INTRODUCTION TO OP-AMP

UNIT-2b

BY

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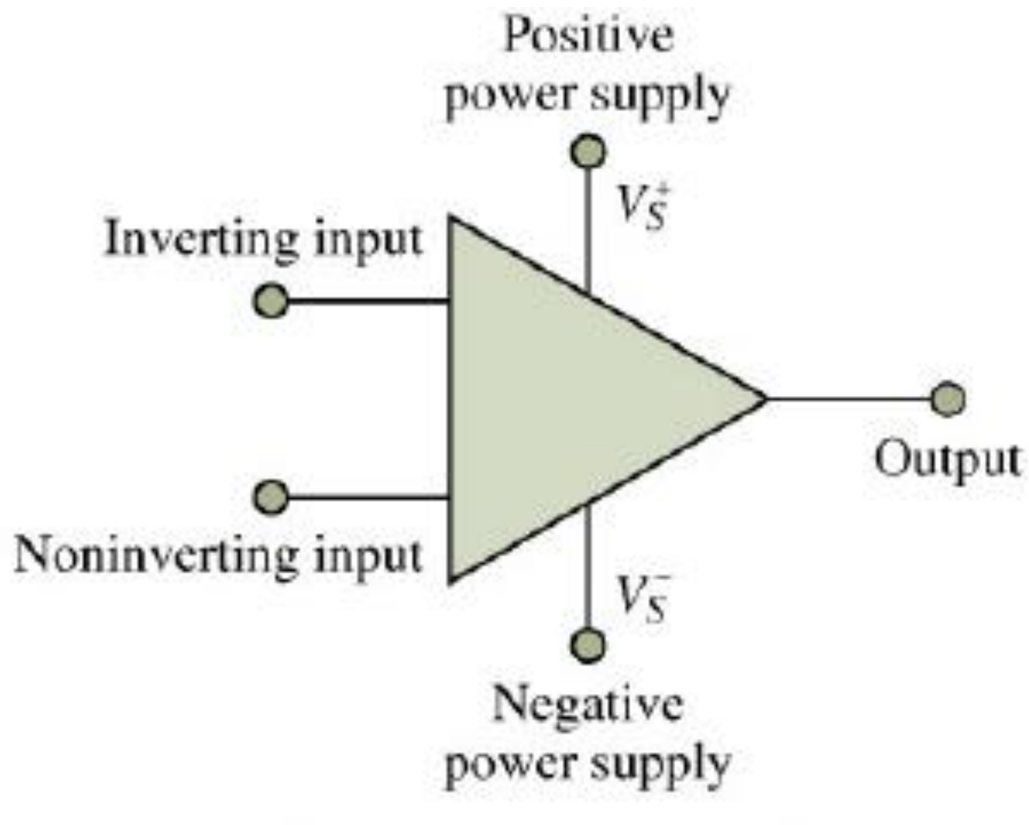
DEPT OF ECE

Operational Amplifier
Op-Amp

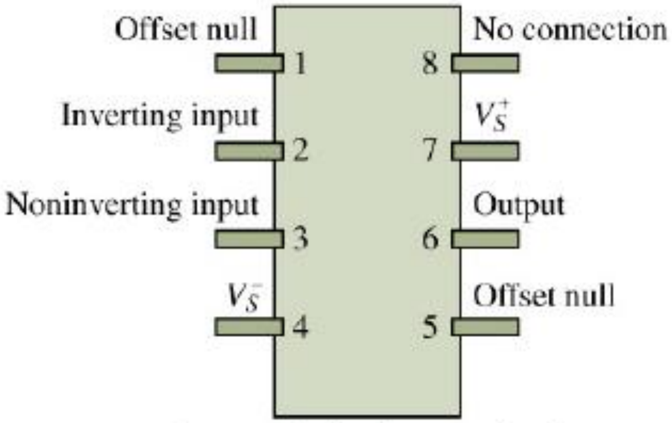
It performs mathematical operations such as:

Addition
Subtraction
Multiplication
Differentiator
Integrator

Operational Amplifier



Simplified circuit symbol



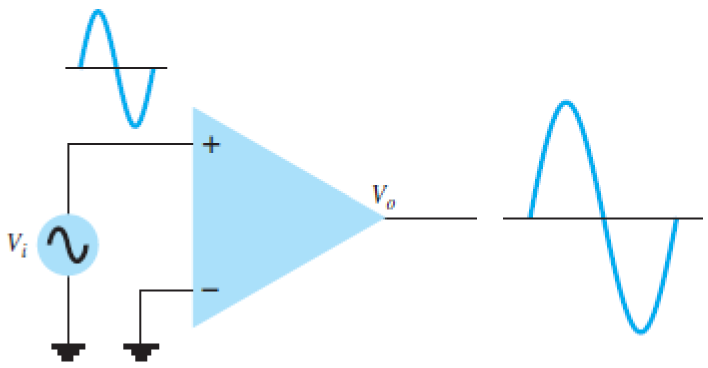
Integrated-circuit operational amplifier (IC op-amp)

•An op amp is a high voltage gain, DC amplifier with high input impedance, low output impedance, and differential inputs.

• Positive input at the <u>non-inverting input</u> produces positive output

• Positive input at the <u>inverting input</u> produces negative output.

Non-inverting Amplifier

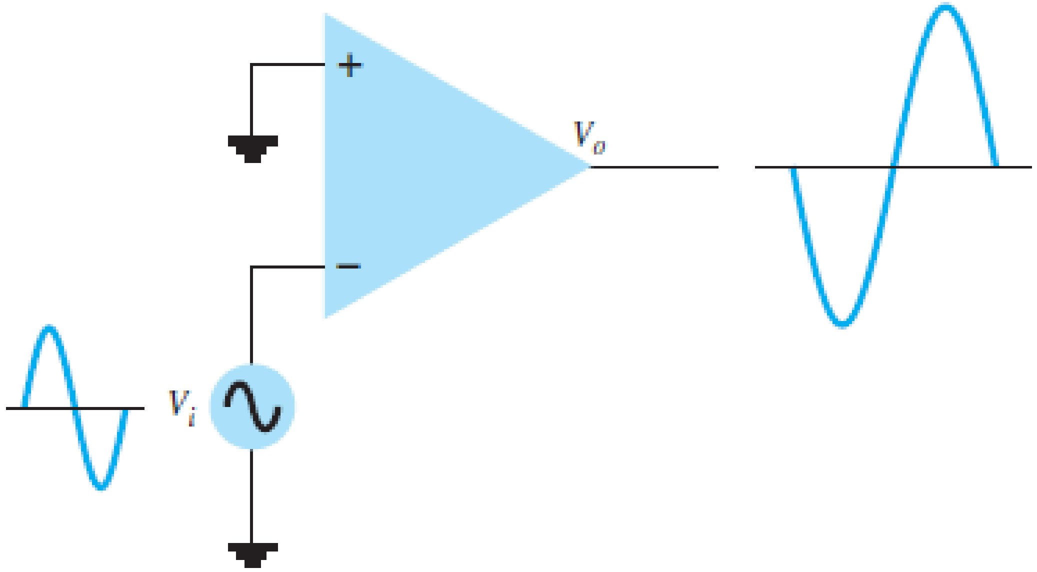


A is the open loop gain of op-amp

Output voltage (Vo)= A (Vi)

The phase of the output is similar to that of the input signal

Inverting Amplifier

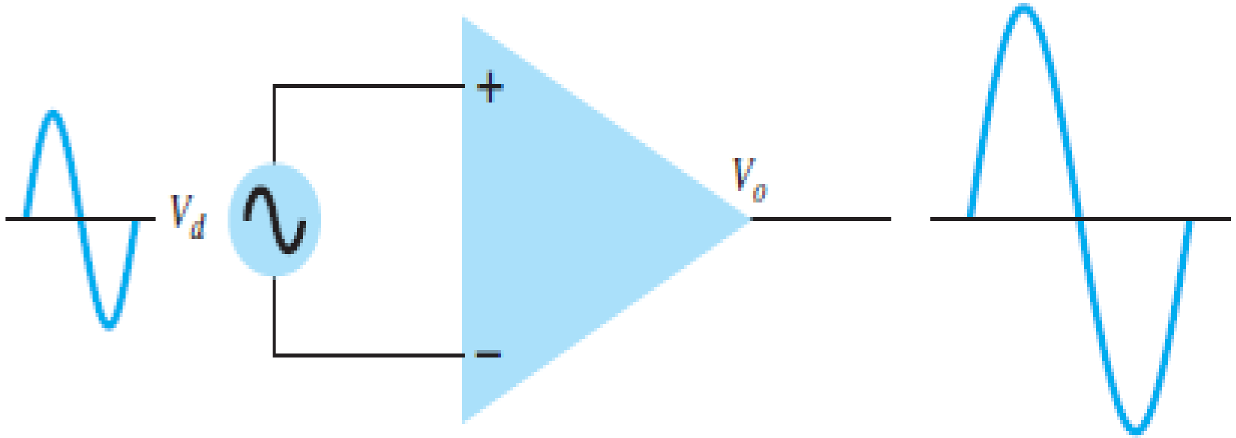


A is the open loop gain of op-amp

Output voltage (Vo)= - A (Vi)

The phase of the output is 180 degree out of phase with respect to that of the input signal

Operational amplifier



Vo= A (Vd)

Concept of Virtual Ground

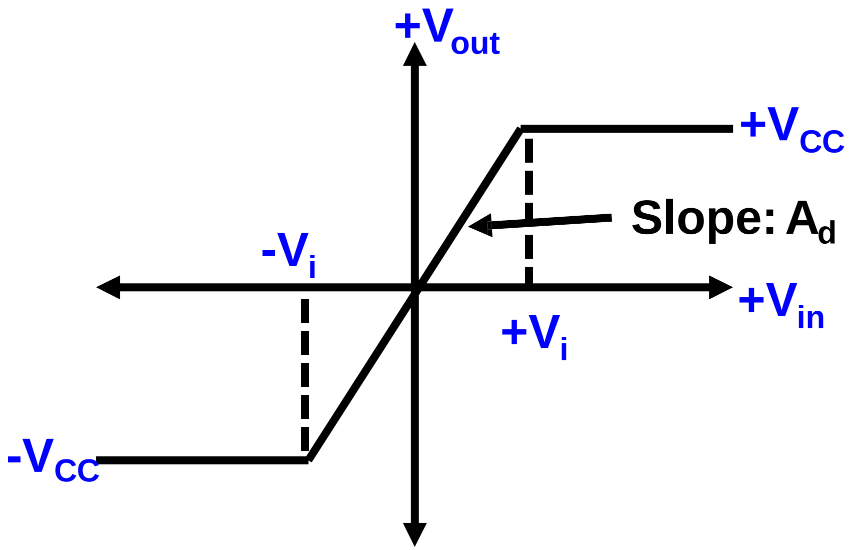
➢An Op-Amp has a very high gain typically order of 10^5.

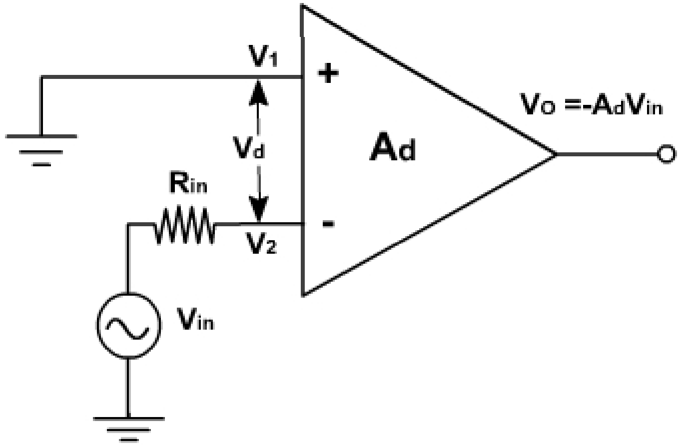
➢If power supply voltage V_{cc} =15V Then maximum input voltage which can be applied

$$V_d = V_{cc} / A_d = 15/\ 10^5 = 150\mu V$$

i.e. Op-Amp can work as a linear amplifier (from $+V_i$ to $-V_i$) if input voltage is less than 150μV. Above that Op-Amp saturates.

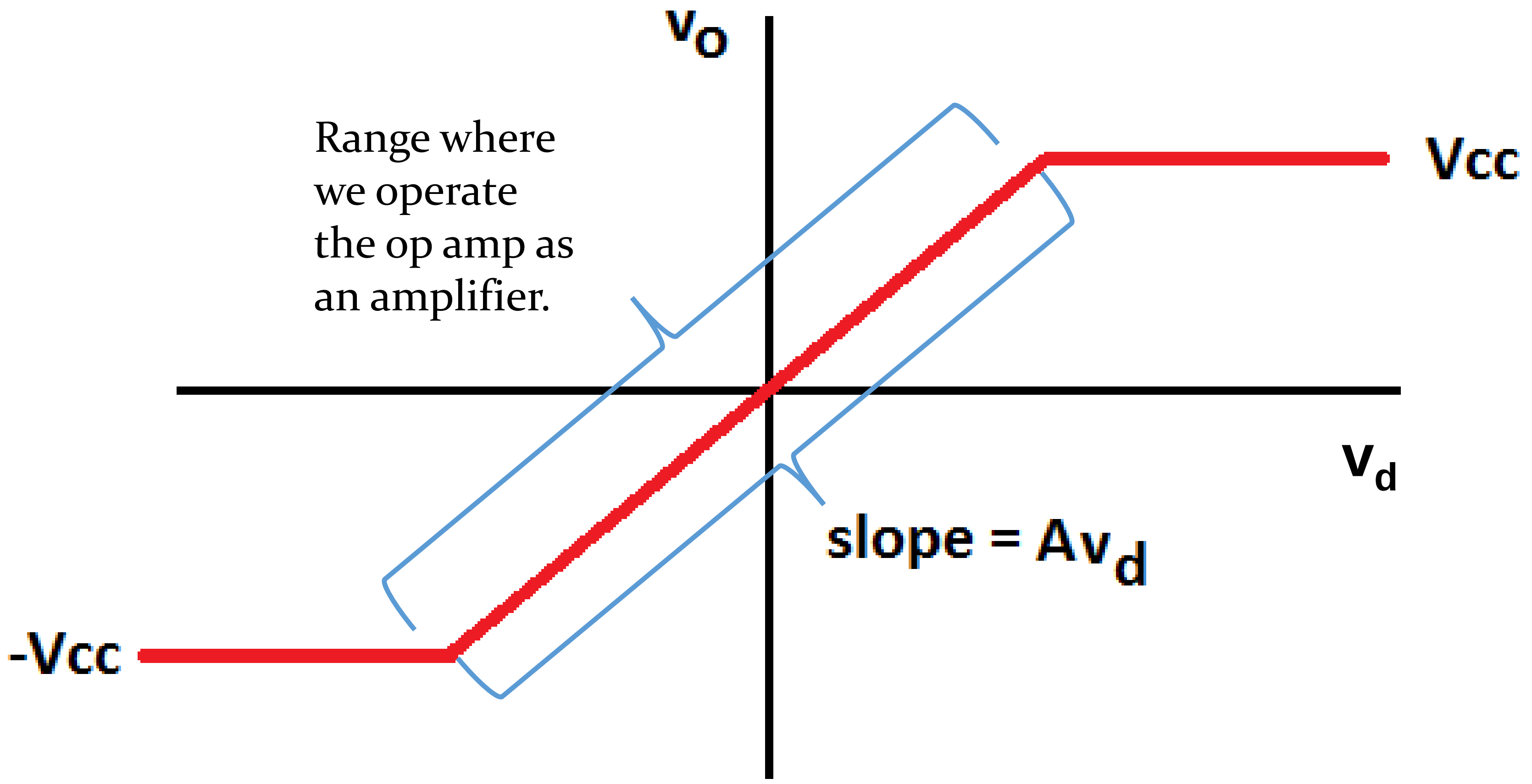
➢if V_1 is grounded then V_2 can not be more than 150 μV which is very very small and close to ground.





➢Therefore V_2 can also be considered at ground if V_1 is at ground. Physically V_2 is not connected to the ground yet we considered V_2 at ground that is called virtual ground

Voltage Transfer Characteristic



Many Applications, e.g.,

- Amplifiers
- Adders and subtractors
- Integrators and differentiators
- Clock generators
- Active Filters
- Digital-to-analog converters
- Analog to digital converter
- Oscillators

Applications

- Audio amplifiers
  - Speakers and microphone circuits in cell phones, computers, mpg players, boom boxes, etc.
- Instrumentation amplifiers
  - Biomedical systems including heart monitors and oxygen sensors.
- Power amplifiers
- Analog computers
  - Combination of integrators, differentiators, summing amplifiers, and multipliers

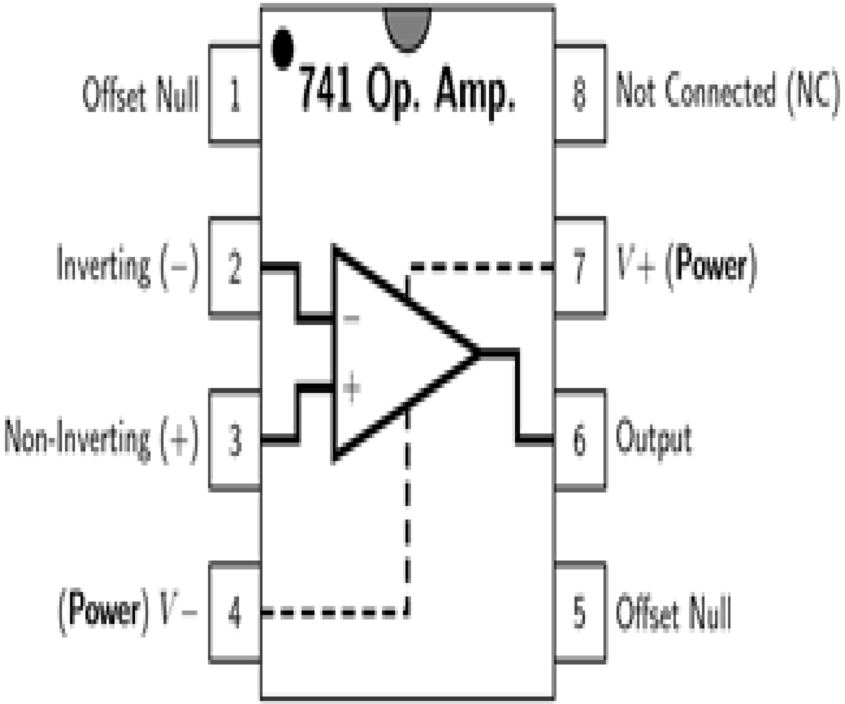
Applications

Originally developed for use in analog computers:

An ideal Op-Amp has the following characteristics.

1. Infinite voltage gain (ie AV =∞)
2. Infinite input impedance (Ri = ∞)
3. Zero output impedance(Ro =0)
4. Infinite Bandwidth (B.W. = ∞)
5. Infinite Common mode rejection ratio (ie CMRR =∞)
6. Infinite slew rate (ie S=∞)
7. Zero power supply rejection ratio (PSRR =0)ie output voltage is zero when power supply VCC =0
8. Zero offset voltage(ie when the input voltages are zero, the output voltage will also be zero)
9. Perfect balance (ie the output voltage is zero when the input voltages at the two input terminals are equal)
10. The characteristics are temperature independent.

PIN DIAGRAM OF 741 OP-AMP



Definitions:

•**Slew rate(S):** It is defined as “ The rate of change of output voltage per unit time”

$$SR = \frac{dV_o}{dt} \quad volts/\mu\ \text{sec}$$

$$SR = f_{max}\, 2\, \Pi\, V_m$$

- **Differential and Common mode Gain:**
- $V_0 = A_d$ (v1 – v2)
- where A_d represents differential gain.
- In practical differential amplifier, the output depends not only on difference signal but also upon the common mode signal (average).
- $v_d = (v_1 – v_d)$
- and $v_C = ½ (v_1 + v_2)$

- **Common Mode Rejection Ratio(CMRR):** It is defined as " The ratio of differential voltage gain to common-mode voltage gain".
- **CMRR = 20log|Ad/Ac| dB**
- **Open Loop Voltage Gain (AV):** It is the ratio of output voltage to input voltage in the absence of feed back.
- Its typical value is AV = 2x105
- **Input Impedance (Zi)**:It is defined as " The impedance seen by the input(source) applied to one input terminal when the other input terminal is connected to ground.
- Zi ≈ 2MΩ

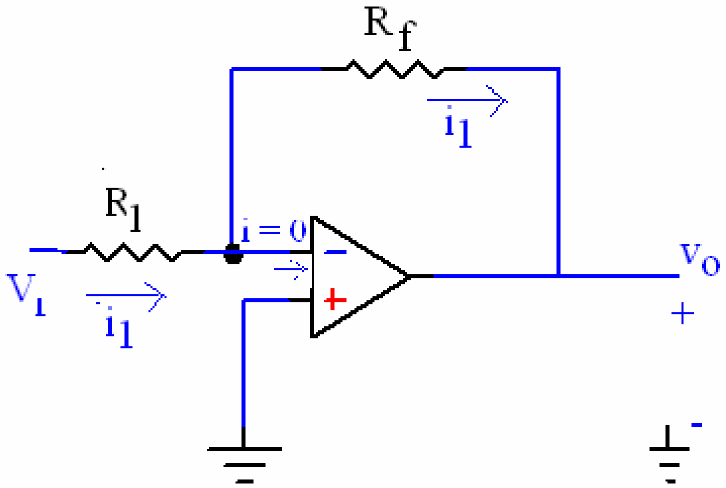
- **Output Impedance (ZO)**: It is defined as " The impedance given by the output (load) for a particular applied input".
- $Zo \approx 75\Omega$
- **Power Supply Rejection Ratio(PSRR)**
- The power supply rejection ratio is defined as the change in the output voltage per unit changes in the DC supply voltage.
- $PSRR = \Delta Vo / \Delta Vcc$

Need for negative feedback in op-amp

- ➢Any input signal slightly greater than zero drive the output to saturation level because of very high gain.

- ➢Thus when operated in open-loop, the output of the OPAMP is either negative or positive saturation or switches between positive and negative saturation levels (comparator). Therefore open loop op-amp is not used in linear applications.

- ➢With negative feedback, the voltage gain (A_{cl}) can be reduced and controlled so that op-amp can function as a linear amplifier.

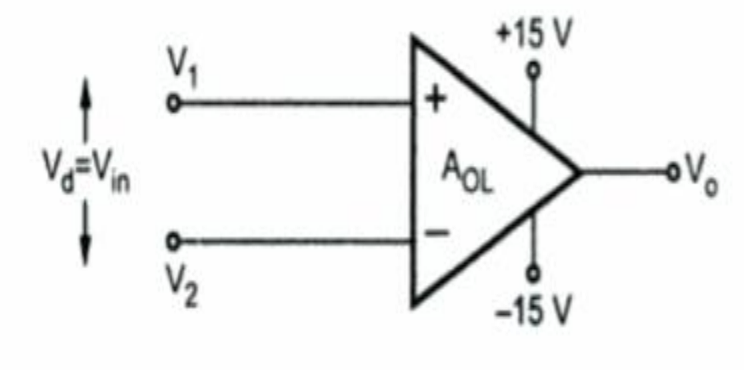


- ➢In addition to provide a control and stable voltage gain, negative feedback provides control of input & output impedance and amplifier bandwidth.

Typical Specifications of general purpose Op-amp

Parameter	Ideal	Typical or Practical Value
Voltage Gain [A_v]	∞	$2*10^5$
Output Impedance	0	75Ω
Input Impedance	∞	2MΩ
Input Offset	0	2mV
CMRR	∞	90dB
Slew Rate	∞	0.5V/µs
Bandwidth	∞	1MHz
PSRR	0	30µV/V
Input Bias Current	0	80nA

SATURABLE PROPERTY OF AN OP-AMP

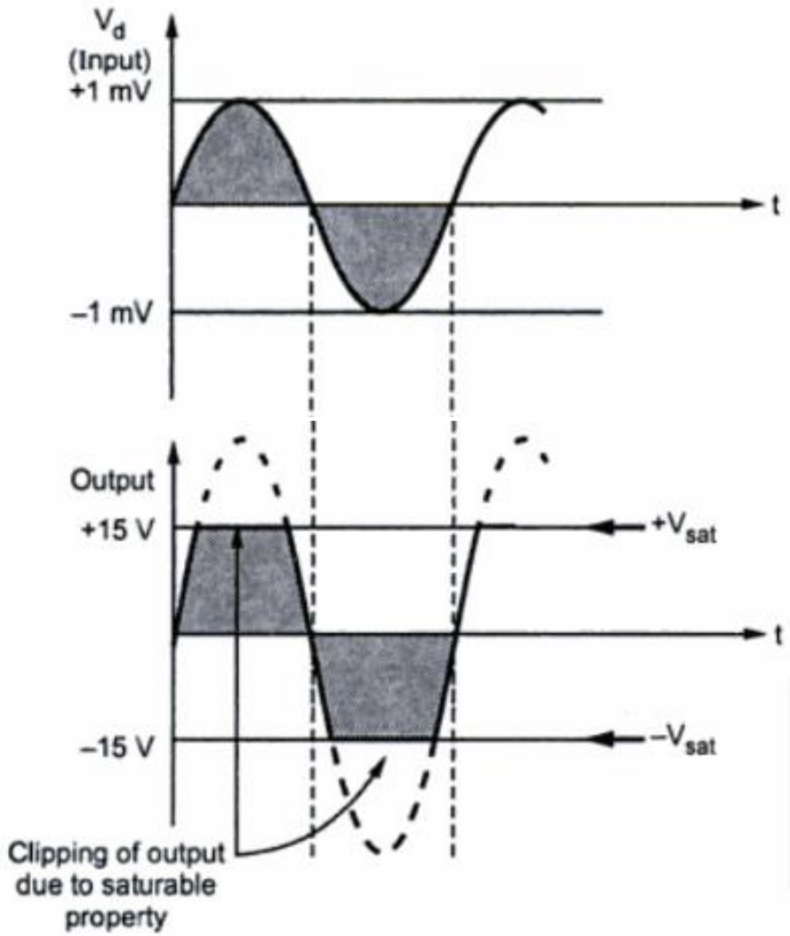


- Saturating property of an op-amp in which the output voltage swinging between saturation voltages i.e. Vcc and –Vee.
- If output tries to rise more than +Vcc or less than –Vee then it gets clipped and gets saturated at the levels almost equal to +Vcc and –Vee.
- Note: The saturation voltage levels are about 90% of the supply voltage levels. Thus for an op-amp of supply +12 V and -12V, the saturation voltage levels are 90% of 12V i.e 10.8 V.

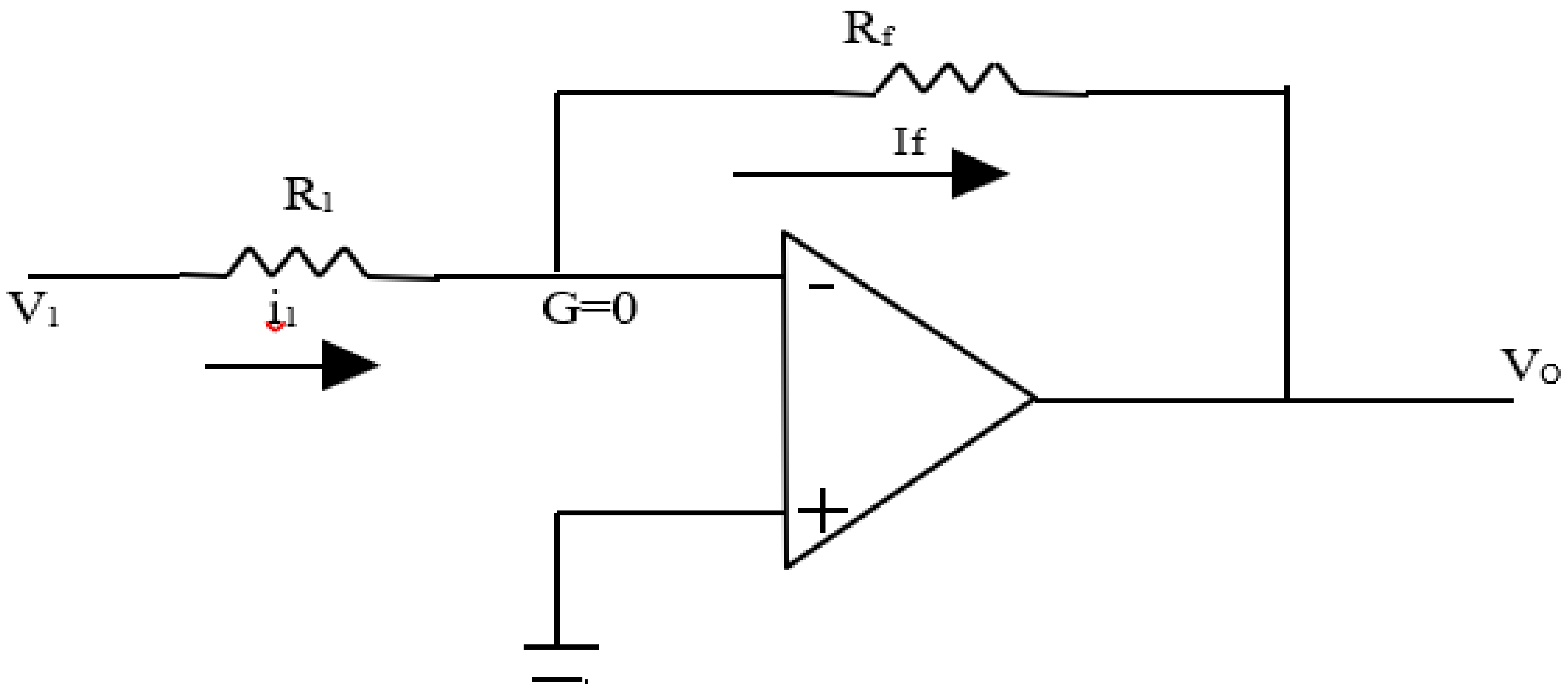
Now $V_o = V_d \times A_{OL}$

$$\therefore \quad V_d = \frac{V_o}{A_{OL}}$$

$$V_d = \frac{\pm V_{sat}}{A_{OL}} = \frac{\pm 15}{10^5} = \pm 150\ \mu V$$



Inverting Amplifier



- Input Signal Vi is applied to the inverting input terminal through resistor R1.
- Non inverting terminal is grounded.
- The feedback from output is given to the inverting terminal through Rf.
- Vd = V2 –V1 = Vo = 0
- From the concept of Virtual ground,
- V_1=V2=0
- Due to high input impedance of Op-amp, current flowing into inverting input terminal is zero. Thus same current flows through R1 and Rf.
- $I_1 = I_F$---(1)

By KCL we have

$$I_1 = \frac{V_i - V_1}{R_1} = \frac{V_i}{R_1} \text{------------------}(2)$$

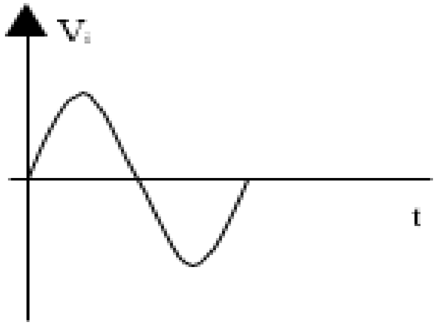
$$I_f = \frac{V_1 - V_0}{R_f} = \frac{-V_0}{R_f} \text{------------------}(3)$$

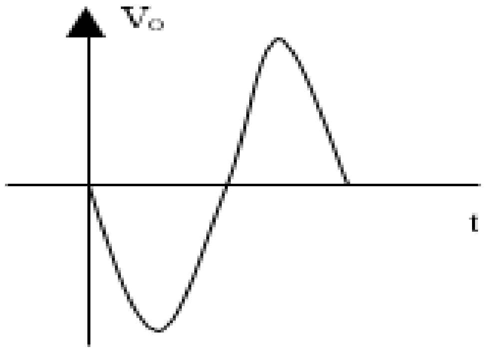
From (1),(2) and (3),

$$\frac{V_i}{R_1} = \frac{-V_0}{R_f}$$

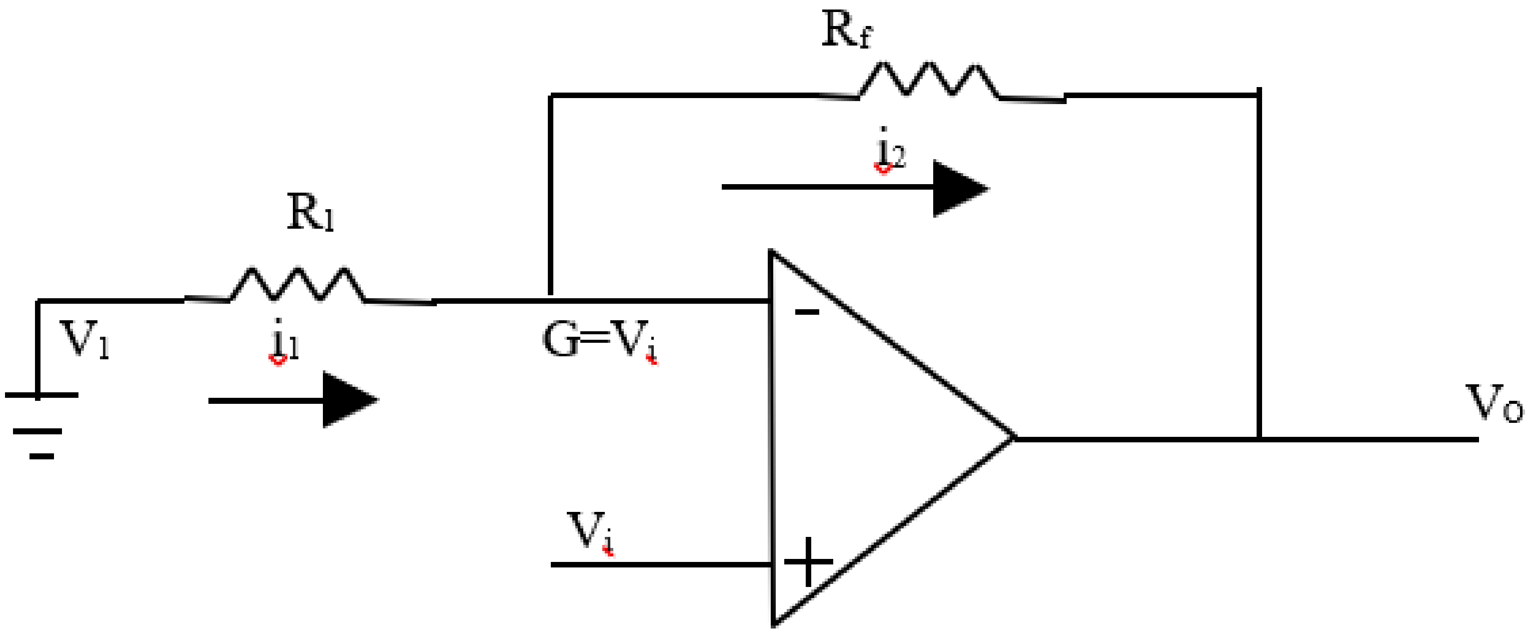
$$A_v = \frac{V_o}{V_i} = \frac{-R_f}{R_1} \text{ ------------Gain for Inverting Op-amp}$$

Where $\frac{R_f}{R_1}$ the gain of the amplifier and negative sign indicates that the output is inverted with respect to the input.





Non-Inverting Amplifier



- Input Signal Vi is applied to the non - inverting input terminal.
- Inverting terminal is grounded through resistor R1.
- The feedback from output is given to the inverting terminal through Rf.
- V_2=V_i------------------------------(1)
- Due to virtual ground,
- V_1=V_2------------------------------(2)
- V_i=V_1=V_2
- Due to high input impedance of Op-amp, current flowing into inverting input terminal is zero. Thus same current flows through R1 and Rf.

$$I_1 = I_F \text{--}(3)$$

$$I_1 = \frac{0-V_1}{R_1} = \frac{-V_i}{R_f} \text{------------------}(4)$$

$$I_f = \frac{V_1 - V_0}{R_f} = \frac{V_i - V_0}{R_f} \text{------------------}(5)$$

Using (3),equating (4) and(5),

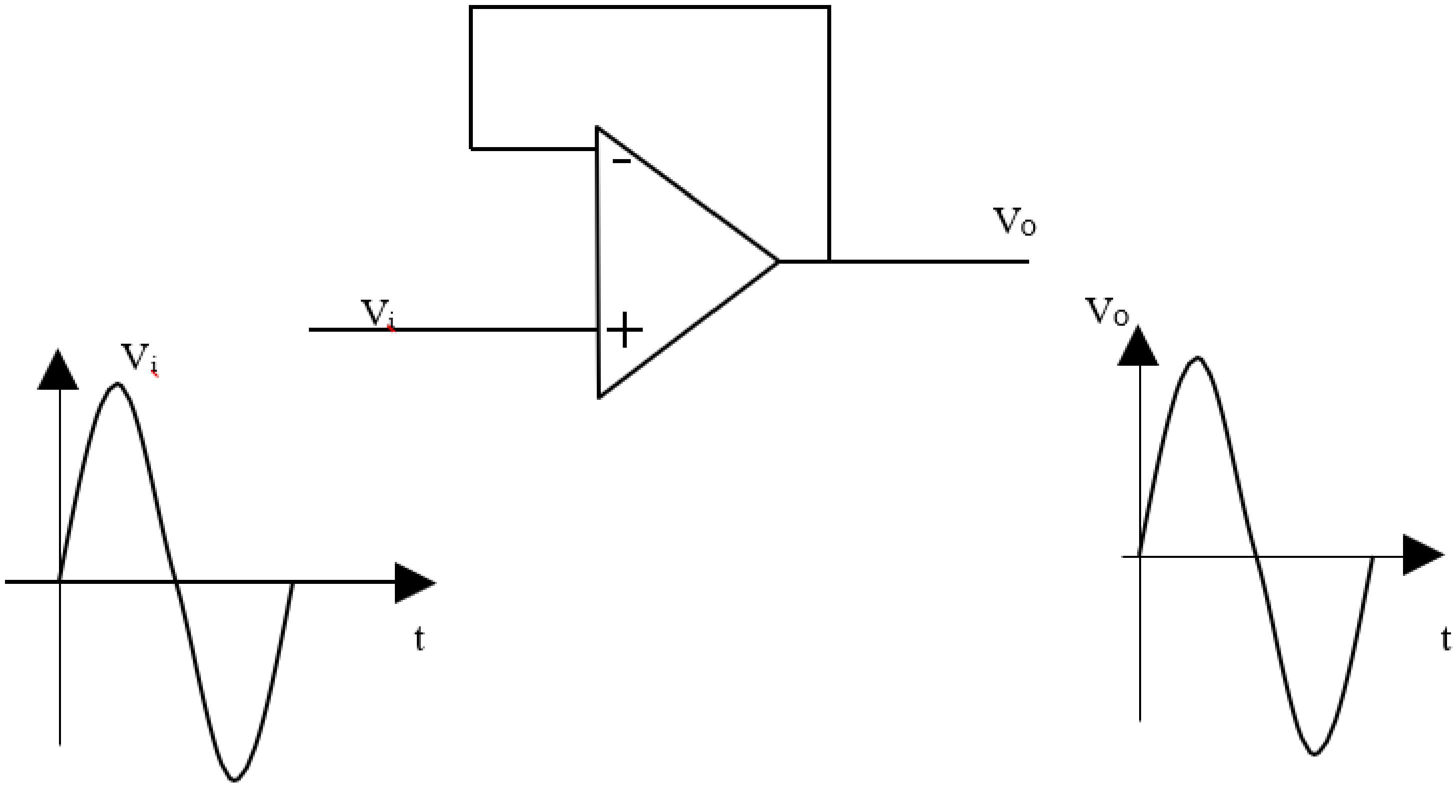
$$\frac{-V_i}{R_1} = \frac{V_i - V_o}{R_f}$$

$$\frac{V_0}{R_f} = V_i\left[\frac{1}{R_1} + \frac{1}{R_f}\right]$$

$$\frac{V_0}{V_i} = R_f\left[\frac{1}{R_1} + \frac{1}{R_f}\right]$$

$\boldsymbol{A_v = \frac{V_0}{V_i} = 1 + \frac{R_f}{R_1}}$ ----------------- Gain for non inverting Op-amp

Voltage Follower



- The voltage follower configuration shown above is obtained by short circuiting “Rf” and open circuiting “R1” connected in the usual non-inverting amplifier.
- Thus all the output is fed back to the inverting input of the op-Amp.
- Consider the equation for the output of non-inverting amplifier
- When Rf = 0 short circuiting R1= ∞ open circuiting
- Input Signal Vi is applied to the non - inverting input terminal.
- V_2=V_i --------------------------------(1)
- Inverting terminal is directly connected to the output..
- V_0=V_1--------------------------------(2)
- From (1) and (2)
- V_0=V_i

$$A_v = \frac{V_0}{V_i} = 1$$

Feedback factor for Voltage Follower

$$A_f = \frac{A}{1 + A\beta}$$

Since β =1

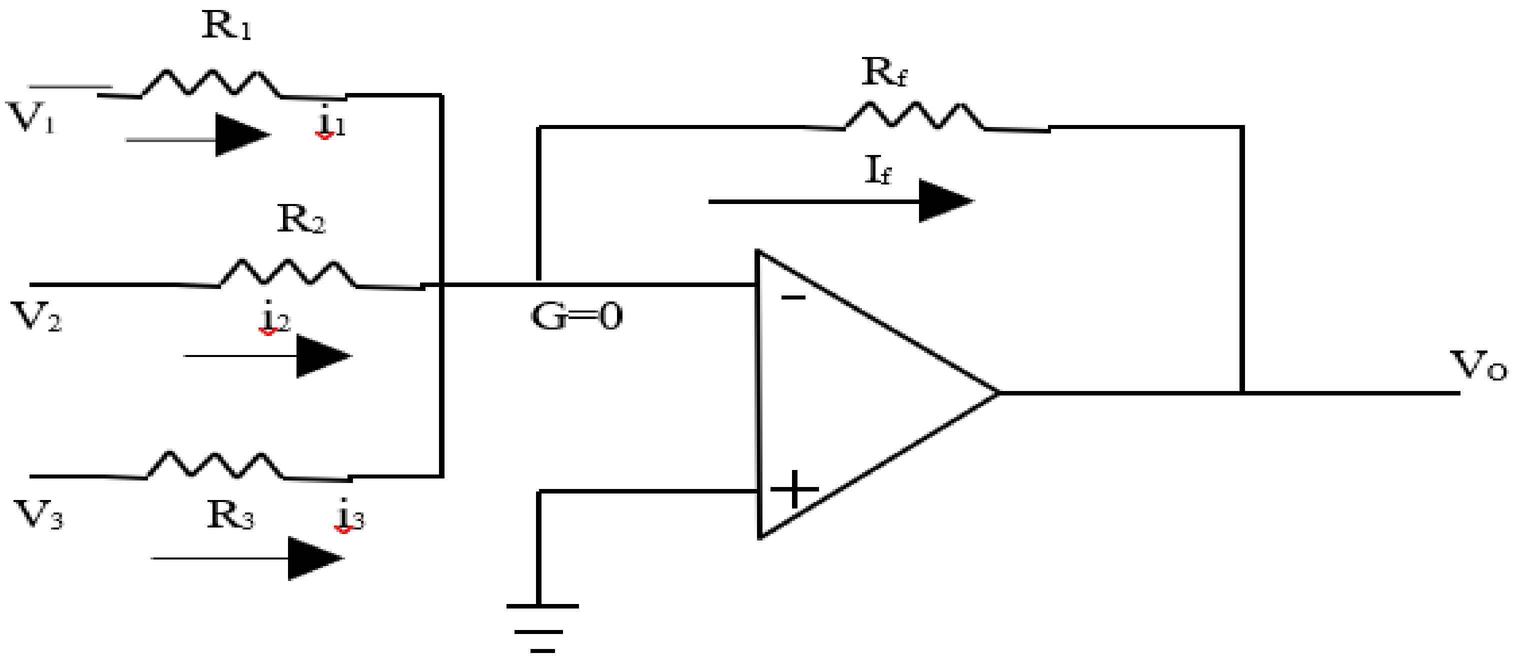
$A_f = \frac{A}{1+A}$-----------Gain for Voltage Follower

Error =[1 - $\frac{A}{1+A}$] x 100%

Therefore the output voltage will be equal and in-phase with the input voltage. Thus voltage follower is nothing but a non-inverting amplifier with a voltage gain of unity.

Summer inverting op-amp

- Inverting adder is one whose output is the inverted sum of the constituent inputs



Since non inverting terminal is grounded,

$V_B = 0$

And

$V_A = V_B = G = 0$ [Virtual Ground]

$$I_1 = \frac{V_1 - V_A}{R_1} = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2 - V_A}{R_2} = \frac{V_2}{R_2}$$

$$I_3 = \frac{V_3 - V_A}{R_3} = \frac{V_3}{R_3}$$

$$I_f = \frac{V_A - V_o}{R_f} = \frac{-V_o}{R_f}$$

Applying KCL at node A

$$I_f = I_1 + I_2 + I_3$$

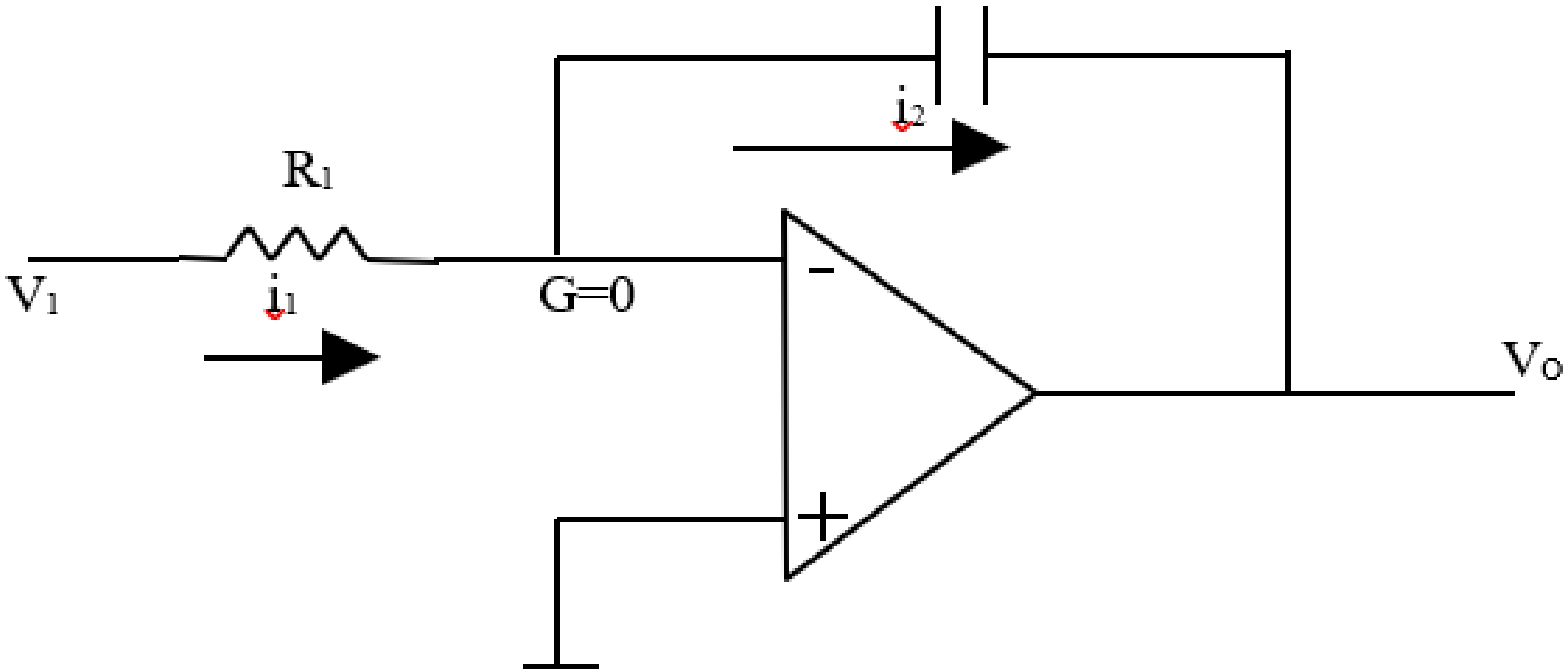
$$\frac{-V_o}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

$$V_o = \left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right]$$

If $R_f = R_1 = R_2 = R_3$

$$V_0 = -[V_1 + V_2 + V_3]$$

Integrator



V_2=V$_1$ = 0 [Virtual Ground]

$$I_1 = I_F$$

$$I_1 = \frac{V_i - V_1}{R} = \frac{V_i}{R}$$

$$I_f = C\frac{d}{dt}(V_1 - V_o) = -C\frac{dV_o}{dt}$$

Since $I_1 = I_F$,

$\frac{V_i}{R} = -C\frac{dV_o}{dt}$

$$\frac{dV_o}{dt} = \frac{-1}{RC}V_i$$

Integrate both the sides to t

$$V_o = \frac{-1}{RC}\int_0^t V_i\,dt + V_o(0)$$

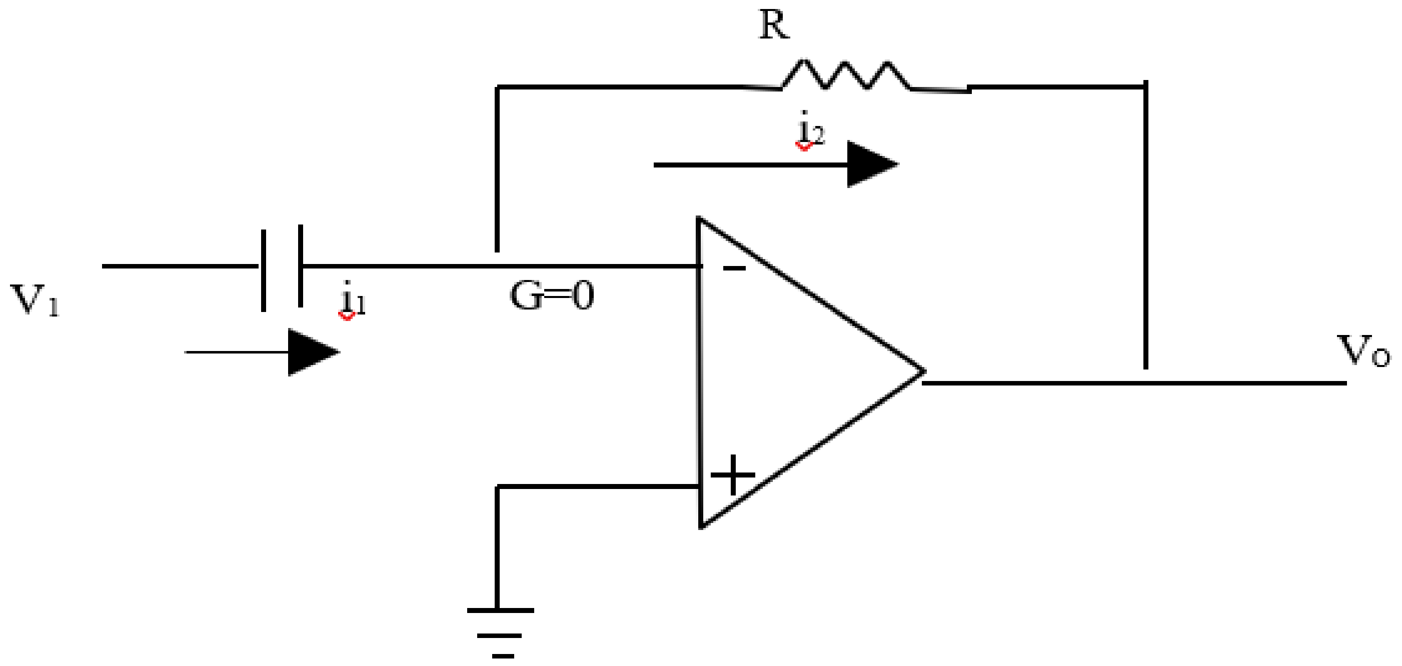
$V_o(0)$ is the initial voltage on capacitor at t=0,which is a constant.

$\boldsymbol{V_o = \frac{-1}{RC}\int_0^t V_i\,dt}$------------Output Voltage for Integrator

- Output is -1/RC times the integral of input. There is phase shift of 180 degree between input and output.

Differentiator

- A differentiator is one whose output is the differentiation of the input



$$V_1 = V_2 = 0 \text{ [Virtual Ground]}$$

$$I_1 = I_F$$

$$I_1 = C\frac{d}{dt}(V_i - V_1) = C\frac{dV_i}{dt}$$

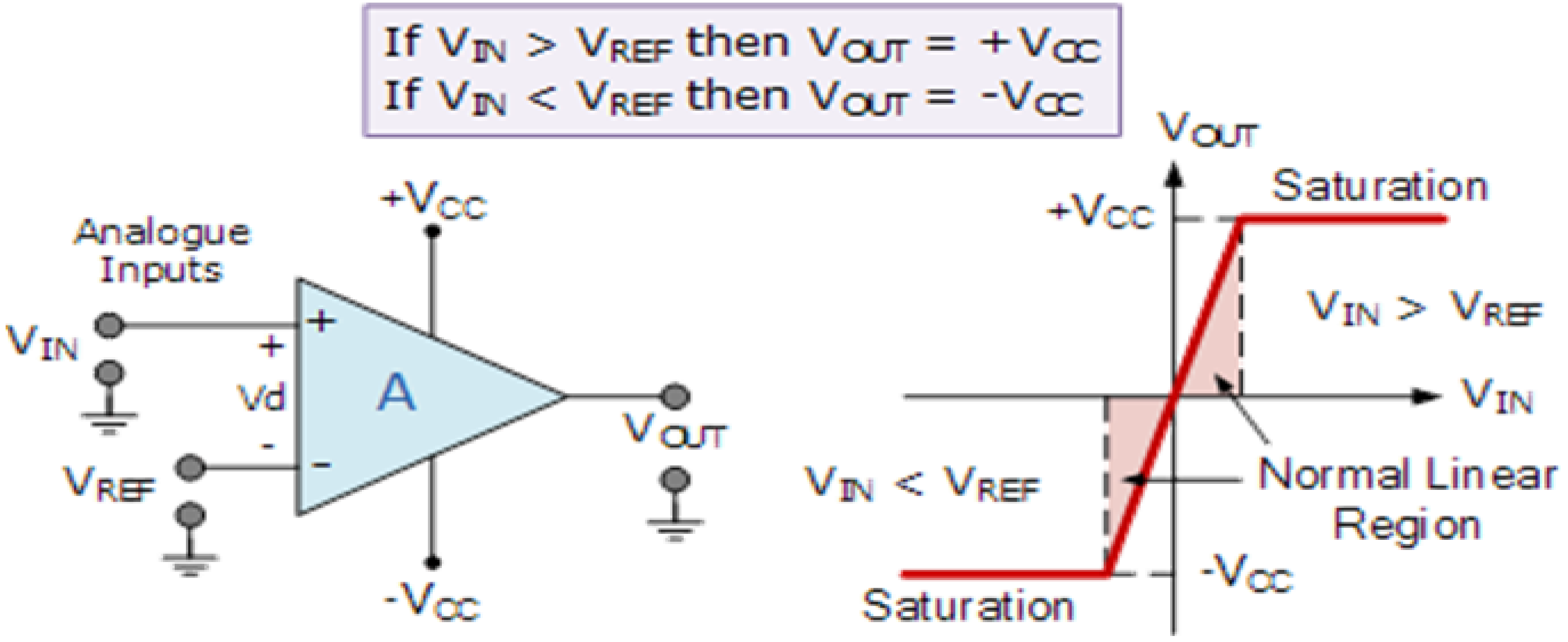
$$I_f = \frac{V_1 - V_o}{R} = \frac{-V_o}{R}$$

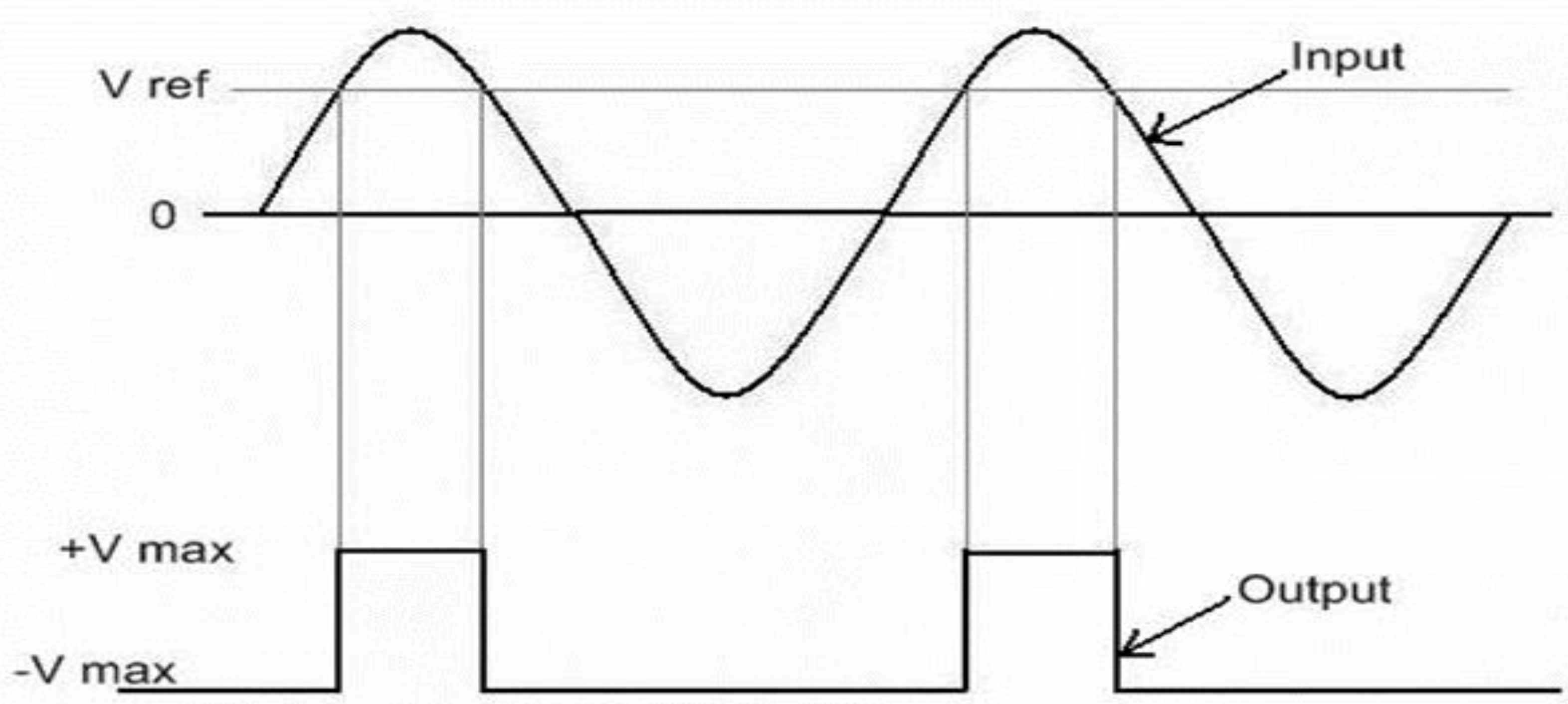
$$C\frac{dV_i}{dt} = \frac{-V_o}{R}$$

$\boldsymbol{V_o = -RC\frac{dV_i}{dt}}$----------Output Voltage of Differentiator.

- Output is -RC times the differential of input. There is phase shift of 180 degree between input and output.
- The main advantage of differentiator is small time constant is required for differentiation.

Op-amp as a Comparator




Input
V ref
0
+V max
Output
-V max