ANALOG AND DIGITAL ELECTRONICS

UNIT 1: LINEAR ICS: OP-AMPS, TIMERS AND THEIR APPLICATIONS

OPERATIONAL AMPLIFIER

Introduction;

OP-AMP was introduced in the year 1940s was designed in 1948 by vacuum tubes used in Analog Computers for various mathematical operation came into the name OPERATIONAL Amplifier

Between (1964-1968) popular Op-Amp IC, 741was fabricated using BJTs and FET along with other supporting components on a single Semiconductor chip (Silicon Chip) or Wafer.

As resistors, capacitors and Operational Amplifiers are the basic building blocks of Analogue Electronic Circuits.Op-amps are linear devices, having all properties required for nearly ideal DC amplification, and are used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation.

In a linear operational amplifier, the output signal is the amplification factor, known as the amplifiers gain (A) multiplied by the value of the input signal.

Op-Amp Summary

High gain DC amplifier that uses one or more external feedback networks to control its response and characteristics.

We can connect external resistors or capacitors to the op-amp in a number of different ways to form basic “building Block” circuits such as, Inverting, Non-Inverting, Voltage Follower, Summing, Differential, Integrator and Differentiator type amplifiers.

Op-amps are available in IC packages of single, dual or quad op-amps within one single device.

ADVANTAGES/BENEFITS OF IC

- Cheap
- Save space
- Low power
- High Flexibility
- Dependability

- High durability

Hence IC 741 OP-AMP has become part of almost every electronic circuit which uses Linear Integrated Circuit.

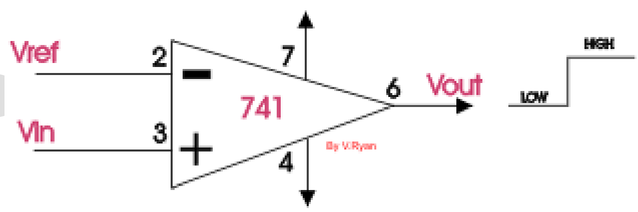
USES OF AN OP-AMP

- In Computers
- In communication
- In display
- In measuring system
- In process control
- In power sources and Signal sources

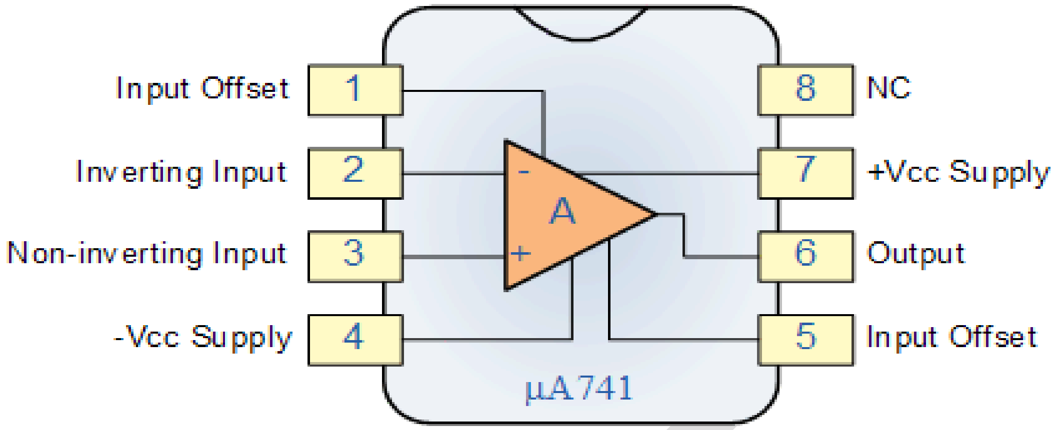
Op-amp is an excellent high gain DC amplifier

OP-AMP SYMBOL, PIN DIAGRAM AND TERMINALS

Symbol



Op-Amp PIN diagram



Terminals

1. Inverting input terminal (Marked as negative, no 2)
2. Non-Inverting input terminal (Marked as positive, no 3)
3. Output terminal (no.6)
4. Positive supply voltage terminal (+Vcc, no 7)
5. Negative supply voltage terminal (-Vee, , no 4)

POWER SUPPLY

OP-AMP works on a DUAL RPS (regulated power supply) consist of two supply voltages, both DC whose middle point is generally the ground terminal.

Categories of dual power supply;

1. **Balanced Dual power supply**

   It is balanced dual power supply if both +Vcc and –Vee are equal in magnitude.

   Commonly ±15V

2. **Unbalanced Dual power supply**

   It is unbalanced dual power supply if +Vcc and –Vee are unequal in magnitude.

   For example, Vcc= +15V and Vee= -12V

NOTE: Mostly, the balanced power supply is used.

IDEAL OP-AMP

The Op-amp amplifies the difference between two input signals.

<u>Ideal Op-amp characteristics</u>:

1) **Infinity input impedance (Rin)**

   This ensures no current through ideal terminals, it draws no current at both input terminals I1=I2=0

   Any source can drive it and no loading on the driven stage.

2) **Infinity Gain (Aol)**

   Due to the infinity input impedance

3) **Zero output impedance (R0)**

   The output voltage is independent to the current drawn from the output terminals. Output can drive infinity number of other circuits.

4) **Zero offset voltage**

   As V1=V2=0 due to small output voltage, this ensures zero output for the zero input signal voltage.

5) **Infinity Bandwidth**

   Bandwidth is the range of frequency over which the amplifier performance is satisfactory. Infinity bandwidth ensures that the Gain of an Ideal Op-Amp will be constant over the frequency range from DC (zero frequency) to infinity frequency.

NOTE: OP-AMP AMPLIFIERS BOTH AC AND DC SIGNALS.

6) **Infinity CMRR**

7) **Infinity SLEW RATE**

8) **No effect of TEMPERATURE**

   OP-AMP does not change with temperature

<u>Op-amp parameters</u>:

- **CMRR (Common mode rejection ratio)**

CMRR is an ability of an OP-AMP to reject the COMMON MODE SIGNALS. When the same values of an input signals (V1=V2) are applied at the terminals of an OP-AMP, differential amplifier said to be operating in the COMMON MODE CONFIGURATION.

Many disturbance signals and noise signals appears as the common input signals to both the input terminals of the differential amplifier. Such common signal should be rejected by the differential amplifier

Simply, CMRR= $\left|\frac{Ad}{Ac}\right|$

Where, Ad=differential Gain

Ac=common mode Gain=0 for common mode configuration

Hence, CMRR= $\frac{Ad}{0}$ = Infinite

Practically, Ad is very large and

AcIs very small

Therefore, CMRR is very large

- **SLEW RATE**

The slew rate of an electronic circuit is the maximum rate of change of the output voltage. Slew rate is usually expressed in units of V/µs.

$$\mathrm{SR} = \max\left(\left|\frac{dv_{\text{out}}(t)}{dt}\right|\right)$$

Where $v_{\text{out}}(t)$ is the output produced by the amplifier as a function of time *t*

Measurement

The slew rate can be measured using a **function generator** (usually square wave) and **oscilloscope**. The slew rate is same for both when feedback is considered ornot considered.

Causes of Slew rate:

- Limited charging rate of the compensating capacitor
- Current limiting
- Saturation of internal stages of an OP-AMP

NOTE: For the large charging rate, the capacitor should be very small; (or) Charging current should be large

If maximum current of internal capacitor of an OP-AMP is known, SLEW RATE is given by

S = $\frac{Imax}{C}$

Any delay of an OP-AMP in slew rate results onto distortion of output signals.

- **PSRR (Power supply rejection ratio)**

It is also called PSV (Power Supply Sensitivity).

Change in input Voltage is due to the change in the supply voltage producing it.. For example, if Vee is constant and due to a certain change in +Vcc cause change in the input offset voltage.

Hence; PSRR= $\frac{\Delta Vios}{\Delta Vcc}\Big|$ Constant: Vee

If Vcc- is constant ,Vee – changes

Since input offset voltage is very small, it is expressed in µ$\frac{V}{v}$

- **VIRTUAL GROUND**

In basic inverting configuration since the positive input is grounded, the op-amp will do everything to keep the negative input at ground as well.

APPLICATIONS OF OP-AMP

The applications of an op-aamp are classified into two categories

Linear op-amp application

Output voltage of an op-amp varies lineary with respect to the input. Negative feedback is used, connected to the negative terminal of an op-amp inputs.
Such application are : Integrator, Adder, Subtractor, instrumentation amplifier

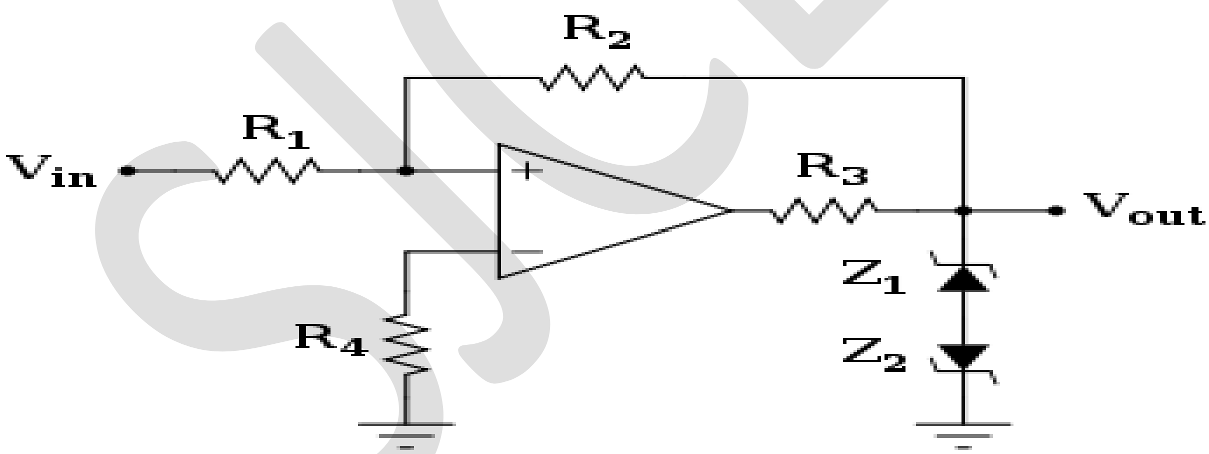
Non linear op-amp application
Feedback is given to non-inverting terminal of an op-amp. Sometime, feedback may get connected to the inverting terminal together with the nonlinear compoments such as DIODES, TRANSISTORS etc
Such application is: Precision rectifier, Log amplifier, Ant lo amplifier, comparator, schmitt trigger circuits
In analysis of various circuits, the assumptions discussed previously are used

i. Op-amp input current is zero.
ii. Potential difference between inverting and non-inverting terminals is zero

1) Inverting Amplifier

This amplifier provides a total phase shift of 180 degree to an input signal. An input is given to terminal number two of an op-amp.
Output of an op-amp is out of phase with respect to an input.

Diagram:



NOTE: Va = Vb (NODES VOLTAGES, Virtual ground concept)
I1 = I2 (High op-amp input impedance)

Current through resistor R1 is I1

I through R1 = $\frac{Vin-Va}{R1}$ = $\frac{Vin}{R1}$ (As Va = 0)

Current through R2 is I2

I through R2 $= \frac{Va - Vo}{Rf} = \frac{-Vo}{Rf}$ (As Va = 0)

Hence; by equating the two currents I1 = I2

$$Vo = \frac{-RfVin}{R1}$$

And Voltage Gain is: $Av = \frac{Vo}{Vin} = \frac{-Rf}{R1}$

Negative sign shows the phase shift of an output signal with respect to the input signal.

OBSERVATIONS:

- ✓ Out put is inverted with respect to the input
- ✓ Voltage gain is independent to open loop gain
- ✓ Gain depends on the ratio of two resistors
- ✓ If:

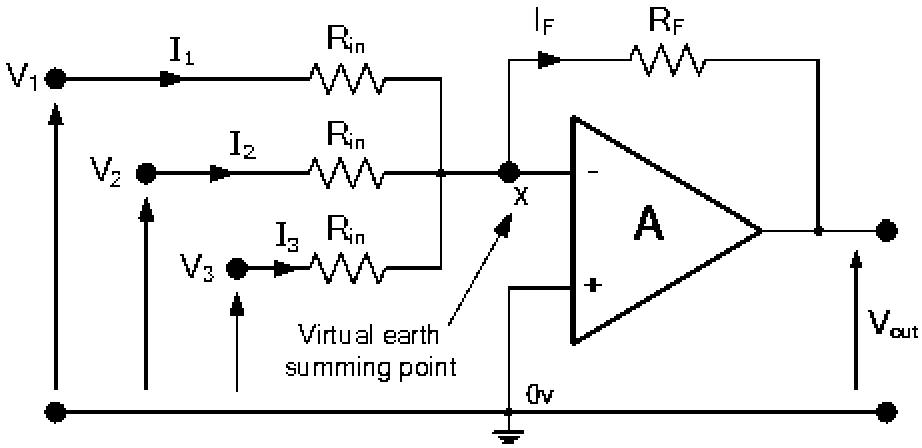
  Rf> R1: Gian is > 1
  Rf < R1: Gian is < 1
  Rf = R1: Gian is = 1

- ✓ If Gain is not one (other than one); Circuit is called SCALER CHANGER, otherwise if Gain is equal to one is called PHASE INVERTER

2) <u>The Summing Amplifier</u>

The output voltage is the Sum of multiple inputs ,Is also called as "*voltage adder*" circuit as shown below.

Diagram:



The output voltage, (Vout) now becomes proportional to the sum of the input voltages, V1, V2, V3. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V1}{Rin} + \frac{V2}{Rin} + \frac{V3}{Rin}\right]$$

$$\text{Inverting Equation: } Vout = -\frac{Rf}{Rin} \times Vin$$

$$\text{then, } -Vout = \left[\frac{R_F}{Rin}V1 + \frac{R_F}{Rin}V2 + \frac{R_F}{Rin}V3\right]$$

However, if all the input impedances, (Rin) are equal in value, we can simplify the above equation .

$$-Vout = \frac{R_F}{R_{IN}}\left(V1 + V2 + V3 \ldots.etc\right)$$

Op-amp circuit will amplify each individual input voltage and produce an output voltage signal that is proportional to the algebraic "SUM" of the three individual input voltages V_1, V_2 and V_3.

A **Scaling Summing Amplifier** can be made if the individual input resistors are "NOT" equal. Then the equation would have to be modified to:

$$-Vout = V1\left(\frac{Rf}{R1}\right) + V2\left(\frac{Rf}{R2}\right) + V3\left(\frac{Rf}{R3}\right) \ldots.etc$$

(Or)

$$-Vout = Rf\left(\frac{V1}{R1} + \frac{V2}{R2} + \frac{V3}{R3}\right) \ldots.etc$$

3) The Non-inverting Op-Amp

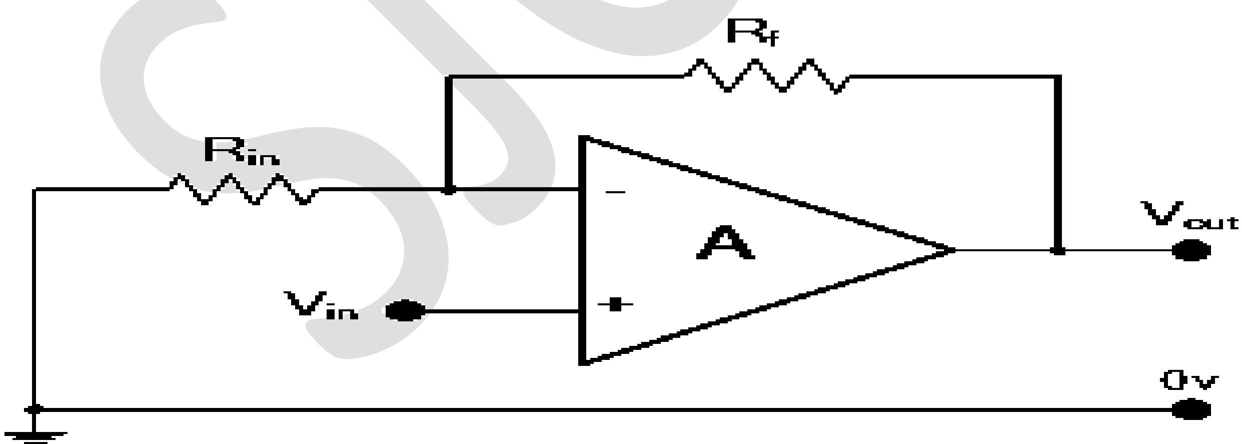
The output signal is “in-phase” with the input signal.

In this configuration, the input voltage signal, (Vin) is applied directly to the non-inverting (+) input terminal.The output gain of the amplifier becomes “Positive”

Feedback control of the non-inverting operational amplifier is achieved by applying a small part of the output voltage signal back to the inverting (-) input terminal via a Rf – R2 voltage divider network, again producing negative feedback.

This closed-loop configuration produces a non-inverting amplifier circuit with very good stability,

Diagram



Junction is a “virtual earth” summing point.

Then using the formula to calculate the output voltage of a potential divider network, we can calculate the closed-loop voltage gain (A V) of the Non-inverting Amplifier as follows:

Then the closed loop voltage gain of a Non-inverting Operational Amplifier will be given as:

$$A_{(v)} = 1 + \frac{R_F}{R_2}$$

Overall closed-loop gain of a non-inverting amplifier will always be

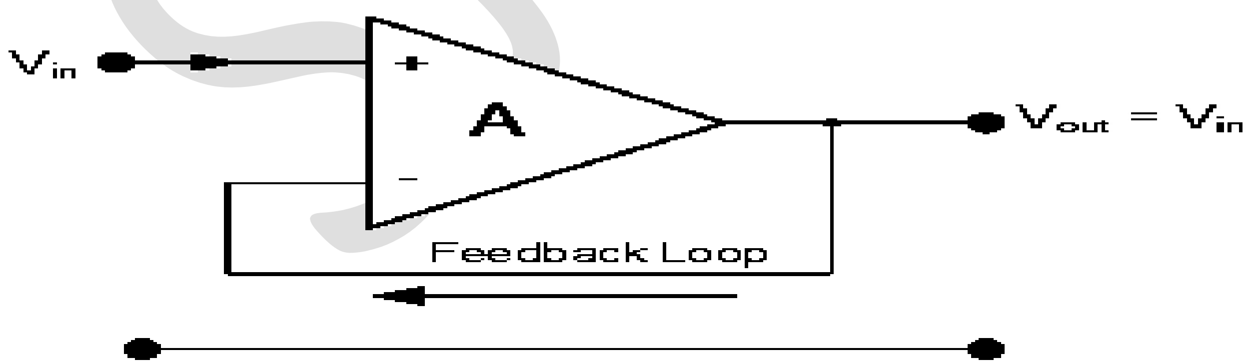
-greater but never less than one (unity),

-positive in nature and

-determined by the ratio of the values of Rf and R2 = Rin.

4) Voltage Follower (Unity Gain Buffer)

This is a unity gain “buffer” The output voltage follows the input voltage



Rf equal to zero, (Rf = 0), and resistor R2 equal to infinity, (R2 = ∞), then the circuit would have a fixed gain of “1″ .

As the input signal is connected directly to the non-inverting input of the amplifier:

$$V_{out} = V_{in}.$$

This then makes the voltage follower circuit ideal as a Unity Gain Buffer circuit.

It also called, the SOURCE FOLLOWER, BUFFER AMPLIFIER or ISOLATION AMPLIFIER

$$V_{out} = A(V_{in})$$

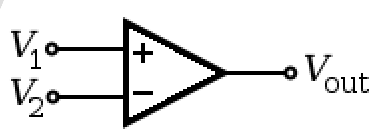
$$(V_{in} = V+) \text{ and } (V_{out} = V-)$$

$$\text{therefore Gain, } (A_V) = \frac{V_{out}}{V_{in}} = +1$$

5) Op- Amp as a Comparator

A **comparator** is a device that compares two voltages or currents and outputs a digital signal indicating which is larger.

It has two analog input terminals V_+ and V_- and one binary digital output V_o.



$$V_o = \begin{cases} 1, & \text{if } V_+ > V_- \\ 0, & \text{if } V_+ < V_- \end{cases}$$

Where 1= HIGH and 0= LOW

A comparator consists of a specialized high-gain differential amplifier.

Application:

-In analog-to-digital converters (ADCs),

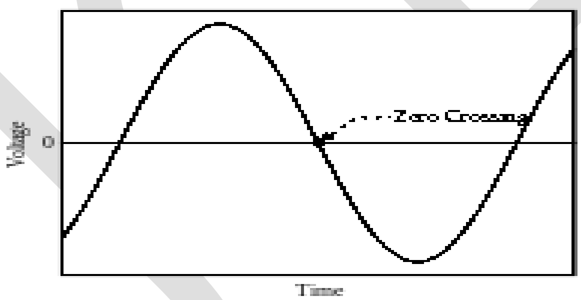
-In relaxation oscillators.

6) Zero crossing detector

Basic comparator can be used as a zero crossing detector.

It answers the questions: Is Vin greater or less to zero

Waveforms



Operation

In +ve half cycle, Vin is +ve above Vreference; hence output is positive saturation.

In –ve half cycle, Vin is –ve below Vreference; hence output is negative saturation.

Generally;

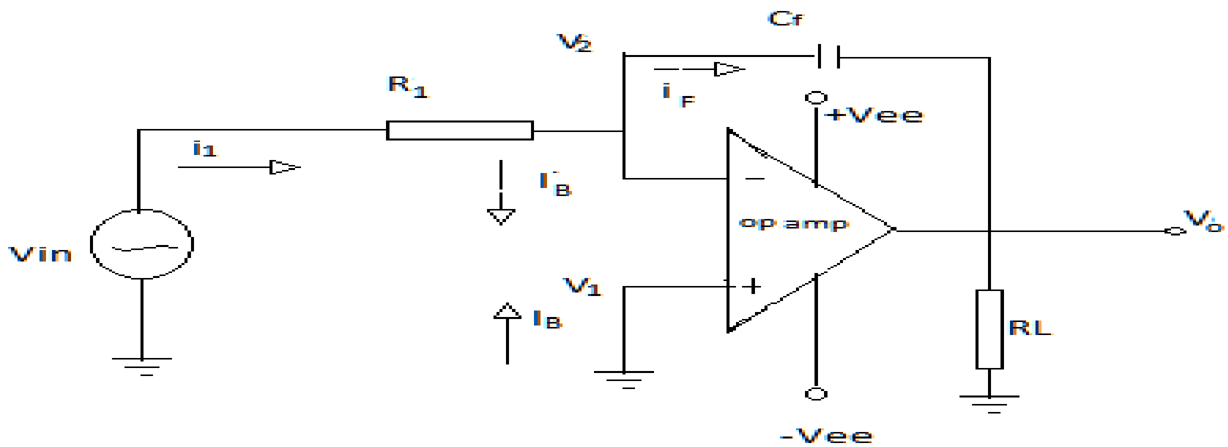
Output switches between positive and negative saturation whenever input signal crosses the zero level. This device can be used as a sine to square wave converter.

7) Op-Amp as an Integrator

The output voltage is thus the integral of the input

The fundamental integrator circuit is constructed by placing a capacitor C, in the feedback loop of an inverting amplifier.

Diagram:



Va =Vb (Virtual ground concept)

I1 = I2 (High op-amp input impedance)

Current through resistor R1 is I1

I through R1 = $\frac{Vin-Va}{R1} = \frac{Vin}{R1}$ (As Va = 0)

Current through R2 is I2

I through R2 $= \frac{Cfd(Va-Vo)}{dt} = \frac{-CfdVo}{dt}$ (As Va = 0)

Hence; by equating the two currents I1 = I2

$$Vo = \frac{-1}{R1Cf}\int_0^t Vindt$$

Negative sign shows the phase shift of an output signal with respect to the input signal.

Integrating from 0 to t, we obtain

. The voltage is the constant of integration and corresponds to the capacitor voltage at time t = 0.

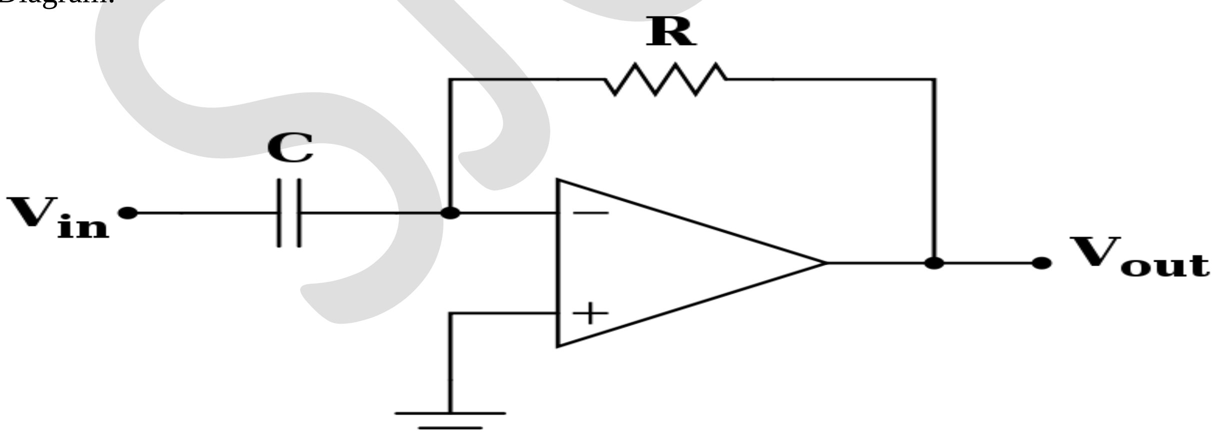
Applications of an Integrator

- Analog computers
- ADC
- Ramp generator
- Wave shaping circuits
- Solving differential equations

8) **Op-Amp as a Differentiator**

The output voltage is thus the differential of the input. A differentiator circuit is obtained by replacing the capacitor with resistor.
For an ideal op-amp, the current flowing through the capacitor, is equal to the current flowing through the resistor and thus;

Diagram:



Va =Vb (Virtual ground concept)
I1 = I2 (High op-amp input impedance)
Current through resistor R1 is I1

$$\text{I through R1} = \frac{C1d(Vin-Va)}{dt} = \frac{C1dVin}{dt} \text{ (As Va = 0)}$$

Current through R2 is I2

$$\text{I through R2} = \frac{(Va-Vo)}{Rf} = \frac{-Vo}{Rf} \text{ (As Va = 0)}$$

Hence; by equating the two currents I1 = I2

$$Vo = \frac{-C1RfdVin}{dt}$$

The output is thus proportional to the derivative of the input.
Applications:

- As a rate of change detector in the FM DEMODULATORS
- Detect high frequency components in the input signal in wave shaping circuit.

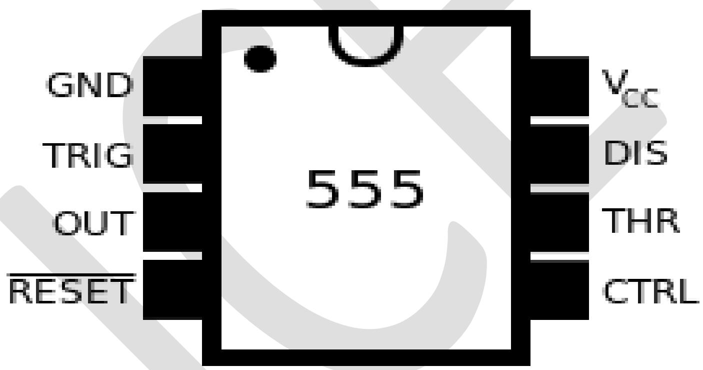
555 TIMER

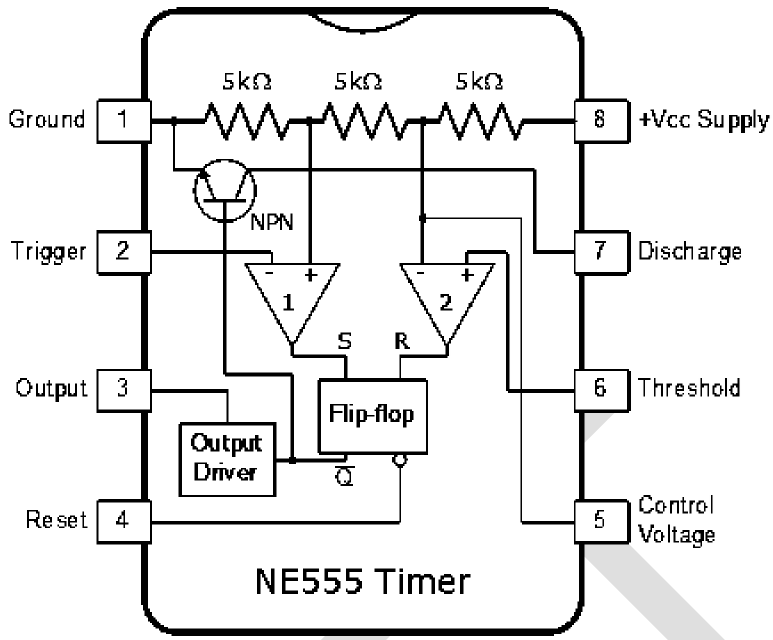
It is a versatile IC (1970) .It is a time monitoring IC. It has three modes of operation which are the **monostable ,astable, bistablemultivibrator**

Operations in the industry are scheduled according to the time requirements. Raw material is processed in stages. Time period for each stage of processing the material is scheduled.
e.g 15minutes for washing

Timing requirement for each stage is done by either ELECTRONIC CIRCUIT or PNEUMATIC (Air) DEVICE. These circuits provides TIME DELAY for each stage.

PIN Diagrams





555 Timer IC Applications

- Monostable multivibrator
- Astable multivibrator
- Linear ramp generator
- Missing pulse detector
- Automatic battery charger

Basic charging circuit

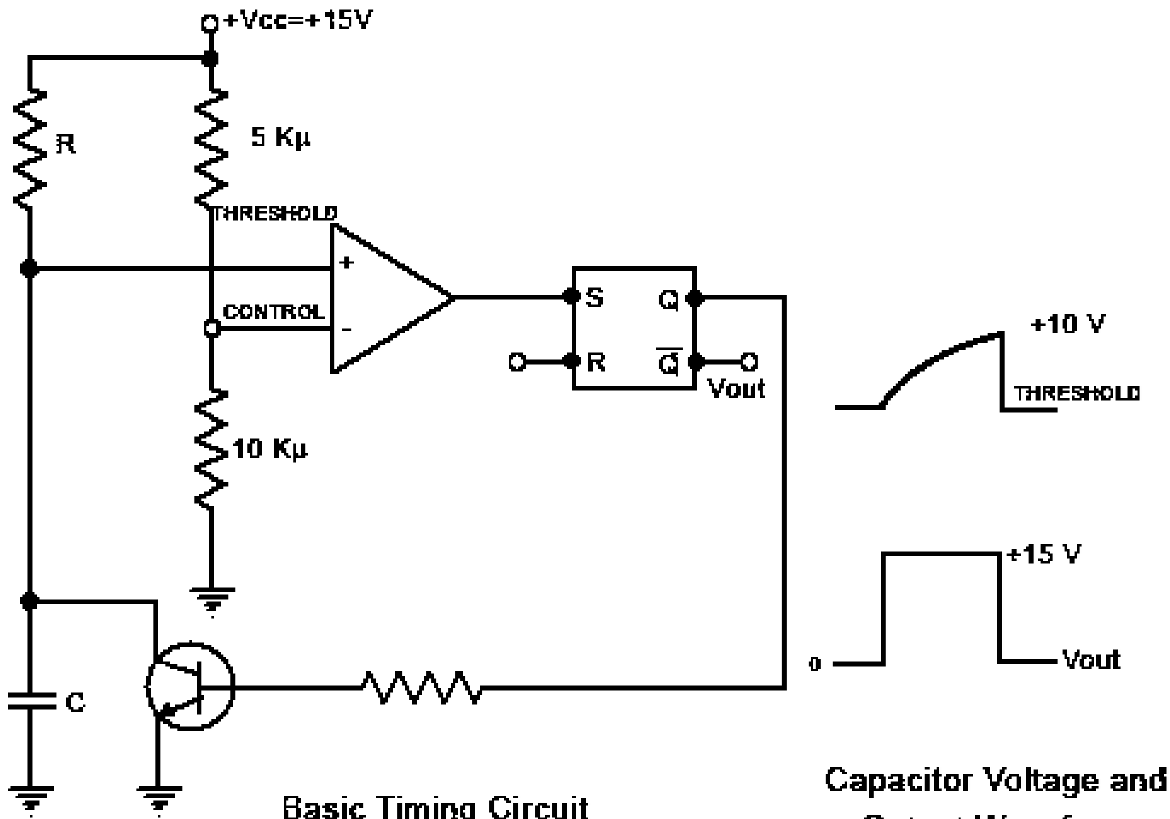
Capacitor is charged instantly to the value of source voltage. Time for charging full and discharging completely the capacitor is called TIME CONSTANT and controlled by the series connected RESISTOR with CAPACITOR to be charged.

So, charging time = Discharging time = Time constant (τ) = RC

Time varies either long or short as the resistance varied.

Basic Timing circuit

555 TIMING CIRCUIT



Basic Timing Circuit

Capacitor Voltage and Output Waveform

www.CircuitsToday.com

Operation Condition:

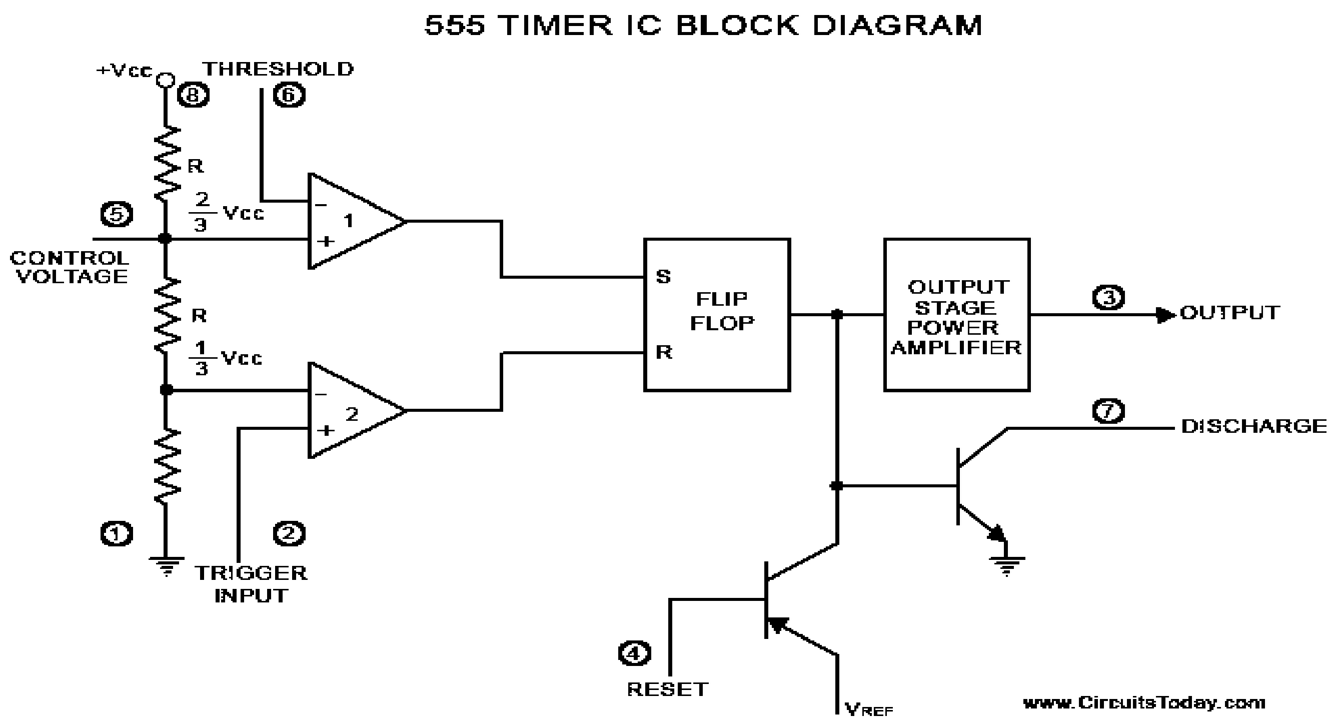
- IF OUTPUT Q (R-S FLIPFLOP, FF) IS HIGH
  --FF SETs
  -Vout is LOW
  -Transistor saturates (As base opens)
  -Capacitor discharges to zero voltage
  -Threshold voltage drops to zero (As Capacitor voltage equal to Threshold voltage)

- IF HIGH VOLTAGE IS APPLIED TO RESET TRMINAL

-FF RESETs
-Vout is HIGH
-Transistor goes into CUTOFF STATE (As base closes)
-Capacitor charges full
-Threshold voltage increases (As Capacitor voltage equal to Threshold voltage)
-When THRESHOLD voltage becomes greater than Vref (control voltage)'
-Comparator output goes HIGH, then
-FF SETs, Vout is LOW, Transistor saturates, then Capacitor discharges again.

NOTE: **Capacitor charges exponentially**

555 Timer block diagram:



Pins description:

1	GND	Ground reference voltage, low level (0 V)
2	TRIG	The OUT pin goes high and a timing interval starts when this input falls below 1/2 of

		CTRL voltage (which is typically 1/3 of V_{CC}, when CTRL is open).
3	OUT	This output is driven to approximately 1.7 V below $+V_{CC}$ or GND.
4	RESET	A timing interval may be reset by driving this input to GND, but the timing does not begin again until RESET rises above approximately 0.7 volts. Overrides TRIG which overrides THR.
5	CTRL	Provides "control" access to the internal voltage divider (by default, 2/3 V_{CC}).
6	THR	The timing (OUT high) interval ends when the voltage at THR is greater than that at CTRL (2/3 V_{CC} if CTRL is open).
7	DIS	Open collector output which may discharge a capacitor between intervals. In phase with output.
8	V_{CC}	Positive supply voltage, which is usually between 3 and 15 V depending on the variation.

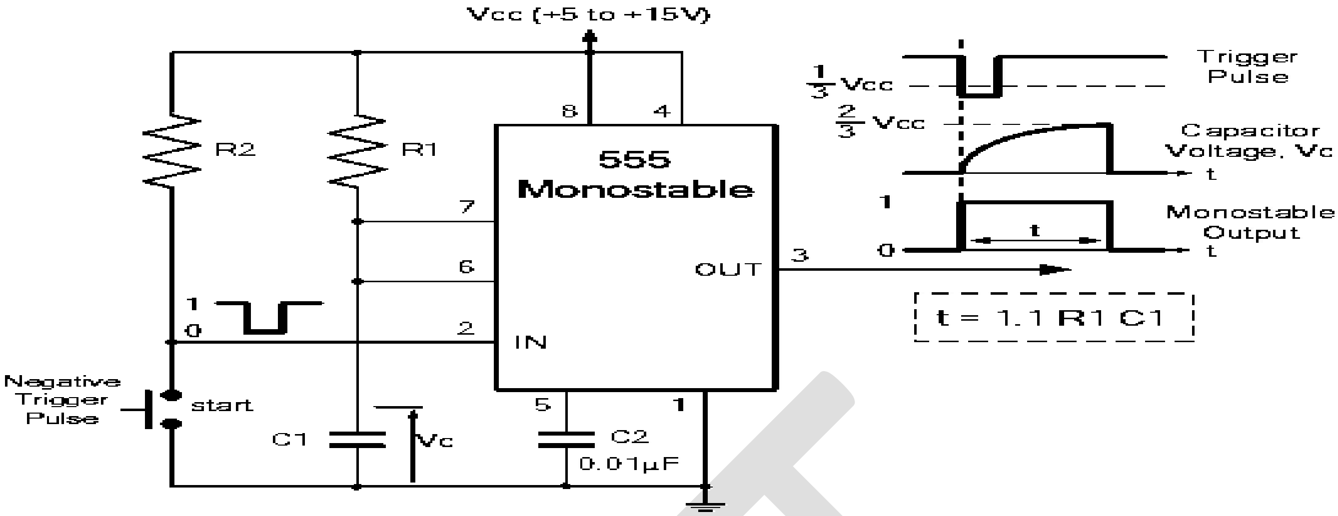
Features of 555 TIMER IC

- Highly stable TIME DELAYS (or) OSCILLATIONS
- Two operation Modes
- Highly temperature stability (55 to 125 degree of centigrade)
- Its output is compatible with TTL, CMOS and Op-Amp Circuits

MONOSTABLE MULTIVIBRATOR

Timer works in this mode when connected with external basic charging circuit (Time delay circuit). Has only one stable state, when trigger is applied it produces PULSE at the output and then returns back to its stable state. Duration of PULSE depends on the value of R and C.

Diagram:



Operation Conditions:

- FF IS INITIALLY SET (HIGH)
  -Vout is LOW
  -Transistor saturates (As base opens)
  -Capacitor discharges to zero voltage
  -Threshold voltage drops to zero (As Capacitor voltage equal to Threshold voltage)

- IF TRIGGER IS APPLIED
  -FF RESETs
  -Vout is HIGH
  -Transistor goes into CUTOFF STATE(As base closes)
  -Capacitor charges full
  -Threshold voltage increases (As Capacitor voltage equal to Threshold voltage)
  -When THRESHOLD voltage becomes greater than Vref (control voltage, PIN 5)'
  -Comparator output goes HIGH, then
  -FF SETs, Vout is LOW ,Transistor saturates, then Capacitor discharges again returns the Multivibrator to its normally **stable state.**

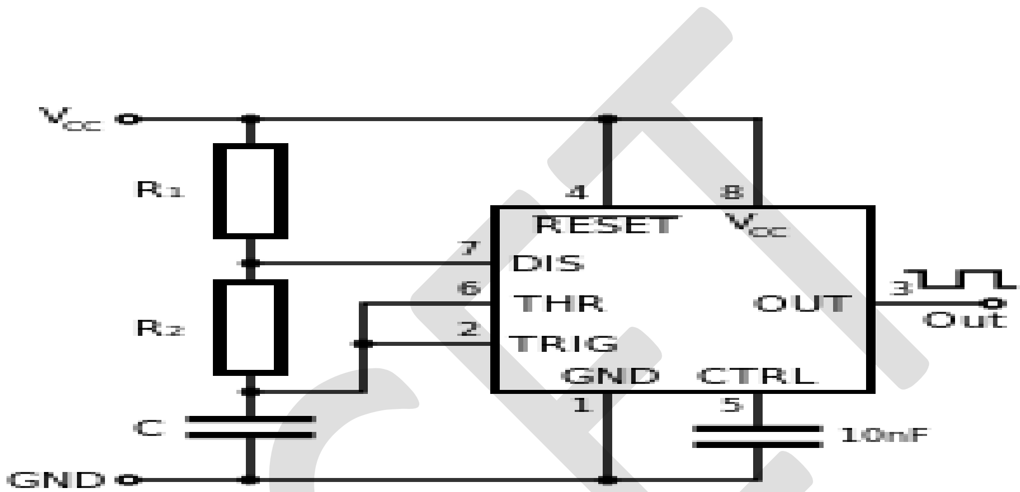
NOTE: **Capacitor charges exponentially**

ASTABLE MULTIVIBRATOR

Has no stable state, it always changes its state alternatively (running non sinusoidal oscillation).

Threshold terminal and trigger terminal are connected together

Also, reset terminal and supply terminal are connected together. Two external resistances together with a capacitor are connected.



Operation:

WHEN FF IS SET (HIGH), Vout is LOW

-Transistor saturates (As base opens)

-Capacitor discharges to zero voltage

-Threshold voltage drops to zero as well as trigger terminal voltage (As Capacitor voltage equal to Threshold and trigger voltage)

-When capacitor discharges to less than 1/3Vcc, Comparator 2 output is HIGH, FF RESETs, Transistor cut off, Capacitor charges through resistors R1 and R2.

-In charging of Capacitor, as the capacitor voltage increases also the threshold voltage increase.

-When threshold voltage becomes greater than 2/3Vcc, Comparator 1 output is HIGH, FF SETs, the Capacitor discharges

NOTE: **Capacitor charges exponentially**

Applications:

- Square wave generator
- Voltage controlled Oscillator (VCO)
- FSK generator

SCHMITT TRIGGER

In electronics, a **Schmitt trigger** is a comparator circuit with hysteresis, implemented by applying positive feedback to the non-inverting input of a comparator or differential amplifier. It is an active circuit which converts an analog input signal to a digital output signal.

The circuit is named a "trigger" because the output retains its value until the input changes sufficiently to trigger a change. In the non-inverting configuration, when the input is higher than a certain chosen threshold, the output is high. When the input is below a different (lower) chosen threshold, the output is low, and when the input is between the two levels, the output retains its value.

.IC VOLTAGE REEGULATORS

This is the circuit provides constant output voltage regardless in change of load current. These ICs are widely used as much as the Op-Amp ICs.

Advantages

- Easy to use
- Low in cost
- Versatile
- Greatly simplify power supply design
- Provided with features like
  -Built in protection
  -Programmable output
  -Current/Voltage boosting
  -Internal short circuit current limiting.

Classification of IC voltage regulator

- Linear regulators
  -Fixed output voltage regulators (positive and negative voltage)
  -Variable (Adjustable) output voltage regulators (positive and negative voltage)
- Switching regulators

3-Terminal fixed voltage regulator

A commonly used voltage regulator.

Capacitor 1 is required if regulator is located at appreciable distance (more than 5cm from power supply filter)

Capacitor 2 is not necessary, but may be used to improve the transient response of the regulator and regulator response to the transient change in the load. It also reduces noise to the output.

With the help of resistors, feedback to the output voltage s made, it compared with the Vref (internally generated with the help of zener diode).

Output control signal adjust the control element in such a way that output voltage remains constant.

Thermal shutdown- is an automatically switch off of the IC if temperature exceed 175 degree

Current Limiting- protect the IC from excessive load current.

Hence IC voltage regulator is almost indestructible.

IC 78XX- This is the POSITIVE voltage IC regulator family,

Such as 7805, 7806, 7812, and 7824 as XX stands for the amount of voltage it regulates.

IC79XX-This is the NEGATIVE voltage IC regulator family,

Such as 7805, 7806, 7812, and 7824 as XX stands for the amount of voltage it regulates

LM 317- This is the 3-terminal adjustable regulator.