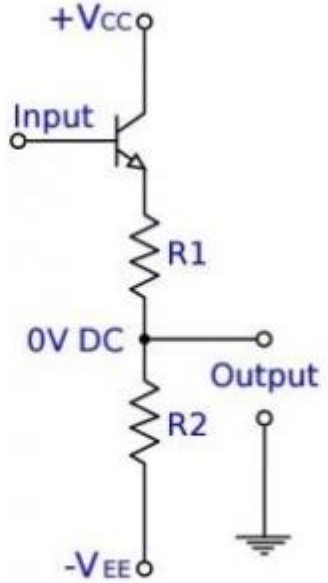
# Block Diagram of an OP Amp

## ❑Level Shifting Stage

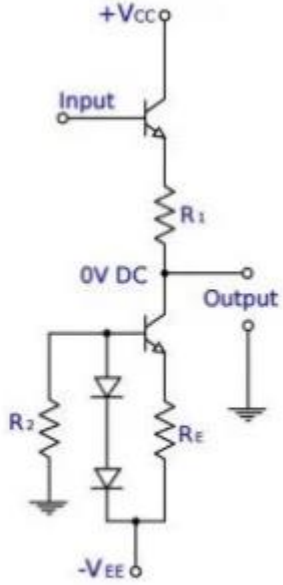
Since op-amps are direct coupled, dc level at the output will be above zero. Each amplifier stage produces AC amplification of the signal but at the same time the DC level is shifted due to the bias voltages. So we need to use level translator circuits to shift dc level to zero. We can use voltage divider emitter follower for that purpose. DC voltage is determined by the ratio of R1 and R2. For better results we may also current mirror or diode current bias circuits as below.




*Emitter Follower Current Mirror – Level Translator*




*Emitter Follower Voltage Divider – Level Translator*

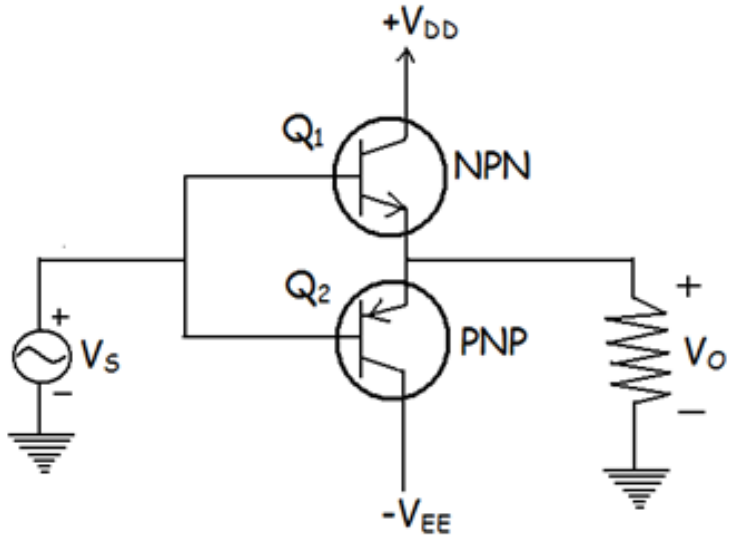



*Emitter Follower Diode Current Bias – Level Translator*

# Block Diagram of an OP Amp

## ❑Output Stage

This stage should be capable of supplying load current and should have low output resistance. Complementary push pull amplifier increases the output voltage swing of the output signal and also increases the current supplying capability of op-amp.




voltage gain of one, and a large current gain thus provide low resistance

# QUICK QUIZ (POLL)

**The input stage of an op amp consists of:**

a) Single input, balanced output
b) double input, unbalanced output
c) Single input, unbalanced output
d) double input, balanced output

# QUICK QUIZ (POLL)

**Complementary Push Pull amplifier is used at which stage of an op amp?**

a) Input Stage

b) Intermediate Stage

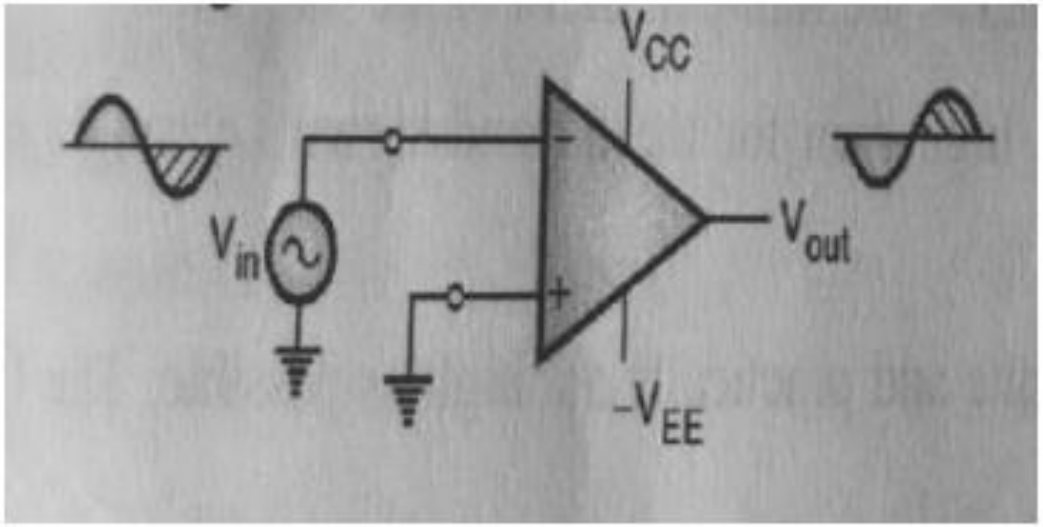
c) Level Shifting stage

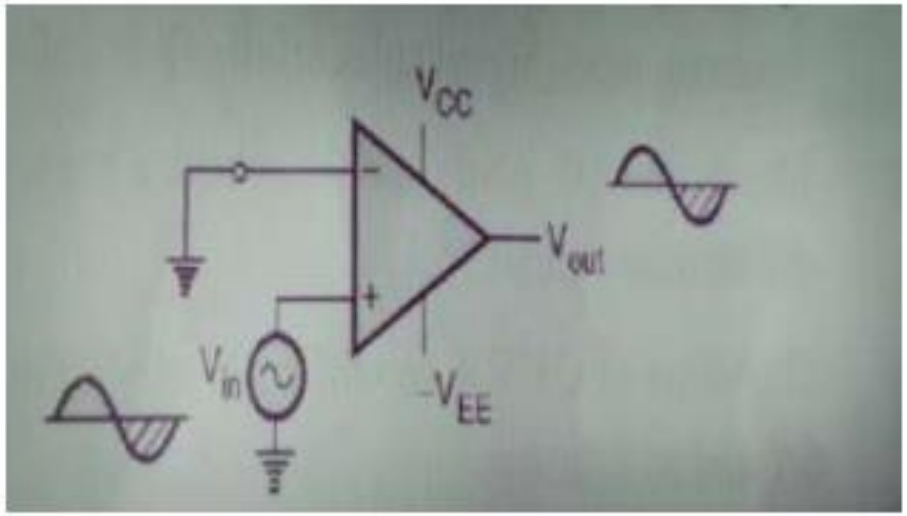
d) Output Stage

# OP Amp Input Modes

## ❑Single ended mode

If the input signal is applied to only one of the inputs and the other input terminal is connected to ground it is said to be operating in single ended mode.

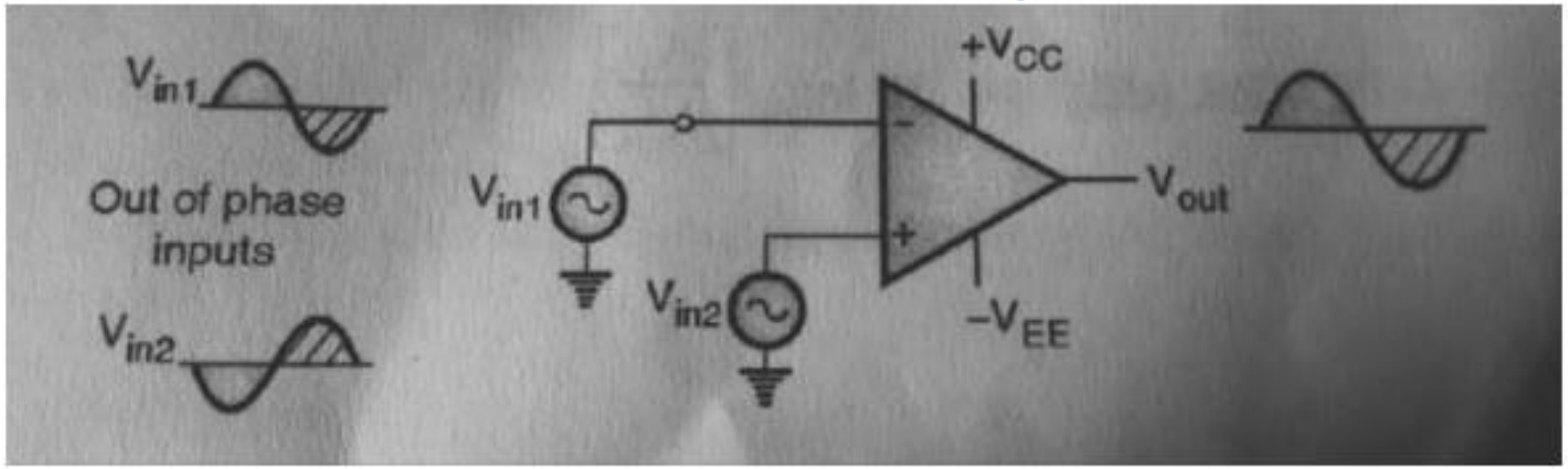


# OP Amp Input Modes

- **Differential mode/double ended**

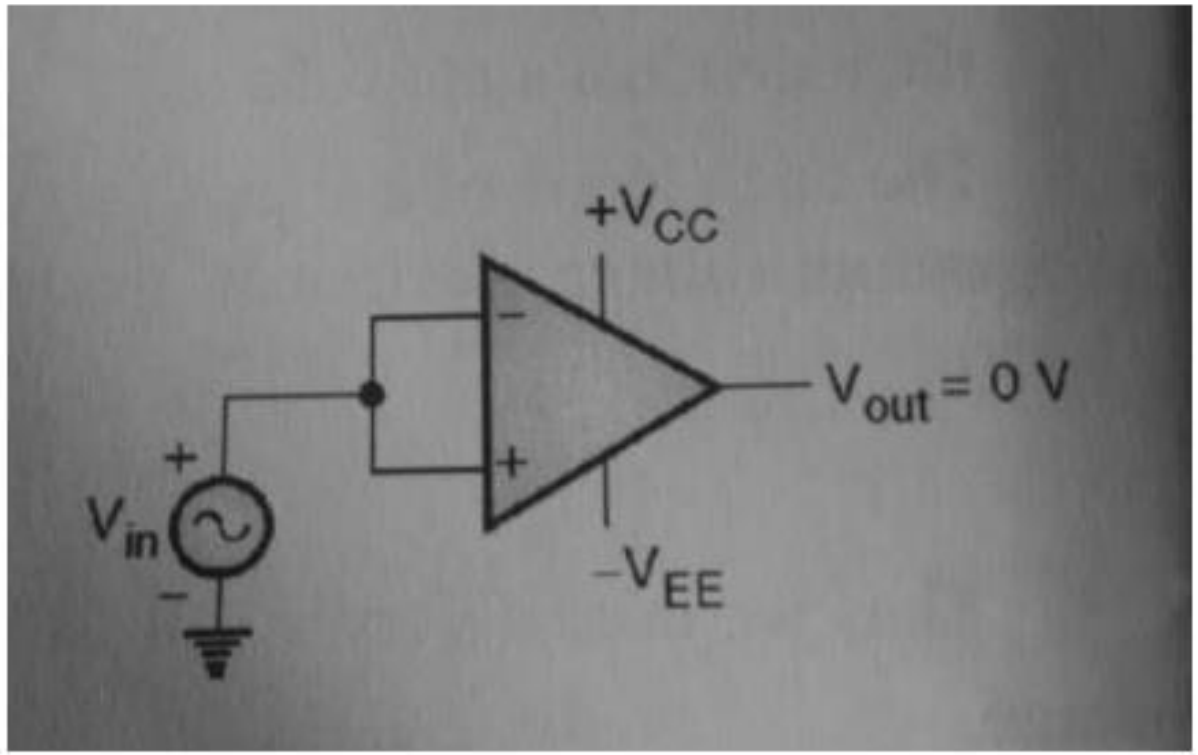
In differential mode ,two opposite polarity signal are applied to the two inputs of op amp. The difference between the input signal is amplified appears at the output.



# OP Amp Input Modes

- **Common mode**
  In the common mode of operation, the same input signal is applied to both the input terminals. Ideally a zero voltage should be produced by the op amp.

Idealy gain ($A_{CM}$) =.....



# QUICK QUIZ (POLL)

**The common-mode gain is …….**

a) very high
b) very low
c) always unity
d) unpredictable

# QUICK QUIZ (POLL)

**The differential-mode gain is …….**

a) very high
b) very low
c) always unity
d) unpredictable

# Ideal Characteristics of an OP Amp

- Input Impedance Zin is infinite
- Output Impedance Zout is zero
- Amplification (Gain) Vout / Vin = ∞
- Common Mode gain is zero.
- Infinite bandwidth
- $V_{out} = 0\ V$, when Voltage inputs = 0 (NO offset)
- Infinite CMRR
- Infinite Slew Rate

# Explanation

# Explanation

# Ideal Characteristics of an OP Amp

## ❑CMRR (Common Mode Rejection Ratio)

Generally, the op amp as two input terminals which are positive and negative terminals and the two inputs are applied at the same point. This will give the opposite polarity signals at the output. Hence the positive and the negative voltage of the terminals will cancel out and it will give the resultant output voltage. The ideal op amp will have the infinite CMRR and with the finite differential gain and zero common mode gain.

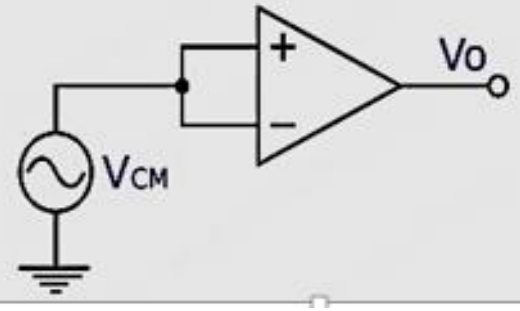
CMRR=Ad/Acm

***CMRR*** *= |differential gain/common mode gain|*

*= |Ad/Ac|*

Unit of CMRR is dB

***CMRR*** *= 20log|Ad/Ac|*



# Ideal Characteristics of an OP Amp

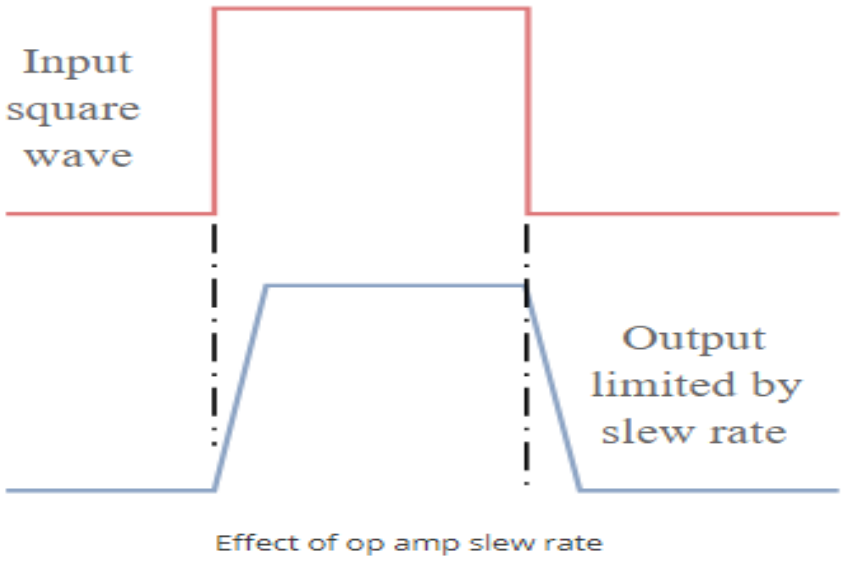
## ❑Slew Rate

The slew rate of an op amp is the rate of change in the output voltage caused by a step change on the input.

- ❑ op-amp's output cannot respond instantaneously to a change in input. Thus, we have an inevitable delay from input change to output change.
- ❑ It is measured as a voltage change in a given time - typically V/µs or V/ms or V/ns.
- ❑ The slew rate should be as high as possible to ensure the maximum undistorted output voltage swing.

$$\text{Slew rate} = 2\pi f V$$

**Slew rate required should be high or low ?**

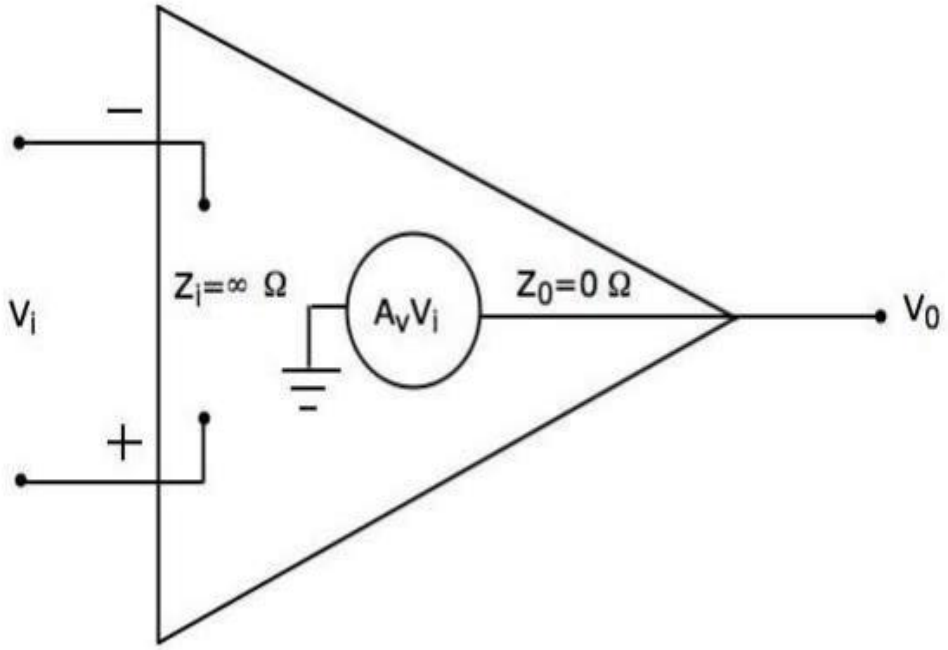


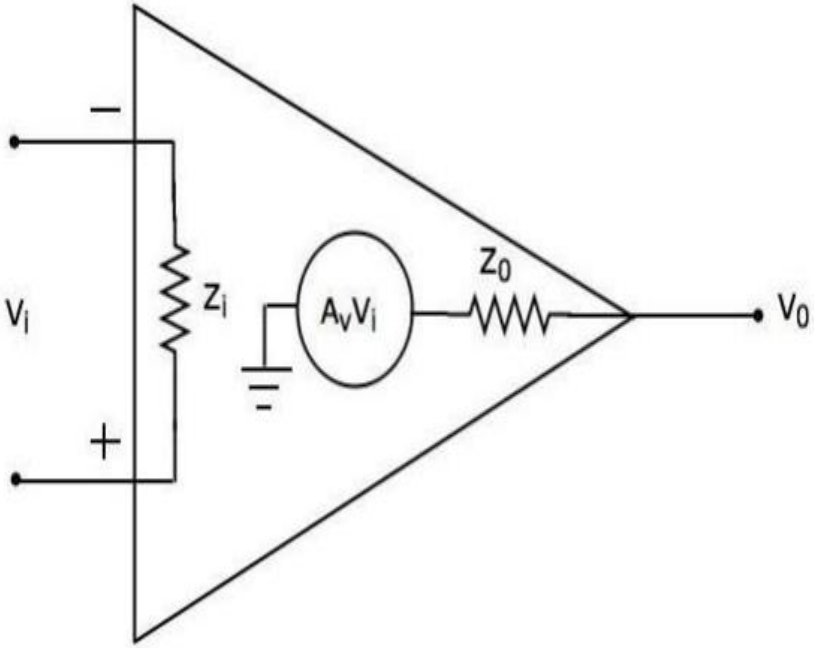

Effect of op amp slew rate

# Typical Values for an Op Amp

| | Ideal Op-Amp | Typical Op-Amp |
|---|---|---|
| Input Resistance | infinity | $10^6\,\Omega$ (bipolar)<br>$10^9\,\Omega$ - $10^{12}\,\Omega$ (FET) |
| Input Current | 0 | $10^{-12}$ – $10^{-8}$ A |
| Output Resistance | 0 | 100 – 1000 $\Omega$ |
| Operational Gain | infinity | $10^5$ - $10^9$ |
| Common Mode Gain | 0 | $10^{-5}$ |
| Bandwidth | infinity | Attenuates and phases at high frequencies (depends on slew rate) |
| Temperature | independent | Bandwidth and gain |

# Ideal and practical Op-amp –**Equivalent circuit**



# QUICK QUIZ (POLL)

**An ideal op-amp requires infinite bandwidth because**

a) Signals can be amplified without attenuation

b) Output common-mode noise voltage is zero

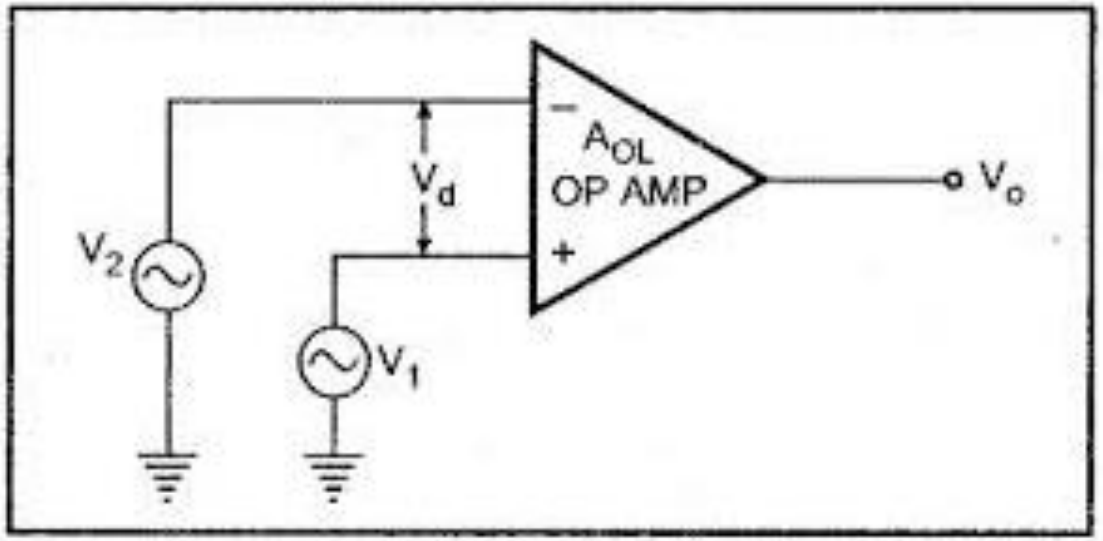
c) Output voltage occurs simultaneously with input voltage changes

d) Output can drive infinite number of device

# Configurations Of Op-amp

## 1. Open Loop Configuration

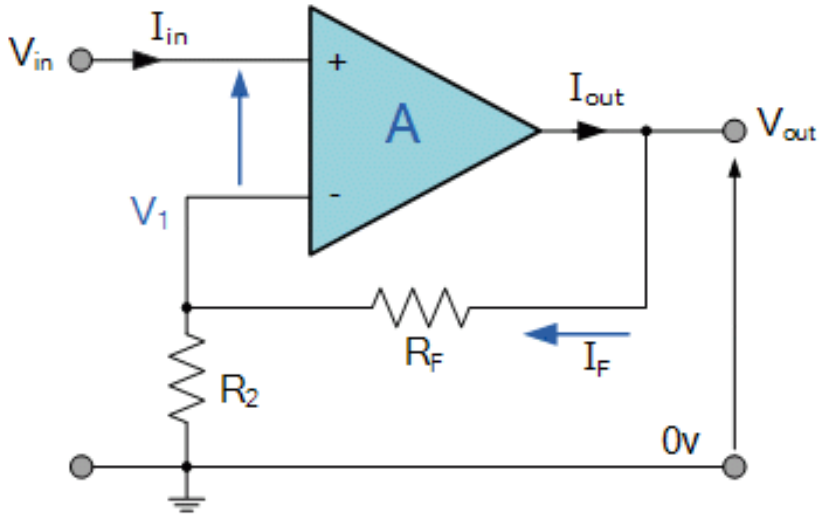
- In open loop configuration , there is no feedback from output to input.
- The differential signal present between the inputs will be amplified by its open loop gain.
- Therefore even for very small magnitude of differential voltage output will reach positive or negative saturation.

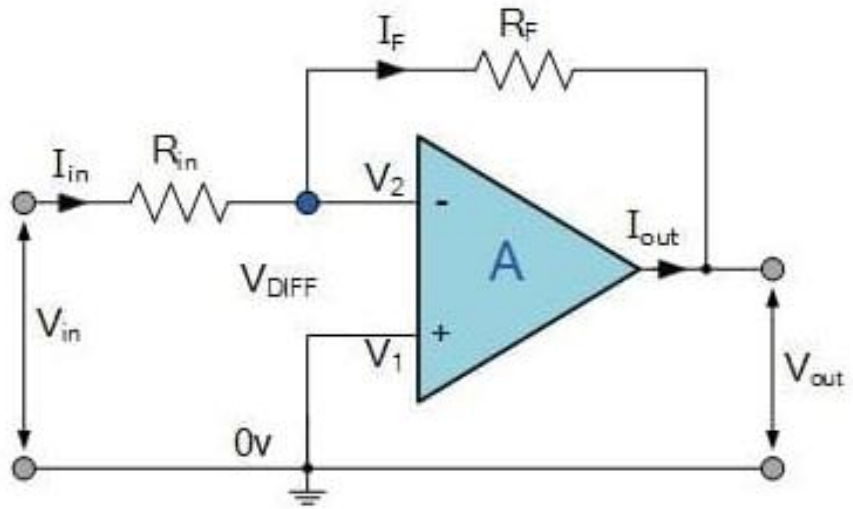


# Configurations Of Op-amp

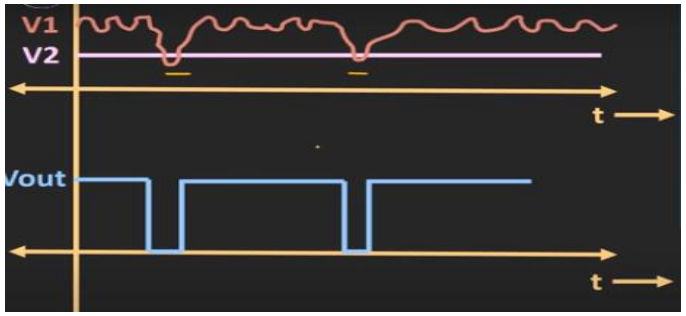
## 2. Closed Loop Configuration

- In close loop configuration , a feedback is introduced i.e. a part of output is fed back to the input.
- The feedback can be of the following two types:
  1. Positive feedback/regenerative feedback
  2. Negative feedback/degenerative feedback



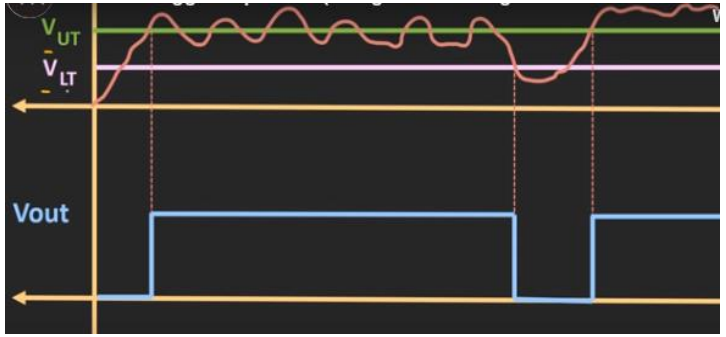
# Configurations Of Op-amp




## Closed Loop Configuration

1. Positive feedback/regenerative feedback

- With positive feedback the output voltage is somehow routed back to the noninverting (+) input.
- It is used in application such as oscillators and schmitt trigger or regenerative comparators.




2. Negative feedback/regenerative feedback

- If we connect the output of an op-amp to its inverting input and apply a voltage signal to the noninverting input, we find that the output voltage of the op-amp closely follows that input voltage
- In application of op amp as an amplifier, the negative feedback is used.

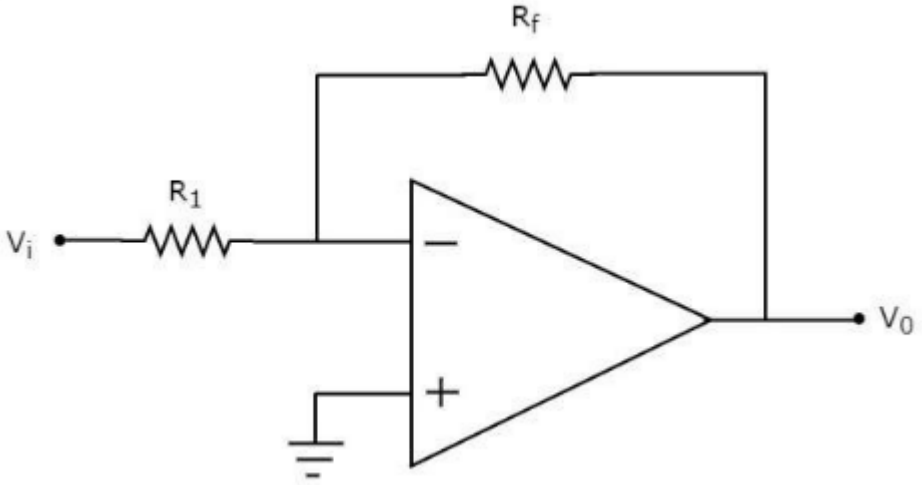
# QUICK QUIZ (POLL)

**For an Op-amp with negative feedback, the output is …….**

a) equal to the input
b) increased
c) fed back to the inverting input
d) fed back to the noninverting input

# Inverting & Non-Inverting Configuration in an OP Amp

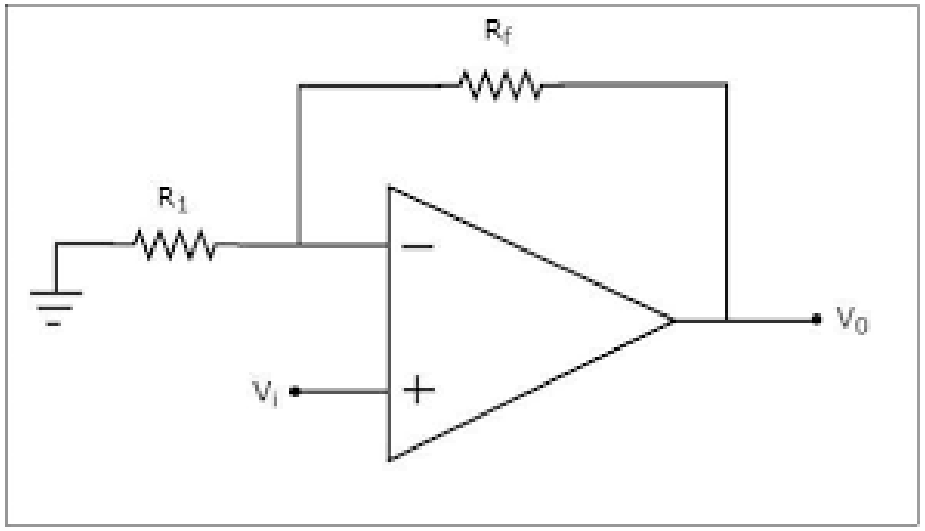
## Inverting Configuration




In this configuration, the input voltage signal, ( $V_{IN}$ ) is applied directly to the inverting ( - ) input terminal which means that the output gain of the amplifier becomes “180 degree” out of phase. wrt input.

https://www.youtube.com/watch?v=_o4ScgRZtNI

## Non-Inverting Configuration




In this configuration, the input voltage signal, ( $V_{IN}$ ) is applied directly to the non-inverting ( + ) input terminal which means that the output gain of the amplifier becomes “in phase” with the input.