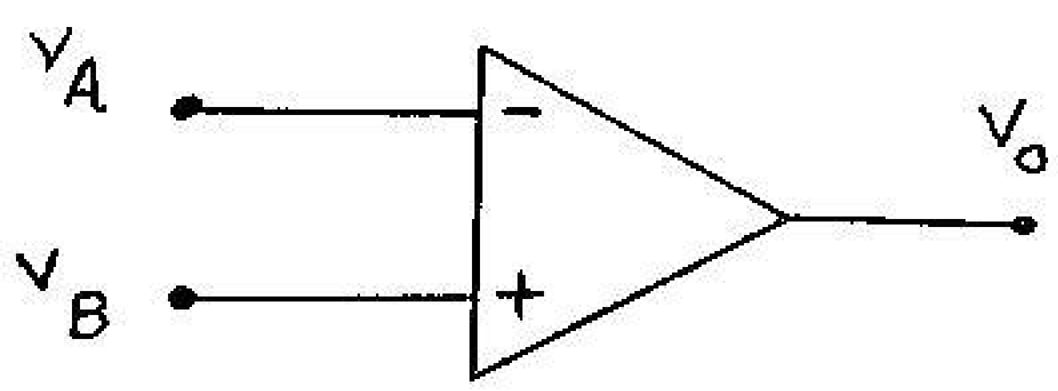
Characteristics of an ideal op-amp

An ideal op-amp exhibits the following characteristics

1. Infinite voltage gain
2. Infinite input impedance
3. Zero output impedance
4. Zero input offset voltage
5. zero input offset current
6. Infinite CMRR
7. Infinite Slew rate
8. Infinite Bandwidth.

Concept of virtual ground



Let V_A and V_B be the voltage at the input terminals. we know that

$$V_o = A_v(V_A - V_B)$$

The A_V is the differential voltage gain and its ideal value is infinity

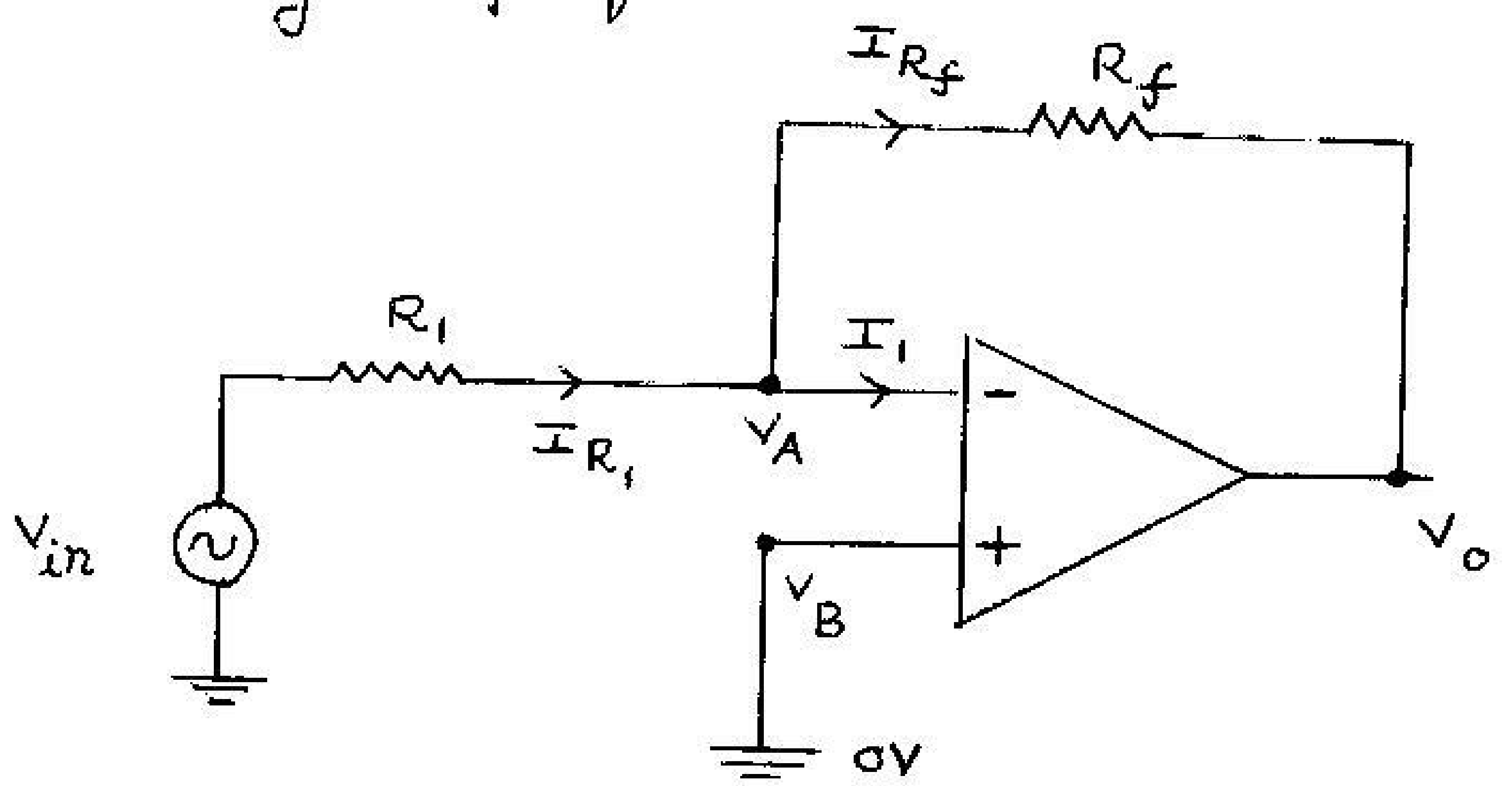
$$A_V = \infty = \frac{V_o}{V_A - V_B}$$

$$\Longrightarrow \quad V_A - V_B = 0$$

This concept is called as virtual ground.

Op-amp as an inverting amplifier

An inverting amplifier is a circuit whose output is amplified and inverted with respect to the input. Figure below shows the circuit diagram of an inverting amplifier.



By the concept of virtual ground, we have

$$V_A - V_B = 0$$

Since V_B is grounded, $V_B = 0V$. Thus we have,

$$V_A = 0V$$

Since the op-amp has infinite input impedance, it does not draw any current. Hence $I_1 = 0$

Hence $I_{R_1} = I_{R_f}$

$$\frac{V_{in} - V_A}{R_1} = \frac{V_A - V_o}{R_f}$$

Substituting $V_A = 0V$ we have

$$\frac{V_{in}}{R_1} = \frac{-V_o}{R_f}$$

$$\therefore \boxed{V_o = -\left(\frac{R_f}{R_1}\right) V_{in}}$$

The term (R_f/R_1) is called the gain of the inverting amplifier. The negative sign indicates that the output is inverted with respect to the input.

Op-amp as an inverting adder (summer)

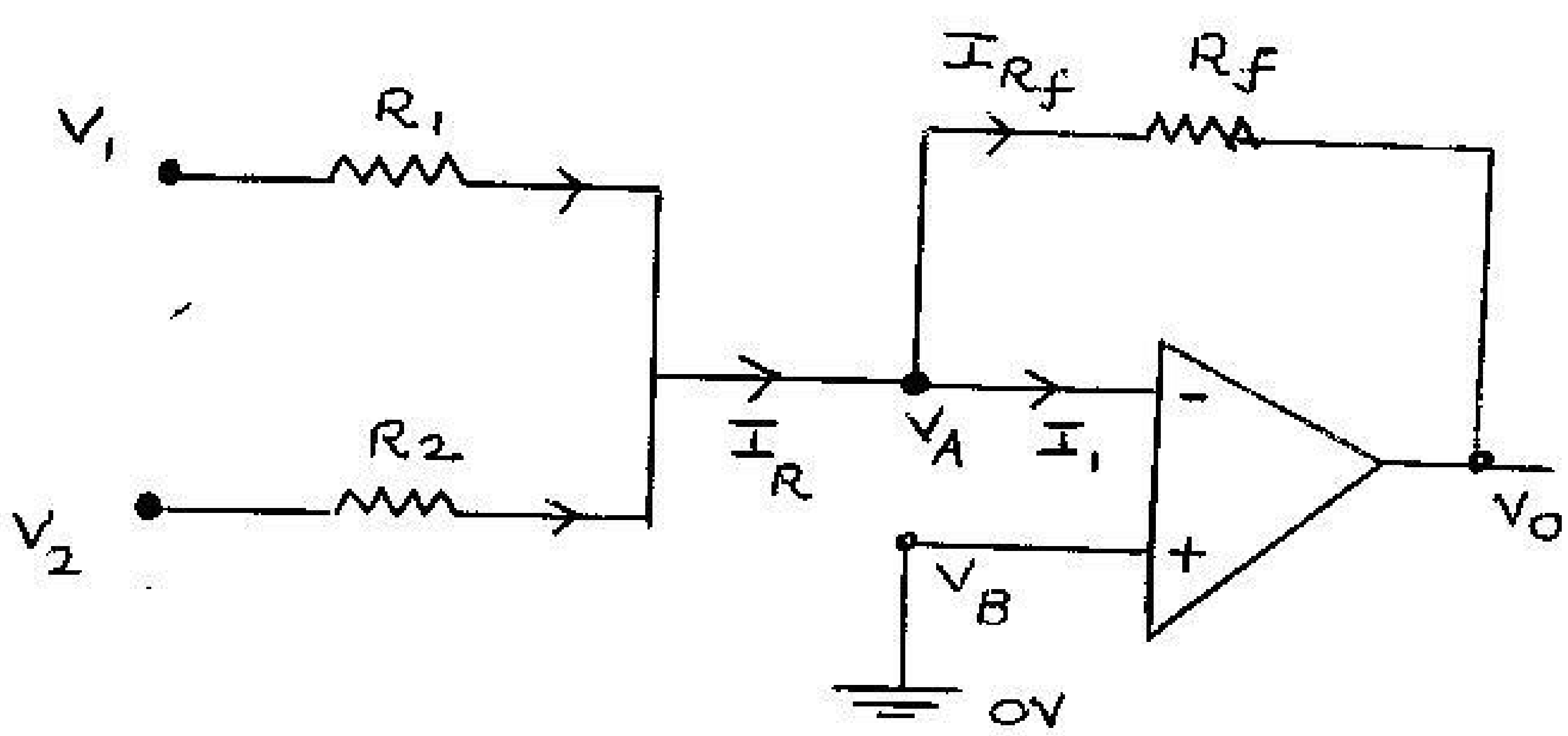


Figure above shows the circuit diagram of an inverting adder. By the concept of virtual ground we have

$$V_A - V_B = 0$$

Since V_B is grounded, $V_B = 0V$. Thus we have,

$$V_A = 0V$$

Since the op-amp has infinite input impedance, it does not draw any current. Hence $I_1 = 0$

Hence

$$I_R = I_{R_f}$$

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

Substituting $V_A = 0$ we have

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

$$\therefore \quad V_o = -\left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2\right]$$

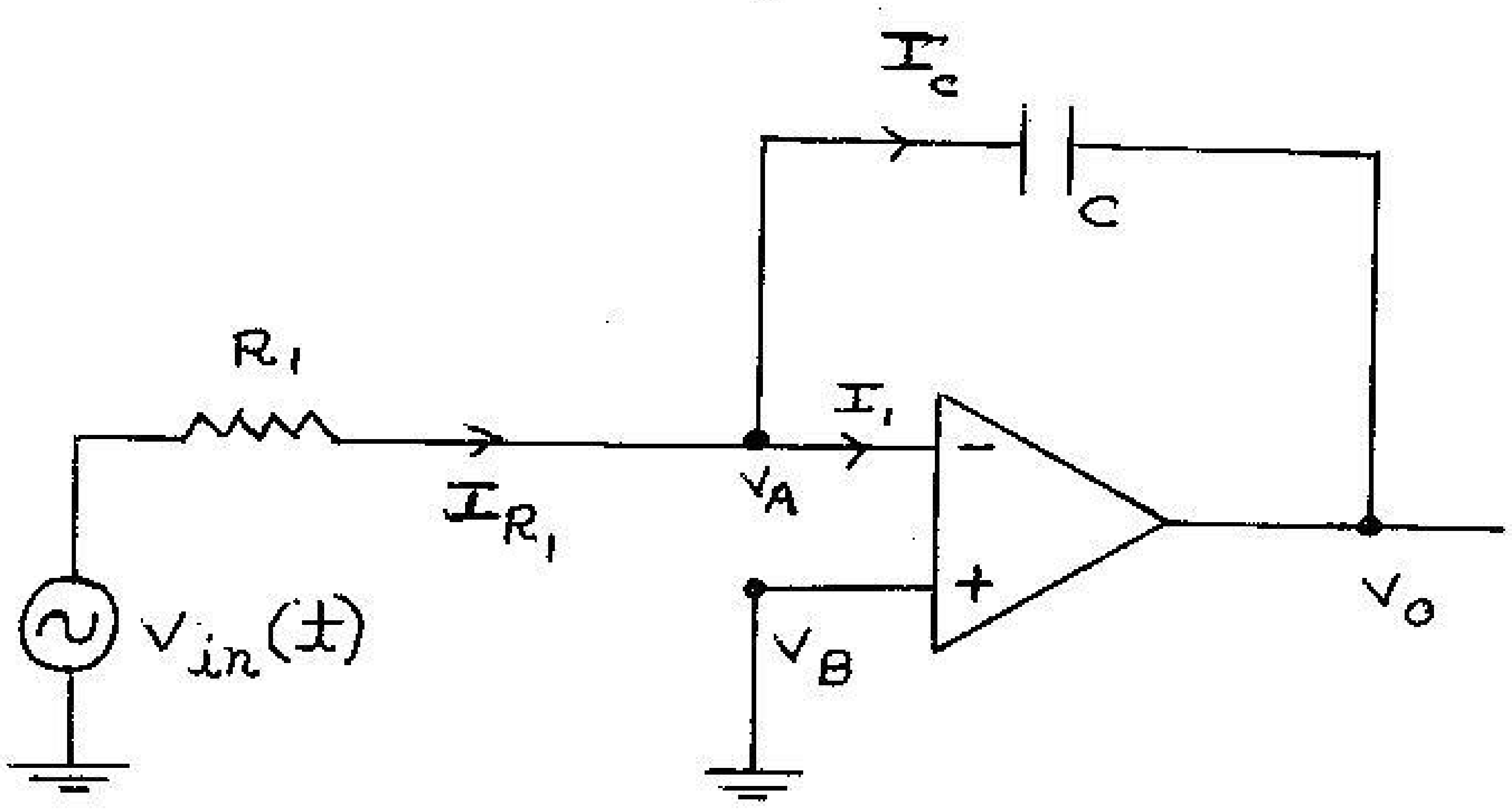
If $R_1 = R_2 = R_f$ is chosen, then we have,

$$V_o = -(V_1 + V_2)$$

Since the output of the circuit is equal to negative of sum of input voltages, the circuit is called as the inverting summer

op-amp as an integrator :-

An integrator is a circuit, in which the output voltage is proportional to the integral of the input voltage. Figure below shows the circuit diagram of the integrator using op-amp



By the concept of virtual ground, we have

$$V_A - V_B = 0$$

Since V_B is grounded, $V_B = 0V$. Thus we have

$$V_A = 0\ V$$

Since the op-amp has infinite input impedance, it does not draw any current. Hence $I_1 = 0$.

Hence $$I_{R_1} = I_C$$

$$\frac{V_{in} - V_A}{R_1} = C \frac{d}{dt}(V_A - V_o)$$

Substituting $V_A = 0$, we have

$$\frac{V_{in}(t)}{R_1} = -c\frac{dV_o}{dt}$$

or $$\frac{dV_o}{dt} = \frac{-1}{R_1 C} V_{in}(t)$$

Integrating on both sides w.r.t t

$$V_o = -\frac{1}{R_1 C}\int_0^t V_{in}(t)\,dt$$

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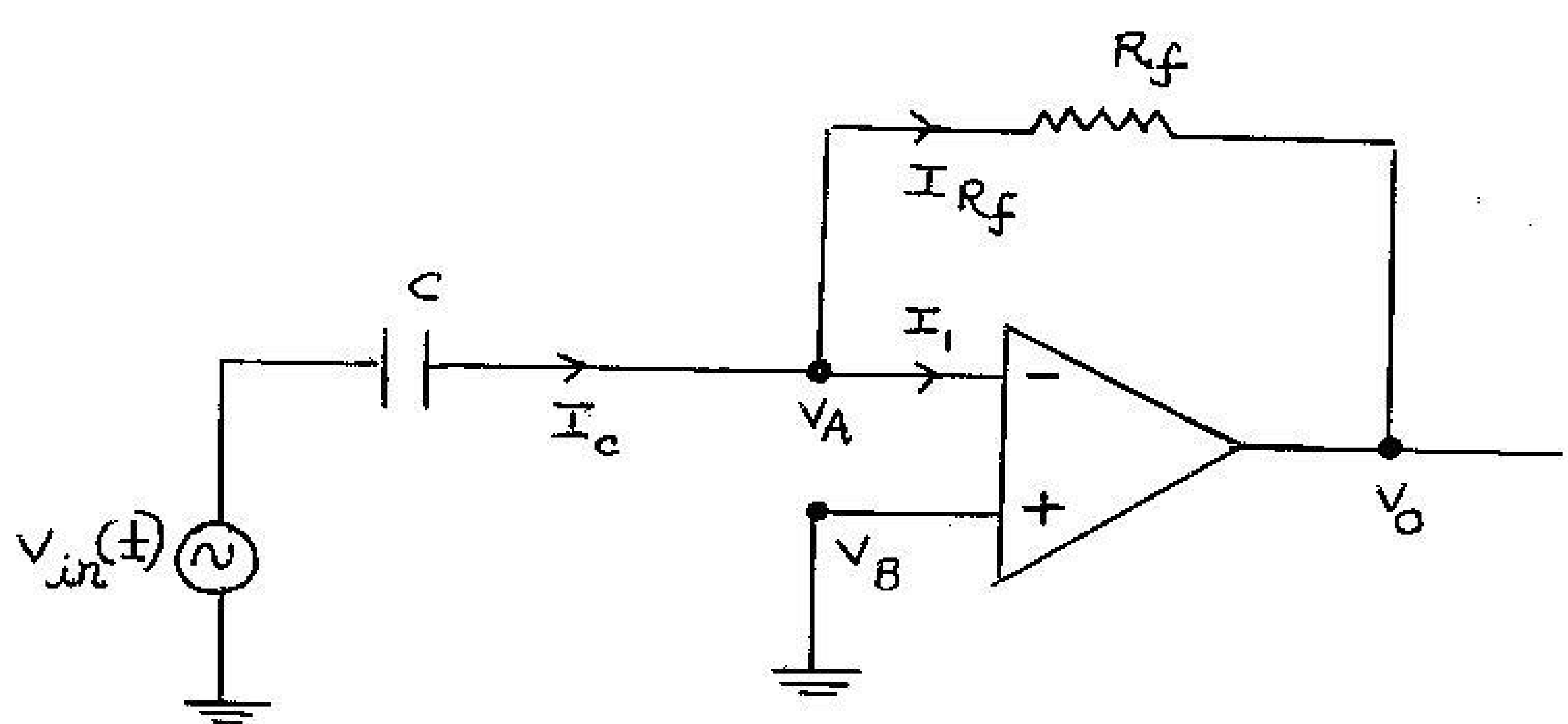
op-amp as a differentiator

A differentiator is a circuit, in which the output voltage is proportional to the time derivative of the input voltage. Figure shows the circuit diagram of a differentiator using op-amp.



By the concept of virtual ground, we have

$$V_A - V_B = 0$$

Since V_B is grounded, $V_B = 0V$. Thus we have

$$V_A = 0V$$

Since the op-amp has infinite input impedance, it does not draw any current. Hence $I_1 = 0$

Hence $$I_C = I_{R_f}$$

$$C \frac{d}{dt}\left\{V_{in}(t) - V_A\right\} = \frac{V_A - V_o}{R_f}$$

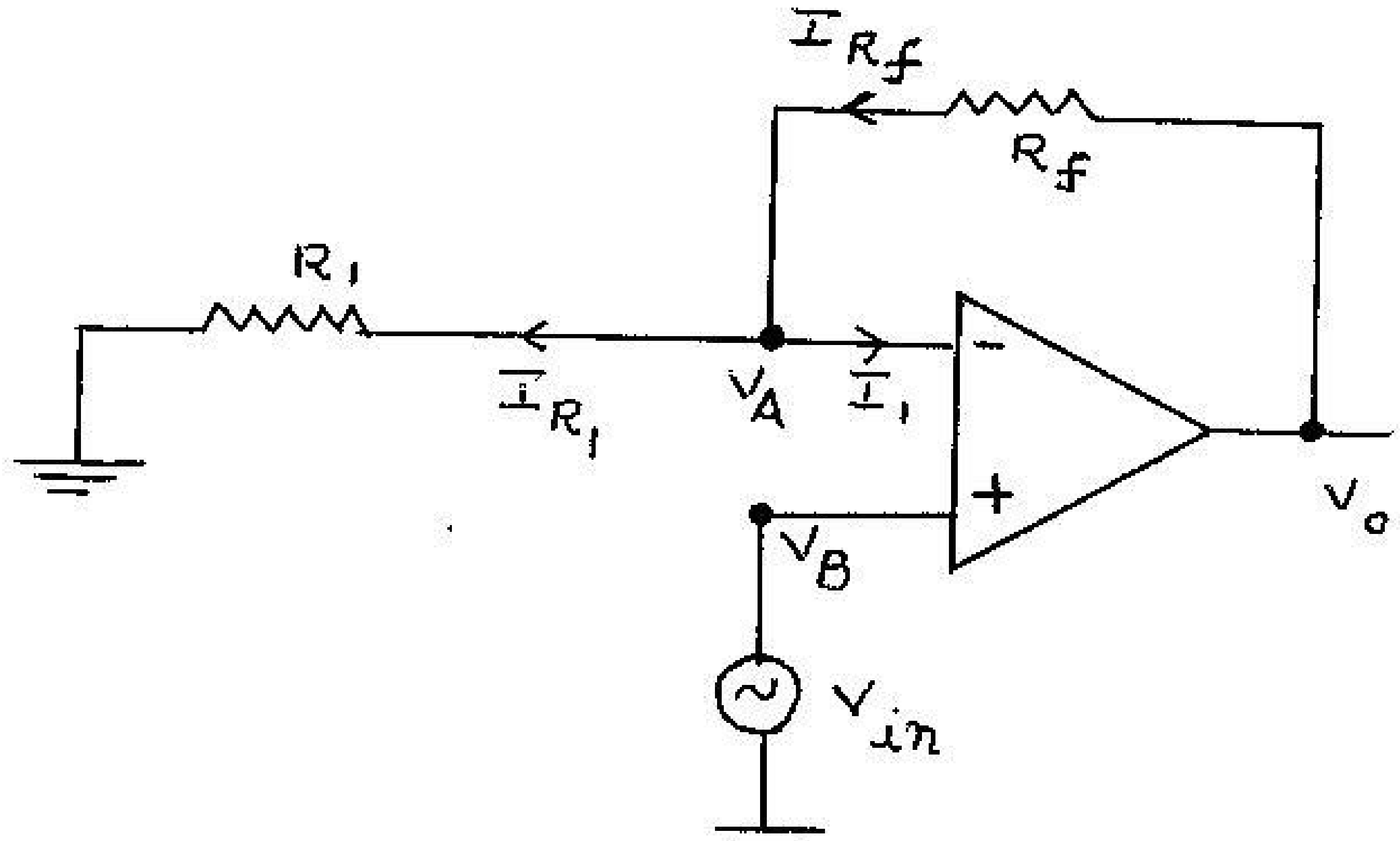
Substituting $V_A = 0$ we have,

$$C \frac{d}{dt} V_{in}(t) = \frac{-V_o}{R_f}$$

or $$V_o = -R_f C \frac{d}{dt} V_{in}(t)$$

Op-amp as a non inverting amplifier :-

Figure below shows the circuit diagram of a non inverting amplifier.



By the concept of virtual ground we have

$$V_A - V_B = 0$$

Since V_B is maintained at a voltage V_{in} we have

$$V_A = V_B = V_{in}$$

Since the op-amp has infinite input impedance, it does not draw any current. Hence $I_1 = 0$.

Hence

$$I_{R_f} = I_{R_1}$$

$$\frac{V_o - V_A}{R_f} = \frac{V_A - 0}{R_1}$$

$$\frac{V_o}{R_f} = \frac{V_A}{R_f} + \frac{V_A}{R_1} = V_A \left[\frac{1}{R_f} + \frac{1}{R_1}\right]$$

Substituting $V_A = V_{in}$ we have

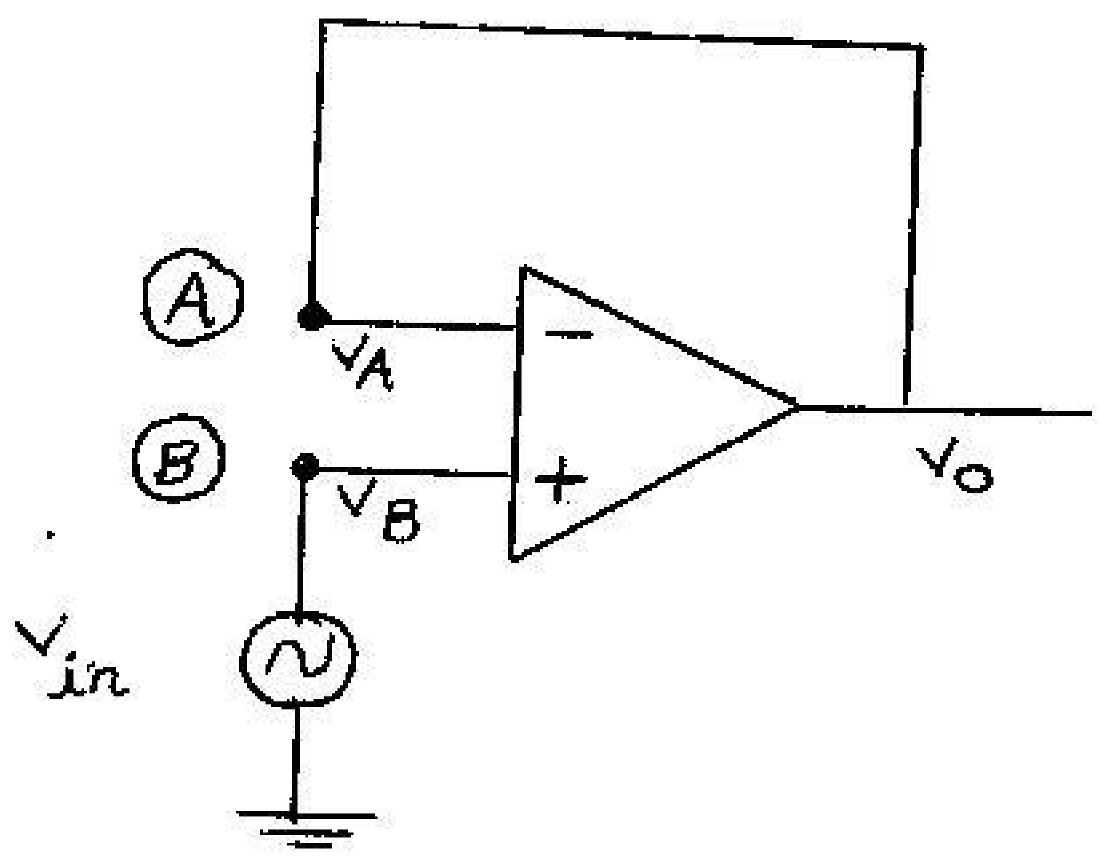
$$\frac{V_o}{R_f} = V_{in}\left[\frac{1}{R_f} + \frac{1}{R_1}\right]$$

$$\therefore \quad V_o = V_{in}\left(1 + \frac{R_f}{R_1}\right).$$

The term $\left(1 + \frac{R_f}{R_1}\right)$ is called gain of the non inverting amplifier.

op-amp as a voltage follower :-

A voltage follower is a circuit in which output voltage is same as the input voltage. Figure below shows the circuit of voltage follower.



The node B is maintained at a potential V_{in}. So

$V_B = V_{in}$

By the concept of virtual ground we have

$$V_A - V_B = 0$$

Since V_B is equal to V_{in}, we have

$$V_A = V_{in}$$

The node A is directly connected to the output. Hence

$V_o = V_A$

$$\therefore \quad V_o = V_{in}$$

Thus the output voltage is equal to the input voltage

op-amp as a comparator :-

A comparator is a circuit which compares a signal voltage applied at one input of the op-amp with a known reference voltage at other input.

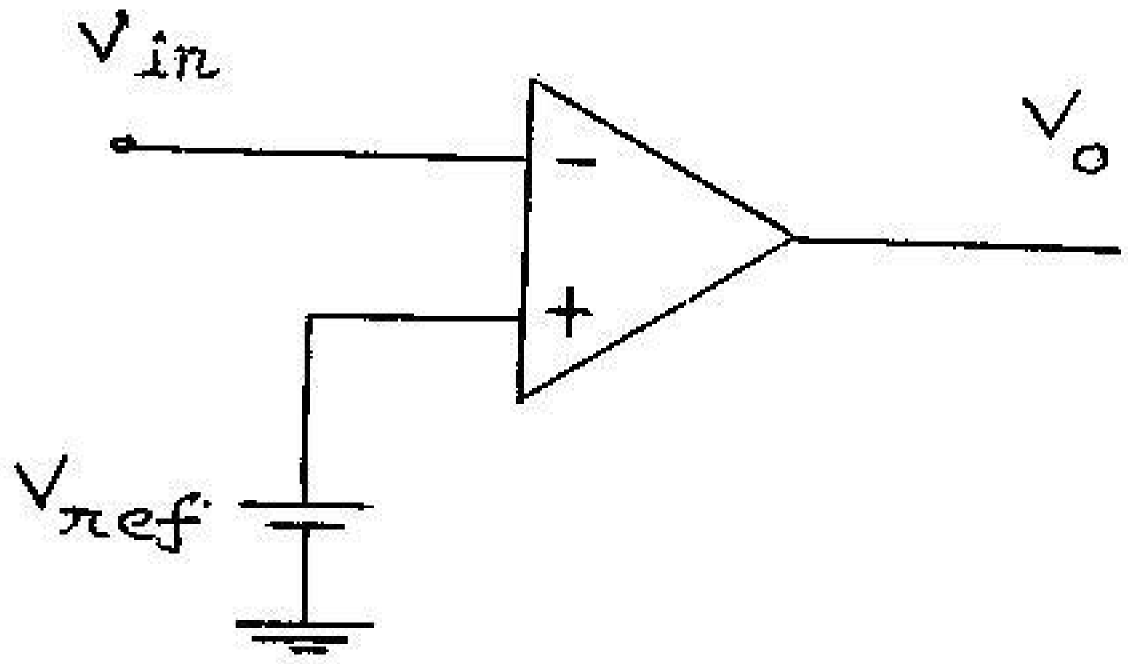
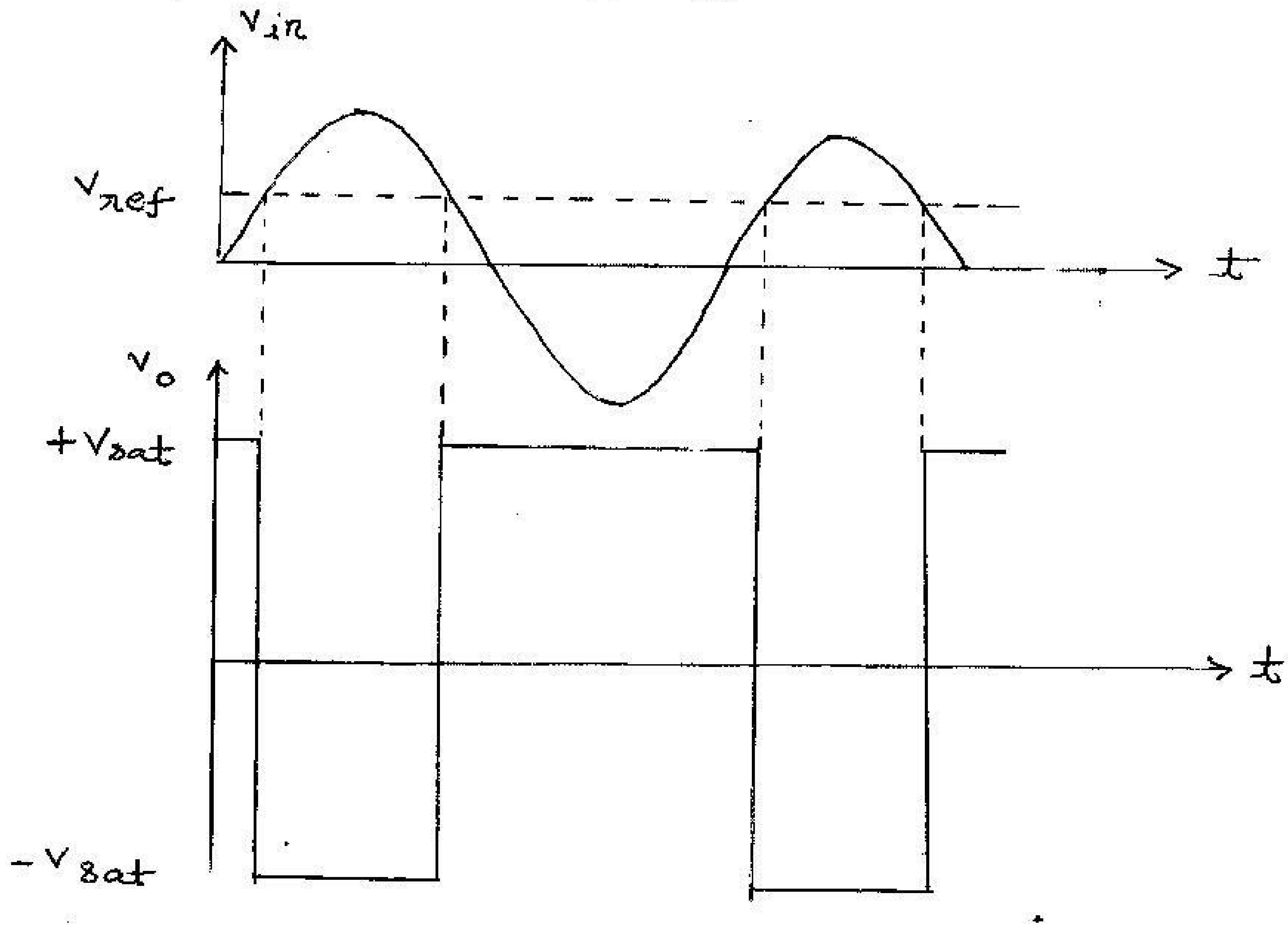


Figure shows the circuit diagram of an inverting comparator with the reference voltage V_{ref} applied at the noninverting input. The input signal is applied at the inverting input.

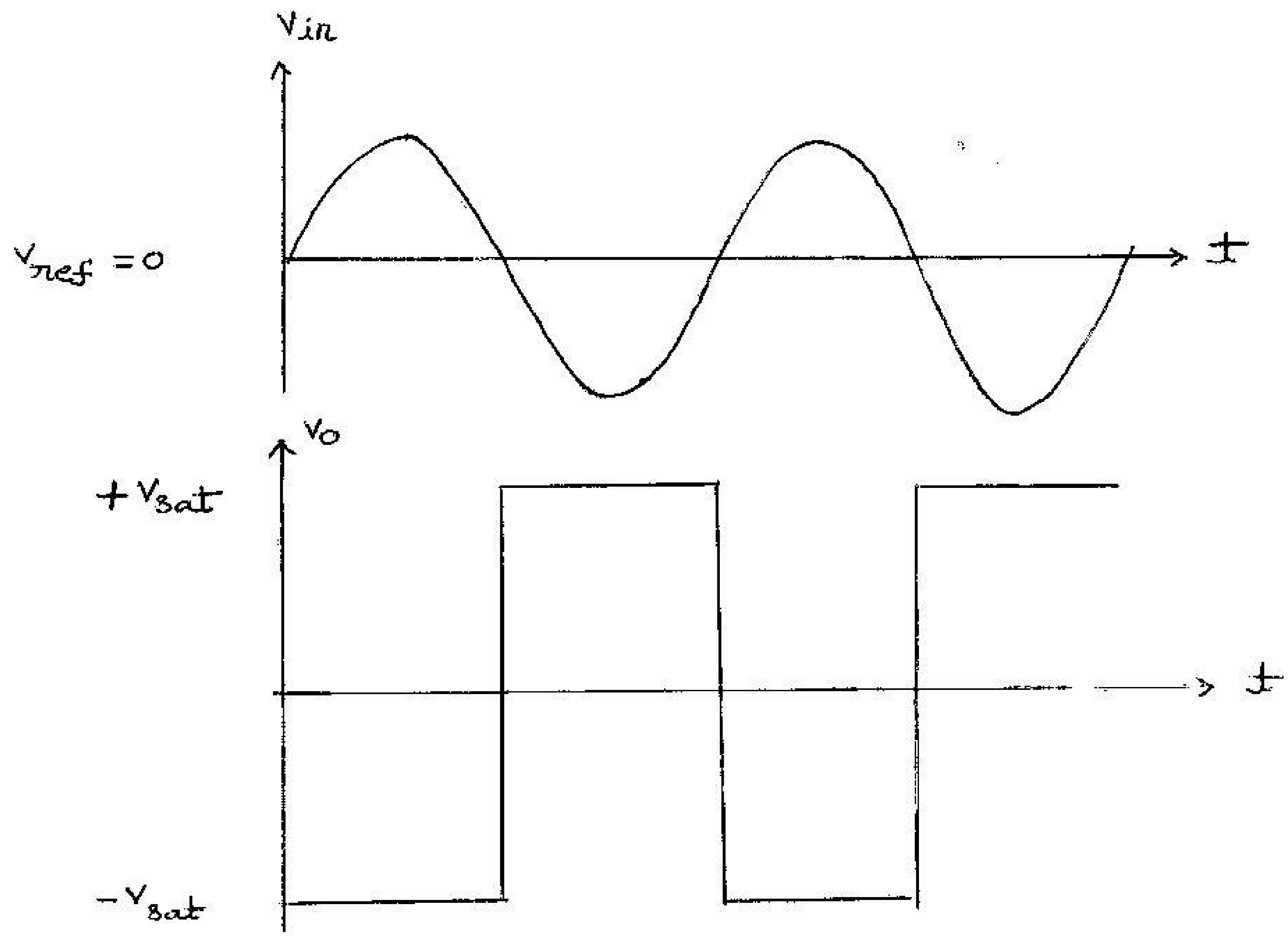
When the input voltage V_{in} is less than the reference voltage V_{ref}, the output voltage is at maximum negative level $-V_{sat}$ ($\simeq -V_{cc}$).

When the input voltage V_{in} is greater than the reference voltage V_{ref}, the output voltage is at maximum positive level $+V_{sat}$ ($\simeq V_{cc}$).

The input and output waveforms are shown below for $V_{ref} > 0$.



When V_{ref} is set to zero, the comparator is called Zero crossing detector. The input and output waveforms are shown below.



Important questions

1. What is an op-amp? With a neat diagram explain the internal blockdiagram of an op-amp.

2. Explain the types of input modes of an op-amp

3. With reference to an op-amp, explain the following

(i) Common Mode Rejection Ratio

(ii) Input offset voltage

(iii) Slew rate.

4. With reference to an op-amp, explain the following

(i) Input bias current

(ii) Input offset current

(iii) Input impedance

(iv) Maximum Voltage swing

5. With a neat circuit diagram derive the expression for output voltage of an inverting op-amp.

6. With a neat circuit diagram derive the expression for output voltage of a non inverting op-amp

7. With a neat circuit diagram show that an op-amp could be used as a summer.

8. With a neat circuit diagram, explain how an op-amp could be used an integrator?

9. Explain how an op-amp can be used as a Voltage follower.

10. With a neat circuit diagram, explain how an op-amp could be used as a differentiator?

11. Explain op-amp as a Voltage comparator.