

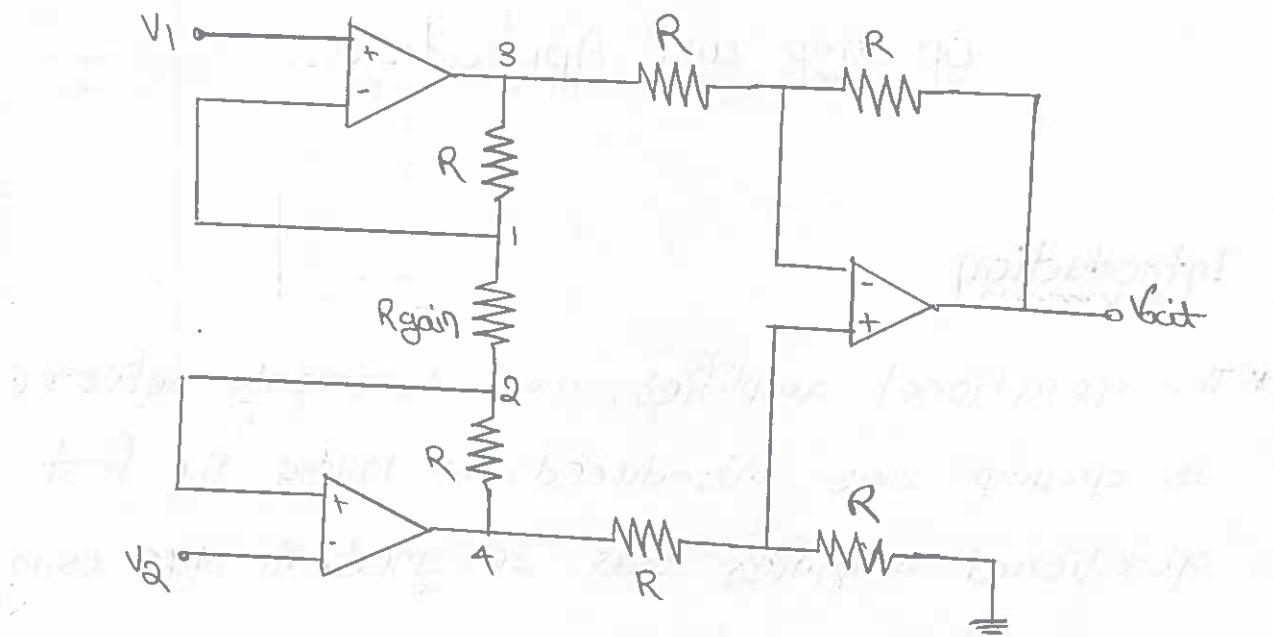
Introduction

- * The operational amplifier, most commonly referred as op-amp was introduced in 1940s. The first operational amplifier was designed in 1948 using vacuum tubes.
- * With the help of IC op-amp, the circuit design becomes very simple.
- * Because of their low cost, small size, versatility, flexibility, and dependability, op-amps are used in the fields of process control, communications, computers, power and signal sources, displays and measuring systems.

Instrumentation Amplifier

An instrumentation amplifier allows an engineer to adjust the gain of an amplified circuit without having to change more than one resistor value. Compare this to the differential amplifier which we covered previously which requires the adjustment of multiple resistor values.

The so called instrumentation amplifier builds on the last version of the differential amplifier to give us that capability.



Instrumentation Amplifier

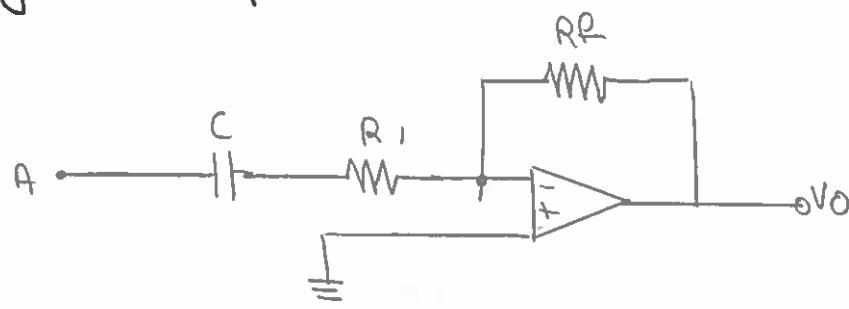
The voltage drop between points 3 & 4

$$V_{3-4} = (V_2 - V_1) \left(1 + \frac{2R}{R_{\text{Gain}}} \right)$$

AC Amplifier

- ⇒ The op-amp responding to A.C signals is called AC amplifier.
- ⇒ For such an AC amplifier, the low and high frequency limits must be considered.
- ⇒ To restrict the amplification of DC component, the coupling capacitors are used in AC amplifier.
- ⇒ The two types of AC amplifiers are
 - i, Inverting AC amplifier
 - ii, Non-inverting AC amplifier

1. Inverting AC amplifier :-



$$A_{CL} = \frac{V_0}{V_1} = -\frac{R_F}{R_1}$$

Inverting AC amplifier

$$A_{CL} = \frac{V_0}{V_p} = \frac{-R_F}{1 + \frac{1}{j\omega C}} \quad [\text{by applying L.T.]}$$

$$A_{CL} = -\frac{R_F}{R_1}, \frac{V_0}{V_{in}} = -\frac{R_F}{R_1 + j\omega C}$$

$$= -\frac{R_F}{R_1 + \frac{1}{j\omega C}}$$

$$= -\frac{R_F}{R_1 \left(1 + \frac{1}{j\omega R_1 C}\right)}$$

$$= -\frac{R_F}{R_1} \times \frac{1}{\left(1 + \frac{1}{j\omega R_1 C}\right)}$$

$$\omega = 2\pi f$$

$$= -\frac{R_F}{R_1} \times \frac{1}{\left(1 + \frac{1}{j2\pi f R_1 C}\right)}$$

$$\text{assume } f_i = \frac{1}{2\pi R_1 C}$$

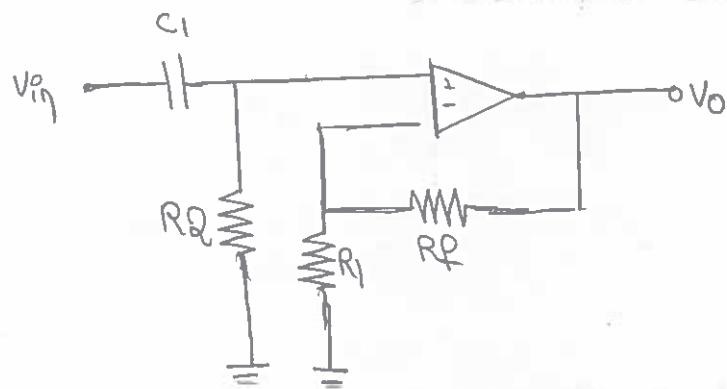
$$\boxed{\frac{V_0}{V_{in}} = -\frac{R_F}{R_1} \times \frac{1}{1 + \frac{jR_1}{f}}}$$

At higher frequencies the capacitor works as a short circuit

$$\boxed{A_{CL} \approx -\frac{R_F}{R_1}}$$

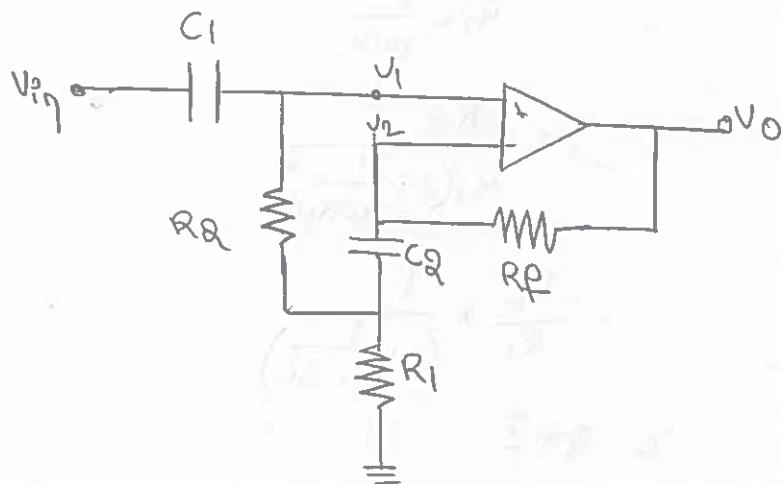
It is used for low frequency applications

ii. Non-inverting AC Amplifier :-



This R_f is provided to eliminate dc components by using this circuit input impedance of the op-amp is decreased.

→ To achieve high input impedance place a capacitor between the resistors of R_d & R_g .



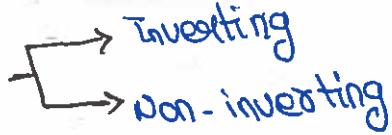
At higher frequencies the C_2 acts as a short circuit element the same potential V_2 is applied at the positive terminal of the op-amp because of this no current flows through the R_g .

Applications of op-Amp

we are using 3 types of basic op-amp

1. Scales & Inverters

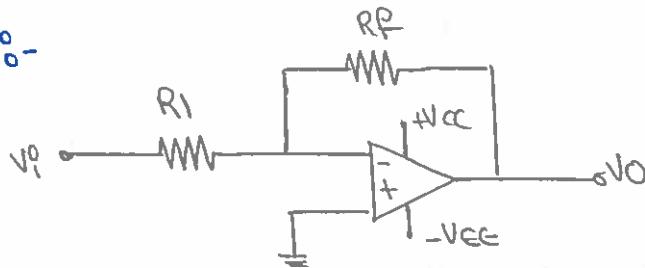
2. Summing Amplifier



3. Adder - subtractor.

1. Scales / Inverters circuit :-

Scales :-



$$A_{CL} = -\frac{R_F}{R_1}$$

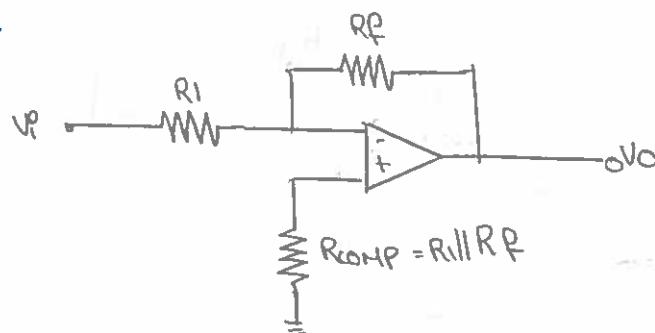
$$\text{Let us assume } k = -\frac{R_F}{R_1}$$

when R_{COMP} is added to the non-inverting terminal
the 'k' acts as scale circuit

$$\text{i.e., } A_{CL} = -k$$

$$R_{COMP} = R_1 \parallel R_F$$

Inverters :-



$$\text{Inverting } V_o = -V_i$$

$$\text{if } R_1 = R_F$$

$$A_{CL} = -\frac{R_F}{R_1} = -\frac{R_1}{R_1} = -1$$

$$\frac{V_o}{V_i} = -1$$

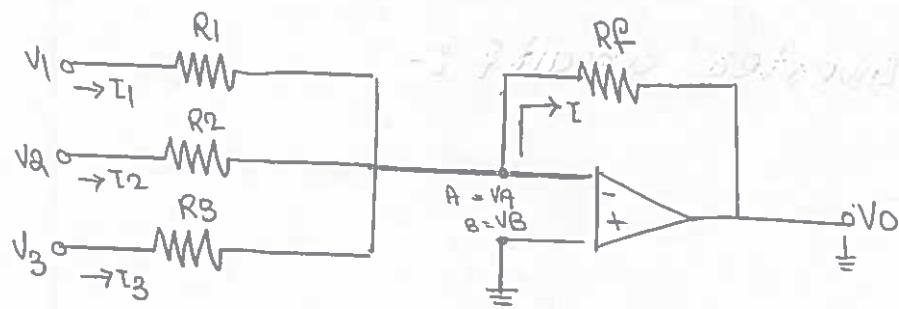
$$V_o = -V_i$$

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2. Summing Amplifiers [OpAmp Adder :-]

As the input impedance of an op-amp is extremely large, more than one input signal can be applied to the inverting amplifier. Such circuit amplifies the addition of the applied signals at the output. Hence it is called summing amplifier [OpAmp Adder].

Inverting summing Amplifier



In the circuit all the input signals to be added are applied to the inverting input terminal of the op-amp.

At point B is ~~is~~ grounded due to virtual ground concept, node A is also grounded hence $V_A = V_B = 0$.

From input side

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

$$I_2 = \frac{V_2}{R_2} \quad \{ \because V_A = V_B = 0 \}$$

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

$$I_B = \frac{V_B}{R_B}$$

Apply KCL at node A

$$I = I_1 + I_2 + I_3$$

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

As op-amp input current is 0. The entire current I passes through R_f from output side.

$$I = \frac{V_A - V_O}{R_f}$$

$$\{ \because V_A = V_B = 0 \}$$

$$I = -\frac{V_O}{R_f}$$

$$\therefore I_1 + I_2 + I_3 = -\frac{V_O}{R_f}$$

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

$$\text{if } R_1 = R_2 = R_3 = R$$

$$\text{Then } V_O = -R_f \left[\frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} \right]$$

$$= -\frac{R_f}{R} [V_1 + V_2 + V_3]$$

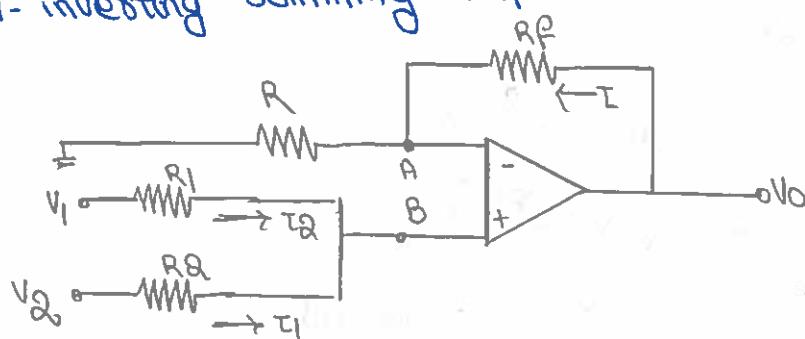
$$\text{if } R = R_f$$

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

Due to the negative sign they exist phase difference of input signal and output hence the circuit is called inverting summing amplifier.

ii) Non-inverting summing Amplifier

A summed circuit that gives amplification of non-inverted sum of the input signals is called non-inverting summing Amplifier.



Both inputs are applied between the non-inverting terminal of the op-amp. Let the voltage at node B is V_B . Now the node A is at the same potential that of B. unit 2, 7/44

$$V_A = V_B$$

From the input side $I_1 = \frac{V_1 - V_B}{R_1}$ }-①
 $I_2 = \frac{V_2 - V_B}{R_2}$

But as the input current of op-amp is zero

$$\text{i.e., } I_1 + I_2 = 0 \quad \text{--- ②}$$

Substitute equation ① & ②

$$I_1 = \frac{V_1 - V_B}{R_1} + \frac{V_2 - V_B}{R_2} = 0$$

$$\frac{V_1}{R_1} - \frac{V_B}{R_1} + \frac{V_2}{R_2} - \frac{V_B}{R_2} = 0$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = V_B \left[\frac{1}{R_1} + \frac{1}{R_2} \right]$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = V_B \left[\frac{R_2 R_1}{R_1 + R_2} \right]$$

$$V_B = \frac{R_2 V_1 + R_1 V_2}{R_1 + R_2} \quad \text{--- ③}$$

Now end node A

$$i = \frac{V_A}{R} = \frac{V_B}{R} \quad \text{--- ④}$$

$$\text{and } I = \frac{V_O - V_A}{R_F} = \frac{V_O - V_B}{R_F} \quad \text{--- ⑤}$$

Equating the two equations ④ & ⑤

$$\frac{V_B}{R} = \frac{V_O - V_B}{R_F}$$

$$\frac{V_O}{R_F} = \frac{V_B}{R} + \frac{V_B}{R_F}$$

$$= \left[\frac{1}{R} + \frac{1}{R_F} \right] V_B$$

$$V_O = V_B \left[\frac{R + R_F}{R} \right] \quad \text{--- ⑥}$$

Substitute equation ③ in equation ⑥

$$V_O = \left[\frac{R_2 V_1 + R_1 V_2}{R_1 + R_2} \right] \left[\frac{R + R_F}{R} \right]$$

$$V_o = \frac{R_Q(R+R_F)}{R(R_1+R_2)} V_1 + \frac{R_1(R+R_F)}{R(R_1+R_2)} V_2 \quad \text{--- ①}$$

If the two resistances R_1 & R_2 are selected equal to that R_Q .

$$R_1 = R_Q$$

then

$$V_o = \frac{R+R_F}{2R} (V_1 + V_2)$$

If $R_1 = R_Q = R = R_F$ we get

$$V_o = V_1 + V_2$$

3. Difference Amplifier [or] Subtractor

To find the relation between the inputs and output let us used superposition principle.

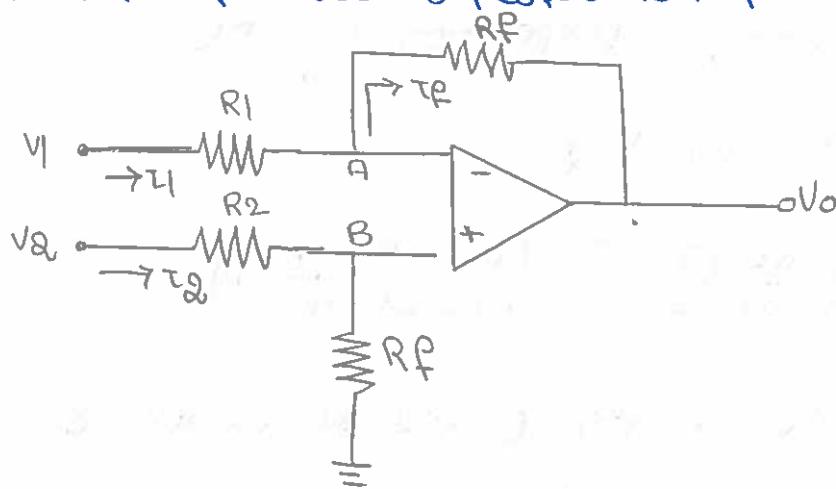


fig :- Subtractor circuit

- * Let V_{o1} be the output, with input V_1 acting alone, assuming V_2 to be zero. And V_{o2} be the output, with input V_2 acting, assuming V_1 to be zero.
- * with V_2 zero, the circuit acts as an inverting amplifier hence we can write

$$V_{o1} = -\frac{R_F}{R_1} \cdot V_1 \quad \text{--- ①}$$

* while v_1 as 0 with v_2 acting this circuit acts as non-inverting amplifier it amplifies the voltage at node B by the factor.

$$\left[1 + \frac{R_f}{R_i}\right].$$

* net potential of node B be v_B .

* Apply voltage divider rule to the input v_2 loop,

Then $v_B = \frac{R_f}{R_f + R_i} v_2 \quad \textcircled{2}$

$$v_{o2} = \left[1 + \frac{R_f}{R_i}\right] v_B \quad \textcircled{3}$$

substituting v_B from equation $\textcircled{2}$ in equation $\textcircled{3}$

$$v_{o2} = \left(1 + \frac{R_f}{R_i}\right) \left(\frac{R_f}{R_f + R_i}\right) v_2 \quad \textcircled{4}$$

Hence using superposition principle

$$v_o = v_{o1} + v_{o2}$$

$$v_o = \left[-\frac{R_f}{R_i} v_1\right] + \left[1 + \frac{R_f}{R_i}\right] \left[\frac{R_f}{R_f + R_i} v_2\right]$$

If the resistance are selected as

$$R_i = R_f$$

$$\begin{aligned} v_o &= \left[-\frac{R_f}{R_i} v_1\right] + \left[1 + \frac{R_f}{R_i}\right] \left[\frac{R_f}{R_i + R_f} v_2\right] \\ &= \left(-\frac{R_f}{R_i} v_1\right) + \left(\frac{R_i + R_f}{R_i}\right) \left(\frac{R_f}{R_i + R_f} v_2\right) \end{aligned}$$

$$v_o = -\frac{R_f}{R_i} v_1 + \frac{R_f}{R_i} v_2$$

$$= \frac{R_f}{R_i} (v_2 - v_1)$$

$\therefore R_i = R_f = R_f$

$v_o = v_2 - v_1$

The output voltage is proportional to the difference between the two input voltages. So it acts as subtractor or difference amplifier.

If $R_1 = R_2 = R_f$ is selected then V_o

$$V_o = V_2 - V_1$$

Voltage Follower [or] Buffer.

- ⇒ A circuit in which the output voltage follows the input voltage is called voltage follower circuit.
- ⇒ The voltage follower using op-amp as shown in diagram.

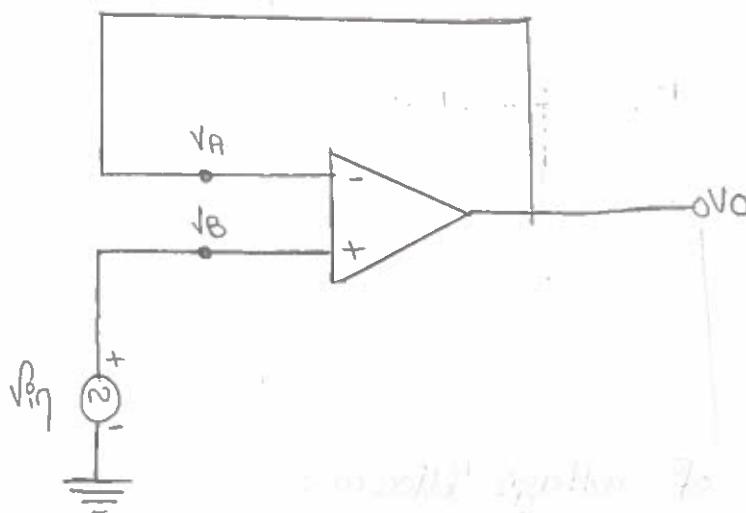


fig :- voltage follower

[or]
Buffer

- ⇒ The node B is at potential V_{in} .
- ⇒ The node A is also at the same potential as B i.e., V_{in} according to the concept of virtual ground.

$$\therefore V_A = V_B = V_{in} \quad \text{--- } ①$$

⇒ Now node A is directly connected to the output. Hence we can write

$$V_o = V_A \quad \text{--- } ②$$

Equating the equations ① & ②

$$V_o = V_{in}$$

⇒ For this circuit, the voltage gain is unity.

⇒ It is also called source follower, unity gain amplifier, buffered amplifier or isolation amplifier.

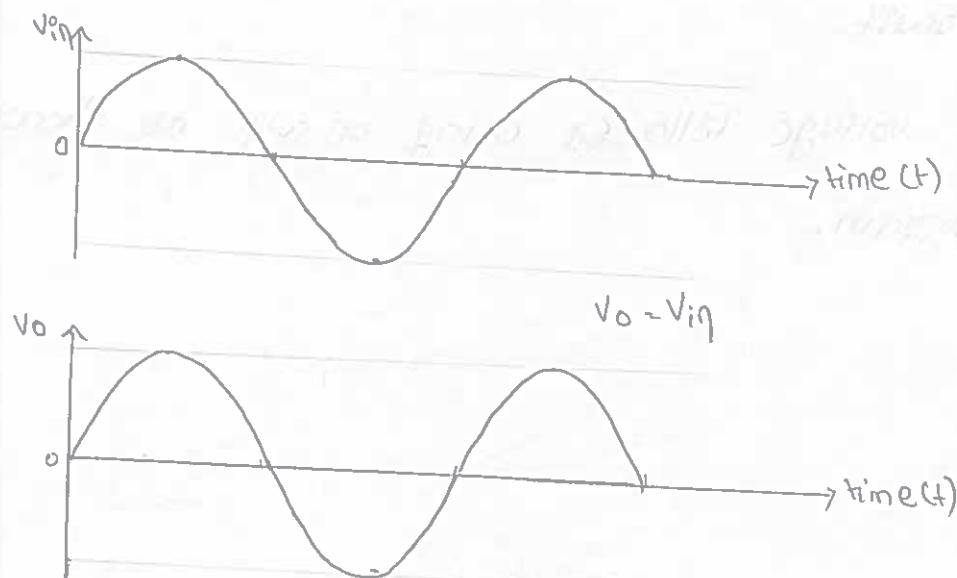


Fig.: The input and output waveforms

Advantages of voltage follower :-

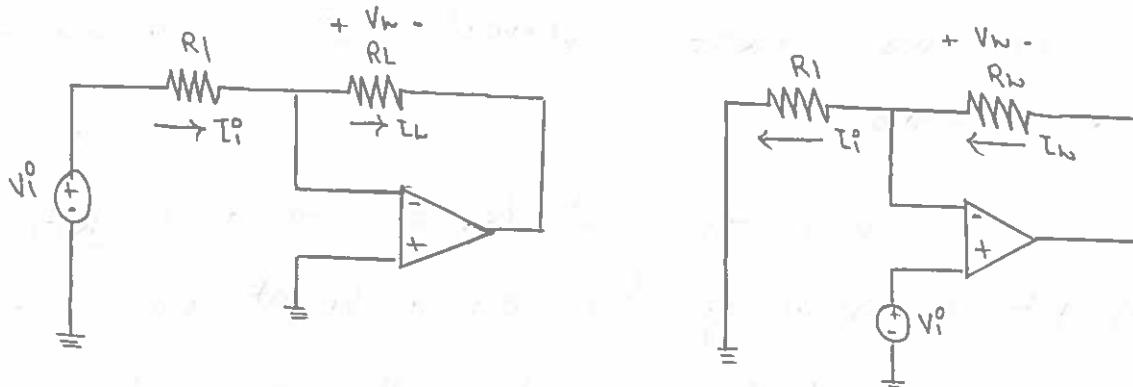
- * Very large input resistance, of the order of $M\Omega$
- * Low output impedance, almost zero
- Hence it can be used to connect high impedance source to a low impedance load, as a buffer. This eliminates the loading effect.
- * It has large bandwidth
- * The output follows the input exactly without a phase shift.

Voltage to Current Converter

- In a voltage to current converter, the output load current is proportional to the input voltage.
- According to the connection of load there are two types of V to I converters.
 - Floating Type
 - Grounded Type.

→ Voltage to current converter with floating Type:-

Voltage to current converter in which load resistor R_L is floating.



Floating load V-I converters

- As input current of op-amp is zero,

$$I_L^o = I_P = \frac{V_i^o}{R_1}$$

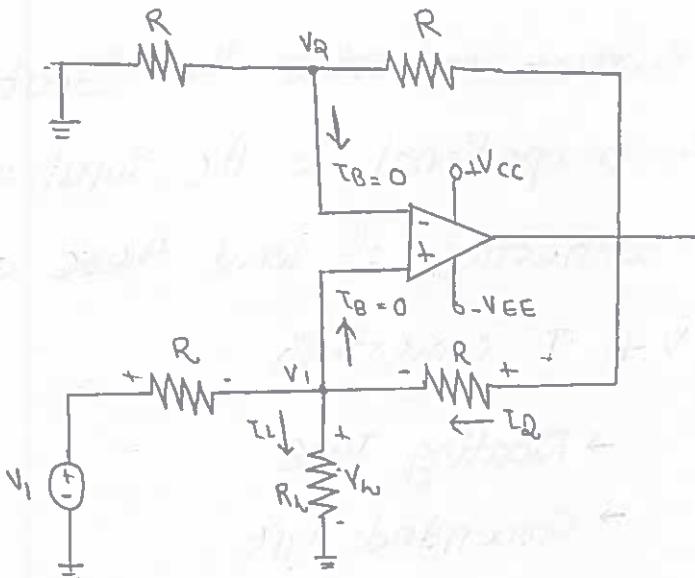
$$I_L^o \propto V_i^o$$

The load current is always proportional to the input voltage & circuit works as V-I converter.

It is also called a voltage control current source.

⇒ The proportionality constant is generally $1/R_1$, hence this circuit is also called transconductance amplifier.

→ Voltage to Current Converter with Grounded Load :-



V-I converter with Grounded load

- Voltage to current converter in which one end of load resistor R_L is grounded. It is also known as 'Howland current converter'. From the name of its inventor.
- * As R_L is grounded the analysis of circuit is getting by 1st determining the voltage V_1 at non-inverting input terminal & the getting the relationship between V_1 & load current.

Applying KCL at node V_1 , we get

$$I_1 + I_2 = I_L$$

$$\therefore \frac{V_i - V_1}{R} + \frac{V_o - V_1}{R} = I_L$$

$$V_i + V_o - 2V_1 = I_L R$$

$$\text{i.e., } V_1 = \frac{V_i + V_o - I_L R}{2}$$

The gain of op-amp in non-inverting mode is given as

$$A = 1 + \frac{R_F}{R_A}$$

For this circuit it is

$$A = 1 + \frac{R}{R} = 2$$

Hence,

output voltage can be written as

$$V_o = 2V_i$$

$$V_o = 2V_i = V^o + V_o - I_L R$$

$$0 = V^o - I_L R$$

$$V_o = I_L R$$

$$I_L = \frac{V_o}{R}$$

$$I_L \propto V^o$$

From the above equation we can say that the load current depends the input voltage V^o & resistor R .

Applications of V-I converters :-

* low voltage DC voltmeter

* low voltage AC voltmeter

* Diode tester & Hatchet filter

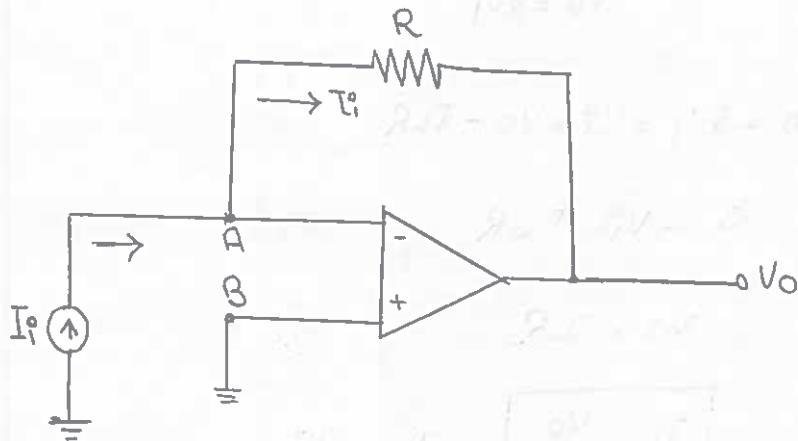
* zener diode tester.

Current to Voltage Converters

- In such a converter, the output voltage is proportional to the input current.
- It accepts an input current I_i and yields an output voltage V_o such that

$$V_o = A \cdot I_i$$

- Since A is the gain of the circuit, A is measured in ohms, it is more appropriate to denote gain by the symbol R .
- Because of this, I-V converters are also called transresistance amplifiers.



current to voltage converter

- The node A is a virtual ground as node B is grounded.

Hence $V_A = 0$.

$$I_i^o = \frac{V_A - V_o}{R} = -\frac{V_o}{R}$$

i.e., $V_o = -I_i^o R$ $V_o \propto I_i^o$

Applications of I to V converter

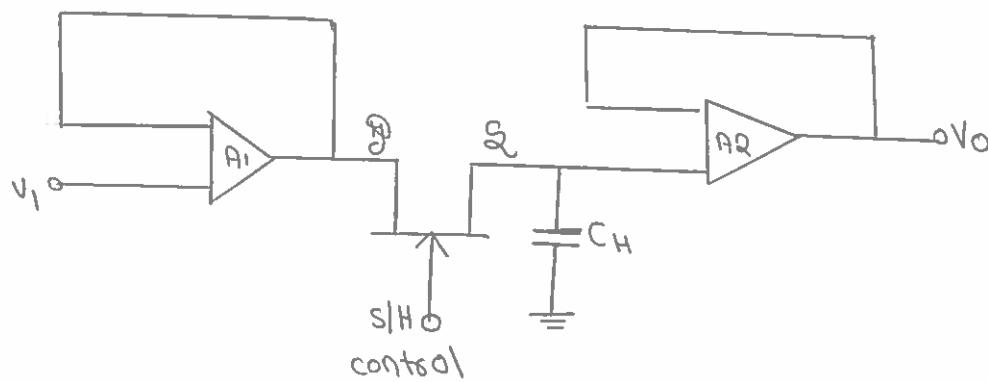
⇒ One of the most frequent applications of I to V converters is in connection with current type photo detectors such as photodiodes, photofets and photomultipliers.

⇒ Another common application is I/V conversion of current output digital to analog converter.

Sample and Hold circuits

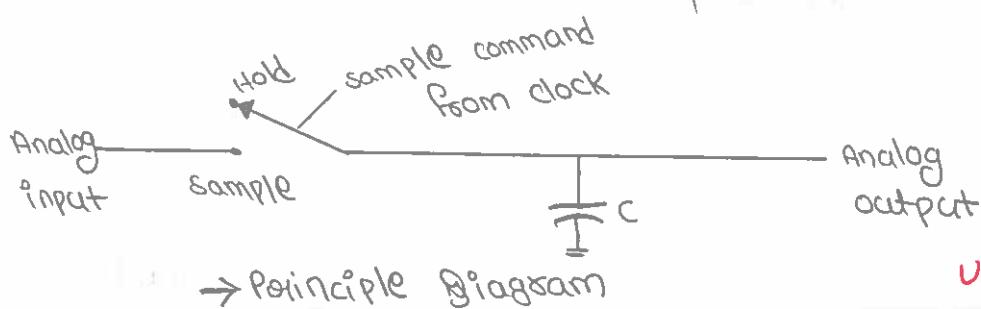
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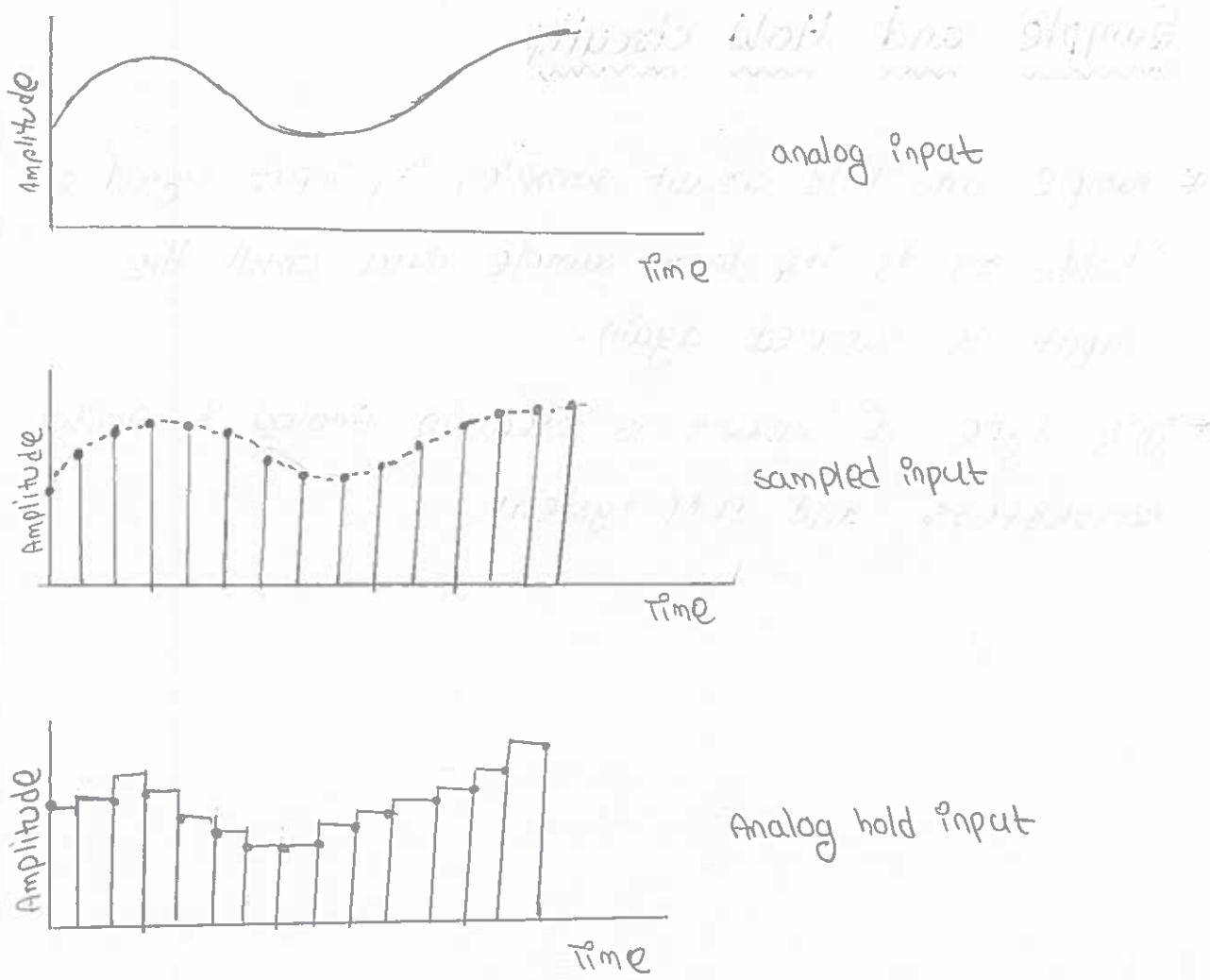
- * Sample and hold circuit samples its input signal and holds on to its last sample data until the input is sampled again.
- * This type of circuit is used in Analog to Digital converters and PCM system.



Basic sample and Hold circuit

- * In this circuit JFET is used as switch.
- * During the sampling time the JFET switch is turned on, and the holding capacitor charges up to the level of the analog input voltage.
- * At the end of this short sampling period, the JFET switch is turned off. This isolates the holding capacitor C_H from the input signal.
- * As a result, the voltage across capacitor C_H & the output voltage will remain essentially constant at the value of the input voltage at the end of the sampling time.





Input and output response of
sample and hold circuit.

- * when $V_{GS} = 0V$ the switch is closed and output voltage V_{out} equal to input voltage V_{in} .
- * when V_{GS} is equal to or more negative than $V_{GS OFF}$, the JFET is open and V_{out} is approximately zero.

Applications of S/H Circuits

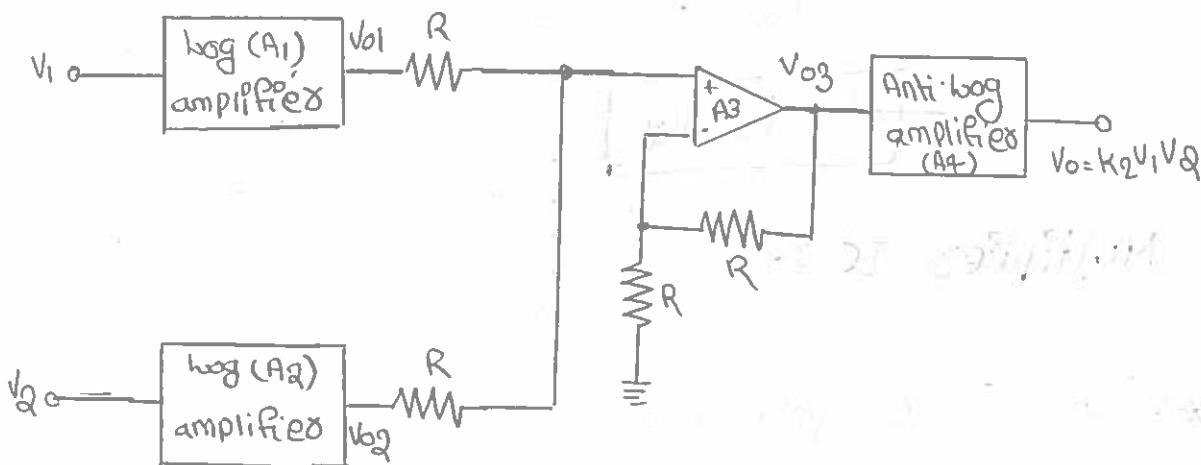
- Digital interfacing.
- Analog to Digital converter circuit.
- Pulse modulation systems.
- In analog demultiplexers.
- In reset-stabilised op-amps.

Multiplexers and Dividers

5

* Analog Multiplier Circuit :-

⇒ Using log and anti-log amplifiers, the circuit can be built to obtain the output proportional to the product of two input signals. This circuit is called analog Multiplier.



Analog voltage Multiplier circuit.

⇒ A_1 and A_2 are the log amplifiers while A_3 is unity gains non-inverting amplifier.

⇒ The two input outputs V_{01} and V_{02} of A_1 and A_2 respectively are given by

$$V_{01} = -k \ln \left[\frac{V_1}{V_{\text{ref}}} \right]$$

$$V_{02} = -k \ln \left[\frac{V_2}{V_{\text{ref}}} \right]$$

where k is constant.

$$\therefore V_{03} = V_{01} + V_{02}$$

$$= -k \ln \left[\frac{V_1}{V_{\text{ref}}} \right] + \left[-k \ln \left[\frac{V_2}{V_{\text{ref}}} \right] \right]$$

$$= -k \ln \left[\frac{V_1}{V_{\text{ref}}} \right] - k \ln \left[\frac{V_2}{V_{\text{ref}}} \right]$$

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$$= -k \left[\ln \left(\frac{V_1}{V_{\text{ref}}} \right) + \ln \left(\frac{V_2}{V_{\text{ref}}} \right) \right]$$

$$V_{o3} = k_1 \ln (k_2 V_1 V_2)$$

The output V_{o3} is applied to A4. It is the Antilog amplifier.

$$\therefore V_{o4} = \frac{1}{k_2} \ln^{-1} \left[\frac{k_1 k_2 (k_2 V_1 V_2)}{k_1} \right]$$

$$V_o = \frac{1}{k_2} [k_2 V_1 V_2]$$

$$V_o = k_2 V_1 V_2$$

Multiplexed IC :-

* V^+ and V^- are supply terminals while X and Y are input terminals.

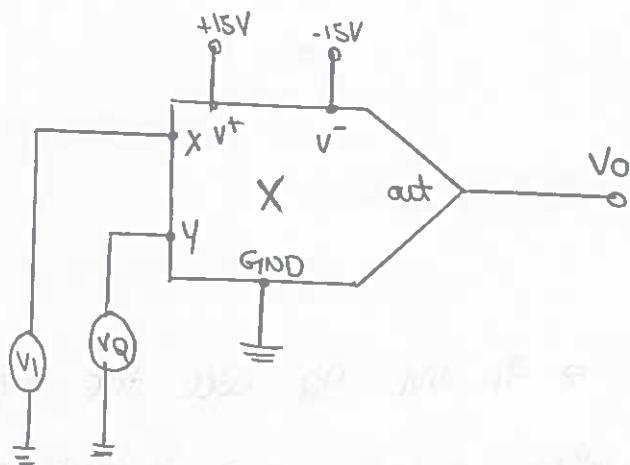
* The output is given by

$$V_o = k V_1 V_2$$

where

$$k = 1/V_{\text{ref}}$$

V_{ref} is set to 10V internally.



Applications of Multiplexed IC :-

- It is used to solve non-linear equations.
- It is used for squaring & square root calculations.
- For voltage controlled attenuators and for voltage controlled amplification.
- It is used for voltage dividers, true r.m.s calculations, rectifier phase shift detection etc.

i, Voltage Divider Using Multiplier

6

The circuit in which output is the division of the two input signals, is called as a voltage divider. The use of multiplier as a voltage divider as shown in the figure.

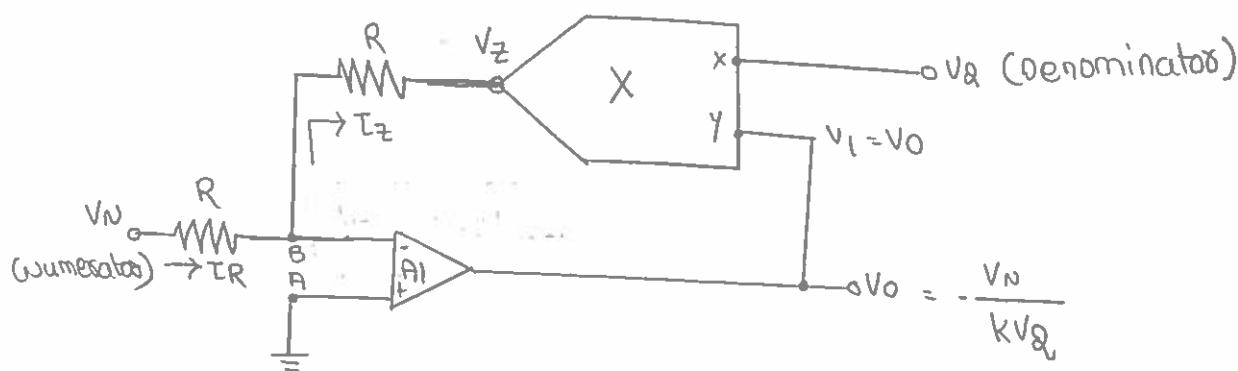


Fig :- Voltage Divider

ii, Squaring circuit using Multiplier

The squaring circuit gives square of the input voltage applied. The multiplied inputs are connected together to get the squaring circuit.

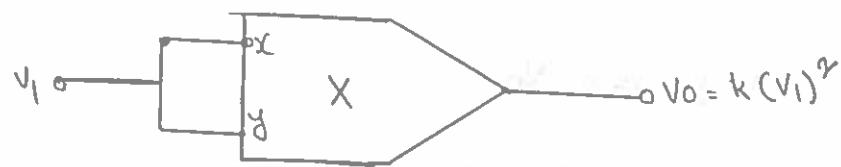
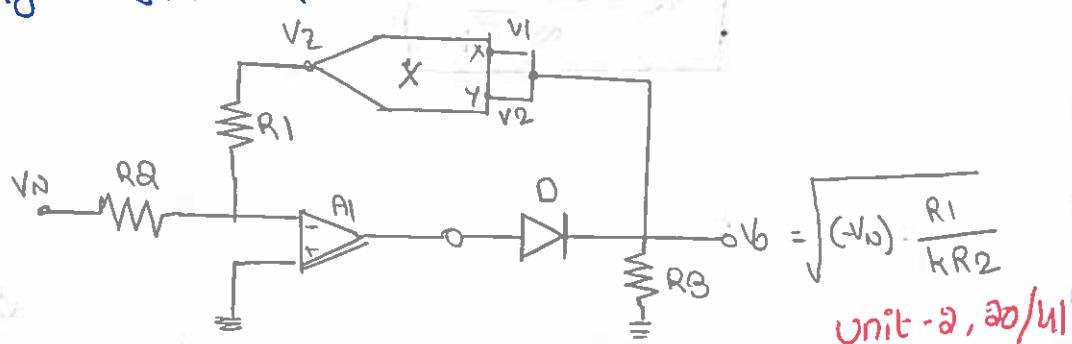


Fig :- Squaring circuit

iii, Square Rooting circuit using Multiplier

similar to the squaring, the square rooting circuit can be obtained using multipliers. A multiplier configured as squaring circuit is used in the feedback loop.



* Analog Divider circuit :

Analog divider circuit can be obtained using log and antilog amplifiers as shown in the fig.

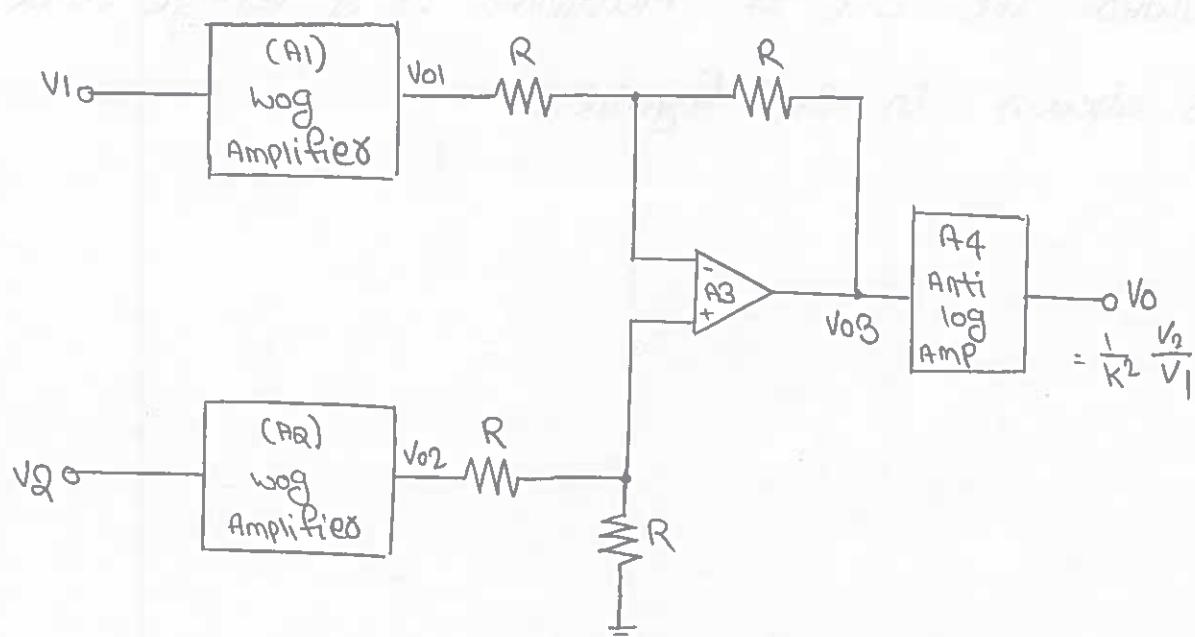


fig :- Analog voltage divider circuit

- For log amplifiers A_1 & A_2 ,

$$V_{01} = k_1 \ln k_2 V_1$$

$$V_{02} = k_2 \ln k_2 V_2$$

- The op-amp A_3 is difference amplifier hence,

$$V_{03} = V_{02} - V_{01}$$

$$= k_2 \ln k_2 V_2 - k_1 \ln k_2 V_1$$

$$= k_1 \ln \left[\frac{V_2}{V_1} \right]$$

- The op-amp A_4 is antilog amplifier giving

$$V_0 = \frac{1}{k^2} \ln^{-1} k_1 \left[\frac{\ln(V_2/V_1)}{k_1} \right]$$

$$V_0 = \frac{1}{k^2} \frac{V_2}{V_1}$$

Differentiators and Integrators

* Integrator :-

In an integrator circuit, the output voltage is the integration of the input voltage. The integrator circuit can be obtained without using active devices like op-amp, transistors etc. In such a case an integrator is called passive Integrator.

- while an integrator using an active devices like op-amp is called active integrator.

i, Ideal Active op-amp Integrator

→ Consider the ideal op-amp integrator.

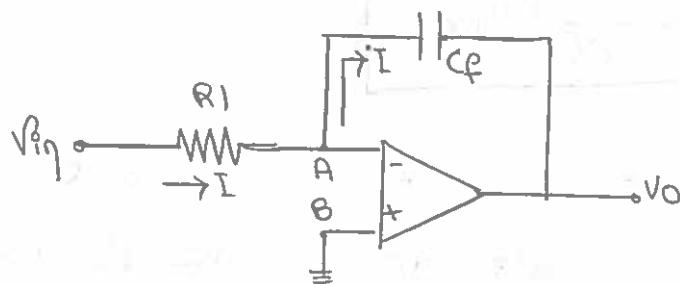


fig :- op-amp Integrator

→ The node B is grounded. Node A is also at the ground potential from the concept of virtual ground.

$$\therefore V_A = V_B = 0$$

→ As input current of op-amp is '0' the entire current 'I' flowing through R_i , and also flows through ' C_f '.

→ From input side we can write

$$I = \frac{V_{in} - V_A}{R_i} = \frac{V_{in}}{R_i}$$

→ From output side we can write

$$I = C_F \frac{d(V_A - V_O)}{dt}$$

$$= -C_F \frac{dV_O}{dt}$$

→ Equating the two equations

$$\frac{V_A}{R_1} = -C_F \frac{dV_O}{dt}$$

→ Integrating both sides

$$\int_0^t \frac{V_A}{R_1} dt = -C_F \int dV_O \cdot dt$$

$$\int_0^t \frac{V_A}{R_1} dt = -C_F V_O$$

$$V_O = -\frac{1}{R_1 C_F} \int_0^t V_A dt$$

→ $R_1 C_F$ is called time constant of integrator.

→ The negative sign indicates phase shift of 180° between input & output.

Applications :-

- step input signal is converted to RAMP output signal due to an integrator.

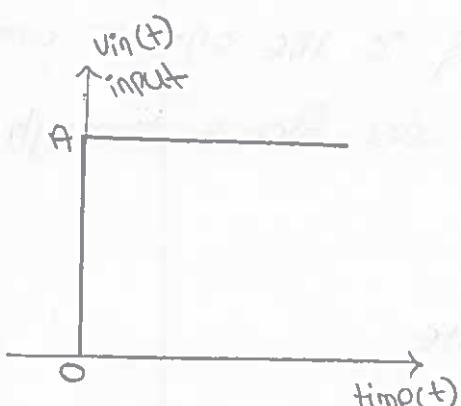


Fig :- step input signal

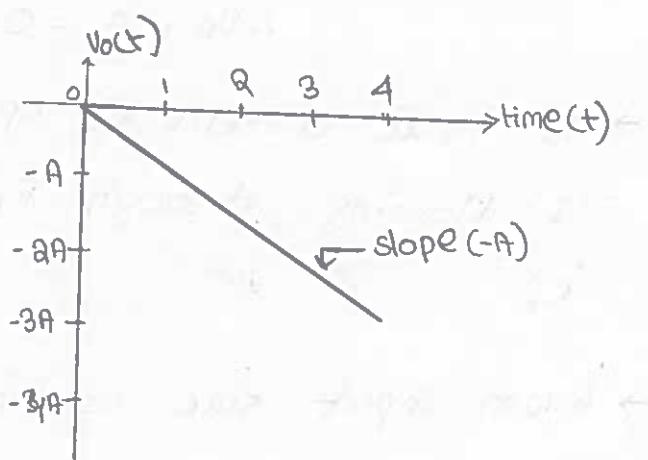
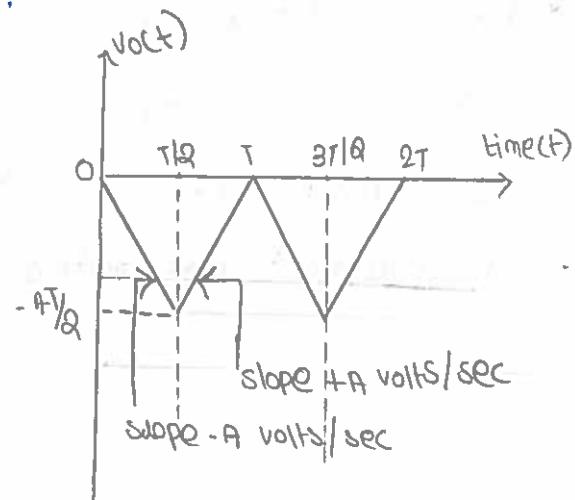
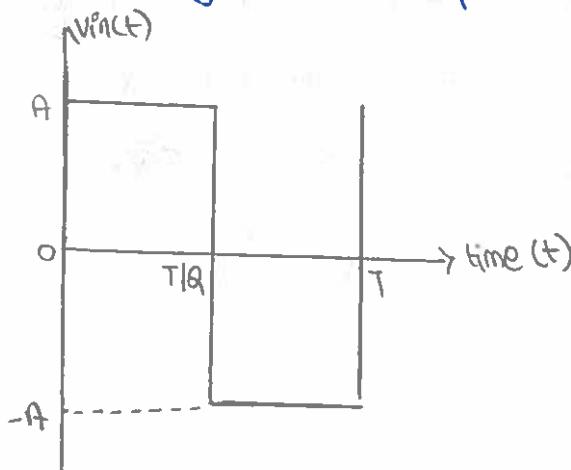
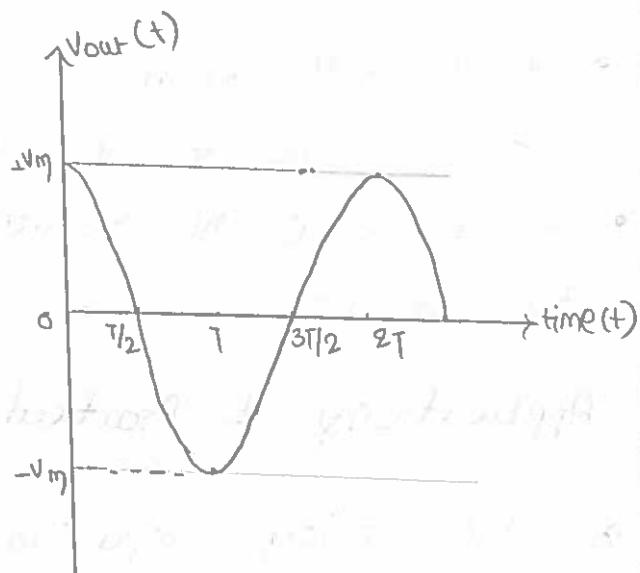
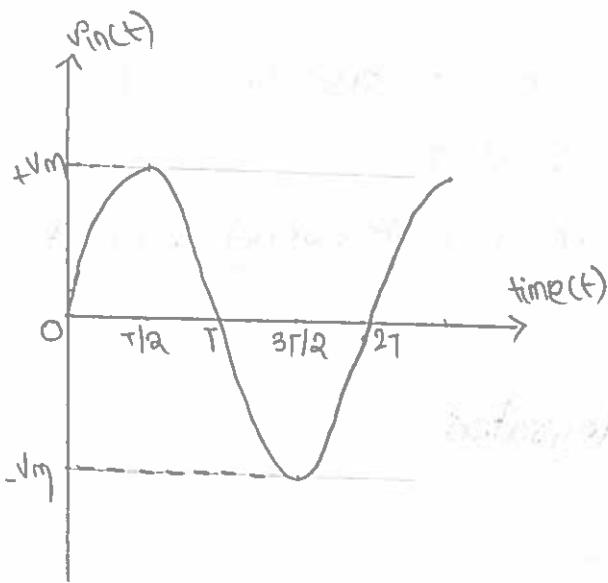


Fig :- output signal for step input

- Square wave input signal is converted into triangular output signal.



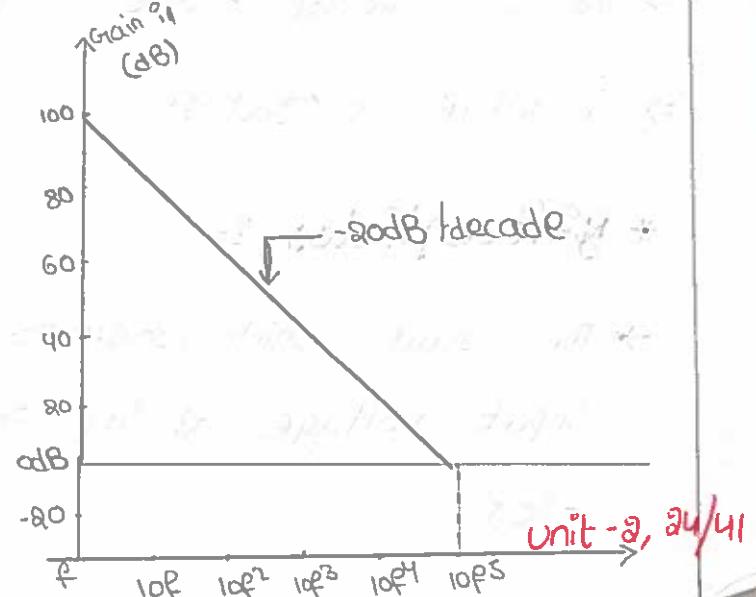
- Sine wave input is converted into cosine output signal.



Frequency Response of Ideal Integrators :-

* Let $f = f_b$ be the frequency at which gain of the op-amp becomes one dB

$$f_b = \frac{1}{2\pi R_1 C_F}$$



ii) Practical Integrator :-

- The limitations of an ideal integrator can be minimised in the practical integrator circuit, which uses a resistance R_F in parallel with the capacitor C_F .
- The practical integrator circuit is shown in fig.

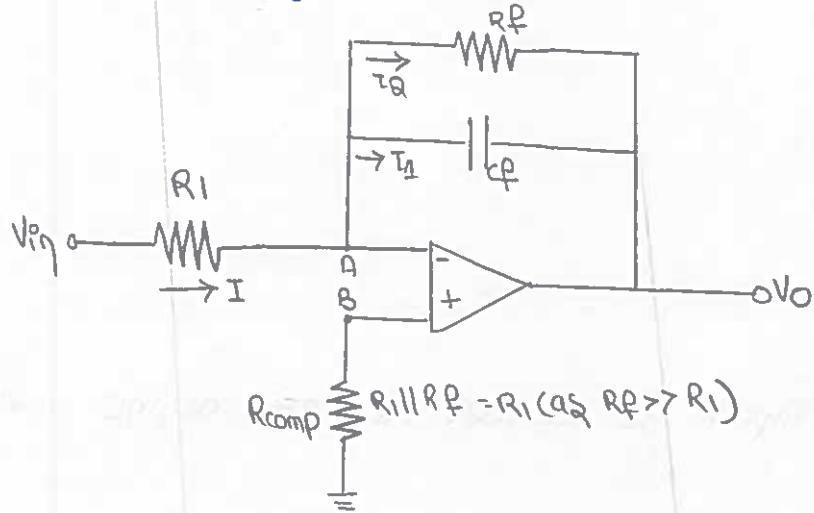


fig:- Practical Integrator circuit.

- The resistance R_{comp} is also used to overcome the errors due to the bias current.
- The resistance R_F reduces the low frequency gain of the op-amp.

Applications of Practical Integrator

- In the analog computers.
- In solving the differential equations.
- In analog to digital converters.
- Various signal wave shaping circuits.
- In RAMP generators.

* Differentiator :-

- The circuit which produces the differentiation of the input voltage at its output is called differentiator.

- The differentiator circuit which does not use any active device is called passive differentiator.
- while the differentiator using an active device like OP-amp is called an active differentiator.

i, Ideal Active op-amp Differentiator

- * The op-amp differentiator circuit is shown in fig.
- * The node B is grounded. The node A is also at the ground potential hence $V_A = 0$.
- * As input current of op-amp is zero, entire current I_1 flows through the resistance R_F .

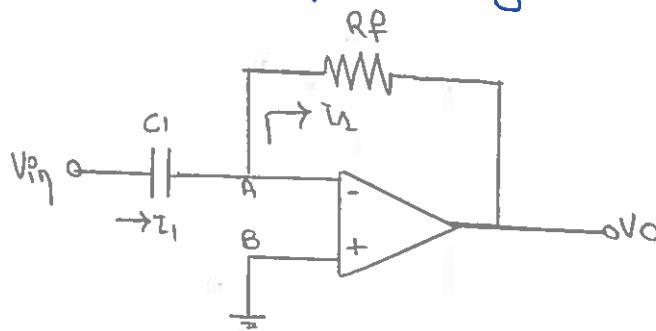


Fig :- op-amp differentiator

- From the input side we can write,

$$I_1 = C_1 \frac{d(V_{in} - V_A)}{dt}$$

$$= C_1 \frac{dV_{in}}{dt}$$

- From the output side we can write,

$$I = \frac{(V_A - V_0)}{R_F} = -\frac{V_0}{R_F}$$

- Equating the two equations

$$C_1 \frac{dV_{in}}{dt} = -\frac{V_0}{R_F}$$

$$V_0 = -C_1 R_F \frac{dV_{in}}{dt}$$

Input & output waveforms

- step input is converted into square wave output signal.

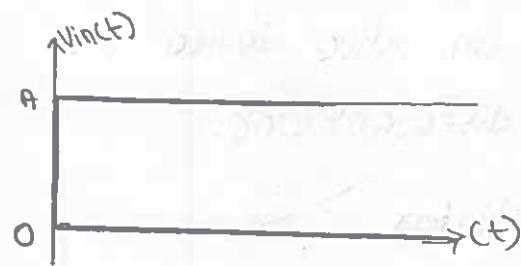


Fig: step input signal

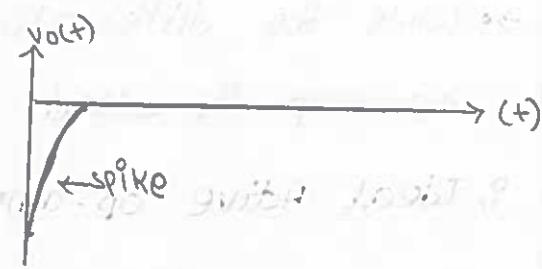


Fig: output signal

- square wave input

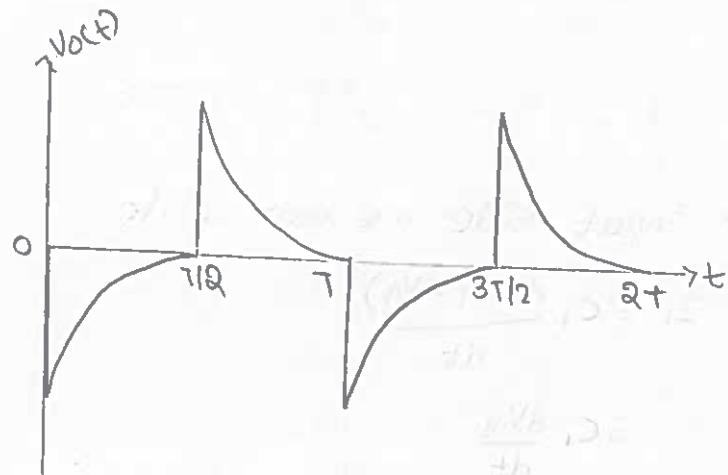
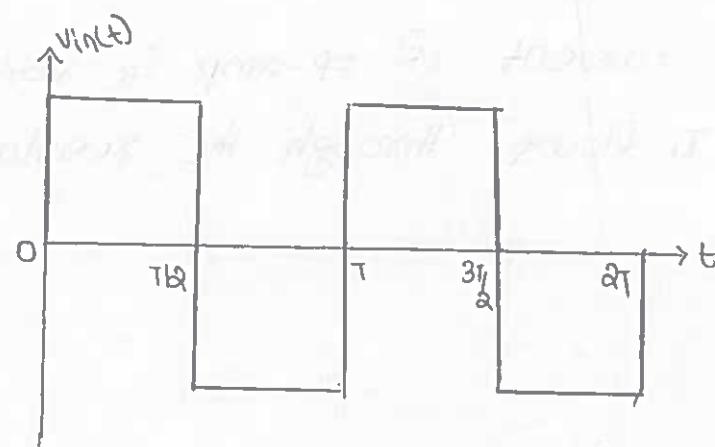


Fig: IIP & O/P for square wave input

- sine wave input.

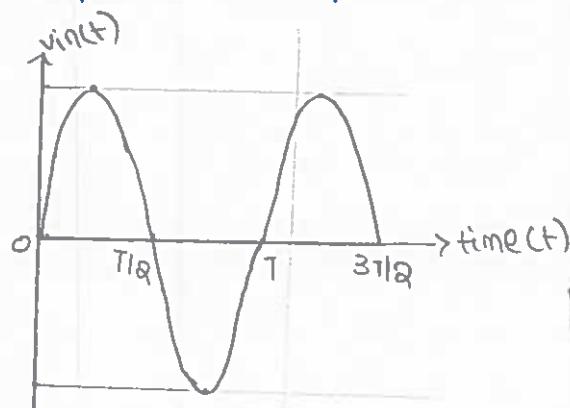
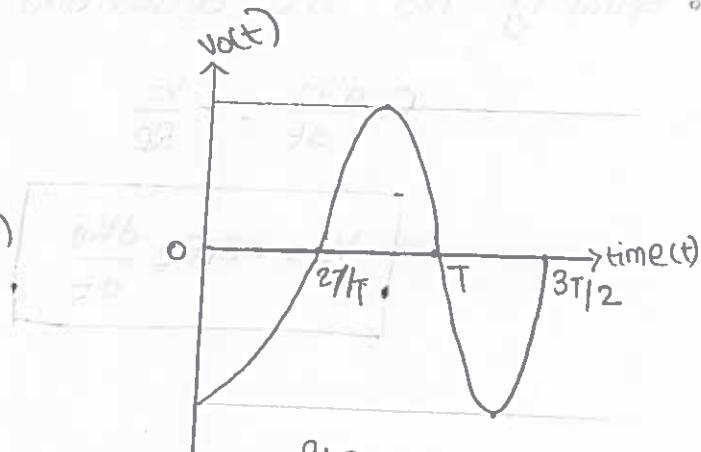


Fig: IIP & O/P for sine wave IIP



unit-2, 27/41

Practical Differentiator

- The noise and stability at high frequency can be corrected, in the practical differentiator circuit using the resistor R_1 in series with C_1 and the capacitor C_F in parallel with resistor R_F .
- The circuit as shown in Figure. The resistance R_{COMP} is used for bias compensation.

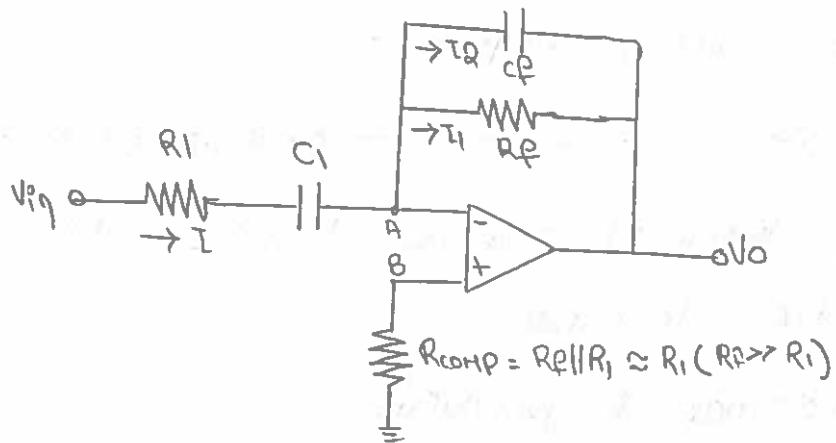


fig :- Practical differentiator circuit.

Applications of Practical Differentiator

- i, In the wave shaping circuits to detect the high frequency components in the input signal.
- ii, As a rate-of-change detector in the FM demodulators.

The differentiator circuit is avoided in the analog computers.

Comparators :-

- ⇒ A comparator is a circuit which compares the signal voltage applied at one input of an op-amp with a known reference voltage at the other input, and produce either a high or low output voltage, depending on which input is higher.

⇒ It produces output voltage which is either positive saturation voltage ($+V_{sat}$) or negative saturation voltage ($-V_{sat}$).

⇒ There are two types of comparator circuits

i, Non-inverting comparator

ii, Inverting comparator.

i, Non-Inverting Comparator

- The basic non-inverting comparator.
- In this comparator, the input voltage is applied to the non-inverting terminal and no reference voltage is applied to other terminal.
- So inverting terminal is grounded.

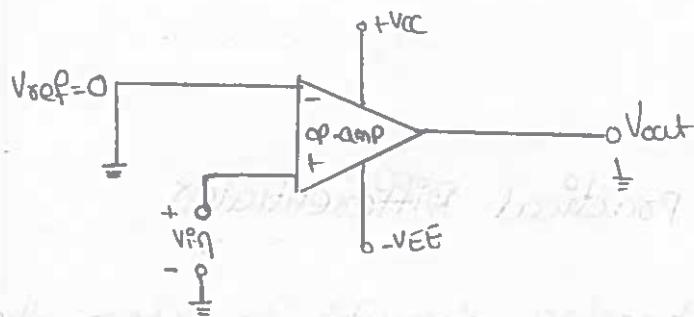


Fig:- Basic non-inverting comparator

- The input voltage is denoted as V_{in} while the voltage applied to other terminal with which V_{in} is compared is denoted as V_{ref} .
- In the basic comparator, $V_{ref} = 0V$.
- In the non-inverting comparator, if V_{in} is greater than V_{ref} then output is $+V_{sat}$ i.e., almost equal to $+V_{CC}$.
- while if V_{in} is less than V_{ref} then output is $-V_{sat}$ i.e., almost equal to $-V_{EE}$.

- Thus for the as $V_{ref} = 0V$ when V_{in} is positive then $V_o = +V_{sat}$ while when V_{in} is negative then $V_o = -V_{sat}$.

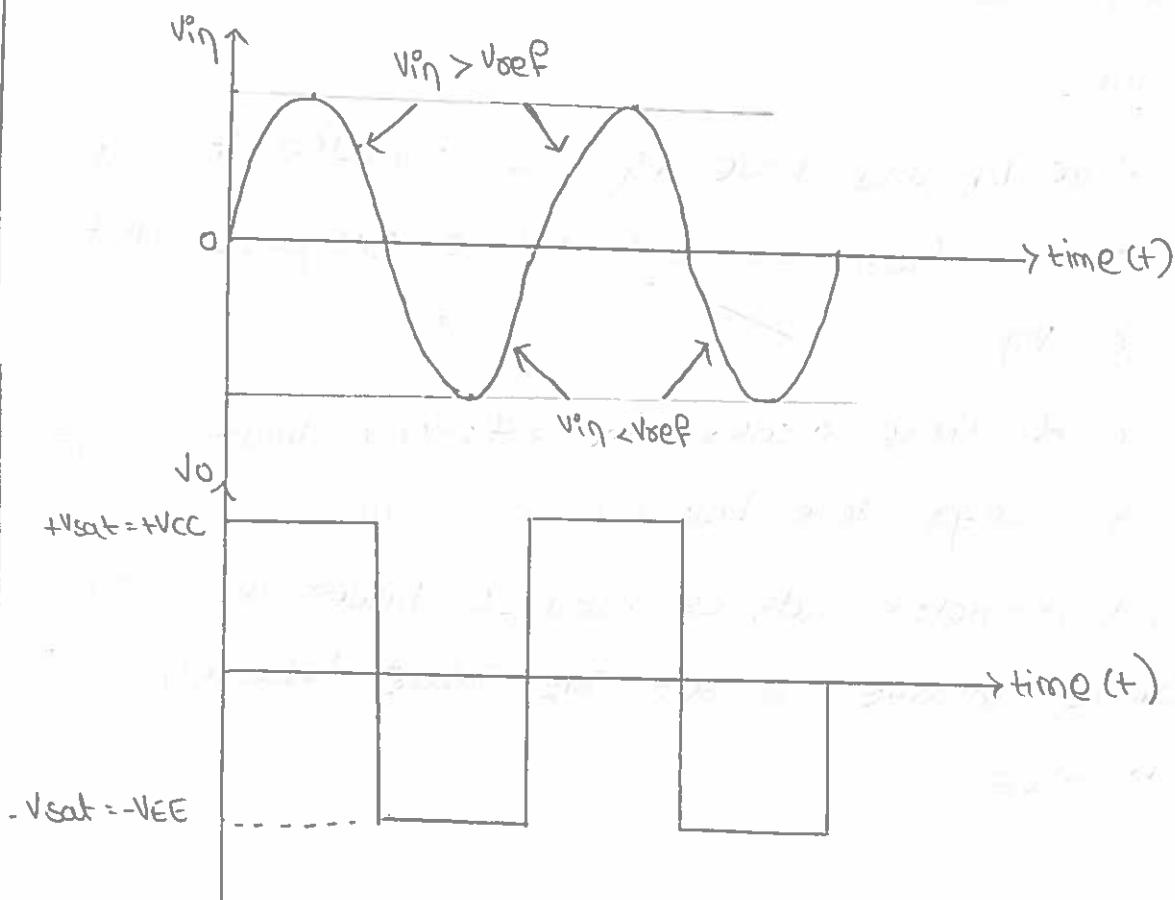
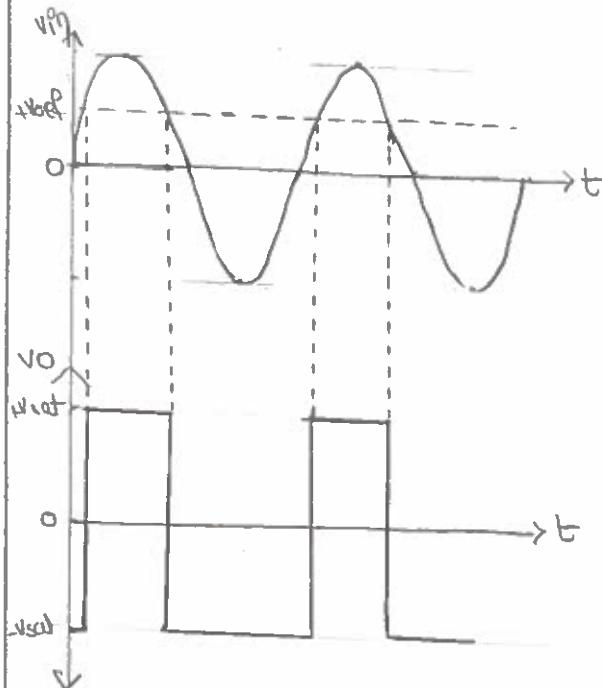
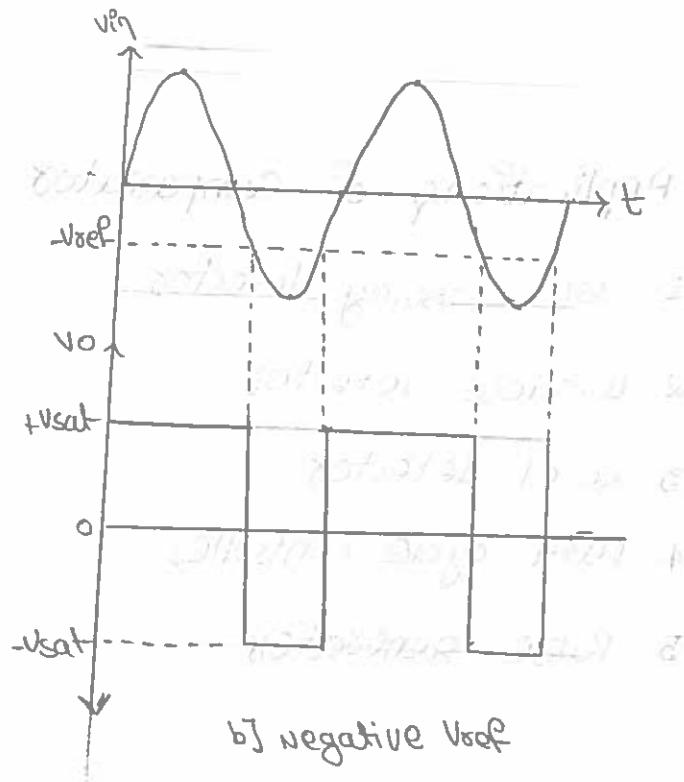


fig :- waveforms of a basic
non-inverting comparators

- If $V_{in} > V_{ref}$ then the output is $+V_{sat}$ while if $V_{in} < V_{ref}$ then the output is at $-V_{sat}$.



a) Positive V_{ref}



b) Negative V_{ref}

fig :- Input and output waveforms.

ii. Inverting Comparator

- Inverting practical comparator consists of protective diodes and potentiometer to adjust the reference voltage.
- The diode D_1 and diode D_2 are connected to protect the op-amp from damage due to excessive input voltage V_{in} .
- Because of these diodes, the difference input voltage V_{id} is always less than $0.7V$ or $-0.7V$.
- The potentiometer acts as a voltage divider and allows reference voltage to set any value between $+V_{cc}$ to $-V_{ee}$.

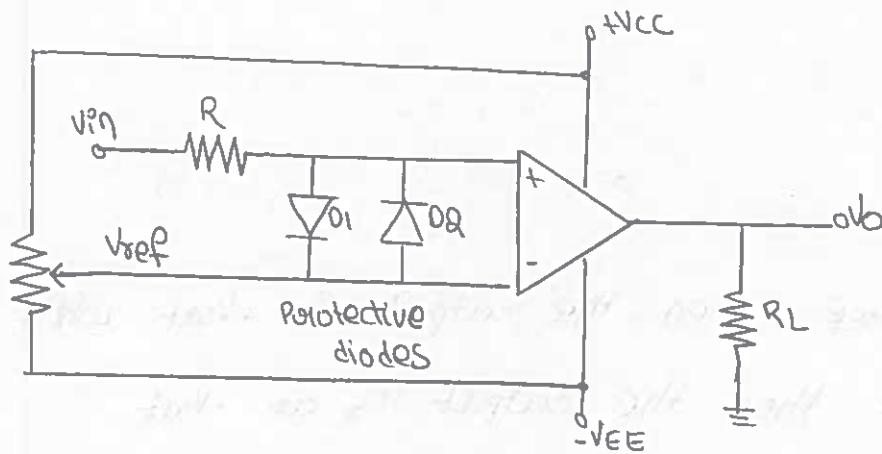


Fig :- Practical comparators circuit

Applications of comparators

- zero crossing detector.
- window detector
- level detector
- duty cycle controller
- pulse generator

Schmitt Trigger

12

- In a basic comparator, a feedback is not used and the op-amp is used in the open loop mode.
- The comparator circuit used to avoid such unwanted triggering is called regenerative comparator or schmitt trigger which basically uses a positive feedback.

i. Inverting Schmitt Trigger

- The inverting mode produces opposite polarity output. This is fed back to the non-inverting input which is of same polarity as that of output. This ensures positive feedback.
- When V_{in} is slightly positive than V_{ref} , the output gets driven into negative saturation at $-V_{sat}$ level.
- When V_{in} becomes more negative than $-V_{ref}$, then output gets driven into positive saturation at $+V_{sat}$ level.

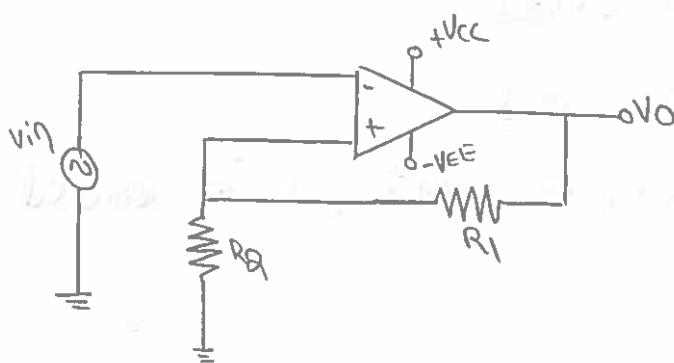


Fig :- inverting schmitt Trigger

- Now R_1 and R_2 forms a potential divider

$$+V_{ref} = \frac{V_o}{R_1 + R_2} \times R_2 = \frac{+V_{sat}}{R_1 + R_2} \times R_2 \quad \text{--- positive saturation}$$

$$-V_{ref} = \frac{V_o}{R_1 + R_2} \times R_2 = \frac{-V_{sat}}{R_1 + R_2} \times R_2 \quad \text{--- negative saturation}$$

→ The value of these threshold voltage levels can be determined and adjusted by selecting proper value of R_1 and R_2 .

$$V_{U_T} = \frac{+V_{sat} R_2}{(R_1 + R_2)}$$

$$V_{L_T} = \frac{-V_{sat} R_2}{(R_1 + R_2)}$$

→ The difference between V_{U_T} and V_{L_T} is called width of the hysteresis denoted as H .

$$H = V_{U_T} - V_{L_T}$$

$$= \frac{+V_{sat} R_2}{R_1 + R_2} - \left[\frac{-V_{sat} R_2}{R_1 + R_2} \right]$$

$$H = \frac{2V_{sat} R_2}{R_1 + R_2}$$

→ For positive V_{in} greater than V_{U_T} , the output becomes $+V_{sat}$ and for negative V_{in} less than V_{L_T} , the output becomes $-V_{sat}$ this is called inverting schmitt trigger.

i, $V_{in} < V_{L_T}$, $V_o = -V_{sat}$

ii, $V_{in} > V_{U_T}$, $V_o = +V_{sat}$

iii, $V_{L_T} < V_{in} < V_{U_T}$, $V_o = \text{previous state achieved.}$

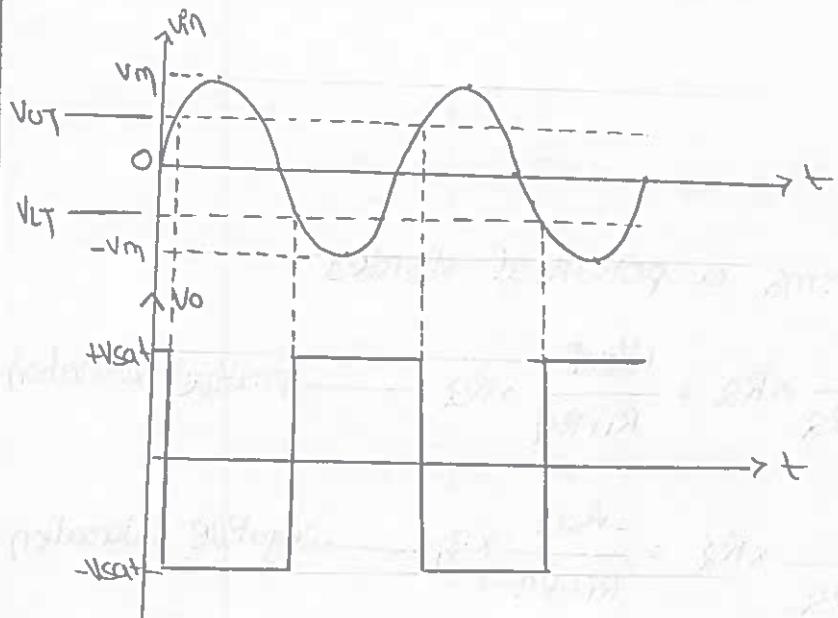


Fig 8:- Input and output wave forms

ii, Non-inverting Schmitt Trigger

- The non-inverting schmitt trigger circuit input is applied to the non-inverting input terminal of the op-amp.
- To understand the working of the circuit, let us assume that the output is positively saturated i.e., at $+V_{sat}$. This is fed back to the non-inverting input through R_1 . This is a positive feedback.

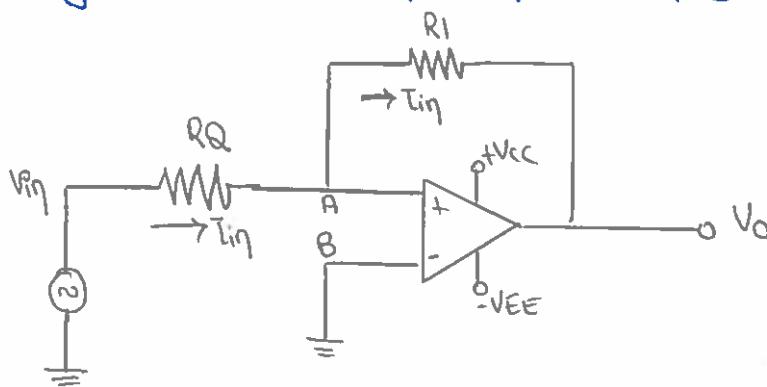


fig 8 - Non-inverting schmitt trigger.

$$V_A = \text{voltage at point A} = I_{in} R_2 \cdot V_{sat}$$

- As op-amp input current is zero, I_{in} entirely passes through R_1 .

$$\therefore I_{in} = \frac{V_o}{R_1} = \frac{+V_{sat}}{R_1}$$

$$V_{UT} = I_{in} R_2 = \frac{R_2}{R_1} (+V_{sat}) = V_{sat} \frac{R_2}{R_1}$$

$$V_{LT} = \frac{R_2}{R_1} (-V_{sat}) = -V_{sat} \frac{R_2}{R_1}$$

$$H = V_{UT} - V_{LT} = 2 V_{sat} \frac{R_2}{R_1}$$

* $V_{in} > V_{UT}$ V_o changes from $-V_{sat}$ to $+V_{sat}$

* $V_{in} < V_{LT}$ V_o changes from $+V_{sat}$ to $-V_{sat}$

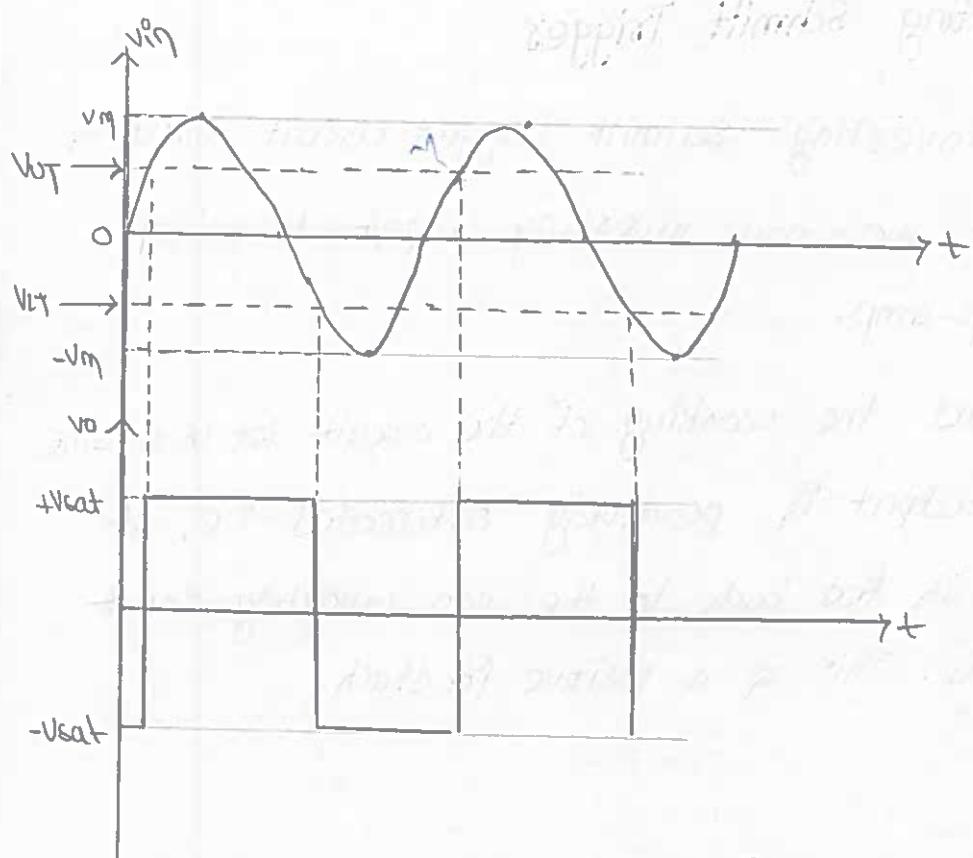


Fig 3- Input and output waveforms.

Multivibrators

A multivibrator is an electronic circuit used to implement a variety of simple two-state devices such as relaxation oscillators, timers, and flip-flops. It consisted of two vacuum tube amplifiers cross-coupled by a resistor-capacitor network. They called their circuit a multivibrator.

There are three types of multivibrator circuits.

i, Bistable Multivibrator

- As the name suggests, the bistable multivibrator has two stable states.
- The multivibrator can exist indefinitely in either of the two stable states.
- It requires an external trigger pulse to change from one stable state to another.
- The circuit remains in one stable state unless an external trigger pulses is applied.

ii, Mono stable Multivibrator

- The monostable multivibrator has only one stable state. The other is unstable referred as quasi-stable state.
- When an external trigger pulse is applied to the circuit, the circuit goes into the quasi-stable state from its normal state.
- After some time interval, the circuit automatically returns to its stable state.
- The circuit does not require any external pulse to change from quasi-stable to stable state.

iii, Astable Multivibrator

- The astable multivibrator has both the states as quasi-stable states. None of the states is stable state.
- Due to this, the multivibrator automatically makes the successive transitions from one quasi-stable state to other, without any external triggering pulse.
- The rate of transition from one quasi-stable state to other is determined by the circuit components.

Introduction to Voltage Regulators

- The voltage regulator circuit keeps the output voltage constant inspite of changes in the load current or input voltage.
- Its input is unregulated pulsating dc voltage obtained from filtered and rectified.
- Its output is constant dc voltage which is almost ripple free.

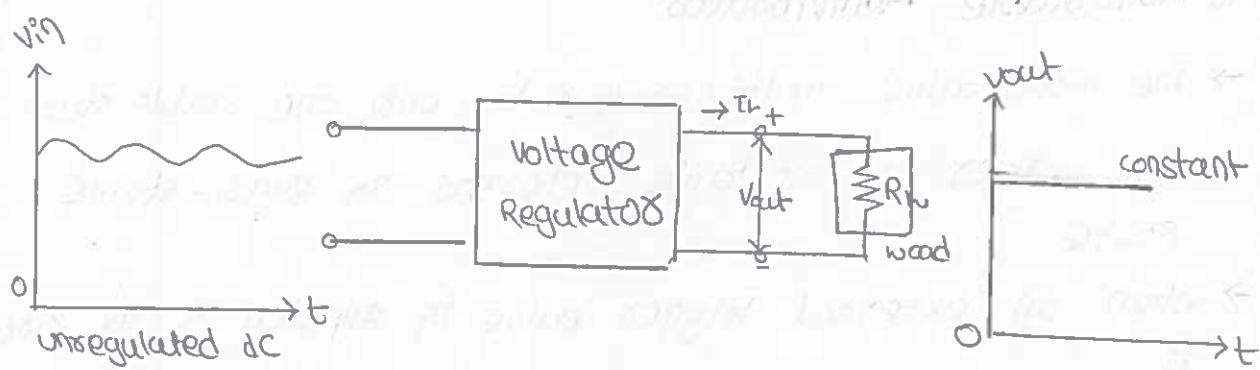


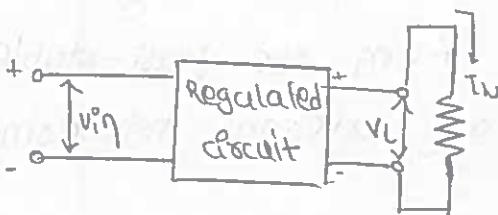
Fig:-concept of voltage Regulator.

\Rightarrow Parameters of Voltage Regulator.

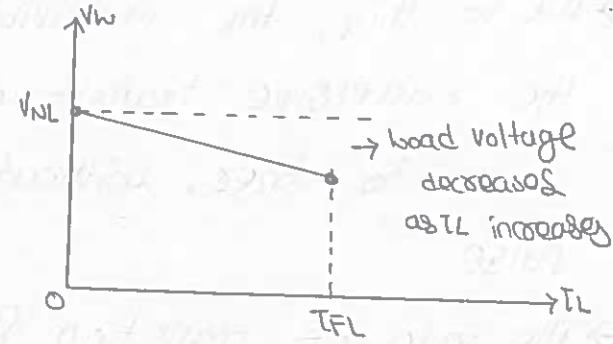
The two important parameters of a voltage regulator are,

i. Load regulation and ii. Line regulation.

- The load regulation is the change in the regulated output voltage when the load current is changed from minimum to maximum.
- Consider the regulator as shown.



a) Regulator



b) load regulation characteristics

- Mathematically load regulation (LR) is defined as

$$\% LR = \frac{V_{OL} - V_{FL}}{V_{FL}} \times 100$$

- The ideal value of load regulation is zero.
- The line regulation is also called source regulation (SR).
- Mathematically it is given by

$$\% SR = \frac{SR}{V_{nom}} \times 100$$

Advantages of IC Voltage Regulators

1. Easy to use.
2. It greatly simplifies power supply design.
3. Due to mass production, low in cost.
4. IC voltage regulators are versatile.
5. Conveniently used for local regulation.
6. These are provided with features like built in protection, programmable output current / voltage boosting, internal short circuit current limiting etc.

Features of 723

- 150 mA output current without external pass transistor.
- Output currents in excess of 10 A possible by adding external transistors.
- Input voltage adjustable from 9V to 37V.
- Can be used as either a linear or a switching regulator.

Problems :-

Design a practical integrated circuit with a.d.c. gain of 10, to integrate a square wave of 10kHz.

Sol

$$|A|_{dc} = \frac{R_f}{R_i} \text{ i.e., } 10 = \frac{R_f}{R_i}$$

The input frequency is $f = 10\text{kHz}$

Now for the proper integration $f \geq 10f_a$ where f_a is the break frequency of the practical integrator.

$$\therefore f/f_a = 10 \text{ i.e., } f_a = \frac{f}{10} = \frac{10 \times 10^3}{10} = 1000\text{Hz}$$

Now for the practical integrator,

$$f_d = \frac{1}{2\pi R_F C_F} \quad \text{i.e., } 1000 = \frac{1}{2\pi R_F C_F}$$

$$\therefore R_F C_F = 1.5915 \times 10^{-4}$$

Selecting $R_1 = 10k\Omega$

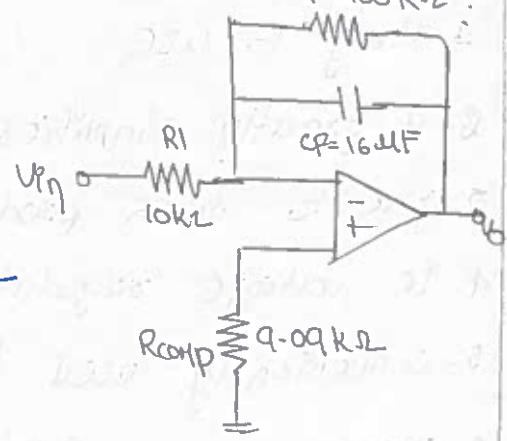
$$R_F = 10R_1 = 10 \times 10 = 100k\Omega$$

$$\therefore C_F = \frac{1.5915 \times 10^{-4}}{100 \times 10^3}$$

$$= 1.5915 \times 10^{-9} F = 16nF$$

$$\text{And } R_{\text{comp}} = R_1 / R_F$$

$$\therefore R_{\text{comp}} = \frac{10 \times 100}{10 + 100} = 9.09k\Omega$$



- Q) For a schmitt trigger shown in the Fig., calculate threshold voltage levels and hysteresis. Assume $V_{\text{sat}} = 0.9V_{\text{cc}}$

All $V_{\text{cc}} = +15V$

$$V_{\text{sat}} = 0.9V_{\text{cc}} = 0.9 \times 15 = 13.5V$$

$$R_1 = 51k\Omega, R_2 = 120\Omega$$

$$V_{OT} = \frac{+V_{\text{sat}} R_2}{R_1 + R_2} = \frac{13.5 \times 120}{51 \times 10^3 + 120}$$

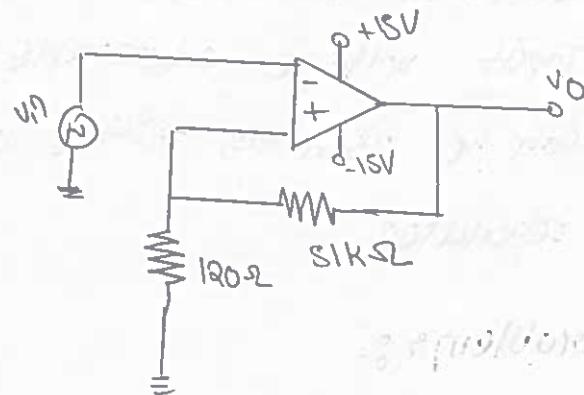
$$V_{OT} = 0.08169V$$

$$V_{LT} = \frac{-V_{\text{sat}} R_2}{R_1 + R_2} = \frac{-13.5 \times 120}{51 \times 10^3 + 120} = -0.08169V$$

$$H = V_{OT} - V_{LT}$$

$$= 0.08169 - (-0.08169)$$

$$H = 68.88 \text{ mV}$$



3. calculate the change in the output voltage if input changes by 5V with FRR for S/H circuit is 80 dB.

$$\text{FRR} = 20 \log_{10} \frac{\Delta V_i}{\Delta V_o}$$

$$80 = 20 \log_{10} \frac{5}{\Delta V_o}$$

$$\text{i.e., } \Delta V_o = 0.5 \text{ mV}$$

- 4 Design a differentiator to differentiate an input signal that varies in frequency from 10 Hz to 1 kHz. If a sine wave of 1V peak at 100 Hz is applied to this differentiator, draw the output waveform.

soln The highest input frequency $f_a = 1 \text{ kHz}$

$$\text{choose } C_1 = 0.1 \mu\text{F}$$

$$f_a = \frac{1}{2\pi R_F C_1} \text{ i.e., } 1 \times 10^3 = \frac{1}{2\pi R_F \times 0.1 \times 10^{-6}}$$

$$\therefore R_F = 1.591 \text{ k}\Omega = 1.5 \text{ k}\Omega$$

$$\text{Let } f_b = 10 f_a = 10 \text{ kHz}$$

$$f_b = \frac{1}{2\pi R_1 C_1}$$

$$\therefore 10 \times 10^3 = \frac{1}{2\pi R_1 \times 0.1 \times 10^{-6}}$$

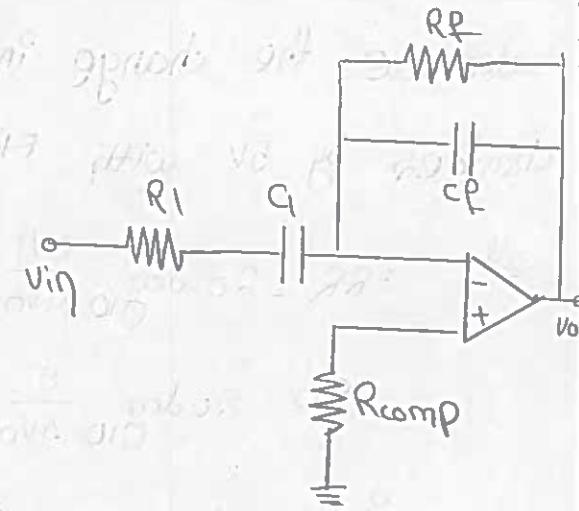
$$\therefore R_1 = 159.15 \Omega$$

$$\text{now } R_1 C_1 = R_F C_F$$

$$\therefore C_F = \frac{R_1 C_1}{R_F} = 0.01 \mu\text{F}$$

$$R_{comp} = R_1 || R_F = 100 \cdot 67 \Omega$$

The designed circuit is shown in the figure.



$$V_o = -R_F C_F \frac{dV_{in}}{dt}$$

$$= -1.5 \times 10^3 \times 0.1 \times 10^{-6} \frac{d}{dt} [\sin 2\pi \times 1 \times 10^3 t]$$

$$= -1.5 \times 10^{-4} \times 2\pi \times 1 \times 10^3 [\cos 2\pi \times 10^3 t]$$

$$= -0.9424 \cos(2\pi \times 10^3 t)$$

waveforms

