PPTS ON

ANALOG ELECTRONICS (EEE)

II B.Tech III semester
(Autonomous R18)
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SYLLABUS

Module-1:DIODE CIRCUITS

Module-2:MOSFET CIRCUITS

Module-3:MULTISTAGE AND POWER AMPLIFIERS

Module-4: FEEDBACK AMPLIFIERS

Module-5:OPERATIONAL AMPLIFIERS

UNIT-I

DIODE AND APPLICATIONS

P-N junction diode,
I-V characteristics of a diode;
review of half-wave and full-wave rectifiers,
clamping and clipping circuits.
Input output characteristics of BJT in CB, CE, CC configurations,
biasing circuits,
Load line analysis,
common emitter,
common base and common collector amplifiers;
Small signal equivalent circuits.

MATERIALS

Based on the electrical properties of the materials like conductivity, materials are divided into three types.

i) Conductors
ii) Semiconductors
iii) Insulators

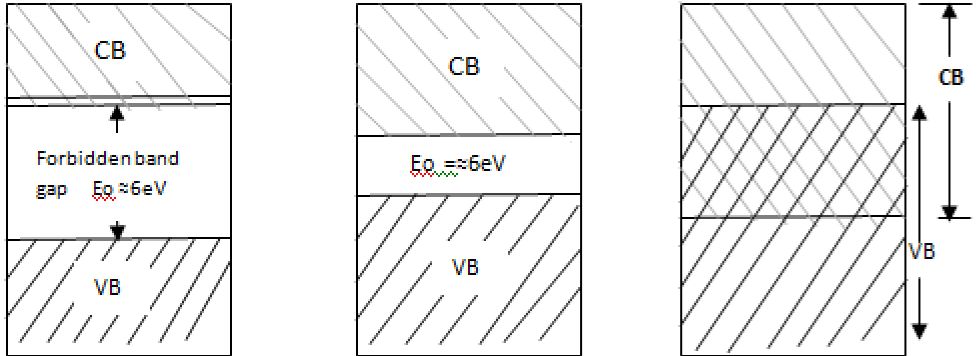


Fig.1: Energy band diagrams for insulator, semiconductor and conductor

Conductors

- A conductor is a material which supports a generous flow of charge when a voltage is applied across its terminals. i.e. it has very high conductivity.
- Ex: Copper, Aluminum, Silver, and Gold. The resistivity of a conductor is in the order of 10^{-4} and 10^{-6} Ω-cm.

Insulators

•An insulator is a material that offers a very low level of conductivity when voltage is applied.

•Ex: Paper, Mica, glass, quartz.

•Typical resistivity level of an insulator is of the order of 10^{10} to 10^{12} Ω-cm.

Semiconductors

- A semiconductor is a material that has its conductivity lies between the insulator and conductor.
- The resistivity level is in the range of 10 and 10^4 Ω-cm.
- Ex: Si & Ge

Types of Semiconductors

i)Intrinsic Semiconductor:

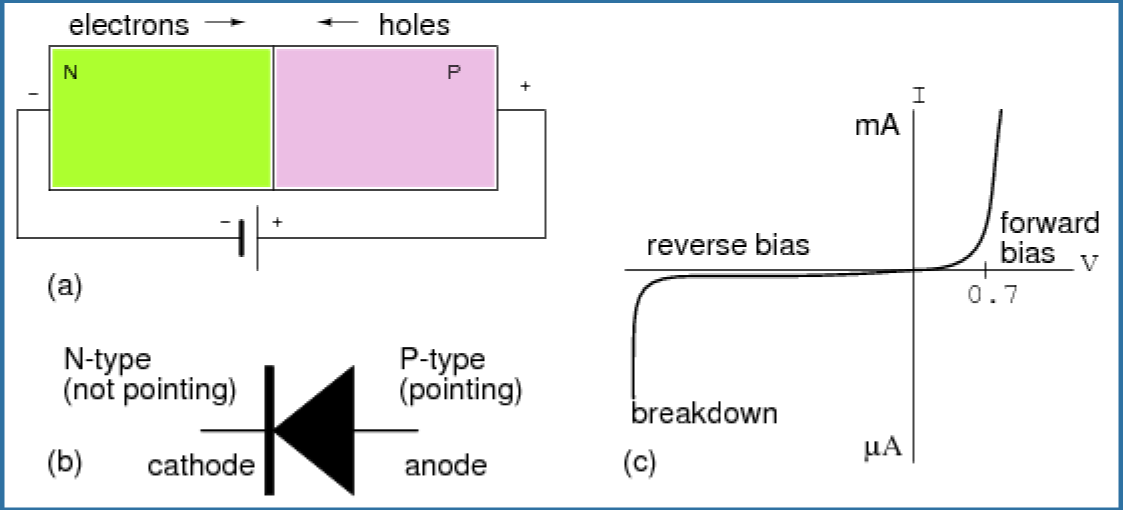
- A pure form of semiconductor is called as intrinsic semiconductor.
- Conduction in intrinsic sc is either due to thermal excitation or crystal defects.
- Ex: Si and Ge

ii) Extrinsic Semiconductor:

- The current conduction capability of intrinsic semiconductor can be increased significantly by adding a small amount of impurity to the intrinsic semiconductor.
- By adding impurities it becomes impure or extrinsic semiconductor.
- ***The process of adding impurities to the intrinsic semiconductor is called as doping.***

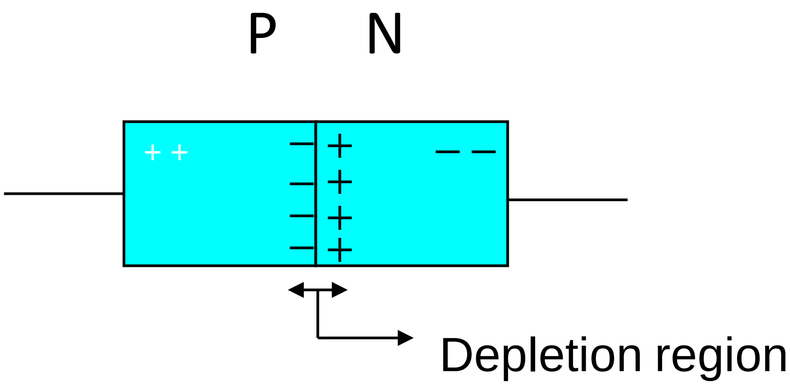
What do you mean by diode?

A PN junction is a device formed by joining p-type with n-type semiconductors and separated by a thin junction is called PN Junction diode or junction diode.



Theory of p-n junction

- When a p-type semiconductor material is suitably joined to n-type semiconductor the contact surface is called a p-n junction.



Theory of PN junction diode

- Suppose the two pieces are suitably treated to form PN junction, then there is a tendency for the free electrons from n-type to diffuse over to the p-side and holes from p-type to the n-side . This process is called **diffusion.**

- The holes from the p-side diffuse to the n-side and the electrons from the n-side diffuse to the p-side. This gives rise to a diffusion current across the junction.

Theory of PN junction diode

- As the free electrons move across the junction from n-type to p-type, +ve donor ions are uncovered. Hence a +ve charge is built on the n-side of the junction.
- At the same time, the free electrons cross the junction and uncover the –ve acceptor ions by filling in the holes. Therefore a net –ve charge is established on p-side of the junction.

Theory of PN junction diode

- When a sufficient number of donor and acceptor ions is uncovered further diffusion is prevented.
- Thus a barrier is set up against further movement of charge carriers. This is called potential barrier or junction barrier Vo. The potential barrier is of the order of 0.1 to 0.3V.
- **Note:** outside this barrier on each side of the junction, the material is still neutral. Only inside the barrier, there is a +ve charge on n-side and –ve charge on p-side. This region is called depletion layer.

Theory of PN junction diode

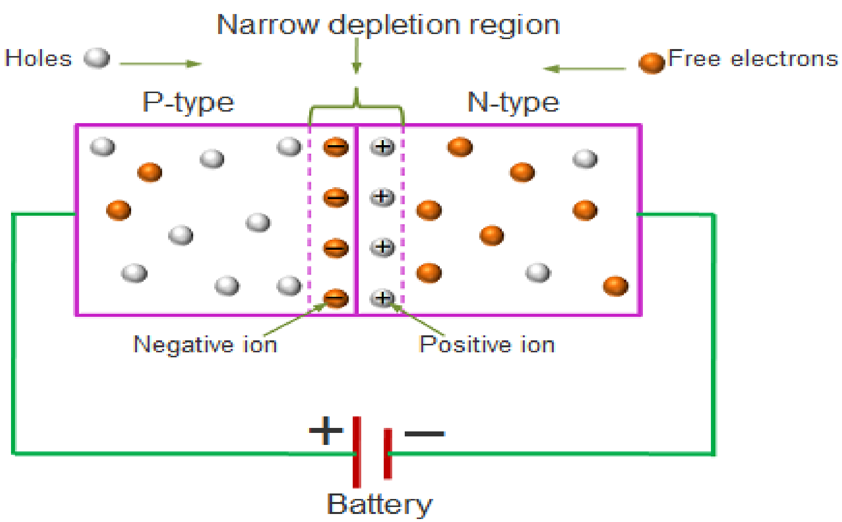
- The depletion layer contains no free and mobile charge carriers but only fixed and immobile ions.
- Its width depends upon the doping level..
- Heavily doped……..thin depletion layer
- lightly doped……..thick depletion layer

PN junction can basically work in two modes, (***A battery is connected to the diode***).

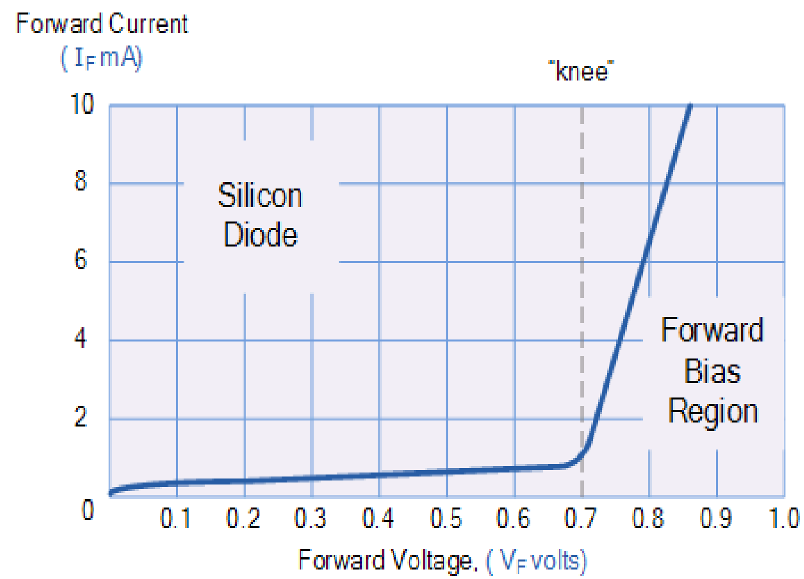
Forward bias mode : positive terminal connected to p-region and negative terminal connected to n region.

Reverse bias mode: negative terminal connected to p-region and positive terminal connected to n region

PN junction –Forward Bias



Forward bias



•It forces the majority charge carriers to move across the junction ….decreasing the width of the depletion layer.

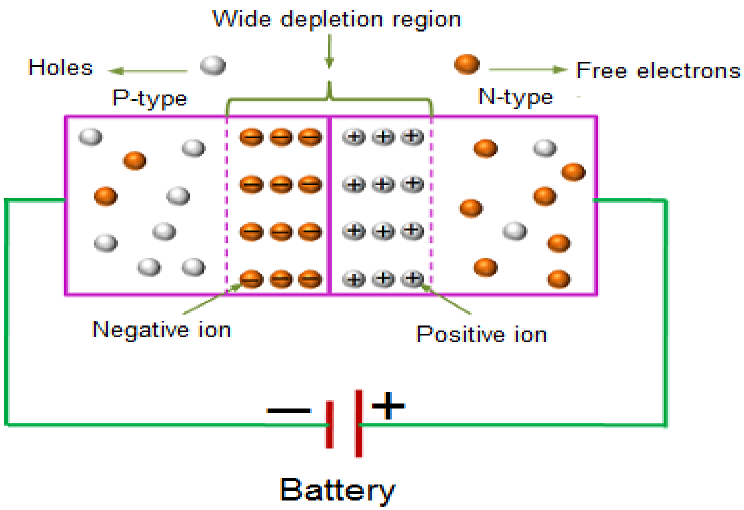
PN junction –Forward Bias

- When a diode is connected in a FB condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material.

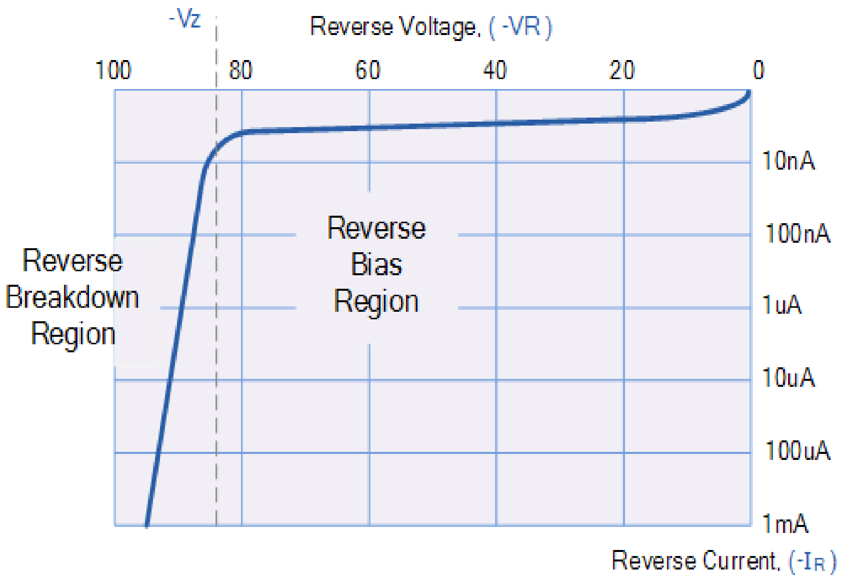
- If this external voltage becomes greater than the value of the potential barrier, i.e. 0.7V for Si and 0.3V for Ge, the potential barriers opposition will be overcome and current will start.

- The application of a FB voltage on the junction diode results in the depletion layer becoming very thin which represents a low impedance path through the junction thereby allowing high currents to flow.

PN junction –Reverse Bias



Reverse bias

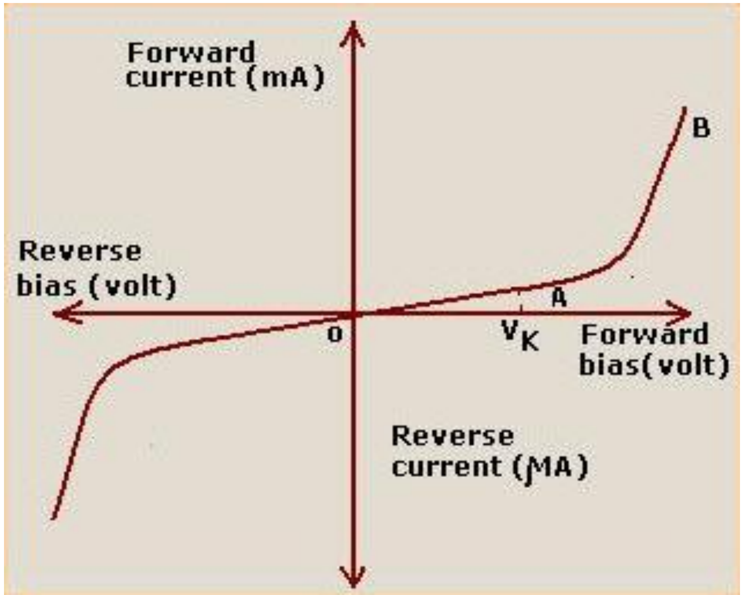


- The free electrons and free holes are attracted towards the battery, hence depletion layer width increases.

PN junction –Reverse Bias

- When a diode is connected in a Reverse bias condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.
- The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.
- The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material.

V-I CHARACTERISTICS OF PN JUNCTION DIODE



V-I characteristics of PN junction diode

V-I CHARACTERISTICS OF PN JUNCTION DIODE

- When the diode is F.B., the current increases exponentially with voltage except for a small range close to the origin.
- When the diode is R.B., the reverse current is constant and independent of the applied reverse bias.
- Turn-on or cut-in (threshold) voltage Vγ: for a F.B. diode it is the voltage when the current increases appreciably from zero.
- It is roughly equal to the barrier p.d.:
- For Ge, Vγ ~ 0.2 – 0.4 V (at room temp.) For Si, Vγ ~ 0.6 – 0.8 V (at room temp.)

Static or DC resistance

The resistance of a diode at a particular operating point is called the dc or static resistance diode.

The resistance of the diode at the operating point can be found simply by finding the corresponding levels of V_D and I_D.

It can be determined using equation

$R_D = V_D / I_D$

The lower current through a diode the higher the dc resistance level

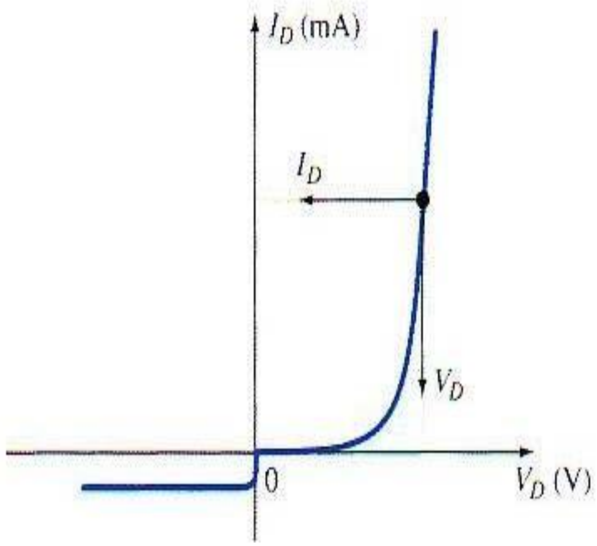


Fig: Static resistance curve

Dynamic or AC resistance

Static resistance is using dc input. If the input is sinusoidal the scenario will be change.

The ac resistance is determined by a straight line drawn between the two intersections of the maximum and minimum values of input voltage.

Thus the specific changes in current and voltage is obtained. It can be determined using equation

$r_d = \Delta V_D / \Delta I_D$

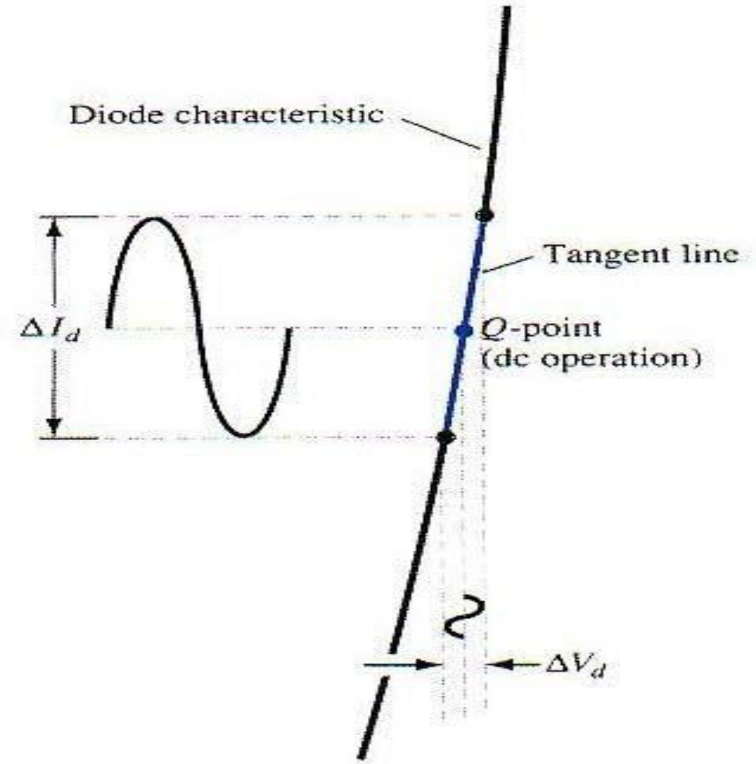
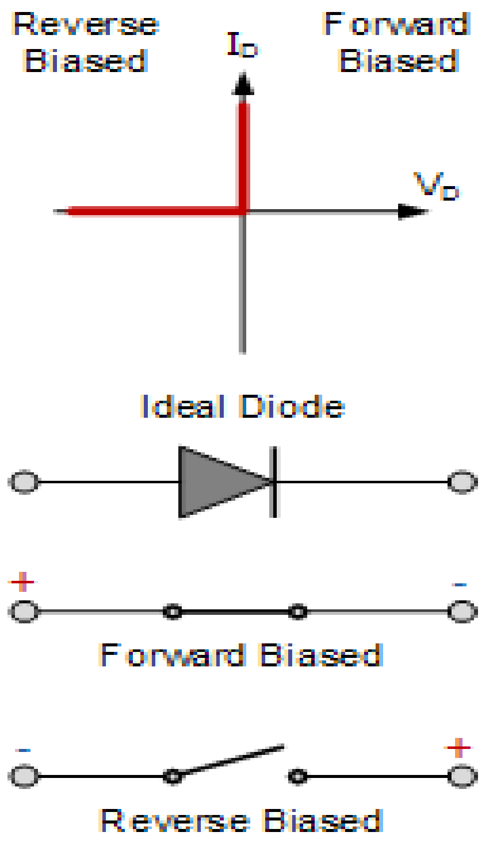


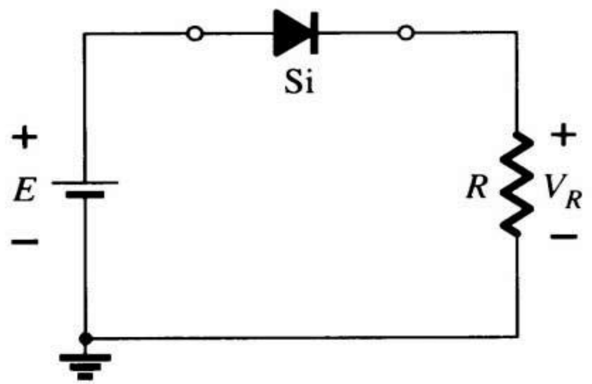
Fig: Dynamic resistance curve

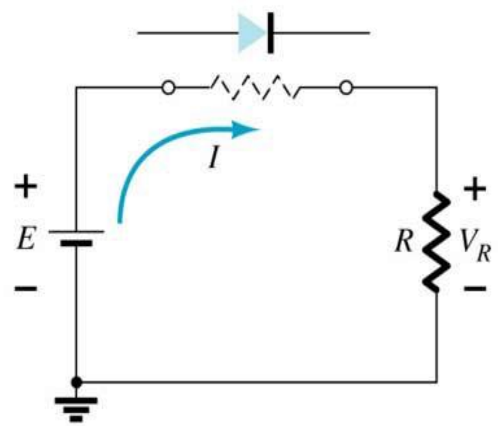
PN Junction Diode Ideal and Real Characteristics

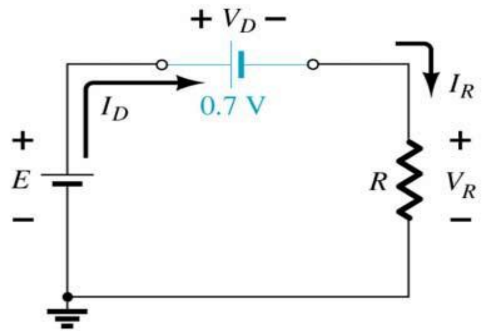


DIODE Equivalent circuit

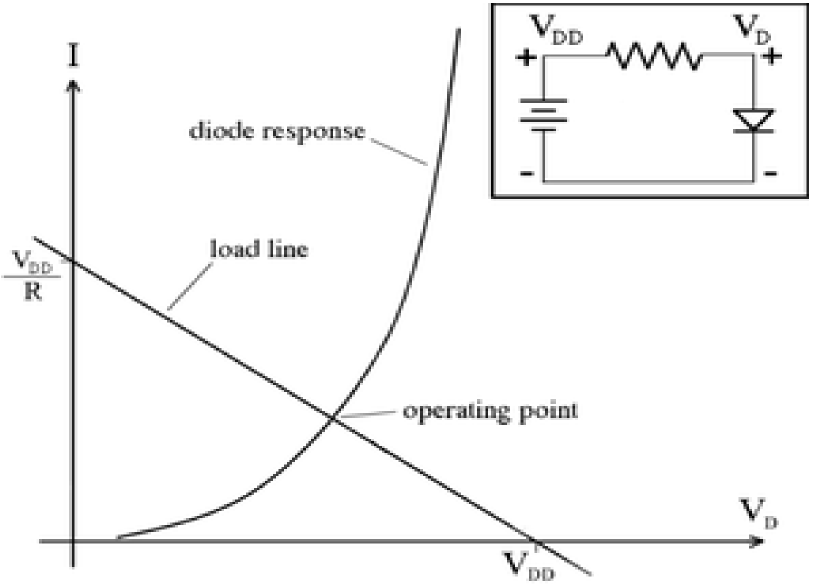
When a diode is F.B, we can use the approximate model for the on state







PN Diode- Load line analysis



A load line is a line drawn on the characteristic curve, a graph of the current vs. voltage in a nonlinear device like a diode.

•The curve shows the diode response (I vs V_D) while the straight line shows the behavior of the linear part of the circuit:

$$I=(V_{DD}-V_D)/R.$$

•The point of intersection gives the actual current and voltage.

Junction Capacitance

In a p-n junction diode, two types of capacitance take place. They are,

- Transition capacitance (C_T)
- Diffusion capacitance (C_D)

Transition Capacitance C_T

The amount of capacitance changed with increase in voltage is called transition capacitance. The transition capacitance is also known as depletion region capacitance, junction capacitance or barrier capacitance.

Transition Capacitance C_T

The change of capacitance at the depletion region can be defined as the change in electric charge per change in voltage.

$$C_T = dQ / dV$$

Where,

C_T = Transition capacitance

dQ = Change in electric charge

dV = Change in voltage

The transition capacitance can be mathematically written as,

$$C_T = \varepsilon A / W$$

Where,

ε = Permittivity of the semiconductor

A = Area of plates or p-type and n-type regions

W = Width of the depletion region

Diffusion capacitance (C_D)

Diffusion capacitance occurs in a forward biased p-n junction diode. Diffusion capacitance is also sometimes referred as storage capacitance. It is denoted as C_D.

The formula for diffusion capacitance is

$$C_D = dQ / dV$$

Where,

C_D = Diffusion capacitance

dQ = Change in number of minority carriers stored outside the depletion region

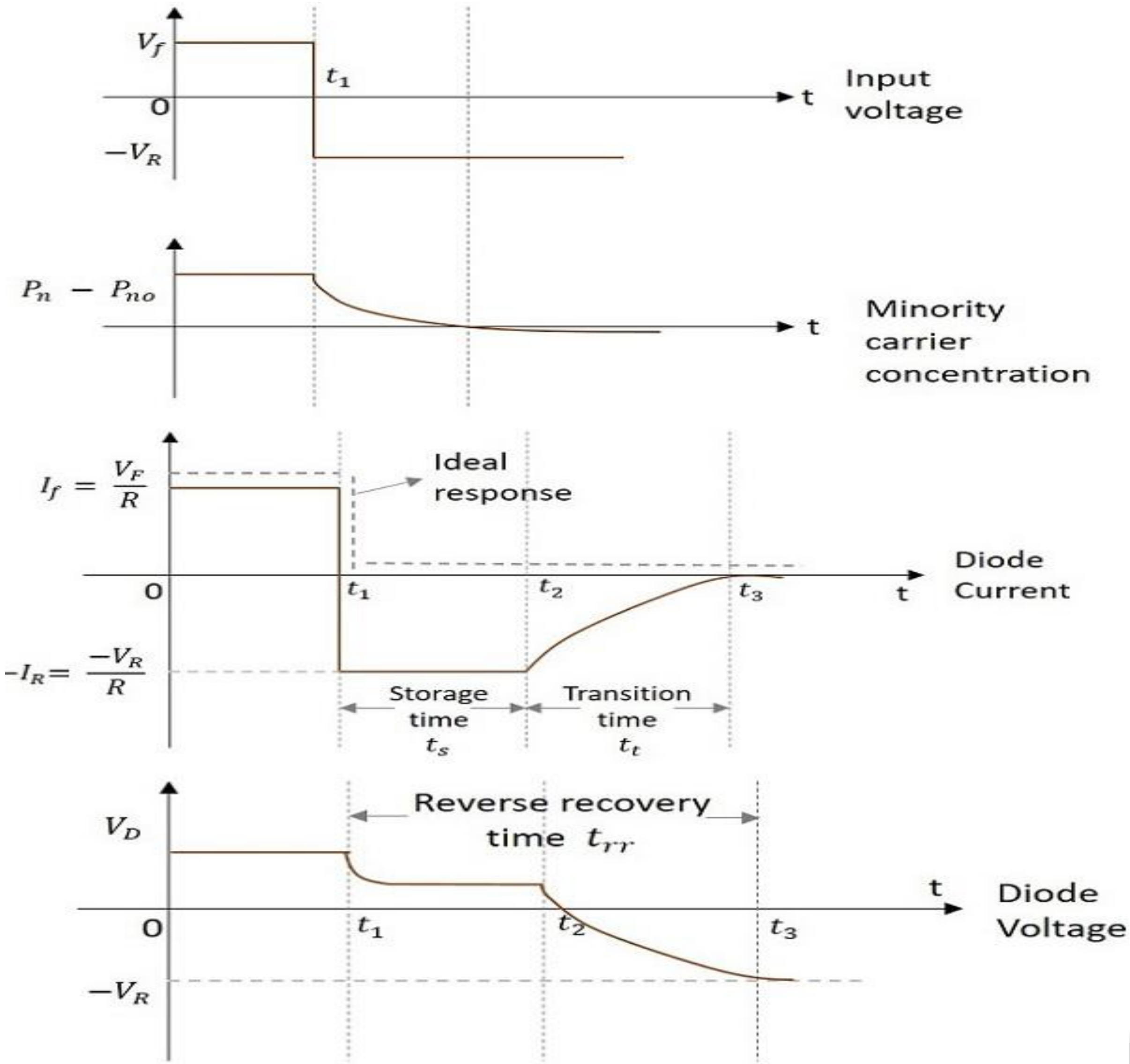
dV = Change in voltage applied across diode

Diode Applications

common applications of diodes are

- Switches
- Rectifiers
- Clipper Circuits
- Clamping Circuits
- Reverse Current Protection Circuits
- In Logic Gates
- Voltage Multipliers

PN Diode Switching times



- The majority carriers in P-type (holes) $= P_{po}$
- The majority carriers in N-type (electrons) $= N_{no}$
- The minority carriers in P-type (electrons) $= N_{po}$
- The majority carriers in N-type (holes) $= P_{no}$

PN Diode Switching times

Storage time − The time period for which the diode remains in the conduction state even in the reverse biased state, is called as **Storage time**.

Transition time − The time elapsed in returning back to the state of non-conduction, i.e. steady state reverse bias, is called **Transition time**.

Reverse recovery time − The time required for the diode to change from forward bias to reverse bias is called as **Reverse recovery time**.

Forward recovery time − The time required for the diode to change from reverse bias to forward bias is called as **Forward recovery time**.

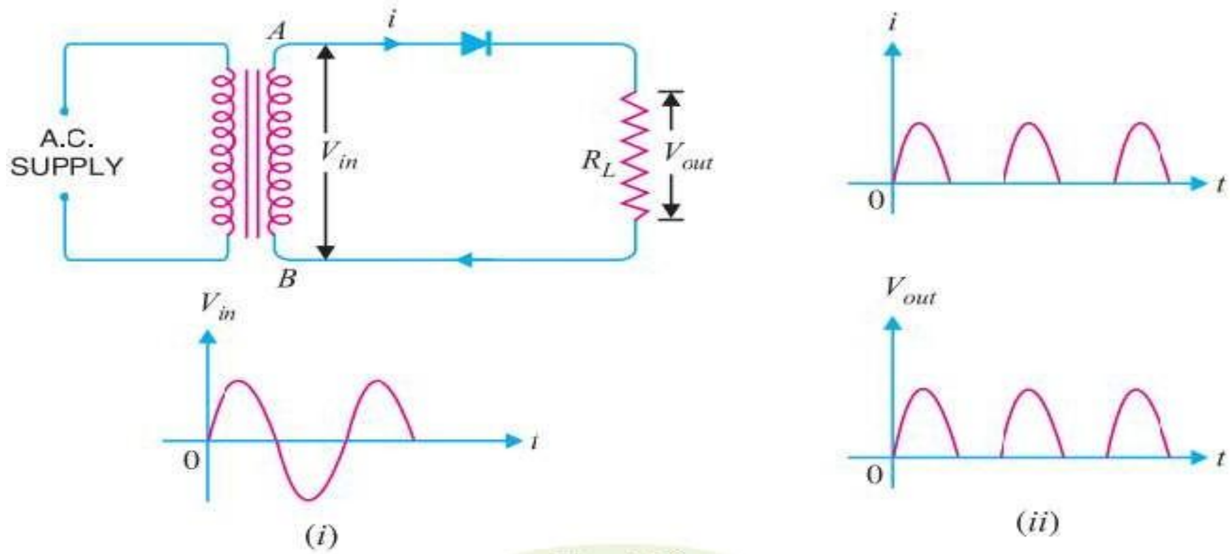
Rectifier

- A circuit that converts ac voltage of main supply into pulsating dc voltage using one or more PN junction diodes is called rectifier.

- Half Wave Rectifier
- Full Wave Rectifier
- Bridge Rectifier

Half Wave Rectifier

- The process of removing one-half the input signal to establish a dc level is called *half-wave rectification.*
- In Half wave rectification, the rectifier conducts current during positive half cycle of input ac signal only.
- Negative half cycle is suppressed.

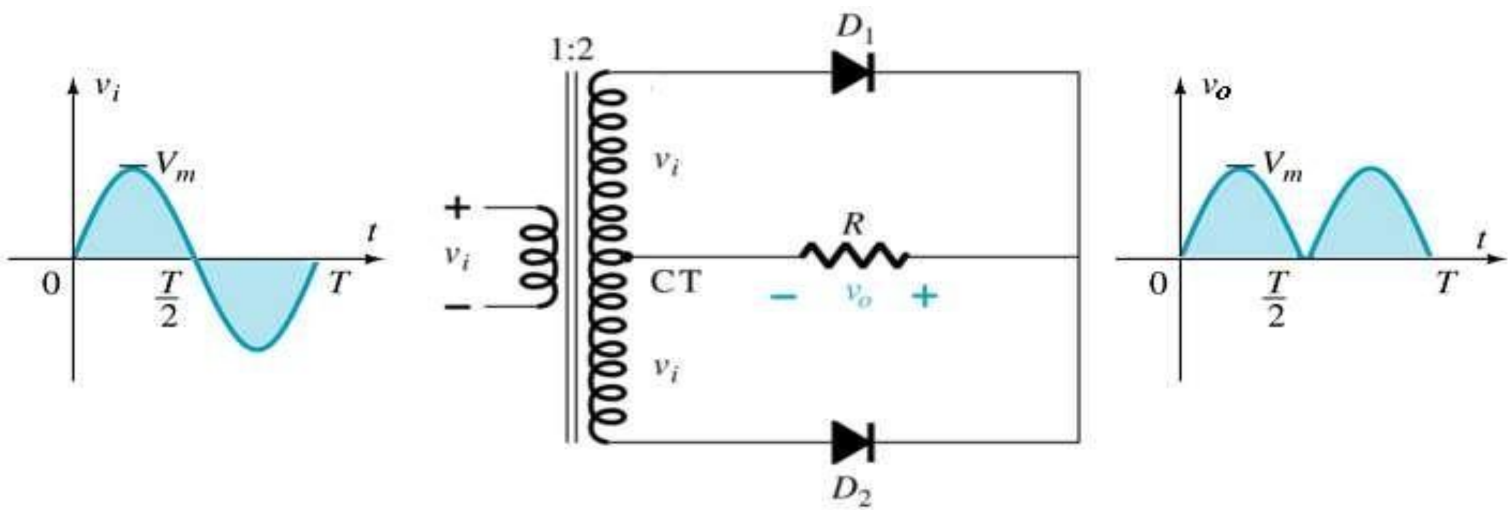


Half Wave Rectifier

- During the positive half cycle, the diode is under forward bias condition and it conducts current to RL (Load resistance). A voltage is developed across the load, which is same as the input AC signal of the positive half cycle.

- During the negative half cycle, the diode is under reverse bias condition and there is no current flow through the diode. Only the AC input voltage appears across the load and it is the net result which is possible during the positive half cycle. The output voltage pulsates the DC voltage.

Full-Wave Rectifier

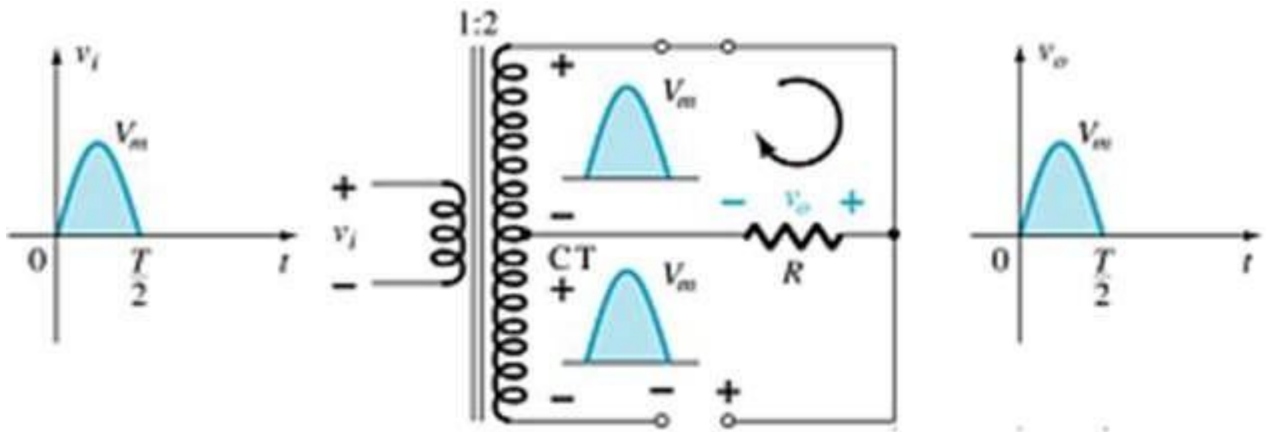


- The full wave rectifier circuit consists of two *power diodes* connected to a single load resistance (R_L) with each diode taking it in turn to supply current to the load.
- When point A of the transformer is positive with respect to point C, diode D_1 conducts in the forward direction as indicated by the arrows.

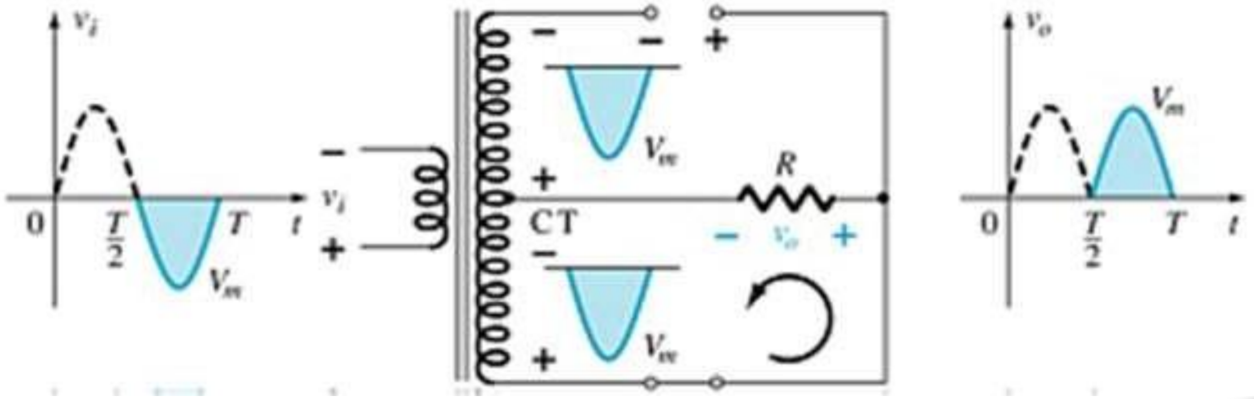
Full-Wave Rectifier

- When point B is positive (in the negative half of the cycle) with respect to point C, diode D_2 conducts in the forward direction and the current flowing through resistor R is in the same direction for both half-cycles.
- As the output voltage across the resistor R is the phasor sum of the two waveforms combined, this type of full wave rectifier circuit is also known as a “bi-phase” circuit.

Full-Wave Rectifier



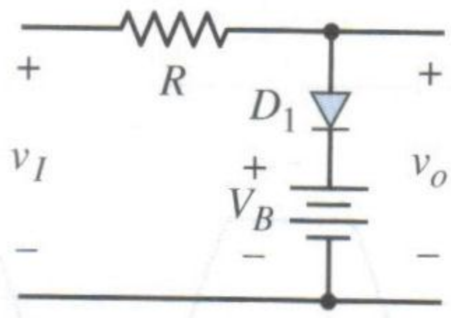
Current Flow during the positive half of the input cycle

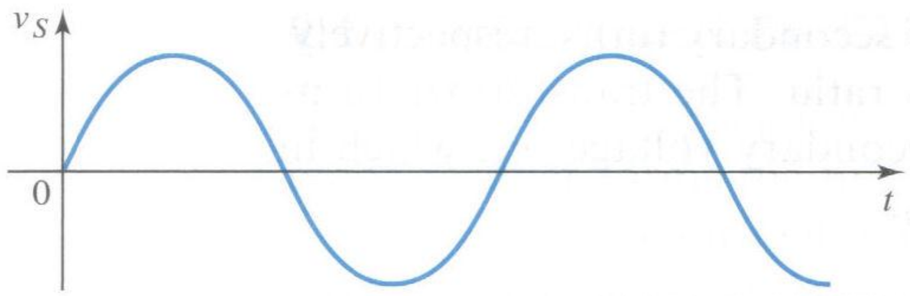


Current Flow during the negative half of the input cycle

Clippers

- Clipper circuits, also called **limiter circuits**, are used to eliminate portion of a signal that are above or below a specified level – clip value.
- The purpose of the diode is that when it is turn on, it provides the clip value
- Clip value = V'. To find V', use KVL at L1
- The equation is : $V' - V_B - V\gamma = 0 \rightarrow V' = V_B + V\gamma$



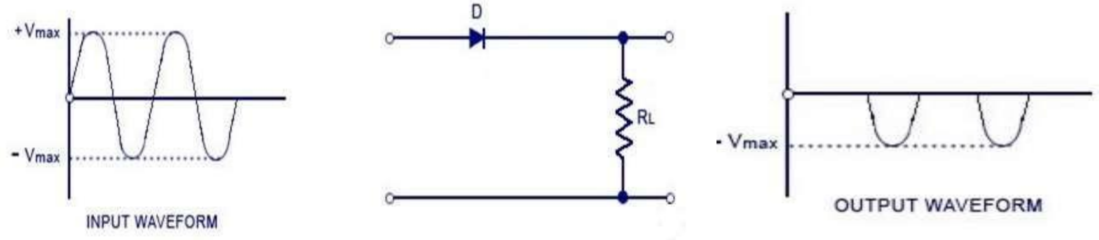


- Then, set the conditions
  - If **Vi > V'**, what happens? → diode conducts, hence Vo = V'
  - If **Vi < V'**, what happens? → diode off, open circuit, no current flow, Vo = Vi

Clipper Circuits

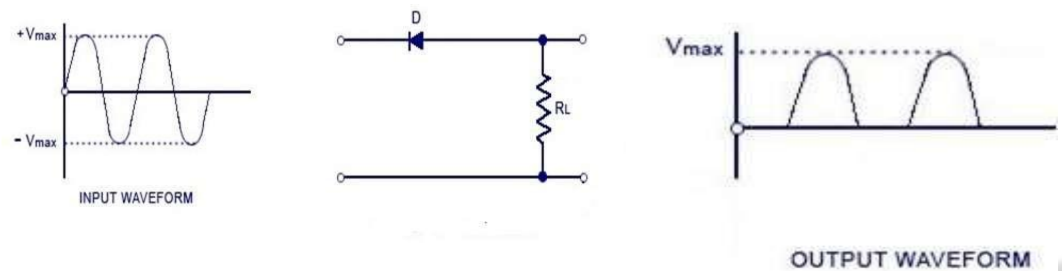
positive clipper:

In a positive clipper, the positive half cycles of the input voltage will be removed.



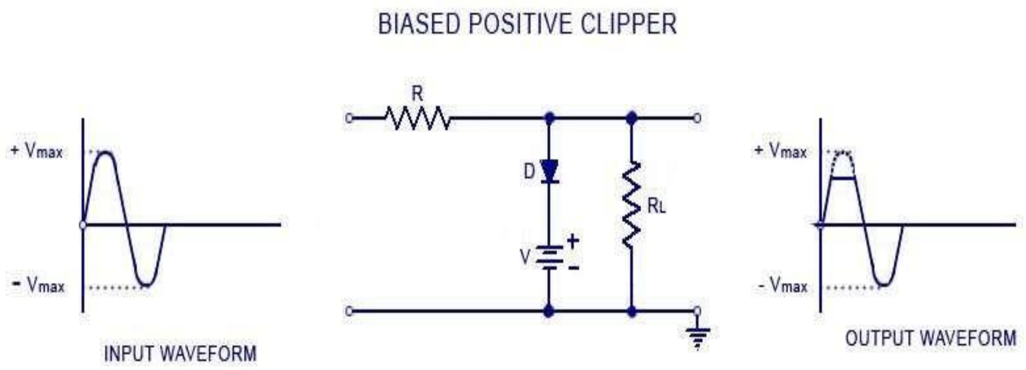
Negative clipper:

In a Negative clipper, the negative half cycles of the input voltage will be removed.



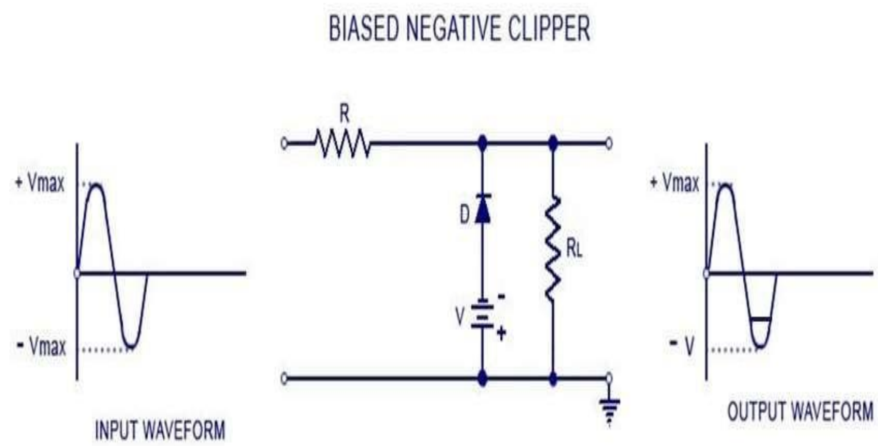
Biased Positive Clipper:

- When the input signal voltage is positive, the diode 'D' is reverse-biased. This causes it to act as an open-switch.



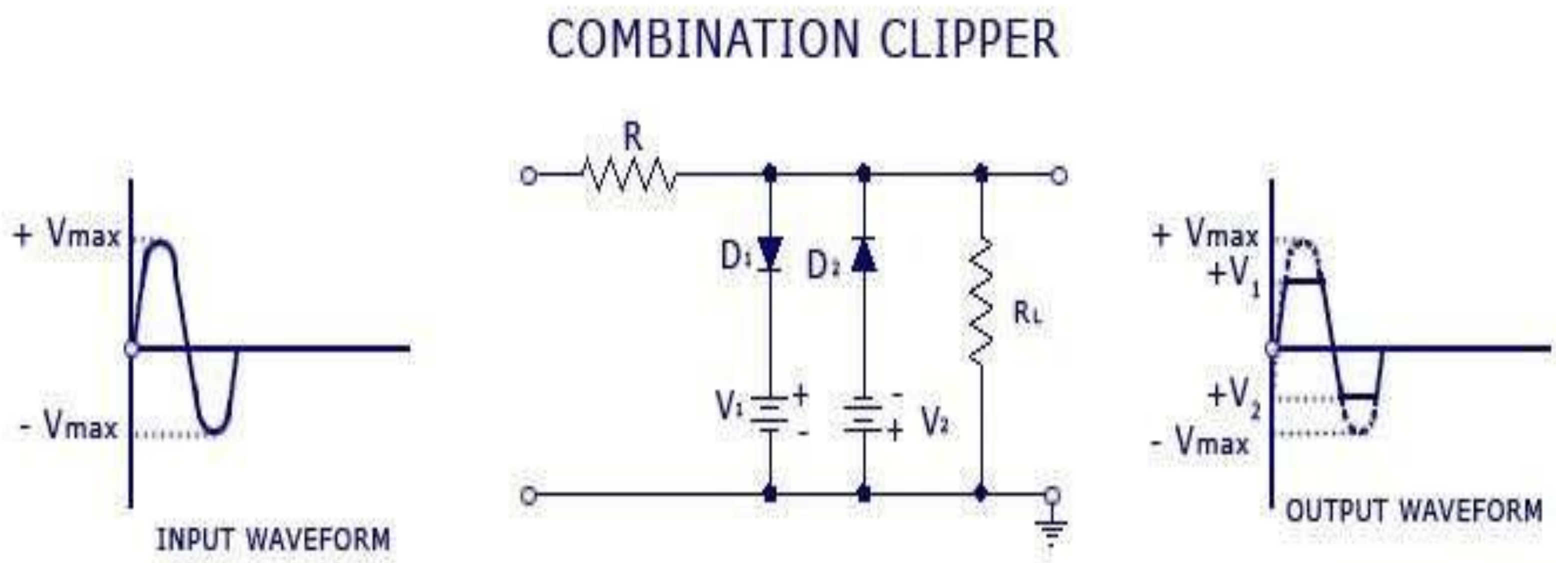
Biased Negative Clipper:

When the input signal voltage is negative its also reverse biased but in this case battery voltage is more than the input voltage so its acts like an close switch.



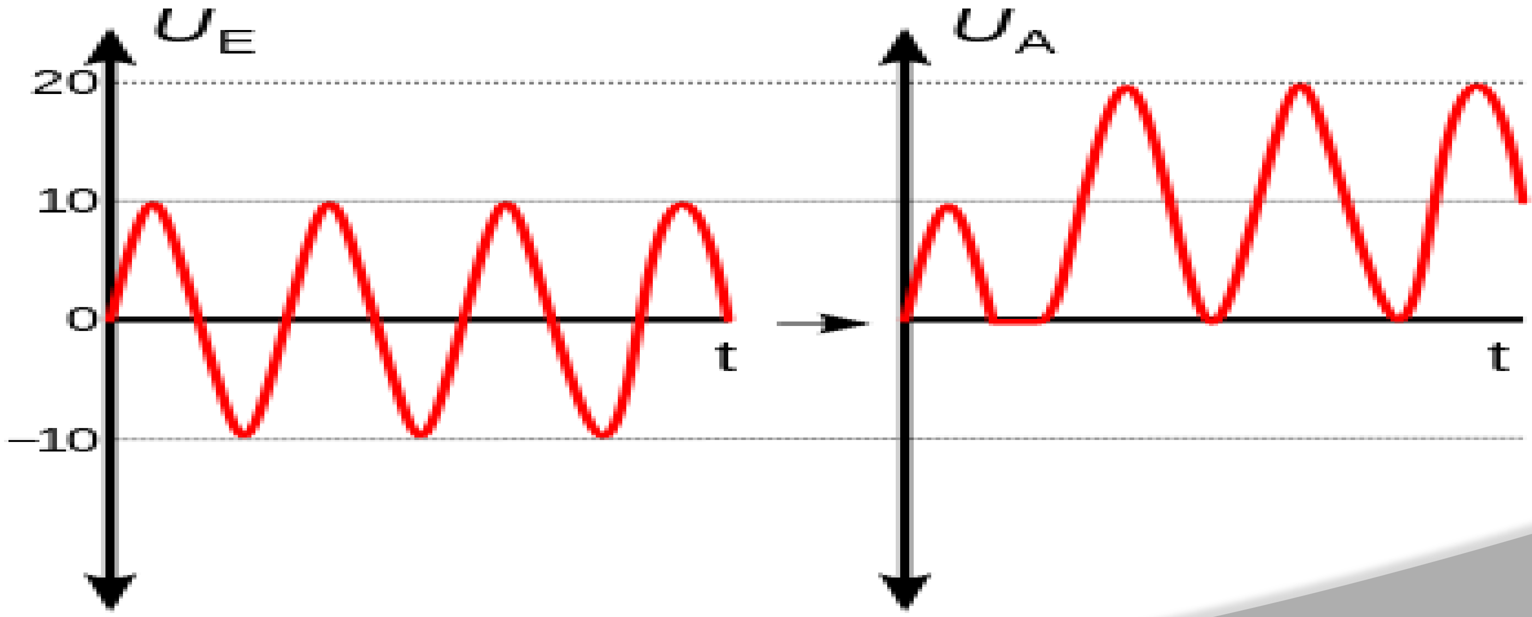
Two level-clipper

- When a portion of both positive and negative of each half cycle of the input voltage is to be clipped (or removed), combination clipper is employed.



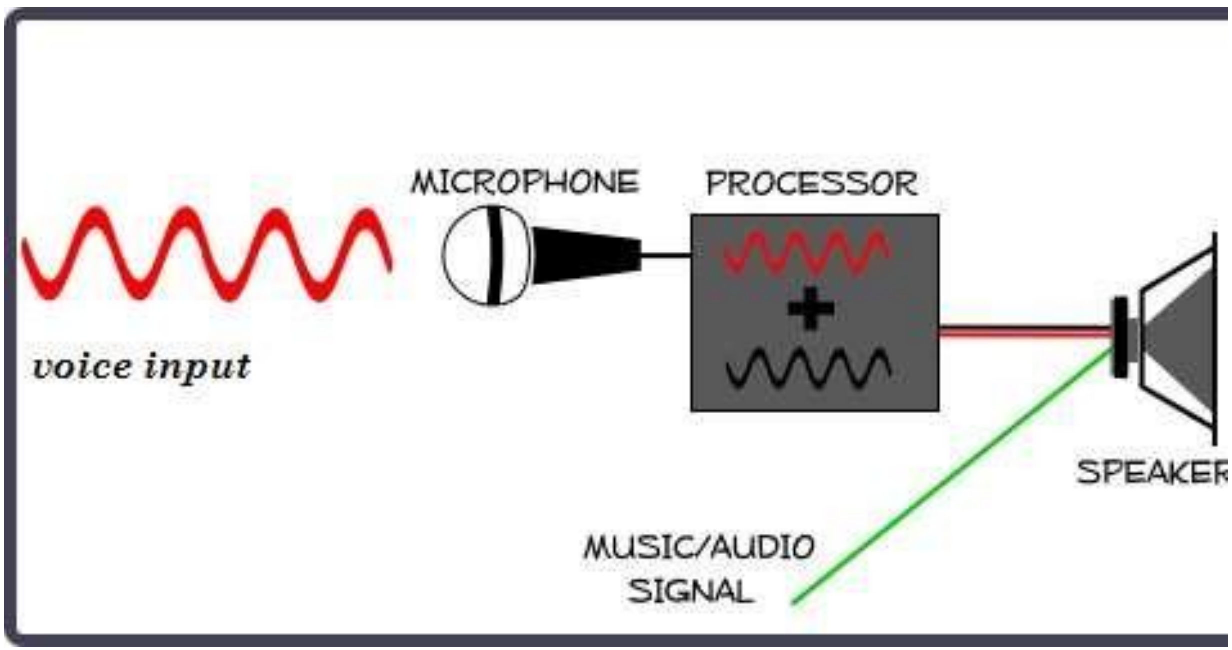
Clampers

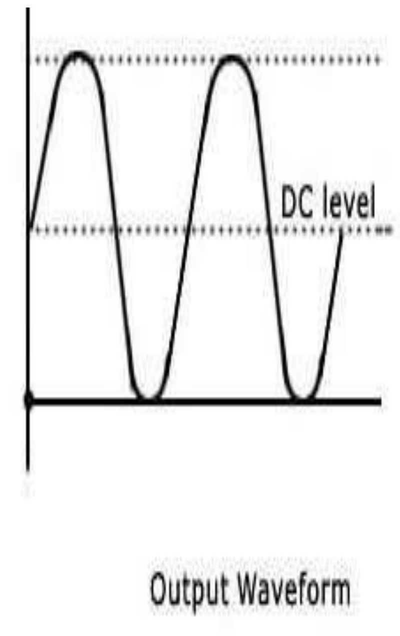
- A circuit which adds DC value to an AC wave form without changing its waveform.
- In this circuit we use a diode and a capacitor and a resistor for measure voltage in our circuit.



Why Clamper use?

- Clamper use to increase the wavelength of input wave.
- Like an sound system amplifier.

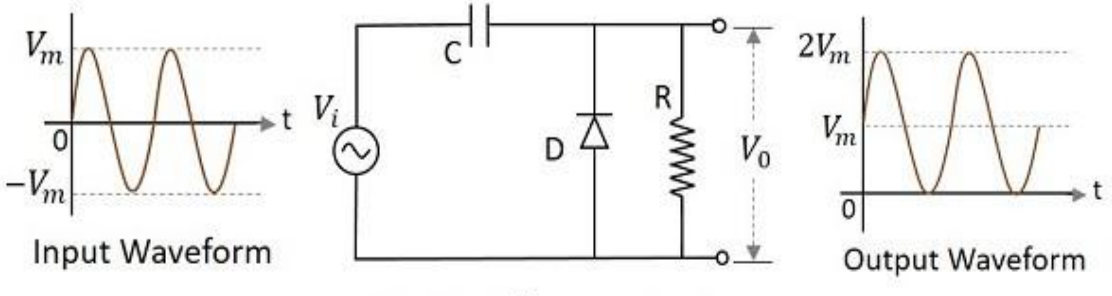




Clampers

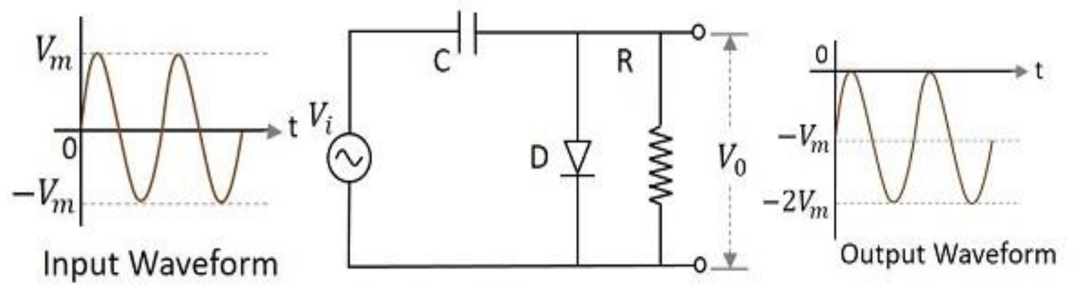
In positive clamper diode is forward biased and current flow is maximum.

Due to the presence of the capacitor it will double the wavelength on positive side.



Positive Clamper circuit

In this capacitor negatively charged and the output is double of the input of the negative side.



Negative Clamper circuit

TRANSISTORS

- The **transistor** is a three layered semiconductor machine and the three layers are an emitter, base, and collector. The emitter is a heavily doped layer, a base is moderately doped and the collector is lightly doped.

- A bipolar junction transistor (BJT) is a three-layer active device that consists of two *p–n junctions connected* back-to-back.

- *A BJT is actually* a current-amplifying device. In a BJT, the operation depends on the active participation of both the majority carrier, and the minority carrier; hence, the name "bipolar" is rightly justified.

Bipolar Junction Transistor (BJT)

- 3 adjacent regions of doped Si (each connected to a lead):
  - Base. (thin layer,less doped).
  - Collector.
  - Emitter.
- 2 types of BJT:
  - npn.
  - pnp.

Developed by Shockley (1949)

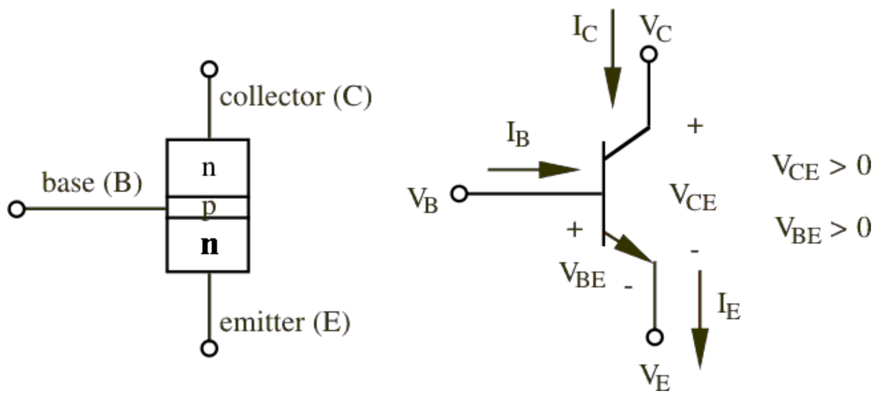


Fig:npn bipolar junction transistor

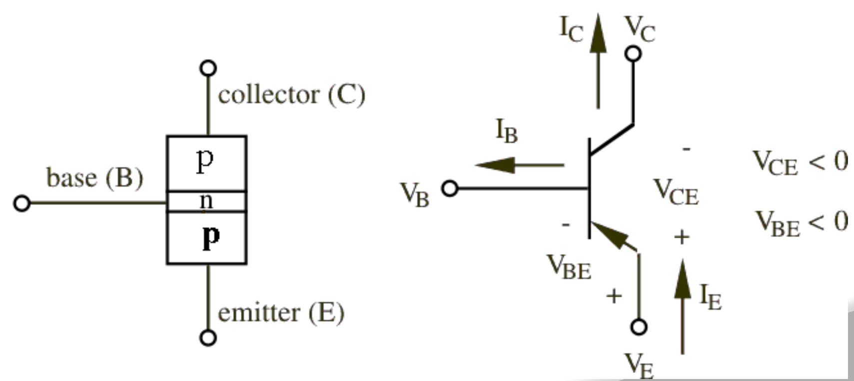
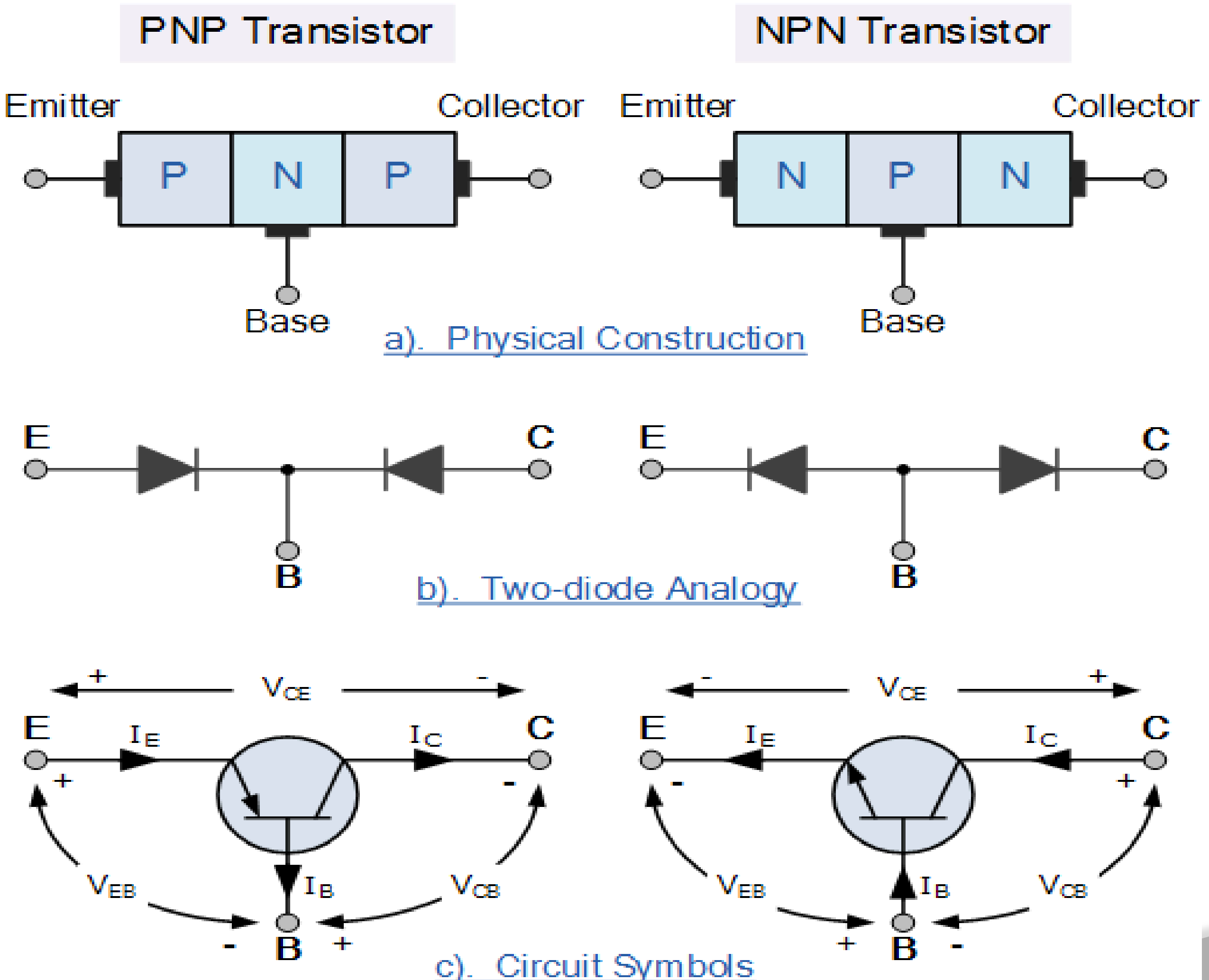


Fig:pnp bipolar junction transistor

TRANSISTORS



TRANSISTORS

The three distinct types of BJT configurations are:

•Common base configuration.

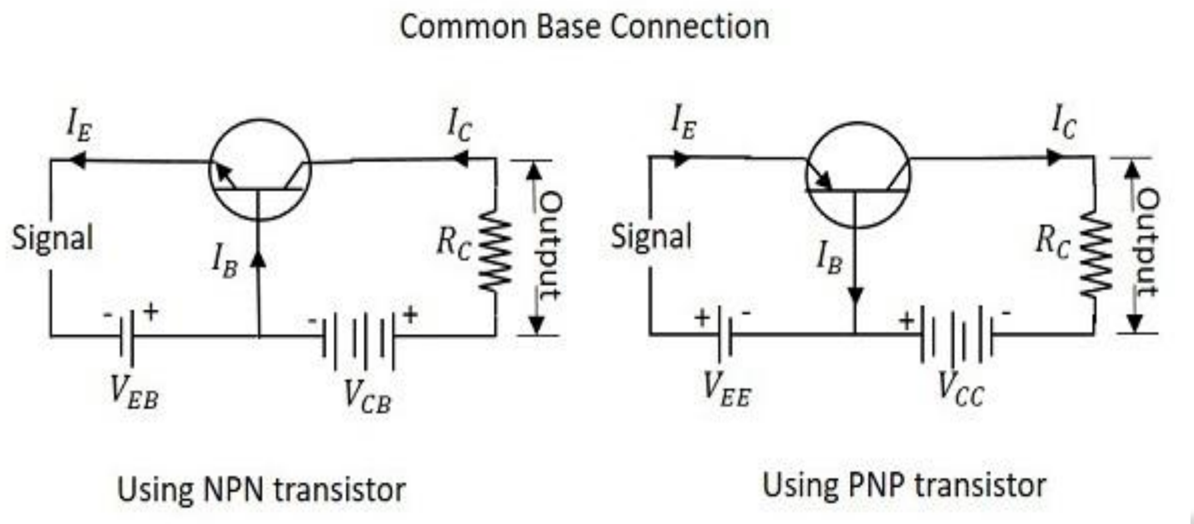
•Common emitter configuration.

•Common collector configuration.

CB configuration: The common base configuration of an NPN transistor, the input is forward biased and whereas the output is reverse biased. In the configuration of common base, a base is common to the input side of configuration and also to the output side of configuration.

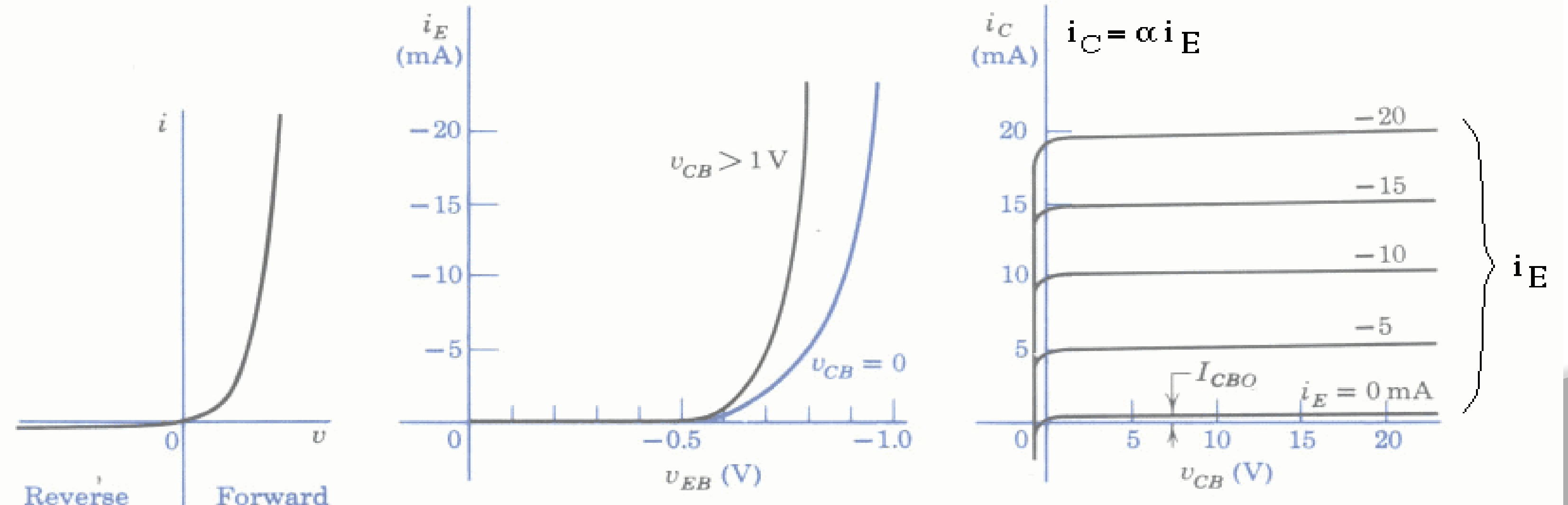
CB Configuration Characteristics

The name itself implies that the Base terminal is taken as common terminal for both input and output of the transistor. The common base connection for both NPN and PNP transistors is as shown in the following figure.



CB Configuration Characteristics

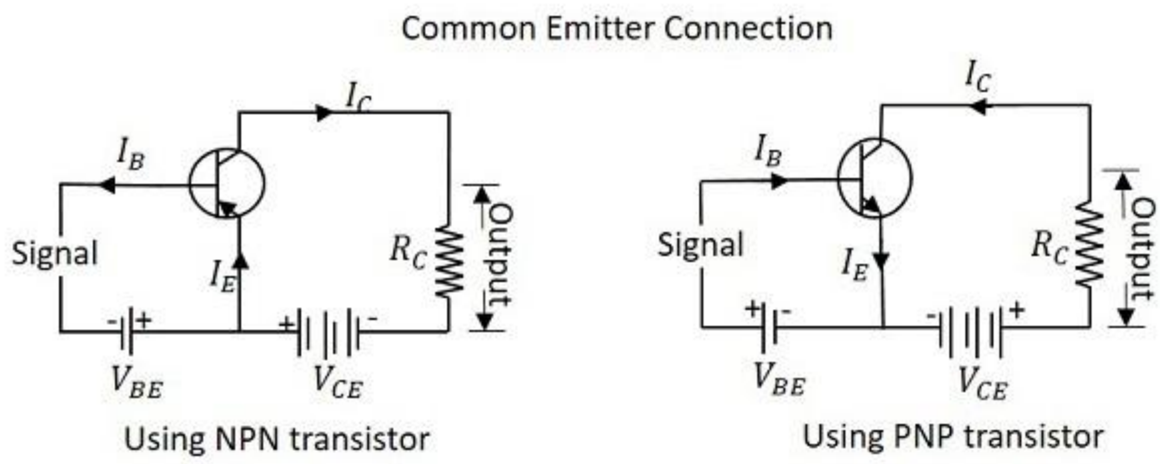
- To describe the behavior of common-base amplifiers requires two set of characteristics:
  - Input characteristics.
  - Output characteristics.
- The output characteristics has 3 basic regions:
  - Active region -defined by the biasing arrangements.



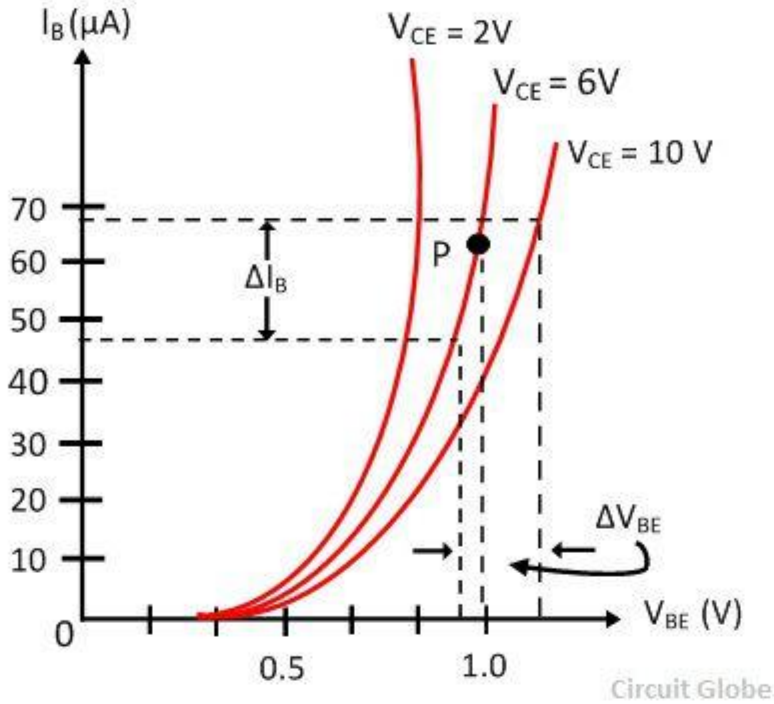
(a) Diode characteristic (b) Emitter characteristics (c) Collector characteristics

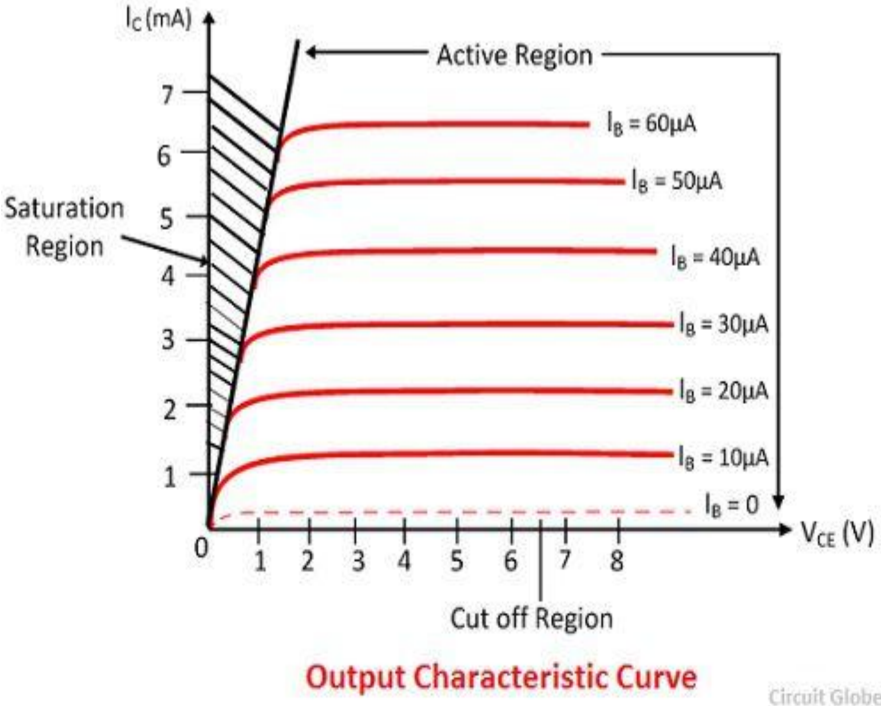
CE Configuration Characteristics

The name itself implies that the **Emitter** terminal is taken as common terminal for both input and output of the transistor. The common emitter connection for both NPN and PNP transistors is as shown in the following figure.



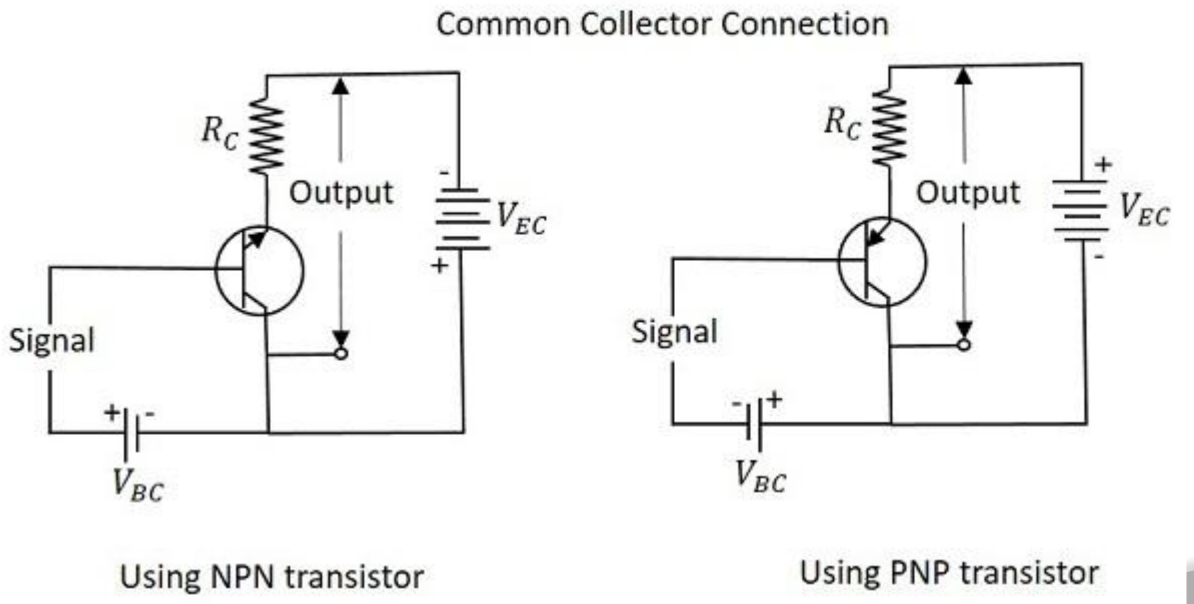
CE Configuration Characteristics





CC Configuration Characteristics

- The name itself implies that the **Collector** terminal is taken as common terminal for both input and output of the transistor. The common collector connection for both NPN and PNP transistors is as shown in the following figure.



CC Configuration Characteristics

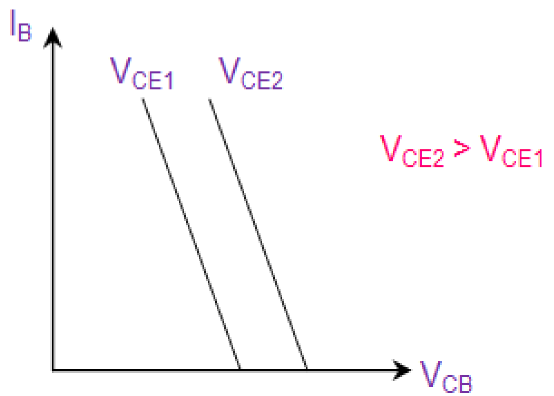
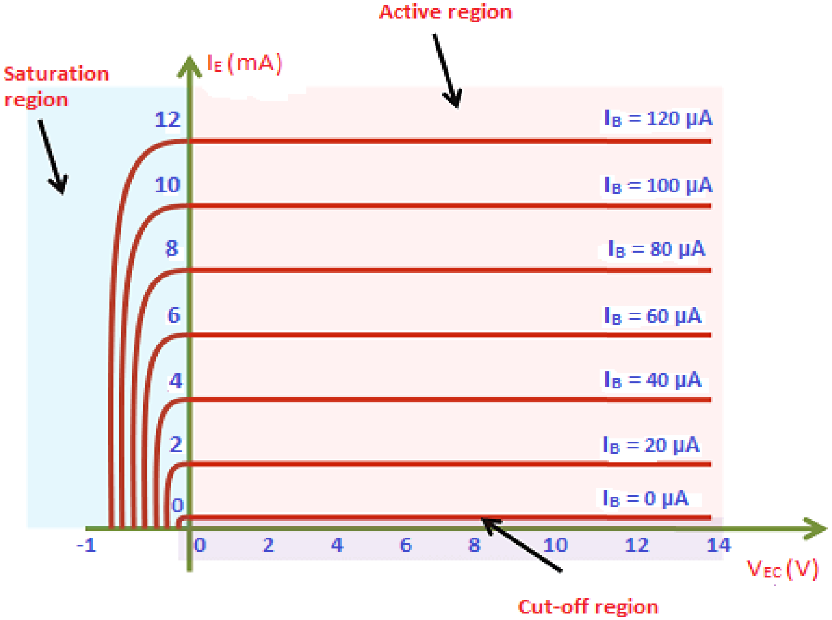


Figure 6 Input Characteristics for CC Configuration



Output characteristics

TRANSISTOR BIASING

- The supply of suitable external dc voltage is called as **biasing**. Either forward or reverse biasing is done to the emitter and collector junctions of the transistor.
- These biasing methods make the transistor circuit to work in four kinds of regions such as **Active region, Saturation region, Cutoff region** and **Inverse active region**.

EMITTER JUNCTION	COLLECTOR JUNCTION	REGION OF OPERATION
Forward biased	Forward biased	Saturation region
Forward biased	Reverse biased	Active region
Reverse biased	Forward biased	Inverse active region
Reverse biased	Reverse biased	Cutoff region

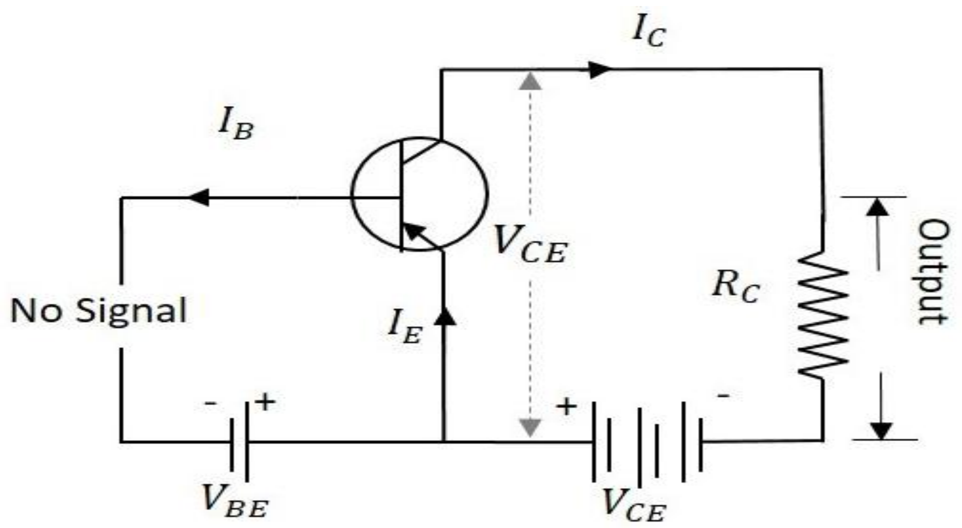
TRANSISTOR BIASING

TYPES OF BIASING CIRCUITS:

- Fixed bias circuit.
- Collector to base bias circuit.
- Voltage divider or self bias circuit.

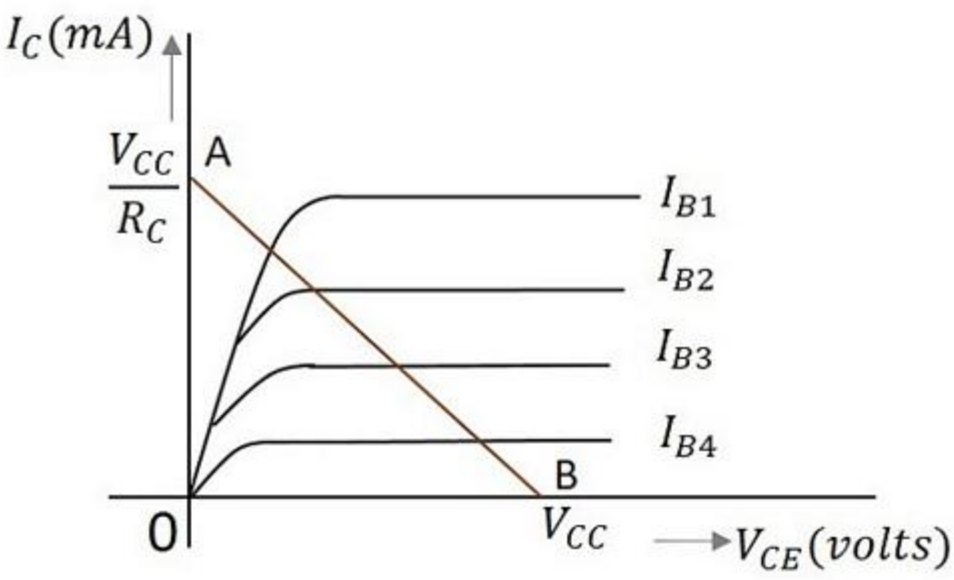
LOAD LINE ANALYSIS

When the transistor is given the bias and no signal is applied at its input, the load line drawn at such condition, can be understood as **DC** condition. Here there will be no amplification as the signal is absent.



LOAD LINE ANALYSIS

As V_{CC} and R_C are fixed values, the above one is a first degree equation and hence will be a straight line on the output characteristics. This line is called as **D.C. Load line**. The figure below shows the DC load line.



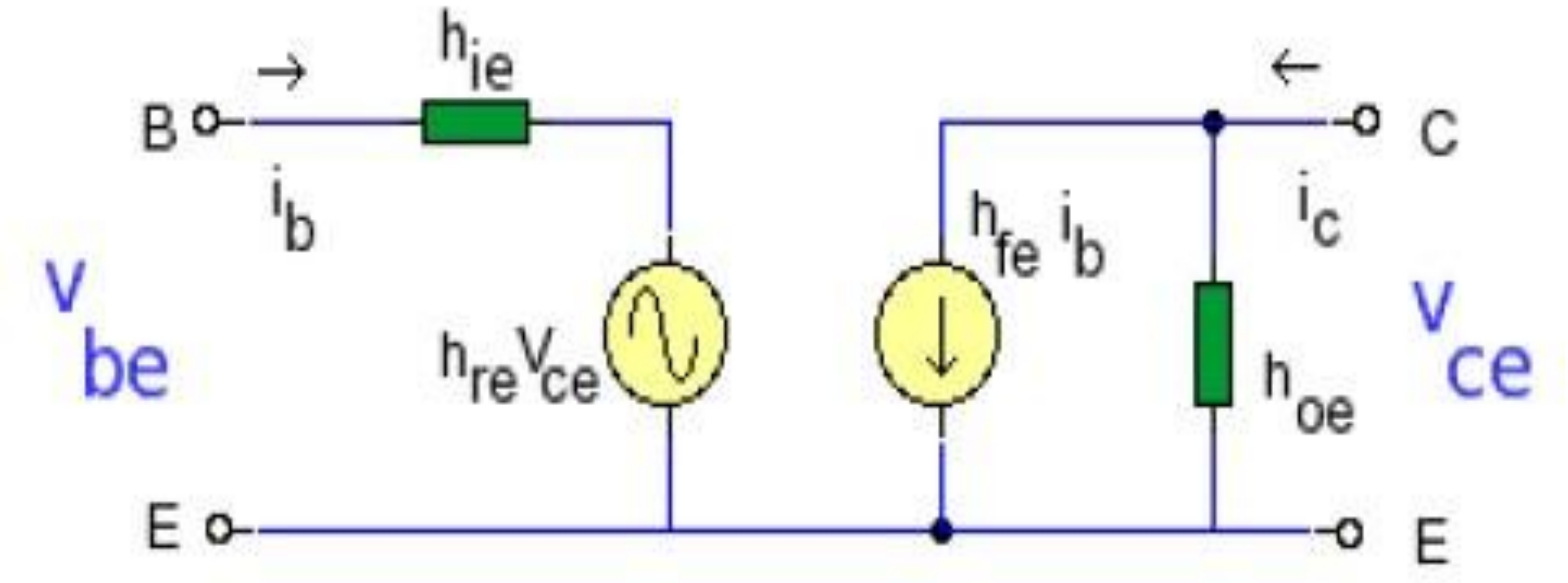
What is a Small Signal Model?

- A small signal model is a linear model which is independent of amplitude.
- The small signal model for a nonlinear component such as a BJT is a linear model about some nominal operating point.
- The hybrid model has four h-parameters. The "h" stands for hybrid because the parameters are a mix of impedance, admittance and dimensionless units. In common emitter the parameters are:
- **hie input impedance (Ω)**
- **hre reverse voltage ratio (dimensionless)**
- **hfe forward current transfer ratio (dimensionless)**
- **hoe output admittance (Siemen)**

SMALL SIGNAL EQUIVALENT CIRCUITS

- The hybrid model is suitable for small signals at mid band and describes the action of the transistor. Two equations can be derived from the diagram, one for input voltage vbe and one for the output ic:
- vbe = hie ib + hre vce
- ic = hfe ib + hoe vce
- If ib is held constant (ib=0) then hre and hoe can be solved:
- hre = vbe / vce | ib = 0
- hoe = ic / vce | ib = 0
- Also if vce is held constant (vce=0) then hie and hfe can be solved:
- hie = vbe / ib | vce = 0
- hfe = ic / ib | vce = 0

SMALL SIGNAL EQUIVALENT CIRCUITS



<u>Typical h-parameter Values</u>

h-parameters are not constant and vary with both temperature and collector current. Typical values for 1mA collector currents are:

$h_{ie} = 1000\ \Omega$ $h_{re} = 3 \times 10^{-4}$ $h_{oe} = 3 \times 10^{-6}S$ $h_{fe} = 250$

SMALL SIGNAL EQUIVALENT CIRCUITS

Common Base	Common Emitter	Common Collector	Definitions
$h_{ib} = \frac{v_{eb}}{i_e}$	$h_{ie} = \frac{v_{be}}{i_b}$	$h_{ic} = \frac{v_{bc}}{i_b}$	Input Impedance with Output Short Circuit
$h_{rb} = \frac{v_{eb}}{v_{cb}}$	$h_{re} = \frac{v_{be}}{v_{ce}}$	$h_{rc} = \frac{v_{bc}}{v_{ec}}$	Reverse Voltage Ratio Input Open Circuit
$h_{fb} = \frac{i_c}{i_e}$	$h_{fe} = \frac{i_c}{i_b}$	$h_{fc} = \frac{i_e}{i_b}$	Forward Current Gain Output Short Circuit
$h_{ob} = \frac{i_c}{v_{cb}}$	$h_{oe} = \frac{i_c}{v_{ce}}$	$h_{oc} = \frac{i_e}{v_{ec}}$	Output Admittance Input Open Circuit

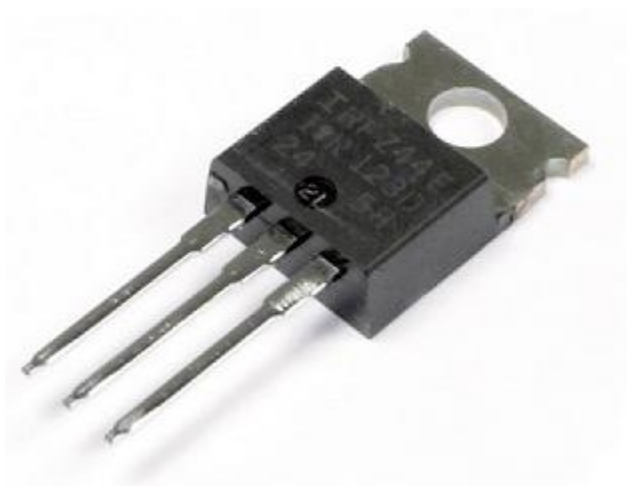
UNIT-II

MOSFET CIRCUITS

MOSFET structure and I-V characteristics.
MOSFET as a switch.
small signal equivalent circuits - gain,
input and output impedances,
small-signal model and common-source,
common-gate and common-drain amplifiers,
trans conductance,
high frequency equivalent circuit.

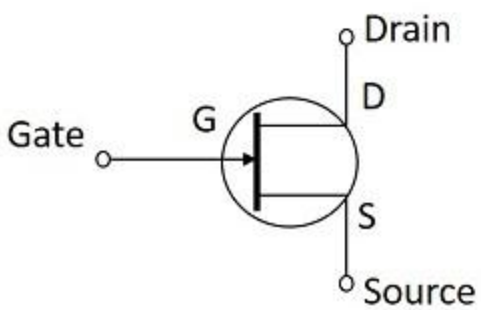
FIELD EFFECT TRANSISTOR

- An FET is a three-terminal unipolar semiconductor device. It is a **voltage controlled device** unlike a bipolar junction transistor.
- The FET is a **unipolar device**, which means that it is made using either p-type or n-type material as main substrate. Hence the current conduction of a FET is done by either electrons or holes.

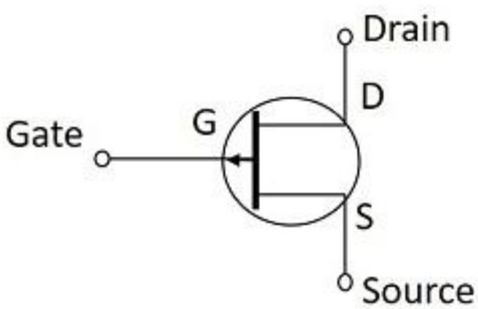


FETs

The three terminals of FET are Gate, Source and Drain. The **Source** terminal in FET is analogous to the Emitter in BJT, while **Gate** is analogous to Base and **Drain** to Collector.



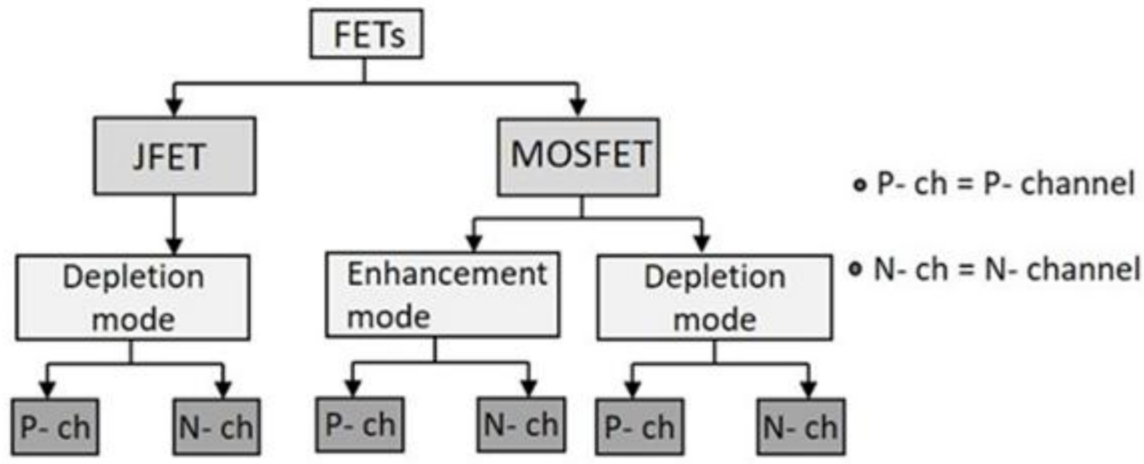
Symbol of n-channel FET



Symbol of p-channel FET

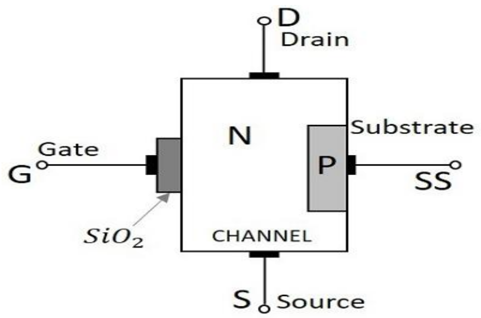
Types of FETs

There are two main types of FETS. They are JFET and MOSFET.

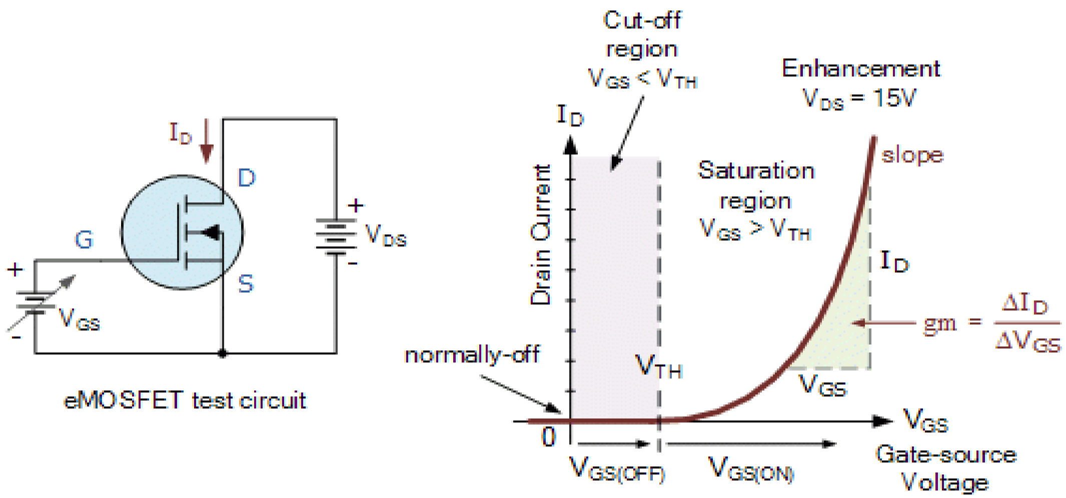


Construction of MOSFET

- The construction of a MOSFET is a bit similar to the FET. An oxide layer is deposited on the substrate to which the gate terminal is connected.
- This oxide layer acts as an insulator and hence the MOSFET has another name as IGFET.
- In the construction of MOSFET, a lightly doped substrate, is diffused with a heavily doped region.
- Depending upon the substrate used, they are called as **P-type** and **N-type** MOSFETs.

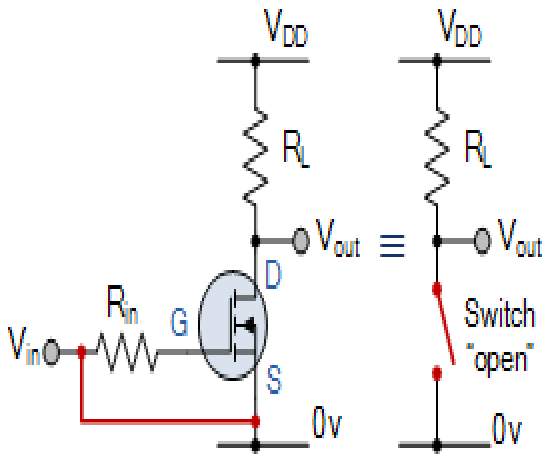


V-I CHARACTERISTICS OF MOSFET



- A **MOSFET** device has three different regions of operation. These regions are called the: Ohmic/Triode region, Saturation/Linear region and Pinch-off point.
- Therefore if we apply a small AC signal which is superimposed on to this DC bias at the gate input, then the **MOSFET** will act as a linear **amplifier.**

MOSFET AS SWITCH

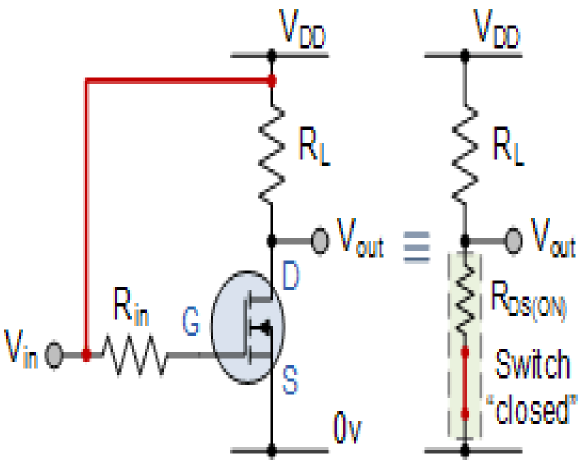


CUT-OFF CHARACTERIOSTICS:

The input and Gate are grounded (0V)

- Gate-source voltage less than threshold voltage $V_{GS} < V_{TH}$
- MOSFET is "OFF" (Cut-off region)
- No Drain current flows ($I_D = 0$ Amps)
- $V_{OUT} = V_{DS} = V_{DD} =$ "1"
- MOSFET operates as an "open switch"

MOSFET AS SWITCH

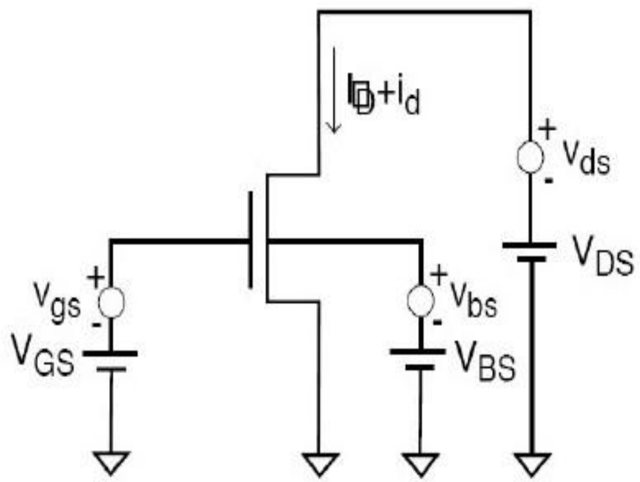


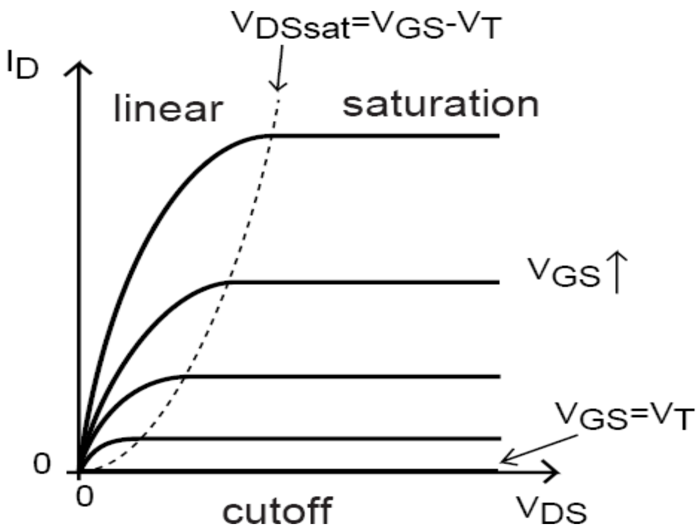
SATURATION CHARACTERIOSTICS:

The input and Gate are connected to $V_{DD.}$

- Gate-source voltage is much greater than threshold voltage $V_{GS} > V_{TH.}$
- MOSFET is "ON" (saturation region)
- Max Drain current flows($I_D = V_{DD} / R_L$)
- V_{DS} = 0V (ideal saturation)
- Min channel resistance $R_{DS(on)} < 0.1\Omega$
- $V_{OUT} = V_{DS} \cong 0.2V$ due to $R_{DS(on)}$
- MOSFET operates as a low resistance "closed switch".

SMALL-SIGNAL OPERATION OF MOSFET





SMALL-SIGNAL OPERATION OF MOSFET

With id linear on small-signal drives:

$$i_d = g_m v_{gs} + g_o v_{ds} + g_{mb} v_{bs}$$

Define: g_m transconductance [S]

g_o output or drain conductance [S]

g_{mb} backgate transconductance [S]

Approach to computing g_m, g_o, and g_{mb}.

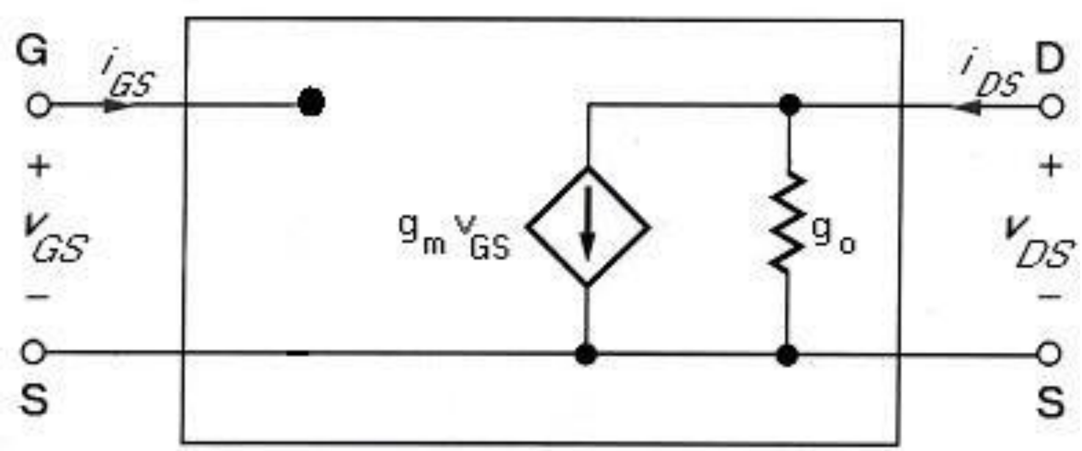
$$g_m \approx \left.\frac{\partial i_D}{\partial v_{GS}}\right|_Q$$

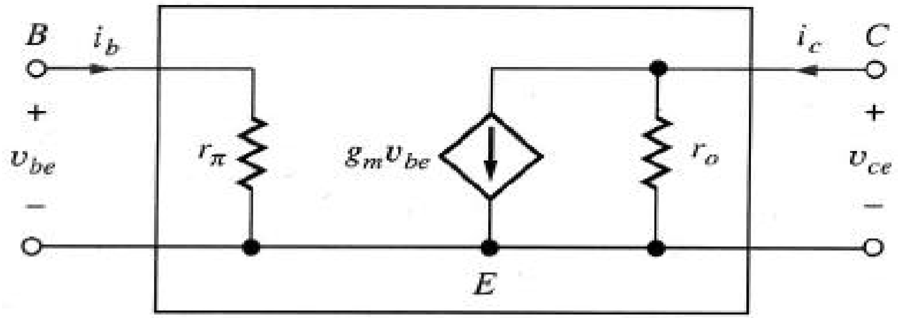
$$g_o \approx \left.\frac{\partial i_D}{\partial v_{DS}}\right|_Q$$

$$g_{mb} \approx \left.\frac{\partial i_D}{\partial v_{BS}}\right|_Q$$

$$Q \equiv [v_{GS} = V_{GS}, v_{DS} = V_{DS}, v_{BS} = V_{BS}]$$

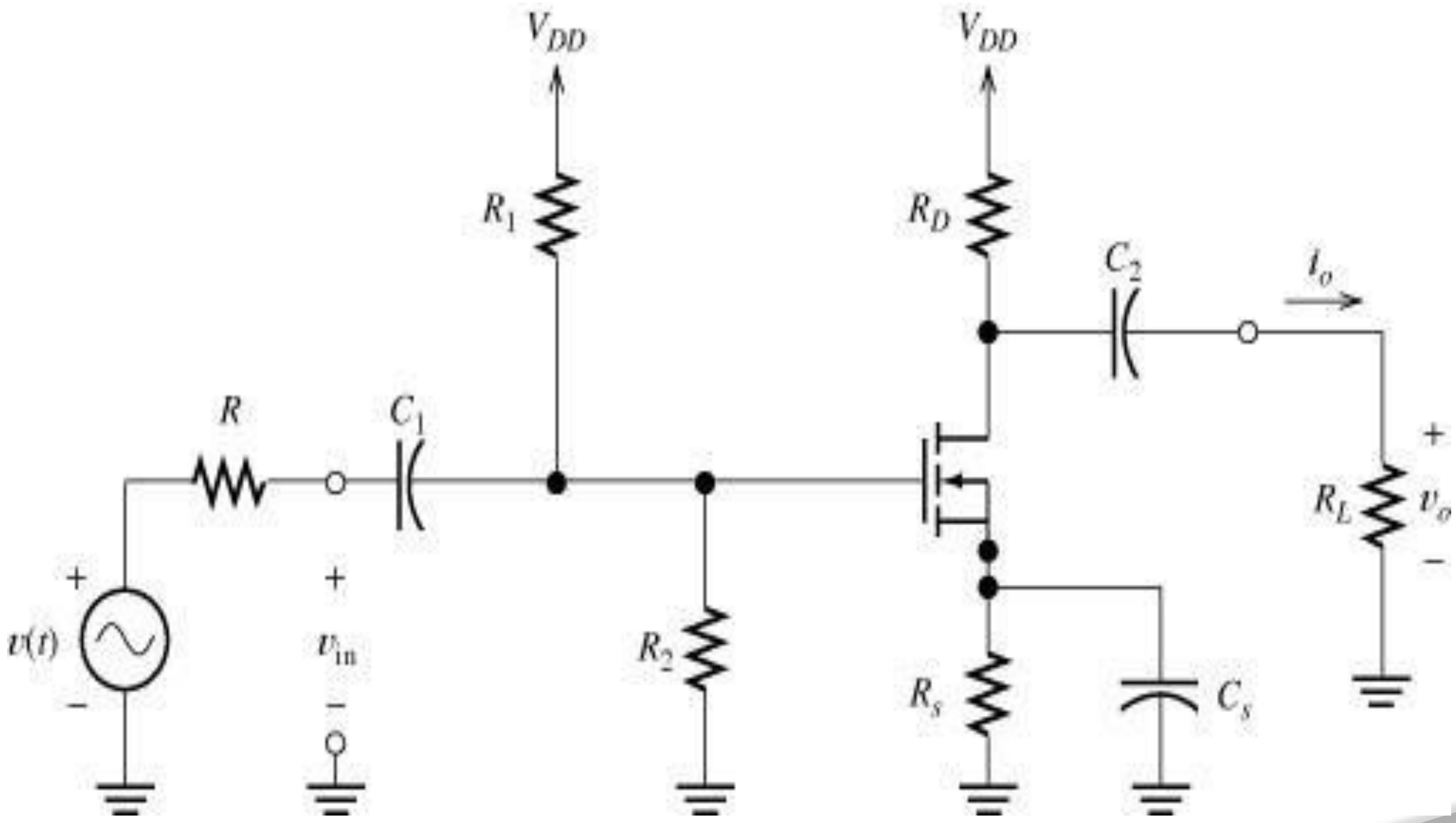
SMALL-SIGNAL OPERATION OF MOSFET





the BJT small signal equivalent circuit

FET as common source amplifier



FET as common source amplifier

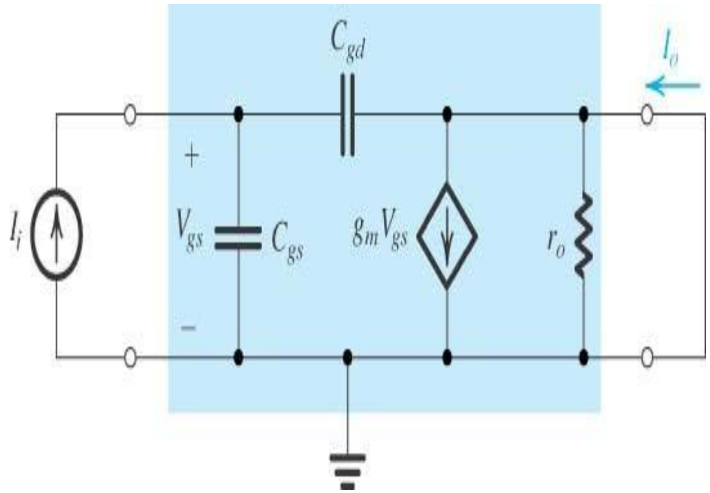
•In electronics, a **common-source amplifier** is one of three basic single-stage field-effect transistor.

FET **amplifier** topologies, typically used as a voltage or transconductance **amplifier**.

•A **common-drain amplifier** is one in which the input signal is applied to the gate and the output is taken from the source, making the **drain common** to both. Because it is **common**, there is no need for a **drain** resistor.

A **common-drain amplifier** is also called a source-follower.

High frequency model of MOSFET



- The MOSFET's internal capacitances limit the high-frequency performance of the MOSFET that means:
  - Limit the switching speed of the circuits in digital applications.
  - Limit the frequency at which useful amplification can be obtained in the amplifiers.

UNIT-III

MULTI-STAGE AND POWER AMPLIFIERS

Classification of Amplifiers,
Distortion in amplifiers,
Different coupling schemes used in amplifiers,
Frequency response and Analysis of multistage amplifiers,
Cascade amplifier,
Darlington pair.
Transistor at High Frequency: Hybrid - model of CE model,
f_α, β and unity gain bandwidth,
Gain band width product.
Differential Amplifiers,
Power amplifiers - Class A, Class B, Class C, Class AB.

MULTISTAGE AMPLIFIERS

- An amplifier formed by connecting several amplifiers in cascaded arrangement such that output of one amplifier becomes the input of other whose output becomes input of next and so on .
- Each amplifier in this configuration is known as stage.
- So several stages are connected to form multistage amplifier.

CLASSIFICATION OF AMPLIFIERS

Classification of Amplifiers:

Type of Signal:

1. Small Signal.
2. Large Signal.

Based on no.of Stages:

1. Single Stage
2. Multistage

Type of Configuration:

1. Common Emitter.
2. Common Base.
3. Common collector.

CLASSIFICATION OF AMPLIFIERS

Classification based on conduction angle:

1. Class A Amplifier Direct Current (DC)
2. Class B Amplifier
3. Class AB Amplifier
4. Class C Amplifier

Frequency of Operation:

1. Radio Frequencies (RF)
2. Audio Frequencies (AF)
3. VHF, UHF and SHF Frequencies

Distortion in Amplifiers

- Amplifier Distortion If the output of an amplifier is not a complete AC sine wave, then it is distorting the output.
- The amplifier is non-linear.
- This distortion can be analyzed using Fourier analysis.
- In Fourier analysis, any distorted periodic waveform can be broken down into frequency components.
- These components are harmonics of the fundamental frequency.

Multi stage amplifiers

- An amplifier formed by connecting several amplifiers in cascaded arrangement such that output of one amplifier becomes the input of other whose output becomes input of next and so on .
- Each amplifier in this configuration is known as stage.
- So several stages are connected to form multistage amplifier.

working

- Each amplifier connected perform the process of amplification.
- They convert their input signal into high amplified output signal.
- Hence the output signal after passing through several amplifiers becomes highly amplified.

Voltage gain

- The overall voltage gain of multistage amplifier is product of voltage gain of individual amplifier.
- If voltage is expressed in dB overall voltage gain is by the sum of voltage gain in dB of individual amplifier.
- If we convert voltage gain into the db voltage gain then we use a relation.

DIRECT COUPLED MULTISTAGE AMPLIFIER

- A direct coupled amplifier is a type of amplifier in which two amplifier are connected in a such a way that one stage is coupled directly to the other without using any coupling or bypassing capacitor.
- In this configuration dc collector voltage of first stage provides base bias to second stage means output of first stage becomes input of second stage.

CASCADE AMPLIFIER

- **SIGNIFICANCE OF CASCADE AMPLIFIER:**
- The most widely used method Coupling a signal from one stage to the another stage and block dc voltage from one stage to the another stage.
- The signal developed across the collector resistor of each stage is coupled into the base of the next stage .
- The overall gain = product of the individual gain

TO IMPROVE THE GAIN

CASCADE AMPLIFIERS

- A cascade amplifier is any two-port network constructed from a series of amplifiers, where each amplifier sends its output to the input of the next amplifier in a chain.
- The complication in calculating the gain of cascaded stages is the non-ideal coupling between stages due to loading.

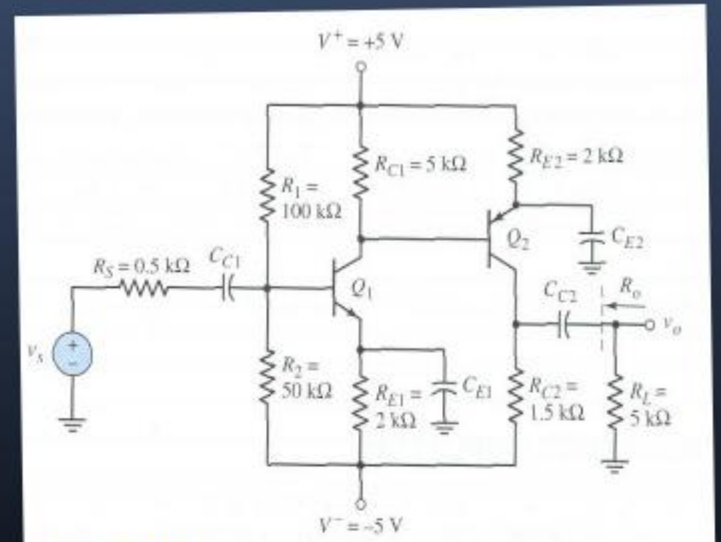


Figure 4.60 A two-stage amplifier in a cascade configuration

CASCADE AMPLIFIERS

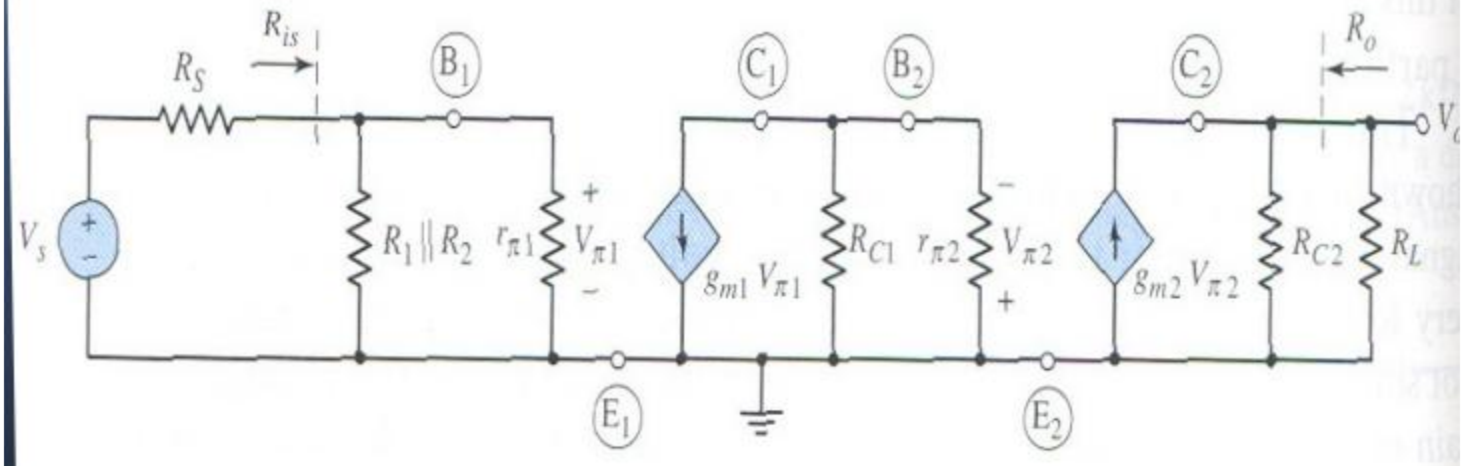
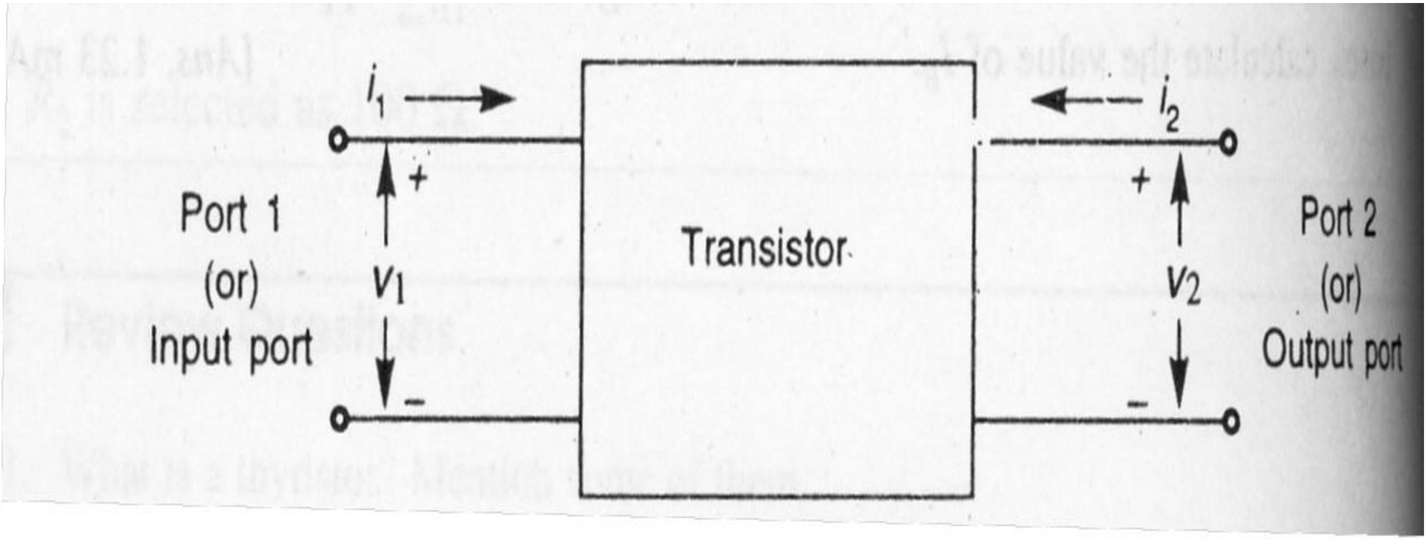


Figure 4.61 Small-signal equivalent circuit of the cascade configuration

Hybrid h-Parameter model for an amplifier

- The equivalent circuit of a transistor can be dram using simple approximation by retaining its essential features.
- These equivalent circuits will aid in analyzing transistor circuits easily and rapidly.
- A transistor can be treated as a two part network. The terminal behavior of any two part network can be specified by the terminal voltages V_1 & V_2 at parts 1 & 2 respectively and current i_1 and i_2, entering parts 1 & 2, respectively.



•Of these four variables $V-_1$, V_2, i_1 and i_2, two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two part parameters out of which the following three are more important.

Hybrid Parameters or h-parameters

If the input current i_1 and output Voltage V_2 are takes as independent variables, the input voltage V_1 and output current i_2 can be written as

$$V_1 = h_{11}\, i_1 + h_{12}\, V_2$$
$$i_2 = h_{21}\, i_1 + h_{22}\, V_2$$

The four hybrid parameters h_{11}, h_{12}, h_{21} and h_{22} are defined as follows.

$$h_{11} = [V_1 / i_1] \text{ with } V_2 = 0$$

= Input Impedance with output part short circuited.

Hybrid Parameters or h-parameters

$h_{22} = [i_2 / V_2]$ with $i_1 = 0$

= Output admittance with input part open circuited.

$h_{12} = [V_1 / V_2]$ with $i_1 = 0$

= reverse voltage transfer ratio with input part open circuited.

$h_{21} = [i_2 / i_1]$ with $V_2 = 0$

= Forward current gain with output part short circuited.

Transistor TWO PORT NETWORK MODEL

The Hybrid Model for Two-port Network:-

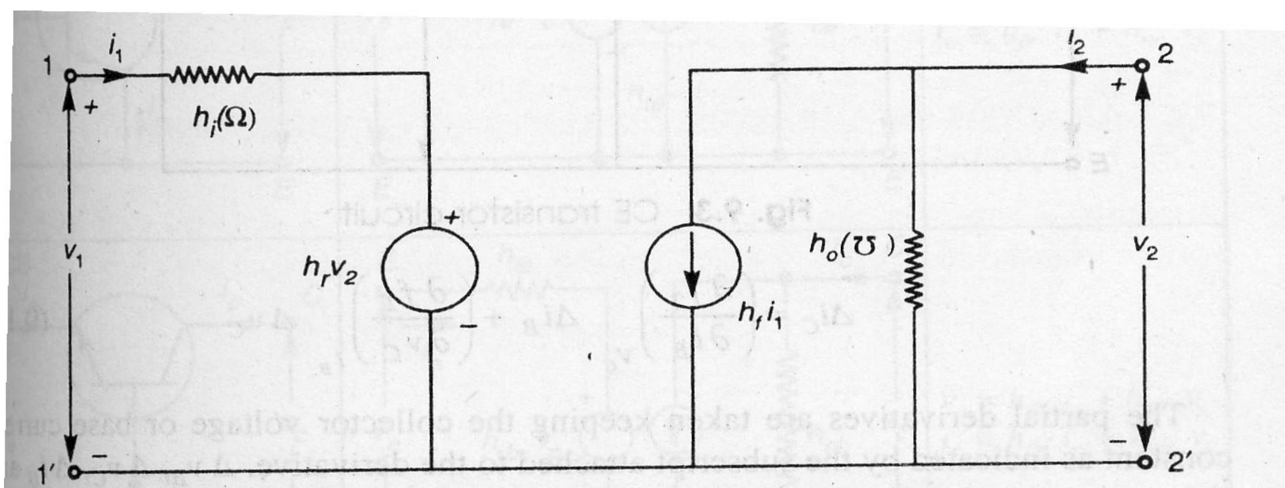
$$V_1 = h_{11} i_1 + h_{12} V_2$$

$$I_2 = h_1 i_1 + h_{22} V_2$$

$$\downarrow$$

$$V_1 = h_1 i_1 + h_r V_2$$

$$I_2 = h_f i_1 + h_0 V_2$$



Transistor Hybrid Model

Use of h – parameters to describe a transistor have the following advantages:

- h – parameters are real numbers up to radio frequencies .
- They are easy to measure
- They can be determined from the transistor static characteristics curves.
- They are convenient to use in circuit analysis and design.
- Easily convert able from one configuration to other.
- Readily supplied by manufactories.

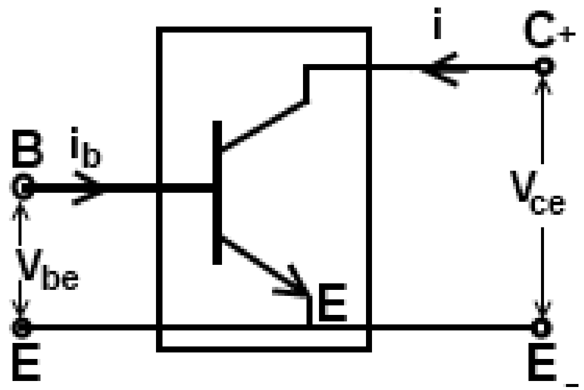
Transistor Hybrid Model CE Configuration

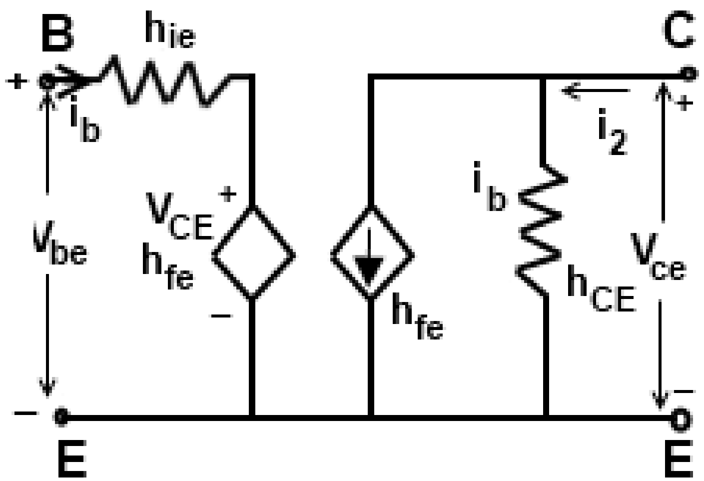
In common emitter transistor configuration, the input signal is applied between the base and emitter terminals of the transistor and output appears between the collector and emitter terminals. The input voltage (V_{be}) and the output current (i_c) are given by the following equations:

$$V_{be} = h_{ie}.i_b + h_{re}.V_c$$

$$i_e = h_{fe}.i_b + h_{oe}.V_c$$

Transistor Hybrid Model CE Configuration





Transistor Hybrid Model CB Configuration

Where

$$h_{ie} = (\partial f_1/\partial i_B)V_c = (\partial v_B/\partial i_B)V_c = (\Delta v_B /\Delta i_B)V_c = (v_b / i_b)V_c$$

$$h_{re} = (\partial f_1/\partial v_c)I_B = (\partial v_B/\partial v_c) I_B = (\Delta v_B /\Delta v_c) I_B = (v_b /v_c) I_B$$

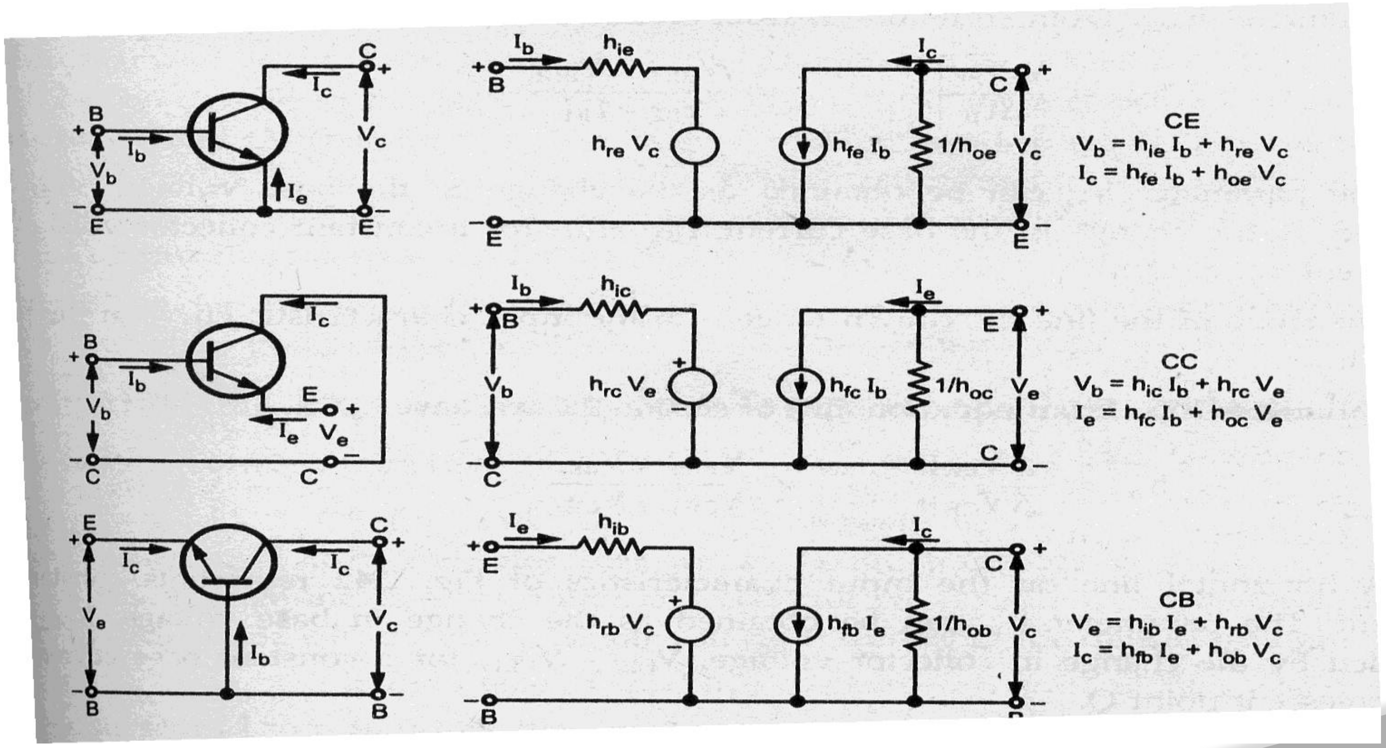
$$h_{fe} = (\partial f_2/\partial i_B)V_c = (\partial i_c /\partial i_B)V_c = (\Delta i_c /\Delta i_B)V_c = (i_c / i_b)V_c$$

$$h_{oe} = (\partial f_2/\partial v_c)I_B = (\partial i_c /\partial v_c) I_B = (\Delta i_c /\Delta v_c) I_B = (i_c /v_c) I_B$$

The same theory is extended to other configurations including CB and CC

Transistor Hybrid Model CB Configuration

Hybrid Model and Equations for the transistor in three different configurations are are given below.



Analysis of Transistor Amplifier using Complete h-Parameter Model

In the h-parameter model consider the load Resistance R_L and input signal V_s. The expressions for Current gain, Voltage gain ,input and output impedance are:

1. Current Gain:

A_i=-h_f/(1+$h_o R_L$)

Where A_i is the current amplification or current gain
The overall current gain taking source resistance is given by:

A_{is}=A_i * (R_s/Z_i + R_s)

where

Z_i input impedance

R_s source resistance

Analysis of Transistor Amplifier using Complete h-Parameter Model

2)Input Impedance(Zi)

$Z_i = h_i + h_r A_i R_L$

3) Voltage Gain(A_v):

$A_v = (A_i * R_L) / Z_i$

Voltage gain taking source resistance is given by

$A_{vs} = (A_v * Z_i)/(Z_i + R_s)$

4) Output Admittance(Y_o)

$Y_o = h_o - h_f * h_r/(h_i + R_s)$

Analysis of Transistor Amplifier using simplified h-Parameter Model

Common Emitter Configuration

Fixed Bias configuration:

Input Impedance $Z_i = R_B \,||\, h_{ie}$

Output Impedance $Z_o=R_C \,||\, (1/h_{oe})$

Voltage gain $A_v=-h_{fe} * (R_C \,||\, (1/h_{oe}) /h_{ie}$

Current Gain $A_i=h_{fe} * R_B/(R_B + h_{ie})$

Voltage Divider Configuration:

Input impedance $Z_i=(R_{B1} \,||\, R_{B2})||\, h_{ie}$

Output Impedance $Z_o=R_C \,||(1/h_{oe})$

Voltage gain $Av=-h_{fe} * [R_C \,||\, (1/h_{oe})]/h_{ie}$

Current gain $A_i=h_{fe} * (R_{B1}||R_{B2})/(R_{B1}||\, R_{B2}) + h_{ie}$

small-signal amplifiers

In small-signal amplifiers the main factors are:

- Amplification
- Linearity
- Gain

Since large-signal, or power, amplifiers handle relatively large

voltage signals and current levels, the main factors are:

- Efficiency
- Maximum power capability
- Impedance matching to the output device

Types of Amplifiers

Class A The amplifier conducts through the full 360°

of the input. The Q-point is set near the middle of the load line.

Class B The amplifier conducts through 180° of the input. The Q-point is set at the cutoff point.

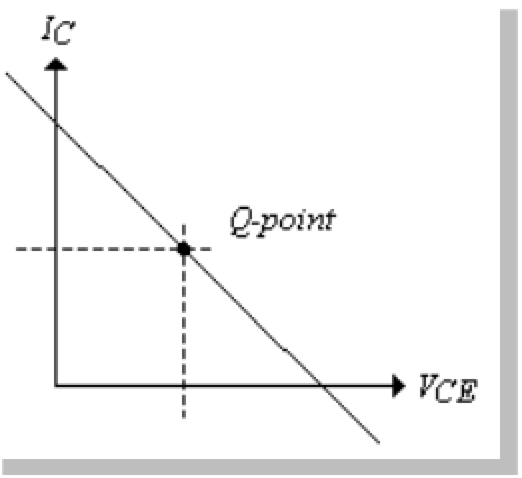
Class AB This is a compromise between the class A and B amplifiers. The amplifier conducts somewhere between 180° and 360°.

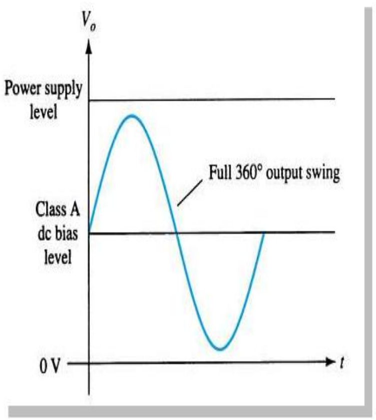
The Q-point is located between the mid-point and cutoff.

Class C The amplifier conducts less than 180° of the input. The Q-point is located below the cutoff level.

Class A power Amplifier

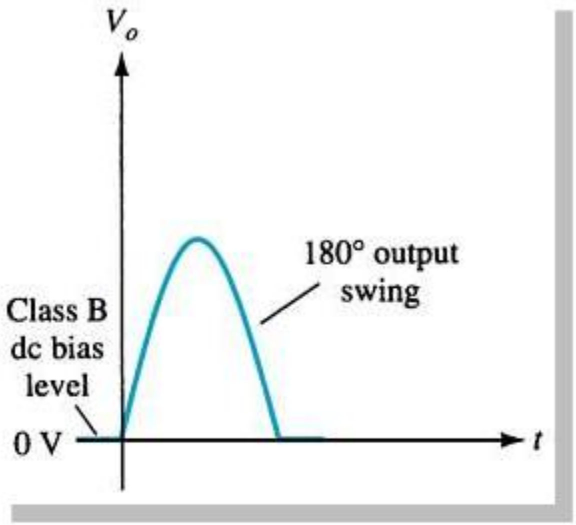
- Class A Amplifier The output of a class A amplifier conducts for the full 360° of the cycle.
- The Q-point is set at the middle of the load line so that the AC signal can swing a full cycle.
- DC load line indicates the maximum and minimum limits set by the DC power supply.

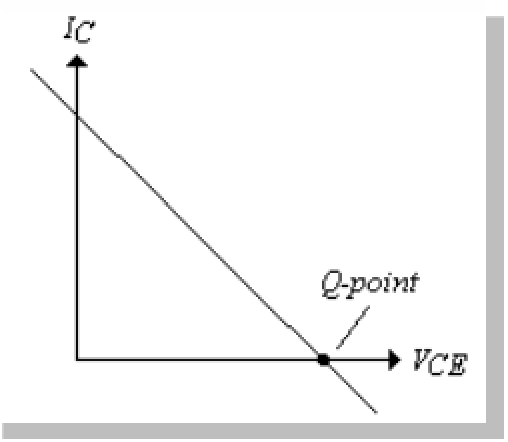




Class B power Amplifier

Class B Amplifier A class B amplifier output only conducts for 180° or one-half of the AC input signal.

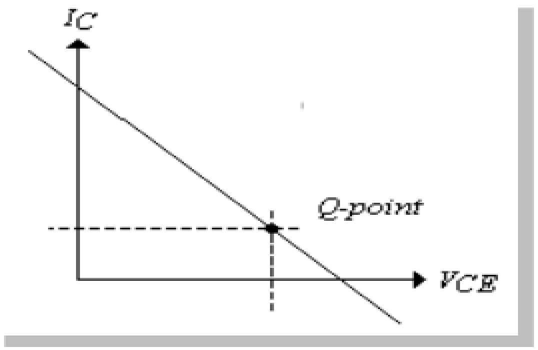




The Q-point is at 0V on the load line, so that the AC signal can only swing for one-half cycle.

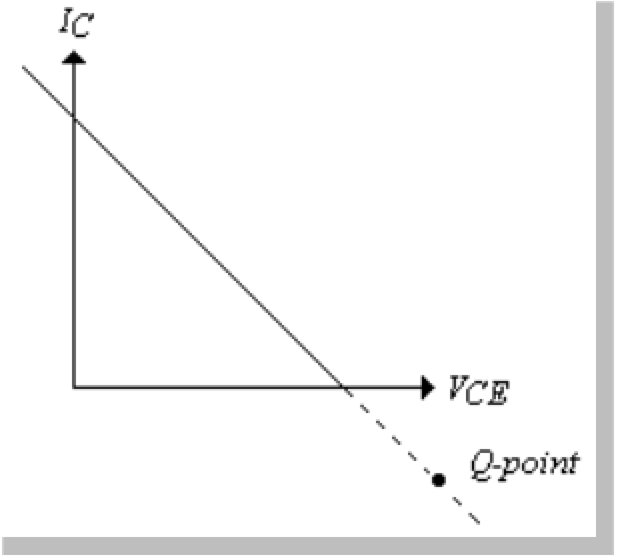
Class AB Amplifier :

- This amplifier is a compromise between the class A and class B amplifier—the Q-point is above that of the Class B but below the class A.
- The output conducts between 180° and 360° of the AC input signal.



Class C Amplifier

Class C: The output of the class C conducts for less than 180° of the AC cycle. The Q-point is below cutoff.



Amplifier Efficiency

Comparison of Amplifier Classes

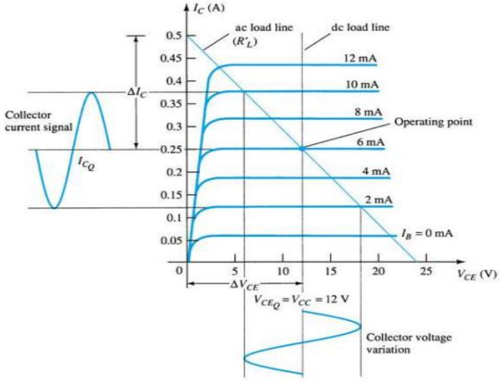
	Class A	Class AB	Class B	Class C*	Class D
Operating cycle	360°	180° to 360°	180°	Less than 180°	Pulse operation
Power efficiency	25% to 50%	Between 25% (50%) and 78.5%	78.5%		Typically over 90%

Class C is usually not used for delivering large amounts of power, thus the efficiency is not given here.

Efficiency refers to the ratio of output to input power. The lower the amount of conduction of the amplifier the higher the efficiency.

Transformer-Coupled Class A Amplifier

- **Transformer-Coupled Class A Amplifier** DC Load Line As in all class A amplifiers the Q-point is established close to the midpoint of the DC load line.
- The dc resistance is small ideally at 0Ω and a dc load line is a straight vertical line.
- AC Load Line The saturation point (ICmax) is at Vcc/R L and the cutoff point is at V2 (the secondary voltage of the transformer).
- This increases the maximum output swing because the minimum and maximum values of IC and VCE are spread further apart.



UNIT-IV

FEEDBACK AMPLIFIERS

Concepts of feedback
Classification of feedback amplifiers,
general characteristics of Negative feedback amplifiers,
effect of feedback on amplifier characteristics,
voltage series, voltage shunt,
current series and current shunt feedback configurations,
Oscillators: Condition for Oscillations,
RC type Oscillators RC phase shift and Wien-bridge Oscillators,
LC type Oscillators, generalized analysis of LC Oscillators,
Hartley and Colpitts oscillators.

Concept of feedback

- In the feedback process a part of output is sampled and fed back to the input.
- The fed back signal can be in phase with or out of phase with the original input signal.

Definition of feedback:

- Feedback is defined as the process in which a part of output signal (voltage or current) is returned back to the input.
- The amplifier that operates on the principle of feedback is known as feedback amplifier.

Types of feedback

There are two types of feedbacks.

1.Positive feedback.

2. Negative feedback.

•If the original input signal and the feedback signal are in phase, the feedback is called as positive feedback.

• However if these two signals are out of phase then the feedback is called as negative feedback.

EFFECT OF FEEDBACK ON AMPLIFIERS

Some of the Advantages of negative feedback:

a) Input resistance increases.

b) Output resistance decreases.

c) Bandwidth increases.

d) Non linear distortion decreases.

e) Frequency distortion decreases.

f) Sensitivity will be decreased.

g) Gain stability.

CHARACTERISTICS OF NEGATIVE FEEDBACK AMPLIFIERS

General characteristics of negative feedback amplifiers are

- Sensitivity of transfer amplification.
- Desensitivity of transfer amplification.
- Frequency Distortion.
- Nonlinear distortion.
- Reduction of noise.
- Increases bandwidth.

CLASSIFICATION OF AMPLIFIERS

Amplifiers can be classified as

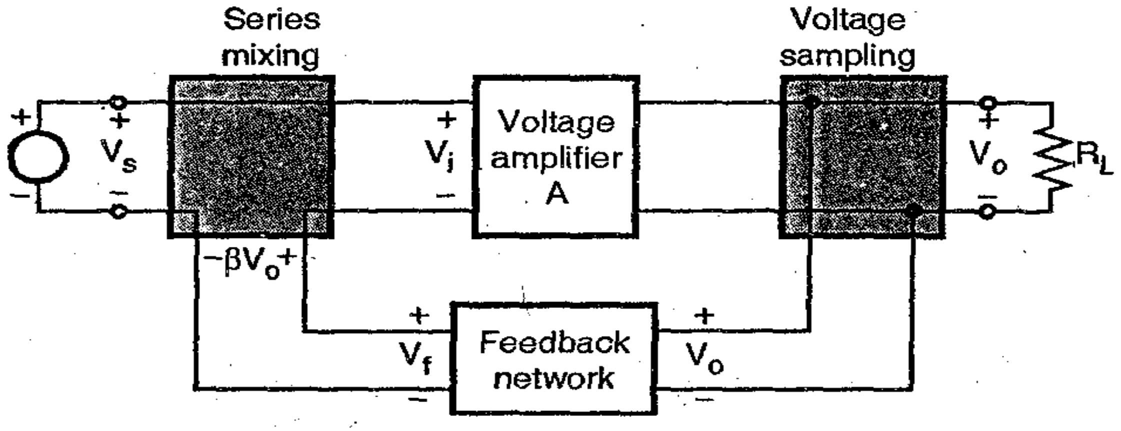
- I. Voltage amplifiers.
- 2. Current amplifiers.
- 3. Transconductance amplifiers.
- 4. Transresistance amplifiers.

VOLTAGE SERIES FEEDBACK AMPLIFIERS

•Voltage series feedback = voltage sampling + series mixing The voltage series feedback is present in the voltage amplifiers.

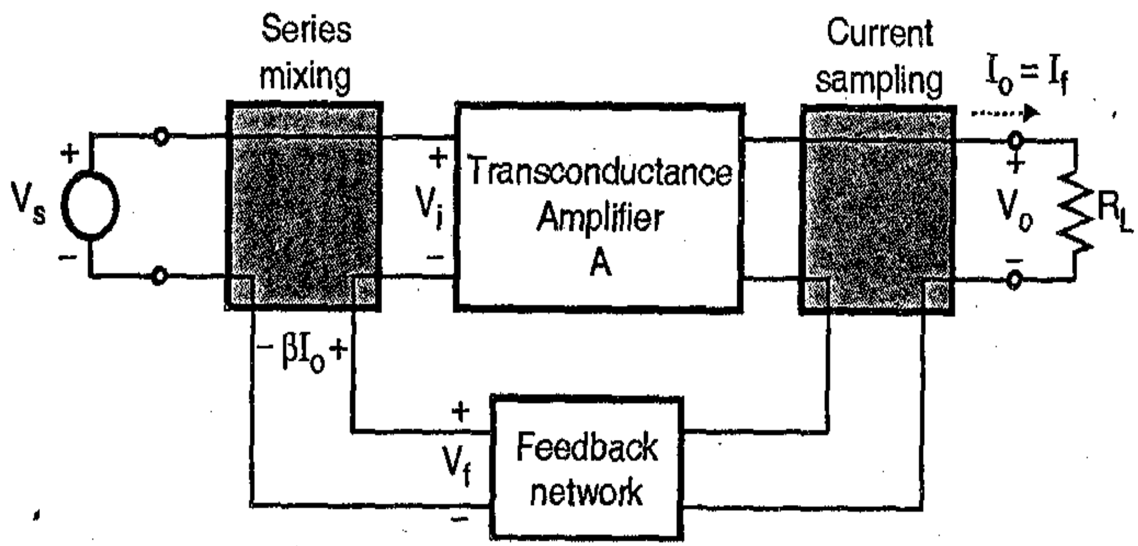
•A transistor amplifier which uses the voltage series feedback is the common collector or emitter follower amplifier:

1. A common collector (or emitter follower) amplifier using BJT.
2. A common drain (or source follower) amplifier using FET



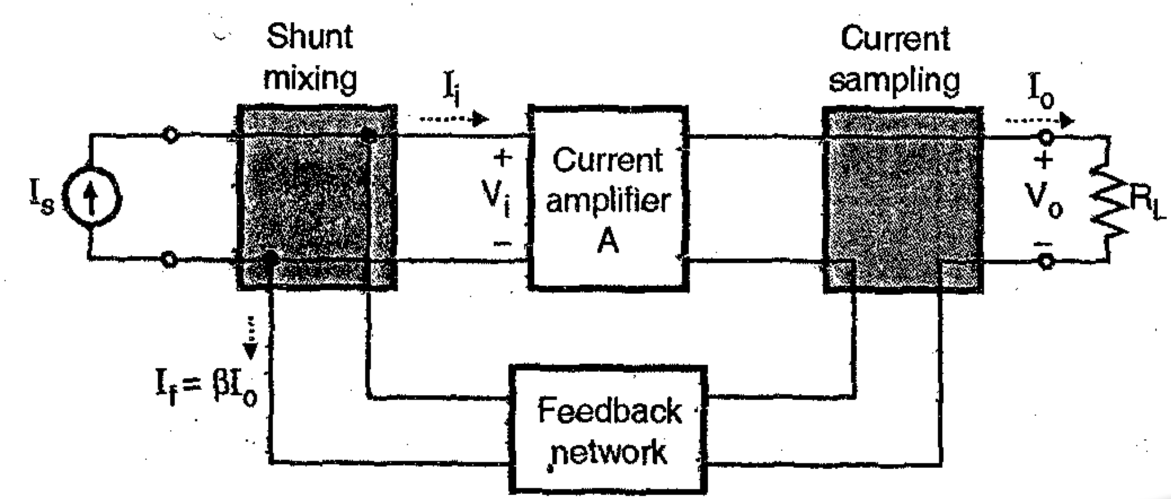
CURRENT SERIES FEEDBACK AMPLIFIERS

- The Current sampling + Series mixing.
- Current series feedback is present in the transconductance amplifiers.



CURRENT SHUNT FEEDBACK AMPLIFIERS

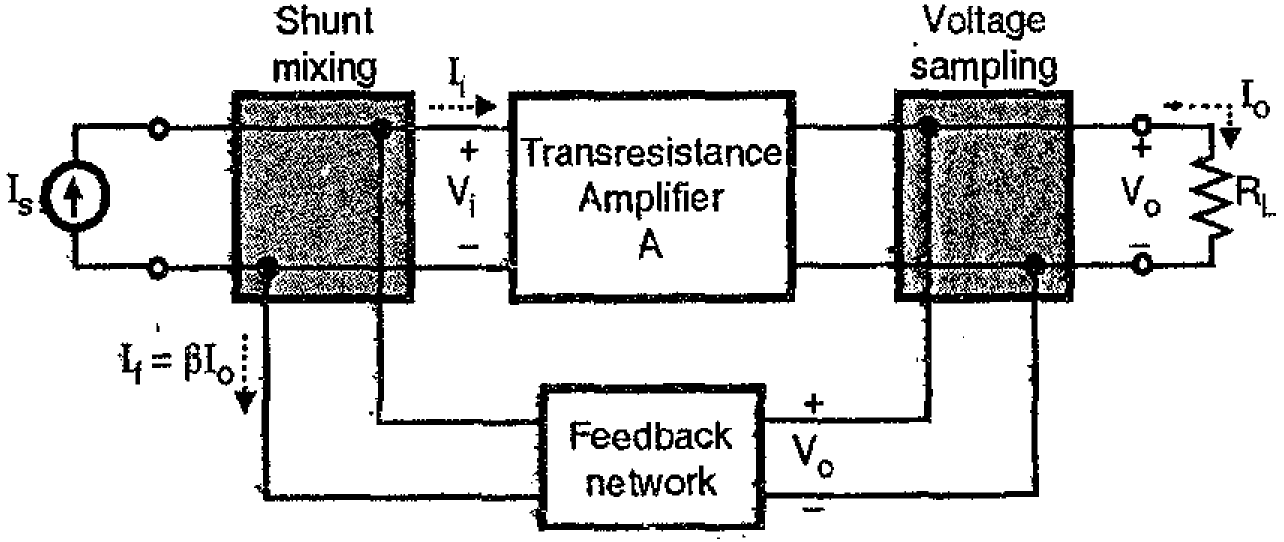
- This is a combination of current sampling and shunt mixing.
- Current sampling + Shunt mixing.
- Current shunt feedback is present in the current amplifiers.



VOLTAGE SHUNT FEEDBACK AMPLIFIERS

Voltage Shunt Feedback = Voltage Sampling + Shunt Mixing.

The voltage shunt feedback is present in transresistance amplifier.



OSCILLATORS

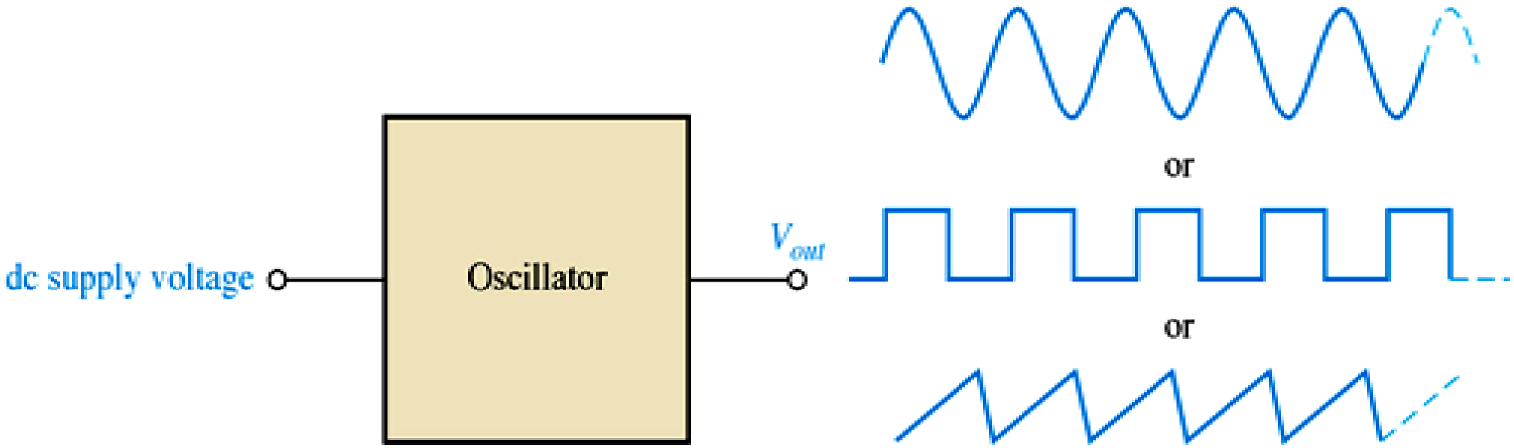
- An **oscillator** is an electronic circuit that produces a periodic, oscillating electronic signal, often a sine wave or a square wave.
- **Oscillators** convert direct current (DC) from a power supply to an alternating current (AC) signal.
- Oscillator: circuit that produces oscillation.
- Characteristics: wave-shape, frequency, amplitude, distortion, stability.

OSCILLATORS

•An oscillator is a circuit that produces a repetitive signal from a dc voltage.

•The feedback oscillator relies on a positive feedback of the output to maintain the oscillations.

•The relaxation oscillator makes use of an RC timing circuit to generate a non-sinusoidal signal such as square wave.



BASIC CONDITION FOR OSCILLATION

- The condition for sinusoidal oscillation of frequency f_0 is

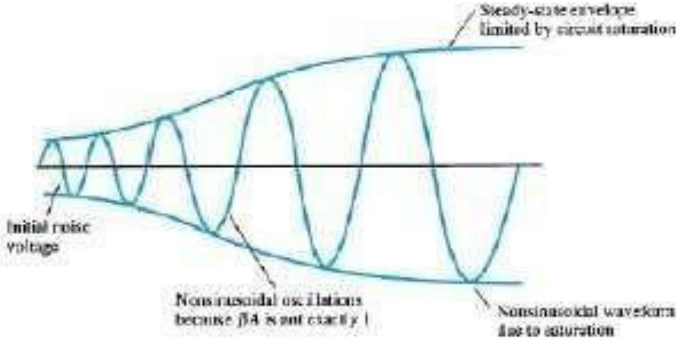
$$A\beta = 1$$

- This is known as **Barkhausen criterion**.

1. *The magnitude of the loop gain must be unity or slightly larger.*
2. *Total phase shift, ϕ of the loop gain must be $0°$ or $360°$*

Oscillators

- If the feedback signal is not positive and gain is less than unity, oscillations dampen out.
- If the gain is higher than unity then oscillation saturates.



Type of Oscillators

Oscillators can be categorized according to the types of feedback network used:

- RC Oscillators: Phase shift and Wien Bridge Oscillators
- LC Oscillators: Colpitt and Hartley Oscillators
- Crystal Oscillators

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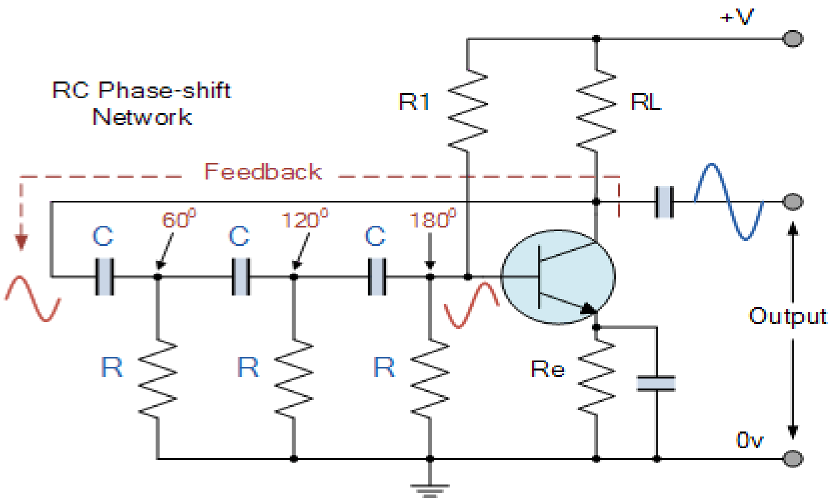
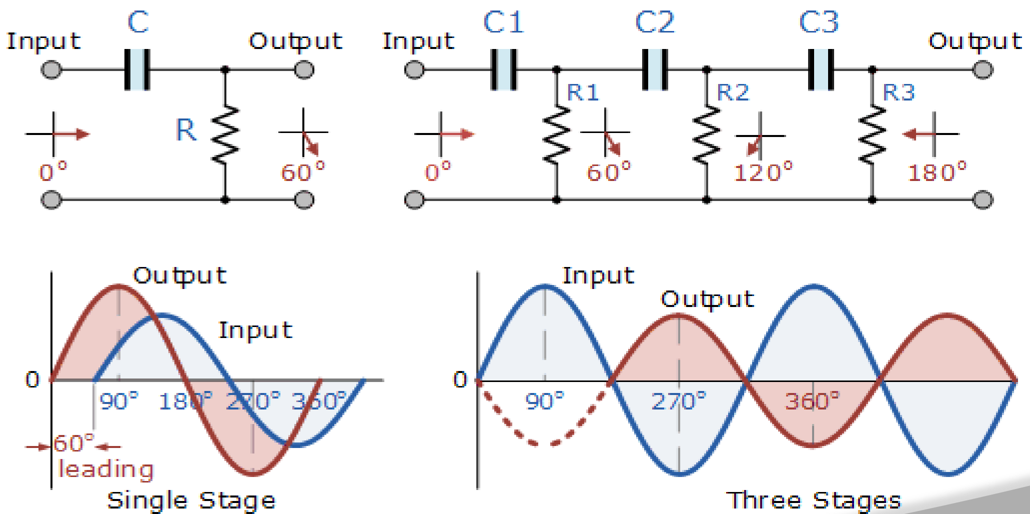
RC PHASE SHIFT OSCILLATOR

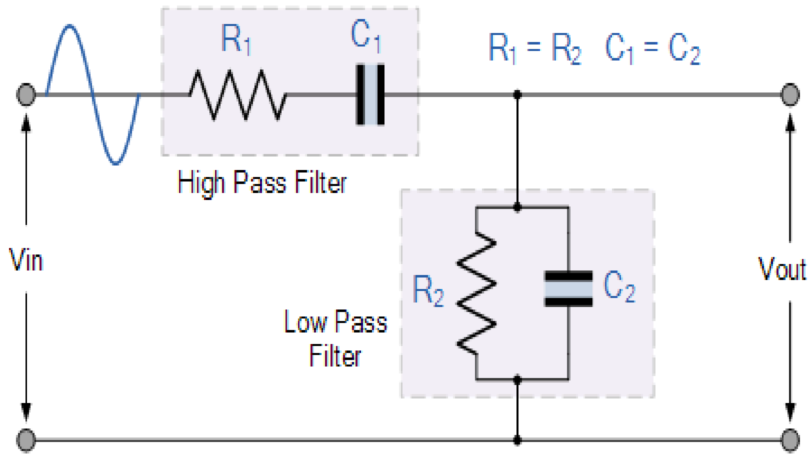




RC PHASE SHIFT OSCILLATOR

- RC Oscillators use a combination of an amplifier and an RC network to produce oscillations due to the phase shift between the stages.
- Then by connecting together three such RC networks in series we can produce a total phase shift in the circuit of 180^o at the chosen frequency and this forms the bases of a "phase shift oscillator" otherwise known as a **RC Oscillator** circuit.

WEIN BRIDGE OSCILLATOR



- The circuit consists of a series RC circuit connected to a parallel RC forming basically a High Pass Filter connected to a Low Pass Filter producing a very selective second-order frequency dependant Band Pass Filter with a high Q factor at the selected frequency, fr.
- At low frequencies the reactance of the series capacitor (C1) is very high so acts a bit like an open circuit, blocking any input signal at Vin resulting in virtually no output signal.

LC OSCILLATORS

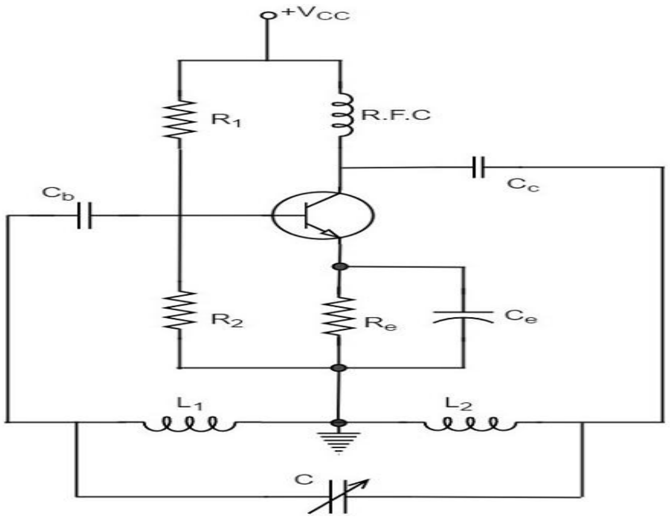
•Tuned circuit oscillators are the circuits that produce oscillations with the help of tuning circuits. The tuning circuits consists of an inductance L and a capacitor C.

• These are also known as **LC oscillators, resonant circuit oscillators** or **tank circuit oscillators**.

Types of LC oscillators are

1. Hartley oscillator.
2. Colpitts oscillator.
3. Crystal oscillator.

HARTLEY OSCILLATOR



The equation for **frequency of Hartley oscillator** is given as

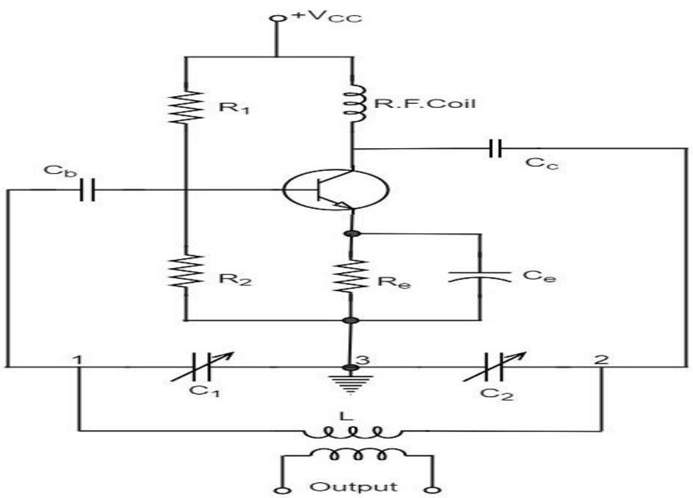
$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

$$L_T = L_1 + L_2 + 2M$$

•The resistors R_1, R_2 and R_E are used to provide d.c. bias to the transistor. The capacitors C_E and C are the by-pass capacitors.

•The secondary of the transformer provides a.c. feedback voltage that appears across the base-emitter junction of R_1 and R_2 is at a.c. ground due to by-pass capacitor C.

COLPITTS OSCILLATOR



$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

C_T is the total capacitance of C_1 and C_2 connected in series.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

- The resistors R_1, R_2 and R_e provide necessary bias condition for the circuit. The capacitor C_e provides a.c. ground thereby providing any signal degeneration.
- The capacitors C_c and C_b are employed to block d.c and to provide an a.c. path. The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c. Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source.

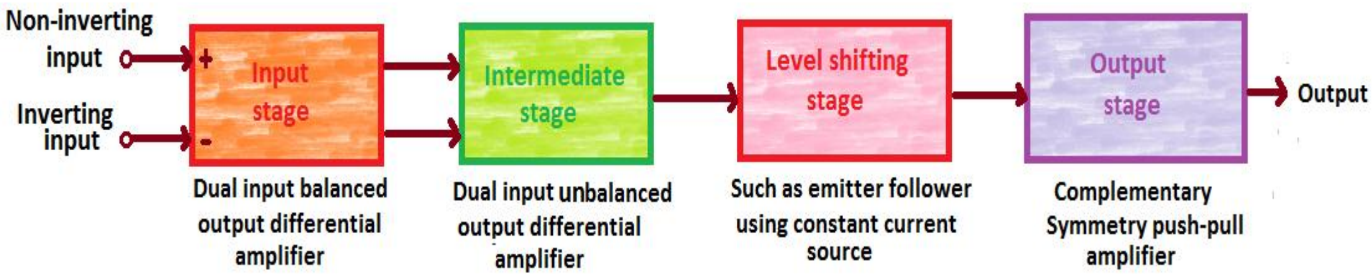
OPERATIONAL AMPLIFIERS

Ideal op-amp,
Output offset voltage,
input bias current,
input offset current,
slew rate,
gain bandwidth product,
Inverting and non-inverting amplifier,
Differentiator,
integrator,
Square-wave generator,
triangular-wave generator.

OPERATIONAL AMPLIFIERS

- An **operational amplifier** (often **op-amp** or **opamp**) is a DC coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output.
- An **operational amplifier** (or an **op**-**amp**) is an integrated circuit (IC) that operates as a voltage **amplifier**. An **op**-**amp** has a differential input. That is, it has two inputs of opposite polarity.
- An **op**-**amp** has a single output and a very high gain, which **means** that the output signal is much higher than input signal.

BLOCK DIAGRAM OF AN OP-AMP



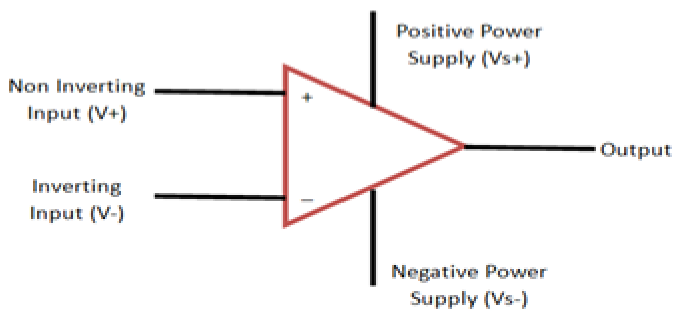


Fig:Basic op-amp symbol

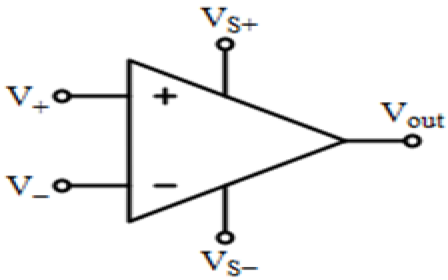
WHAT DO YOU MEAN BY IC?

•**An integrated circuit (IC)** is a miniature, low cost electronic circuit consisting of active and passive components fabricated together on a single crystal of silicon. The active components are transistors and diodes and passive components are resistors and capacitors.

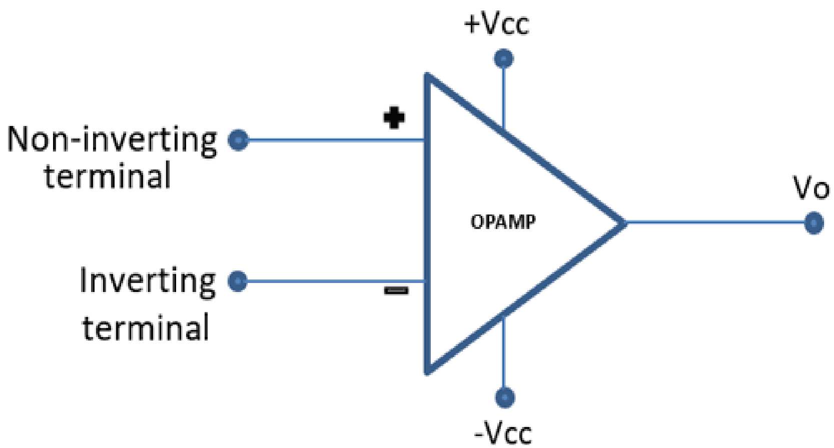
•**An integrated circuit (IC),** sometimes called a *chip* or microchip is a semiconductor wafer on which thousands or millions of tiny resistors, capacitors, and transistors are fabricated.

•**An IC** can function as an amplifier, oscillator ,timer, counter, computer memory (or) microprocessor.

SYMBOL OF AN OP-AMP



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

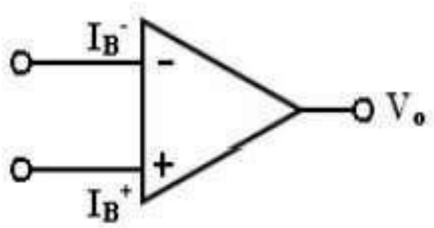


Op-amp symbol

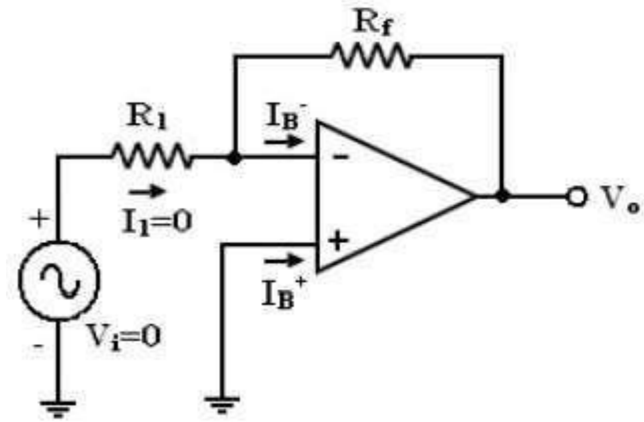
DC CHARACTERISTICS OF OP-AMP

- Input bias current
- Input offset current
- Input offset voltage
- Slew rate

Input bias current:



Input bias current

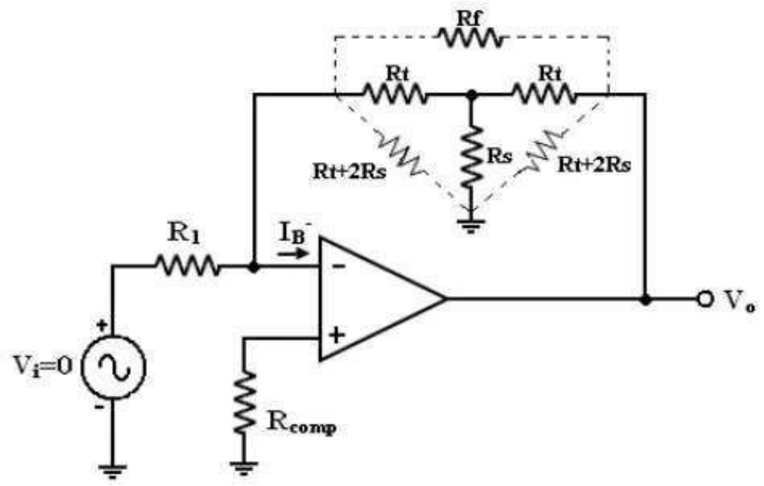


Inverting amplifier with bias current

$$I_B = (I_B^{\,+} + I_B^{\,-})/2$$

The input bias current I_B is the average of the current entering the input terminals of a balanced amplifier.

Input offset current:

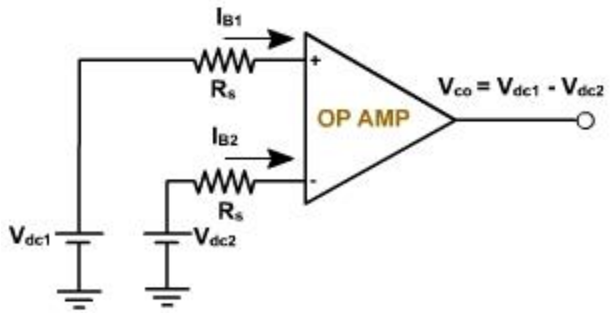


The input offset current I_{io} is the difference between the currents into inverting and non-inverting terminals of a balanced amplifier.

$$I_{io} = | \quad I_{B1} - I_{B2} \; |$$

The I_{io} for the 741C is 200nA maximum.

Input offset voltage:



Input offset voltage is defined as the voltage that must be applied between the two input terminals of an OPAMP to null or zero the output.

$$V_{io} = V_{dc1} – V_{dc2}$$

SLEW RATE

- The **slew rate of an op amp** or any **amplifier** circuit is the **rate** of change in the output voltage caused by a step change on the input.
- The maximum rate of change of output voltage caused by a step input voltage and is usually specified in V/µs.
- It is given by $\mathbf{dV_c/dt = I/C}$.
- For large charging rate, the capacitor should be small or the current should be large.

$$S = I_{max} / C$$

GAIN BANDWIDTH PRODUCT

- When designing an op amp circuit, a figure known as the op amp gain bandwidth product is important.
- The op amp gain bandwidth product is generally specified for a particular op amp type an open loop configuration and the output loaded:

GBP=Av * f

Where:

GBP = op amp gain bandwidth product.

Av = voltage gain.

f = cutoff frequency (Hz).

- The op amp gain bandwidth product is constant for voltage-feedback amplifiers.
- Therefore decreasing the gain by a factor of ten will increase the bandwidth by the same factor.

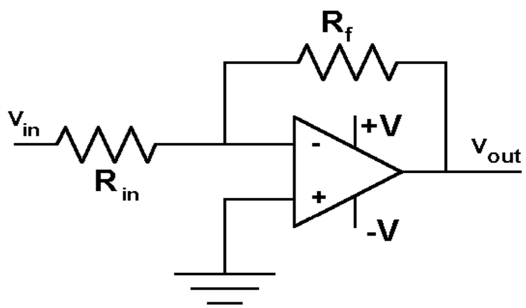
Open loop op-amp configurations

- The configuration in which output depends on input, but output has no effect on the input is called open loop configuration.
- No feed back from output to input is used in such configuration.
- The op-amp works as high gain amplifier
- The op-amp can be used in three modes in open loop configuration they are:

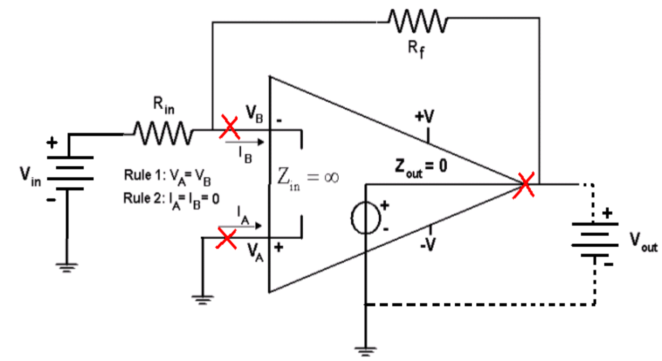
  1.Differential amplifier.

  2.Inverting amplifier.

  3.Non inverting amplifier.



$$V_{out} = -\frac{R_f}{R_{in}} V_{in} \qquad A = -\frac{R_f}{R_{in}}$$

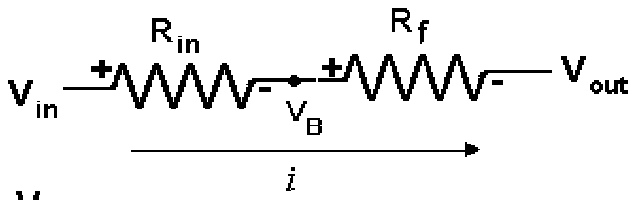


Inverting Amplifier

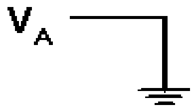
- **Inverting Amplifier** is a normal OP-**Amp** in which the output is given as feedback to the **inverted** terminal of input by means of a feedback resistor.
- Now the Op-**Amp** becomes Closed Loop **Inverting Amplifier** which uses negative feedback to control the overall gain of the **amplifier**.
- *The amplifier in which the output is inverted i.e. having 180^o phase shift with respect to the input is called an inverting amplifier.*

INVERTING AMPLIFIER ANALYSIS

1) $-:$



$+:$



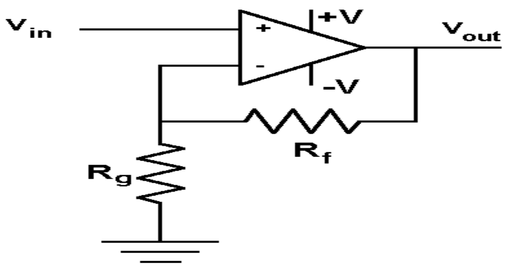
2) $-: \quad i = \dfrac{V}{R} = \dfrac{V_{in} - V_B}{R_{in}} = \dfrac{V_B - V_{out}}{R_f}$

$+: \quad V_A = 0$

3) $V_A = V_B = 0 \quad \dfrac{V_{in}}{R_{in}} = \dfrac{-V_{out}}{R_f}$

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

NON-INVERTING AMPLIFIER



$$V_{out} = \left(1 + \frac{R_f}{R_g}\right) V_{in}$$

$$A = 1 + \frac{R_f}{R_g}$$

•The gain of the **non-inverting** circuit for the operational amplifier is easy to determine.

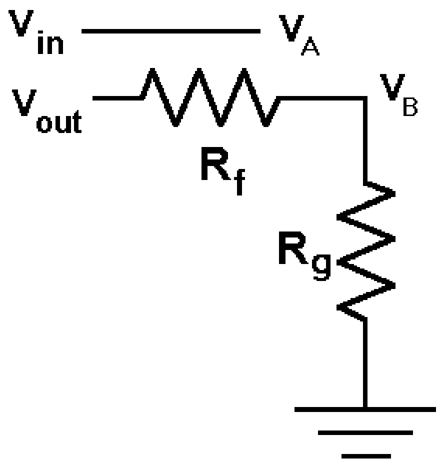
•If the output of the circuit remains within the supply rails of the **amplifier**, then the output voltage divided by the gain means that there is virtually no difference between the two inputs.

•The amplifier in which the output is amplified without any phase shift in between input and output is called non inverting amplifier.

NON-INVERTING AMPLIFIER ANALYSIS

1) $+:$

$-:$



2) $+: \quad V_A = V_{in}$

$$-: \quad V_B = \frac{R_g}{R_f + R_g} V_{out}$$

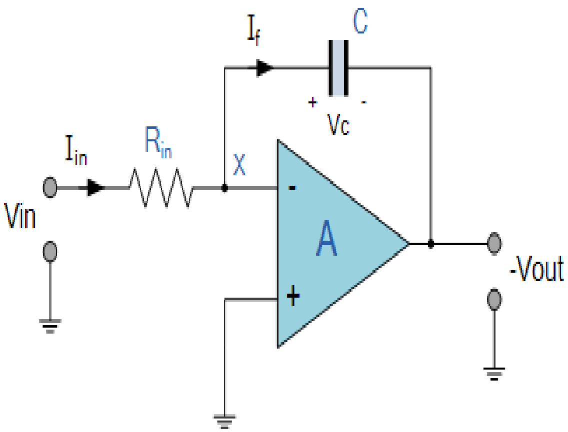
3) $V_A = V_B \quad V_{in} = \dfrac{R_g}{R_f + R_g} V_{out}$

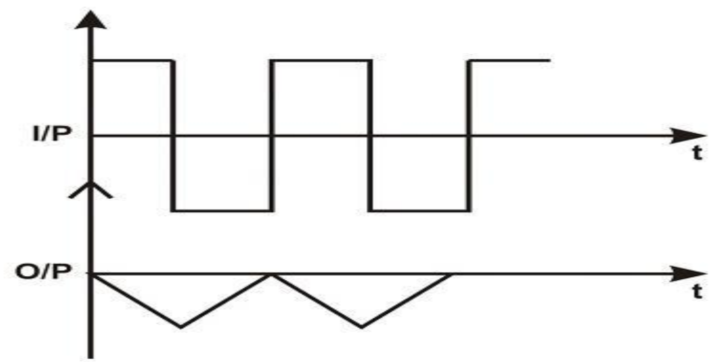
$$\frac{V_{out}}{V_{in}} = \frac{R_f + R_g}{R_g}$$

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_g}$$

Note that step 2 uses a voltage divider to find the voltage at V_B relative to the output voltage.

OP-AMP INTEGRATOR

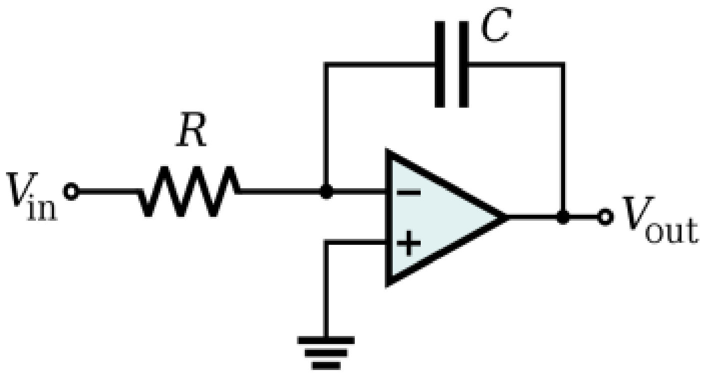




The **Op-amp Integrator** is an operational amplifier circuit that performs the mathematical operation of **Integration**, that is we can cause the output to respond to changes in the input voltage over time as the op-amp integrator produces an output voltage which is proportional to the integral of the input voltage.

OP-AMP INTEGRATOR

- If feedback component used is a capacitor ,the resulting connection is called integrator.
- The circuit diagram of ideal op-amp integrator



$$V_{out} = -\frac{1}{j\omega RC} V_{in}$$

$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\,dt = -\int_0^t V_{in}\frac{dt}{R_{in}.C}$$

OP-AMP INTEGRATOR

$$V_{out} = -\frac{1}{j\omega RC} V_{in}$$

- The output voltage is negative of input voltage and inversely proportional to time constant R and C .

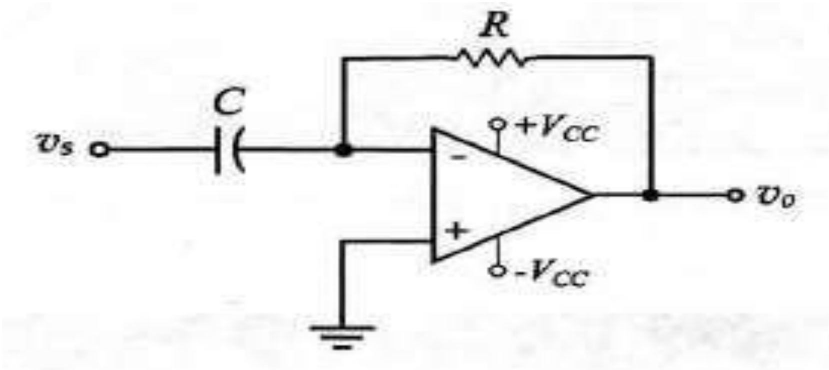
Vo(s)= -Vin(s) %SRC

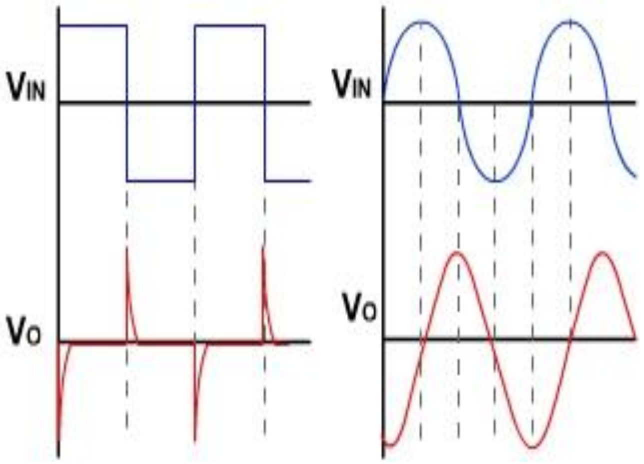
- The gain A, A=Vo(s)%Vin(s) = - 1/(jwCR)
- Taking magnitude of A A= 1/(wCR) = W/Wa Where Wa=1/CR

OP-AMP INTEGRATOR

- The integrator work as a low pass filter circuit when time constant is very large .
- At w=0, the gain A is infinite for an ideal op- amp .
- At dc , the capacitor C behaves as an open circuit and there is no negative feedback.
- But in practice output never becomes infinite.

OP-AMP DIFFERENTIATOR





$$\frac{-v_o}{R} = C\frac{dv_s}{dt}$$

$$v_o = -RC\frac{dv_s}{dt}$$

OP-AMP DIFFERENTIATOR

- The output voltage Vo is a constant (-RC) times the derivative of the input voltage V1 .
- In Laplace form ,s=jw Vo(s)= -sCRVin(s)
- The gain is ,A=Vo(s)/Vin(s)

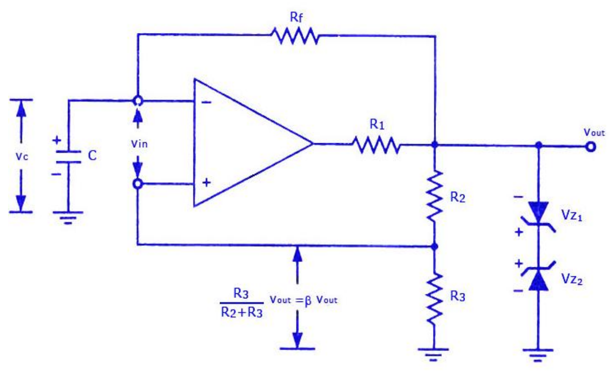
A=-sCR = -jwCR

- The magnitude of A=wCR
- A=W/Wa = f/fa where Wa=1/CR

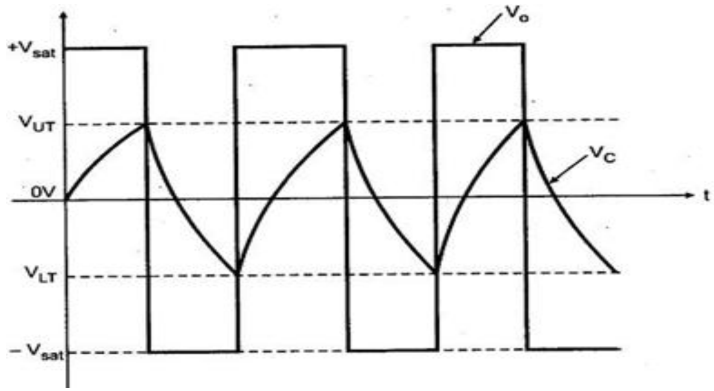
OP-AMP DIFFERENTIATOR

- At high frequency a differentiator may become unstable and break into oscillation .
- The input impedance (Xc=1/wc) decrease with increase in frequency ,otherwise making the circuit sensitive to high frequency noise .
- To overcome through the problem of instability and high frequency noise we use the practical differentiator .

SQUARE WAVE GENERATOR



OP-Amp Squre-Wave Generator



- The Square Wave Generator Using Op amp means the astable multivibrator circuit using op-amp, which generates the square wave of required frequency.
- It looks like a comparator with hysteresis (schmitt trigger), except that the input voltage is replaced by a capacitor. The circuit has a time dependent elements such as resistance and capacitor to set the frequency of oscillation.

SQUARE WAVE GENERATOR

Frequency of Oscillation:

•The frequency of oscillation is determined by the time it takes the capacitor to charge from VUT to VLT and vice versa.

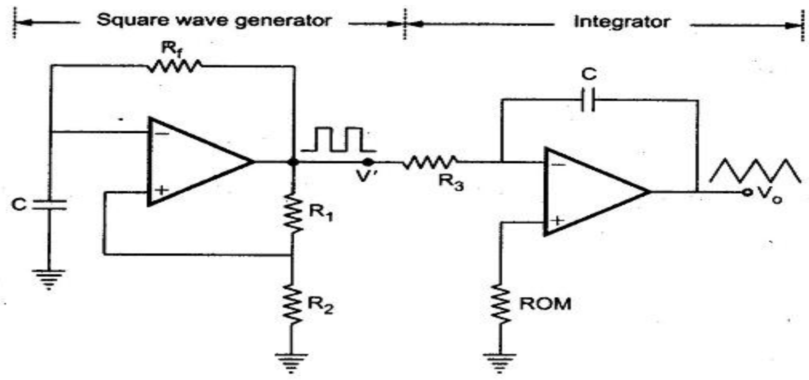
•The voltage across the capacitor as a function of time is given as where Vc(t) is the instantaneous voltage across the capacitor.

•Vinitiail is the initial voltage, Vmax is the voltage toward which the capacitor is charging.

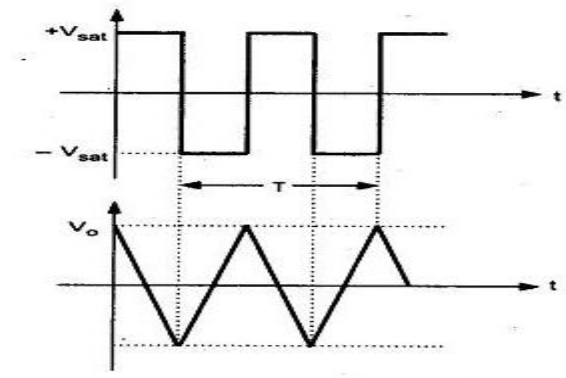
•Total time required for one oscillation is given as The frequency of oscillation can be determined as fo=1/T, where T represents the time required for one oscillation.

$$f_o = \frac{1}{2 R_f C \, ln\left(\frac{+V_{sat} - V_{LT}}{+V_{sat} - V_{UT}}\right)}$$

TRIANGULAR WAVE GENERATOR



Triangular wave generator



Waveforms of triangular wave generator

- The triangular Wave Generator Using Op amp can be formed by simply connecting an integrator to the square wave generator.
- Basically, triangular wave is generated by alternatively charging and discharging a capacitor with a constant current. This is achieved by connecting integrator circuit at the output of square wave generator.

TRIANGULAR WAVE GENERATOR

- It consists of a comparator (A) and an integrator (B).
- The output of comparator A is a square wave of amplitude ± Vsat and is applied to the inverting (—) input terminal of the integrator B.
- The output of integrator is a triangular wave and it is feedback as input to the comparator A through a voltage divider R2 R3.

$$f_o = \frac{1}{T} = \frac{R_3}{4 R_1 C_1 R_2}$$